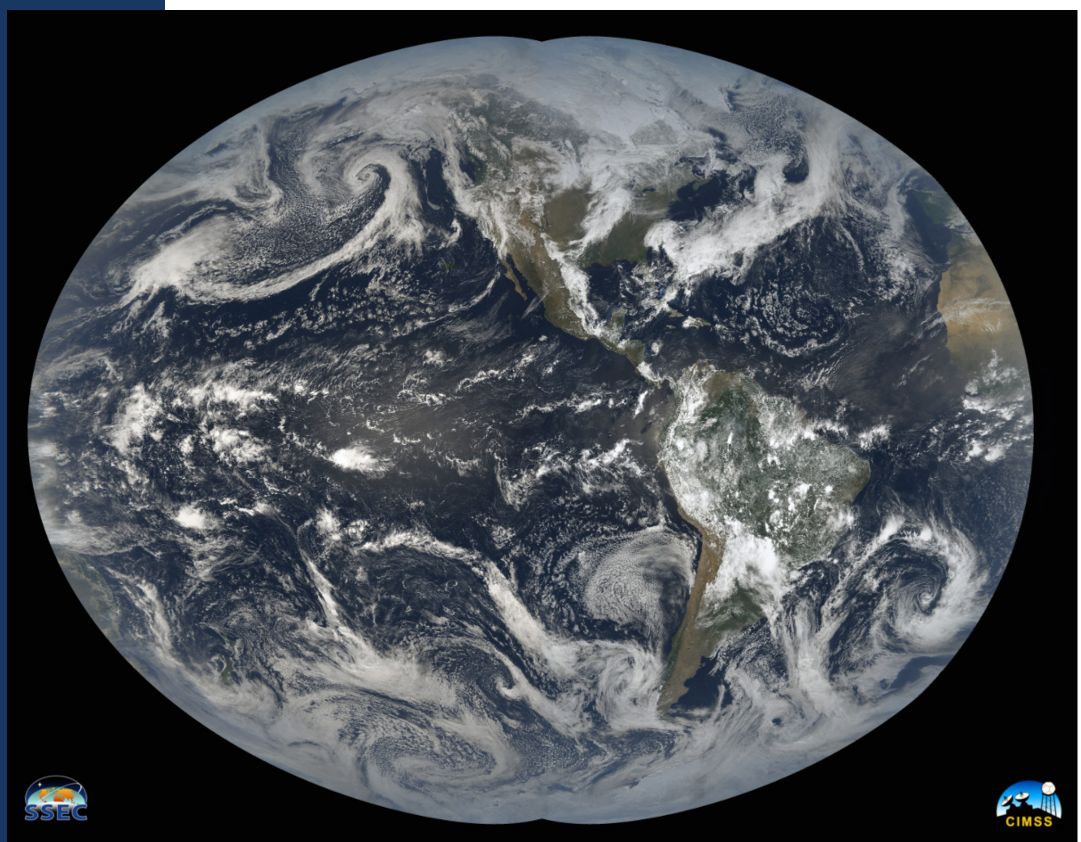
CIMSS Cooperative Agreement Annual Report

for the period
1 April 2018 to 31 March 2019



Submitted by the
Cooperative Institute for
Meteorological Satellite Studies
University of Wisconsin-Madison

April 2019

University of Wisconsin–Madison

Cooperative Institute for
Meteorological Satellite Studies (CIMSS)
http://cimss.ssec.wisc.edu/

Cooperative Agreement Annual Report

for the period
1 April 2018 to 31 March 2019
Cooperative Agreement Number: NA15NES4320001

Submitted to:
National Oceanic and Atmospheric Administration
(NOAA)

Cooperative Agreement Annual Report from the Cooperative Institute for Meteorological Satellite Studies University of Wisconsin–Madison

1 April 2018 to 31 March 2019

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Cover image: GOES-17 (West) and GOES-16 (East) image using CIMSS Natural True Color enhancement from March 20, 2019.

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I. Director's Executive Summary

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin–Madison (UW–Madison) has been engaged in a strong collaborative partnership with the National Oceanic and Atmospheric Administration (NOAA) since its formation in 1980. We share the goals of monitoring the earth environment more thoroughly through improved remote sensing measurements, maximizing their utilization to realize more accurate and earlier weather prediction, and gaining long term climate perspectives. Through the foundation established by NOAA and the UW-Madison memorandum of understanding, scientists from NOAA/NESDIS and the UW–Madison Space Science and Engineering Center (SSEC) conduct ongoing collaborative research and education. Five scientists from the NOAA/NESDIS Advanced Satellite Product Branch (ASPB) and one scientist from the National Center for Environmental Information (NCEI) are currently stationed at the UW-Madison campus.

This annual report gives detailed updates on the projects supported through the cooperative agreement. Our work is aimed at three mission goals: (1) Foster collaborative research between NOAA and UW–Madison in those aspects of atmospheric and earth science that exploits the use of satellite technology. (2) Serve as a center at which scientists and engineers working on problems of mutual interest may focus on satellite related research in atmospheric studies and earth science. (3) Stimulate the training of scientists and engineers in those disciplines comprising the atmospheric and earth sciences.

Highlights from the past year have been chronicled in the semi-annual magazine "Through the Atmosphere" which can be found at http://www.ssec.wisc.edu/through-the-atmos/. The scope of our activities in observations, modelling, atmospheric physics, mentoring, outreach, and operational support is nicely covered in twelve articles from last year.

1. Research at UW-Madison changes student lives
   https://www.ssec.wisc.edu/news/articles/11902

2. Nuo Chen to receive William L. Smith Graduate Scholarship
   https://www.ssec.wisc.edu/news/articles/11859

3. 2019 Virtual Science Fair for students and teachers
   https://www.ssec.wisc.edu/news/articles/11831

4. When the rains stop: Flash drought research assists farmers and ranchers
   https://www.ssec.wisc.edu/news/articles/11592

5. Tim Schmit: Fellow of the American Meteorological Society
   https://www.ssec.wisc.edu/news/articles/11525

6. NOAA plan to improve weather forecasting includes UW-Madison
   https://news.wisc.edu/noaa-plan-to-improve-weather-forecasting-includes-uw-madison-2/

7. A case for geo-sounders: Investigating the utility of hyperspectral sounders aboard geostationary satellites
   https://www.ssec.wisc.edu/news/articles/11426

8. Center of the storm: A global analysis of hurricane eyes
https://www.ssec.wisc.edu/news/articles/11238

9. MODIS + ASTER = CAMEL
https://www.ssec.wisc.edu/news/articles/11037

10. Margaret Mooney recognized for public service and outreach
https://www.ssec.wisc.edu/news/articles/10709

11. Hurricanes are slowing down, and that's bad news
https://news.wisc.edu/hurricanes-are-slowing-down-and-thats-bad-news/

12. UW collaboration builds resilience in the wake of Hurricane Maria
https://news.wisc.edu/uw-collaboration-builds-resilience-in-the-wake-of-hurricane-maria/

In the last twelve months, CIMSS contributed to implementing and testing of several operational GOES-16 and GOES-17 algorithms as well as training NWS forecasters and other GOES users in the use of these products. CIMSS also played a key role in studying the Loop Heat Pipe issue on GOES-17 and developing a prototype fusion methodology to generate imagery during outage periods. The CIMSS Geostationary Community Satellite Processing Package (CSPP Geo) has become widely adopted by U.S. government agencies, researchers, private industry, and foreign meteorological services to process GOES Rebroadcast (GRB) data from GOES-16 and GOES-17. CIMSS GOES-R Risk Reduction activities have led to advances in several high-impact weather products in support of NOAA's mission to serve society's weather needs.

CIMSS also contributed significantly to the calibration, validation, and independent verification of Suomi-NPP and NOAA-20 VIIRS and CrIS instruments and associated data products and is pioneering studies to assess the value of assimilating water vapor, atmospheric motion vectors, and trace gas information to improve weather and pollution forecasts. CIMSS continued in their support of NOAA's education and outreach goals with involvement in K-12, undergraduate, graduate and professional training. CIMSS scientists published 73 peer-reviewed papers in 2018-19 about two-thirds of which featured NOAA co-authors (see Appendix 2). These include a study in *Nature* on the slowdown of tropical cyclones and a featured paper in the *Bulletin of the American Meteorological Society* on flash droughts. CIMSS supported 16 graduate students in the UW–Madison Department of Atmospheric and Oceanic Sciences (AOS) (see Appendix 4) who work closely with CIMSS and ASPB scientists. Through this close association with AOS, CIMSS contributed to sustaining the pipeline of talent into the NOAA enterprise through the hiring of Mark Kulie and Yinghui Liu, two recent CIMSS graduate students.

CIMSS and SSEC also maintain several web sites for external audiences. In addition to the news stories noted earlier (in http://www.ssec.wisc.edu/news/articles), they include

- Educational resources for students and teachers:
  https://cimss.ssec.wisc.edu/education/
- The CIMSS Satellite Blog for case study discussion and analysis:
  http://cimss.ssec.wisc.edu/goes/blog/
- Curated library resources for researchers, students, and teachers:
  http://library.ssec.wisc.edu/

- Data and imagery used by external media outlets, researchers, and many others: http://cimss.ssec.wisc.edu/data/ and http://www.ssec.wisc.edu/data/

In summary, CIMSS is in the fourth year of the 5-year cooperative agreement with NOAA. The remainder of this report provides a description of the activities undertaken during the period April 1, 2018 through March 31, 2019.

II. Background Information on the Cooperative Institute for Meteorological Satellite Studies (CIMSS)

1. Description of CIMSS, including research themes, vision statement and NOAA research collaborations

The Cooperative Institute for Meteorological Satellite Studies (CIMSS) was formed through a Memorandum of Understanding between the University of Wisconsin–Madison (UW–Madison) and the National Oceanic and Atmospheric Administration (NOAA). The CIMSS formal agreement with NOAA began in 1980 and was continued through a competitive review process in 2010. Following a thorough review of the CIMSS, the Review Panel unanimously agreed to a performance rating of Outstanding. CIMSS completed its 5-year review in December 2013 and a new cooperative agreement funding number was in place in 2015. CIMSS is scheduled to be recompeted for another 10-year funding cycle in late 2019.

The CIMSS mission includes three goals:

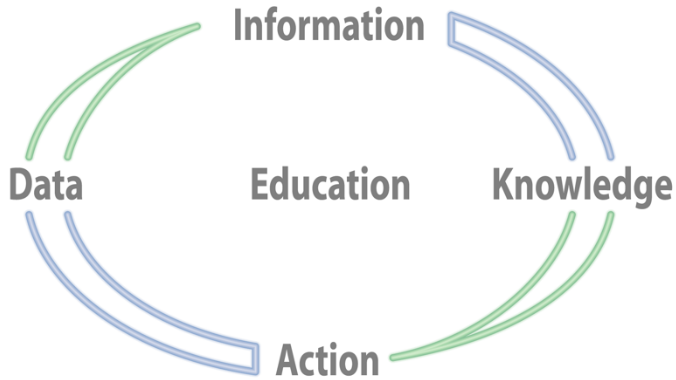
- **Foster collaborative research among NOAA, NASA, and the University in those aspects;**
- **Serve as a center at which scientists and engineers working on problems of mutual interest can focus on satellite-related research in atmospheric and earth system science; and**
- **Stimulate the training of scientists and engineers in the disciplines involved in atmospheric and earth sciences.**

To achieve these mission goals CIMSS conducts a broad array of research and education activities, many of which are projects funded through this Cooperative Agreement with NOAA. This Cooperative Agreement identifies four CIMSS themes:

1. **Satellite Meteorology Research**
2. **Satellite Sensors and Techniques**
3. **Environmental Models and Data Assimilation**
4. **Outreach and Education.**

The collaborative relationship between NOAA and the UW–Madison that led to the establishment of CIMSS has provided outstanding benefits to the atmospheric science community and to the nation through improved use of remote sensing measurements for weather forecasting, climate analysis and environmental issues. CIMSS research investigations increase understanding of remote sensing and its numerous applications to weather and nowcasting / forecasting, clouds, aerosols and radiation, the global hydrological cycle, environmental trends, and climate, as well as education and outreach.

CIMSS scientists are engaged in a broad array of research activities and applications as noted in the executive summary and presented in detail in the following sections. CIMSS develops algorithms that are applied to remote sensing measurements to yield information about Earth. This information leads to knowledge about the Earth system that can be utilized in decision-making processes. CIMSS also demonstrates the advantages of improved observations, and works with partners, within and beyond SSEC, in designing and testing advanced instrumentation. At the center of this research process is education - the training of students, professionals and CIMSS itself.



CIMSS conducts a broad array of activities that engages researchers and students in a variety of research and education endeavors.

CIMSS plays a unique role to NOAA as a non-profit partner, advisor, consultant and link to UW-Madison students and researchers. As a long-term partner of NOAA, CIMSS helps to serve as part of the NESDIS corporate memory, particularly when government staff changes positions and roles. For example, original CIMSS/SSEC staff associated with GOES VAS (the first geostationary sounding instrument) and GOES-8/14 design, testing, and checkout are now assisting with similar activities in GOES-16/17/T/U. On the polar orbiting satellite side, our decades long work with the TOVS and ATOVS sounders and the aircraft HIS (High spectral resolution Interferometer Sounder) and scanning-HIS are aiding in the development of applications for the CrIS (Cross-track Infrared Sounder) hyperspectral sounder on Joint Polar Satellite System (JPSS). In addition to bringing "corporate memory" to these new GOES and JPSS programs, the senior staff help to train the next generation of CIMSS scientists who will support future partnerships between CIMSS and NOAA.

CIMSS scientists work side-by-side with the NESDIS/STAR/ASPB (Advanced Satellite Products Branch) scientists who are stationed in Madison. The advantages of collocation in the same building and similar research interests generate productive collaborations. In addition, ASPB scientists often mentor graduate students on research projects that address NOAA needs while helping to satisfy UW–Madison degree requirements. Based on this positive experience, many of these students go on to work with NOAA and supporting contractors.

Within the NOAA National Weather Service (NWS), CIMSS collaborates on data assimilation projects with the National Centers for Environmental Prediction (NCEP). The CIMSS tropical cyclone research team maintains close collaboration on new products development with the Tropical Prediction Center (NCEP/TPC) in Miami. CIMSS works with the Storm Prediction Center (NCEP/SPC) and the National Severe Storms Laboratory (NSSL) in Norman, OK on satellite applications to severe weather analysis and forecasting. CIMSS collaborates with the Aviation Weather Center (NCEP/AWC) in Kansas City on aviation safety projects that utilize weather satellite data.

2. CIMSS Management and Administration

CIMSS resides as an integral part of the University of Wisconsin-Madison Space Science and Engineering Center (SSEC). The CIMSS Principal Investigator on most programs is Tristan L'Ecuyer. Executive Director – Science Wayne Feltz provides day-to-day oversight of the CIMSS staff, science programs, and facilities. The individual science projects are led by University Principal Investigators (PIs) in conjunction with a strong and diverse support staff who provide additional expertise to the research programs. CIMSS is advised by a Board of Directors and a Science Advisory Council (Section II. 4 below).

The CIMSS administrative home is within the Space Science and Engineering Center (SSEC), a research and development center within the UW–Madison's Office of the Vice Chancellor for Research and Graduate Education (OVCGE). The independent CIMSS 5-year review panel for administration wrote that they were "…impressed by the people, systems and processes in place." The SSEC mission focuses on geophysical research and technology to enhance understanding of the Earth, other planets in the Solar System, and the cosmos. To conduct its science mission on the UW–Madison campus, SSEC has developed a strong administrative and programmatic infrastructure. This infrastructure serves all SSEC/CIMSS staff.

SSEC support infrastructure includes:

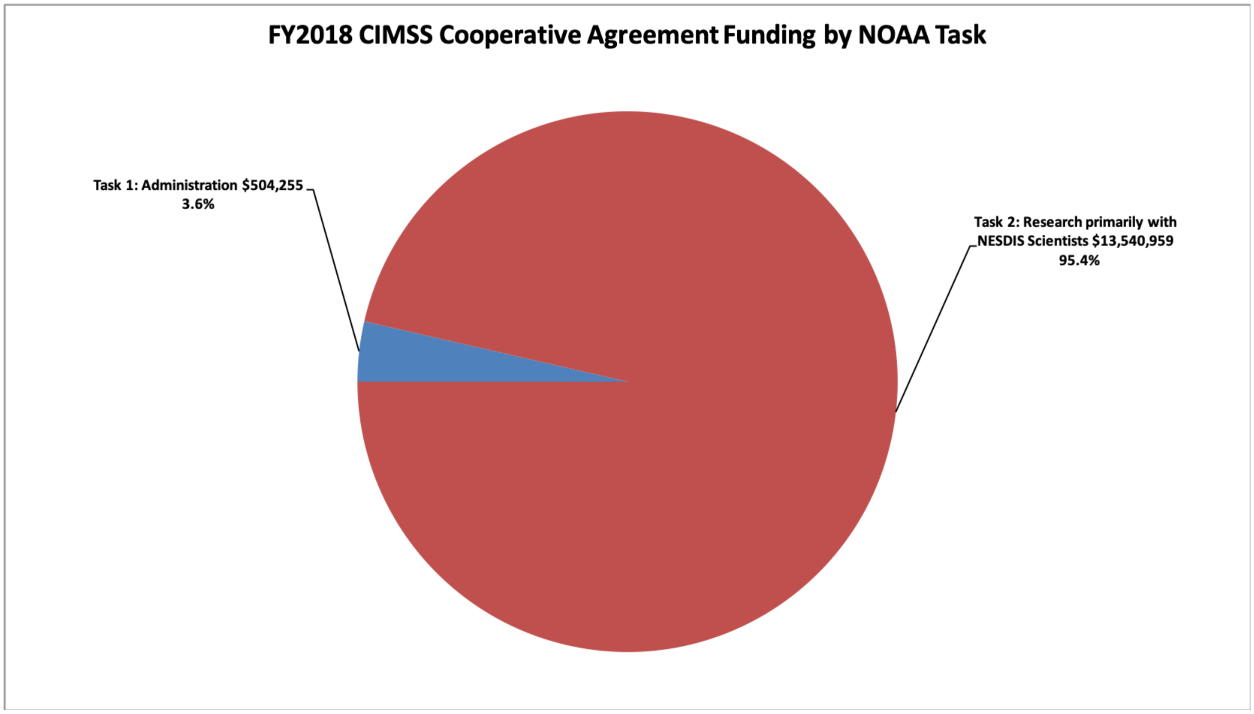
- **Administrative support**
  The administrative support team includes approximately 14 full-time staff and several students providing services that include human relations, proposal processing and publishing, grant and contract management, accounting, financial programming, purchasing and travel.
- **Technical Computing**
  The technical computing support team includes 6 full-time staff and several students providing consultation and implementation on system design, networking infrastructure, and full support for Unix and pc computing.
- **Data Center**
  The SSEC Data Center provides access, maintenance, and distribution of real-time and archive weather and weather satellite data. The Data Center currently receives data from 8 geostationary and 7 polar orbiting weather satellites in real time and provides a critical resource to SSEC/CIMSS researchers.
- **Library and Communications**
  SSEC maintains an atmospheric science library as part of the UW–Madison library system. Professional staff include a full-time librarian and director. SSEC also employs a full-time communications specialist and webmaster to support the dissemination of information on scientist activities and research results, to develop in-house publications, and to lead web development activities.
- **Visualization Tools**
  SSEC is a leader in developing visualization tools for analyzing geophysical data. The Man-computer Interactive Data Access System (McIDAS and McIDAS-V), Vis5D and VisAD software are used worldwide in a variety of research and operational environments. The VISITView and Satellite Information Familiarization Tool (SIFT) software is used extensively as a tele-training tool by the NWS and others. To further support NOAA NWS forecast offices, CIMSS is developing satellite products for AWIPS and AWIPS2, maintaining both systems within our facilities.

3. Summary of NOAA Funding to CIMSS in FY2018

In FY2018, funding to CIMSS through Cooperative Agreement Federal Funding Opportunity NOAA-NESDIS-NESDISPO-2018-2005404 totaled $14,045,214 (includes Task I and Task 2 funding). FY2019 funding is not sufficiently known at this time to include in this report. The following tables and graphics show the distribution of these funds by Task, by NOAA Strategic Goal and by CIMSS Research and Outreach Theme. The total represents FY2018 funds provided to CIMSS under the Cooperative Agreement period of performance for 1 April 2018 - 30 March 2019.

FY2018 Funding by NOAA Task

CIMSS Task	Funding in dollars	Percentage
Task 1: Administration	$ 504,255	3.6%
Task 2: Research primarily with NESDIS Scientists	$ 13,540,959	95.4%
Task 3: Research with other NOAA Programs	$ 0	0%
CIMSS FY18 Total Budget	$14,045,214	100%

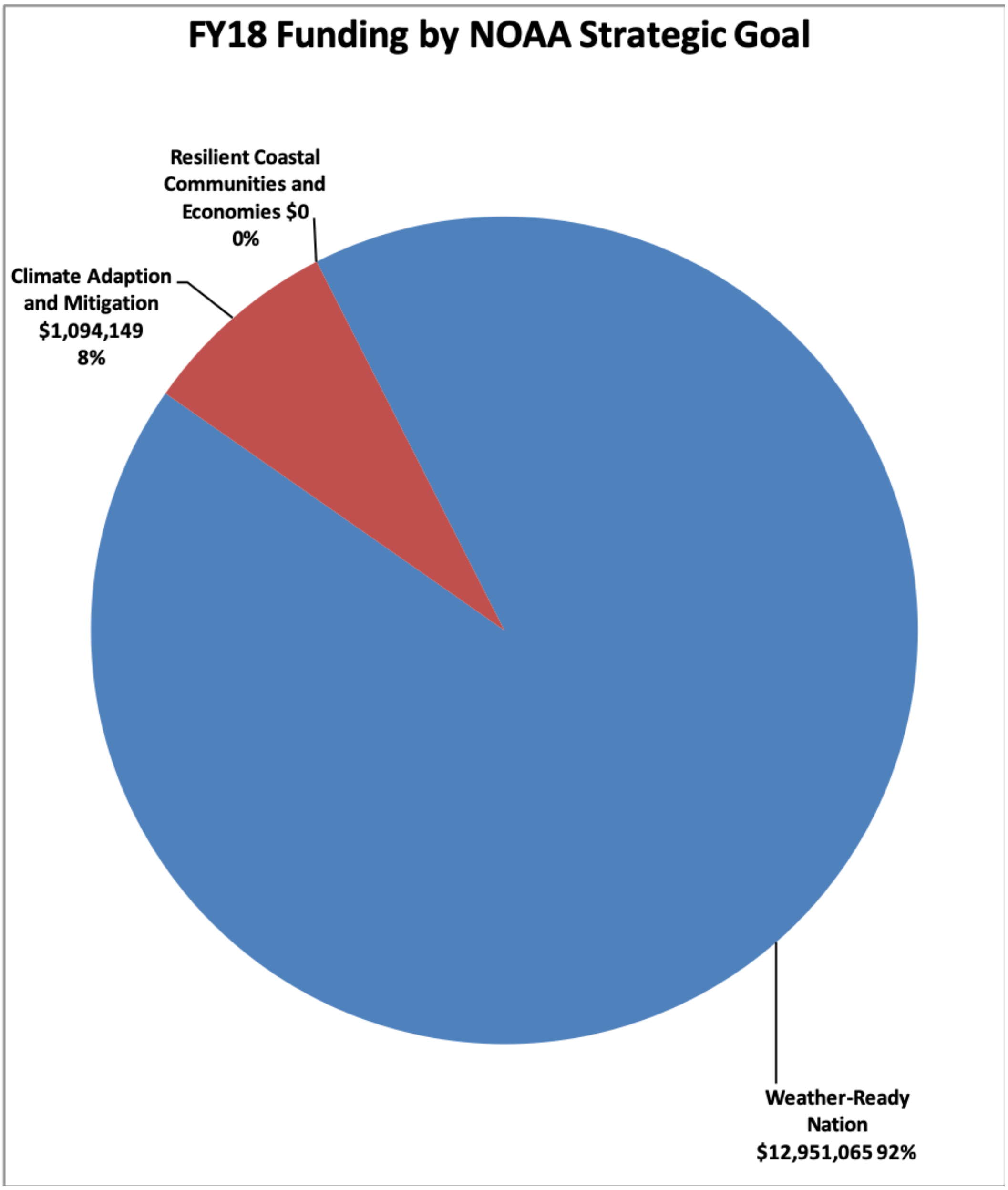


Nearly 96% of CIMSS funding is for Task 2 (~73 employees FTE funded at 50% or greater) and is research conducted with NOAA NESDIS ASPB scientists.

Research primarily falls under NOAA's Strategic Goal Weather Ready Nation.

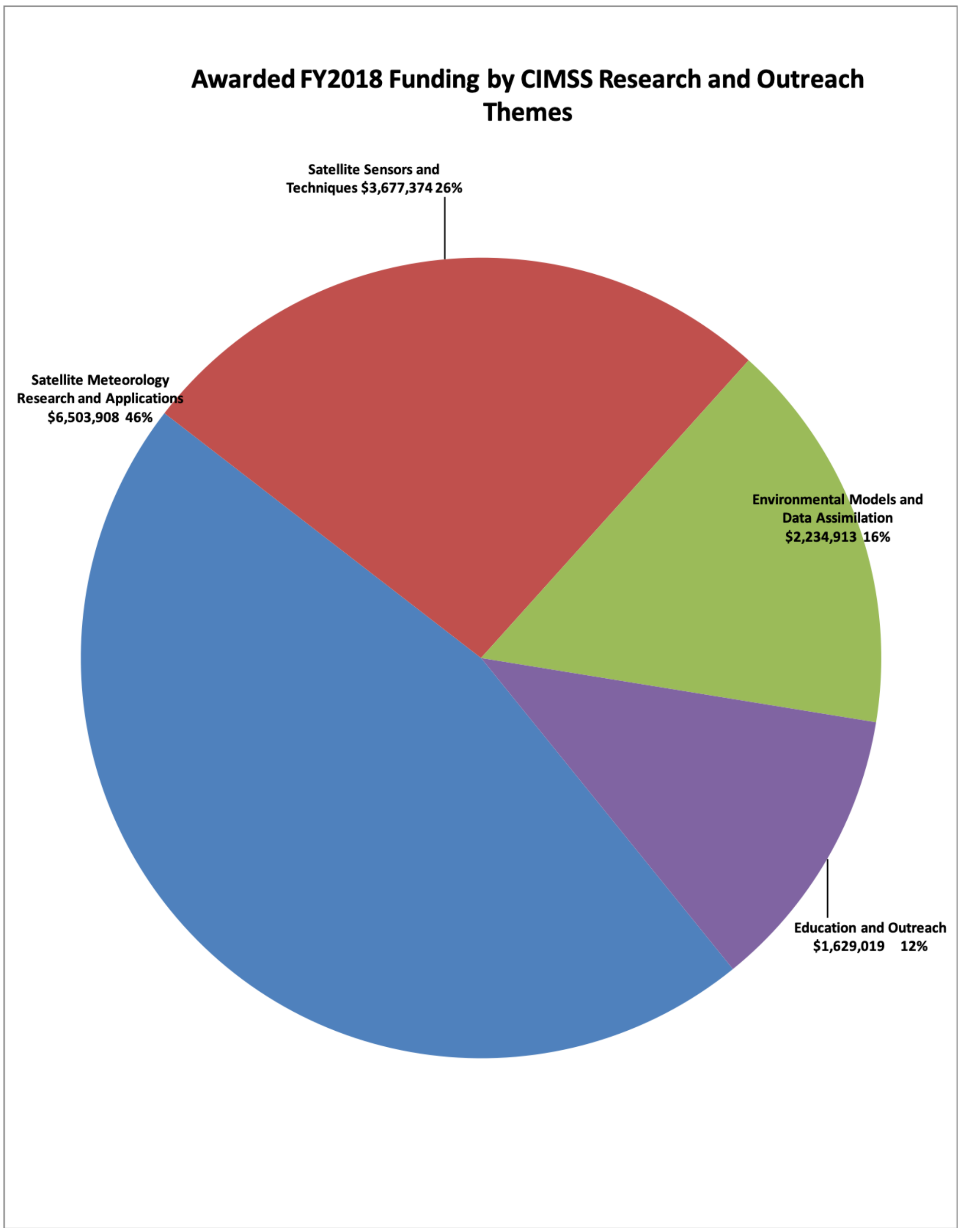
FY2018 Funding by NOAA Strategic Goal

NOAA Strategic Goal	Funding in dollars	Percentage
Weather-Ready Nation	$12,951,065	92%
Climate Adaption and Mitigation	$1,094,149	8%
Healthy Oceans	$0	0%
Resilient Coastal Communities and Economies	$0	0%
CIMSS FY18 Total Budget	$14,045,214	100%



Task 2 Funding by CIMSS Research and Outreach Themes

CIMSS Theme	Funding in dollars	Percentage
Satellite Meteorology Research and Applications	$6,503,908	46%
Satellite Sensors and Techniques	$3,667,374	26%
Environmental Models and Data Assimilation	$2,234,913	16%
Education and Outreach	$1,629,019	12%
CIMSS FY18 Total Budget	$14,045,214	



III. Project Reports

The sections below provide two-three page summaries for each of the various projects funded by NOAA through the CIMSS cooperative agreement. Each summary lists the project leader, the NOAA goals and the CIMSS themes followed by a summary of the project accomplishments this past year. Where appropriate, relevant publications and conference presentations are listed.

1. CIMSS Task 1A Support

CIMSS Task Leader: Tristan L'Ecuyer, Wayne Feltz
CIMSS Support: Maria Vasys, Leanne Avila, Wenhua Wu, Jenny Hackel, Margaret Mooney

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective

The CIMSS Task I funds continue to support the administrative needs for the CIMSS Director, the CIMSS Executive Director - Science and the CIMSS Staff Program Assistant Maria Vasys who also provides that support along with student hourly employees to maintain a consistent presence in the CIMSS administrative office.

Project Overview

The CIMSS Task 1 funding supports activities related to CIMSS administration and non-research programs that are important to the workplace environment of CIMSS. Partial administrative support is provided for the CIMSS Director, Executive Director - Science, the Program Assistant, and the CIMSS Webmaster. Task I activities also include leveraging support for education and outreach projects, per diem support for visiting scientists, post doctoral positions and first year graduate students.

Milestones with Summary of Accomplishments and Findings

Task I activities are related to the overall management of CIMSS, as well as general education and outreach activities. These activities support the operation of CIMSS; provide outreach platforms to transmit CIMSS science to varied audiences; train and develop future scientists in the workforce; and provide capabilities requested under the Federal Funding Opportunity NOAA-NESDIS-NESDISPO-2019-2005866, but which are not tied to a specific project or projects. Task I funding includes partial funding/salary support for the CIMSS PI/Director, and other support staff, travel, and visiting researcher support. Also, inclusive of Task I are educational and outreach activities including support of post-docs and graduate students within CIMSS not assigned to specific projects or research; support of undergraduate research interns; development of community outreach, education, and training programs; and support for CIMSS education and outreach staff.

Task I funding supports the development and updates of the CIMSS Web page (see http://cimss.ssec.wisc.edu/). The CIMSS Web page is closely linked to the NOAA ASPB Web site (http://cimss.ssec.wisc.edu/aspb/) and to the SSEC Web site (http://www.ssec.wisc.edu).

CIMSS has created the "NOAA-CIMSS Collaborative Award for developing NOAA's Strategic Satellite Plan to balance requirements, observation capabilities, and resources." These awards may be given to CIMSS scientists who have worked closely with NOAA scientists who have received a NOAA award. The CIMSS award is to recognize the partnership that occurs in research with ASPB and UW-Madison scientists.

2. CIMSS Task 1B Support – Education and Public Outreach

CIMSS Task Leaders: Margaret Mooney and Tristan L'Ecuyer
CIMSS Support Scientists: Scott Bachmeier, Rick Kohrs, Scott Lindstrom
NOAA Collaborators: Tim Schmit, Steve Goodman, LuAnn Dahlman
Budget: $80,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Education and Outreach

Objective
To raise satellite remote sensing awareness and promote weather and climate literacy.

Project Overview
CIMSS Education and Public Outreach (EPO) initiatives prioritize satellite remote sensing awareness and weather and climate literacy while working to ensure that CIMSS research products provide maximum benefits to society.

Milestones with Summary of Accomplishments and Findings
In April 2018, CIMSS EPO Director Margaret Mooney received the UW-Madison's Robert and Carroll Heideman Award for Excellence in Public Service and Outreach. Included in her nomination packet was a letter co-signed by NOAA's Steve Goodman and Tim Schmit commending her work on the GOES-R Education Proving Ground. While receiving a plaque from Chancellor Rebecca Blank, former Acting Secretary of Commerce, Mooney acknowledged their mutual connection to our nation's satellite program, thanking Blank for her service.

Figure 1. Chancellor Blank, Margaret Mooney and Carrol Heideman.

CIMSS EPO is involved in a variety of formal and informal education projects, ranging from classes and workshops at the UW-Madison to presentations at conferences, museums and schools. CIMSS has been on the forefront of educational software design for over two decades and currently supports several on-line curriculums, educational tools, social media sites and blogs.

In the digital domain, CIMSS maintains educational content via on-line curriculum for students and teachers linked from the CIMSS education webpage, (https://cimss.ssec.wisc.edu/education/) CIMSS also maintains two twitter accounts and a Facebook page. The main twitter account, @UWCIMSS, covers a broad range of content with 9K followers and annual reach of 8 million. The CIMSS Facebook page (https://www.facebook.com/CIMSS.UW.Madison) has 13K fans.

@UWCIMSS 2018 Twitter Analytics

MONTH	IMPRESSIONS	TOP TWEET TOPIC
January	1.07M	Great Lakes Lake Effect via VIIRS DNB
February	405K	VIIRS Day/Night Band Great Lakes
March	629K	"While you were sleeping" VIIRS Aurora
April	603K	Great Lakes Aurora via NOAA-20 VIIRS
May	587K	Kilauea Volcano via S-NPP VIIRS
June	705K	AA Flight 1897 track
July	482K	Typhoon Maria
August	899K	Typhoon Soulik
September	976K	Super Typhoon Mangkhut
October	937K	Hurricane Michael GOES East IR
November	531K	VIIRS California Camp Fire
December	325K	GOES-16 water vapor cyclogenesis
2018 total reach:	**8.15 Million**	

The CIMSS Satellite Blog (http://cimss.ssec.wisc.edu/goes/blog/) has been showcasing examples of meteorological satellite images and products for over a decade. The associated twitter account (@CIMSS_Satellite) has over 41K followers!

CIMSS has also been producing content for NOAA’s Science On a Sphere® (SOS) and published 4 quarterly Climate Digest this past year, one for each season. (http://sphere.ssec.wisc.edu/)

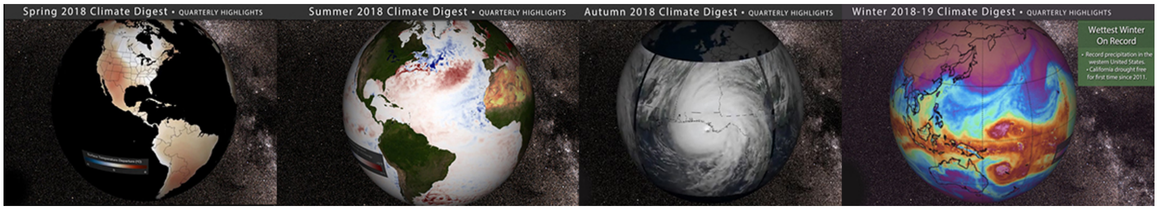


Figure 2. Screenshots from the seasonal Climate Digest product.

CIMSS has hosted a STEM summer Workshop on Atmospheric, Satellite, and Earth Sciences for high school students since 1991. In June 2018, 20 students from 8 different states participated in five days of science education and fun. They stayed on campus in lakeside dorms and experienced remote sensing research and technology through hands-on activities, working directly with CIMSS and NOAA scientists, graduate students, and professors.

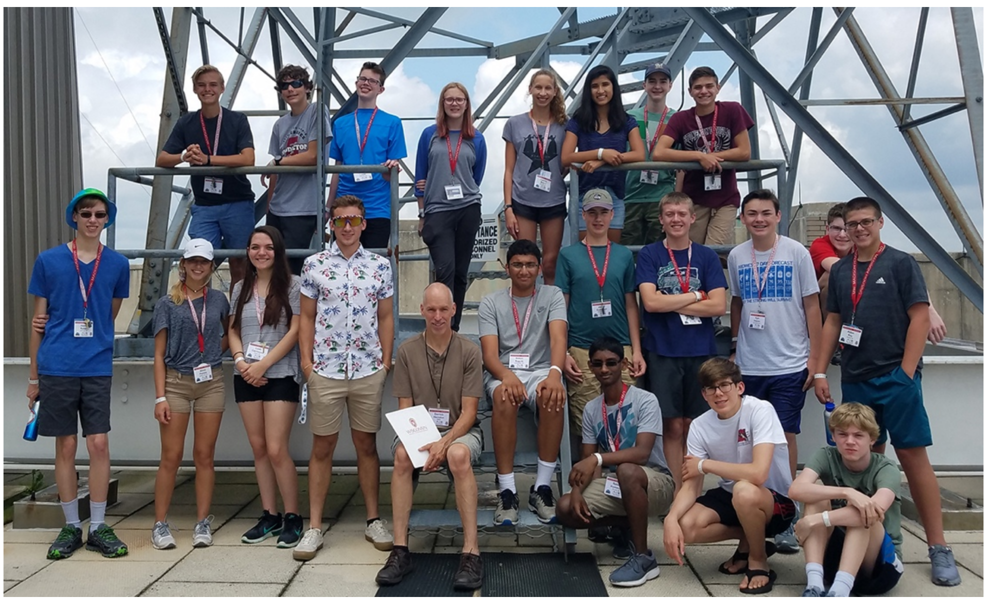


Figure 3. Group photo from the 2018 Student Workshop on Atmospheric, Satellite and Earth Sciences.

In autumn 2018, CIMSS launched a new citizen science project to leverage public fascination with the Aurora Borealis to raise awareness of the JPSS satellite series. The VIIRS-Aurora citizen science project features a new App called SatCamAurora, which enables ground truth observations of the Northern Lights at the same time and location that an Earth observing satellite carrying the VIIRS instrument is passing overhead. SatCamAurora observations will help scientists compare features on photographs captured from below with features revealed via the VIIRS Day/Night Band in satellite images, with location and timing coordinated by the App. SatCamAurora currently supports the Suomi-NPP and NOAA-20 satellites.

Finally, the **GOES-R Education Proving Ground** (http://cimss.ssec.wisc.edu/education/goesr/) continues to promote data and information from GOES-16 and GOES-17. Efforts over the past year involved establishing a Virtual Science Fair. With an eye toward the 2020 American Meteorological Society (AMS) Centennial meeting, the GOES-R Education Proving Ground purposely recruited New England educators in 2018 to participate and help develop guidelines for a spring 2019 Virtual Science Fair requiring students from grades 6-14 to use data from GOES-16 or GOES-17 to investigate weather and natural hazards. Three winning teams will be announced in June 2019: middle school, high school and grades 13/14. Students from the winning teams will receive $25 gift cards AND official GOES-T launch viewing invitations to KSC (but no travel support). Teachers coaching the winning teams will garner launch invites (no travel support) and conference travel support to attend and present at the AMS Centennial meeting in Boston.

Publications and Conference Reports

Mooney, Margaret. GOES-16/17 Virtual Science Fair, Symposium on Education, 28th, Phoenix, AZ 6-10 January 2019. American Meteorological Society, Boston, MA, 2018, Abstract 107.

Straka, William. VIIRS–Aurora–SatCam Citizen Science Project, Space Weather and Society: Education and Communication. Phoenix, AZ 6-10 January 2019. American Meteorological Society, Boston, MA, 2018.

3. CIMSS Participation in the Product Systems Development and Implementation (PSDI) and Enterprise Algorithm Maintenance for 2018

3.1 Polar Winds Products: Metop-C

CIMSS Task Leader: David Santek
CIMSS Support Scientist: Rich Dworak
NOAA Collaborator: Jeff Key
Budget: $41,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

This project supports the development of polar wind products using the AVHRR data from the Metop-C satellite. It also provides for collaboration with NESDIS in the transition of the polar wind products to NESDIS operations.

Project Overview

Satellite-derived wind fields are most valuable for the oceanic regions where few observations exist, and numerical weather prediction model forecasts are less accurate as a result. Like the oceans at lower latitudes, the polar regions also suffer from a lack of observational data. Since 2001 we have generated tropospheric wind vectors in the polar regions using the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites. We also generate winds from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA-15, -18, -19, and Metop-A and -B. Both the MODIS and AVHRR winds are operational.

In addition to Metop-A and -B, the recently launched Metop-C carries an AVHRR instrument. As part of NESDIS' Metop-C Operational Readiness project, we will (a) adapt the Metop-A, -B polar winds software for use with Metop-C, including changes to wind generation code and

BUFR encoder; (b) validate the Metop-C product; (c) work with users on testing product in models.

Milestones with Summary of Accomplishments and Findings

Metop-C was launched in early November 2018 and is currently flying in formation with Metop-A and -B, with a time separation ranging from 30-38 minutes between each satellite. To process the Metop-C data required changes primarily to the driver scripts, as the underlying winds code was already Metop-C ready. Also, changes were necessary to the BUFR encoder. All of these modifications are complete.

SSEC's Satellite Data Services acquires the Metop-C AVHRR data from NOAA, using the same procedures in place for all the other AVHRR real-time data. This allowed the polar winds team at CIMSS to begin deriving winds over the Arctic and Antarctic (Figure 4) soon after the data was available. The product utilizes the same technique that is applied to the AVHRR 11μ images from the other Metop and NOAA polar orbiting satellites. Initial evaluation of the Metop-C winds at CIMSS and Fleet Numerical Meteorology and Oceanography Center (FNMOC) indicate the quality is similar to the Metop-A and -B AVHRR polar winds. For example, the histogram of speed differences between Metop-C and Metop-B is as expected (Figure 5), with a bias of 0.10 ms^{-1} and RMS of 3 ms^{-1}. Moreover, the Metop-C winds are now being assimilated into the Navy operational global model.

Also, this three-satellite configuration provides a unique opportunity to apply the winds algorithm to three successive passes from different polar satellites, with a temporal resolution similar to geostationary satellites, resulting in a higher density of winds and increased spatial coverage. An example can be found here:
https://www.ssec.wisc.edu/~daves/MIXMETOP_anim.

Note: The Metop-C polar winds product currently uses the heritage winds algorithm. The transition to the cluster algorithm is ongoing.

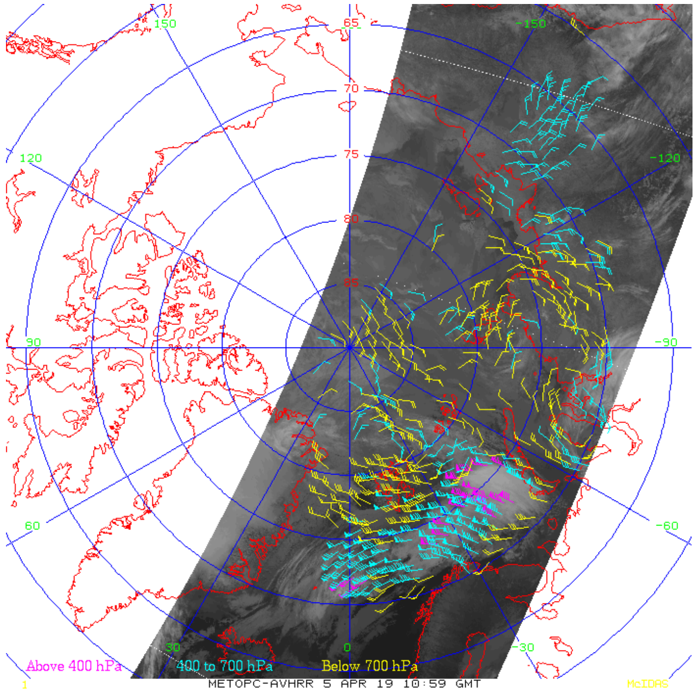


Figure 4. Cloud drift winds over the Arctic derived from a time sequence of Metop-C AVHRR 11µm images. The wind vectors are color-coded according to height as noted in the figure.

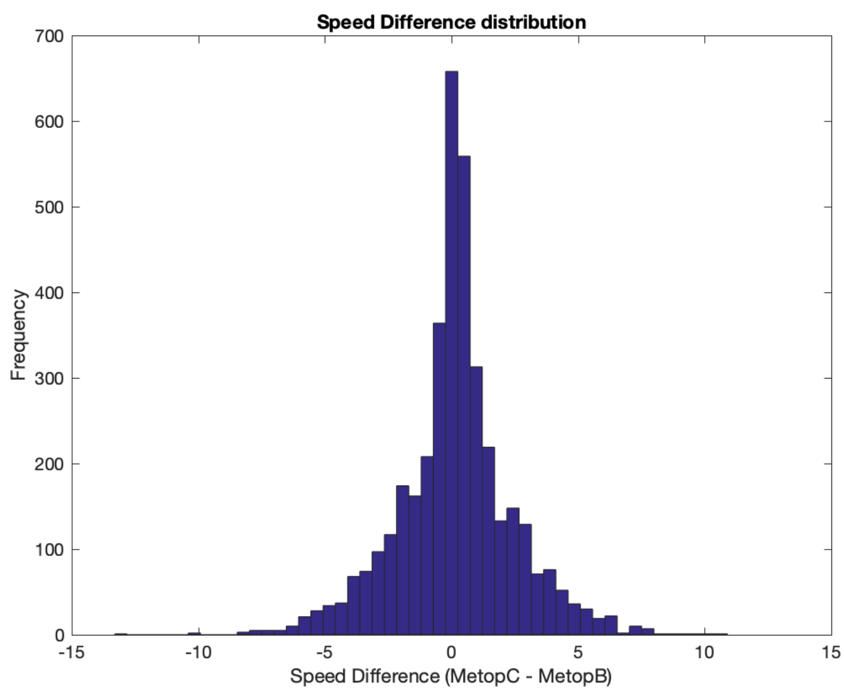


Figure 5. Histogram of speed differences between Metop-C and Metop-B for 02 April 2019 over the Arctic. The mean difference is 0.10 ms^{-1} with an RMS of 3 ms^{-1}.

3.2 Enterprise Snow Algorithm Evaluation and Migration
CIMSS Task Leader: Aaron Letterly

CIMSS Support Scientist: Yinghui Liu (first part of the year)
NOAA Collaborators: Jeff Key, Yinghui Liu
Budget: $75,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications

Objective
The goal of this project is to test, implement, and document the fractional snow cover (FSC) algorithm for the Advanced Baseline Imager (ABI). The ABI baseline product uses the GOES-R Snow Cover and Grain size (GOESRSCAG) algorithm, which employs an optimized spectral mixture analysis using two visible and three near-infrared bands. An operational algorithm that uses single-band reflectances to estimate fractional snow cover for the Visible Infrared Imaging Radiometer Suite (VIIRS) was also developed. This work evaluates both FSC products and will provide justification for one or the other to become the Enterprise algorithm for snow fraction derived from all NOAA optical instruments.

Project Overview
CIMSS has played the leading role in developing ice products for ABI. The snow cover algorithm was developed by members of the AWG Cryosphere Team at the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC) and the University of Utah (Tom Painter, now UCLA/JPL) (Dozier et al. 2009, Painter et al. 2009). For long-term maintenance of the algorithm it is decided that CIMSS and the NOAA Advanced Satellite Products Branch (ASPB) will take ownership of the software and documentation to ensure long-term viability as a NESDIS operational product.

Previous work has been focused on becoming familiar with the Fractional Snow Cover software package, documentation, and its test data. The software has been compiled, tested, and implemented at CIMSS. The team has developed an automated validation system for GOES-16 FSC. This tool routinely acquires snow cover products of different sources, including National Ice Center's Interactive Multisensor Snow and Ice Mapping System (IMS) Northern Hemisphere snow cover at 1 km and snow cover derived from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS) at 1 km over the Continental United States (CONUS) and southern Canada. These snow cover pixels are then remapped to the GOES-16 footprint and then IMS and SNODAS FSC at each GOES-16 footprint are calculated as the ratio of snow-covered pixels to all pixels. All of the acquired FSC products are then plotted and simple statistical comparisons with GOES-16 FSC are made. The GOESRSCAG (GOES-R Snow Cover And Grain Size) algorithm requires surface reflectance as inputs. The current products are derived using reflectance at TOA as inputs. We have implemented a system to generate near real-time FSC using surface reflectance and other products from MODIS as a proxy of GOES-R. MODIS surface reflectance product, MOD09, geolocation data, MOD03, and Level 2 cloud mask product, MOD35, are the inputs of this algorithm. In the MOD09 product, 5 bands (band 3, 1, 2, 6, and 7 of MODIS) are selected as proxy for GOES-R channels 1, 2, 3, 5, and 6. The output includes snow fraction and quality information. The algorithm is run daily on all MODIS overpasses over North America, and the retrieved snow fraction and its quality information for each overpass are archived. With the GOES-16 FSC becoming available soon, we are ready to calibrate/validate GOES-16 FSC against FSC from other snow products. In order to evaluate the accuracy of the product, we are using FSC estimates from higher resolution imaging systems (e.g., LANDSAT) under a variety of conditions and geographic areas.

Milestones with Summary of Accomplishments and Findings

The team has developed a method that remaps LANDSAT snow cover data to the GOES-16 footprint. The LANDSAT data, remapped to a 1 by 1 km grid, will be compared with the GOESRSCAG and the VIIRS algorithm output. Initially, MODIS data will be used as a proxy for ABI data. The high spatial resolution of the derived LANDSAT snow/ice concentration, seen in Figure 6, allows comparison to both algorithms on a pixel-by-pixel basis, which is not possible for other traditional snow cover products. We also implemented a system to generate a FSC from MODIS as proxy of GOES-R to test our validation/evaluation system, and we will be ready to test GOES-R FSC using surface reflectance when they become available soon. Figure 7 shows FSC using MODIS on March 30, 2019.

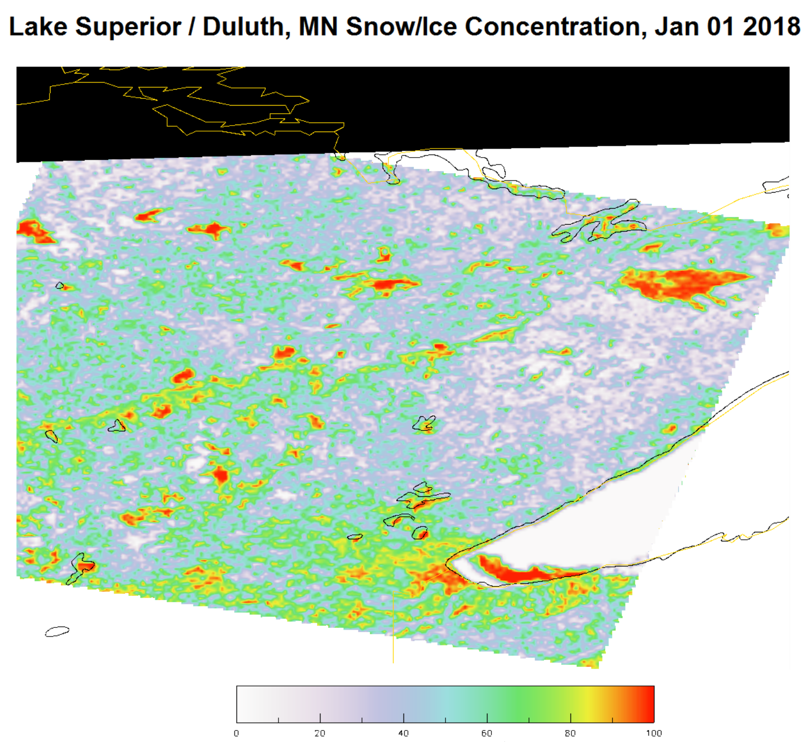


Figure 6. Snow/Ice Concentration from LANDSAT data over southern Lake Superior and Duluth, MN for comparison with GOESRSCAG output.

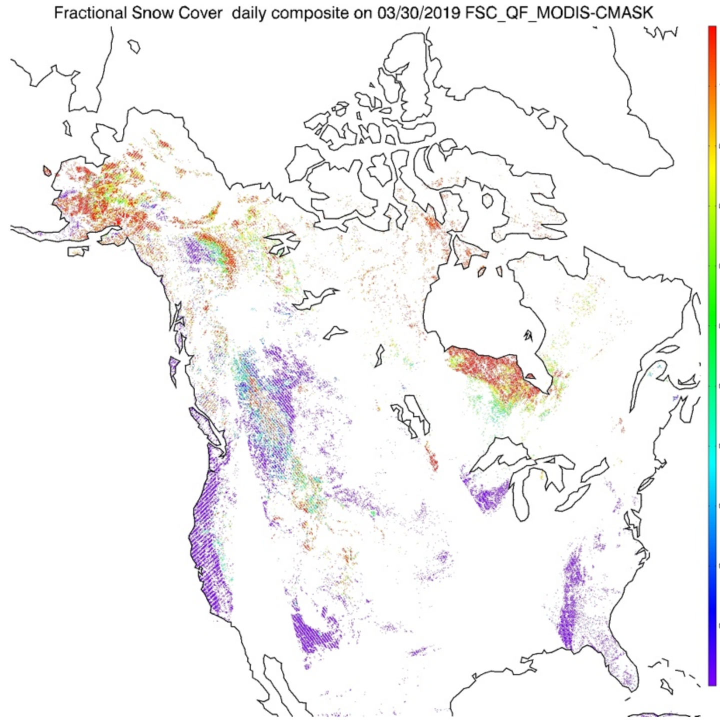


Figure 7. FSC daily composite from MODIS as a proxy of GOES-R on March 30, 2019.

Publications and Conference Reports

Yinghui Liu, Jeffrey Key, Aaron Letterly, Status of the GOES-R Fractional Snow Cover Product, 75th Annual Eastern Snow Conference, June 5-8, 2018, College Park, MD.

Yinghui Liu, Jeffrey Key, and Peter Romanov, Validation of the GOES-R Fractional Snow Cover Product, *The 99th AMS Annual Meeting,6-10 January 2019 Phoenix, AZ*

References

Dozier, J., R. O. Green, A. W. Nolin, and T. H. Painter (2009), Interpretation of snow properties from imaging spectrometry, *Remote Sensing of Environment*, doi: 10.1016/j.rse.2007.07.029.

Thomas H. Painter, Karl Rittger, Ceretha McKenzie, Peter Slaughter, Robert E. Davis, Jeff Dozier, 2009, Retrieval of subpixel snow covered area, grain size, and albedo from MODIS, *Remote Sensing of Environment*, 113, 868-879, 2009.

3.3 Blended Advanced Dvorak Technique (ADT) Upgrades
CIMSS Task Leaders: Chris Velden and Tim Olander
NOAA Collaborators: Jeff Key, Walter Wolf (STAR), Liqun Ma (OSPO)
Budget: $172,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society’s needs for weather and water

- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
This project addresses the operational transition component of the ADT, and will help carry the recent and expected improvements into the operational version now supported by NESDIS.

Project Overview
The Advanced Dvorak Technique (ADT) is an algorithm designed to provide objective estimates of hurricane intensity from GOES and other geostationary satellites. Its long-term development has been partially supported by GIMPAP, and the upgraded algorithm versions have been transitioned through previous PSDI efforts into NESDIS operations at the Satellite Analysis Branch. The National Hurricane Center (NHC) now routinely accesses the ADT data as part of its hurricane analysis suite of tools.

In support of the importance of the ADT in hurricane analysis at the U.S. operational centers, a joint User Request was submitted to the SPSRB by NHC, CPHC (Central Pacific Hurricane Center), and JTWC (Joint Typhoon Warning Center). The request, Request No: 1412-0015, Title: "Continue operational transition and upgrade support of the ADT," was approved by the SPSRB for funding considerations starting in FY16. The work performed in this PSDI project addresses the operational transition component, which will help carry the recent and expected improvements into the operational version now supported by NESDIS.

Milestones with Summary of Accomplishments and Findings
Efforts this year have focused on implementing the latest experimental ADT version code (V9.0) that will transition into the operational framework at OSPO. Specifically, new science/upgrades have been implemented, as well as operability with new satellites such as Himawari-8/9, GOES-16/17, F-19, GCOM and GPM. Experimental real-time testing and validation has been completed at CIMSS. An updated code package (ADT V9.0) was delivered during this reporting period. CIMSS is responding to periodic questions/tasks from the STAR Enterprise framework migration team.

3.4 CIMSS Support for MetOp-C/AVHRR Cloud Algorithm Product Development, Implementation, and Validation with the Enterprise Framework

CIMSS Task Leader: William Straka III
CIMSS Support Scientists: Andi Walther, Steve Wanzong
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis
Budget: $124,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation

- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Project Overview

The National Environmental Satellite, Data, and Information Service, Center for Applications and Research (NESDIS/STAR) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) have been developing a suite of products that will offer advanced cloud detection and retrievals of cloud properties utilizing the AVHRR instrument on-board the recently launched MetOp-C satellite. This will allow continuity of the current CLAVR-x products being routinely produced for all current polar orbiters with the AVHRR sensor. These algorithms are based on the enterprise algorithms originally developed for VIIRS and expanded to multiple sensors. The Cloud AWG has developed five algorithms that generate fourteen independent cloud products. These include the clear sky mask, cloud top phase, cloud top height, cloud top pressure, cloud top temperature, and daytime cloud microphysical properties.

Milestones with Summary of Accomplishments and Findings

The MetOp-C satellite launched on 7 November 2018 from French Guiana. In the subsequent months, the Cloud team has adapted the CLAVR-x processing system to operate on AVHRR on MetOp-C. Using the spectral response functions, the lookup tables for DCOMP have been generated and initially tested.

The images below show the visualization of DCOMP look-up-tables for ice and water phase.

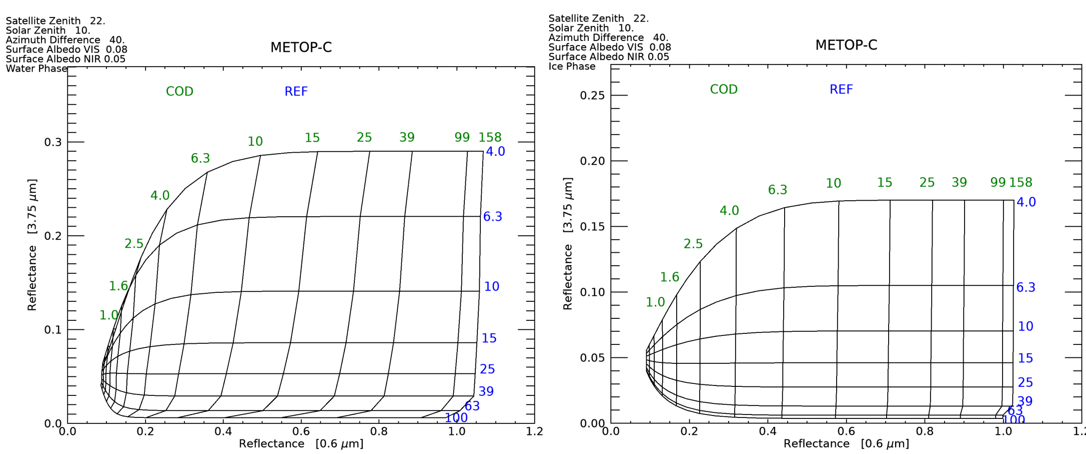


Figure 8. A visualization of DCOMP look-up-tables for ice and water phase.

Once enough data is collected, the algorithms will be validated with output from the SAPF. This will ensure the algorithms perform as expected. The Cloud AWG has extensively used other satellite sensors, such as spaceborne lidars, (CALIPSO), passive microwave satellite sensors (AMSU, AMSR-E), ground based lidars (HRSL), ground microwave profilers (MWR at ARM site) and passive imagers (MODIS, AVHRR), as independent validation data sources. In addition, the Cloud AWG has made extensive use of the lidar (CALIOP) on-board CALIPSO to tune the cloud mask for the least number of false detections.

In addition to offline validation studies, the cloud algorithms have been used in a near-real-time field campaigns as well as international workshops on cloud properties. For example, the cloud top height algorithm, which also relies on the cloud mask and type/phase algorithms, will be used during NOAA Shout Program (Sensing Hazards with Operational Unmanned Technology). Cloud heights are used to aid in flight path decisions for the Global Hawk Unmanned Aerial Vehicle (UAV) over and around the path of tropical cyclones.

3.5 Ice Product Checkout

CIMSS Task Leader: Xuanji Wang
CIMSS Support Scientist: Aaron Letterly
NOAA Collaborators: Yinghui Liu, Jeffrey Key
Budget: $50,000

NOAA Long Term Goals

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications

Objective

The goal of this project is to evaluate and support the operational ice products from geostationary satellites for weather, environment, and climate applications.

Project Summary

A few years ago, the National Weather Service (NWS) requested five new GOES-R products: Cloud Cover Layers, Aerosol Particle Size, Ice Concentration, Ice Thickness and Age, and Ice Motion. The NWS Operational Advisory Team (NOAT) identified these as the top new product priorities. The three ice products were implemented for the GOES-R Advanced Baseline Imager (ABI) and become operational in 2018.

The goal of this project is to evaluate the operational ice products from GOES-16. The primary users of the ice products are the National Ice Center (NIC), the National Centers for Environmental Prediction (NCEP), and NWS forecasters. CIMSS has played the leading role in developing ice products for ABI. The three ice products – ice concentration, ice thickness/age, and ice motion – were originally developed around 2008 as part of the GOES-R Algorithm Working Group (AWG) effort. They were delivered by the AWG for implementation in the Ground System in 2011. Due to funding cuts, further development and implementation of many GOES-R products, including the ice products, was ended. They were then termed "Option 2" products. Option 2 products were later called "future capability."

Work this project year has focused algorithm and documentation refinements before the products are operational, and a thorough evaluation ("checkout") of the operational products. We have improved our validation system, expanded the validation data sets to include similar ice products from other instruments, and implemented more robust statistical comparisons. We will continue to refine the retrieval algorithms if the checkout reveals any problems in the future as well.

Milestones with Summary of Accomplishments and Findings

We have worked together with GOES-R AIT team to test, validate, and improve the all algorithms of ice concentration, temperature, thickness/age, and motion products to ensure the all ice products meet the requirements. All of the ice product algorithms have been updated, implemented, and validated with other similar ice products from different resources including MODIS, AMSR2, CryoSat-2, and EUMETSAT Oceans and Sea Ice Satellite Applications Facility (OSI-SAF).

The GOES-R NOAT Cryosphere Products Algorithm Readiness Review (ARR) was held March 3, 2019. Participants from STAR presented the risks and actions, requirements, software architecture, and the algorithm package for three Advanced Baseline Imager (ABI) products: ice concentration, ice thickness and age, and ice motion. The algorithm developers at CIMSS and STAR presented validation results for those products. The results were positive, with all products meeting accuracy requirements. Figure 9 shows an example of the ice thickness from NOAA-19 and GOES-R ABI and their differences, which are small, less than 2% overall.

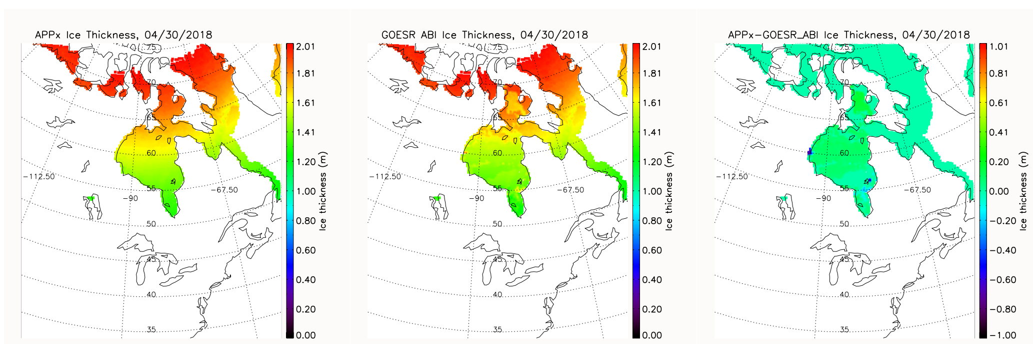


Figure 9. Ice thickness from NOAA-19 (left), GOES-R ABI, and their difference (right) for the Hudson Bay area on April 30, 2018.

Figure 10 shows an example of the ice motion data product from GOES-R ABI regrided output, OSI-SAF, and the local AMSR2 motion output for the Hudson Bay area by day-of-year (DOY) 039-040 in 2018. Some cloud interference can be seen on western shoreline.

Figure 11 shows an example of ice concentration validation results. The GOES-R ABI ice concentration matches the AMSR2 ice concentration well enough to satisfy the requirement of 10% accuracy and 25% precision.

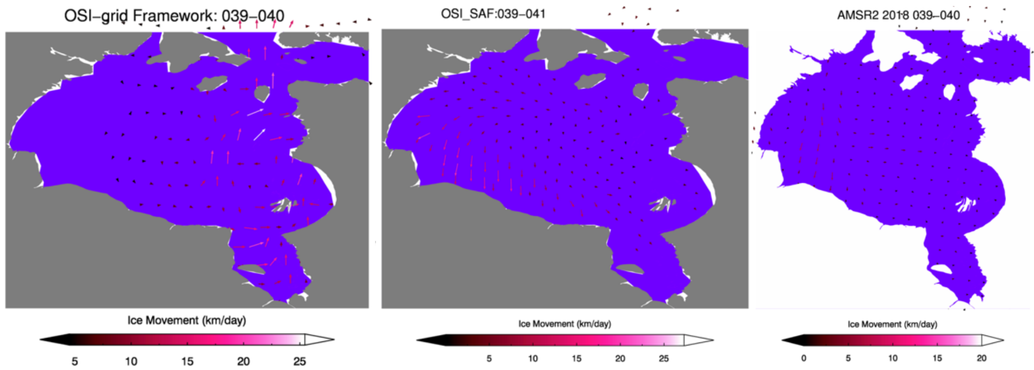


Figure 10. Ice motion from GOES-R ABI, OSI-SAF, and local AMSR2 on the Day of Year (DOY) 039-040 in 2018.

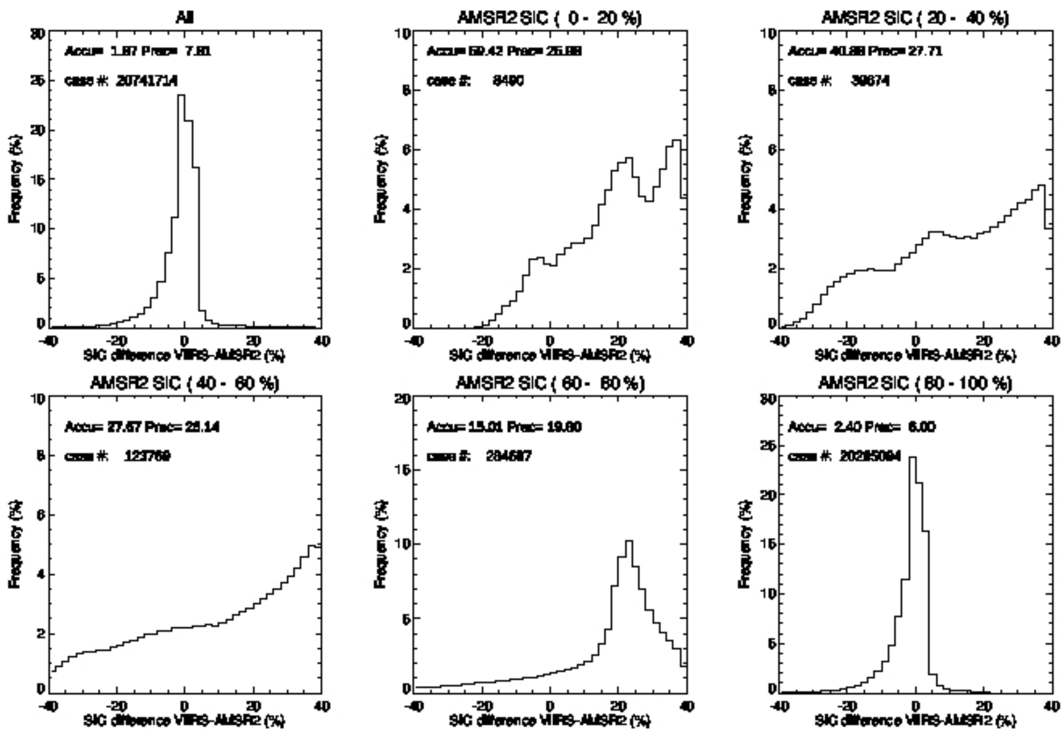


Figure 11. The relative frequency of the differences in ice concentration between GOES-R ABI and AMSR2 in terms of ice concentration value range bins and all (upper left one).

Publications and Conference Reports

J. Key, Y. Liu, X. Wang, A. Letterly, and T. Painter, 2019, Snow and Ice Products from ABI on the GOES-R Series. In Geostationary Weather Satellites, S. Goodman, T. Schmit, J. Daniels, D. Reynolds, and R. Redmond (eds.), Elsevier (forthcoming).

References

Xuanji Wang, Jeffrey Key, Ron Kwok, Jinlun Zhang, 2016, Comparison of Sea Ice Thickness from Satellites, Aircraft, and PIOMAS Data, Remote Sens., Special Issue: Sea Ice Remote Sensing and Analysis, 2016, 8(9), 713; doi:10.3390/rs8090713.

Xuanji Wang, Jeffrey Key, and Yinghui Liu, 2010, A thermodynamic model for estimating sea and lake ice thickness with optical satellite data, J. Geophys. Res., Vol. 115, C12035, 14 PP., doi:10.1029/2009JC005857.

3.6 Algorithm Integration Team Technical Support

CIMSS Task Leader: R. Garcia
CIMSS Support Scientists: G. Martin, E. Schiffer, W. Straka, A. De Smet
NOAA Collaborators: M. Pavolonis, W. Wolf
Budget: $215,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Provide integration and technical support for the GOES-R Algorithm Working Group teams at CIMSS.

Project Overview

The AIT-Midwest handles aspects of computer science cross-cutting AWG algorithm development teams at CIMSS/SSEC, and works in cooperation with the ASSISST team in Washington, DC. This includes software development practices, software process management, documentation, testing and automation, infrastructure, general computing assistance, and systems design and optimization.

Principal Activities:

- Review and update software and deliverables with CIMSS science staff, for integration by NESDIS STAR ASSISST, in support of updates to GOES-R development environment (DE).
- Maintain, extend, and deploy verification and automation test tools in coordination with ASSISST.
- Provide guidance to science staff to improve computer science aspects of algorithm reference software, including authoring tools, example implementations and libraries.
- Provide test data, software, storage and computing resources as needed for GOES-R series verification, validation, integration and research uses within CIMSS/SSEC.
- Feedback and technical interchange with ASSISST and Harris/AER regarding computer science concerns and verification of algorithm implementations and operational framework interfaces.
- Profile reference algorithm implementations and explore performance, accuracy, and reproducibility improvements.

Milestones with Summary of Accomplishments and Findings

- Continued work on verification testing of updated CIMSS reference algorithms in SAPF (STAR Algorithm Processing Framework) for use at NOAA.
- Verified algorithm fixes for Baseline Algorithms
  - Primarily this dealt with updates to the Cloud Mask algorithm, but also included other algorithms including Fires and DCOMP
- Improvements to Glance verification toolset, responding to AWG and ASSISST team requests and objectives. Released ready-to-install Glance 0.3.5 to AWG, ASSISST, and OSPO teams, improving support for operational ABI data formats.
- Supported Harris test product verification, providing necessary feedback. This included support the GOES-R Ground Segment Project with the verification of the Level-2 product output generated by the GOES-R Ground Segment Contractor (Harris), as well as familiarization and review of Level-2 product software developed by the GOES-R Ground Segment Contractor (Harris / AER).
- Assisted in the verification of GOES-17 mitigation assessments. These included the Band 2 (0.64um) radiance adjustment as well as the implementation of the Temperature DQF within the GS. This involved assessing the impact of the invalid mask on L2 products once the TDQF was implemented.
- Continued maintenance on 'libHimawari' C/Fortran/Python callable toolbox used for algorithm development systems to access Himawari Standard Data and HimawariCast formats.
- Development of additional framework-agnostic reusable libraries, including an ABI scan-line-time generator.
- Tool and library development to assist in visualizing, navigating, verifying, and manipulating ABI and AHI data in Product Users Guide (PUG) conformant files.
- Technical and product feedback to GOES-R PRO team regarding ABI and associated products.
- Acquired and distributed test and ancillary datasets in support of AWG deliverables, validation, and verification.
- Continued involvement in SAPF reference framework development and maintenance, including work toward "container-ized" build and deployment options for science software as used both within and outside CIMSS/SSEC.
  - This includes CIMSS configuration management, build and execution automation for the SAPF. This will provide routine local processing of the SAPF specifically for CIMSS AWG uses.
  - Integration activities for CIMSS algorithm updates for delivery to ASSISST.
- Familiarization and testing of SAPF 2.0, a substantial ASSISST re-engineering effort encompassing performance and flexibility improvements.
- Management and coordination of schedules, deliveries, software configuration items in cooperation with AWG and Harris/AER.
- Participated in ongoing training for ground segment Algorithm Test Tools (ATT).
- Supported the storage and distribution of GOES-16 PDA and GRB for GOES-16 datasets as well as Himawari-8 HSD/HimawariCast datasets for verification, validation, integration and research uses within CIMSS/SSEC. This includes acquisition of further storage-area-network (SAN) resources at CIMSS/SSEC to buffer multiple weeks of ABI and AHI for cluster and workstation use by researchers.
- Worked with scientists and SSEC Data Center staff to further deploy AMQP-based messaging architecture for event-driven production of test data and experimental products.

3.7 JPSS Risk Reduction Algorithm Integration Team Midwest
CIMSS Task Leader: W. Straka
CIMSS Support Scientists: R. Garcia, G. Martin
NOAA Collaborator: W. Wolf
Budget: $390,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications

Objective
Provide integration and technical support for the integration of the Enterprise algorithms for JPSS.

Project Overview
For GOES-R, a substantial number of algorithms have been researched, implemented and demonstrated for operational integration. As a risk reduction to JPSS, NOAA is selecting and applying compatible GOES-R algorithms to demonstrate pseudo-operational processing capability using JPSS sensor data, by adapting the NOAA SAPF implementation and science software. JPSS AIT Midwest is principally a programming and integration support group providing computing, coding and process expertise in order to bridge research to operations and preserve algorithm interoperability, to assist science teams in developing and adapting algorithms for JPSS and to prototype and develop common software facilities and infrastructure.

Activities
- Provide coding expertise, design input, and review for enhancements to AIT framework.
- Continue development of algorithm testbed (Geocat) and common algorithm interface and infrastructure as needed to support SNPP / JPSS algorithms
- Assist in validation and verification of test products, including comparisons with IDPS products.
- Develop any required testing tool enhancements required to validate or verify SNPP products processed with adapted GOES-R algorithms.
- Improve compatibility (algorithm APIs, libraries and components, toolsets) as needed between research, pseudo-operational, and IDPS operational systems.

Milestones with Summary of Accomplishments and Findings
- Integrated and verified updates to the CIMSS JPSS Enterprise algorithms to STAR Algorithm Processing Framework (SAPF). This included all of the Cloud algorithms, Volcanic Ash, and several of the cryosphere algorithms for use with JPSS instrumentation.
- Successfully compiled and ran SAPF 1.0 and 2.0 locally at CIMSS for use by JPSS algorithm developers; assisted scientists in performing integration and testing work on

up-to-date SAPF code drops. SAPF 2.0 is the next iteration of the SAPF, which will support parallel processing, which has a significant impact on processing time.
- Provided coding expertise, design input, and review for enhancements to SAPF.
- Continued development of algorithm testbed (Geocat and CLAVR-x) and common algorithm interface and infrastructure as needed to support SNPP / JPSS algorithms.
- Assisted in validation and verification of test products, including comparisons with IDPS products.

3.8 JPSS VIIRS Derived Winds Validation and Science for 2018

CIMSS Task Leader: David Santek
CIMSS Support Scientists: Rich Dworak, Steve Wanzong
NOAA Collaborator: Jeff Key
Budget: $55,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society’s needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
The VIIRS polar winds product is currently operational for the Suomi National Polar-orbiting Partnership (S-NPP) satellite and provides wind speed, direction, and pressure of cloud-tracked features at high latitudes. This project will provide validation and science support for the S-NPP and NOAA-20 product. Adjustments to the algorithm will be made, as necessary, and long-term monitoring tools will be developed.

Project Overview
The Suomi National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) polar winds product provides wind speed, direction, and pressure of cloud-tracked features at high latitudes. The VIIRS winds have been produced operationally by NESDIS since May 2014 and are also being distributed via the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) EUMETCast broadcast. The VIIRS winds are being assimilated in the Naval Research Lab's (NRL) Atmospheric Variational Data Assimilation System - Accelerated Representer (NAVDAS-AR) and are currently being monitored in NCEP’s pre-operational version of the Global Data Assimilation System/Global Forecast System GDAS/GFS. They are also used by some numerical weather prediction centers abroad.

The objective of this project is to continue to assess the quality of the operational S-NPP VIIRS winds and begin monitoring and validation of VIIRS winds from the first Joint Polar Satellite System (JPSS) satellite (JPSS-1), now NOAA-20. Deficiencies will be identified, and solutions proposed. Improvements will be explored, though the project is not intended to support extensive, basic research.

Scientists from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) will work with NOAA scientists in Madison and Washington, D.C. to jointly address validation methodologies, develop monitoring tools, and explore algorithm improvements.

Milestones with Summary of Accomplishments and Findings

The primary tasks for 2018 were to:

1. Routinely generate S-NPP and NOAA-20 VIIRS winds at CIMSS,
2. Provide any code changes to NOAA,
3. Implement long-term monitoring tools for the real-time winds product, and,
4. Revive wind production at the Sodankylä direct broadcast site.

Progress was made on all of these tasks and is described in the following paragraphs, except for #4 which is on hold pending the completion of packaging the code in a Docker container, which is described in Section 3.10.

We are routinely generating and monitoring VIIRS polar winds from both S-NPP (Figure 12) and NOAA-20 (Figure 13) using the same algorithm developed for GOES-R and used in the operational S-NPP VIIRS winds processing. With the two satellites in the same orbital plane but delayed in time by ½ orbit (approximately 50 minutes), there is substantial overlap in the winds geographic coverage, which results in very good statistical comparisons over the polar regions. Generally, there is good agreement: The NOAA-20 VIIRS winds at both poles are about 0.10 ms^{-1} faster than those from S-NPP, with an RMS difference of 2.0 ms^{-1} in the Arctic and 2.5 ms^{-1} in the Antarctic. These statistical comparisons are produced daily for each pole; the figures shown below are produced for each pass over the polar regions, for both satellites.

Code changes were necessary in the CIMSS environment, since we ported the code from Intel Fortran (IFORT) to gfortran/gcc and changes were also needed to accommodate NOAA-20. The modifications included the handling of array for writing netCDF files, latitude values out of range when computing the Quality Indicator (QI), and updates for NOAA-20. These modifications were communicated to our colleagues at NOAA/STAR.

The experimental shortwave infrared (SWIR, 2.1 μm) winds that were demonstrated for the JPSS-PGRR proposal continue to be developed and tested. MODIS is still being used due to its availability, but the processing will be switched to VIIRS in the near future. An example comparing the SWIR winds to water vapor (6.7 μm) and infrared window (11 μm) winds is shown in Figure 14. New statistics comparing the various winds are given in Table 1, demonstrating that the SWIR winds are high quality.

Table 1. Statistics for MODIS Aqua and Terra SWIR and IR winds, Arctic only, Apr-Sep 2017, for collocated vectors (within 10 km).

	Count	SWIR Vector RMSE	IR Vector RMSE	SWIR Mean Pressure	IR Mean Pressure
Aqua	645	6.02	6.26	535.91	526.71
Terra	838	5.87	6.08	532.52	519.09

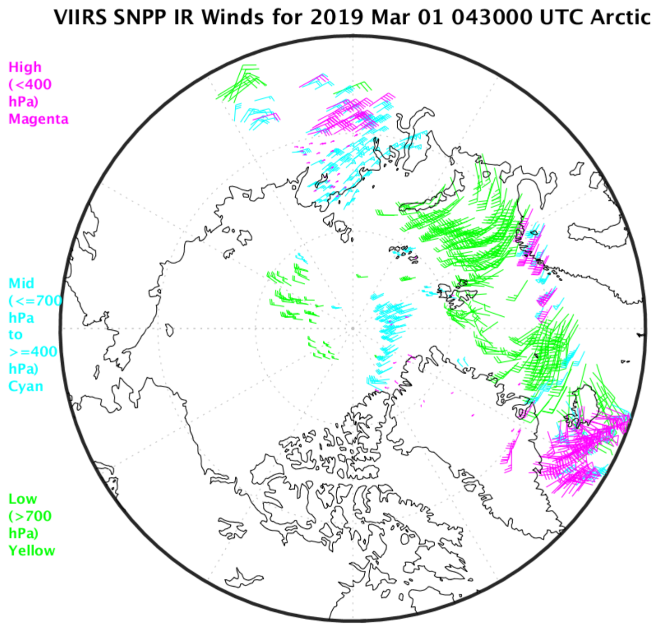


Figure 12. Satellite-derived VIIRS winds from S-NPP on 01 March 2019 at 0430 UTC.

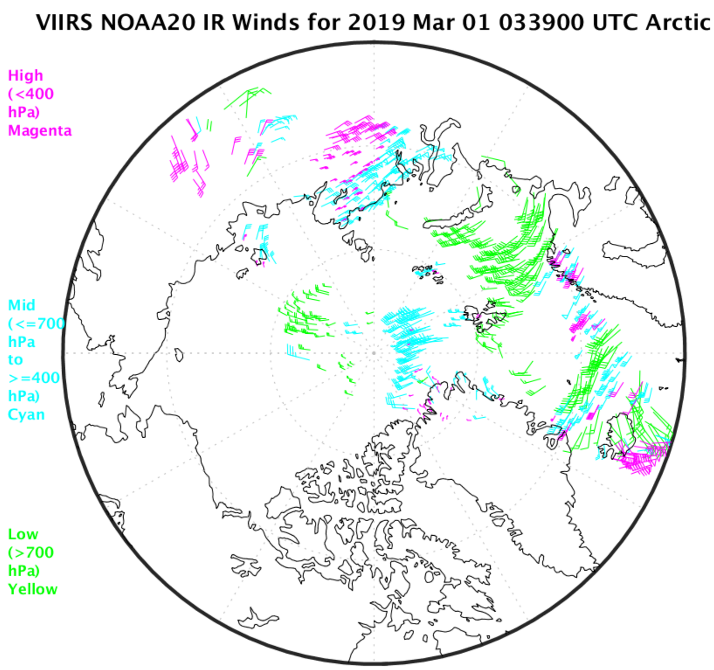


Figure 13. Satellite-derived VIIRS winds from NOAA-20 on 01 March 2019 at 0339 UTC.

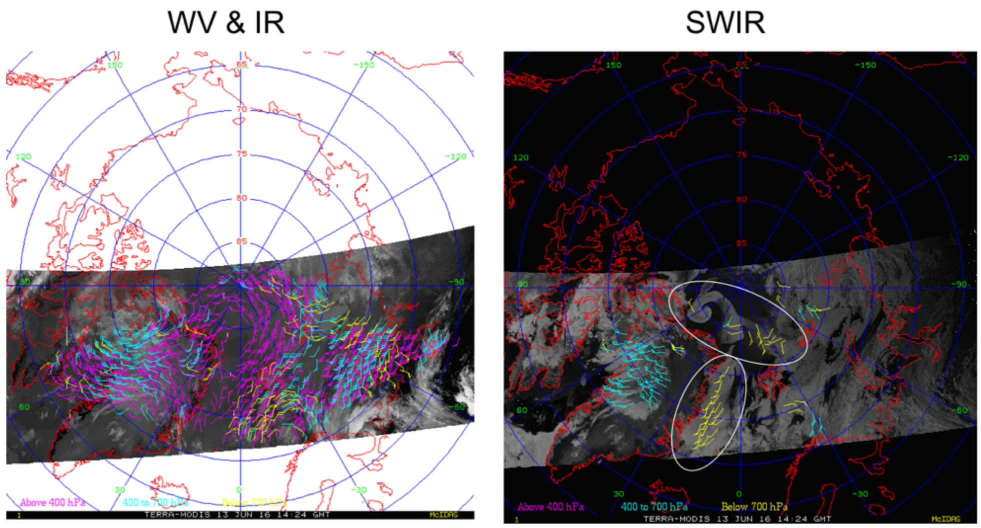


Figure 14. Water vapor and infrared (cloud-track) winds from MODIS (left), and SWIR winds for the same scene (right).

Publications and Conference Reports

The VIIRS winds products were presented 14th International Winds Workshop, Jeju City, South Korea, 23-27 April 2018. At IWW14. The future tandem winds product was briefly discussed.

3.9 JPSS Cal/Val Support – Volcanic Ash EDR

CIMSS Task Leader: Justin Sieglaff
CIMSS Support Scientist: Jason Brunner
NOAA Collaborator: Michael Pavolonis
Budget: $48,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

The team will validate, maintain, and improve the JPSS Volcanic Ash EDR.

Project Overview

Volcanic ash is a major aviation hazard. Satellites are the primary tools used to identify, track, and characterize volcanic ash clouds. The VIIRS sensor on the S-NPP and JPSS satellites is key for identifying volcanic ash emissions. As such, a requirement for a JPSS volcanic ash Environmental Data Record (EDR), at the VIIRS spatial resolution, was established for the NDE system. The algorithm used to produce the JPSS Volcanic Ash EDR in NDE is similar to the algorithm utilized within the GOES-R Ground System. Currently, only VIIRS data are utilized to generate the Volcanic Ash EDR, which consists of ash loading, height, and effective radius products. The goals of this project are to validate, maintain, and improve the JPSS Volcanic Ash EDR. Validation is primarily accomplished through regular comparisons with space borne lidar measurements, either by direct or vicarious means. The insufficient matchups of volcanic observations from NOAA-20 VIIRS and space borne lidar required comparisons between SNPP and NOAA20 volcanic ash EDRs and wind-height validation techniques. Maintenance is achieved through the provision of optimized thresholds and look-up tables for each JPSS satellite, and by ensuring that the thresholds and LUTS remain optimal over time. This project also seeks to improve the JPSS Volcanic Ash EDR through incorporation of CrIS measurements.

Milestones with Summary of Accomplishments and Findings

- Assembled collection of non-trivial NOAA-20 VIIRS observations of volcanic ash used in validation analysis for the provisional review. This included 8 cases, totaling 2,739 ash pixels.
- NOAA-20 volcanic ash EDR was validated using a wind-height technique. The wind-height technique utilizes motion (speed and direction) of volcanic ash clouds derived from geostationary imagery. The speed and wind estimate of the ash cloud is then compared to nearby radiosondes, and should sufficient vertical wind shear be present, a range of possible heights is determined for the ash cloud (generally in layers 500 to 1500 m). The wind-height derived range of heights is then compared to the volcanic ash EDR height estimates. Figure 15 shows the NOAA-20 volcanic ash EDR ash heights agreed well with the wind-height ranges, with best-case mean error of -1.25 km and worst-case mean error of -2.00 km, both well within the 3 km specifications. The mass loading analysis (not shown) also was within the product specifications.
- NOAA-20 volcanic ash EDR validation was complimented with a comparison to S-NPP volcanic ash EDRs (the two satellite orbits are only separated by 50 minutes). The analysis shown in Figure 16 shows very good agreement between NOAA-20 and S-NPP volcanic ash height and mass loading EDRs.
- The review panel favorably received the validation analysis presented at the NOAA-20 Provisional review and the NOAA-20 volcanic ash EDRs were declared at provisional maturity.

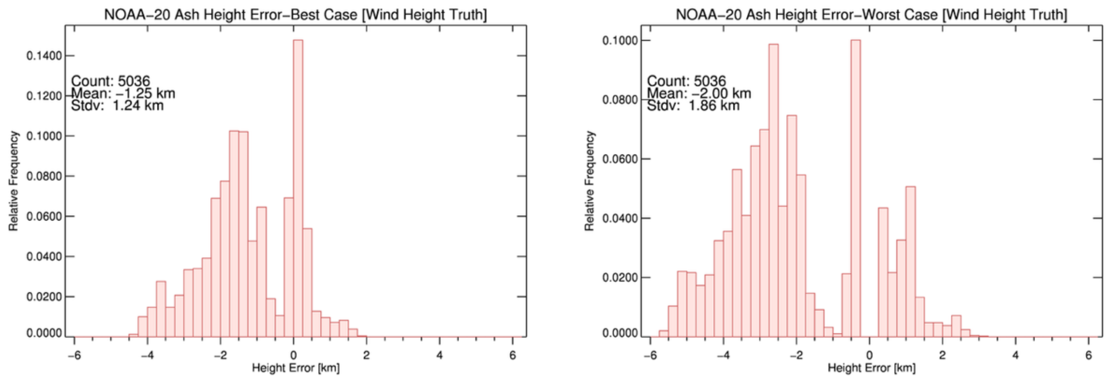


Figure 15. NOAA-20 volcanic ash height EDR error relative to wind-height derived truth prepared for the NOAA-20 provisional volcanic ash EDR review. The left panel is the best case (where wind-height truth and EDR difference is minimized) and the right panel is the worst case (where wind-height truth and EDR difference is maximized). The mean differences -1.25 km for best case and -2.00 km for worst case, both fall well within the 3 km specification.

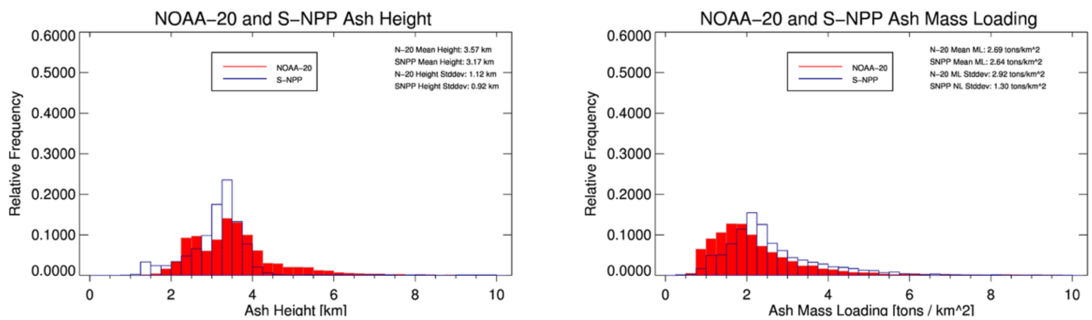


Figure 16. NOAA-20 and S-NPP volcanic ash EDR comparisons for ash height (left) and ash mass loading (right) prepared for the NOAA-20 provisional volcanic ash EDR review. S-NPP and NOAA-20 ash EDRs exhibit very good agreement.

References

Pavolonis, M. J., A. K. Heidinger, and J. Sieglaff (2013), Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, *J. Geophys. Res. Atmos.*, **118**, doi:10.1002/jgrd.50173.

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures. Part I: Theory. *J. Applied Meteorology and Climatology*, **49**, 1992-2012.

3.10 Updates for JPSS-1 VIIRS Derived Motion Winds
CIMSS Task Leader: David Santek
CIMSS Support Scientists: Steve Wanzong, Rich Dworak
NOAA Collaborator: Jeff Key
Budget: $50,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

The objective of this project is to continue to work with STAR scientists and contractors to maintain and update the VIIRS winds code at CIMSS, validate the VIIRS winds product using radiosondes and intercomparison with other polar winds, and deploy and maintain the software at Direct Broadcast (DB) sites.

Project Overview

The VIIRS polar winds product is currently operational for the Suomi National Polar-orbiting Partnership (S-NPP) and NOAA-20, and provides wind speed, direction, and pressure of cloud-tracked features at high latitudes. These winds, based on the infrared window channel, have been produced operationally by NESDIS since May 2014 and are also being distributed via the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) EUMETCast broadcast.

To realize product improvement, not only will the base algorithm be updated, but the addition of other spectral bands may provide complementary information. For example, low-level winds can be extracted from the shortwave IR band during polar summer and potentially year-round from the Day/Night Band (DNB). These additional channels will be investigated and quality of the derived AMVs quantified.

Another area for product improvement, is improved latency. At this time, the operational product is delayed several hours from real-time. By running the algorithm at DB reception sites, the delay is on the order of an hour or less. However, deploying the winds code at remote sites is problematic due to differences in operating systems, remote access restrictions, etc. Therefore, we are investigating ways to package the algorithm for ease in deployment.

Milestones with Summary of Accomplishments and Findings

We continue to work with STAR scientists and contractors to keep the version that runs at CIMSS to be as close as possible to the NESDIS operational version. Also, we communicate any code modifications we've made back to STAR, due to compiler differences (Intel Fortran vs. gfortran).

Since the code is occasionally improved and updates provided, we also continually monitor the quality of the winds product as compared to radiosondes and other polar winds product. An example of the comparison is shown in Figure 17, which depicts speed differences for co-located AMVs from NOAA-20 VIIRS and Terra MODIS. A bias of nearly zero and a low RMS of 2.7 ms^{-1} indicates good agreement between these products. Comparison to rawinsondes from 18 December 2018 through 28 February 2019 indicate an accuracy of 5.91 ms^{-1} over the Arctic (5.39 ms^{-1} over the Antarctic). As additional spectral bands are added to derive winds, these monitoring tools can be easily updated.

Progress has been made in our ability to more easily deploy the software to DB sites. We are currently testing a 'containerized' version of the winds code using Docker. Unlike a Virtual Machine (VM) which is a hardware virtualization (think, a virtual computer), a container virtualizes at the operating system level, which should make it easier to maintain, deploy, and configure in varied environments compared to a VM.

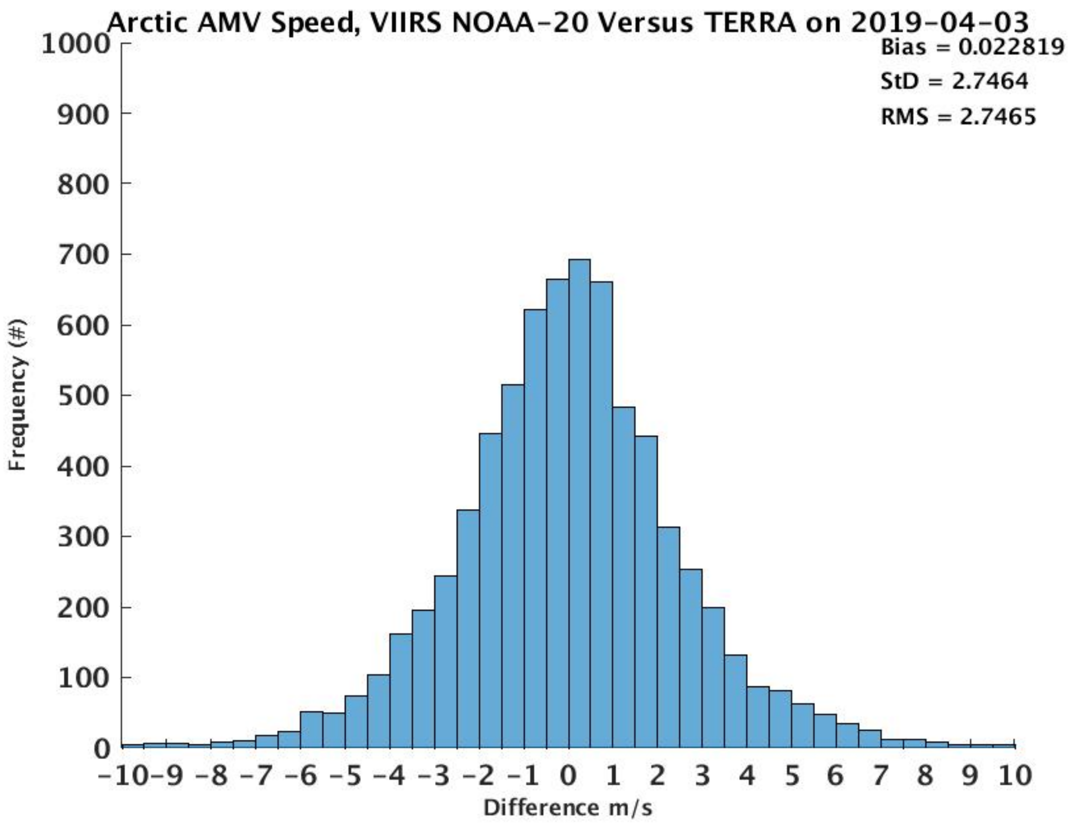


Figure 17. Histogram of Arctic AMV speed differences between NOAA-20 VIIRS and Terra MODIS on 3 April 2019.

4. CIMSS Participation in the GOES-R Algorithm Working Group (AWG) for 2018-2019

4.1 ABI Cloud Products

CIMSS Task Leader: William Straka III
CIMSS Support Scientists: Denis Botambekov, Corey Calvert, Pat Heck, Jay Hoffman, Yue Li, Andi Walther, Steve Wanzong
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis
Budget: $425,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

To develop techniques for advanced cloud detection and retrievals of cloud properties using the ABI.

Project Overview

The National Environmental Satellite, Data, and Information Service, Center for Applications and Research (NESDIS/STAR) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) have been developing a suite of products that will offer advanced cloud detection and retrievals of cloud properties utilizing the GOES-R ABI instrument. The Cloud AWG has developed five algorithms that generate fourteen independent cloud products. These include the clear sky mask, cloud top phase, cloud top height, cloud top pressure, cloud top temperature, and both day and nighttime cloud microphysical properties.

Milestones with Summary of Accomplishments and Findings

The focus of the Cloud AWG this reporting period was maintaining and updating the various algorithms, validating the updated algorithms and supporting the GOES-R Ground Segment System Prime, Harris Corporation, in their implementation of the cloud algorithms. This primarily meant observing the cloud products produced from the Ground System and evaluating their operational readiness.

The various cloud algorithms have been, or are in the process of, being adapted for sensors other than ABI. These include the current GOES GVAR sensors, COMS, Himawari-8 (ABI like imager), Meteosat SEVIRI, MODIS, VIIRS as well as making sure that the baseline algorithms work on the GOES-16 Advanced Baseline Imager (ABI) datasets. In addition, work began on evaluating cloud algorithm output from the GOES-16 Ground System (GS) starting in early 2017 and continued throughout the post launch period.

Cloud Mask

Several issues were found and addressed with the BCM during the post launch checkout as the PLPTs were being run. This included fixing several cloud mask tests which were not performing as expected as well as updating the cirrus reflectance test and fixing the issue regarding false cloud due to fresh snow missing from the ancillary snow mask data. In addition, analysis on the BCM performance once the correction to the 0.64 μm reflectance, which is currently too bright, was done. The analysis show that, even in the brightest times of the day, there is negligible impact on the BCM, as can be seen in the comparison between the development environment, which had the reflectance correction applied, and the operational environment, which was ~6.9% to bright.

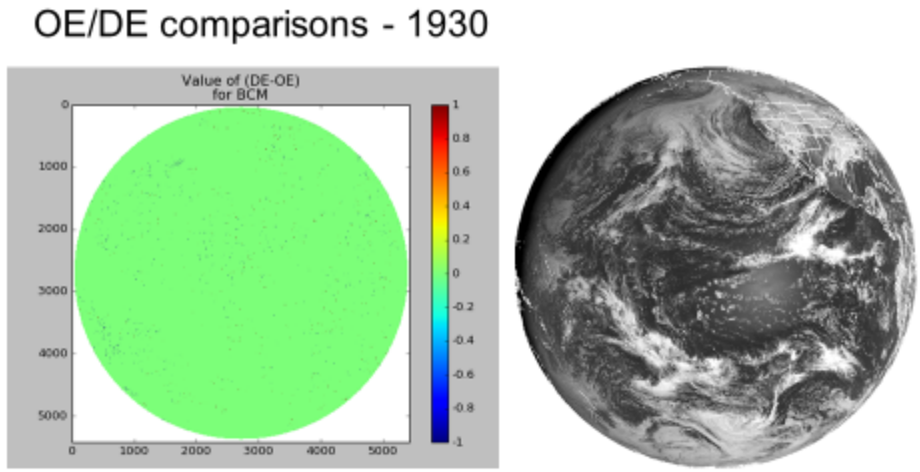


Figure 18. Comparison of the BCM from the GOES-R Development environment (which had the reflectance correction applied) and Operational environment from 6 March 2019 at 1930Z.

CIMSS developed a web page that shows GOES-16 and GOES-17 level2 product trends. Included are ACMF (full disk cloud mask), CTPF (full disk cloud top pressure), CODF (full disk cloud optical depth), and CPSF (full disk cloud effective radius). This page is located at the following address: http://cimss.ssec.wisc.edu/clavrx/goesr_img/trend.html. Weekly, monthly, and seasonal plots are available. Standard deviation plots are also included. It is a useful tool in helping to point to potential issues on any given day. Figure 19 shows the GOES-16 cloud mask from April until the end of 2018. Except for a period in June, the mask, for GOES-16 has remained stable.

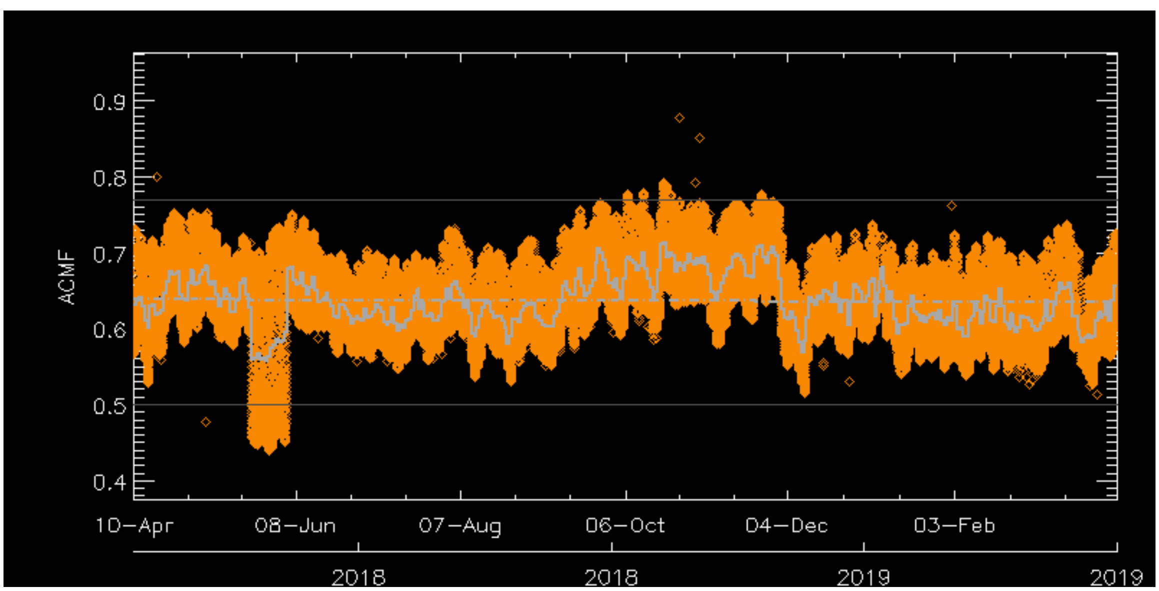


Figure 19. Trend plot of the operations GOES-16 baseline cloud mask for 2018. Note that issues in June were identified and determined to be a ground system issue and fixed by PRO.

The primary focus, though, has been on the GOES-17 analysis due to the loop heat pipe (LHP) issue that was discovered. Mitigation work started in August 2018 and continues. While the GOES-16 Full validation date has been pushed back, the GOES-17 Provisional date has been set for May 2019. At this time, validation during the “cool” period of the day will be presented while mitigation work continues through 2020. GOES-17 discussion can be found in section 5.1 of this report.

Cloud Top Phase

During the previous reporting period the AWG cloud team provided analysis showing the cloud phase product comfortably meets the ABI RIMP requirement of a measurement accuracy of 80% correct classification when compared to the CALIOP cloud top phase product. However, some situational performance issues that impact downstream products and may impact downstream user applications we also discovered. One such issue is that liquid water cloud edges are sometimes misclassified as ice clouds. Another issue is developing cumulus clouds and mid-level clouds are too often classified as ice. These may contribute to the over-estimation of the cloud height produced by downstream algorithms.

Based on previously published research, preliminary work has begun to incorporate near-infrared measurements to mitigate the misclassification of liquid clouds as ice. Inclusion of the 1.6μm and 3.9μm near-infrared channels, along with high-resolution (0.5km) 0.65μm visible reflectance channel, has produced positive results. However, the use of near-infrared measurements is complicated by highly variable surface reflectance and sun geometry and will likely contribute to inconsistencies in the cloud top phase product through the diurnal, and seasonal, cycle. For this reason further guidance on the application of these algorithm enhancements will be necessary.

Cloud Top Parameters

The Derived Motion Winds (DMW) team is reliant on accurate CTP products in their algorithms. From the DMW Provisional discussion, there are sub optimal cloud height assignments causing precision specifications to be missed in the 350 – 500 hPa layer, negative speed biases in the upper levels, and positive speed biases in the middle levels. A library of outlier cases is being built by the DMW team which will allow the Cloud team to address the height assignment issues. However, the CTP products still need to attain a balance between meeting CTP requirements, as well as providing accurate products for the DMW team. Future work will include diagnosing the reasons why these outlier cases are failing to deliver accurate cloud heights during the retrieval process. To address this, the GOES-R Ground System has a pilot project to replace the Baseline Cloud Height Algorithm with the Enterprise Cloud height Algorithm (ACHA) within the GOES-R Ground system (GS). This will be done by wrapping the actual science code developed by the Cloud team. This will allow for the GS to choose an appropriate channel selection to provide the best possible heights for the GOES-R winds algorithm. It is anticipated that the first data from the pilot project will be available for evaluation in mid-2019.

A major effort during this reporting period was preparing for the GOES-16 full validation presentation. This has been delayed by the GOES-17 mitigation effort. Figure 20 shows the mean trend of CTPF (full disk, cloud top pressure) product from the Ground System. GOES-16 CTP has remained stable through this reporting period.

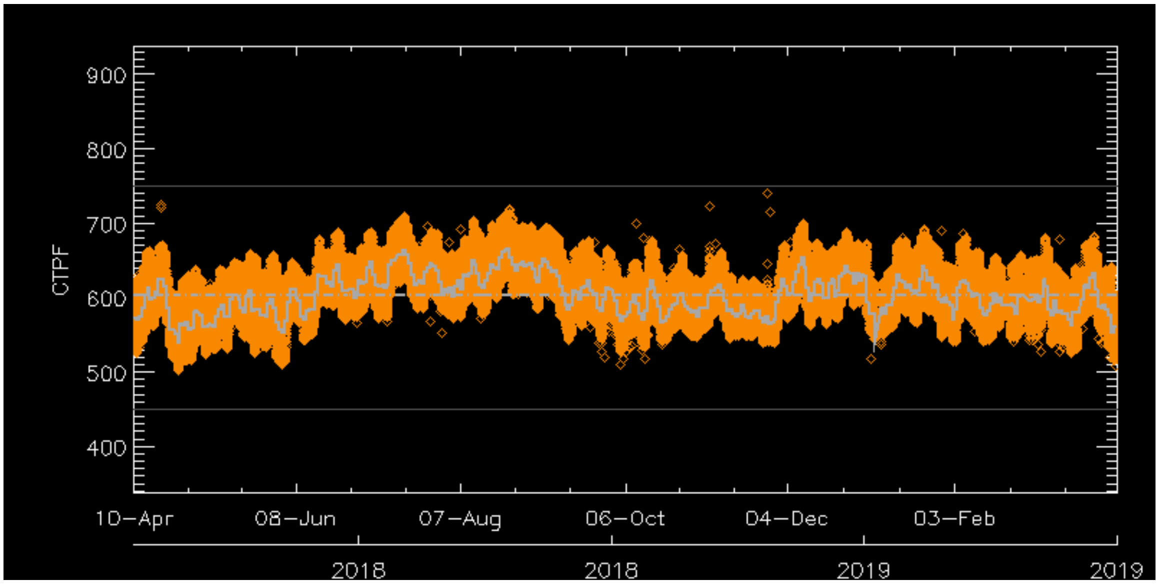


Figure 20. Mean cloud top pressure for nearly a year in 2018 – 2019.

As mentioned in the cloud mask section, Figure 20 is pulled from a CIMSS web page that monitors the mask, cloud top pressure, cloud optical depth and cloud effective radius.

The cloud team also compares overlapping AQUA MODIS Collection 6 (C6) products with GOES-16 and GOES-17. Figure 21 shows a year of AQUA MODIS and GOES-16 collocations. The data contained in the below figure contains data from every 5th day in 2018. Accuracy and precision full specifications are met for cloud top pressure. Accuracy is met for cloud top height, with precision nearly met. Cloud top temperature is a bit outside specifications when compared to MODIS.

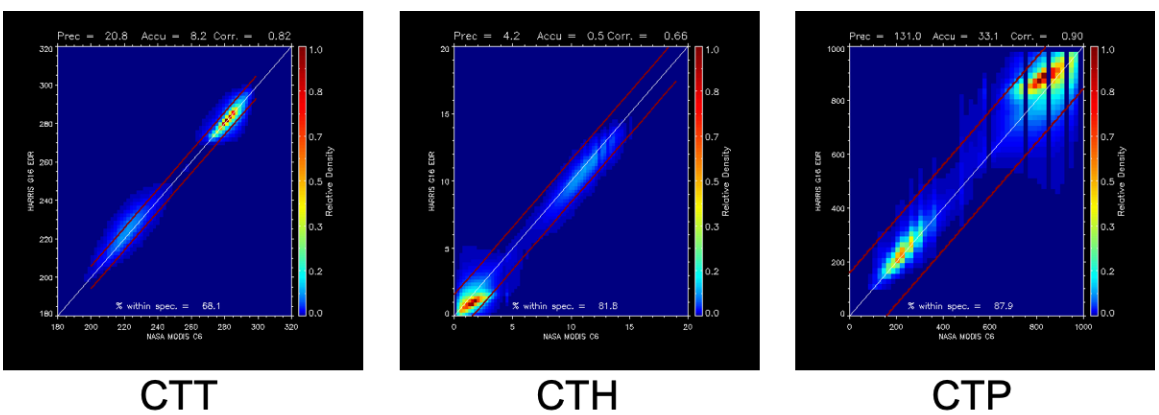


Figure 21. AQUA MODIS C6 product comparisons to GOES-16 for 2018.

Comparisons of the GOES-16 cloud products to CALIPSO is shown in Figure 22. The full validation specifications of GOES-16 compared to CALIPSO nearly match the MODIS comparisons. Both CTP and CTH reach full validation maturity. Accuracy is met in CTT, with precision just falling out of range.

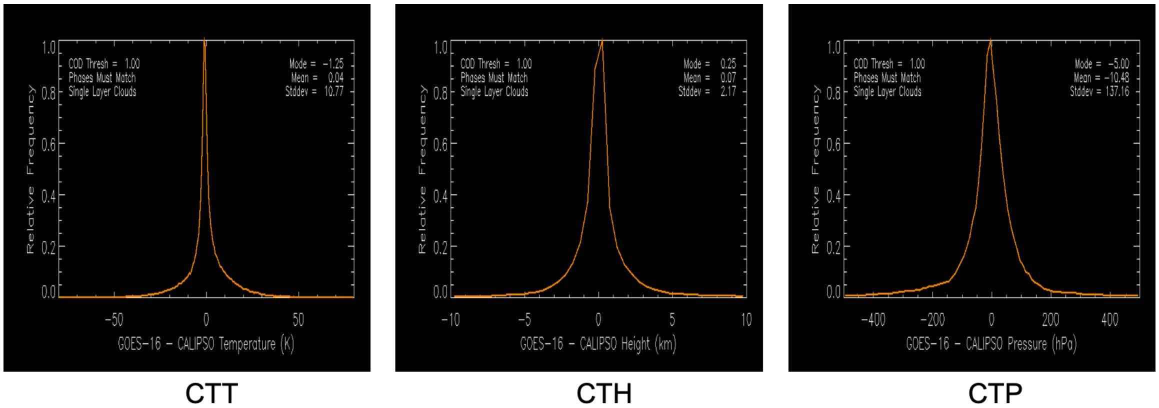


Figure 22. GOES-16 cloud top parameters compared to CALIPSO.

Figure 23 shows the zonal plot of the cloud top parameters of GOES-16 and CALIPSO. The GOES-16 CTPs are consistent to CALIPSO when looking over latitude regions as well.

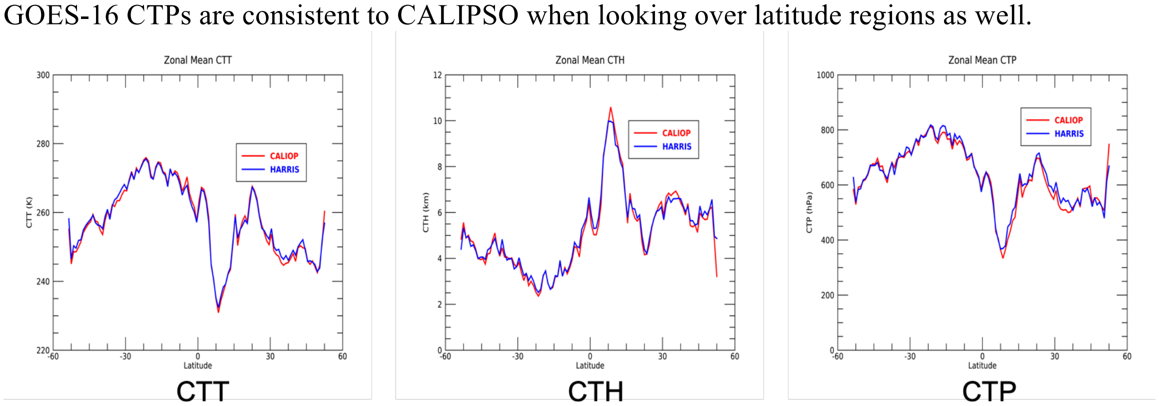


Figure 23. Zonal mean plots of CALIPSO and GOES-16 cloud properties.

Even though the GOES-16 Full validation discussion is postponed until 2019, it is clear from the above discussion that the CTPs most likely would be declared fully validated. The pilot project will allow the AWG Cloud Team the ability to give changes to the GS that should bring all CTPs into fully validated range, and hopefully satisfy the DMW requirements too. The discussion for GOES-17 will appear in section 5.1 of the report.

DCOMP

The major effort during this reporting period was the GOES-R revisit for the Daytime Cloud Top Parameters Cloud Optical and Microphysical Properties (cloud optical depth and cloud particle size). This was caused by concerns related to abnormally high cloud particle sizes observed in DCOMP, as can be seen in the figure below, which was taken from the GOES-16 DCOMP provisional review.

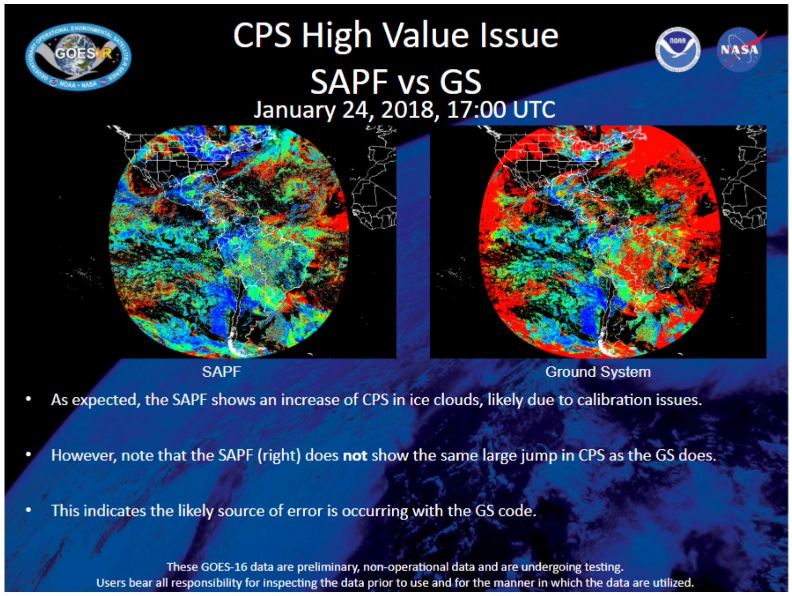


Figure 24. A slide from the GOES-16 DCOMP Provisional review demonstrating the issue of unusually high Cloud Particle Sizes.

After an exhaustive set of analysis, which included a side by side comparison of the inputs, intermediate variables, and outputs (~70 variables) from a select number of pixels within the DCOMP in the SAPF and Ground System (GS) codes, it was found that two issues existed in the GS implementation of the DCOMP algorithm. The first was that the DCOMP algorithm in the GS is using the incorrect convention for the relative azimuth angle. The second was that the GS incorrectly output the retrieved COD and CPS values from the Optimal Estimation module when the Optimal Estimation retrieval loop does not converge when the fill value should have been output. Both of these issues were addressed within the Ground System and have now allowed COMP to attain provisional validation for all products.

In addition to the CPS issue, an analysis of the impact of the correction to the 0.64µm reflectance, which is currently to bright, is implemented was performed. The analysis show that, while there are noticeable impacts, as can be seen by the image below, they are constrained to the brightest of clouds. The impact to DCOMP is as the algorithm developers expect, given that it uses reflectances in an iterative method in log space.

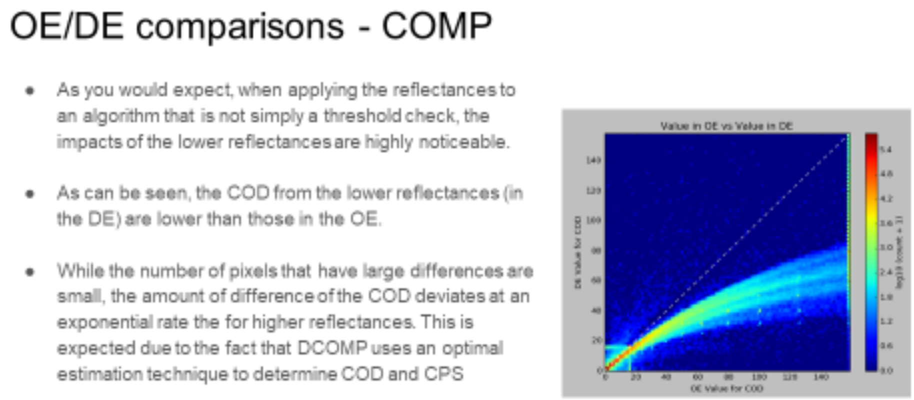


Figure 25. Slide from the 0.64µm correction analysis for DCOMP, showing the expected impacts of the correction to the 0.64µm reflection. The impacts for larger particle size is expected given how the reflectance is used in DCOMP

In regards to the GOES17 issue, while DCOMP is not affected by the LHP issue, NCOMP is significantly impacted. There is currently no method for mitigation for COMP during the hot parts of the day using the existing GOES-R or enterprise NCOMP algorithms.

Future work will include further DCOMP COD comparisons with MODIS and further NCOMP COD comparisons with CALIOP. DCOMP CPS, once any ground system errors are identified, will also be compared to MODIS. Both DCOMP and NCOMP LWP products have been compared to AMSR-2 as indirect methods of assessing both COD and CPS reliabilities and those comparisons will continue.

Validation of the current and updated algorithms is important to ensure the algorithms perform as expected during the post-launch check out for GOES-R. The Cloud AWG has extensively used other satellite sensors, such as spaceborne lidars, (CALIPSO), passive microwave satellite sensors (AMSU, AMSR-E), ground based lidars (HRSL), ground microwave profilers (MWR at ARM site) and passive imagers (MODIS, AVHRR), as independent validation data sources. In addition, the Cloud AWG has made extensive use of the lidar (CALIOP) on-board CALIPSO to tune the cloud mask for the least number of false detections. The Cloud AWG team also continues to work with the other Algorithm Working Groups, such as the Derived Motion Winds AWG, as well as other groups to continue to validate and improve the algorithms. Automated validation tools were also worked on in the previous year so that there can be automatic validation of the various cloud algorithms after launch.

In addition to offline validation studies, the cloud algorithms have been used in a near-real-time field campaigns as well as international workshops on cloud properties. For example, the cloud top height algorithm, which also relies on the cloud mask and type/phase algorithms, will be used during NOAA Shout Program (Sensing Hazards with Operational Unmanned Technology). Cloud heights are used to aid in flight path decisions for the Global Hawk Unmanned Aerial Vehicle (UAV) over and around the path of tropical cyclones.

The Cloud AWG has also implemented a web-based monitoring system, which applies predefined parameters to detect low quality product in near real time as well as helping identify when abnormal trends occur. The image below is a screenshot of the web-monitoring tool, showing the time series of the full disk average Cloud Optical Depth for GOES-17 from the GOES-R Ground System (GS). Since the product from the GS combines both DCOMP and

NCOMP, the affects of the loop heat pipe issue on GOES-17 can be seen by the COD becoming extremely large during the nighttime periods.

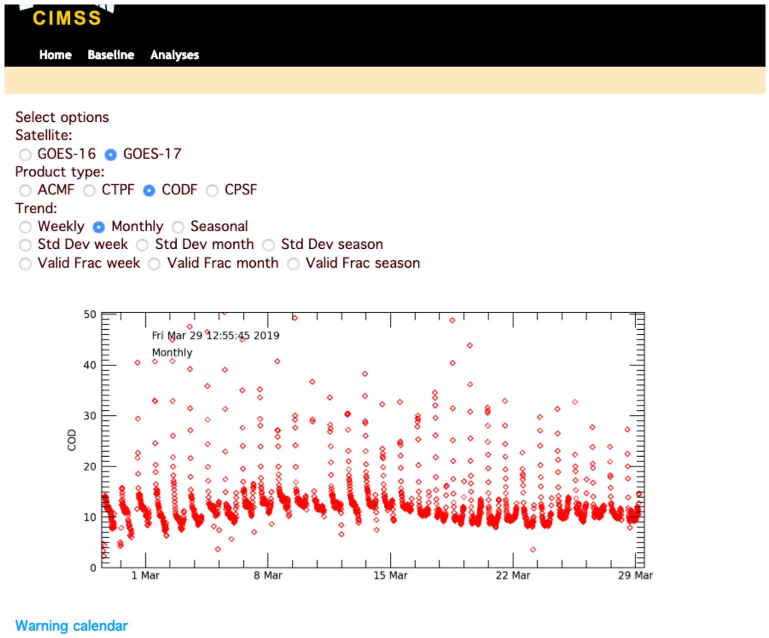


Figure 26. A screenshot of the web-monitoring tool, showing the time series of the full disk average Cloud Optical Depth for GOES-17 from the GOES-R Ground System (GS)

As of early March 2019 all of the cloud algorithms have reached provisional maturity for GOES-16, meaning that the algorithms will be made available to users. However, this does not mean that the algorithms are considered operational and will continue to be improved on. GOES-17 Provisional reviews for the cool period of the day only are expected to be done in mid to late 2019.

In 2019, the Cloud AWG will continue to improve the various cloud algorithms, support the GS in their effort as they produce output from the baseline cloud algorithms, provide analysis on the output from the GS in support of operational status for GOES-16 and evaluate the products for GOES-17 and develop mitigation strategies for the affected algorithms, continue development on the automated tools for the validation of the cloud algorithm, support international validation efforts and continue support of near-real-time usage of the cloud algorithms by field campaigns.

Publications and Conference Reports

Feltz, Wayne; Pierce, R. Bradley; Eloranta, Ed; Schmidt, Sebastian; Heidinger, Andrew; Kondragunta, Shobha; Walther, Andi and LeBlance, Samuel. GOES-R cloud and aerosol validation during the NSF DC3 field mission. NOAA 2013 Satellite Conference for Direct Readout, GOES/POES, and GOES-R/JPSS Users, College Park, MD, 8-12 April 2013. NASA, Goddard Space Flight Center, GOES-R Program Office, Greenbelt, MD, 2013, poster presentation.

Hamann, U.; Walther, A.; Baum, B.; Bennartz, R.; Bugliaro, L.; Derrien, M.; Francis, P. N.; Heidinger, A.; Joro, S.; Kniffka, A.; Le Gleau, H.; Lockhoff, M.; Lutz, H.-J.; Meirink, J. F.; Minnis, P.; Palikonda, R.; Roebeling, R.; Thoss, A.; Platnick. S.; Watts, P. and Wind, G.. Remote sensing of cloud top pressure/height from SEVIRI: Analysis of ten current retrieval algorithms. *Atmospheric Measurement Techniques*, Volume: 7, Issue: 9, 2014, pp.2839-2867

Heidinger, Andrew. Algorithm Theoretical Basis Document: ABI cloud height. Version 2.0. NOAA, NESDIS, Center for Satellite Applications and Research, 2011.

Heidinger, Andrew. Algorithm Theoretical Basis Document: ABI cloud mask. Version 2.0. NOAA, NESDIS, Center for Satellite Applications and Research, 2011.

Heidinger, Andrew K. Applicability of GOES-R AWG cloud algorithms for JPSS/VIIRS. Annual Symposium on Future Operational Environmental Satellite Systems, 7th, Seattle, WA, 23-27 January 2011. American Meteorological Society (AMS), Boston, MA, 2011, abstract only.

Heidinger, Andrew K. Performance of the NOAA AWG cloud height algorithm applied to current geostationary and polar orbiting imagers. International Winds Workshop, 12th, Copenhagen, Denmark, 15-20 June 2014. University of Copenhagen, Copenhagen, Denmark, 2014, abstract only.

Heidinger, Andrew K.; Evan, Amato T.; Foster, Michael J. and Walther, Andi. A naive Bayesian cloud-detection scheme derived from CALIPSO and applied within PATMOS-x. *Journal of Applied Meteorology and Climatology*, Volume: 51, Issue: 6, 2012, pp.1129-1144.

Heidinger, Andrew K.; Wanzong, S. and Walther, A. Analysis of convective clouds viewed from GOES during DC3. Conference on Severe Local Storms, 27th, Madison, WI, 2-7 November 2014. American Meteorological Society, Boston, MA, 2014, abstract only.

Heidinger, Andrew; Baum, Brian and Roebeling, Rob. The Cloud Retrieval Evaluation Workshop (CREW). Meeting on the Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms within WMO SCOPE-Nowcasting, Madison, WI, 28 June-2 July 2015. University of Wisconsin-Madison, Space Science and Engineering Center, Madison, WI, 2015, PowerPoint presentation.

Heidinger, Andrew; Pavolonis, Michael; Walther, Andi; Heck, Pat; Minnis, Pat and Straka, William. GOES-R AWG product validation tool development: Cloud products. GOES-R AWG Annual Meeting, Fort Collins, CO, 14-16 June 2011. NASA, Goddard Space Flight Center, GOES-R Program Office, Greenbelt, MD, 2011.

Heidinger, Andrew; Walther, Andi; Foster, Mike and Ackerman, Steve. State of the NOAA AWG cloud algorithms. 2011 EUMETSAT Cloud Retrieval Evaluation Workshop, 3rd, (CREW-3), Madison, WI, 15-18 November 2011. University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies (CIMSS), Madison, WI, 2011, abstract only.

Heidinger, Andrew; Wanzong, Steve and Walther, Andi. Status of cloud products from HIMAWARI-8 AHI. 2015 GOES-R/JPSS OCONUS Satellite Proving Ground Technical Interchange Meeting, Anchorage, AK, 12-15 May 2015. National Oceanic and Atmospheric Administration (NOAA), 2015.

Kelly, Michael; Wu, Dong; Yee, Jeng-Hwa; Boldt, John; Demajistre, Robert; Reynolds, Edward; Tripoli, Gregory; Oman, Luke; Prive, Nikki; Heidinger, Andrew and Wanzong, Steve. C3Winds: A novel 3D wind observing system to characterize severe weather events. AGU Fall Meeting, San Francisco, CA, 14-18 December 2015. American Geophysical Union, Washington, DC, 2015, abstract only; Abstract A51G-0150.

Kinne, Stefan; Stubenrauch; Rossow, W. B.; Pearl, C.; Heidinger, A.; Walther, A.; Guignard, A.; Ackerman, S.; Platnick, S.; Maddux, B.; Minnis, P.; Sun-Mack, S.; DiGirolamo, L.; Menzies, A.; Menzel, P.; Olsen, E.; Riedi, J.; Zeng, S.; Winker, D.; Getzewich, B.; Chepfer, H.; Gesana, G.; Poulsen, C. and Sayer, A. GEWEX cloud assessment: A review. 2011 EUMETSAT Cloud Retrieval Evaluation Workshop, 3rd, (CREW-3), Madison, WI, 15-18 November 2011. University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies (CIMSS), Madison, WI, 2011, abstract only.

Madani, Houria; Carr, James; Heidinger, Andrew and Wanzong, Steve. Inter-comparisons between radiometric and geometric cloud top height products. AGU Fall Meeting, San Francisco, CA, 14-18 December 2015. American Geophysical Union, Washington, DC, 2015, abstract only; Abstract A33E-0220.

Mecikalski, John R.; Jewett, C. P.; Weygandt, S.; Smith, T. L.; Heidinger, A. K.; Straka, W. and Benjamin, S. Convective initiation of 0-6 hr storm nowcasting for GOES-R. Conference on Weather Analysis and Forecasting, 26th, and Conference on Numerical Weather Prediction, 22nd, Atlanta, GA, 2-6 February 2014. American Meteorological Society, Boston, MA, 2014, abstract only.

Monette, Sarah A.; Velden, C. S.; Heidinger, A. K.; Zipser, E. J.; Cecil, D. J.; Black, P. G. and Braun, S. A. Validation of Automated Cloud Height Algorithm (ACHA) cloud top heights in tropical cyclones using observations from the NASA Global Hawk. Conference on Hurricanes and Tropical Meteorology, 31st, San Diego, CA, 31 March-4 April 2014. American Meteorological Society, Boston, MA, 2014, abstract only.

Roebeling, R.; Baum, B.; Bennartz, R.; Hamann, U.; Heidinger, A.; Thoss, A. and Walther, A. Outcome of the Third Cloud Retrieval Evaluation Workshop. IRS 2012: International Radiation Symposium, Berlin, Germany, 6-10 August 2012. Radiation Processes in the Atmosphere and Ocean (IRS2012). American Institute of Physics, Melville, NY, 2013, pp.416-419. Reprint # 7142.

Roebeling, R.; Baum, B.; Bennartz, R.; Hamann, W.; Heidinger, A.; Melrink, J. F.; Stengel, M.; Thoss, A.; Walther, A. and Watts, P. Outcome of the fourth Cloud Retrieval Evaluation Workshop. 2014 EUMETSAT Meteorological Satellite Conference, Geneva, Switzerland, 22-26 September 2014. Abstracts. European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Darmstadt, Germany, 2014, abstract only.

Roebeling, Rob; Baum, Bryan; Bennartz, Ralf; Hamann, Ulrich; Heidinger, Andy; Thoss, Anke and Walther, Andi. Evaluating and improving cloud parameter retrievals. *Bulletin of the American Meteorological Society*, Volume: 94, Issue: 4, 2013, ES41-ES44.

Roebling, Rob; Baum, Bryan; Bennartz, Ralf; Hamann, Ulrich; Heidinger, Andrew; Meirink, Jan Fokke; Stengle, Martin; Thoss, Anke; Walther, Andi and Watts, Phil. Summary of the fourth Cloud Retrieval Evaluation Workshop. *Bulletin of the American Meteorological Society*, Volume: 96, Issue: 4, 2015, ES71-ES74.

Schmit, Timothy J.; Goodman, Steven J.; Gunshor, Mathew M.; Sieglaff, Justin; Heidinger, Andrew K.; Bachmeier, A. Scott; Linstrom, Scott S.; Terborg, Amanda; Feltz, Joleen; Bah, Kaba;

Rudlosky, Scott; Lindsey, Daniel T.; Rabin, Robert M. and Schmidt, Christopher C.. Rapid refresh information of significant events: Preparing users for the next generation of geostationary operational satellites. *Bulletin of the American Meteorological Society*, Volume: 96, Issue: 4, 2015, pp.561-576, supplement

Schreiner, Anthony J.; Menzel, W. Paul; Straka, William and Heidinger, Andrew. Comparison of CO2 and H2O Atmospheric Motion Vector height assignment techniques using the GOES-13 imager. International Winds Workshop, 11th, Auckland, New Zealand, 20-24 February 2012. EUMETSAT, Darmstadt, Germany, 2012.

Schreiner, Anthony; Menzel, W. Paul; Straka, William and Heidinger, Andy. Comparing CO2/IRW and H2O/IRW CTPs. International Winds Workshop, 11th, Auckland, New Zealand, 20-24 February 2012.

Walther, A. and Heidinger, A. K. The consistency of cloud climatologies derived from several sensors. AGU Fall Meeting, San Francisco, CA, 5-9 December 2011. American Geophysical Union, Washington, DC, 2011, abstract only; Abstract A13B-0275.

Walther, Andi and Heidinger, A. The Daytime Cloud Optical and Microphysical Properties (DCOMP) algorithm. Conference on Satellite Meteorology, Oceanography and Climatology, 18th, and Joint AMS-Asia Satellite Meteorology Conference, 1st, New Orleans, LA, 22-26 January 2012. American Meteorological Society, Boston, MA, 2012, abstract only.

Walther, Andi and Heidinger, Andrew K. Implementation of the Daytime Cloud Optical and Microphysical Properties algorithm (DCOMP) in PATMOS-x. *Journal of Applied Meteorology and Climatology*, Volume: 51, Issue: 7, 2012, pp.1371-1390.

Walther, Andi; Heidinger, Andrew and Park, Chang-Hwan. Sources of error in satellite derived cloud products. 2011 EUMETSAT Cloud Retrieval Evaluation Workshop, 3rd, (CREW-3), Madison, WI, 15-18 November 2011. University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies (CIMSS), Madison, WI, 2011, abstract only.

Walther, Andi; Straka, William and Heidinger, Andrew K. Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Daytime Cloud Optical and Microphysical Properties (DCOMP) Version 2.0. NOAA, NESDIS, Center for Satellite Applications and Research, 2011

Wu, Dong L; Baum, Bryan A.; Choi, Yong-Sang; Foster, Michael J.; Kalsson, Karl-Goran; Heidinger, Andrew; Poulsen, Carolin; Pavolonis, Michael; Riedi, Jerona; Roebeling, Robert; Sherwood, Steven; Thoss, Anke and Watts, Philip. Toward global harmonization of derived cloud products. Bulletin of the American Meteorological Society, Volume: 98, Issue:2, 2017, ES49-ES52. Reprint #7907.

4.2 Active Fire/Hot Spot Characterization
CIMSS Task Leader: Chris Schmidt
NOAA Collaborators: Ivan Csiszar, Wilfrid Schroeder, Shobha Kondragunta
Budget: $100,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective
This effort has adapted the legacy GOES Wildfire Automated Biomass Burning Algorithm (WFABBA) to the GOES-R series and supported upgrades to meet requirements.

Project Overview
This activity has been building on historical and current expertise at CIMSS in fire algorithm development for the legacy GOES Imager and the global geostationary fire observation network (MSG, MTSAT, COMS, etc). CIMSS revised the WFABBA to address GOES-R ABI observational requirements utilizing the improved fire monitoring capabilities on GOES-R. This work is now focused on demonstrating and validating the GOES-R ABI Fire Detection and Characterization Algorithm (FDCA) using GOES-16 and GOES-17 data. This effort includes collaboration with MODIS and NPOESS VIIRS fire product development experts to maximize future use of multiple data sources (geo and leo) that take advantage of the strengths of each system to create improved fused fire products. The collaboration also has led to the development of innovative "deep-dive" validation tools. This activity ensures enhanced future geostationary fire detection, diurnal monitoring, and characterization in the GOES-R era. The validation component of this work is performed in conjunction with Dr Wilfrid Schroeder from NOAA. Work from this project is also used in GOES-R training, primarily for NWS forecasters and broadcasters utilizing various media outlets.

Milestones with Summary of Accomplishments and Findings
The primary task for this year was continued development and validation of the FDCA and working with ASSISTT and the ground system contractor on updating the operational algorithm. In April 2018, shortly after the GOES-16 FDCA was declared provisional, a problem report was filed regarding false alarms present in the data. While the sources were known and documented as part of the Provisional review, the degree of user concern drove the ongoing algorithm improvement efforts thereafter. It was found that the primary cause of false alarms, from 75-90% of the detected fires in a given scene during the worst periods of the day, were due to an approximation used in the code that was a holdover from the days before CPUs had integrated floating point units, as is standard today. The removal of that approximation, which scaled the radiance difference between bands 7 and 14 in band 7 radiance space to the nearest tenth,

resolved a great number of issues the algorithm had been encountering, and made it possible to begin to address other issues that need resolution. This fix, along with other adjustments to the background temperature calculation, were delivered to ASSISTT as an update to the operational algorithm, which is expected to be completed in May 2019.

Further algorithm updates are in development. The requirement for full validation of the FDCA is to essentially satisfy a key user base with respect to the detection rate and commission error rates. In order to reach that goal several approaches are being considered. A mask for persistent heat sources is being developed in conjunction with our NOAA partners, which, once applied, will result in new codes in the output mask to alert users that those particular hotspots may not be fires. Those pixels will not be excluded completely, however, since some sources, like solar farms, produce intermittent signals and could experience fire at other times. Additionally, the background temperature calculations will be improved by utilizing the aforementioned radiance difference. The advantage to using this information is that it allows handling of situations where brightness temperature thresholds are less useful, such as over tropical forests at night where the algorithm often struggles to calculate background temperatures. That technique, along with the potential inclusion of additional information from bands 5 and/or 6, will also assist the algorithm in addressing bright surfaces that often look like they could be clouds.

Validation is an ongoing effort. The validation work at CIMSS consists primarily of providing feedback and when needed updated data processed with algorithm upgrades to the "deep-dive" validation team at NOAA. Additionally, CIMSS assesses algorithm performance by examination of the L1b and FDCA data, and other fields as needed. Figure 27 shows an example of such work from the Camp Fire that started near Paradise, CA on 8 November 2018. The operational code had difficulty finding the fire initially due to the issues mentioned above. To assess the performance of the updated code, multi-panel images were produced. The leftmost panel for each row is 0.64 µm data, which is dominated by noise until the sun rises. Dynamically scaled 3.9 and 11.2 µm data is shown in the next two panels. The fourth panel includes the radiance difference between the 3.9 and 11.2 µm bands represented in 3.9 µm radiance space. Red indicates positive differences, which could be due to fire, solar reflections, and other phenomenon. That radiance difference shows the Camp Fire at 14:22 UTC, prior to it being clearly discernible in the 3.9 µm data. PG&E reports that the powerline came down at 14:13 UTC. The radiance difference was initially very small, however, and it wasn't clearly a fire until later. The FDCA metadata mask shows a cloud at 14:42 UTC and then a possible fire at 14:47. The last row shows the fire later in its evolution. While time consuming, comparisons like these are very instructive in terms of assessing algorithm accuracy and sensitivity.

During the reporting period Chris Schmidt wrote the chapter on fire detection for the upcoming book on GOES-R, as well as provided the figures and animations.

While funded separately, the FDCA team continued to teach about ABI fire detection to various audiences, including the GOES-R Short Course at the AMS Annual Meeting and at the annual Incident Meteorologist (IMET) training in Boise, ID.

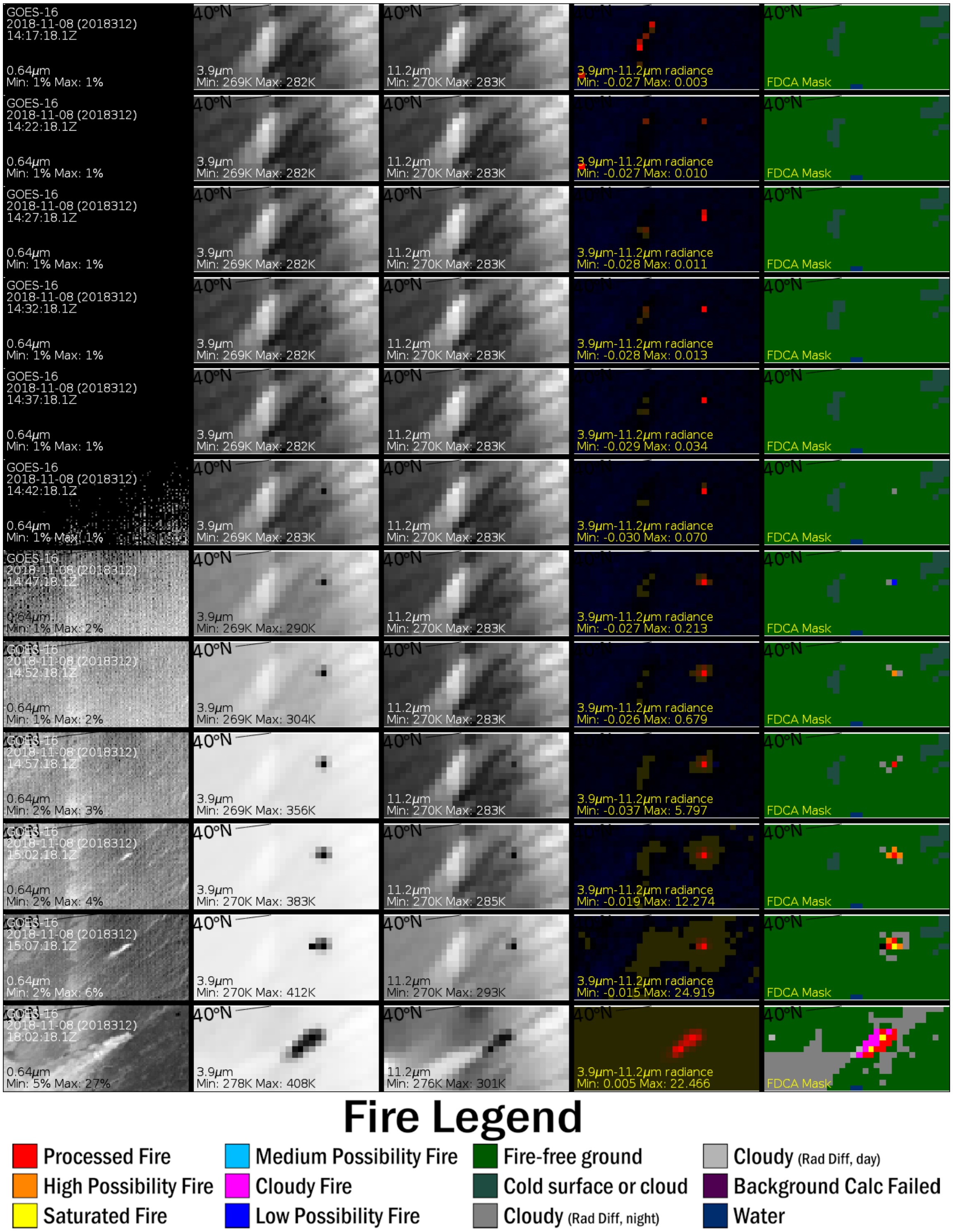


Figure 27. Dynamically scaled ABI and FDCA data from the beginning of the Camp Fire on 8 November 2018.

4.3. GOES-R Legacy Atmospheric Profile (LAP), Total Precipitable Water (TPW), and Atmospheric Instability Indices

CIMSS Task Leader: Jun Li

CIMSS Support Scientists: Zhenglong Li, Kevin Baggett, Richard Dworak, and William Straka
NOAA Collaborators: Tim Schmit, Walter Wolf
Budget: $185,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
The objective is to develop and validate GOES-R series operational legacy atmospheric profile (LAP) algorithms/products to meet the users' requirements.

Project Overview
The main focus of this project is to develop the legacy atmospheric profile (LAP) algorithm for the next generation Geostationary Operational Environmental Satellites (GOES-R series) Advanced Baseline Imager (ABI) (Schmit et al. 2005; 2017) product generation and validation. The algorithm retrieves atmospheric temperature and moisture profiles and the derived products including total precipitable water (TPW), layered precipitable water (PW), lifted index (LI), convective available potential energy (CAPE), total totals index (TT), Showalter index (SI), and the K-index (KI) from the clear sky infrared (IR) radiances. This project requires CIMSS scientists to develop and validate the GOES-R series LAP algorithm to be able to process high temporal and spatial resolution ABI data efficiently. This project provides prototype science codes and updates to the GOES-R series algorithm integration team (AIT) for algorithm integration and helps the system provider to implement the prototype codes and updates into the GOES-R series ground system. CIMSS scientists also evaluate and validate the GOES-R series LAP baseline products to assure that the GOES-R series legacy atmospheric temperature and moisture profiles, TPW, LI, CAPE, TT, SI and KI products meet the science/user requirements and operational applications.

Milestones with Summary of Accomplishments and Findings

CIMSS LAP near real-time validation tool updated to include GOES-17
CIMSS near real-time LAP product validation "tools"(soundingval.ssec.wisc.edu) has been further developed to include GOES-17, now both GOES-16 and GOES-17 baseline LAP products are included in the webpage. The operational ABI LAP products are monitored daily with reference datasets at this validation tool, and the ABI LAP products under near real-time monitoring include those from disk, CONUS and mesoscale regional observations.

2018 HWT participation

Participated in 2018 HWT spring experiment, the GOES-16 baseline clear sky LAP products were accessed for 2018 HWT experiments and forecast applications. The GOES-16 baseline derived products were evaluted in the HWT experiment. There was a heavier emphasis on the derived products this year than the imagery since the imagery had already been declared operational. The forecasters mainly focused on products of relative importance to convective initiation and forecasting, as well as those which could be useful for warning operations. Following are some feedback on these derived products:

- "Yes, I looked at baseline derived CAPE and PWATS for assessment of downstream environment from ongoing convection. They provided additional confidence in what I was seeing on the SPC mesoanalysis fields."
- "Yes, I utilized some of the derived CAPE data which was useful for diagnosing, to a degree, the environment far downstream of active convection."
- "Yes, All-Sky Lap CAPE, LI & TPW on the Mesoscale 1 sector over NC/VA These products are particularly useful in helping with highlighting pre-convective environments, gradients in particular, and they can also help the forecaster build a multi-dimensional perception of the atmosphere to begin looking at more specific severe threats."
- "I watched the trends and where a tongue of CAPE or moisture was increasing. I used these along with the mesoscale analysis."
- "I used the LAP products to study the low-level environment and see if any moisture was moving toward the area and decreasing the stability. This showed up best with the CAPE and to a lesser extent with the LI."
- "I could see the low level moisture advection and increasing instability quite well over the CWA throughout the afternoon. Once the nose of low level moisture and CAPE reached the boundary across the north, storms fired."
- "These products performed quite well, and they showed an increasing trend in PW/Instability parameters through the afternoon. The instability parameters, as in days past, appeared to be a bit low biased."

One of the more unique products from the all-sky suite of products not available with the operational LAP dataset was the layered PW (LPW) fields. When asked at the end of each week if they would like to see the layered PW become operational, the answer was unanimously "yes".

The layered PW fields proved to be beneficial in a number of cases while analyzing the pre-convective environment. One such case was in the Des Moines, Iowa, CWA on 03 May 2018. During the early afternoon mesoscale analysis, the forecasters noticed that the two lower layers show relatively high levels of moisture over the area, while the upper level reveals a nose of dryer air advancing toward the CWA (Figure 28). The forecaster noted that this should increase convective instability throughout the afternoon and that initiation would begin on this tongue of dry mid to upper level air. As the afternoon progressed, storms fired along this gradient in dry air aloft and moved across the Des Moines CWA producing all hazards of severe weather.

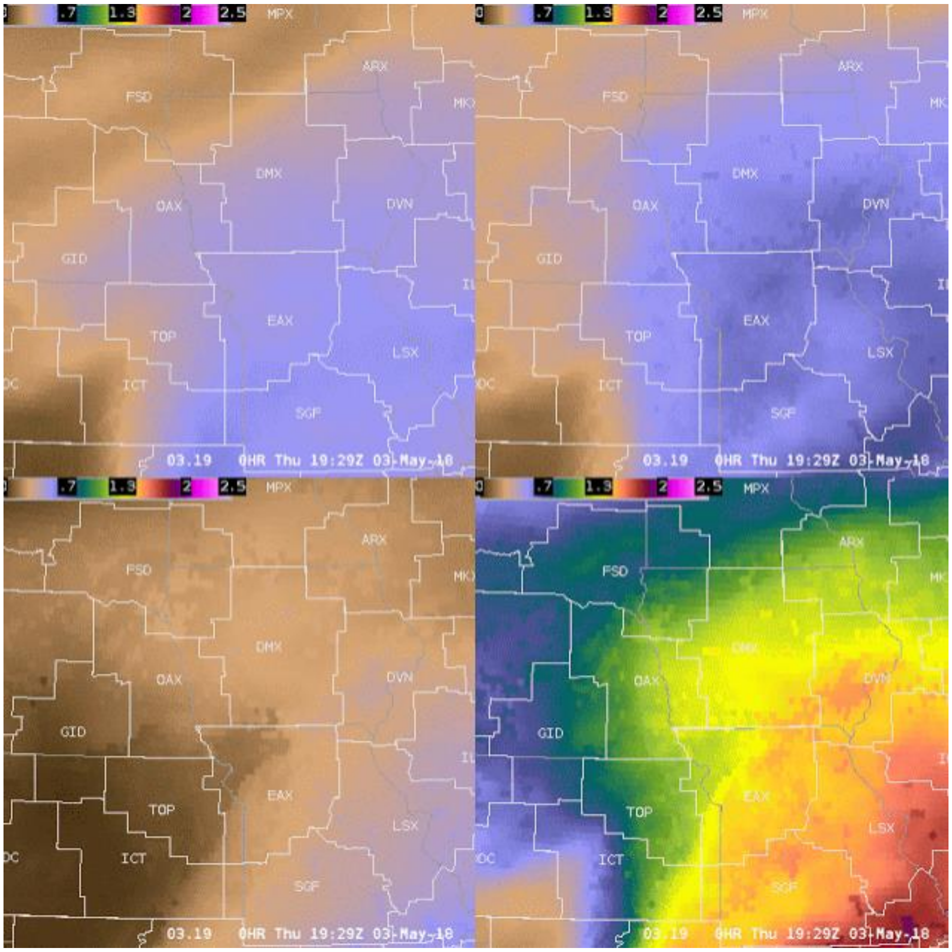


Figure 28. 03 May 2018 1929 UTC LAP layer precipitable water fields. Sfc-0.9 sigma level (upper left), 0.9-0.7 sigma level (upper right), 0.7-0.3 sigma level (lower left), and Total Precipitable Water (lower right) across the Midwest.

GOES-17 mitigation studies

LAP comparison between GOES-16 and GOES-17 with updated G17 CRTM coefficients
The time period from 2018-09-09 19z to 2018-09-10 03z was used for comparisons; selected variables include temperature at 500 hPa, RH at 500 hPa, TPW, LI over the GOES-17/GOES-17 overlap region. No abnormal results found.

GOES-17 ABI channel sensitivity study for LAP products using GOES-16 ABI
The overall considerations on G-17 LAP mitigation are based on two facts: (a) during LHP period, some IR bands such as 13.4 μm band might not be available, while some bands such as WV absorption bands might have higher observation noise than those of GOES-16; and (b) GOES-R series LAP algorithm has two components: regression followed by 1Dvar based physical retrieval. Therefore, the overall strategies on G-17 mitigation during LHP period are to remove regression step, using NWP as input directly instead of using regression results as input, and also remove channels not available during LHP period, in addition, increase observation errors for those bands with increased noise during LHP period. It is important to address the mitigation related questions such as: What is the impact of removing 13.4 μm band in the GOES-R series LAP algorithm? How to handle the increased observation noise during LHP period in LAP algorithm and what is the impact on LAP product quality? What is the recommended

mitigation strategies and approaches for operational GOES-17 LAP product during LHP period? Using GOES-16 ABI LAP products as standard, the algorithm is tested with different mitigation approaches such as removal of regression and certain channels. It is found that:

- Regression step has substantial impact on LAP results;
- Using ozone band has little impact on LAP;
- Removing band 16 has little impact on LAP;
- Removing band 15 has slight impact on LAP;
- Removing band(s) might slightly reduce successful retrievals.

It is also shown that removal of channel(s) might slightly reduce the successful retrieval field-of-regards (FORs). Figure 29 shows the TPW differences (mean as images, STD as numbers) due to removal of channel 15, 16, 15&16, respectively.

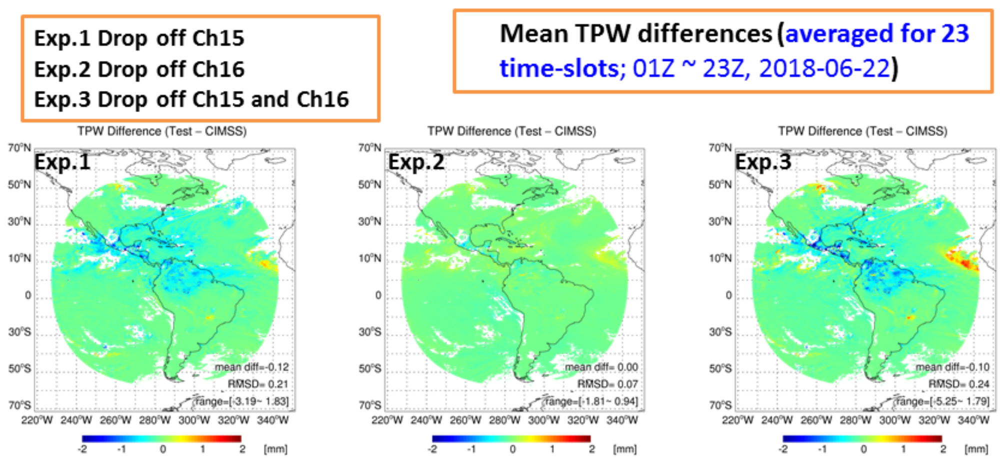


Figure 29. TPW differences due to removal of channel 15, 16, 15&16, respectively.

GOES-17 LAP products analyzed during LHP
It is found that:

- The FPM changes on August 26 – 27, 2018, the entire ABI instrument heats up between about 06 - 14 UTC. It rapidly starts to heat up before 06 UTC, and then it can't keep it cool enough between 06 – 14 UTC;
- The LAP products (T500, RH500, TPW, CAPE, KI, SI, LI, TOTO) from GOES-17 are compared with those of GOES-16 during this time period;
- When the FPM temperature changes rapidly, the STD and MEAN difference of the GOES-17 LAP products are also significantly larger than those of other times. The STD and MEAN changes are consistent with FPM temperature changes;
- For the current GOES-17 LAP products, the usable products should be avoided during the period of FPM temperature rapid changes. Therefore, the GOES-17 LAP products from 13 UTC to 24 UTC and from 00 UTC to 06 UTC are fine to use, which is around 17 hours per day;
- To reduce the impacts from the FPM temperature rapid change, one possible way is to adjust the observation errors for the algorithms. When the FPM temperature changes rapidly, the observation errors should be larger than those of other times, which can mitigate the impacts from FPM changes. Another possible way is to adjust the channels used in the algorithms.

Figure 30 shows the time series of TPW difference (Julian Day 238 - 239), which clearly indicates the large difference during GOES-17 LHP.

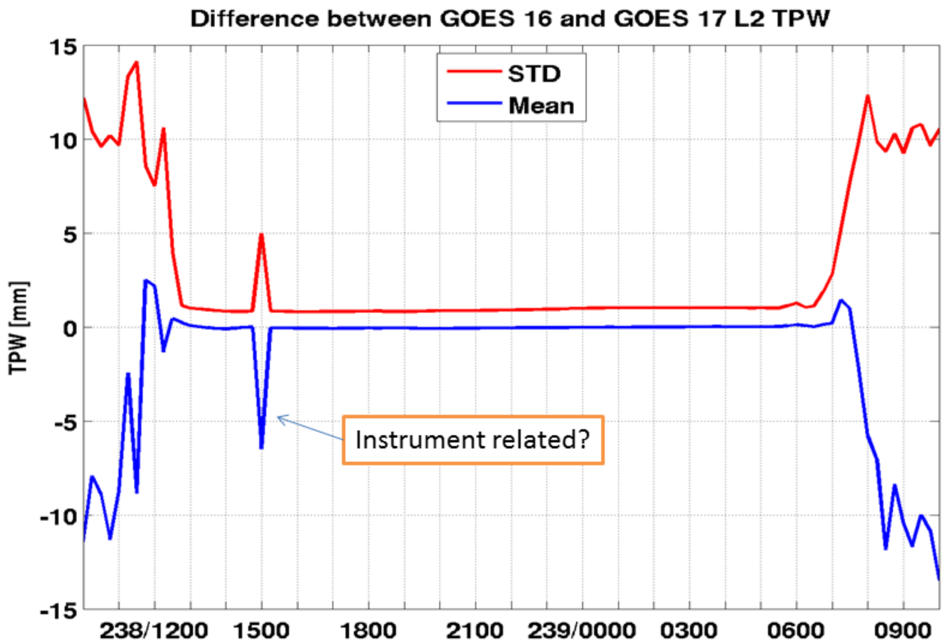


Figure 30. Time series of TPW difference (Julian Day 238 - 239).

Continue GOES-16 ABI LAP validation

Through almost 1 year time period validation, it is found that the LAP product performance has been stable and meeting the requirements, when compared against reference data including Suomi-Net GPS (Global Positioning System), AMSR2 (Advanced Microwave Scanning Radiometer 2), RAOB, ECMWF analysis and GDAS analysis, and AERI (Atmospheric Emitted Radiance Interferometer) boundary layer profiles from a GOES-16 field campaign. accuracy specification (1 mm) and precision specification (3 mm) are met for TPW product; accuracy specification (1 K above boundary layer and below 400 hPa) and precision specification (2 K above boundary layer and below 400 hPa) are met for LVT, accuracy specification (18 % between sfc and 300 hPa, 20 % between 300 and 100 hPa) and precision specification (same as accuracy specification) are met for LVM; accuracy specification (2 K, 1000 J/kg, 1 K, 2 K, 2K) and precision specification (6.5 K, 2500 J/kg, 4 K, 5 K, 6.5 K) are met for LI, CAPE, TT, KI, SI, respectively, except TT and KI when compared to radiosonde observations (RAOBs). The inclusion of only the atmospheric unstable cases makes the TT (>44) and KI (>26) results closer to the requirements.

It is specific worth noting from the validation results that the ABI LVM has improved accuracy and precision over the NWP short-range forecasts with its three water vapor absorption bands centered at 6.3, 6.9 and 7.3 µm, respectively, when compared with RAOBs, ECMWF and GFS analysis, considering the fact that ABI has much better temporal and spatial resolutions than the current GOES Sounder, it makes the water vapor products (TPW, LVM, LPW) have unique value in nowcasting, weather forecasting and NWP assimilation applications. A manuscript titled “Legacy atmospheric profiles and derived products from GOES-16: validation and applications” has been written for publishing.

Prepare for GOES-17 LAP provisional review

Following the same procedures of GOES-16 ABI LAP validation, the GOES-17 ABI LAP validation is under preparation, focus will be on the G17 ABI good time period.

Related Publications and Conference Presentations

Wang, Pei, Jun Li, Bing Lu, Timothy J. Schmit, Jiazhen Lu, Yong-Keun Lee, Jinlong Li, and Zhiquan Liu, 2018: Impact of moisture information from Advanced Himawari Imager measurements on heavy precipitation forecasts in a regional NWP model, Journal of Geophysical Research - Atmospheres, 123, 6022 - 6038. https://doi.org/10.1029/2017JD028012.

Lu, J., T. Feng, Jun Li, Z. Cai, X. Xu, L. Li, and Jinlong Li, 2019: Impact of assimilating Himawari-8 derived layered precipitable water with varying cumulus and microphysics parameterization schemes on the simulation of Typhoon Hato, Journal of Geophysical Research – Atmosheres (in press).

Lee, Jung-Rim, Jun Li, Zhenglong Li, Pei Wang, and Jinlong Li, 2019: The impact of GOES-16 data on TCs forecasts, 99th AMS Annual Meeting, 06 – 10 January 2019, Phoenix, AZ.

4.4 ABI Derived Motion Winds

CIMSS Task Leaders: Chris Velden and Steve Wanzong
CIMSS Support Scientist: David Stettner
NOAA Collaborator: Jaime Daniels (STAR)
Budget: $90,000

NOAA Long Term Goals

- Weather-Ready Nation

NOAA Strategic Goals

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Support the testing and optimization of the NESDIS atmospheric motion vector derivation algorithm to operate with GOES-R imagery and provide accurate wind estimates.

Project Overview

The NOAA GOES-R Algorithm Working Group (AWG) winds team lead by STAR and supported by CIMSS is demonstrating derived motion vector (DMV) algorithms and their applications. The software is being tested with GOES-16/17 imagery, with the resultant DMVs validated against "truth" data sets. The DMV height assignment methodologies continue to be closely integrated with the developments by the AWG Cloud Team ACHA algorithm. CIMSS R&D efforts are focusing on the optimization and applications of the DMVs to tropical cyclone environments. New DMV processing methodologies to capture the smaller scale flow fields are being designed, developed and tested.

Milestones with Summary of Accomplishments and Findings

Milestone 1

The AWG winds team helped support GOES-R program reviews by providing DMV validation, case study analyses, and promising applications. CIMSS is assisting STAR in this effort when needed, and team member Wanzong is a key liaison with the AWG Cloud Team.

Milestone 2

The application of new DMV processing strategies for tropical cyclones was successfully demonstrated using recent Atlantic hurricanes as development cases. The strategy employs the GOES-16 1-min. meso-sectors to retrieve very high density multispectral DMVs around a targeted tropical cyclone. See the example for Hurricane Maria in the figures below. The progress with this research was reported on at the 14th International Winds Workshop (Stettner et al. 2018).

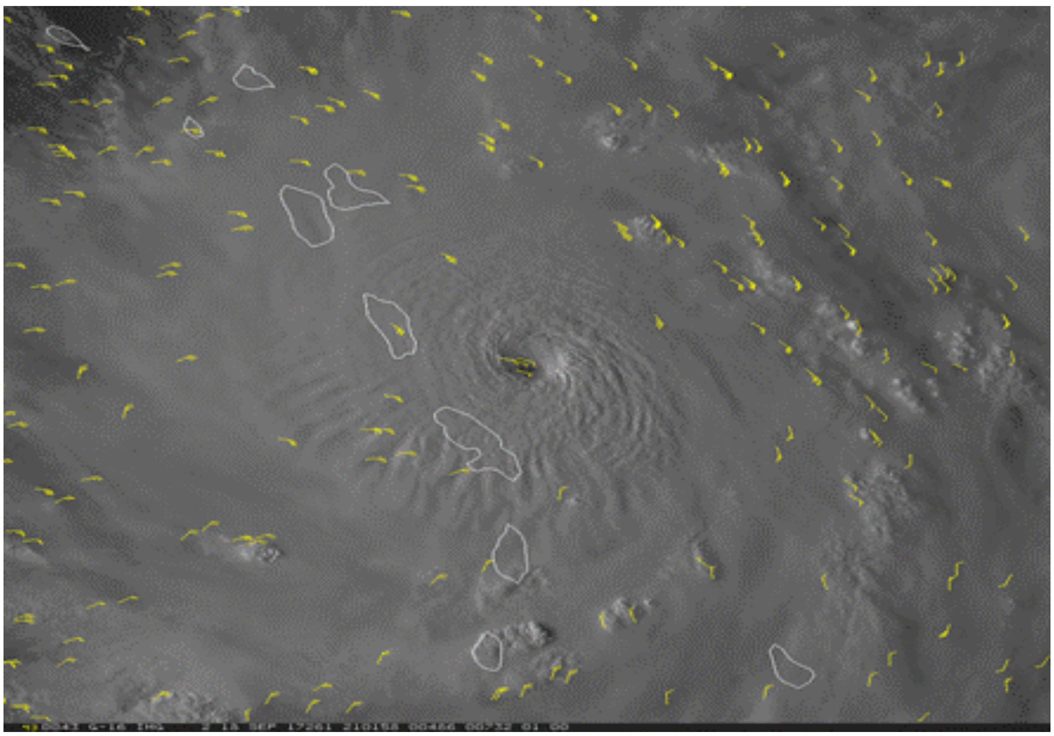


Figure 31. GOES-16 VIS image of Hurricane Maria (2017) with a plot of routine operational AMVs (yellow) produced from 15-min FD images.

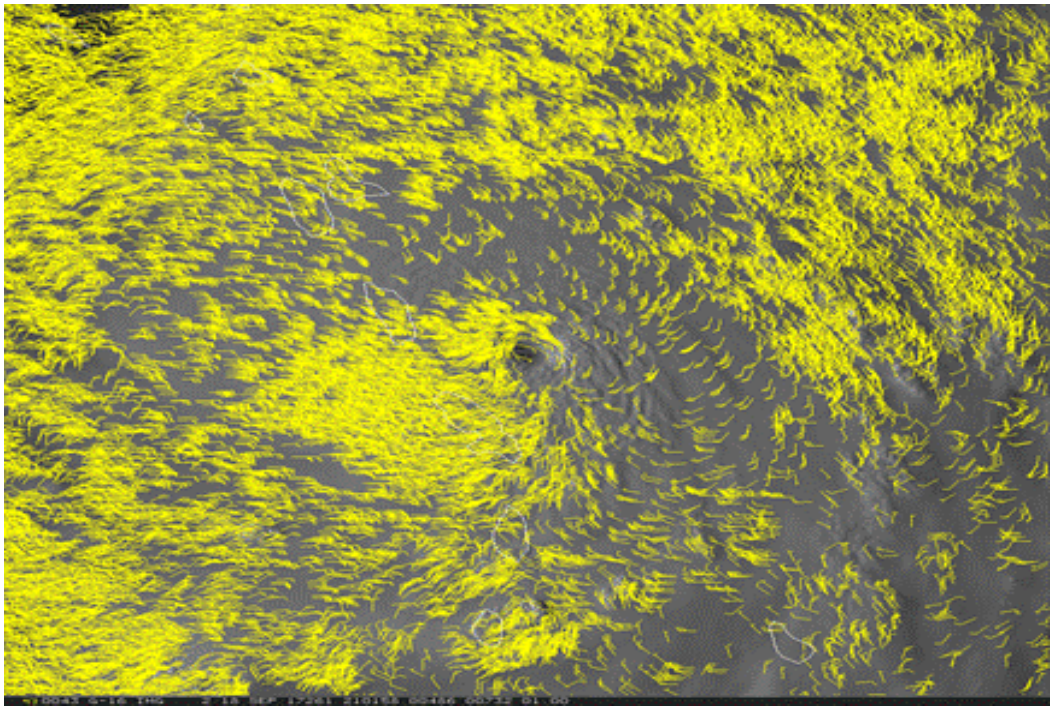


Figure 32. Same image but with enhanced AMVs produced from 1-min meso-sector images.

References

Stettner, D., C. Velden, S. Wanzong, J. Daniels, W. Bresky, R. Rabin, 2018: Telescoping In to the Convective Scales: Development of AMV Processing Strategies and Applications. 14th Int. Winds Workshop. http://cimss.ssec.wisc.edu/iwwg/iww14/program/index.html

4.5 Hurricane Intensity Estimation Algorithm
CIMSS Task Leaders: Chris Velden and Tim Olander
NOAA Collaborator: Jaime Daniels (STAR)
Budget: $100,000

NOAA Long Term Goals
- Weather-Ready Nation

NOAA Strategic Goals
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
Adapt the existing operational Advanced Dvorak Technique algorithm to operate with GOES-R imagery and provide accurate tropical cyclone intensity estimates.

Project Overview

The CIMSS Advanced Dvorak Technique (ADT) was selected to be the operational hurricane intensity estimation algorithm to operate within the GOES-R framework. The ADT will provide tropical cyclone (TC) intensity estimates using the GOES-R Advanced Baseline Imager (ABI) infrared imagery. The ADT was selected due to its longstanding use at several operational TC centers worldwide, and because of its proven record for accuracy and reliability in providing objective TC intensity estimates, especially where aircraft reconnaissance is not available. This project is helping to validate/evaluate the framework ADT TC intensity estimates using GOES-16 data on Atlantic and Eastern Pacific TCs.

Milestones with Summary of Accomplishments and Findings

ADT validation exercises using routine GOES-16 data were conducted during the 2018 hurricane season. The evaluation involved a full-season real-time demo of the latest version of the ADT (V9.0), as well as a more careful examination of Hurricanes Florence and Michael which were notable long-lived TCs that covered multiple intensity ranges. The ADT intensity estimates were benchmarked against the NHC Best Track intensities. The full-season in-house real-time demo was successful, and validation results showed an acceptable level of performance (see examples from Florence and Michael below).

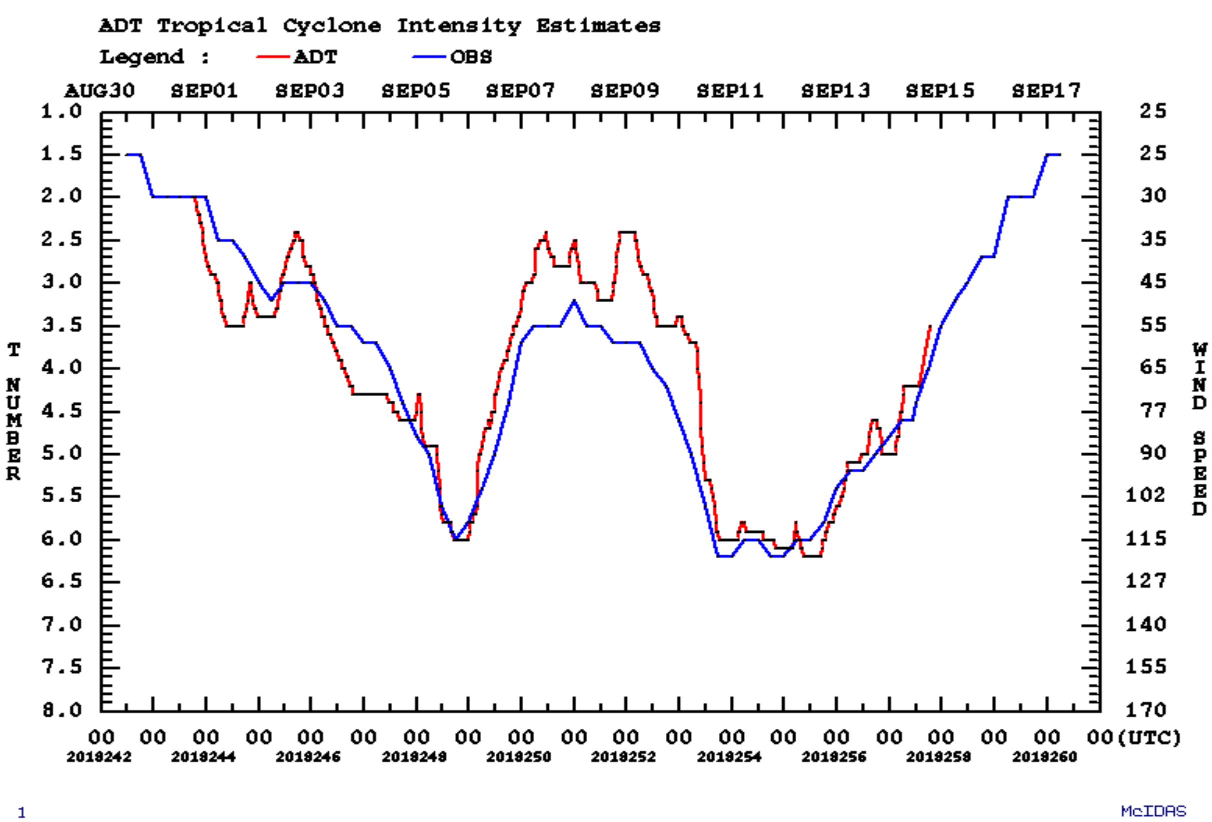


Figure 33. Plot of Hurricane Florence intensity from NHC Best Track (blue) and ADT (red).

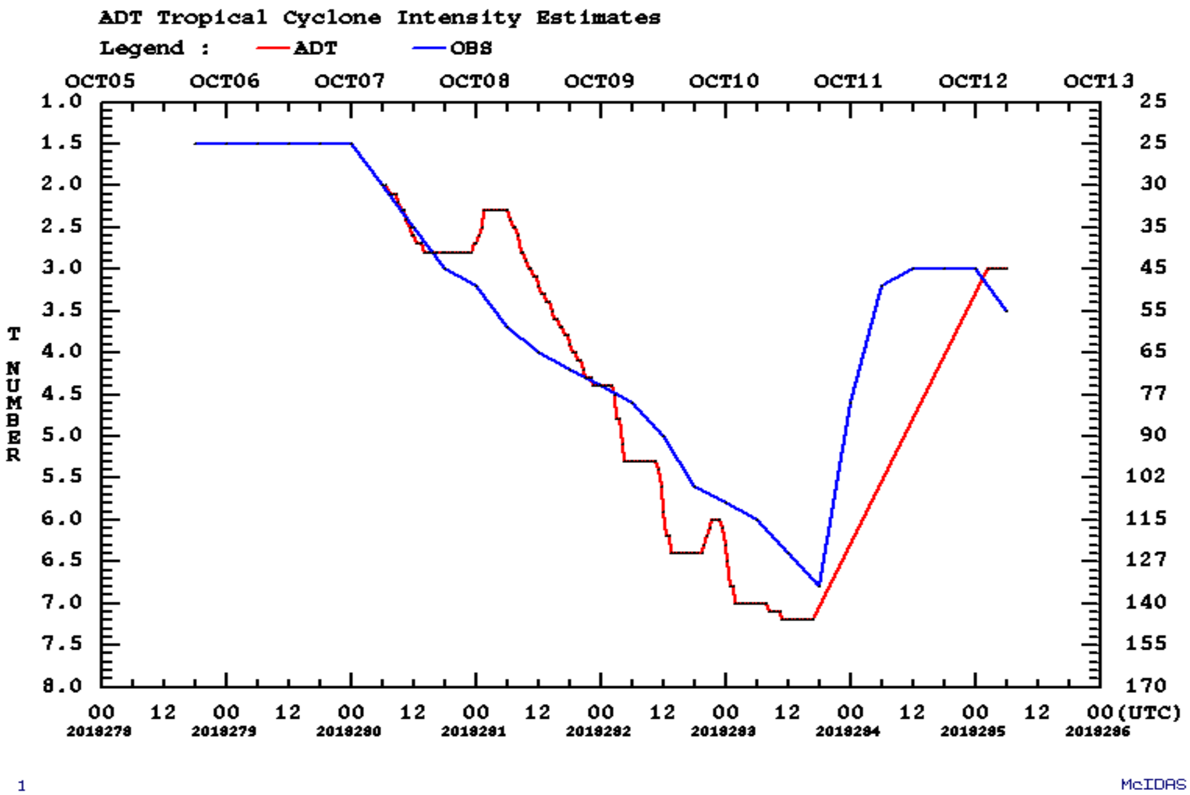


Figure 34. Plot of Hurricane Michael intensity from NHC Best Track (blue) and ADT (red).

4.6 Volcanic Ash

CIMSS Task Leader: Justin Sieglaff
CIMSS Support Scientist: Jason Brunner
NOAA Collaborator: Michael Pavolonis
Budget: $105,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

The GOES-R Volcanic Ash team will ensure the volcanic ash products produced by the GOES-R Ground System meet required specifications.

Project Overview

We have adopted an infrared-based approach for detecting the presence of ash. This information is supplied to an ash cloud height and mass loading retrieval scheme. In this project we have continued to conduct the cal/val and development work required to assure that we achieve the F&PS specifications for the volcanic ash products. We will perform extensive validation using spaceborne lidar (e.g., CALIPSO) observations of volcanic ash and dust clouds. Any problems discovered in the cal/val process will continue to be addressed. Much of the work will also be aimed at providing GOES-R Ground System (GS) contract support. This work will insure the readiness of the volcanic ash algorithm for operational implementation upon the deployment of GOES-R.

Milestones with Summary of Accomplishments and Findings

- In preparation for the GOES-16 volcanic ash provisional review, we assembled 21 volcanic ash cases since the volcanic ash algorithm ABI Band 13/14 band swap was completed in October 2017. The 21 cases encompassed the diurnal cycle as well as land and water backgrounds (land is more challenging than water surfaces).
- Consistent with our validation plan, given the rare nature of CALIPSO observations of volcanic ash in the GOES-16 domain, alternative validation methods are necessary. In preparation for the GOES-16 provisional status review, the following validation analyses were performed:
    - Detection: manual analysis using RGB imagery loops. Used to assess detection and constrain height and mass loading validation statistics.
    - Height: A wind-height validation technique was used to validate GOES-16 ash top height for the chosen cases. The wind-height technique utilizes motion (speed and direction) of volcanic ash clouds derived from geostationary imagery. The speed and wind estimate of the ash cloud is then compared to nearby radiosondes, and should sufficient vertical wind shear be present, a range of possible heights is determined for the ash cloud (generally in layers 500 to 1500 m). The wind-height derived range of heights is then compared to the GOES-16 derived ash heights.
    - Mass Loading: Satellite-derived mass loading is a strong function of the assigned cloud height. Thus, the cloud motion derived height range can be used to compute a highly representative range of "truth" mass loading.
- The wind-height validation for ash height and mass loading (Figure 35) shows the products are meeting the specifications. The mean best (worst, not shown) case ash height error was -0.38 (-0.60) km. The median best (worst, not shown) case ash mass loading error was 1.39 (1.80) g/m^2.
- The GOES-16 volcanic ash algorithm was approved for Provisional Maturity in July 2018.

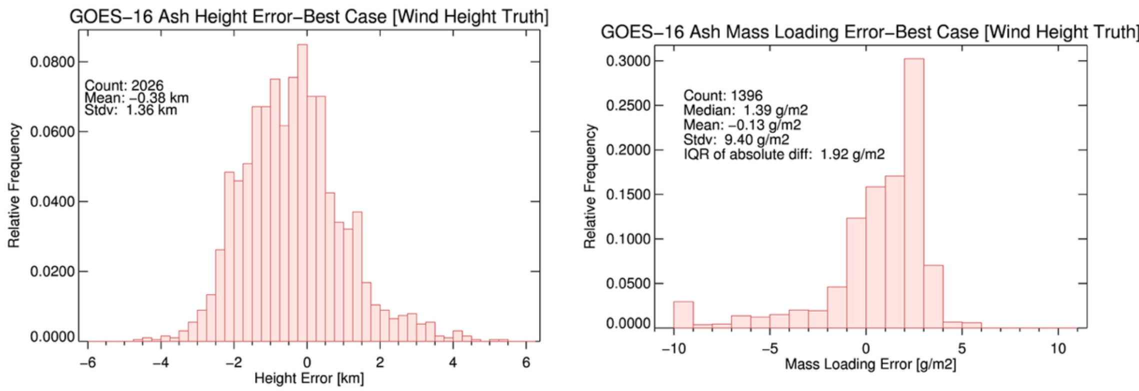


Figure 35. GOES-16 ash height best-case error (left) and ash mass loading best-case error (right) relative to wind-height derived truth. This analysis indicates the GOES-16 ash height and ash mass loading products are meeting specifications. (Not shown worse case errors, which still meet specifications.)

Publications and Conference Reports

Pavolonis, M. J., A. K. Heidinger, and J. Sieglaff, 2013: Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, J. Geophys. Res. Atmos., 118, doi:10.1002/jgrd.50173.

References

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures. Part I: Theory. *J. Applied Meteorology and Climatology*, **49**, 1992-2012.

4.7 Imagery and Visualization
CIMSS Task Leader: Mat Gunshor
CIMSS Support Scientist: Jim Nelson
NOAA Collaborator: Tim Schmit (ASPB)
Budget: $240,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
This project's primary objective is to support the GOES-R program in providing Advanced Baseline Imager (ABI) Cloud and Moisture Imagery Product (CMIP) to users.

Project Overview

The AWG Imagery Team developed the ABI L2 Cloud and Moisture Imagery Product (CMIP) and wrote the ATBD on the methodology for converting L1b radiances to CMI. Now in the post-launch-test phase, this project addresses post-launch checkouts for GOES-16 and GOES-17. Validation tools previously developed are now being used to validate the imagery product for beta, provisional, and full maturity status. The Imagery Team is primarily focused on data quality and the discovery, and analysis, of imagery product anomalies, which are sometimes closely tied to calibration and navigation instrument issues.

The AWG Imagery Team continues to work with the SSEC McIDAS development team, NWS AWIPS Satellite Enhancement Team (SET), and others on the user experience visualizing ABI imagery. The team assisted the GOES-R “First Light Imagery Team” with the first GOES-16 and -17 ABI images generated and continues to assist various visualization efforts to get images to users, outreach specialists, educators, trainers, the media, and others.

Milestones with Summary of Accomplishments and Findings

The Imagery Team continued to support the GOES-R post launch test/post launch product test efforts, especially concerning the quality of the ABI Cloud and Moisture Imagery Product (CMIP). GOES-16 ABI CMIP went through Full Maturity status product review and GOES-17 ABI CMIP went through Beta and Provisional status product reviews. This included validating the consistency between L1b radiance files and L2 CMIP file outputs.

The Mollweide projection centered at 106W, the midpoint between GOES-East and GOES-West, has been used on several occasions by the Imagery Team to highlight interesting features and to show off the geographical coverage NOAA has with the two GOES system. Figure 36 is one such example where the data have been combined and displayed in a Mollweide projection, showing the broad area of coverage provided by the current GOES constellation, which reaches from far eastern Australia to far western Europe and Africa. It took about 15 hours (from 12:00UTC on 3/20/19 to 03:00UTC on 3/21/19) to collect the data used to generate this GOES-17 (GOES-West) and GOES-16 (GOES-East) ABI CIMSS Natural True Color image. The image is generated by collecting data in 15 minute increments for just the region experiencing local solar noon. This way the entire coverage area can be displayed with the same solar illumination as the earth rotates. Mollweide projection images of several bands appear in realtime on the SSEC Geo Browser webpage: https://www.ssec.wisc.edu/data/geo/#/animation?satellite=goes-16-17-comp

Some highlights from this year include:

- GOES-16 Full Maturity PS-PVR
- GOES-17 Beta and Provisional Maturity PS-PVRs
- GOES-17 First Light Images generated for NESDIS press release
- Mollweide projection imagery made available regularly online
- ABI Book Figures generated for Imagery chapter and for other teams.
- Cold Pixels Around Fires – this issue has been around since GOES-16 and is being worked on in conjunction with the GOES-R Fire Detection team as well.
- ABI Mode-6 timeline development and testing. Also known as 10-minute full disk flex mode, which aligns the United States’ full disk image frequency with that of Japan and Europe.

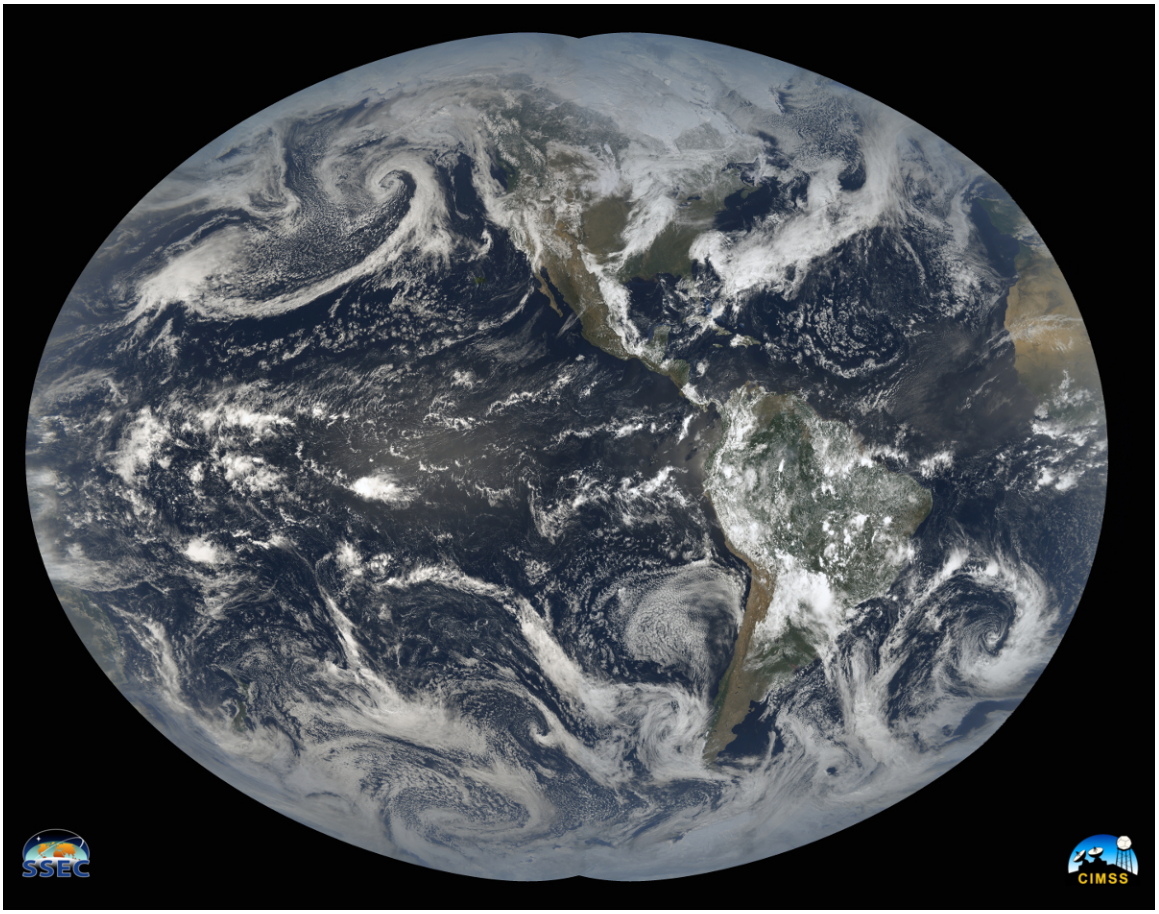


Figure 36. Mollweide projection GOES-17 (West) and GOES-16 (East) centered at the midpoint (106W) between the two satellites, shown here with the CIMSS Natural True Color enhancement from the spring equinox on March 20, 2019.

Publications and Conference Reports

Bah, M. K., Gunshor, M. M., & Schmit, T. J. (2018). Generation of GOES-16 true color imagery without a green band. Earth and Space Science, 5, 549–558. https://doi.org/10.1029/2018EA000379

Gunshor, Mathew. GOES-R: What's new in orbit. AWPA Reporter, Volume 85, Issue 1, 2018, pp.57-59.

Kalluri, S., J. Daniels, M. Gunshor, D. Lindsey, T. Schmit, X. Wu, 2018: The First Year of Advanced Baseline Imager. IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium, 22-27 July 2018. DOI: 10.1109/IGARSS.2018.8517459

Schmit, T. J., S. S. Lindstrom, J. J. Gerth, M. M. Gunshor, 2018: Applications of the 16 spectral bands on the Advanced Baseline Imager (ABI). J. Operational Meteor., 6 (4), 33-46, doi: https://doi.org/10.15191/nwajom.2018.0604

4.8 Estimate of Fractional Snow Cover with ABI
CIMSS Task Leader: Xuanji Wang
CIMSS Support Scientist: Aaron Letterly

NOAA Collaborators: Yinghui Liu, Jeffrey Key
Budget: $120,000

NOAA Long Term Goals
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications

Objective
The objectives of this project are to test, implement, and document the fractional snow cover (FSC) algorithm for the GOES-R Advanced Baseline Imager (ABI). This product provides the sub-pixel area covered by snow. The primary users of the snow cover product are the National Ice Center (NIC), NCEP, and NWS.

Project Summary
The ABI snow cover algorithm was developed by members of the AWG Cryosphere Team at the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC) and the University of Utah (Tom Painter, now UCLA/JPL) (Dozier et al. 2009, Painter et al. 2009). For long-term maintenance of the algorithm it was decided that CIMSS and the NOAA Advanced Satellite Products Branch (ASPB) will take ownership of the software and documentation to ensure long-term viability as a NESDIS operational product.

Previous work has focused on implementing and testing the Fractional Snow Cover software package at CIMSS. Our implementation shows good agreement with that provided by the STAR Algorithm Integration Team (AIT). The GOESRSCAG (GOES-R Snow Cover And Grain Size) algorithm has been implemented to routinely (daily) generate near real-time FSC over the North America, with inputs of MODIS surface reflectance and other products as a proxy of GOES-R.

With the GOES-16 FSC becoming available last year, but without the true surface reflectance product that it depends on, we have started to calibrate/validate GOES-16 FSC against FSC from other snow products. We will continue with algorithm validation, which is largely an effort to expand the scope of validation to a broader range of geographic areas and conditions. Independent estimates of fractional snow cover retrieved from higher resolution imaging systems (e.g., LANDSAT) under a variety of conditions will also be used to evaluate the accuracy of the product.

Milestones with Summary of Accomplishments and Findings
Building upon the automated validation system that compares the National Ice Center's Interactive multisensor Snow and Ice Mapping System (IMS) with the GOES-16 FSC, the team has developed a method that remaps LANDSAT snow cover data to the GOES-16 footprint. The LANDSAT data, remapped to a 1 km by 1 km grid, will be compared with the GOESRSCAG and the VIIRS algorithm output. Initially, MODIS data will be used as a proxy for ABI data.

The high spatial resolution of the derived LANDSAT snow/ice concentration, seen in Figure 37, allows comparison to both algorithms on a pixel-by-pixel basis, which is not possible for other traditional snow cover products. We also implemented a system to generate a FSC from MODIS as proxy of GOES-R to test our validation/evaluation system, and we will be ready to test GOES-R FSC using surface reflectance when they become available soon. Figure 38 shows a FSC using MODIS on April 1, 2019.

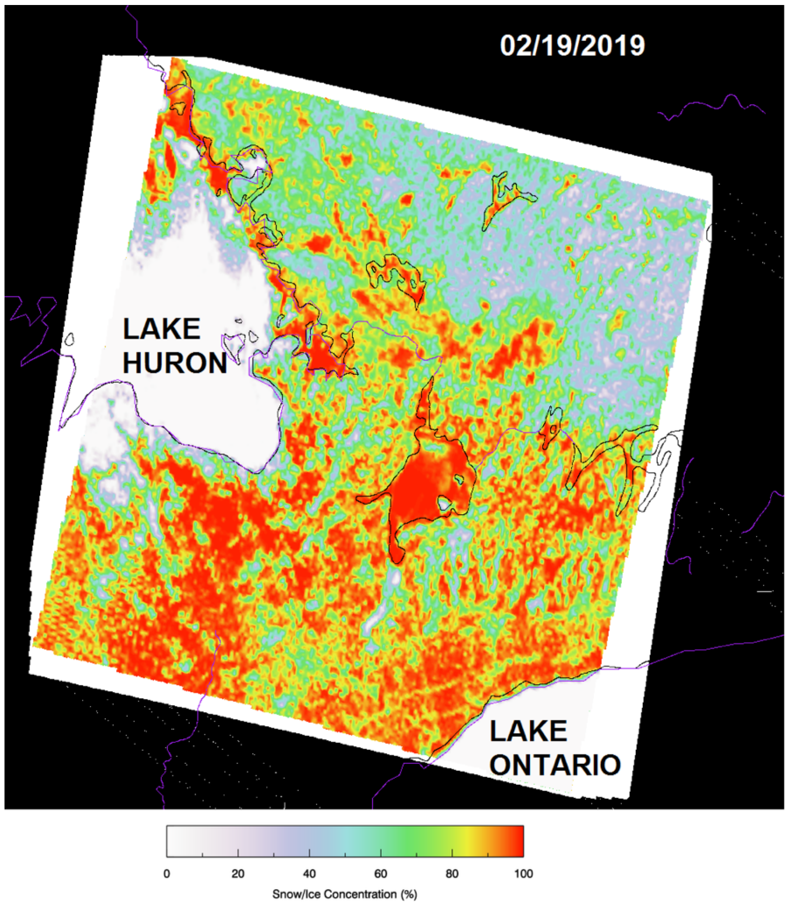


Figure 37. Snow/Ice Concentration from LANDSAT data over eastern Lake Huron and northern Lake Ontario for comparison with GOESRSCAG output.

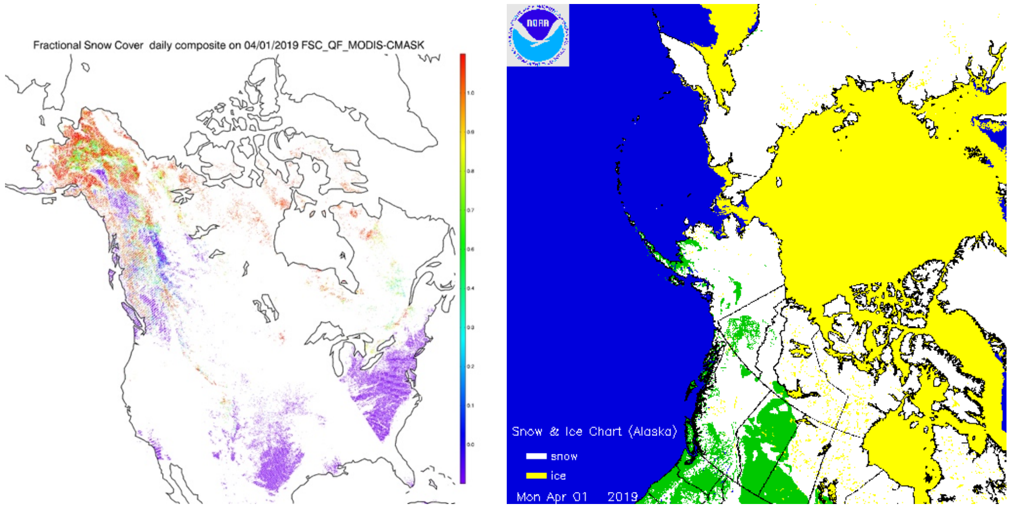


Figure 38. FSC daily composites from MODIS as a proxy of GOES-R (left), and snow and ice cover from NOAA IMS on April 1, 2019.

This year we have continued testing and improving two approaches to screen clouds. The first is based on all quality flags imbedded in the GOES-16 FSC product. The second uses the GOES-16 cloud mask and all GOES-16 FSC quality flags except cloud mask flag. We recommend that the GOES-R 16 FSC quality flags be used to screen cloud and to remove other low-quality retrievals. The other approach that we are testing is to use snow grain size retrieval to screen cloud. Clouds are best addressed are high-flying, small-particle snow. Because the particle size is small, snow grain size retrieval less than a threshold of 50 microns is flagged as cloud.

Publications and Conference Reports

Key, Y. Liu, X. Wang, A. Letterly, and T. Painter, 2019, Snow and Ice Products from ABI on the GOES-R Series. In Geostationary Weather Satellites, S. Goodman, T. Schmit, J. Daniels, D. Reynolds, and R. Redmond (eds.), Elsevier (forthcoming).

References

Dozier, J., R. O. Green, A. W. Nolin, and T. H. Painter (2009), Interpretation of snow properties from imaging spectrometry, *Remote Sensing of Environment*, doi: 10.1016/j.rse.2007.07.029.

Thomas H. Painter, Karl Rittger, Ceretha McKenzie, Peter Slaughter, Robert E. Davis, Jeff Dozier, 2009, Retrieval of subpixel snow covered area, grain size, and albedo from MODIS, *Remote Sensing of Environment*, 113, 868-879, 2009.

5. CIMSS Supplemental Support to GOES-R Algorithm Working Group (AWG) Validation, Enterprise System Transition, and GOES-17 Impact Studies for 2018

5.1 Enterprise ABI Cloud Products Product Transition, GOES-17 Problem Mitigation, and AWG Product Validation

CIMSS Task Leader: William Straka III
CIMSS Support Scientists: Denis Botambekov, Steve Wanzong, Corey Calvert, Pat Heck, Jay Hoffman, Yue Li, and Andi Walther
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis

Budget: $96,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Project Overview

Recent analysis of the preliminary GOES-17 data has shown large negative impacts in some of the GOES-R Baseline Cloud Algorithms. Notably, the cloud mask has proven to be susceptible to the level of noise expected in the GOES-17 thermal data during nighttime hours. The cloud height algorithm uses several channels that are affected by the loop heat pipe (LHP) issue as well. This will require mitigation strategies based on what the operational strategy will be. They will need to be evaluated and then integrated into the GS, which will also have to be validated using both the SAPF as proxy and actual output from the GOES-R GS.

Milestones with Summary of Accomplishments and Findings

Cloud Mask

The focus of the Cloud AWG this reporting period was doing an initial evaluation of the LHP issue and its impacts on the Cloud Mask and Height algorithms. There were several focus periods during the hottest parts of the solar cycle, notably during August and late Feburary. Part of the mitigation on the GOES-R Ground Segment System (GS) was the implementation of the Temperature Data Quality Flag (TDQF). This flag is an additional value in the Quality Flag variable to indicate when the focal plane temperature (FPT) went above a certain temperature threshold. While not currently implemented in the Operational Envriroment (OE), an initial dataset was provided to the teams for evaluation using data from the GOES-R GS Development Environment (DE). What this showed was that the internal data mask in the GOES-R GS did what was expected, namely masking out data that was either invalid or had a TDQF applied. This meant the algorithms not being able to access the radiance and brightness temperature data, resulting in the algorithms returning a fill value, as shown below.

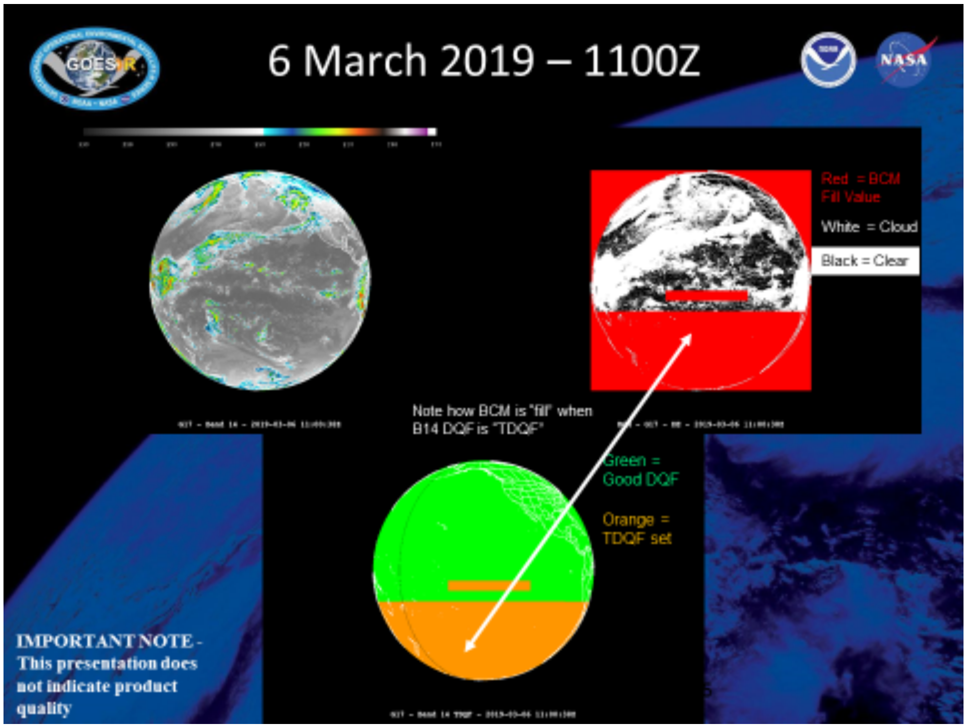


Figure 39. Impact of using TDQFs during LHP events.

CIMSS hosts a web page that shows trend plots for a few of the baseline products. The cloud mask is one of them. You can see weekly, monthly, and seasonal cloud fraction, cloud top pressure, daytime cloud optical depth, and daytime cloud effective radius. Standard deviations and valid fractions are also available at: http://cimss.ssec.wisc.edu/clavrx/goesr_img/trend.html.

Figure 40 shows the binary cloud mask cloud fraction from January to April 2019. From this plot, the effect of the LHP event in February is evident. Mitigation efforts would target the abnormally high cloud mask fractions.

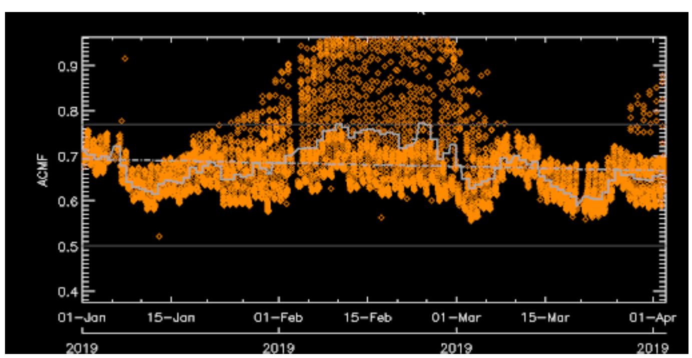


Figure 40. Binary Cloud Mask fraction for January through March, 2019. The over-masking from the LHP event is evident in February and again beginning in early April.

Because of this, further thought will be needed to implement the mitigation steps planned. A first pass at a mitigation strategy for the baseline cloud mask is shown in Figure 41. The left most image in Figure 41 is what would be observed currently in the baseline mask during a LHP event. The middle image is what the predictive calibration gets back at the same time period. The right most image is using the predictive calibration image plus algorithm modifications (substitute 10.3 μm instead of 11.2 μm, and drop the 12.3 μm channel tests).

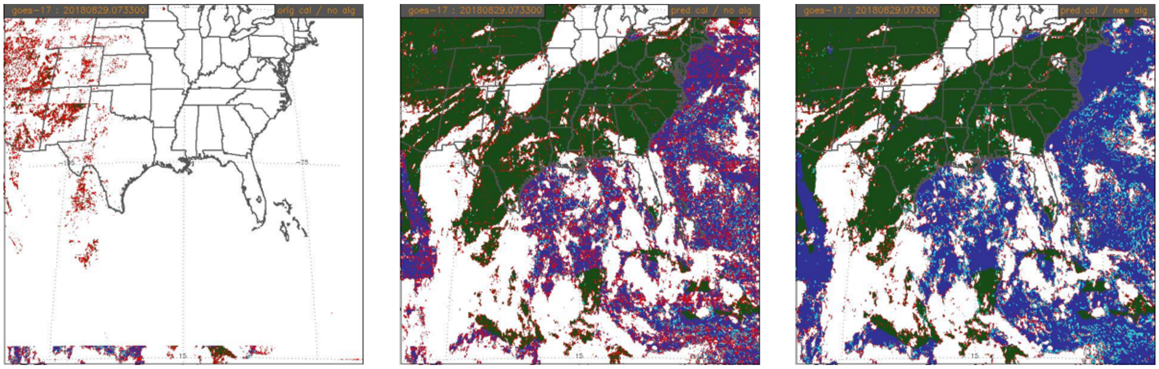


Figure 41. Baseline cloud mask for current data (left), predictive calibration (middle), and predictive calibration with algorithm changes (right).

Cloud Top Phase

During the previous reporting period the AWG cloud team provided analysis showing the cloud phase product comfortably meets the ABI RIMP requirement of a measurement accuracy of 80% correct classification when compared to the CALIOP cloud top phase product. However, some situational performance issues that impact downstream products and may impact downstream user applications we also discovered. One such issue is that liquid water cloud edges are sometimes misclassified as ice clouds. Another issue is developing cumulus clouds and mid-level clouds are too often classified as ice. These may contribute to the over-estimation of the cloud height produced by downstream algorithms.

Based on previously published research, preliminary work has begun to incorporate near-infrared measurements to mitigate the misclassification of liquid clouds as ice. Inclusion of the 1.6μm and 3.9μm near-infrared channels, along with high-resolution (0.5km) 0.65μm visible reflectance channel, has produced positive results. However, the use of near-infrared measurements is complicated by highly variable surface reflectance and sun geometry and will likely contribute to inconsistencies in the cloud top phase product through the diurnal, and seasonal, cycle. For this reason further guidance on the application of these algorithm enhancements will be necessary.

Cloud Height

The GOES-R Ground System also has a pilot project to replace the Baseline Cloud Height Algorithm with the Enterprise Cloud height Algorithm (ACHA) within the GOES-R Ground system (GS). This will be done by wrapping the actual science code developed by the GOES-R AWG Cloud team. This will allow for the GS to choose an appropriate channel selection to provide the best possible heights for the GOES-R winds algorithm or apply the mitigiations to the ACHA algorithm during the warm periods of the day. This is the only option to potentially recover some cloud data during LHP events.

As mentioned in the cloud mask section, trend plots of the cloud top pressure product are available. Figure 42 shows the operational cloud top pressure trend from January through March of 2019. The variability in the cloud mask corresponds to the variability in the cloud top pressure. Qualitatively, when the mask tends to saturate, the cloud top pressures tend to high pressures (closer to the surface).

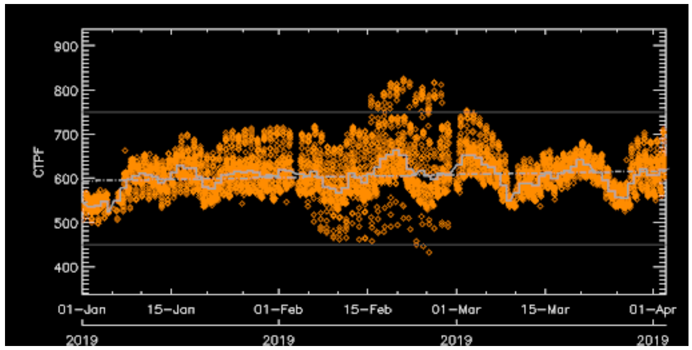


Figure 42. Cloud Top Pressure trend plot.

ACHA has been modified to provide more flexibility in channel selection during the LHP events. The current baseline cloud height algorithm uses the 11.2 μm (ABI Band 14), 12.3 μm (ABI Band 15), and 13.3 μm (ABI Band 16). Bands 15 and 16 are two of the most affected channels during LHP events. A new channel combination using 3.9 μm (ABI Band 7) and 10.4 μm (ABI Band 13) for cloud top heights is being investigated. Band 7 and 13 are largely unaffected by LHP events. Figure 43 shows cloud top pressure examples.

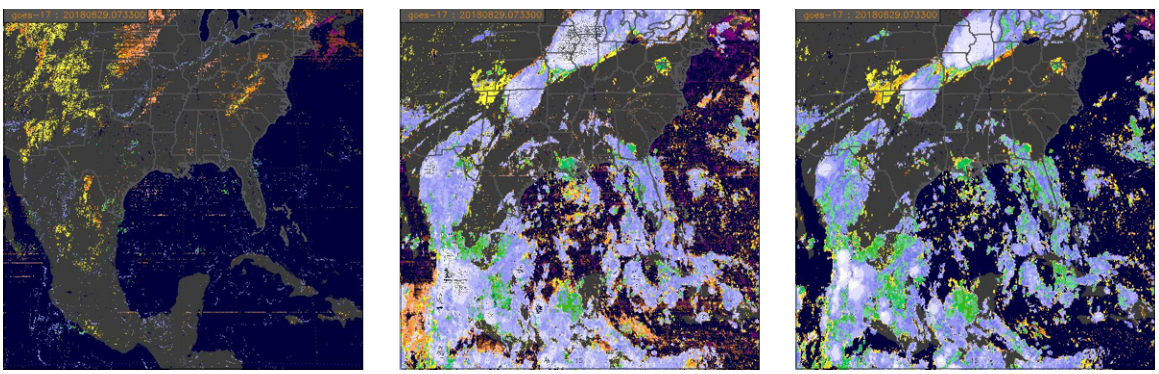


Figure 43. Baseline cloud top pressure for current data (left), predictive calibration (middle), and predictive calibration with algorithm changes (right).

There is much work left to be done. The most urgent will be to automatically switch into a mitigation channel suite on the fly. Investigations into using the DQFs and maximum LHP temperatures compared to a threshold show promise.

5.2 Enterprise Active Fire/Hot Spot Characterization (FIRE)
CIMSS Task Leader: Chris Schmidt
NOAA Collaborator: Ivan Csiszar
Budget: $43,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water

- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective

To develop Fire Detection and Characterization Algorithm (FDCA) mitigations for the GOES-17 ABI loop heat pipe anomaly and to provide support for NOAA's effort to create an enterprise fire algorithm.

Project Overview

The supplemental task provides funding to support the extra time required beyond the GOES-R AWG effort to address the loop heat pipe problem that reduces ABI L1b data quality from GOES-17, as well as to cover time to support the work to develop an "enterprise" fire algorithm at NOAA which combines the geostationary and polar orbiting algorithms. The GOES-17 mitigation is highly dependent upon the status of GOES-17 L1b data, which has been under continual improvement over the last several months. The choice of mitigation techniques depends upon those improvements to the L1b data. Mitigation may be as simple as replacing band 14 with band 13, either at all times or certain times. However, that depends on the quality of band 13 after things like predictive calibration have been applied. Other approaches to mitigation have also been considered.

Milestones with Summary of Accomplishments and Findings

GOES-17 ABI L1b data has been continuously improved over the last year, and that has caused the FDCA team to modify its plans for mitigation. Due to the nature of the fire algorithm and its reliance on band7, which is largely unaffected, and band 14, which is strongly affected, the algorithm is impacted by the problem. However, since band 14 warms when the sensor warms, that causes the algorithm to identify fewer fires overall since it causes the brightness temperature difference between bands 7 and 14 to decrease.

Initially it appeared that bands 5 or 6, shortwave IR bands not affected by the cooling problem, could be used at night, when they would only show fire signal. That would lead to a notable loss in sensitivity, but at night the signal in those bands is almost exclusively from fire. However, moving the satellite west shifted the affected time of day, and now about half of the time when the cooling problem is impacting data there is sunlight in the scene. The presence of sunlight makes use of shortwave IR, like bands 5 and 6, much more difficult and the effort to develop daytime detection with those bands beyond the funding available. However, predictive calibration will apparently improve both bands 13 and 14. At this time the plan is to integrate band 13 to operate alongside band 14, with the reliance on one or the other being determined either by available L1b metadata (the content of which is TBD) or by using the data itself to estimate when problems are occurring, due to the general similarities between bands 13 and 14.

The effort to create an "enterprise" fire algorithm is underway at NOAA and in its very early stages. The effort may or may not result in major changes to the FDCA, or in an extreme case its replacement (though this is unlikely). Thusfar efforts at CIMSS have focused on investigating the use of other bands in the fire detection and characterization process (apart from the GOES-17 mitigation) and on coming up with a way to label fire output that is consistent across platforms. Currently the FDCA produces six classes of fires and the polar algorithms report a percent confidence. Both have advantages and disadvantages, for example percent confidence doesn't carry information about cloud cover or sensor saturation, which the FDCA method does, and discussions are ongoing.

5.3 Enterprise Advanced Dvorak Technique (ADT): GOES-17 Problem Assessment and Mitigation Strategies

CIMSS Task Leader: Chris Velden
CIMSS Support Scientist: Tim Olander
NOAA Collaborator: Jaime Daniels (STAR)
Budget: $43,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications

Objective

Provide a performance assessment of the ADT algorithm during GOES-17 ABI image anomalies.

Project Overview

The UW-CIMSS team was tasked by NESDIS to perform an algorithm performance evaluation resulting from the periodic corrupt GOES-17 IR imagery. The algorithm is the Advanced Dvorak Technique (ADT) which was selected to be the operational hurricane intensity estimation algorithm to operate within the GOES-R framework. The ADT will provide tropical cyclone (TC) intensity estimates using the GOES-16/17 Advanced Baseline Imager (ABI) infrared imagery. The ADT was selected due to its longstanding use at several operational TC centers worldwide, and because of its proven record for accuracy and reliability in providing objective TC intensity estimates, especially where aircraft reconnaissance is not available. Its long-term development has been partially supported by the GOES GIMPAP and Risk Reduction programs, and the upgraded algorithm versions have been transitioned through previous PSDI efforts into NESDIS operations at the Satellite Analysis Branch. The National Hurricane Center (NHC) now routinely accesses the ADT data as part of its hurricane analysis suite of tools.

Milestones with Summary of Accomplishments and Findings

The evaluation involved the latest version of the ADT (V9.0) and a careful examination of its performance Hurricane Pola which was in the view of GOES-17. The ADT intensity estimates utilize Channel 13, which has exhibited marginal performance degradation during the GOES-17 heat pipe issue periods. The ADT was run on raw GOES-17 images, as well as a subset of images with predicted calibration for channel 13 during an affected period. The ADT estimates were benchmarked against the Best Track intensities, as well as compared to ADT estimates using GOES-15 images. The figures below show the results. The conclusion from this limited study is that the impact from the periodic GOES-17 ABI image calibration issue is expected to be minimal on the ADT performance. However, this was not a "worst-case" example, and it may be necessary to continue the assessment on other TCs this coming fall during the Eastern Pacific hurricane season and coincident with peak image degradation periods.

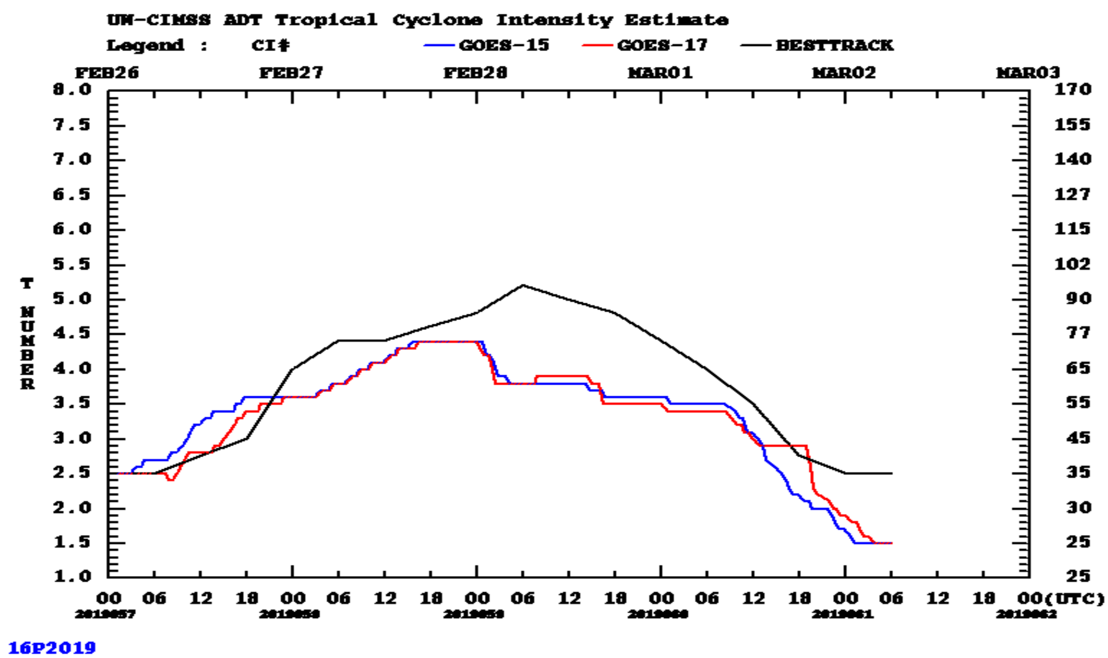


Figure 44. Hurricane Pola (2019) intensity trace (max winds, kts) from JTWC Best Track. ADT estimates in blue (GOES-15) and red (GOES-17) show only minor differences which may be due to slightly differing can angle effects.

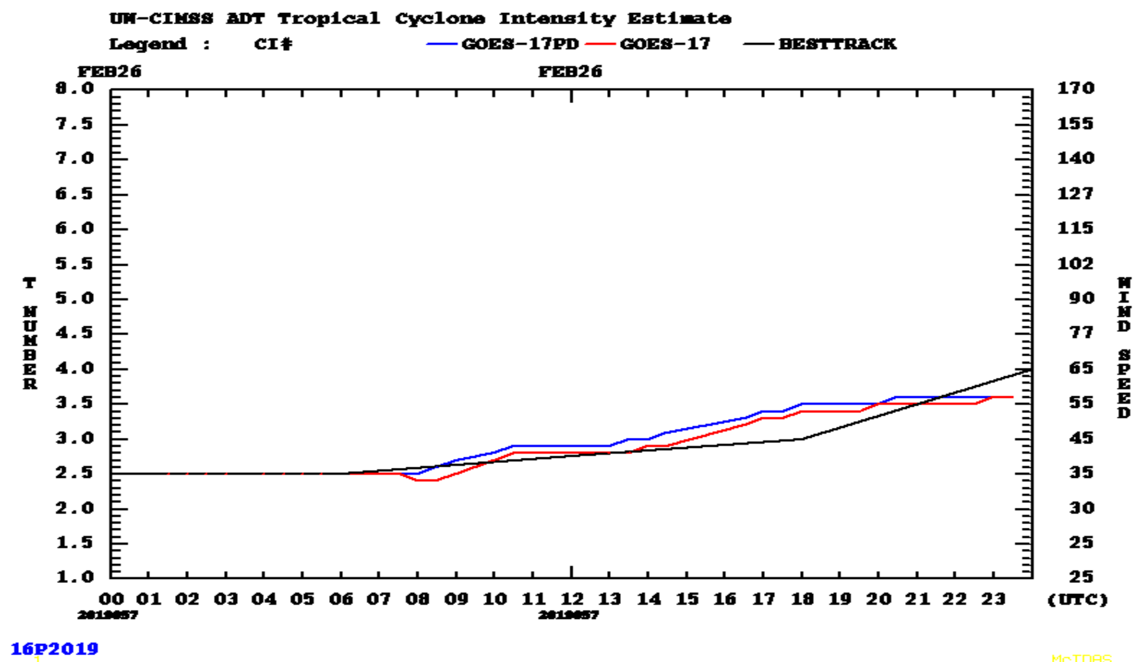


Figure 45. Hurricane Pola (2019) intensity trace (max winds, kts) on Feb. 26 from JTWC Best Track. ADT estimates in blue (GOES-17 predicted cal. imagery) and red (GOES-17 regular imagery) show only minor differences.

5.4 Enterprise Volcanic Ash Product Transition, GOES-17 Problem Mitigation, and AWG Product Validation

CIMSS Task Leader: Justin Sieglaff
CIMSS Support Scientists: Jason Brunner, Corey Calvert
NOAA Collaborator: Michael Pavolonis
Budget: $48,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

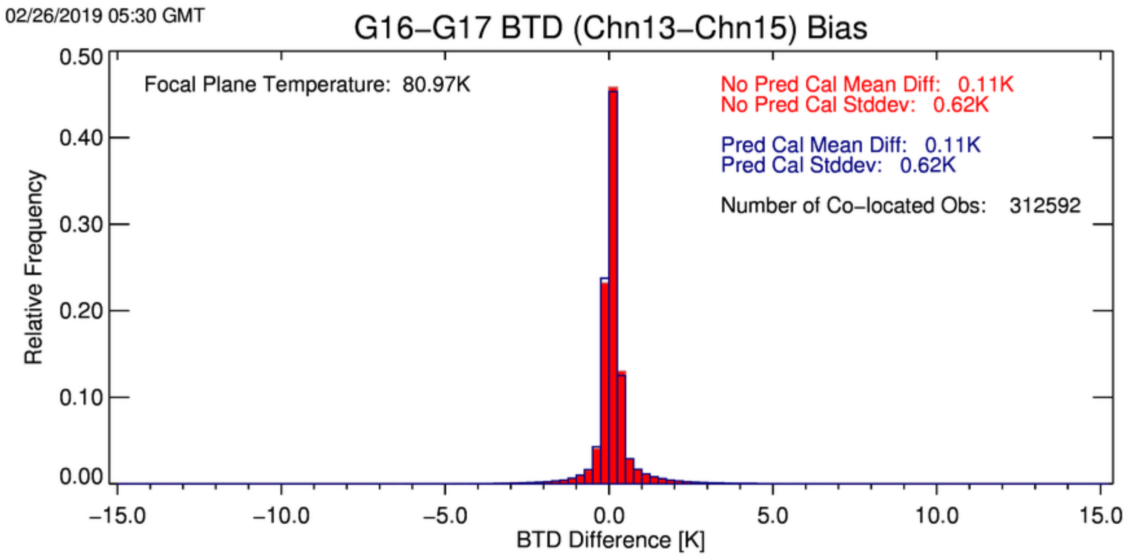
The GOES-R Volcanic Ash team will ensure the volcanic ash products produced by the GOES-R Ground System using GOES-17 ABI meet required specifications and work to mitigate algorithm issues related to instrument problems unique to GOES-17.

Project Overview

We have adopted an infrared-based approach for detecting the presence of ash. This information is supplied to an ash cloud height and mass loading retrieval scheme. In this project we have continued to conduct the cal/val and development work required to assure that we achieve the F&PS specifications for the volcanic ash products. We will perform extensive validation using spaceborne lidar (e.g., CALIPSO) observations of volcanic ash and dust clouds. Any problems discovered in the cal/val process will continue to be addressed. Due to the loop pipe heating issues present with GOES-17 ABI, we will also assess the impact to the volcanic ash algorithm and devise any potential mitigation strategies for the algorithm.

Milestones with Summary of Accomplishments and Findings

- In preparation for the GOES-17 volcanic ash provisional review, we are in the process of assembling volcanic ash cases and beginning the validation analysis, including CALIPSO comparisons (if possible), wind-height validation, and comparison to GOES-16 products (where possible).
- Given the GOES-17 ABI loop heat pipe cooling issues, we have assessed those impacts on GOES-17 ABI data by comparing to spatially and temporally co-located GOES-16 ABI data. The comparisons were made using GOES-17 ABI with and without predictive calibration corrections. Figure 46 shows brightness temperature difference bias (ABI channel 13 – channel 15; GOES-16 minus GOES-17) for an important channel combination for the volcanic ash algorithm. The top panel shows excellent agreement between GOES-16 and GOES-17, both for with (blue) and without (red) predictive calibration during a period when the GOES-17 ABI focal plane temperature was operating at the nominal temperature (81 K). The bottom panel is during a period of warm GOES-17 focal plane temperature (90 K) and shows poor agreement between GOES-16 and GOES-17 without predictive calibration (red) but much better agreement when predictive calibration is applied (blue). The biases present without predictive calibration would result in poor algorithm performance, while the predictive calibration will extend periods of usable data (until the channels completely saturate).



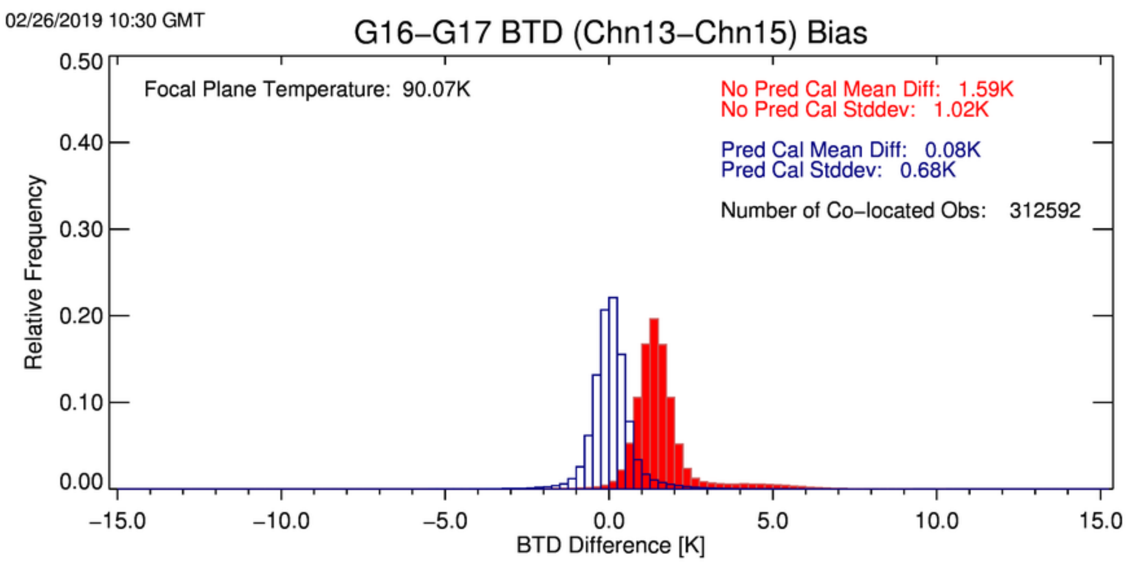


Figure 46. Co-located (spatially and temporally) GOES-16 minus GOES- ABI Channel 13-15 brightness temperature differences with (blue) and without (red) predictive calibration. The top panel is a period where the GOES-17 focal plane temperature is operating at the nominal temperature (~81K). The bottom panel is a period where the GOES-17 focal plane temperature is elevated (~90 K). GOES-17 data agrees well with GOES-16 when the GOES-17 ABI focal plane temperature is operating at nominal temperatures (top). GOES-17 diverges significantly (red, bottom) when the GOES-17 ABI focal plane temperature is elevated. However, predictive calibration significantly reduces impacts (blue, bottom) of increased GOES-17 ABI focal plane temperature and may lengthen the time periods where quantitative product generation (such as volcanic ash) is possible.

References

Pavolonis, M. J., A. K. Heidinger, and J. Sieglaff (2013), Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, J. Geophys. Res. Atmos., 118, doi:10.1002/jgrd.50173.

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures. Part I: Theory. *J. Applied Meteorology and Climatology*, **49**, 1992-2012.

5.5 Enterprise Imagery and Visualization Product Transition, GOES-17 Problem Mitigation, and AWG Product Validation

CIMSS Task Leader: Mat Gunshor
CIMSS Support Scientists: Elisabeth Weisz, Paul Menzel, Jim Nelson
NOAA Collaborator: Tim Schmit (NESDIS/STAR/ASPB)
Budget: $38,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

GOES-17 Loop Heat Pipe (LHP) issue mitigation for the ABI Cloud and Moisture Imagery Product (CMIP).

Project Overview

The AWG Imagery Team developed the ABI L2 Cloud and Moisture Imagery Product (CMIP) and wrote the ATBD on the methodology for converting L1b radiances to CMI. Now in the post-launch-test phase, this project addresses post-launch checkouts for GOES-16 and GOES-17. Validation tools previously developed are now being used to validate the imagery product for beta, provisional, and full maturity status. The Imagery Team is primarily focused on data quality and the discovery, and analysis, of imagery product anomalies, which are sometimes closely tied to calibration and navigation instrument issues.

Given the Loop Heat Pipe (LHP) issues on the GOES-17 ABI, there is more work that needs to be done to support the GOES-R program's mitigation strategy. This includes understanding the trade-offs between increased noise and decreased outage periods. Given that this work was needed before GOES-17 was deemed operational, time was of the essence.

Milestones with Summary of Accomplishments and Findings

The Imagery Team has continued to support the post launch test/post launch product test efforts, especially concerning the quality of the Cloud and Moisture Imagery Product (CMIP) and the IR bands. This includes understanding the trade-offs between increased noise and decreased outage periods associated with the Loop Heat Pipe (LHP) issue. For example, a shorter integration time increased the noise for those data, but decreased the outage period.

Task list for this supplemental funding for the Imagery and Visualization team this year:

- Intensive Post-launch validation of the GOES-17 ABI CMI products
    - Using off-line processed ABI data files.
    - When appropriate, using Ground System produced ABI files

- Generation of case-study imagery for training team, social media content, and GOES-R program presentations to better explain the performance of the GOES-17 ABI data throughout the day.
- Demonstrate GOES-17 ABI Imagery performance over time (as data become available)

In addition the Imagery Team:

- Briefed other AWG teams on the relationships between GOES-17 Focal Plane Module (FPM) temperature and data quality.
    - GEO-GEO comparisons at the midpoint between GOES-17 and GOES-16 are produced regularly by CIMSS and shared online, along with longwave IR FPM temperatures, here:
        - http://cimss.ssec.wisc.edu/goes-r/abi-/band_statistics_imagery.html
- Helped review the plans for new DQFs to go into ABI L1b files related to the LHP issue.
    - Dubbed "TDQF" the DQF for L1b Radiance and L2 CMIP have been expanded to a 5th value; DQF=4 is set when the FPM temperature exceeds the threshold for a particular band.
- Introduced Fusion, which is the methodology used in the JPSS program, to generate simulated imagery during the LHP outage time.
    - The concept of fusion is to use the IR window (IRW) band on GOES-17 to transfer the other IR bands from a good time (t0), when all bands are still good, to a bad time (t) when the IR bands are saturated or poorly calibrated due to the heating. The results from the search for similar measurements in the IRW from time (t0) for each IRW measurement in a later time (t) is transferred to the other spectral bands to simulate the missing/bad bands.
    - Qualitatively, this is a promising approach where clouds and clear sky scenes are effectively reproduced. The process is fairly fast, though some latency is added to generate multiple IR bands.
    - More work could be done to fine-tune the algorithm, perhaps optimize it for speed, and to analyze the quantitative quality of the output.

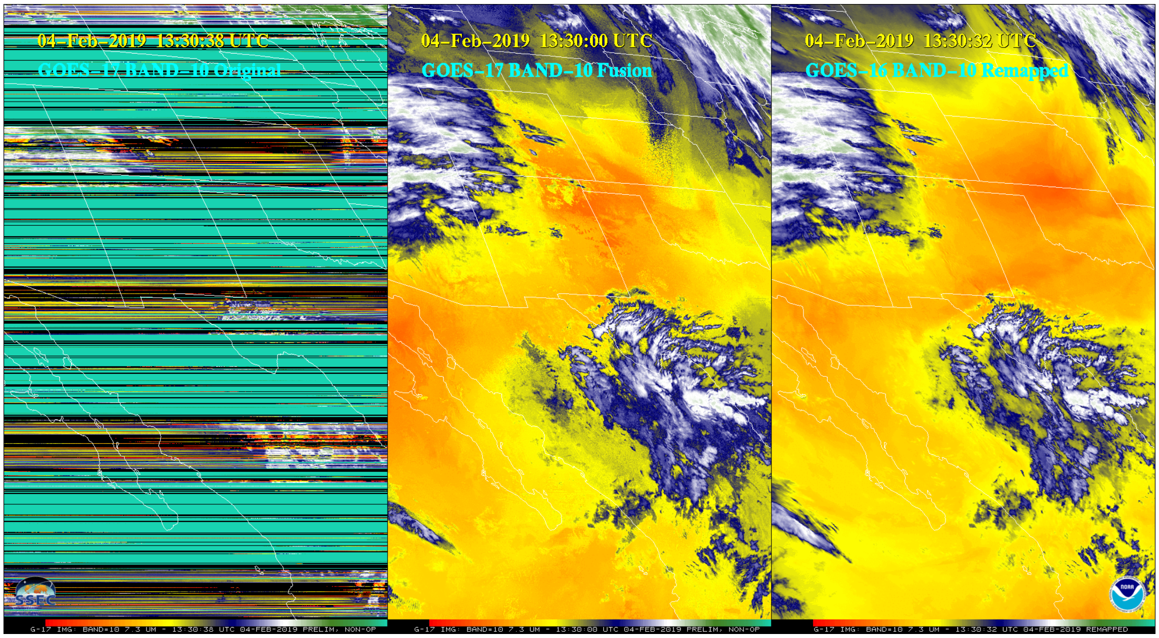


Figure 47. GOES--17 ABI Fusion Band 10 (7.3um) example from 04 Feb 2019, at 13:30UTC, one of the hottest times of the day for the ABI. The left panel is the original GOES-17 data, almost entirely saturated due to the over-heating of the instrument. The right panel is GOES-16 at the same time as a "truth" reference. The middle panel is the GOES-17 Fusion image. All 3 images were remapped to the same projection for ease of comparison.

5.6 Enterprise Ice Product Transition, GOES-17 Problem Mitigation, and AWG Product Validation

CIMSS Task Leader: Xuanji Wang
CIMSS Support Scientist: Aaron Letterly
NOAA Collaborator: Yinghui Liu, Jeffrey Key
Budget: $38,000

NOAA Long Term Goals

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

The overall goal of this project is to test, validate, implement, improve, and document the Advanced Baseline Imager (ABI) fractional snow cover and ice algorithms and products for the GOES-16/-17 satellites.

Project Summary

Three ice products have been developed for the Advanced Baseline Imager (ABI): ice concentration (with ice surface temperature as an intermediate product), ice thickness, and ice motion. These products are being prepared for operational implementation. The goal here is to implement and improve the products, then test and validate them for both GOES-16 and -17.

The work of this project year has focused on 1) working with STAR ASSISTT to aid in transitioning the NOAA Enterprise ice products to the GOES-R Ground System; 2) exploring the impact of GOES-17 IR noise/saturation issues on the Enterprise ice products and formulating mitigation strategies; 3) performing additional evaluation and validation of the accuracy of the GOES-16/-17 ice products using in situ, satellite-derived, and model-simulated ice and snow products.

Milestones with Summary of Accomplishments and Findings

We have worked together with STAR ASSISTT team to transition the Enterprise ice products to operational status in the Ground System. All ice product retrieval algorithms have been tested, implemented, improved, updated, and validated to ensure that the all ice products meet accuracy requirements. Ice concentration, thickness/age, and motion products have been thoroughly validated with other similar ice products from different resources including MODIS, AMSR2, CryoSat-2, and EUMETSAT Oceans and Sea Ice Satellite Applications Facility (OSI-SAF).

The GOES-R Algorithm Readiness Review (ARR) was successfully held in March 2019, and all GOES-R NOAT Cryosphere Products were shown to meet the accuracy and precision requirements. Figure 48 shows an example of the ice thickness from CryoSat-2 and GOES-R ABI and their difference (mean of absolute biases) that is 7.39% of CryoSat-2 mean.

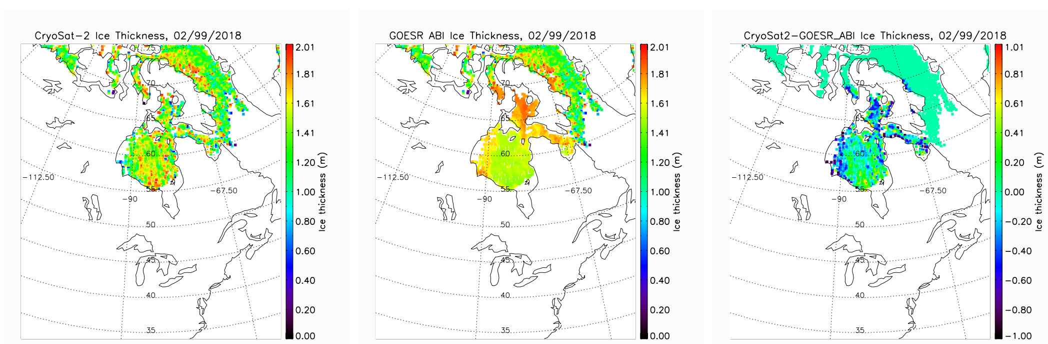


Figure 48. Ice thickness from CryoSat-2 (left), GOES-R ABI, and their difference (right) for the Hudson Bay area for the period of February 1 - 28, 2018.

Figure 49 shows an example of ice motion data product from GOES-R ABI regrided output and local (CIMSS) run output for the Hudson Bay area on the Day of Year (DOY) 039-040 in 2018.

Figure 50 shows an example of ice concentration validation results. The GOES-R ABI ice concentration matches the AMSR2 ice concentration well enough to satisfy the requirement of 10% accuracy and 25% precision.

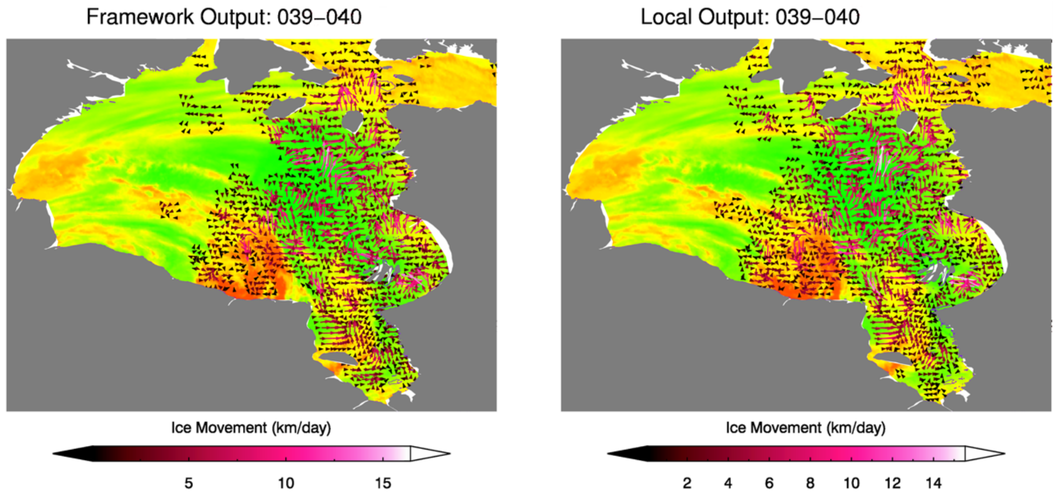


Figure 49. Ice motion from GOES-R ABI (left) and local (CIMSS) run on Day of Year (DOY) 039-040 in 2018.

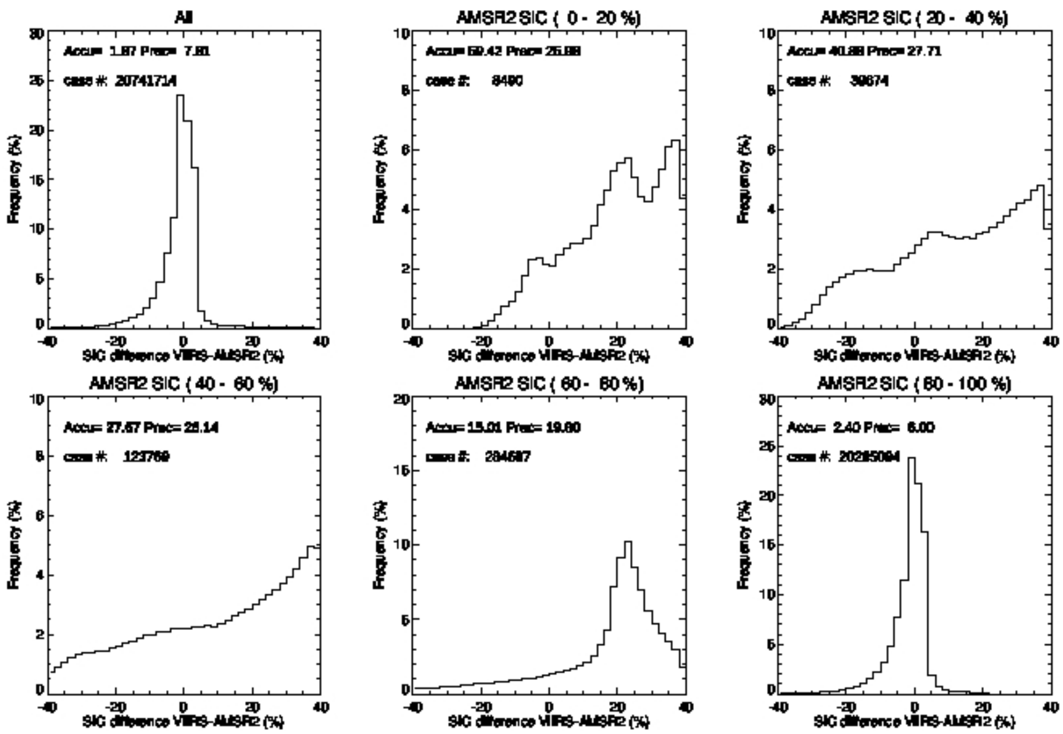


Figure 50. The relative frequency of the differences in ice concentration between GOES-R ABI and AMSR2 in terms of ice concentration value range bins and all (upper left one).

GOES-17 mitigation issues are beginning. The loop heat pipe issue will have some impact on ice concentration, ice surface temperature, and ice motion. It will indirectly affect ice thickness via errors in ice surface temperature. It will not impact fractional snow cover except through errors in the cloud mask.

Publications and Conference Reports

J. Key, Y. Liu, X. Wang, A. Letterly, and T. Painter, 2019, Snow and Ice Products from ABI on the GOES-R Series. In Geostationary Weather Satellites, S. Goodman, T. Schmit, J. Daniels, D. Reynolds, and R. Redmond (eds.), Elsevier (forthcoming).

Y. Liu, J. Key, and A. Letterly, 2018, Status of Fractional Snow Cover from GOES-R. The 75th Eastern Snow Conference, 5-8 June 2018, College Park, MD.

Y. Liu, J. Key, and P. Romanov, 2019, Validation Status of GOES-R Fractional Snow Cover Product. The 99th AMS annual Meeting, 6-10 January 2019, Phoenix, AZ.

References

Xuanji Wang, Jeffrey Key, Ron Kwok, Jinlun Zhang, 2016, Comparison of Sea Ice Thickness from Satellites, Aircraft, and PIOMAS Data, Remote Sens., Special Issue: Sea Ice Remote Sensing and Analysis, 2016, 8(9), 713; doi:10.3390/rs8090713.

Xuanji Wang, Jeffrey Key, and Yinghui Liu, 2010, A thermodynamic model for estimating sea and lake ice thickness with optical satellite data, J. Geophys. Res., Vol. 115, C12035, 14 PP., doi:10.1029/2009JC005857.

6. CIMSS Support to GOES-16/17 Priority Research Reduction 2018

6.1 VOLCAT Development for GOES-R: Volcanic Ash and SO_2
CIMSS Task Leaders: Justin Sieglaff, John Cintineo
NOAA Collaborator: Michael Pavolonis
Budget: $72,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective
We have continued to advance the VOLCAT system to better detect, characterize and track volcanic clouds for use by NOAA Volcanic Ash Advisory Centers and integration into NOAA HYSPLIT model.

Project Overview
Research conducted previously under the GOES-R Risk Reduction (GOES-R3) program has led to the development of a fully automated, satellite-based, system for detecting and characterizing

clouds that contain volcanic ash (Pavolonis et al., 2006; Pavolonis, 2010; Pavolonis et al., 2013; Pavolonis et al., 2015a; Pavolonis et al., 2015b; Pavolonis et al., 2018). The Volcanic Cloud Analysis Toolkit (VOLCAT) utilizes spectral, spatial, and temporal metrics derived from geostationary and/or low earth orbit satellite sensors to detect and characterize volcanic ash clouds. Upon detecting a new (e.g. previously undetected) ash cloud, VOLCAT generates an email and/or Short Message Service (SMS) message that alerts users to the presence of the ash cloud. VAAC's, the USGS, the United States Air Force, and airlines regularly utilize VOLCAT products via our web site (http://volcano.ssec.wisc.edu/). VOLCAT also includes a suite of multi-sensor SO_2 products being developed under this GOES-R project. Thus, VOLCAT is evolving into an end-to-end enterprise application system for volcanic clouds (ash and SO_2). VOLCAT is significantly more capable than the baseline GOES-R volcanic ash algorithm (development of the baseline algorithm was frozen in 2010).

Through the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO), aviation stakeholders have requested that the science community develop capabilities that will eventually allow for new information (e.g. ash mass loading, longer dispersion forecasts, and confidence metrics) to be included in volcanic ash advisories produced by VAACs (WMO, 2015a). Not coincidently, this request coincides with the ongoing transition to next generation geostationary meteorological satellites such as GOES-R. Next generation satellites, like GOES-R, have the spectral, spatial, and temporal capabilities needed to develop products for improved operational volcanic ash advisories. While previous research efforts have had positive impacts within the Proving Ground and international user community, additional development of the VOLCAT is needed to reach the ultimate goal of a truly end-to-end enterprise application system as required to meet the demand from the aviation industry for more accurate and detailed volcanic ash advisories (WMO, 2015a). NOAA/NESDIS/STAR, in collaboration with university partners, propose to build upon previous research as follows.

Milestones with Summary of Accomplishments and Findings

Development of VOLCAT v3

VOLCAT algorithm development for GOES-R continued in earnest, as we progress towards our ultimate goal of a fully integrated tool that supports Volcanic Ash Advisory Centres, modelling centres, and state volcano observatories. The VOLCAT feature-tracking algorithm has several tuneable parameters that need to be optimized for each GOES-R scan strategy. Heuristic tuning was used to improve the tracking performance at 1, 5, 10, 15, and 20, and 30-minute image refresh intervals. The 20 and 30-minute intervals were tested to account for any image gaps that may be encountered in real-time processing. Future enhancements are planned to improve the tracking of features that split into two or more distinct regions due to strong wind shear.

The initial detection of ash emissions was also improved; primarily through the incorporation of brightness temperature difference (BTD) time tendencies computed using Eulerian and Lagrangian frameworks. The Eulerian and Lagrangian (supported by k-d tree based nearest neighbour matching) frameworks are needed to distinguish between advection and new cloud development. Cloud objects composed of pixels with an overall multispectral signature that is reasonably consistent with volcanic ash (assessed using machine learning and a spectral/spatial correlation analysis), and contain at least one pixel with BTD time tendencies consistent with volcanic ash cloud formation, are chosen for further analysis. The additional analysis is used to determine if the candidate ash object(s) are sufficiently close to a volcano, have a plume-like shape, and exhibit sufficient contrast, in multispectral space, with the surrounding environment. If the required conditions are met, all of the pixels in the selected object(s) are classified as volcanic ash and an alert is generated. Newly identified ash features are assigned unique identification metadata and are tracked in subsequent ABI images until they can no longer be distinguished from the background. An example GOES-16 ABI based ash alert is shown in Figure 51. Note how the algorithm is able to identify the ash emission in the very early stages of development (often the first image where the feature is apparent to the human expert), when it is composed of just a few ABI pixels. Such early detection is critical for timely issuance of volcanic ash advisories. While validation is ongoing, the VOLCAT algorithm detects most ash emissions that human experts can identify in multispectral ABI imagery. On most days, correct detections outnumber false alerts, which is difficult to achieve given that relatively few ABI pixels will contain ash at any given time. The false alerts can generally be attributed to co-registration errors and sub-pixel cloud effects.

Volcanic emissions are often preceded or accompanied by hot gases and lava that produce thermal signatures that can be detected by the ABI. The very basic volcanic thermal anomaly detection algorithm, utilized within VOLCAT, has been significantly upgraded. New developments include:

1. Increased overall sensitivity to volcanic thermal anomalies, including in the presence of cloud cover
2. Daytime thermal anomaly detection
3. Estimation of Volcano Radiative Power (VRP)

The upgraded algorithm, which builds upon established techniques (e.g. Wooster et al., 2015) while improving capabilities under cloudy conditions (common near volcanoes), supports improved volcanic activity alerting and monitoring. For instance, the time evolution of VRP can often be used to detect the onset of explosive activity prior to a volcanic cloud becoming apparent in ABI imagery. Early detection of explosive activity is critical for aviation safety and efficiency. An example of the VRP time series capability is shown in Figure 52, where the VRP (red line), associated with thermal anomalies at Popocatepetl volcano (Mexico), is estimated every 5-minutes on 6-7 March 2019. In order to provide insight on background conditions, the ABI 12µm brightness temperature, associated with the pixel with the greatest VRP in the thermal anomaly region, is also shown (green line) (the 12µm brightness temperature is insensitive to the sub-pixel volcanic thermal signatures). Volcanic activity can vary on very short time scales, so the 5-minute ABI sampling rate available for Popocatepetl is extremely valuable. The VRP time series for Popocatepetl includes periods of significant variability, including two rapid increases in VRP that top out above 1 GW (10^9 W). The VRP "jumps" that occur shortly after 14 UTC on 6 March and near 00 UTC in 7 March are both associated with the onset of explosive events which generated ash clouds that eventually rose to jet cruising altitudes. All other ash emissions observed during this time period were minor and generally associated with more subtle jumps in the VRP. The VRP jumps systematically preceded the unambiguous appearance of a volcanic cloud in ABI imagery by at least one 5-minute scan. The automated GOES-R VRP time series application has the potential to transform volcano monitoring, as rapid changes in VRP are not adequately captured using traditional low earth orbit satellite based approaches (e.g. MODVOLC - http://modis.higp.hawaii.edu/, MIROVA - http://www.mirovaweb.it/). A "VRP jump" based alerting algorithm is currently under development and a journal publication is being planned.

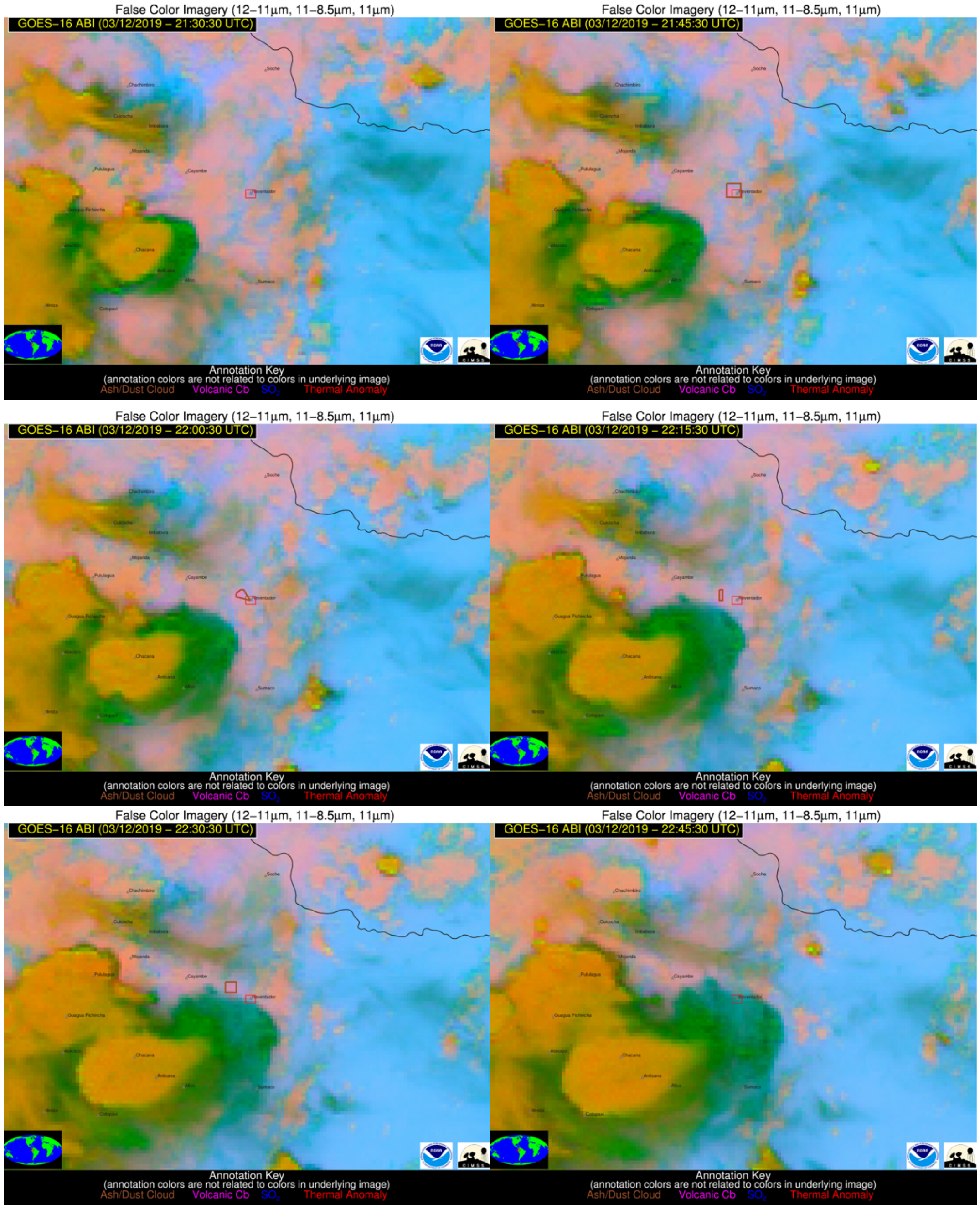


Figure 51. The improved VOLCAT ash detection capability is demonstrated using a minor ash emission from Reventador (Ecuador) on 12 March 2019. A time sequence of GOES-16 ABI "ash/dust" false color images from 21:30 – 22:45 UTC shows how the ash emissions was promptly detected when it first became discernible in the 21:45 UTC image and was successfully tracked until it was no longer discernible, beginning in the 22:45 UTC. The brown polygon overlaid on the false color images denotes where ash was automatically detected.

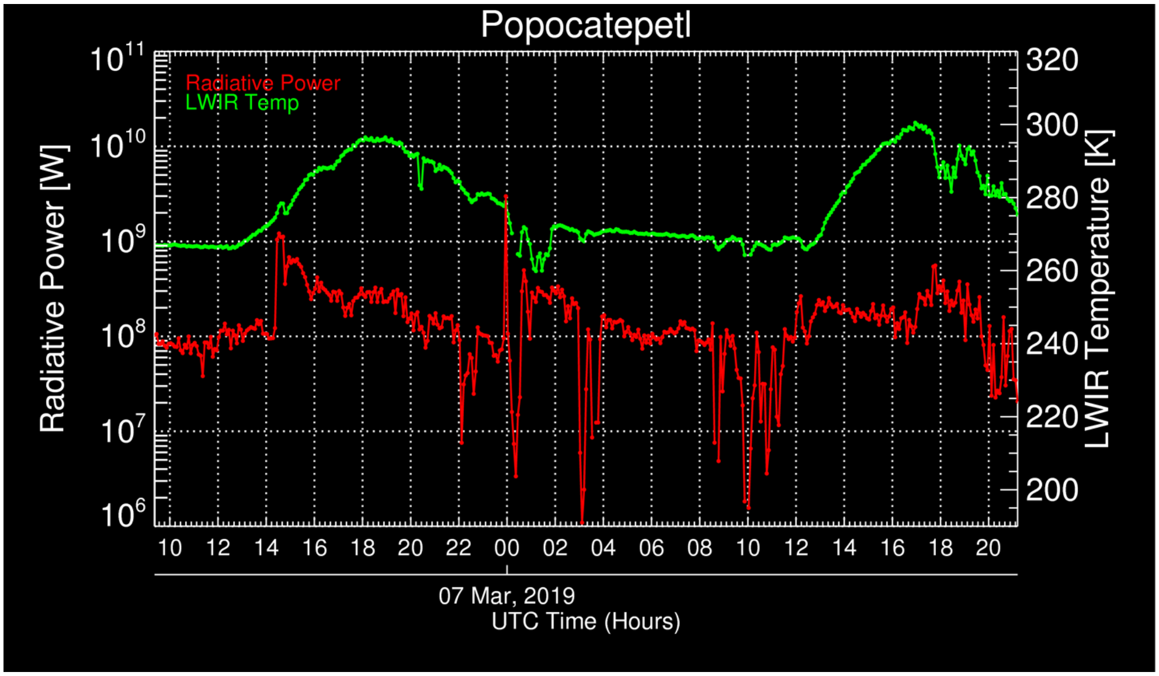


Figure 52. Auto-generated time series of volcano radiative power (VRP), at Popocatepetl volcano (Mexico), is shown in red. The time series spans from about 09:45 UTC on 6 March 2019 to 21:00 UTC on 7 March 2019. In order to provide insight on background conditions, the ABI 12µm brightness temperature, associated with the pixel with the greatest VRP in the thermal anomaly region, is also shown (green line) (the 12µm brightness temperature is insensitive to the sub-pixel volcanic thermal signatures). The large "jumps" on VRP around 14 UTC (6 March) and 00 UTC (7 March) are associated with the two most significant ash emissions observed during this time period.

Publications and Conference Reports

Pavolonis, M.J., J. Cintineo, and J. Sieglaff, 2018: Automated Detection of Explosive Volcanic Eruptions Using Satellite-derived Cloud Vertical Growth Rates, *Journal Geophysical Research*, **5(2)**, 903-928.

Pavolonis, M.J., J. Cintineo, and J. Sieglaff, 2018: Remote Sensing of Volcanic Ash with GOES-R. Chapter in *Geostationary Weather Satellites*, Submitted.

References

Pavolonis, M.J., J. Cintineo, and J. Sieglaff, 2018: Automated Detection of Explosive Volcanic Eruptions Using Satellite-derived Cloud Vertical Growth Rates, *Journal Geophysical Research*, **5(2)**, 903-928.

Wooster, M. J., Roberts, G., Freeborn, P. H., Xu, W., Govaerts, Y., Beeby, R., He, J., Lattanzio, A., Fisher, D., and Mullen, R, 2015: LSA SAF Meteosat FRP products – Part 1: Algorithms, product contents, and analysis, *Atmos. Chem. Phys*., **15**, 13217-13239, https://doi.org/10.5194/acp-15-13217-2015.

6.2 Evaluation of Turbulence-Detection Methods on ABI/AHI

CIMSS Task Leader: Anthony Wimmers
CIMSS Support Scientists: Sarah Griffin, Jordan Gerth, Lee Cronce
NOAA Collaborators: Bill Ward, David Barber
Budget: $96,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

The creation of new, real-time turbulence viewing tools for Himawari-8 and GOES-16 (online and through AWIPS) and their ongoing refinement based on feedback from NOAA aviation hazard forecasters.

Project Overview

Stakeholders in the Pacific Region have stated the need for products that provide warning for atmospheric conditions leading to aircraft turbulence, and these are underrepresented in the GOES-R generation ABI product stream. In the previous year we found one product, the High-Pass filter gravity wave product, to be especially effective. In this year we have developed a preliminary machine learning model to relate the high-pass product to turbulence observations. Results show that the model predicts 50% of the turbulence events with a very low (~5%) false alarm rate. We will pursue more elaborate comprehensive versions of this approach in the upcoming year and explore compensations for GOES-17 degradations.

Milestones with Summary of Accomplishments and Findings

Development of machine learning model

We have focused on developing machine learning techniques to holistically determine turbulence potential from the image-filtering tools that were implemented previously. Specifically, we are using a Deep Learning framework with a Tensorflow API. Deep Learning is particularly well-suited to this task, because of the ability to operate on structured image information through Convolutional Neural Networks (CNNs). CNNs allow an algorithm to assimilate thousands of data points in a window within an image and apply the most relevant patterns that enable the desired predictions. Thus, they are not only applicable to two-dimensional imagery but also easily scalable to multispectral imagery in the future.

Determination of model skill

When compared to an independent sample, results show that the model correctly assigns a high probability of MOG (>80%) to about half of the true MOG events, with a false alarm rate of less than 5%. This is by far the highest accuracy of any existing satellite-based turbulence model, and a significant accomplishment in light of the erratic occurrence of turbulence even in highly favorable environments. Furthermore, the results show a skill at 10-minute resolution that would be very complementary to existing NWP model capabilities.

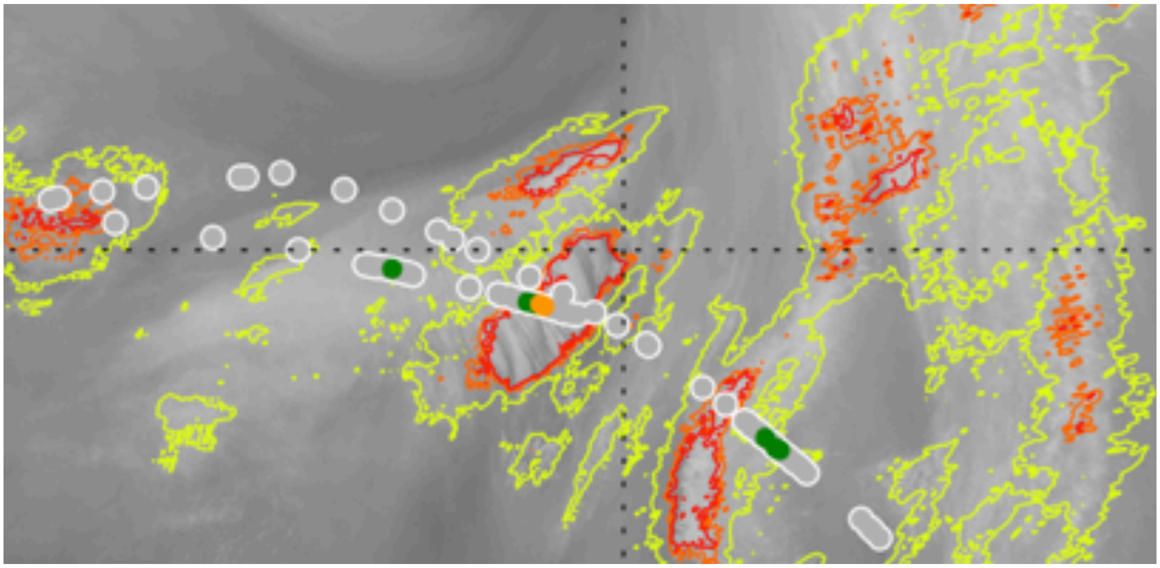


Figure 53. Detail of the deep learning model estimate of turbulence probability (red contours: >33% likelihood, orange: >25%, yellow: >10%), and automated flight data of turbulence (orange disks: moderate turbulence, green disks: light turbulence, gray disks: no turbulence) overlayed on an upper-troposphere water vapor Himawari-8 image (grayscale).

Publications and Conference Reports

Sarah Griffin presented the High Pass product at the FAA workshop in Boulder, Colorado in July. Kris Bedka presented an update on this research at the Third Turbulence Workshop on the impacts and mitigation of atmospheric turbulence encounters in National Airspace System operations. Tony Wimmers presented the latest results of the machine learning model at the AMS Annual conference in January 2019.

7. CIMSS GOES-R Risk Reduction Program 2018-2019

7.1 Integration of GOES-R/ABI Data in Flood Mapping Software for Flood Monitoring and Forecasting

CIMSS Task Leader: Jay Hoffman
CIMSS Support Scientist: Dave Santek
Budget: $28,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society’s needs for weather and water
- Understand climate variability and change to enhance society’s ability to plan and respond

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
Support GMU in the development of a flood detection algorithm from GOES-R/ABI.

Project Overview
A river flood product, originally developed for VIIRS at George Mason University (GMU), has been adapted for GOES-ABI. By taking advantage of the frequent imaging, the ABI flood product reduces the extent of cloud coverage by building a mosaic of daylight clear-sky observations. Because clouds move over time, the composite from a time-series of observations provides greater spatial coverage than can be achieved from a single image. Building on the partnership established for the JPSS flood product, the support CIMSS provides for the GOES-ABI flood product includes access to computing resources, to low-latency GOES-16 data, and product distribution networks.

Milestones with Summary of Accomplishments and Findings
The ABI flood algorithm is now running routinely with every daylight GOES-16 CONUS image. The maximum floodwater concentration is published as hourly and daily composite flood products. These hourly and daily flood products are distributed to NOAA RFCs via LDM for AWIPS, the products are pushed to a FEMA ftp server, products are publically available on an ftp server hosted by the dedicated flood product hardware, and are also made publically available via SSEC's RealEarth web service. An example of a recent flooding event in the Midwest is shown as a daily composite from 20 March 2019 is shown in Figure 54; the flooding appears primarily as shades of yellow and red; persistent clouds appear as grey.

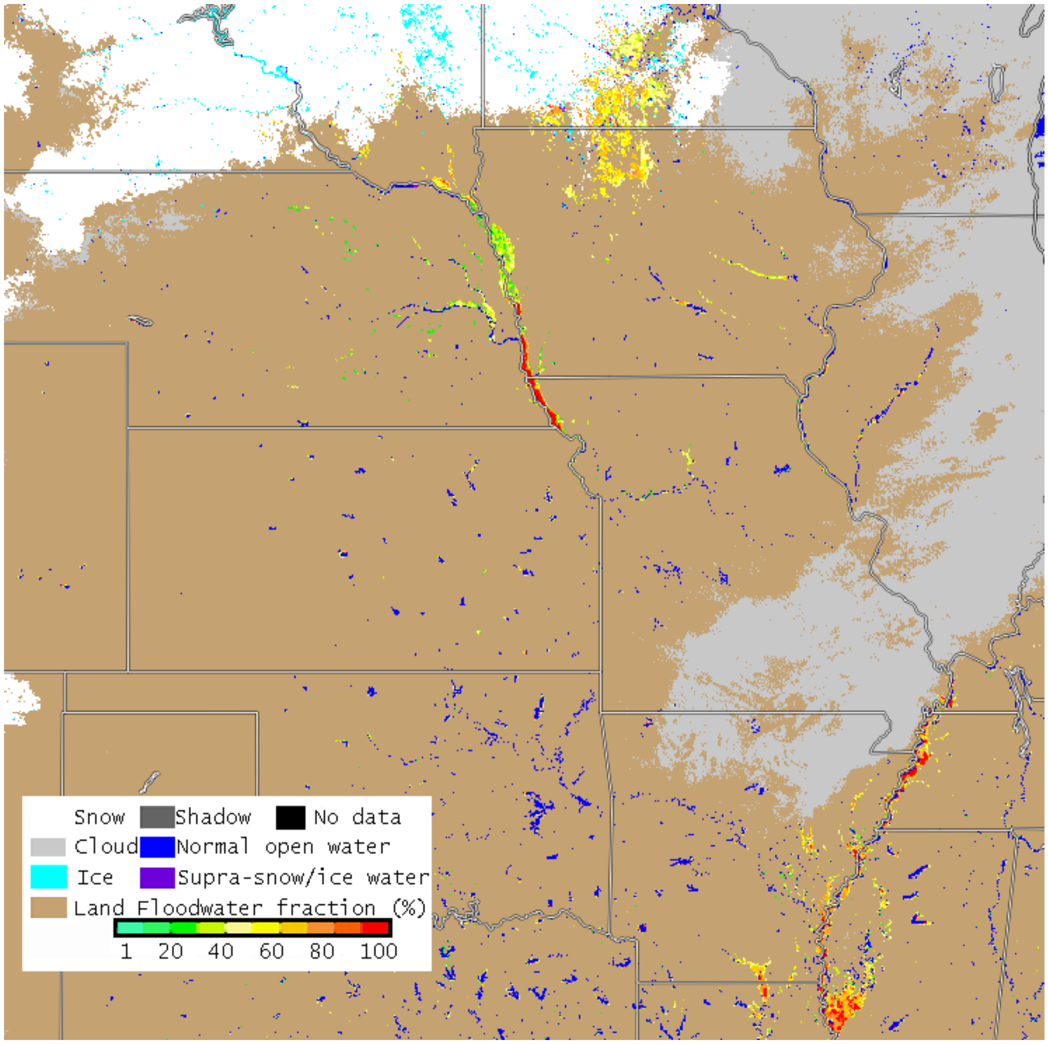


Figure 54. Example ABI Flood product mosaic from 20 March 2019.

7.2 ProbSevere: Upgrades and Adaptation to Offshore Thunderstorms
CIMSS Task Leader: John Cintineo
CIMSS Support Scientists: Justin Sieglaff, Jason Brunner
NOAA Collaborator: Mike Pavolonis
Budget: $123,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

The goals are: 1) to improve ProbSevere over land with the incorporation of GLM data, more ABI fields, and HRRR data; 2) to create a ProbSevere-like product adapted for offshore thunderstorms, where radar data are not available.

Project Overview

Severe thunderstorms endanger lives and can cause damage in excess of $10 billion dollars in a single year (USA Today, 2016). Timely and accurate severe thunderstorm and tornado warnings are critical for protecting life and property. The Science and Technology Plan of the NWS's Weather-Ready Nation Roadmap (NWS 2013) highlights the value of data fusion techniques for improving operational decision-making, including severe weather warning operations. In an effort to support severe weather warning operations through data fusion, the NOAA/CIMSS ProbSevere model (Cintineo et al., 2013; Cintineo et al., 2014, Cintineo et al., 2018) was developed under a previous GOES-R Risk Reduction project. ProbSevere utilizes NWP, GOES, NEXRAD, and ground based lightning data to estimate the probability that a developing thunderstorm will produce severe weather up to 90 minutes in the future, including hazard specific predictions of severe hail, severe wind gusts, and tornadoes. This project focuses on feedback from NWS user requests for improving ProbSevere. The two primary topics include upgrades to ProbSevere for improved WFO severe weather warning operations within the current warning paradigm (as well as within the FACETS warning paradigm) and developing a version of ProbSevere for predicting which offshore thunderstorms will produce gale force winds. The Ocean Prediction Center (OPC) requested that an offshore version of ProbSevere be developed to assist with their real-time warnings to mariners.

Milestones with Summary of Accomplishments and Findings

Progress toward AWIPS-2 plug-in development

At the HWT in 2018, forecasters expressed a desire to be able to simultaneously display the overall probability of severe and the probability of tornado (ProbTor). Based on NWS forecaster feedback from a field survey last summer, we have developed a new AWIPS-2 plug-in capability to do just that. Figure 55 highlights a storm with two contours around it – the inner contour is the traditional probability of any severe (in ProbSevere v2, this is the max[ProbHail, ProbWind, ProbTor]), and the outer contour is the ProbTor value. Forecasters can configure the minimum ProbTor value when a second contour will appear, with an option of completely disabling the display of the second contour, if desired. To facilitate quick interpretation, both contours correspond to the same colormap. Now forecasters will be able to more easily see rapid changes in the probability of tornado for a given storm. This capability will be evaluated in the 2019 HWT.

Development is still ongoing with respect to a time series capability for ProbSevere in AWIPS-2, and we expect that a prototype will be ready for the 2020 HWT.

Progress toward improvement of ProbSevere v2 and creation of ProbSevere Offshore

We have added GLM derived metrics to our storm object database, which includes over 10,000 severe storms and 121,000 non-severe storms that occurred between March and September of 2018. The following GLM metrics were added to the database, which also includes Earth Networks, Inc. (ENI) lightning products: Flash Extent Density, Flash Centroid Density, Total Optical Energy, Average Flash Area, Group Extent Density, and Group Centroid Density. The GLM gridded fields were aggregated over five minutes. Analysis of the updated database reveals the following first order conclusions:

- While in a bulk statistical sense, the GLM and Earth Networks, Inc. (ENI) flash rates are fairly similar, there are some interesting differences. In a large percentage of the severe storms, the ENI flash rates significantly exceed the GLM flash rates at times during the storm lifecycle. The discrepancy in flash rates between ENI and GLM could be leveraged for ProbHail, as the probability of producing large hail generally increases as the ratio between ENI / GLM flash rates increases in combination with an increase in ENI flash rate (see Figure 56). The smaller GLM flash rates are likely due to attenuation of the optical energy from lightning generated within the core of the storm.
- When only GLM data are considered, the flash rate and flash extent density products are best for discriminating between severe and non-severe storms.
- The ratio of total optical energy and average flash area (TOE / AFA) is better for discriminating between severe/non-severe storms than either field alone. We hypothesize that the ratio constrains large TOE to convection with robust updrafts.

With the aforementioned updated 2018 database, we have begun exploring several fields of convection allowing model data from the HRRR. The 10m wind gust field has shown the best discrimination between severe and non-severe thunderstorms over CONUS (not shown). The 10m-wind field from the HRRR may also be useful for gale-force wind prediction over the Ocean Prediction Center (OPC) offshore regions. We are working on incorporating the HRRR into both ProbSevere v2 and ProbSevere Offshore.

Progress is continuing on incorporating 1-min GOES-R mesoscale sector data into ProbSevere. The current object identification and tracking method works well, but is too computationally intensive from real-time applications. We are working on modifications to the object tracking that will allow for real-time utilization.

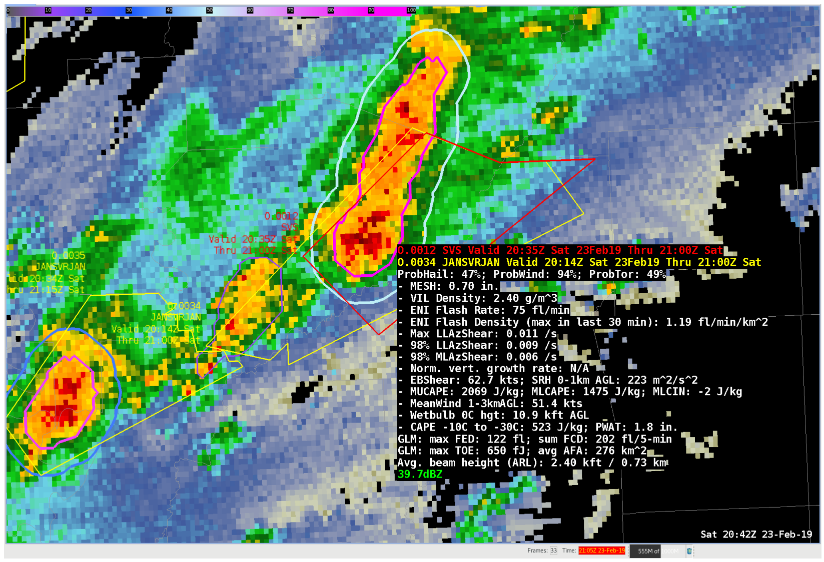


Figure 55. An example of the two contour ProbSevere display option within AWIPS-2. The inner contour is the normal probability of severe. The outer contour is the probability of tornado (ProbTor). For this storm, the probability of severe is 94% (pink inner contour) and the probability of tornado is 49% (light cyan outer contour).

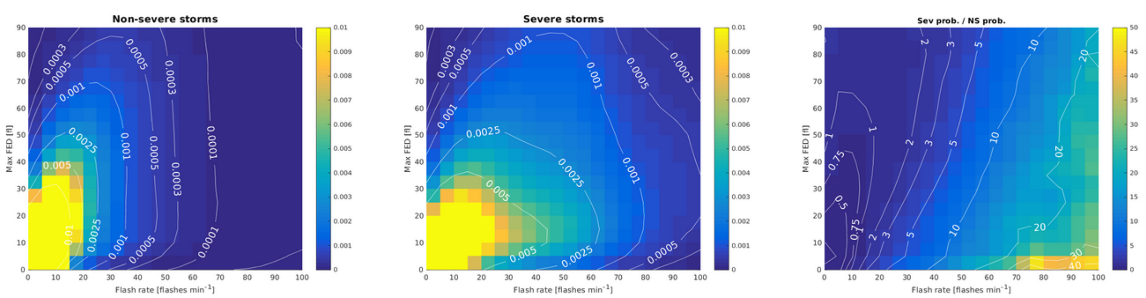


Figure 56. The joint conditional probability distributions of ENI flash rates and GLM flash extent density (FED) for non-severe storms (left), severe hail-producing storms (center) and the ratio of the severe to non-severe classes (right). The region between 5-20 GLM max FED (y-axis) and 20-80 ENI flash rate (x-axis) highlights an area of large ENI flash rates relative to GLM FED, where severe hail is more probable.

Publications and Conference Reports

Published with support of another GOES-R3 project, but relevant to ProbSevere Offshore development:

Pavolonis, M.J., J. Cintineo, and J. Sieglaff, 2018: Automated Detection of Explosive Volcanic Eruptions Using Satellite-derived Cloud Vertical Growth Rates, *Journal Geophysical Research*, **5(2)**, 903-928.

ProbSevere work was presented at the 2018 Coordination Group for Meteorological Satellites (CGMS) International Cloud Working Group workshop in Madison, WI (Pavolonis)

References

Cintineo, J. L., M. J. Pavolonis, J. M. Sieglaff, D. T. Lindsey, L. Cronce, J. Gerth, B. Rodenkirch, J. Brunner, and C. Gravelle, 2018: The NOAA/CIMSS ProbSevere Model - incorporation of total lightning and validation. *Wea. Forecasting*, **33**, 331-345.

Cintineo, J. L., Pavolonis, M. J.; Sieglaff, J. M. and Lindsey, D. T., 2014: An empirical model for assessing the severe weather potential of developing convection. Weather and Forecasting, 29(3), 639–653.

Cintineo, J. L., Pavolonis, M. J.; Sieglaff, J. M. and Heidinger, A. K., 2013: Evolution of severe and nonsevere convection inferred from GOES-derived cloud properties. Journal of Applied Meteorology and Climatology, 52(9), 2009–2023.

NWS, 2013: National Weather Service Weather-Ready Nation Roadmap. [Available online at: http://www.nws.noaa.gov/com/weatherreadynation/files/nws_wrn_roadmap_final_april17.pdf]

Pavolonis, M.J., J. Cintineo, and J. Sieglaff, 2018: Automated Detection of Explosive Volcanic Eruptions Using Satellite-derived Cloud Vertical Growth Rates, Journal Geophysical Research, 5(2) 903-928.

USA Today, 2016: Tornadoes, severe storms cost $10 billion in 2015.
[Available online at: http://www.usatoday.com/story/weather/2016/01/03/tornadoes-severe-storms-insured-losses/78234474/]

7.3. Improving the Assimilation of High-Resolution GOES-16 Water Vapor Variables and Atmospheric Motion Vectors in the HWRF Model

CIMSS Task Leader: Jun Li
CIMSS Support Scientists: Chris Velden, Jinlong Li, William E. Lewis, and Dave Stettner
NOAA Collaborators: Jason Sippel (NOAA/NHC), Zhan Zhang (NOAA/EMC), and Timothy J. Schmit (CoRP/STAR/NESDIS)
Budget: $130,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
The objective is to improve the assimilation of high resolution moisture and atmospheric motion vector (AMV) information from GOES-R series satellites in NOAA's operational HWRF model.

Project Overview

Reliable forecasts of landfalling tropical cyclones (TCs) such as Hurricane Sandy (2012), Matthew (2016), Harvey (2017), Irma (2017) and Maria (2017) are critical for decision making and better preparation. Obtaining good TC intensity forecasts remains one of the most challenging aspects in NOAA operations. Observations of atmospheric water vapor variables and winds in the TC environment as well as in the inner core at high spatiotemporal resolution are very important to the prediction of the storm evolution and landfall impacts. Optimizing the assimilation of that information into the operational Hurricane WRF (HWRF) model is a vital step towards improving TC forecasts. To help address this need, the Advanced Baseline Imager (ABI) (Schmit et al. 2005; 2007) onboard NOAA's next generation of geostationary weather satellites (GOES-R series), beginning with GOES-16 launched on 19 November 2016, will routinely provide high temporal (every 5 minutes) and spatial (2 km) resolution moisture variables and atmospheric motion vector (AMV) information not previously available. This proposed work is to optimize the impact of the high spatiotemporal resolution GOES-R series water vapor information and AMVs for improving TC analyses and forecasts in HWRF. In particular, our study will focus on using GOES-16 observations in the analysis-sensitive regions associated with the TC near-environment, exploring and optimizing the effective assimilation of these data into HWRF for improving TC moisture, wind, track, and intensity forecasts.

Milestones with Summary of Accomplishments and Findings

Implementing and testing HWRF/hybrid GSI systems on S4 for hurricane forecast experiments

CIMSS scientists have conducted experiments using near real-time (NRT) research testbed called "Satellite Data Assimilation for Tropical storm forecasts (SDAT) http://cimss.ssec.wisc.edu/sdat) and showed tropical cyclone (TC) forecast improvements from better assimilation of satellite data, especially in cloudy skies, however, tests in SDAT only show relative improvements, and it is hard to judge the true value of data and assimilation schemes in the operational numerical weather prediction (NWP) models for TC forecasts. Therefore, testing, using the latest version of HWRF, needs to be performed in a modeling system as close to operations as possible. In order to use the latest version of HWRF for GOES-16 data assimilation, CIMSS scientists have tested the latest version of the operational HWRF model at S4. The community HWRF_v3.9a from DTC was installed on S4 in November 2017 and tested with Hurricane Irma (2017) (including DA with hybrid GSI). Figure 57 shows the forecasts from control (HWRF/S4) and NOAA operational HWRF (HWRF/Op), for track and categories. The forecasts between HWRF/S4 and HWRF/Op are similar. The RMSE (root mean square error) statistics for track and maximum wind speed forecasts are also reasonably close (not shown) between HWRF/S4 and HWRF/Op. Therefore, HWRF/S4 can be used for DA research.

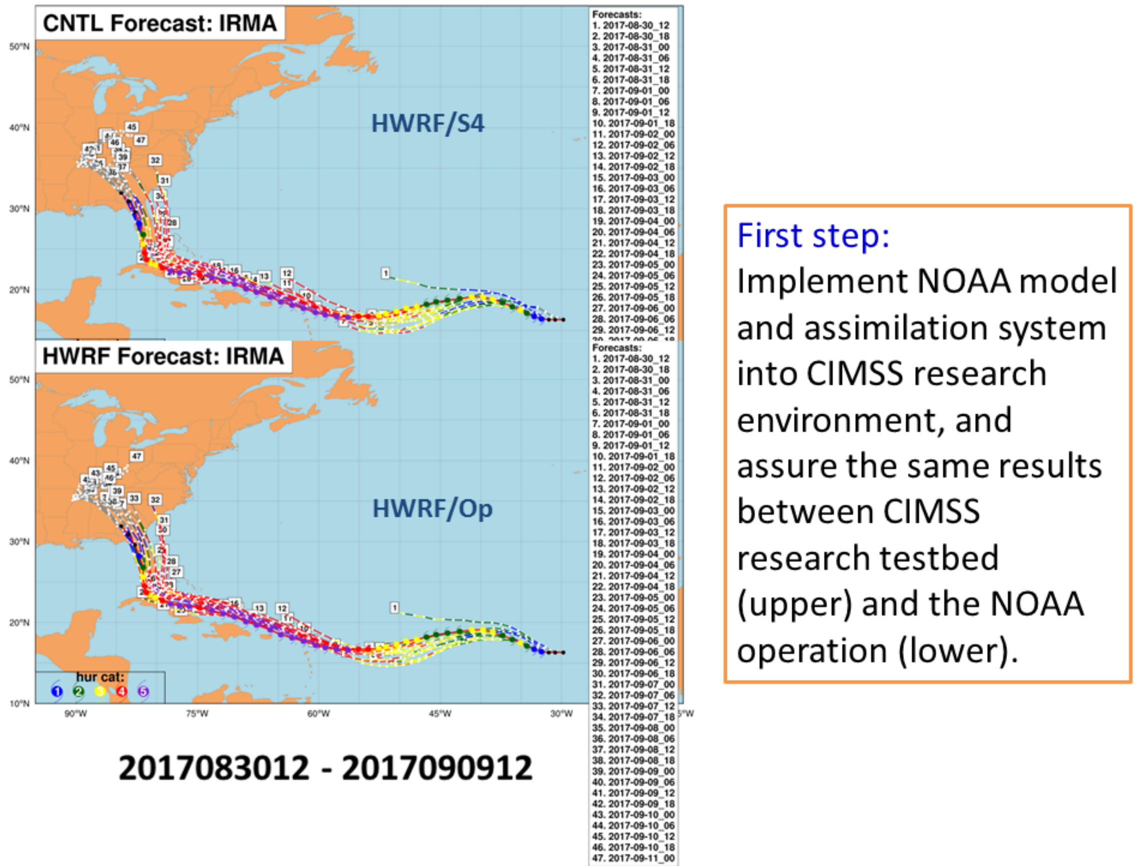


Figure 57. Forecasts from HWRF/Op (left) and HWRF/S4 (right) for hurricane Irma (2017).

ABI rapid-scan-based dynamical information over the inner-core region improves HWRF hurricane forecasts

Observations of dynamic information in the tropical cyclone (TC) inner core at high spatiotemporal resolution are very important to the prediction of the storm evolution and landfall impacts, and they are only possible from the new generation of geostationary weather satellites. Understand the utilization and impact that information on Numerical Weather Prediction (NWP) model is a vital step towards improving TC forecasts. The atmospheric motion vectors (AMVs) in the inner core have been developed with 1-min rapid scan observations from the advanced baseline imager (ABI) onboard GOES-16 (Schmit et al. 2005; 2017), assimilation of the dynamic information on top of the current data used operational in HWRF/S4 indicate consistent improvements on hurricane Harvey, Irma and Maria (2017) forecasts, and the improvements are mainly resulted from better initialization of atmospheric fields in the inner core region.

Results are evaluated using the NCEP verification packages and are compiled based on the HWRF track and intensity forecasts for the selected case studies. Evaluation metrics include verification of storm size and structure, and assessment of improvements in hurricane track and intensity forecast skill. GOES-16 rapid scan ABI AMVs have been tested for three typical TCs in 2017 (Hurricane Harvey, Irma and Maria). Based on the ABI rapid scan mode during TC development, the observations are focused on the storm center domain (10 x 10 degree coverage centered on the TC storm), following the storm movement with time. The rapid scan based AMV datasets are produced at 15 minutes interval based on a set of sequential images scanned every minute for targeted mesoscale sectors. To enhance the coverage, modifications of the minimum gradient, coherency and QC requirements are included, types of wind to be assimilated include:

VIS (0.64 µm) for low level AMVs, SWIR (3.9 µm) for cloud drift and low level, WVCT (6.19 µm) for upper level and IR (11.2 µm) for cloud drift AMVs. The control contains all the observations including operational AMVs used by NOAA operation. The AMV experiment has the ABI rapid scan based AMV with QI (quality indicator) greater than 80, on top of the data used operationally in HWRF. Analysis is updated every 6 hours, and a 120-hour forecast is followed after each analysis. The periods for three TCs in our experiments are Harvey (2017082306 – 2017082612 with 14 analysis cycles), Irma (2017090418 – 2017091000 with 22 analysis cycles), and Maria (2017091700 – 2017092318 with 28 analysis cycles), respectively. There are total 64 groups of analyses/forecasts obtained in our statistics. Figure 58 shows the value added impact from ABI rapid scan AMVs on three TC track forecasts, respectively. It shows consistent improvement for all three TCs, improvement is significant for Maria and Irma.

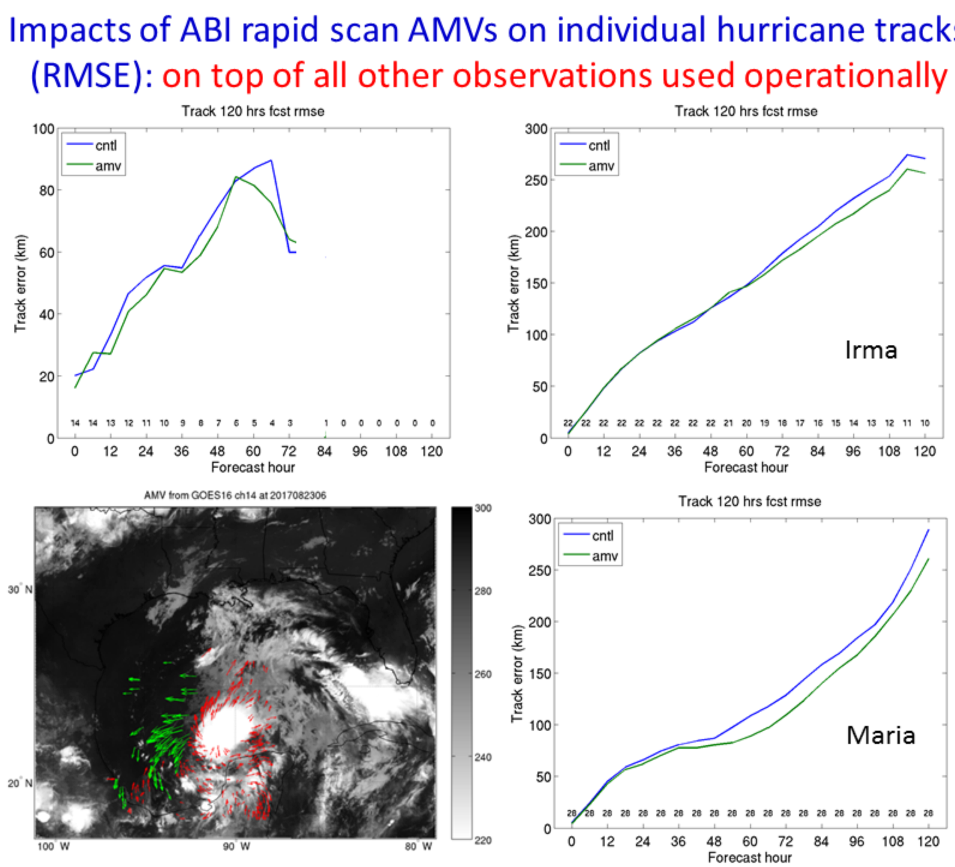


Figure 58. Track forecast RMSE from control and ABI rapid scan based AMV experiment for three hurricanes in 2017, Harvey, Irma and Maria, respectively. An example of inner core AMVs assimilated and overlaying on ABI 11µm BT image is shown in lower left panel.

Figure 59 shows the overall value added impact from ABI rapid scan AMVs on track forecasts. Total 64 groups are included in the statistics; forecast improvement gets bigger with longer forecast time, indicating consistent improvement on TC track forecasts by including the new information – the ABI rapid scan AMVs.

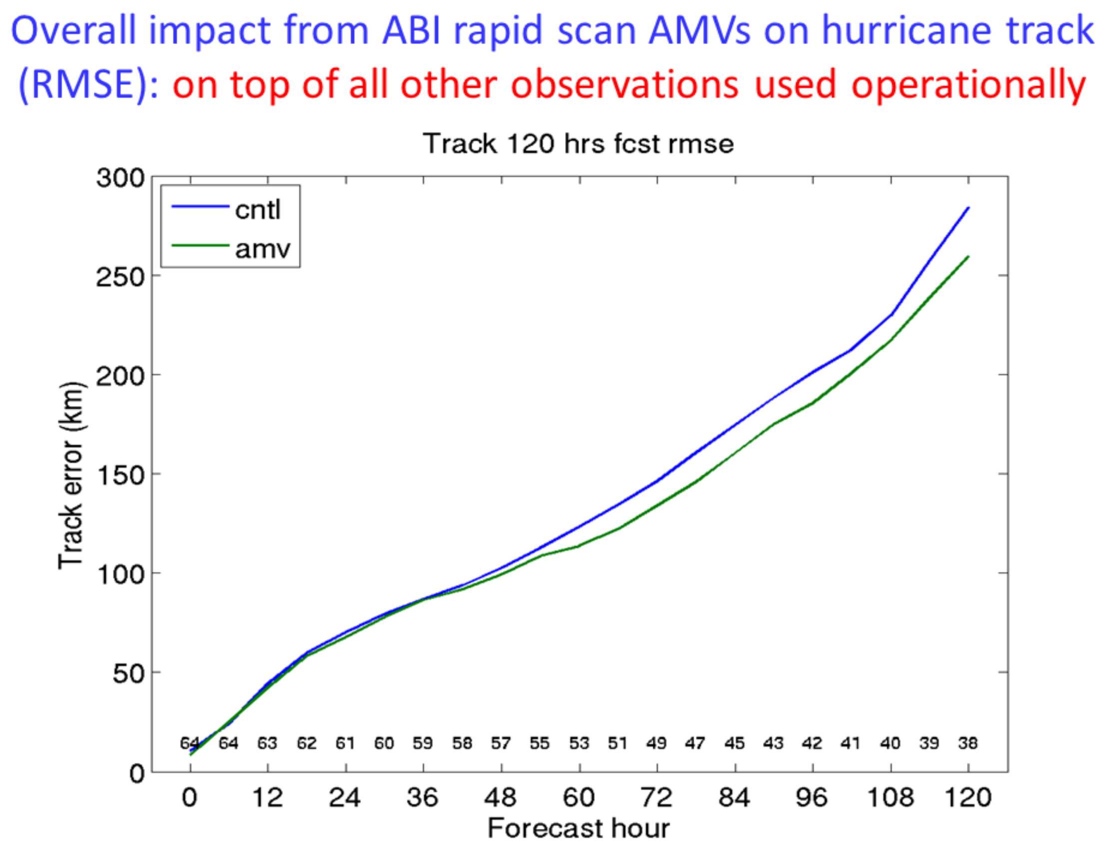


Figure 59. Track forecast RMSE from the control and the ABI rapid scan based AMV experiment for three hurricanes in 2017, Harvey, Irma and Maria altogether.

Publications and Conference Presentations

Wang, Pei, Jun Li, Bing Lu, Timothy J. Schmit, Jiazhen Lu, Yong-Keun Lee, Jinlong Li, and Zhiquan Liu, 2018: Impact of moisture information from Advanced Himawari Imager measurements on heavy precipitation forecasts in a regional NWP model, Journal of Geophysical Research - Atmospheres, 123, 6022 - 6038. https://doi.org/10.1029/2017JD028012.

Lu, J., T. Feng, Jun Li, Z. Cai, X. Xu, L. Li, and Jinlong Li, 2019: Impact of assimilating Himawari-8 derived layered precipitable water with varying cumulus and microphysics parameterization schemes on the simulation of Typhoon Hato, Journal of Geophysical Research – Atmospheres (in press).

Jinlong Li, Jun Li, Christopher Velden, Pei Wang, Jung-Rim Lee, William E. Lewis, David Stettner, Jason A. Sippel, and Zhan Zhang, 2019: The Impact of GOES-16 ABI Derived Products on HWRF Analyses and Forecasts, 99th AMS Annual Meeting, 06 – 10 January 2019, Phoenix, AZ.

7.4 Assimilation of High-resolution GOES-R Infrared Water Vapor and Cloud-sensitive Radiances Using the GSI-based Hybrid Ensemble-variational Data Assimilation System to Improve Convection Initiation Forecasts

CIMSS Task Leader: Jason Otkin
CIMSS Support Scientist: Yafang Zhong

Budget: $55,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Objective

The primary objective of the project is to extend the capabilities of the operational GSI-based hybrid data assimilation system to assimilate ABI infrared brightness temperatures and to assess their impact on convection forecasts in high-resolution numerical weather prediction models.

Project Overview

In this collaborative project between the University of Wisconsin-Madison and the University of Oklahoma, we will extend the capabilities of the operational GSI hybrid data assimilation system to assimilate infrared brightness temperatures from the GOES-16 ABI sensor in high-resolution numerical weather prediction models. This goal will be accomplished by 1) modifying the GSI so that high-resolution ensemble output from the convection-permitting model can be used instead of coarse-resolution ensemble output from the Global Forecasting System, 2) updating cloud hydrometeor variables during the data assimilation step, 3) improving the use of GOES-16 ABI water vapor and cloud sensitive brightness temperatures by refining data quality procedures, 4) using high-resolution infrared land surface emissivity databases, and 5) exploring the use of all-sky bias correction and observation error methods. We will also test different data assimilation configurations. The impact of assimilating water vapor and cloud sensitive infrared brightness temperatures on convection forecasts will be assessed using case study experiments.

Milestones with Summary of Accomplishments and Findings

Though this is a collaborative project, this report focuses only on the UW-CIMSS contribution to it. During the past year, we explored the ability of the nonlinear bias correction method developed by Otkin et al. (2018) to remove complex biases from all-sky GOES-16 ABI infrared brightness temperatures. This method uses a Taylor series polynomial expansion of the observation-minus-background (OMB) departures to remove linear and nonlinear conditional biases from the OMB departures. For example, if a third-order Taylor series expansion is used, this means that the first two terms represent the constant and linear bias components, whereas the last two terms represent the nonlinear second-order (quadratic) and third-order (cubic) bias components. This methodology was initially used as an off-line tool to more efficiently explore the ability of various predictors to remove linear and nonlinear biases from the observation departures.

In preparation for real data assimilation experiments, preliminary analyses focused on using output from a data assimilation experiment in which the ABI brightness temperatures were passively monitored. Figure 60 shows 2-D probability distributions of the OMB departures for the ABI 6.9 μm band when the observed 6.9 μm brightness temperatures are used as the bias predictor. The departures are plotted as a function of the predictor along the x-axis. The results are evaluated separately for the original OMB departure distribution and for distributions for which the biases were removed using a zeroth- (constant), first- (linear), second- (quadratic), third- (cubic), or fourth- (quartic) order Taylor series polynomial expansion. The short horizontal black lines on each panel depict the conditional bias in each column of the distribution and are used to assess how the bias varies as a function of the predictor value. The horizontal red line shows the mean bias of the entire distribution.

Inspection of Figure 60a reveals a strong nonlinear pattern in the conditional biases, with a tendency for the simulated brightness temperatures to be too warm (cold) when the observed brightness temperatures are colder (warmer) than approximately 239 K. Though the mean bias of the entire distribution is relatively small (~ 1.0 K), the nonlinear pattern in the conditional biases indicates that constant and linear bias correction terms alone will be unable to remove all of the bias. For example, even though the constant bias correction term removes the mean bias from the distribution (Figure 60b), its shape remains the same and, therefore, large conditional biases remain throughout the distribution. Likewise, the first-order bias correction (Figure 60c) removes the linear bias component by raising (lowering) the cold (warm) end of the distribution, which reduces the conditional biases for the coldest brightness temperatures but turns a positive bias into a negative bias for the warmest brightness temperatures (Figure 60c). Removal of the constant and linear bias components exposes an asymmetric arch shape pattern in the conditional biases that is largely removed when the second-order quadratic term is used (Figure 60d). Finally, when the third-order cubic and fourth-order quartic terms are used (Figure 60e-f), the general shape of the distribution remains unchanged; however, subtle improvements were made to it. Together, these results show that even though each OMB departure distribution technically has zero mean bias, the conditional biases are smaller when higher-order, nonlinear bias correction terms are applied to the OMB departures.

We also explored the impact of other bias predictors, such as the observed cloud top height, total-column water content, satellite zenith angle, simulated brightness temperature, simulated cloud top height, and symmetric brightness temperature (e.g., the average of the observed and simulated brightness temperatures). Figure 61 and Figure 62 depict the results for the upper-level water vapor band when using these bias predictors. Overall, it is found that the non-linear bias correction terms were best able to remove biases from the all-sky OMB departures when the observed cloud top height or observed brightness temperature was used as the bias predictor. For these two predictors, the nonlinear bias correction terms were able to effectively remove the conditional biases across the entire distribution. The non-linear terms also worked well when using the simulated brightness temperature, total water content at 100-700 hPa layer, or simulated cloud top height as the bias predictor, as they were likewise able to remove the conditional biases for each of the water vapor bands but reduced the OMB departures to a lesser extent. The non-linear correction terms did not have as much impact when using the satellite zenith angle or symmetric brightness temperature as the bias predictor because the OMB departures only had a weak dependence on these predictors.

Following these sensitivity experiments, the nonlinear bias correction method was implemented into the GSI. The GSI uses the CRTM when computing the simulated brightness temperatures. The first-guess profiles of temperature, humidity, and cloud hydrometeors are input to the CRTM. In the bias correction implementation, the observed brightness temperature is used as the bias predictor. Figure 63 shows an example of the implementation using the ensemble mean first-guess model fields for a convective initiation case that occurred at 1710 UTC on 18 May 2017. It can be seen that the first guess departures are large, especially for brightness temperatures < 230 K. This is likely due to the high clouds present in those regions, which can be confirmed from the cloud top pressures derived from the GOES-16 observations. It can also be seen that the first guess OMB departures are greatly reduced after using the nonlinear bias correction. The improvement is most evident in regions containing the coldest observed brightness temperatures.

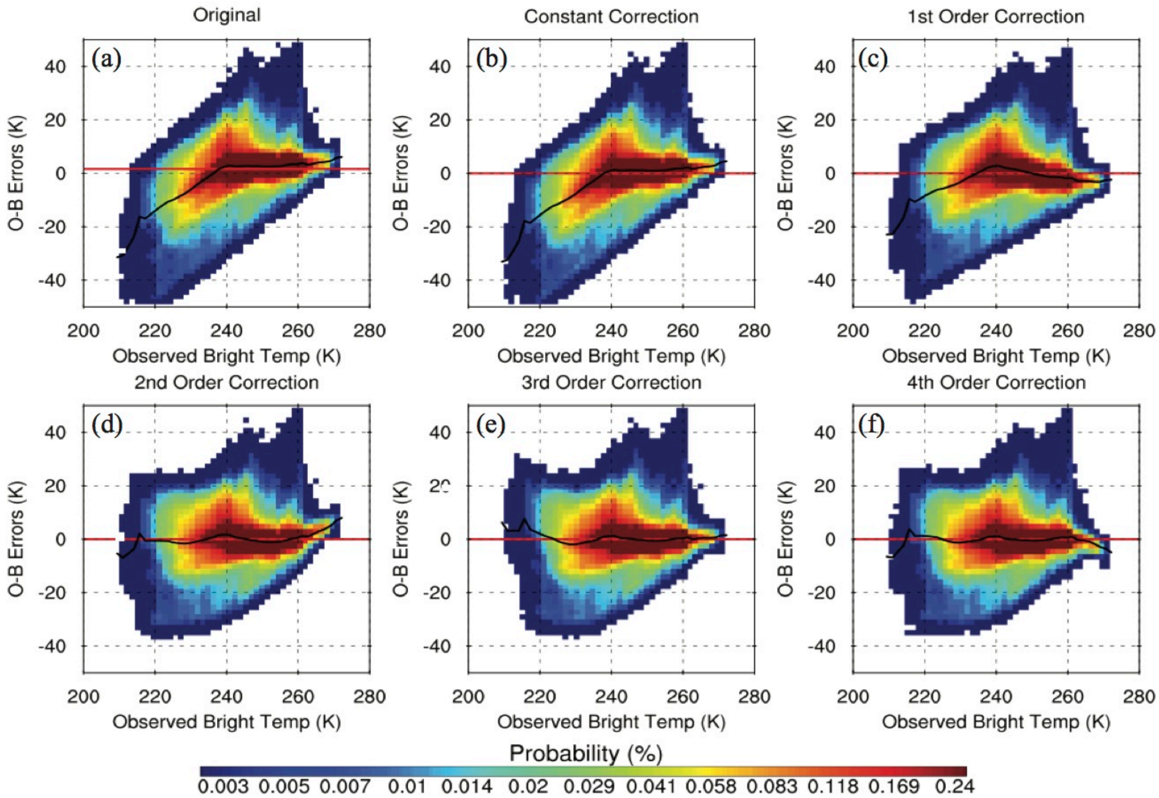


Figure 60. Probability distributions of 6.9 μm OMB departures plotted as a function of the observed 6.9 μm brightness temperatures (K) for the (a) original data, and (b) constant, (c), 1st order, (d) 2nd order, (e) 3rd order, and (f) 4th order bias corrected observations when the observed 6.9 μm brightness temperature is used as the predictor. The horizontal black line segments in each panel represent the conditional bias in each column. The distributions were generated using data from a single assimilation cycle in which the 6.9 μm brightness temperatures were passively monitored.

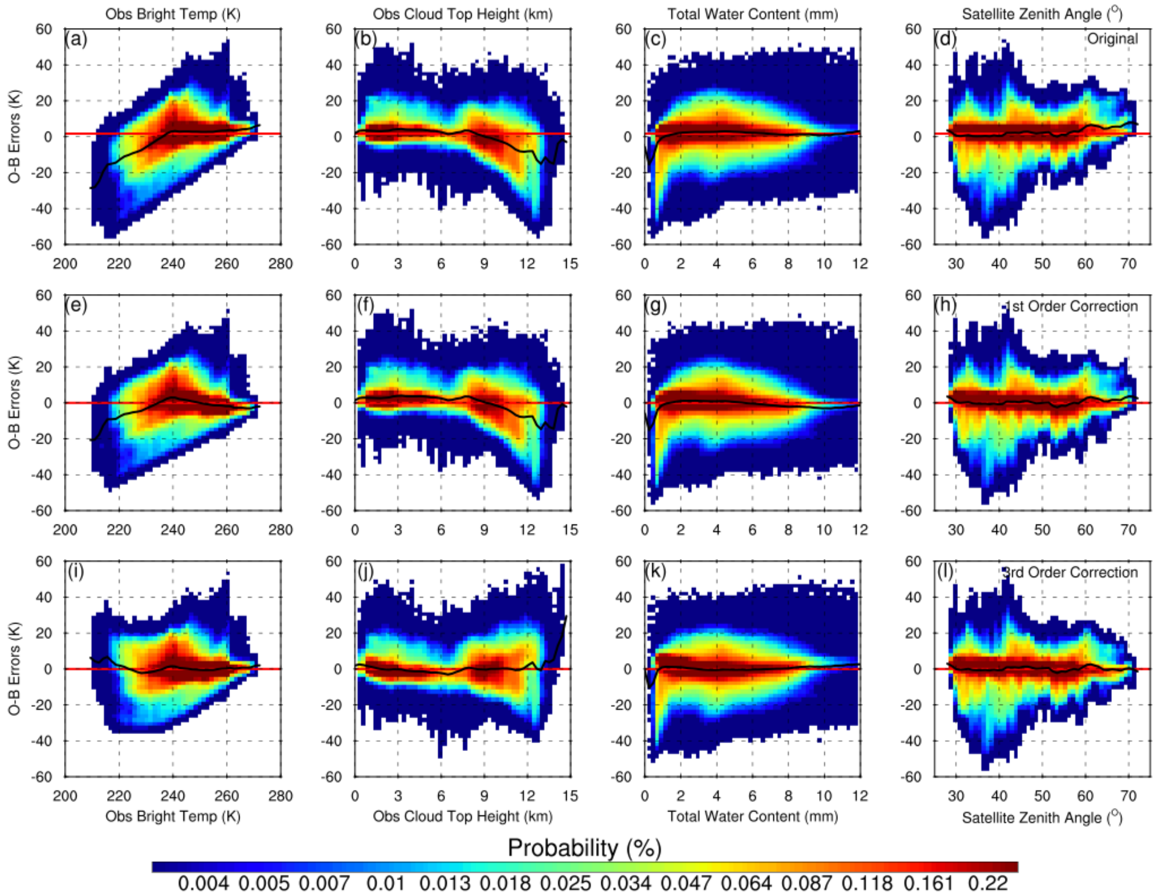


Figure 61. Probability distributions of 6.9 µm OMB departures plotted as a function of the observed 6.9 µm brightness temperatures for the (a) original data, and for (e) 1st order and (i) 3rd order bias corrections when the observed 6.9 µm brightness temperatures are used as the bias predictor. (b, f, j) Same as above, except when using the cloud top height as the bias predictor. (c, g, k) Same as above, except when using the total water content as the bias predictor, (d, h, l) Same as above, except when using the satellite zenith angle as the bias predictor. The horizontal black line segments in each panel represent the conditional bias in each column, whereas the red line shows the mean bias of the entire distribution. The distributions were generated using data from seven assimilation cycles in which the 6.9 µm brightness temperatures were passively monitored.

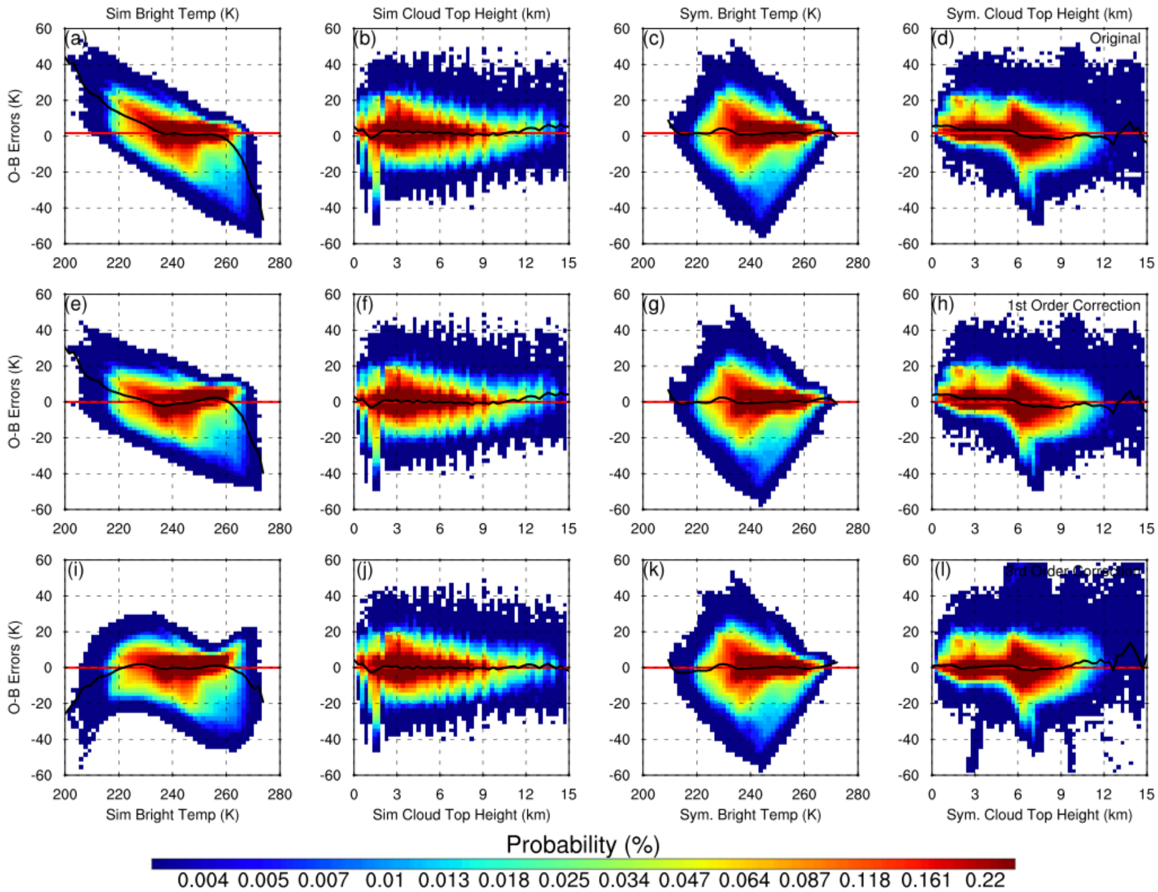


Figure 62. Probability distributions of 6.9 µm OMB departures plotted as a function of the simulated 6.9 µm brightness temperatures for the (a) original data, and € 1st order and (i) 3rd order bias corrections when the simulated 6.9 µm brightness temperatures are used as the bias predictor. (b, f, j) Same as above except for using the simulated cloud top height as the bias predictor. (c, g, k) Same as above except for using the symmetric brightness temperature as the bias predictor. (d, h, l) Same as above except for using the symmetric cloud top height as the bias predictor. The horizontal black line segments in each panel represent the conditional bias in each column, whereas the red line shows the mean bias of the entire distribution. The distributions were generated using data from seven assimilation cycles in which the 6.9 µm brightness temperatures were passively monitored.

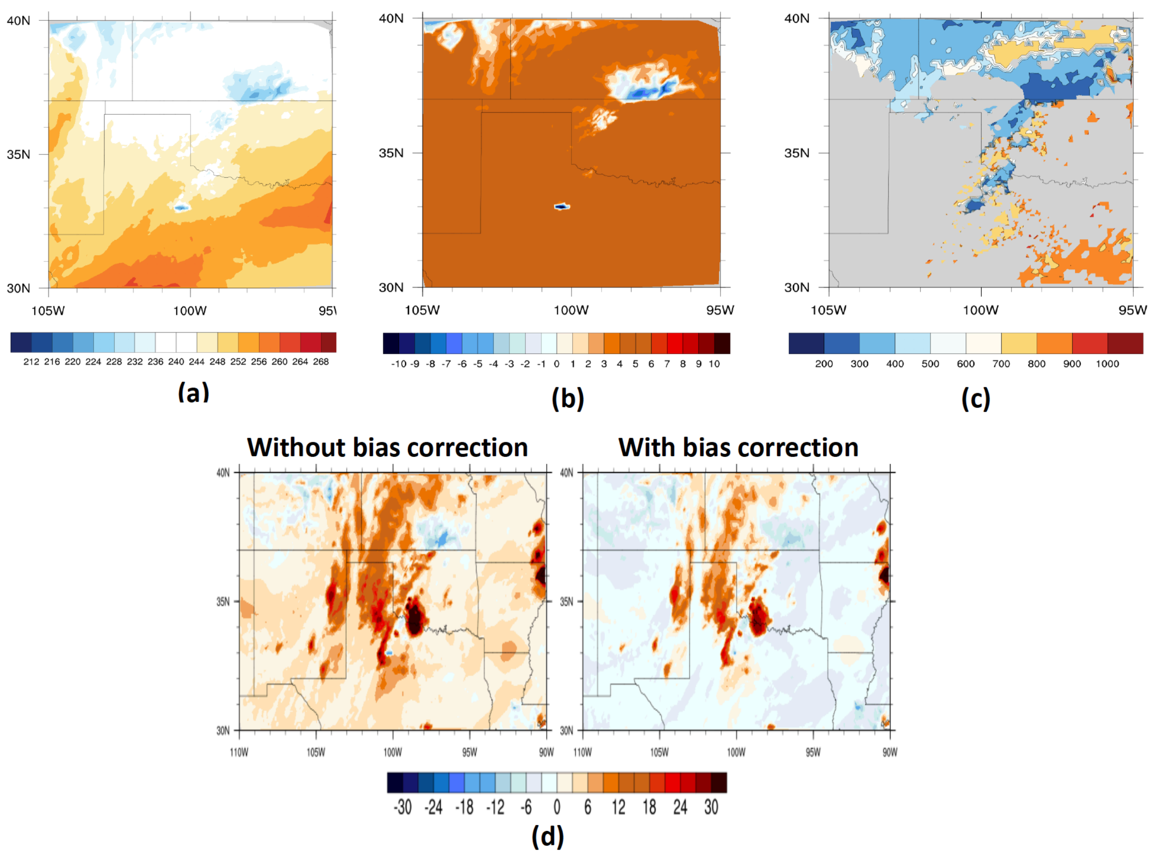


Figure 63. (a) Observed 6.9 µm brightness temperatures (K), (b) total bias (K) predicted when using observed 6.9 µm brightness temperatures as the predictor for the ensemble mean first guess at 1710 UTC on 18 May 2017, (c) cloud top pressure derived from GOES-R ABI observations, and (d) OMB departures (K) for the 6.9 µm brightness temperatures without and with using the bias correction method.

Publications and Conference Reports

Preliminary results from this project were presented at the AMS Annual Meeting in Phoenix, AZ:

Johnson, A., X. Wang, T. A. Jones and J. Otkin, 2019: Improving Convection Initiation Forecasts by Assimilating High-Resolution GOES-16 ABI Infrared Water Vapor and Cloud Sensitive Radiances Using GSI-Based EnKF/EnVar. AMS annual meeting, Phoenix.

7.5 An Enhanced Lake-Effect Snow Nowcasting Tool Using Synergistic GOES-R, NEXRAD, and Ground-Based Snowfall Microphysics Observations
CIMSS Task Leader: Claire Pettersen
CIMSS Support Scientists: Tim Wagner, Steve Wanzong
NOAA Collaborators: Mark Kulie, Andy Heidinger
Budget: $82,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation
- Resilient Coastal Communities and Economies

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
The primary goal of the proposed work is to develop an enhanced lake-effect snow (LES) nowcasting product from GOES16 observations.

Project Overview
Development of the LES nowcasting product utilizes concurrent GOES16, NEXRAD, and ground-based snow microphysical observations in the product development phase to create a near real-time satellite-based snowfall rate product for the Great Lakes region. Snowfall rate estimates from ground-based in situ instrumentation will improve NEXRAD-derived snow rates for identified LES events. Additionally, GOES16 products are collocated with NEXRAD-derived snowfall rates to illuminate relationships between the satellite-obtained cloud properties and snow rates during LES events. Combining the surface-based estimates and satellite-derived cloud properties can improve forecasts of LES snow events. The project builds on a strong pre-existing working relationship between CIMSS researchers and Marquette, MI (MQT) National Weather Service (NWS) Weather Forecast Office (WFO) staff, for both the data collection and product testing/training phases.

Milestones with Summary of Accomplishments and Findings
Collaboration with the MQT NWS WFO site continued throughout the 2018 – 2019 winter season, with over five years of continuous enhanced snowfall observations. Drs. Pettersen and Kulie expanded the site capabilities through implementation and redeployment of a network of Pluvio gauges to assess the spatial variation of snow accumulation. Additionally, the MicroRain Radar (MRR) and Precipitation Imaging Package (PIP) underwent seasonal maintenance and data collection in preparation for the winter season. Drs. Pettersen and Kulie worked with the NOAA Algorithm Working Group (AWG; Dr. Heidinger and Mr. Wanzong) to obtain GOES16 observations and cloud products for LES events in the 2017 – 2018 winter season. Figure 64 shows an example of the cloud liquid water path (LWP) product and 0.65 μm band observations from GOES16 during an LES event. Dr. Wagner obtained the NEXRAD data from the MQT NWS site and averaged and collocated the radar observations with the GOES16 footprint. This merged dataset allows for comparison of products from GOES16 (i.e., cloud LWP) and the NEXRAD-derived snow rate. An example of this comparison for the January 3, 2018 LES event is illustrated in Figure 65.

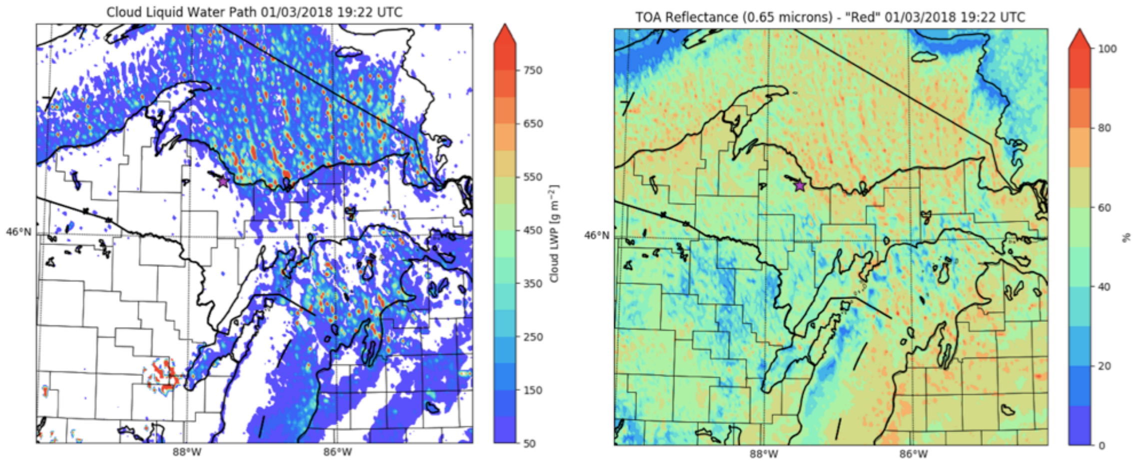


Figure 64. GOES16 products and observations during an identified LES event on January 3, 2018. The cloud liquid water path (LWP) AWG product is shown in the left panel and the "red", 0.65 µm band is shown in the right panel. The NWS MQT WFO is location is indicated with the magenta star.

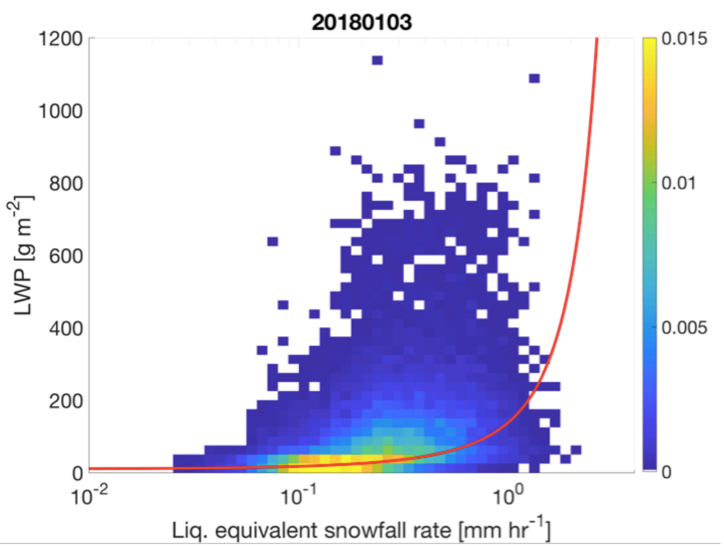


Figure 65. GOES16 LWP compared to the NEXRAD-derived snow rate in a normalized histogram.

Publications and Conference Reports

Pettersen, C., Kulie, M.S., Wagner, T.J., et al.: A composite analysis of snowfall modes in Marquette, Michigan. Journal of Applied Meteorology and Climatology, *submitted*

Pettersen, C. et al.: A Composite Analysis of Snowfall Modes from Four Winter Seasons in Marquette, Michigan. AMS Cloud Physics and Radiation, July 2018.

7.6 Development of a GOES-R IR Clear-Sky and ALL-Sky Radiance Products for NCEP

CIMSS Task Leader: James A. Jung
CIMSS Support Scientist: Sharon Nebuda
NOAA Collaborators: Walter Wolf (NESDIS/STAR), Andrew Collard (NCEP/EMC)
Budget: $72,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

Determine the radiance data algorithm settings and quality control to optimize the product for data assimilation use.

Project Overview

The GOES-16 ABI All Sky and Clear Sky Radiance (ASR/CSR) products are derived from the 2 km infrared pixels of channels 7-16 combined with the GOES-R cloud mask to identify clear and cloud impacted pixels. The full scene of 2 km pixels are subset into samples defined by a processing box to aid in the assignment of brightness temperatures, cloud amounts, and other information desired by NWP centers for quality control. This approach has been used by EUMETSAT for SEVIRI ASR/CSR products as well as JMA for AHI CSR products. Consistency of algorithm and data information from different geostationary imagers is desirable for NWP use in data assimilation.

To optimize the quality of the GOES-16 ABI ASR/CSR products, a validation effort is included in this project. The radiance product generation requires a selection of processing box size, data quality control, and metrics for NWP use in data assimilation. To evaluate the impact of these choices on the ASR/CSR product quality, the analysis from the NOAA/NCEP GFS Data Assimilation System (GDAS) has been used to provide collocated simulated brightness temperatures. By examining the differences between the GDAS brightness temperatures and the ABI ASR/CSR product, selection of the optimal settings for NWP use can be made. Also included in the effort is the validation of the radiance products using the Enterprise channel dependent cloud masks. Settings that are chosen for products using the GOES-R cloud mask will also be investigated for products generated using the Enterprise cloud masks.

Milestones with Summary of Accomplishments and Findings

Collaboration between CIMSS, NESDIS/STAR, and NWP Centers including NCEP/EMC has been vital during this project to determine the optimal product design for data assimilation use. Feedback and requests for algorithm design change has occurred by email and meetings during the past year. This product algorithm is on track to be delivered to NOAA/OSPO.

NWP users were provided preliminary ABI CSR data to test in their data assimilation systems. In June 2018, a NWP user meeting was conducted with NESDIS/STAR and CIMSS to allow discussion of results and concerns. NWP attendees included researchers from NCEP/EMC, ESRL/GSD, ECMWF, UK Met Office and the Navy Research Lab. Results using the Version 1 ABI CSR data indicated the product could be successfully assimilated in the different NWP data assimilation systems.

The Critical Design Review for this CSR/ASR product was conducted on Sept 25, 2018 in which CIMSS contributors presented slides related to algorithm design. An overview of the GOES-16 ABI CSR/ASR product was also presented at the International Cloud Working Group Workshop on Oct 31, 2018 in Madison, WI. Software modifications were delivered to NESDIS/STAR to make improvements to the Version 1 CSR/ASR product and allow NESDIS/STAR to release a Version 2 for NWP testing.

Version 2 was released on Oct 25, 2018 by NESDIS/STAR for near real-time generation concurrently with Version 1 for testing by NWP users. Changes from Version 1 to Version 2 include:

- Limiting data to ABI Channels 7-16
- Removal of cold outliers in averaging sample for clear sky
- Water-only or land-only sample average for mixed surface type in processing box
- Cloud top pressure information added to the ASR product
- Increased the allowed sensor zenith angle to that limited by the cloud mask definition (70°)
- Sensor zenith angle calculation based on the nominal sub-satellite longitude, now available in the L1b ABI radiance input files. Previously the projection longitude was used.
- 2 km IR pixel with negative radiances are excluded from the averaging sample

In a parallel effort, the ABI CSR product using the Enterprise cloud mask was also evaluated. NWP collaborators have requested this improved naïve Bayesian cloud mask for its superior cloud detection in processing the CSR/ASR product. Figure 66 shows improved statistics for ABI Channel 13 CSR brightness temperatures when compared to collocated GDAS simulated values. The Enterprise algorithm also provides a channel dependent cloud mask with the intent to classify more pixels clear if it is determined the presence of a low clouds has not impacted that channel's radiance measurement. This mask is created for the water vapor sensitive channels 8-10 as well as the CO_2 sensitive channel 16. Preliminary results indicate the cloud mask is working as intended but may need more restrictive selection. Adaption of the CRTM routines is underway to assist in the determination the pixel is not cloud impacted.

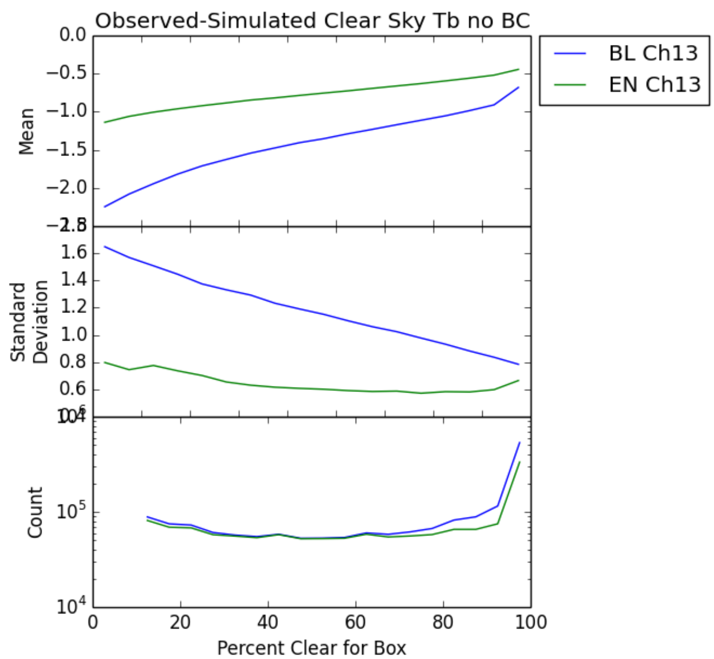


Figure 66. ABI CSR Channel 13 brightness temperature compared to the GDAS simulated values without GSI bias correction. Bias, standard deviation, and count is shown as a function of percent clear in the 15x15 2km pixel processing box for the Baseline (BL) and Enterprise (EN) cloud mask. Data is limited to water surface with sensor zenith angle less than 60° for 13-27 Nov 2017.

8. CIMSS Participation in the Development of GOES-R Proving Ground in 2018-2019

CIMSS Task Leader: Wayne Feltz

CIMSS Support Scientists: Chris Velden, Sarah Griffin, Scott Bachmeier, Scott Lindstrom, Lee Cronce, Justin Sieglaff, Kaba Bah

NOAA Collaborators: Michael Pavolonis (NESDIS/STAR), Bradley Pierce (NESDIS/STAR), Andy Heidinger (NESDIS/STAR), and Tim Schmit (NESDIS/STAR)

Budget: $310,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Education and Outreach

Objective
CIMSS researchers will expand partnerships with NWS Forecast Offices and NOAA National Centers to provide these products, train forecasters in their applications, and evaluate their utility. This work will help to ensure that GOES-16 products will be available and useful to forecasters soon after launch.

Project Overview
UW-CIMSS supported the GOES-16/17 Proving Ground demonstrations by evaluating the GOES-16/GOES-17 Algorithm Working Group demonstration algorithms and baseline products, testing enhancements and advanced products (Risk Reduction), and providing user assessments and feedback to the product developers. Partnerships were expanded with NWS Forecast Offices in 2018-2019 to help train additional forecasters in product applications and to evaluate their utility. This work helped to ensure that GOES-16 products were available and useful to forecasters soon after launch.

In 2018-2019 research period of performance, the primary focus was to test, apply, and improve select GOES-16/GOES-17 satellite baseline, future capability, and risk reduction imagery/products in support of National Centers and local NWS offices. CIMSS researchers and scientists attended the June 2018 Proving Ground and User Readiness Satellite Science week in Kansas City, MO to determine goals/milestones of the GOES-16/GOES-S Risk Reduction and Proving Ground tasks and were present at regular by-monthly GOES-16/GOES-S Proving Ground coordination/reporting teleconferences. GOES-16/GOES-S PG oral and poster presentations occurred at various conferences in 2018-2019 including the American Meteorological Society (AMS) Conference, the National Weather Association (NWA) Conference, and the EUMETSAT Annual conference in Tallinn, Estonia.

Test and apply algorithms for expected GOES-16/GOES-S satellite data imagery/products in support of National NOAA Testbeds/PG Demonstrations
The following Proving Ground activities occurred in 1 April 2018 – 30 March 2019 funding cycle where several GOES-16/GOES-17 proxy decision support products developed at CIMSS were demonstrated with operational forecasters to obtain feedback:
- Hazardous Weather Testbed (HWT) Spring Experiment (1 April 2018 – 1 June 2018). https://www.goes-r.gov/users/docs/pg-activities/HWT2018_SE_GOESRPG_Final_Report.pdf

Demonstrated Product	Category
Advanced Baseline Imager (ABI) imagery, baseline derived products	GOES-R Baseline
RGB Composites and Channel Differences	National Weather Service
ProbSevere Model	GOES-R Risk Reduction
GLM Lightning Detection	GOES-R Baseline
NUCAPS Temperature and Moisture Profiles	JPSS
All-Sky LAP Stability Indices, Total Precipitable Water, and Layered Precipitable Water Products	GOES-R Risk Reduction
Convective Initiation Probability	GOES-R Risk Reduction
Category Definitions: **GOES-R Baseline Products** – GOES-R Level 1 Requirement products that are funded for operational implementation **GOES-R Risk Reduction** – New or enhanced GOES-R applications that explore possibilities for improving Algorithm Working Group (AWG) products. These products may use the individual GOES-R sensors alone, or combine with data from other in-situ and satellite observing systems or NWP models with GOES-R **National Weather Service** – Products created within AWIPS-II **JPSS** – Products funded through the JPSS program	

- National Hurricane Center (NHC) Tropical Cyclone Demonstration Participants included forecasters from NHC
- Aviation Weather Center (AWC) Summer Experiment. Participants included AWC forecasters and FAA representatives.
- HPC/ OPC/ TAFB/ and SAB demonstrations (ongoing: focus on precipitation and ocean applications).
- High Latitude and Arctic Testbed (ongoing: focus on snow/ cloud/ volcanic ash/ and aviation applications). Participants include NWS Alaska Region
- Air Quality (ongoing: focus on aerosol detection).
- Pacific Region OCONUS Demonstration (ongoing: focus on tropical cyclones/ heavy rainfall/ and aviation applications). Participants include Jordan Gerth, NWS forecasters and scientists from the University of Hawaii.

UW-CIMSS scientists were engaged with the demonstrations listed above by providing the following GOES-16/GOES-17 Baseline, Future Capability, or Risk Reduction decision support proxy data. Product assessment highlights for eight of the UW-CIMSS decision support products are listed below as reported in the GOES-16/GOES-17 PG 2018 Annual report (to be published) and HWT/AWC/NHC Testbed final evaluation reports located at: http://www.goes-r.gov/users/proving-ground.html

UW-CIMSS Decision Support Product GOES-16/GOES-17 Proving Ground Significant Outcomes and Product Assessment Highlights:

1. **The Fog and Low Stratus Products** - are currently scheduled to be operationalized on OSPO ESPC systems and will be delivered to NWS users via Satellite Broadcast Network (SBN), NCEP Central Region Operations (NCO) backbone, Direct Broadcast, and possibly AWIPS Data Distribution Service (DDS) as an alternative. This product was also delivered to the Alaska Aviation Weather Unit for testbed utility discussions. There is a current activity due to Proving Ground success to transition from research to operations.
2. **ProbSevere** - The NOAA/CIMSS ProbSevere model was evaluated in the HWT for the sixth consecutive year, with minor updates made since last year’s experiment. The statistical model produces a probability that a developing storm will first produce any severe weather in the next 60 minutes but now contains specific severe weather type (wind, hail, and/or tornado). The data fusion product merges NWP-based instability

and shear parameters, satellite vertical growth and glaciation rates, lightning detection and radar derived maximum expected size of hail (MESH). A developing storm is tracked in both satellite and radar imagery using an object-oriented approach. As the storm matures, the NWP information and satellite growth trends are passed to the overlapping radar objects. The product updates approximately every two minutes and are displayed as contours that change color and thickness with probability to be overlaid on radar imagery with probability of severe wind, hail, and tornado probable occurence. Data readout is available by mousing over the probability contour, revealing the probability of severe along with the model predictor values. This algorithm is being translated from research to operations at NOAA MDL for NWS use in all Weather Forecast Office's.

3. **GOES-R Legacy Atmospheric Profile Products –** Tested again at NOAA HWT this year were moisture and stability fields generated via a fusion of GOES Sounder radiance observations and Numerical Weather Prediction (NWP) forecast data using a GOES-16/GOES-17 Risk Reduction (GOES-R3) algorithm.
4. **ABI Cloud Height Algorithm (ACHA) -** The Algorithm Working Group's Cloud Height Algorithms (ACHA), including the Cloud Top Height, Cloud Top Temperature, and Cloud Emissivity products, were provided to the AWC in 2012. Cloud Top Heights saw the most use, and as a result of forecaster feedback over the past two years, a Cloud Top Altitude product was developed for the 2014 demonstration. This product provides cloud tops in feet instead of meters, as feet (or flight levels) are the common unit in aviation forecasting. Multiple concepts for this product were explored in the 2015 demonstration and continued evaluation was requested. Additionally, the need for more ceiling and visibility specific products was noted. From this came the Cloud Cover Layers and the Cloud Base Heights in the 2016 demonstration. The latter of these two was evaluated in both experiments, while the Cloud Cover Layers was evaluated in only the Summer Experiment. The domain of both of these was focused on the CONUS and both were available in N- AWIPS and AWIPS-2 D2D.
5. **Atmospheric Motion Vectors (AMV) -** Satellite Derived Motion Winds or Atmospheric Motion Vectors, are wind vectors generated by tracking cloud features in visible, IR, and water vapor satellite imagery. The generation process utilizes three satellite images, the first and third to track the cloud feature, and the second to target the features themselves. Heights of these wind vectors are assigned based on 1) measured radiances of the targets and the spectral responses of the satellite and channel that is being sampled
6. **Icing Product -** Aircraft icing is a major hazard to aviation and no phase of aircraft operations is immune to the threat. This proposal addresses a high National Weather Service (NWS) priority to improve the diagnosis of dangerous aircraft icing conditions for the aviation community. A capability to determine the in-flight icing (IFI) threat to aircraft has been developed that uses satellite derived cloud parameters. The methods are applicable to cloud parameters now commonly retrieved in real-time from meteorological satellite data, and are particularly well suited for application to the high spatial and temporal resolution operational cloud products from the GOES-R ABI. Verification studies indicate that relative to traditional icing forecasting techniques based on NWP analyses, the satellite methods significantly improve the resolution of icing conditions, including the dangerous conditions found to be associated with several recent aviation incidents and accidents. The objectives of this proposal are to (1) integrate a state of the art satellite based icing algorithm into the NOAA GOES-R Proving Ground (PG) processing system at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), (2) validate and tune the algorithm, if necessary, using icing PIREPS as guidance, (3) generate and deliver satellite-based flight icing threat (S-FIT) products to

the major NWS aviation weather forecast offices and to the PG with the current CIMSS product suite, (4) develop training materials for the S-FIT products, and (5) participate in and conduct S-FIT product evaluations to acquire feedback. The expected benefits to the NWS and the aviation community include better definition and situational awareness of the in-flight icing threat, improved icing forecasts, and the potential for safer, more efficient aviation.

7. **Legacy Atmospheric Profiling Product -** The algorithm retrieves atmospheric temperature and moisture profiles and the derived products including total precipitable water (TPW), layered precipitable water (PW), lifted index (LI), convective available potential energy (CAPE), total totals index (TT), Showalter index (SI), and the K-index (KI) from the clear sky infrared (IR) radiances. This project requires CIMSS scientists to develop and validate the GOES-R series LAP algorithm to be able to process high temporal and spatial resolution ABI data efficiently. This project provides prototype science codes to the GOES-R series algorithm integration team (AIT) for algorithm integration and helps the system provider to implement the algorithm and prototype codes into the GOES-R series ground system. CIMSS scientists also evaluate and validate the GOES-R series LAP products to assure that the GOES-R series legacy atmospheric temperature and moisture profiles, TPW, LI, CAPE, TT, SI and KI products meet the science/user requirements and operational applications.

1. Fog and Low Stratus Detection (Future Capability)

AWC Input

Forecasters would like to keep this product in operations and also focus more on LIFR probabilities. Additionally, it is possible that an Aviation Weather Statement for C&V will be developed. During the Summer Experiment this was explored and the FLS was found to be a valuable tool here as well. It was requested that evaluation to this end be continued in future experiments.

Furthermore, forecasters would like to look more closely at a comparison of the MVFR, IFR, and LIFR probabilities to observed flight conditions, ceilings and visibilities. To this end, a qualitative view of the product has been designed as a web tool. Twenty of the major terminals that deal with ceiling issues on a regular basis have been input into the tool, with analysis of the past 24-hours available at 3-hour intervals.

2. Probability of Severe Model

HWT Input

The NOAA/CIMSS ProbSevere statistical model, planned for operational implementation by NCO as an update to MRMS in 2018, was evaluated in the HWT for the fifth consecutive year, with updates made since last year's experiment. ProbSevere is currently undergoing tuning and assessment with the in-orbit ABI and GLM data for future demonstrations. The statistical model produces a probability that a storm will first produce any severe weather in the next 60 minutes (Cintineo et al. 2014). The data fusion product merges RAP model-based instability and shear parameters, satellite vertical growth and glaciation rates, radar derived maximum expected size of hail (MESH), and Earth Networks (ENI) total lightning information. Additional RAP and Multi-Radar Multi-Sensor (MRMS) fields such as azimuthal shear were used in the model this year to provide guidance on specific severe hazards of tornado, wind, and hail. ProbSevere tracks a developing storm incorporating data from both satellite and radar imagery using an object-oriented approach. As the storm matures, the Numerical Weather Prediction (NWP) information, lightning data, and satellite growth trends are applied to the overlapping radar objects. The product updates approximately every two minutes and is displayed as contours with different colors and thicknesses corresponding to different probability value bins that are overlaid on radar imagery. Data readout is available by moussing over the probability contour, revealing the probability of severe for each hazard (hail, wind, and tornado), along with the model predictor values. The product was evaluated on its ability to increase forecaster confidence and skillfully extend lead time to severe hazards for NWS warnings during potential severe weather situations. Additionally, feedback regarding the product display and readout was solicited:

> "Similar to above, the fact that ProbHail values were increasing due to environment and lightning, faster than what was apparent in radar imagery, provided enough confidence to pull the trigger earlier than I otherwise would have. This was especially the case with the second storm, after experiencing this with the first storm, having more confidence."
> *Forecaster, End-of-Day Survey*

> "It provided early-on confidence for warnings for hail. As a line of thunderstorms formed, it showed the wind threat before I realized it."
> *Forecaster, End-of-Day Survey*

> "When used in conjunction with other products and datasets, ProbSevere helped increase confidence and lead times with warning issuance."
> *Forecaster, End-of-Day Survey*

> "Used in conjunction with GLM products I was able to issue a SVR warning ~15 minutes earlier than I normally would have using "conventional" storm interrogation tools. When I initially issued the warning ProbSevere values were still quite low (less than 30% on ProbHail) but the increasing trend from the single digits I noticed along with the lightning activity from GLM was enough to give me confidence to issue a warning. ProbSevere aided my decision making on continuing to issue warnings on the storm even as GLM data showed a decreasing trend. Probhail values remained above 50% on the storm & MESH values were above 1"."
> *Forecaster, End-of-Day Survey*

At the very least, ProbSevere enhanced forecaster confidence when issuing severe thunderstorm warnings, but played a bit of a lesser role for tornado warnings, though there were not many tornado days during this year's experiment. Forecasters were asked to assess the role that ProbSevere played in there warning decision making as it relates to confidence in the warning decision and lead time provided. Approximately 82% of forecasters responded that they felt ProbSevere increased their confidence in issuing severe thunderstorm warnings compared to approximately 61% responding that it increased their confidence in issuing tornado warnings. Similarly, 57% of forecasters responded that they felt ProbSevere helped increase their lead tim for issuing severe thunderstorm warnings, compared to only 16% responding that they felt ProbTor helped increase their lead time for tornado warnings. Again, there were very few tornadoes during this experiment which could have prevented a more robust evaluation of the ProbTor probabilities. Forecasters noted that the most important value out of the ProbSevere model were the trends in the probabilities. A quick jump in the probabilities was a key indicator to forecasters that the storm was intensifying rapidly and required close examination for a possible warning. Forecasters recommend that it is still best to wait a couple of scans to see the

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trend in ProbSevere and to examine the base data further before issuing any warnings. When asked at the end of each shift whether they would use ProbSevere back at their office in operations, 66 out of 67 responses were that yes, they would use ProbSevere during operations back at their office.

https://www.goesr.gov/users/docs/pgactivities/HWT2018_SE_GOESRPG_Final_Report.pdf

3. Legacy Temperature and Moisture Profile - Nearcast Atmospheric Stability Indices (Risk Reduction)

HWT Input

The enhanced NearCast analyses and short-range forecasts were the primary ways that forecasters used the GOES Moisture and Temperature soundings in their forecasting process. Without the NearCasts, forecasters would have been unlikely to use the GOES retrievals as stand-alone observations. The NearCast products were especially effective in increasing situational awareness to where convection was more and less likely to initiate in the 0-6 hour range and how on-going convection was likely to evolve. The training was certainly an important part of this success, as it focused on what features to look for in the NearCast fields via multiple examples. The theta-e difference instability field was very well-received by the forecasters, garnering an average rating of 4.41 out of 5 from participants when asked how useful its addition would be to their forecast office. Finally, although the data gaps were undesirable, participants understood why they occurred and didn't let that deter them from using the NearCast products due to the valuable and unique information they provide in areas where GOES data have recently been available.

"I watched the trends and where a tongue of CAPE or moisture was increasing. I used these along with the mesoscale analysis."
Forecaster, End-of-Day Survey

"I used the LAP products to study the low-level environment and see if any moisture was moving toward the area and decreasing the stability. This showed up best with the CAPE and to a lesser extent with the LI."
Forecaster, End-of-Day Survey

"I could see the low level moisture advection and increasing instability quite well over the CWA throughout the afternoon. Once the nose of low level moisture and CAPE reached the boundary across the north, storms fired."
Forecaster, End-of-Day Survey

"It would be helpful to have more of the current combined parameters like SCP, STP, MLCAPE, MUCAPE, etc. rather than Total Totals, K-Index, Showalter. Those latter indices are quite dated."
Forecaster, End-of-Day Survey

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"These products performed quite well, and they showed an increasing trend in PW/Instability parameters through the afternoon. The instability parameters, as in days past, appeared to be a bit low biased."
Forecaster, End-of-Day Survey

AWC Input
The CWSU forecasters were particularly pleased with this product. While they noted that the concept of the NearCast required a bit of a learning curve, they liked the fact that the color bar made it very easy to interpret, in this case the dry air associated with the trough sinking into the middle of the country as compared to the higher instabilities associated with the obvious frontal features of the low. All of the CWSU offices in attendance requested the weblink for the imagery as it is not currently available in their AWIPS.

4. ACHA Cloud products - (Baseline)

AWC Input
Estimating cloud bases is a challenging prospect given the lack of information in the satellite observations for some cloud types. How they are derived is therefore highly dependent upon the cloud type. The method is to first derive the cloud top height from ACHA and then to derive the geometrical thickness of the cloud layer. The cloud base height (CBH) is computed as the difference between the two. For cirrus and low-level water cloud, a direct estimation of the cloud geometrical thickness is possible from the satellite observations. For moderately thick clouds throughout the atmosphere, a set of regressions derived from CloudSat are used. Both the direct retrieval and CloudSat regressions use (1) the estimated cloud top, and (2) an estimated cloud layer thickness from cloud optical depth, cloudfrom GOES generated statistics. For the thickest clouds, the satellite observations provide little skill and the CCL Level from the NWP ancillary data is used to estimate the geometrical thickness. However, it is often the case that there are multiple layers of clouds which overlap. In these cases, the derived base is most indicative of that for the highest cloud layer. Treatment of these cases is being actively researched. The Cloud Base Heights were first evaluated in the 2016 Winter Experiment for the C&V effort. As mentioned in earlier sections, one of the major foci of the AWT experiments this year has been the Digital Aviation Services efforts and associated grid editing through GFE. The Winter Experiment was the first deep dive into this process and such was mainly an exercise in knobology. However, a cursory evaluation was done of the Cloud Base Height (hereafter referred to as CBH) product. The initial observation of this product by many forecasters was its high accuracy in single layer clouds. However, it did also have a marked struggled in areas multiple cloud layers. In those multiple layers, the bases were far too high, and it appeared the algorithm was estimating the base of the top most layer of clouds when compared to visible imagery.

5. Atmospheric Motion Vectors Product - (Baseline)

AWC Input
One of the main concepts for the AMVs taken from last year was the possibility of utilizing them to aid in the forecast or verification of compression issues around major terminals. Compression is caused when the winds at upper levels are much higher than winds near the surface. As arrivals near the terminal, these stronger upper level winds cause aircraft to quickly catch up with those at lower levels in lighter winds. It is the opposite on take off if there are strong surface winds and lighter winds aloft. Because of the minimum distance requirements between aircraft, traffic flow managers are required to spread traffic out further in these cases and often end up having to delay or hold other flights. O'Hare and the New York area terminals are those where compression is a common issue and causes the biggest problems.

In 2016 the AWC began producing forecasts of vertical winds using the SREF, the idea being to provide traffic flow managers a forecast vertical profile of winds. However, this would not be limited to just the terminal point. The arrival and departure points of each terminal contain an expansive chunk of airspace and wind conditions and differ from one end to the other. Therefore, plots from the various approach and departure gates around the main hubs are also created. The first airport this has been explored for is ORD.

This is a very new concept and currently these plots are being verified using aircraft sounds and also RAOBs. The latter are typically only available at the center of the main hub and not at the various departure/arrival points. Additionally, aircraft soundings can be limited at times as they are only produced from certain types of aircraft.

It is here where AMVs could perhaps become useful. While AMVs are derived only for cloud objects in the top layer of clouds, the addition of many spectral channels from which winds can be derived will increase the density of winds in these layers. The layers themselves will not be consistent to a specific point, but by examining winds from various points within a region, forecasters may be able to get a better perspective on the vertical profile of winds. These could be compared to SREF wind forecast departure/arrival points as well as RAOBs and RAOB sounds to potentially 1) provide at least some wind forecast verification, 2) provide more insight on the accuracy and reliability of satellite derived winds, and 3) gauge whether satellite derived winds provide any information over and above current modeled winds.

6. Icing

AWC Input

The Flight Icing Threat (FIT) integrates various cloud properties from the GOES-R baseline DCOMP algorithm to generate a probability and intensity of icing conditions. It is composed of three components including (1) an icing mask available day and night which discriminates regions of possible icing, (2) an icing probability, estimated during the daytime only, and (3) a two-category intensity index which is also derived during the daytime only. While it is difficult to validate a product such as this given the lack of icing PIREPs and other methods of ice measurement, it has been shown to have skill in identifying areas of more significant icing conditions.

Funding to continue work on this algorithm was received in late 2015. As such, it was evaluated during Evaluation Period I of the 2018 GOES-R/JPSS Demonstration, and underwent a detailed examination during the Winter Experiment. Prior to this, several improvements had already been made after the 2017 GOES-R/JPSS demonstration. These included the addition of a ‘heavy’ category to identify the more intense icing associated with supercooled large droplets and convection, as well as improved estimates of cloud vertical structure that enable the inference of icing conditions embedded beneath glaciated clouds. Additionally, this year’s evaluation was expanded to include an AWIPS-2 version of the product, which was examined by forecasters in D2D.

In general, forecasters continue to note that the FIT has a lot of potential. It provides situational awareness not typically available for icing conditions, typically in areas that don’t see a lot of in situ icing reports from aircraft. This is beneficial both to G-AIRMET and SIGMET issuances. The product was also found useful in the non-convective CAWS portion of the Winter Experiment. While a non-convective CAWS is not likely to be made an operationally issued product, the concept explored the need for a product that would fit in between a G-AIRMET and a SIGMET, similar to what is currently issued at the Alaskan Aviation Weather Unit. This ‘in-between’ product would identify icing areas not as broad as the forecasted moderate or greater conditions in a G-AIRMET, but less specific than the severe conditions within a SIGMET or ‘warning’ product.

Its ability to discern icing intensities (during the day only) within the clouds helped to narrow down smaller areas in which a non-convective CAWS may need to be issued. In some cases of widespread clouds of multiple layers, the FIT product is more uncertain and it became somewhat difficult to determine which particular areas to really key in on. While this ‘messiness’ depicted the inherent nature of multi-layer clouds, forecasters mentioned that it might be helpful to apply some sort of smoothing technique in some cases as N-AWIPS does not current support this capability. AWIPS-2 D2D, however, does provide the ability to interpolate, and forecasters were able to utilize this if they chose.

While the algorithm did show continued improvement over the past few years, there were still a few caveats forecasters noted. Firstly, intensities were overestimated in the terminator region. Low sun angles and the shift from day to nighttime retrievals were the culprits behind this issue. Eclipse periods were also somewhat problematic. With the stray light during these periods, there was a significant erroneous increase in intensities. This occurred at relatively the same time each day and so was easy become accustomed to. Additionally, there were some cases in which undetected thin cirrus clouds overlapping liquid clouds were interpreted as SLD causing an overestimation of the icing threat. Lastly, thin cirrus over snow covered ground also caused overestimation at times. All of these caveats –terminator regions, eclipse periods, and cirrus cloud contamination- were significant, but with a good understanding of the cloud environment, not particularly difficult for forecasters to become accustomed to and subsequently keep in mind when issuing icing forecasts.

Beyond the non-convective CAWS, there were a number of CWSUs who noted the potential benefit of the product in their operations. CWSUs advise the traffic flow managers within their air space of various weather hazards that may impact air traffic. Icing is not typically one of the highest priority issues to forecast for in their daily duties, however it was suggested that the FIT would become useful in and around a major terminal, particularly the top and base of the icing layer. Icing is commonly seen in the ascent or descent phase of flight as a layer of clouds conducive to icing settles over a particular hub. Identifying the extent of the icing layer within these clouds as well as the estimated intensity of icing with the FIT would provide valuable situational awareness. There were several cases were the FIT showed high skill in identifying smaller scale areas of icing around terminals that would have provided this situational awareness

7. GOES-16/GOES-17 Legacy Atmospheric Profiling Products - (Baseline)

HWT Input

The GOES Sounder LAP products were viewed most often by forecasters at the beginning of the shift as they conducted their initial environmental analysis. Additionally, some forecasters viewed the products throughout the shift to get an update on how moisture and instability were evolving. Oftentimes they would use the LAP information as a check on the models and other environmental information (SPC meso-analysis, NUCAPS, etc). Participants liked the full-CONUS coverage of these environmental fields. Past product demonstrations have revealed that a portion of forecasters prefer fields with little-to-no data gaps, even if that means filling in the gaps with NWP data. In addition to the complete spatial coverage, the hourly availability and low-latency of the LAP products were appreciated, keeping forecasters aware of significant environmental trends as they occurred.

Participants consistently commented that gradients, maxima/minima, and trends in the LAP fields provided them with the most unique and accurate information, rather than the absolute values themselves. It was along the moisture/instability gradients and within the areas of increasing moisture/instability that convection most often developed. Alternatively, decreasing moisture/instability trends were often a sign that convective activity would cease. Forecasters would look back at the fields at the end of the day and see that convection had indeed developed along the gradients and in areas of increasing moisture/instability. Observing this early in the week gave forecasters confidence when using the tools as the week progressed. Additional forecast situations in which the LAP products aided participants included: dryline progression, depth of moisture in the atmosphere, progression of moisture return, elevated or surface-based storms, severe vs. non-severe storms, and convection in data sparse regions.

While the PW values appeared to be reasonably consistent with that from other data sources (e.g., Rapid Refresh Model, SPC meso-analysis, radiosondes), the LAP CAPE absolute values were often substantially different. This led participants to lose trust in the absolute values of the LAP CAPE field, which is the instability field of choice for most operational forecasters. The other major issue with the LAP products was the apparent "blotchiness" and unrealistic spatial variations that oftentimes appeared in the fields. This anomaly was addressed and mostly resolved by the developers after week 3, but deficiencies in the Sounder instrument cause some striping to remain.

Development of New GOES-R Weather Event Simulations and AWIPS-II Transition Support

CIMSS remains committed to assuring a smooth transition of all CIMSS research to operations products from the existing AWIPS software to the upcoming AWIPS-II. Preliminary work has been done finding a new product implementation approach for AWIPS-II. AWIPS-II activities are rapidly accelerating on the national scale to transition local applications between the two software environments. An AWIPS archive capable of archiving 60 days worth of AWIPS formatted files has been acquired through SSEC funding to support easier generation of WES cases. AWIPS-II will soon be accessible for use at CIMSS, with training modules employing the new AWIPS software included as part of the VISIT/COMET training programs for operational satellite meteorology professional development. UW-CIMSS participated in multiple GOES-16/GOES-S Proving Ground organizational and testbed/PG demonstration planning telecons.

Publications (2015-2018)

Cintineo, Rebecca M.; Otkin, Jason A.; Jones, Thomas A.; Koch, Steven and Stensrud, David J. Assimilation of synthetic GOES-R ABI infrared brightness temperatures and WSR-88D radar observations in a high-resolution OSSE. *Monthly Weather Review*, Volume 144, Issue 9, 2016, pp.3159-3180. Reprint # 7698

Feng, Lian; Hu, Chuanmin; Barnes, Brian B.; Mannino, Antonio; Heidinger, Andrew K.; Strabala, Kathleen and Iraci, Laura T. Cloud and sun-glint statistics derived from GOES and MODIS observations over the Intra-Americas Sea for GEO-CAPE mission planning. *Journal of Geophysical Research-Atmospheres*, Volume: 122, Issue: 3, 2017, pp.1725-1745. Reprint # 7878.

Gravelle, Chad M.; Mecikalski, John R.; Line, William E.; Bedka, Kristopher M.; Petersen, Ralph A.; Sieglaff, Justin M.; Stano, Geoffrey T. and Goodman, Steven J. Demonstration of a GOES-R satellite convective toolkit to 'bridge the gap' between severe weather watches and warnings: An example from the 20 May 2013 Moore, Oklahoma, tornado outbreak. *Bulletin of the American Meteorological Society*, Volume 97, Issue 1, 2016, pp.69-84. Reprint # 7564.

Greenwald, Thomas J.; Pierce, R. Bradley; Schaack, Todd; Otkin, Jason; Rogal, Marek; Bah, Kaba; Lenzen, Allen; Nelson, Jim; Li, Jun and Huang, Hung-Lung. Real-time simulation of the GOES-R ABI for user readiness and product evaluation. *Bulletin of the American Meteorological Society*, Volume 97, Issue 2, 2016, pp.245-261. Reprint # 7570.

Gunshor, Mathew. GOES-R: What's new in orbit. *AWPA Reporter*, Volume: 85, Issue: 1, 2018, pp.57-59. Reprint # 8230.

Lindstrom, Scott; Schmit, Timothy J.; Gunshor, Mathew M.; Daniels, Jaime; Bah, Kaba and Goodman, Steven J. Latest assessment of GOES-R (16) Advanced Baseline Imager (ABI) data quality from an application and training perspective. Piscataway, NJ, Institute of Electrical and Electronic Engineers, Inc. (IEEE), 2017, pp.283-285. Reprint # 8238.

Line, William E.; Schmit, Timothy J.; Lindsey, Daniel T. and Goodman, Steven J. Use of geostationary super rapid scan satellite imagery by the Storm Prediction Center. *Weather and Forecasting*, Volume 31, Issue 4, 2016, pp.483–494. Reprint # 7587.

Miller, Steven D.; Schmit, Timothy; Seaman, Curtis J.; Lindsey, Daniel T.; Gunshor, Mathew M.; Kohrs, Richard A.; Sumida, Yasuhiko and Hillger, Donald. A sight for sore eyes: The return of true color to geostationary satellites. *Bulletin of the American Meteorological Society*, Volume 97, Issue 10, 2016, pp.1803-1816. Reprint # 7780.

Rabin, Robert M.; Gultepe, Ismail; Kuligowski, Robert J. and Heidinger, Andrew K. Monitoring snow using geostationary satellite retrievals during the SAAWSO Project. *Pure and Applied Geophysics*, Volume 173, Issue 9, 2016, pp.3085-3102. Reprint # 7732.

Schmit, Timothy J.; Lindstrom, Scott S.; Gerth, Jordan J. and Gunshor, Mathew M. Applications of the 16 spectral bands on the Advanced Baseline Imager (ABI). *Journal of Operational Meteorology*, Volume: 6, Issue: 4, 2018, pp.33-46. Reprint # 8306.

Schmit, Timothy J.; Griffith, Paul; Gunshor, Mathew M.; Daniels, Jaime M.; Goodman, Steven J. and Lebair, William J. A closer look at the ABI on the GOES-R series. *Bulletin of the American Meteorological Society*, Volume: 98, Issue: 4, 2017, pp.681-698. Reprint # 7913.

9. CIMSS Support for Development of Himawari-8 Decision Support Products

CIMSS Task Leader: Michael Foster
CIMSS Support Scientist: Chris Velden, Tim Olander, Wayne Feltz
NOAA Collaborator: Andy Heidinger
Budget: $181,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

Our objective is to collaborate with the Central Weather Bureau (CWB) of Taiwan to provide them decision support products from the Himawari-8 satellite using the knowledge and expertise at CIMSS gathered through development of products for GOES-16 and GOES-17.

Project Overview

We transitioned products developed at CIMSS for use in GOES-16 and GOES-17 to CWB for use with Himawari-8. Specific products include the Advanced Dvorak Technique (ADT) typhoon intensity estimation and SST. We also provide support in generating Himawari-8 RGB products for use in an AWIPS-2 environment. The vehicle for many of these products is the Clouds from AVHRR Extended (CLAVR-x) processing system.

Milestones with Summary of Accomplishments and Findings

Delivery of the ADT code to CWB is complete. Milestones to reach this goal include:

- Validate automated 'first guess' typhoon eye location.
- Integrate microwave measurements
- Provide latest version of code and perform test case between CIMSS and CWB package implementation

Implementation of Himawari-8 SST product at CWB is complete. Milestones include:

- Derive SST fit coefficients for Himawari-8/AHI domain using in situ data
- Upgrade CLAVR-x installation at CWB to produce SST product

Provided CLAVR-x technical training and support for True color/RGB imagery. Milestones include:

- Deliver tools to convert Himawari-8/CLAVR-x products to SCMI format for display in AWIPS2 at CWB.
- Provide atmospheric corrections for AHI channels 1, 2, and 6 for RGB products. (see Figure 67 for example of true color image generated using the atmospherically corrected channels).
- Provide support for RGB products

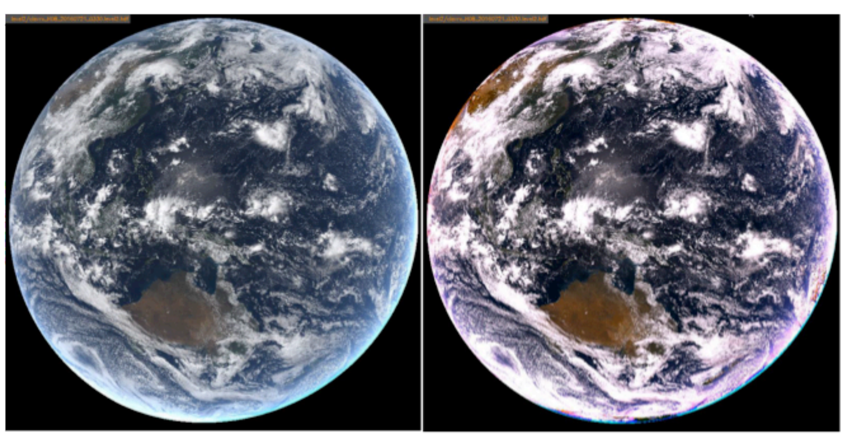


Figure 67. Example of true color Himawari-8 image before (left) and after (right) atmospheric correction.

10. CIMSS Support to GOES-16/17 Program Support, GIIRS/HIRAS Evaluation, and McIDAS-V Tasks 2018

10.1 CIMSS Support of the GOES-R Program and Studies of the GIIRS for Nowcasting Applications

CIMSS Task Leader: W. Paul Menzel
CIMSS Support Scientist: Jun Li
NOAA Collaborator: Dan Lindsey
Budget: $150,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Education and Outreach

Objective

The objective is to understand the added value of a geostationary advanced IR sounder on nowcasting applications.

Project Overview

Monitoring moisture with large spatial and temporal variability requires more frequent observations. Such high temporal resolution (1 h or better) atmospheric observations can be provided by geostationary satellites. Advanced imagers such as ABI and AHI, providing legacy atmospheric profile (LAP) information with high temporal resolution, have proven to be very useful in nowcasting (see HWT 2015 – 2018 reports on LAP proving ground demonstration). But those sensors lack vertical resolution due to the broader spectral response functions (SRFs) and limited number of spectral channels; forecasters need more vertical layers in the moisture product for applications according to feedback from 2015 – 2018 HWT.

A hyperspectral IR sounder in geostationary orbit can provide four-dimensional atmospheric temperature, moisture, and wind profiles. It has distinct advantages for nowcasting, forecasting, and NWP applications (Li et al. 2018) over a polar orbit satellite-based sounders by providing rapid refresh measurements for severe weather events (Schmit et al. 2009). An advanced IR sounder called InfraRed Sounder (IRS) is planned for the EUMETSAT Meteosat Third Generation (MTG) sounding mission to be launched in 2023 time frame. The Geostationary Interferometric InfraRed Sounder (GIIRS) onboard FY-4A (Yang et al., 2017) is already in orbit. It is the first geostationary based advanced IR sounder and is providing data for research and applications. Even though the Hyperspectral Environmental Suite (HES) was removed from the GOES-R series, NOAA continues to need measurements from an advanced IR sounder in geostationary orbit (Schmit et al., 2009).

In order to understand the unique value of a geostationary advanced IR sounder for rapid changing weather events such as local severe storms (LSS), and get ready for the application of IRS data, two tasks have been proposed in this study emphasizing nowcasting applications. This study is supplemental to another SSEC GIIRS project which is focused on GIIRS radiance data evaluation and subsequent assimilation (DA) in numerical weather prediction (NWP) models through collaboration with the National Weather Service (NWS/NOAA).

Additionally, the project includes (1) facilitating research demonstrations of new capabilities from GOES-R and JPSS, (2) teaching remote sensing seminars to new researchers, (3) participating in Technical Advisory Committees, JPSS Reviews, and other evaluations, (4) presenting research results at appropriate venues, and (5) collaborating with international partners pursuing the same goals.

Milestones with Summary of Accomplishments and Findings

GEO IR sounder radiative transfer model (RTM) enhancement using local training profiles for better representing the atmospheric characteristics of the specific weather regime

A fast radiative transfer model is a key component for quantitative applications of GIIRS radiance measurements, including deriving soundings in near real-time for situation awareness and radiance assimilation in numerical weather prediction (NWP) models. The weighted least squares method for enhancing the accuracy of RTTOV (Radiative Transfer for TOVS) for GIIRS has been developed. Currently, fast radiative transfer models for IR sensors are based on global training profiles, but GIIRS is targeted for regional observations hence it is advantageous to use local training profiles. These better represent the characteristics of that weather regime and thus are more beneficial for local weather related applications. A local training profile data set has been developed for GIIRS using the RTTOV approach. Comparisons with line-by-line radiative transfer models indicate that a weighted least squares method provides better accuracy (smaller root-mean-square error) in the brightness temperature simulation for the mid-wavelength band of GIIRS than the ordinary least squares method, and the local training profiles have made possible further improvements on brightness temperature simulation over the global training profiles, especially for GIIRS longwave band. Figure 68 shows the sample distribution (upper), and the brightness temperature RMSE (K) of two approaches (global training and local training) when compared with LBLRTM (middle), along with percentage of channels with different RMSE ranges (lower), 200 independent profiles are used in the comparisons It indicates that local training has improvement on global training, especially in the absorption region. The local training coefficients have been now used by ECMWF and UK Met Office for their GIIRS studies. The methods can be added to RTTOV for other IR sensors onboard the geostationary satellites.

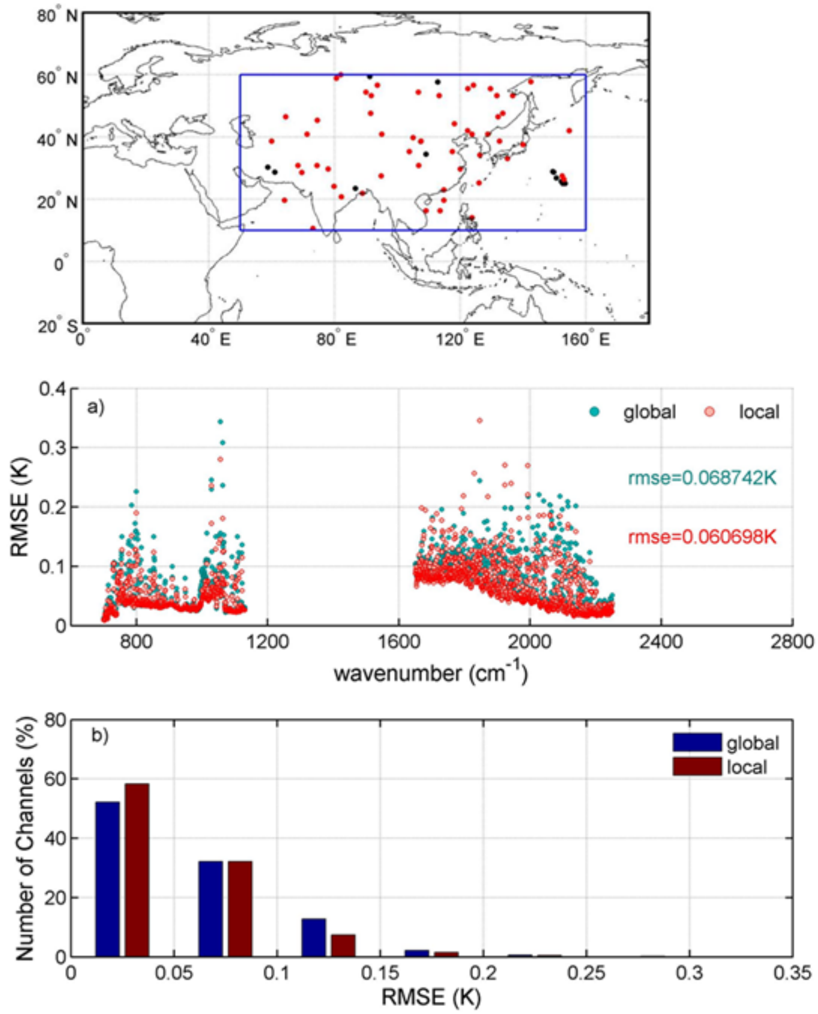


Figure 68. The sample distribution (upper), and the brightness temperature RMSE (K) of two approaches (global training and local training) when compared with LBLRTM (middle), along with percentage of channels with different RMSE ranges (lower), 200 independent profiles are used in the comparisons.

A paper on this study titled "Enhancing the Fast Radiative Transfer Model for FengYun-4 GIIRS by Using Local Training Profiles" has been published in Journal of Geophysical Research – Atmospheres (Di et al. 2018). See the following link for the paper:
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2018JD029089
The significance is that by using this method, local training profiles can be developed and used to enhance the fast RTM (e.g., CRTM) for geostationary IR sounder applications.

Enhance channel selection for GEO IR sounder applications

Li and Han (2018) reviewed various methodologies developed for a hyperspectral infrared sounder; the information entropy iterative method from Rodgers (2000) is closest to optimal. This method does not take into account the diurnal changes of the atmospheric state, thus it needs to be improved for the geostationary hyperspectral infrared sounder, which provides continuous monitoring of fast-changing mesoscale environments and generates measurements useful for severe weather nowcasting and forecasting.

A spectral channel selection approach is being developed for the applications of the measurements from the Geosynchronous Interferometric Infrared Sounder (GIIRS). Specifically, a new index that represents the temporal changes of the atmospheric state has been developed using the information entropy iterative method. The methodology, testing, and verification on GEO IR sounder channel selection are ongoing; this work will be continued in FY 19 with another GIIRS project team at SSEC. Methodologies will be developed for GEO IR sounder channel selection, and a set of channels are expected to be selected specifically for GIIRS data assimilation in NWP and nowcasting applications.

Here the significance lies in the fact that a set of channels sensitive to diurnal variation can be selected specifically from the geostationary advanced IR sounder for NWP and nowcasting applications.

Chapter in Geostationary Weather Satellites

Dr Menzel contributed chapter 2 titled "The history of geostationary weather satellites" to the GOES-R book being published by Elsevier.

GOES-17 mitigation strategies studied

A study was undertaken to map the GOES-15 Imager infrared bands into the GOES-17 ABI infrared bands at 2 km resolution. The approach is briefly summarized as follows: (1) Good ABI and Imager IR data at time t0 are used to establish a collocated data pair. (2) At later time t, use radiance k-d tree search to find best 5 Imager fovs from time t0 matching each Imager fov at time t. (3) Average the collocated ABI IR bands to get fusion bands at time t. This approach demonstrated the capability to fill in missing water vapor images during the data outage (see the figure below).

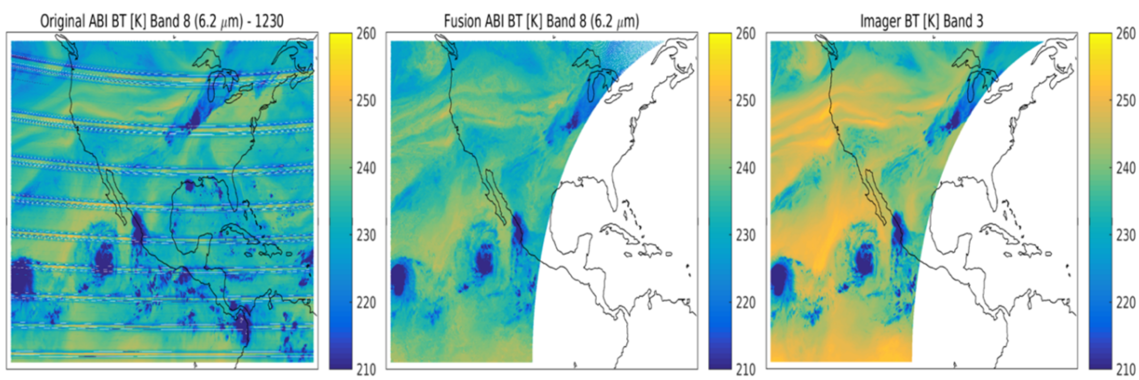


Figure 69. GOES-17 measured 6.2 micron water vapor BT (left), fusion water vapor BT (middle) and GOES-15 measured 6.7 micron water vapor BT (right). The fusion BTs restored the corrupted water vapor BTs.

Finally, a GOES-17 only solution was demonstrated using the ABI IRW radiances to remap the missing water vapor radiances. In this fusion approach (1) at time t perform a k-d tree search on time t0 IRW band 14 measurements to find the five t0 pixels that best match each time t band 14 pixel. (2) Average the five k-d tree time t0 matches for each pixel for all ABI bands to estimate ABI bands at time t. The figure below demonstrates that retaining the GOES-15 data flow, while desirable, is not necessary to produce water vapor images through the data outage, provided the ABI IRW remains intact.

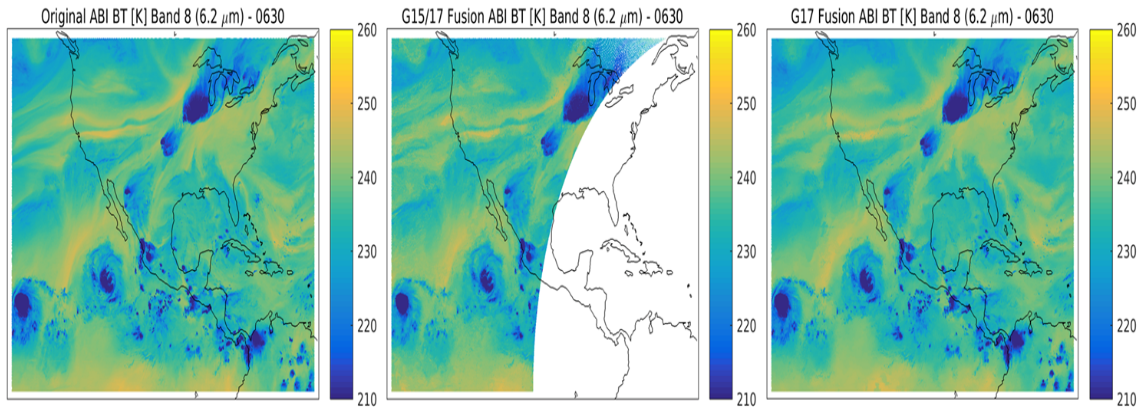


Figure 70. GOES-17 measured 6.2 micron water vapor BT (left), GOES-15 and -17 fusion water vapor BT (middle), and GOES-17 only fusion water vapor BT (right). The GOES-17 only fusion BTs restore the corrupted water vapor BTs reasonably well, but not as sharply as the GOES-15 and -17 fusion results.

Publications and Conference Reports

Di, D., Jun Li, W. Han, W. Bai, C. Wu, and W. Paul Menzel, 2018: Enhancing the fast radiative transfer model for FengYun-4 GIIRS by using local training profiles, Journal of Geophysical Research - Atmospheres, DOI: 10.1029/2018JD029089.

Li, Zhenglong, Jun Li, Pei Wang, Agnes Lim, Jinlong Li, Timothy J. Schmit, Robert Atlas, Sid-Ahmed Boukabara, and Ross N. Hoffman, 2018: Value-added Impact of Geostationary Hyperspectral Infrared Sounders on Local Severe Storm Forecasts—via a Quick Regional OSSE, Advances in Atmospheric Sciences, 35(10): 1217-1230.

Menzel, W. Paul, Timothy J. Schmit, Peng Zhang, and Jun Li, 2018: Satellite based atmospheric infrared sounder development and applications, Bulletin of American Meteorological Society. 99, 583 - 603.

References

Di, D., Jun Li, W. Han, W. Bai, C. Wu, and W. Paul Menzel, 2018: Enhancing the fast radiative transfer model for FengYun-4 GIIRS by using local training profiles, Journal of Geophysical Research - Atmospheres, DOI: 10.1029/2018JD029089.

Li, Jun, and Wei Han, 2017: A Step Forward toward Effectively Using Hyperspectral IR Sounding Information in NWP, Advances in Atmospheric Sciences, 34, 1263 - 1264.

Li, Zhenglong, Jun Li, Pei Wang, Agnes Lim, Jinlong Li, Timothy J. Schmit, Robert Atlas, Sid-Ahmed Boukabara, and Ross N. Hoffman, 2018: Value-added Impact of Geostationary Hyperspectral Infrared Sounders on Local Severe Storm Forecasts—via a Quick Regional OSSE, Advances in Atmospheric Sciences, 35(10): 1217-1230.

Rodgers, Clive D., 2000: Inverse methods for atmospheric sounding: theory and practice. Vol. 2. World scientific.

Menzel, W. Paul, Timothy J. Schmit, Peng Zhang, and Jun Li, 2018: Satellite based atmospheric infrared sounder development and applications, Bulletin of American Meteorological Society. 99, 583 - 603.

10.2 McIDAS-V Support for GOES-R Development
CIMSS Task Leader: Tom Rink
NOAA Collaborator: Brad Pierce, Tim Schmit
Budget: $35,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective
Develop enhancements to 3D visualization capabilities in McIDAS-V.

Project Overview
We worked on designing and developing forward/reverse wind parcel trajectory computation and visualization through 2D/3D, earth navigated, gridded Eulerian wind fields with interactive control in McIDAS-V. Potential applications relevant to GOES-R, and under development, include: display 3D trajectories through time based on ABI retrieved Aerosol optical depth (AOD) and numerical model wind forecast, visualize the forward trajectories of parcels in the vicinity of volcanic eruption with respect to ash/SO2 retrievals, trace conservative atmospheric stability parameters such as Equivalent Potential Temperature from NWP or analysis wind field.

Milestones with Summary of Accomplishments and Findings
We implemented parcel displacement according to Runge-Kutta 4th order (RK4) for improved accuracy with user configurable choice between (RK4), (RK2 endpoint) and Euler method. A cursory validation against NOAA's HySplit trajectory model showed good agreement though a more rigorous comparison, while potentially interesting, is beyond the scope of this effort. We leveraged built in data fusion capability afforded by McIDAS-V to initialize trajectory parcels from the ABI L2+ Fire Mask Hot Spot product. In addition, we implemented continuous parcel streaming from a fixed location in space. Finally, we created python-based tools to select a set of parcels on constant theta or theta-e surfaces.

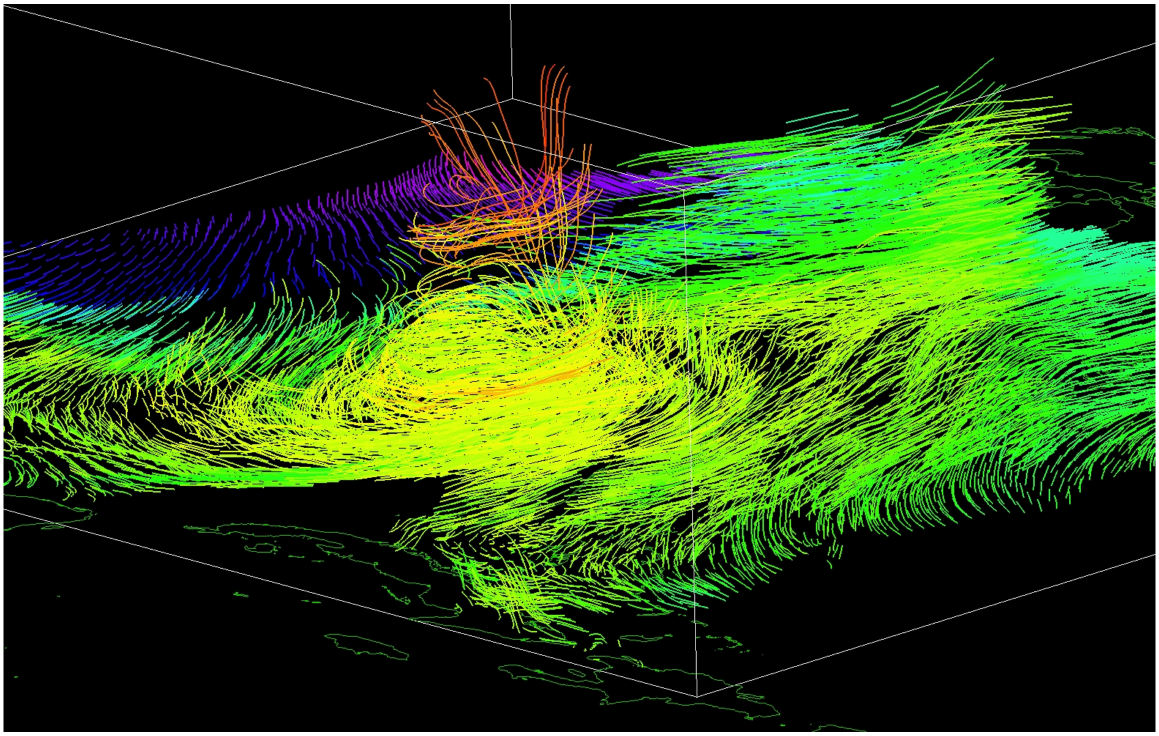


Figure 71. High density of parcels initialized at 900mb in hurricane Michael. Colored by Equivalent Potential Temperature at the initial time.

Publications and Conference Reports

AMS Annual Meeting (IIPS): 2005-2016, 2018, 2019
AMS Satellite Meteorology Conference: 2007, 2009, 2010, 2012, 2016, 2019
AGU Fall Meeting: 2005, 2007-2011
SPIE Photonics: 2007-2011
NOAA Direct Broadcast: 2008, 2011
GOES-R User's Conference: 2009 (workshop), 2010, 2011
EUMETSAT Satellite Conference: 2008 (workshop), 2009-2012
International TOVS Working Group Meeting: 2007, 2008, 2010 (workshop), 2012
McIDAS Users Group: 2006-2018 (workshops 2008-2018)

11. CIMSS Support to the Development of a Geostationary Community Satellite Processing Package (CSPP) Tasks 2018-2019

CIMSS Task Leaders: Liam Gumley (PI), Graeme Martin (PM)
CIMSS Support Scientists: Nick Bearson, Jessica Braun, Geoff Cureton, Alan De Smet, Ray Garcia, Dave Hoese, Tommy Jasmin, Scott Mindock, Eva Schiffer, Kathy Strabala
NOAA Collaborators: Dan Lindsey, Jim McNitt, Matt Seybold, Andrew Heidinger, Michael Pavolonis, Walter Wolf

Budget: $341,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
The CSPP Geo project supports the U.S. and international direct broadcast community by developing and distributing software allowing users to process data received directly from geostationary satellites, generating data products locally in real-time with low latency.

Project Overview
The primary goal of the project is to support processing of GOES Rebroadcast (GRB) data received from GOES-16 and GOES-17 by direct broadcast users. Additional goals are to support processing of direct broadcast data from the GOES-13, GOES-15 and Japanese Himawari-8 satellites.

Each CSPP Geo software package is designed to be run on a relatively modest rack-mounted Linux server located at a direct broadcast receive site. The software is freely available, is easy to install and run, and comes with all required third-party software bundled in the software package. Test datasets are provided, to allow users to verify correct installation and operation. Users can optionally plot products using "quicklook" image software. A high level of technical support is provided.

A processing chain at a GRB receive site might consist of CSPP Geo software generating Level 1B ABI and space weather products and Level 2 GLM products, and further processing the ABI data to generate Level 2 geophysical products and high-quality RGB images.

CSPP Geo software is widely used by vendors of direct broadcast receiving and processing systems, U.S government agencies, including the National Weather Service (NWS) and NASA, providers of data products and services, foreign meteorological agencies and forecast offices, and the academic and research community, including NOAA cooperative institutes. To date, users from more than 30 countries have registered to download CSPP Geo software. Based on information from the GRB User Group, the majority of direct broadcast users who operate GRB receiving stations are running CSPP Geo software.

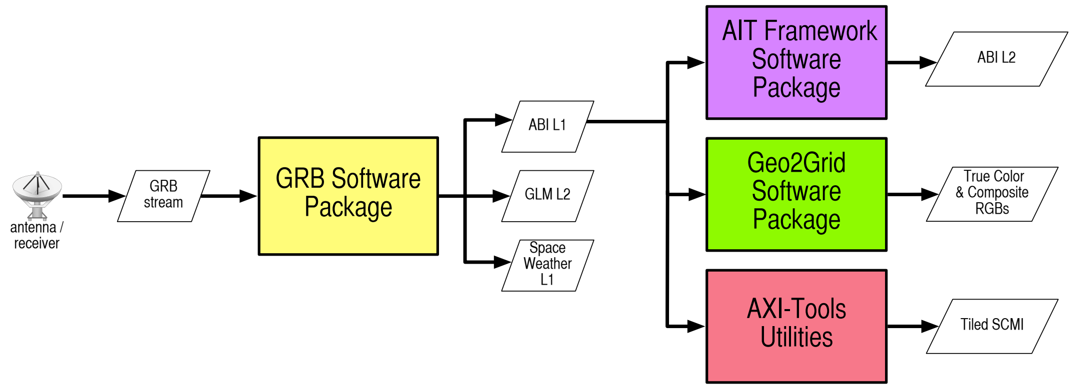


Figure 72. CSPP Geo processing chain for GOES-R Series.

Milestones with Summary of Accomplishments and Findings

Major milestones during the reporting period included multiple releases of the GRB software package for GOES-R series, including the Version 1.0 milestone. These releases allowed users to begin processing direct broadcast data received from the GOES-17 satellite, and to continue generating GOES-16 products after changes were made to the ground system affecting the format and content of the GRB data stream. Progress was made toward the V1.0 release of the AIT Framework Level 2 package. The initial version of the Geo2Grid package was released, allowing creation of high-quality RGB and single-band images from GOES-16, GOES-17 and Himawari AHI data received via direct broadcast. Each software release included high-quality user documentation and a test data package. User support was provided, including assistance with configuration and implementation of GOES-17 processing.

GRB Package

The initial software component in the GOES-R series processing chain runs as a server, ingesting data from a DVB-S2 demodulator and generating Level 1 ABI and space weather and Level 2 GLM products locally in real-time. The software was developed following the technical specifications described in the GOES-R Product Users' Guide. Early prototype versions of the software were distributed in the GOES-R pre-launch period to encourage GOES-R preparedness. The GRB software has been widely adopted at direct broadcast sites receiving GRB data from GOES-16 and GOES-17, within the U.S. and internationally.

During the reporting period, Version 1.0 of the GRB package was released. This milestone release included user interface changes, improved handling of edge cases and overall robustness, performance and logging improvements, as well as various features requested by users. Support for ABI Mode 6 was added. Extensive testing was performed, including analysis and tuning of program performance during localized or system-wide GRB anomaly events.

Also included in V1.0 was support for GOES-17 GRB processing. As data from each GOES-17 instrument was added to the GRB stream, products were generated locally using data from the GRB antenna at SSEC/CIMSS and checked for problems. Findings were reported to the GOES-R Program / PRO Team, though overall participation in GOES-17 Post-Launch Testing (PLT) was at a lower level compared to GOES-16 due to resource constraints. Assistance was provided to users as they set up their GOES-17 GRB processing systems and brought them online.

During the reporting period, three GRB package releases were made in response to planned updates to the GOES-R Ground System affecting GRB data format and content. In these cases, users must update the software running at their receive sites in order to continue generating the affected products. Software patches were developed using updated technical documentation and sample data provided by OSPO / PRO team, and additional information was obtained in technical walk-throughs. The patches were provided to users in advance of the ground system updates to allow uninterrupted product generation.

Other improvements to GRB software included fixes for SUVI FITS file problems reported by users, enhanced configurability, migration to a new quicklooks codebase offering better performance, added product attributes for data provenance, development of a user-callable diagnostic script, and explicit support for CentOS 7. In addition to the previously mentioned releases, a maintenance release was issued incorporating various bug fixes and minor improvements based on user feedback following the V1.0 release.

Multiple issues affecting the GRB stream were identified and reported to NOAA (metadata issues, SUVI compression, GRB/CLASS discrepancies, issues affecting EXIS EUV). We participated in technical discussions via the GRB User Group.

AIT Framework Level 2 Software Package for ABI

The second software component in the GOES-R Series processing chain allows users to process GOES-16 ABI data, generating a subset of the GOES-R baseline Level 2 products. During the reporting period we worked toward the Version 1.0 release of the AITF package, which is now planned for Spring 2019 due to the large number of GRB package releases that were needed.

This software package was developed as part of an ongoing collaboration with the GOES-R Algorithm Scientific Software Integration and System Transition Team (ASSISTT) at NOAA, who are the maintainers of the core science software. The CSPP Geo package consists of research implementations of the operational product algorithms running in the AIT Framework, and a CSPP Geo-developed scripting infrastructure that allows it to run on a relatively inexpensive shared-memory multi-core server in a direct broadcast setting. The primary tasks of the logic developed by the CSPP Geo team are job sequencing, ancillary data downloads, data format conversion, CMI product creation, segmentation and stitching to allow parallel processing, logging, error recovery and quicklook image generation.

During this reporting period we accepted delivery of updated algorithms, LUTs, static ancillary data and core processing software from ASSISTT via a common git repository, and integrated the updates to the CSPP Geo package. Changes were made to the user interface, program installation procedure, run-time configuration and logging. Program behavior was evaluated and standardized. Feedback from beta testers was incorporated and various issues affecting the beta were fixed. Overall robustness and performance were improved. Issues affecting products were resolved in collaboration with ASSISTT. The segmentation scheme was further tuned for the default architecture to optimize performance and reduce artifacts. Downloading and handling of dynamic ancillary data was improved, including migration to HTTPS for improved security. Quicklooks were improved based on feedback gathered from domain experts. Testing of preliminary Version 1.0 release candidates included tests of new features and bug fixes, regression tests and routine forward processing. Comparisons with reference output provided by ASSISTT are ongoing.

Technical issues were discussed in biweekly telecons with ASSISTT.

A patch for the beta software was released before the transition to ABI Mode 6, allowing users to continue to generate products.

Geo2Grid Software Package for High-quality Image Creation

Version 1.0 of the Geo2Grid package was developed and released during the reporting period, allowing users to create high-quality images from GOES-16, GOES-17 and Himawari AHI data. Supported images include composite RGB (true color, natural color, airmass, ash, dust, fog, night microphysics), as well as single-band images. Output can be written to GeoTiff and PNG format, and a script is provided to create animations. In addition, imagery can be reprojected to pre-defined or user-defined grids. Geo2Grid true color images include Rayleigh correction, artificial green band, sharpening to 500m, solar zenith angle correction, and logarithmic stretching to bands (enhancement).

The Geo2Grid software relies on the SatPy open-source Python library for much of its functionality. In addition, Geo2Grid leverages work that was done for the very successful Polar2Grid software package, which was developed under the CSPP LEO project with JPSS funding and offers similar functionality for LEO satellite data. Based on the very positive user response to Geo2Grid, we expect that it will become a widely-used package which will have a significant positive impact on the utilization of GOES-R series data and dissemination of imagery.

Activities during the reporting period in addition to implementation of the previously mentioned features included user interface definition and refinement, testing and incorporation of user feedback, performance benchmarking, identification of hardware requirements, and creation of documentation and test data sets.

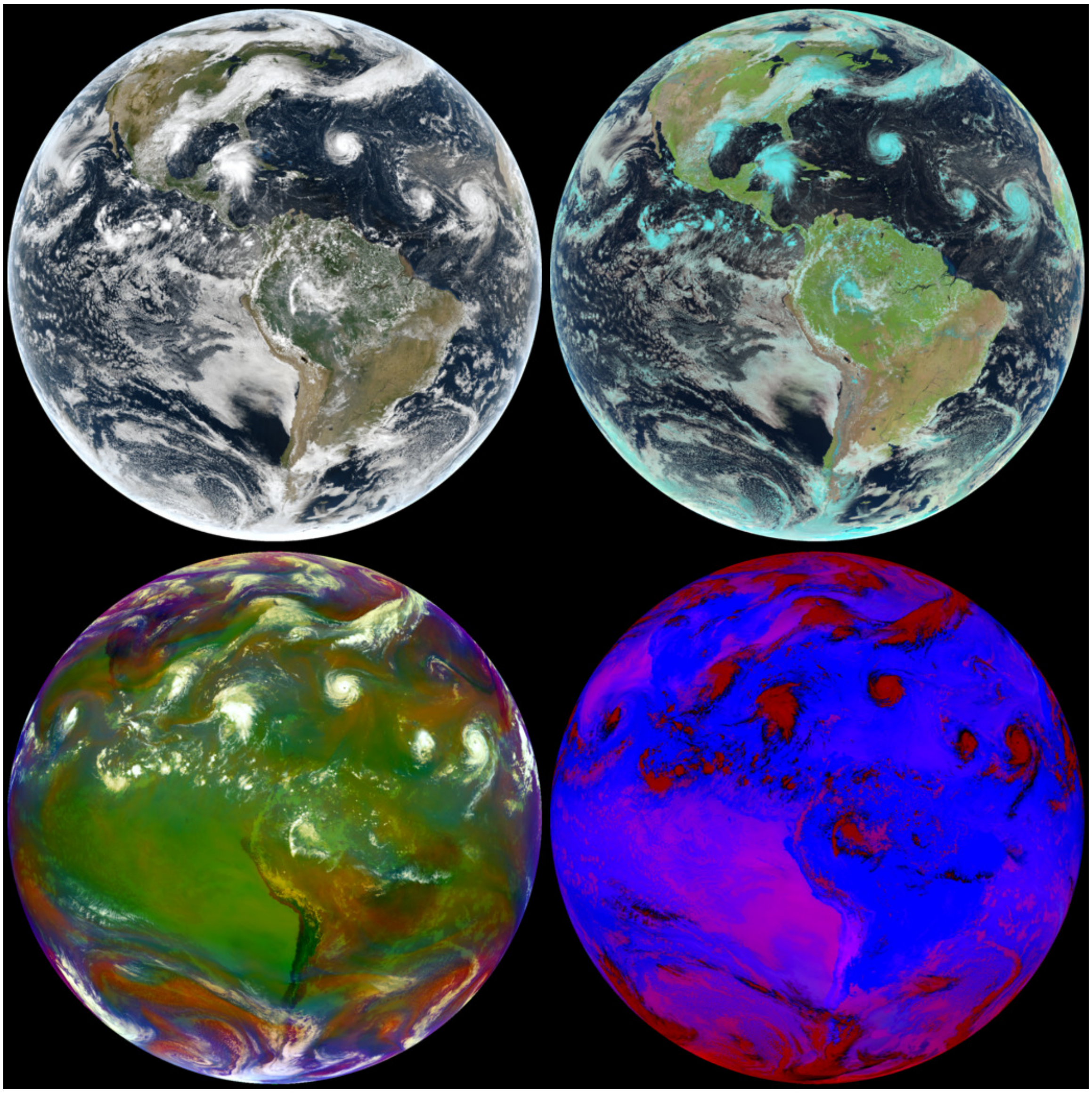


Figure 73. RGB images created by CSPP Geo Geo2Grid software. Clockwise from upper left: true color, natural color, night microphysics, airmass.

Additional Software and Common Tasks

Contributions were made to development of AXI-Tools, a script library for data tiling and format conversion. AXI-Tools is used in the AITF package to create the ABI Cloud Moisture Imagery (CMI) product. AXI-tools is currently being used at NWS direct broadcast receiving sites to convert products to Sectorized CMI (SCMI) format, for compatibility with AWIPS 2.

Progress was made on the GEOCAT Level 2 package for Himawari-8 AHI. The software package was developed in collaboration with the groups that maintain the core GEOCAT software and science algorithms, led by Michael Pavolonis and Andrew Heidinger. The current beta version allows users to run research versions of the GOES-R Level 2 algorithms which have been adapted to process data from the Advanced Himawari Imager. During this period work toward V1 included improvements to ancillary data handling, user interface, quicklooks and documentation, as well as integration of updated core processing software.

We continued to maintain the CSPP Geo website and user forum as the distribution point for software packages, patches, system requirements information and technical documentation. Software release announcements and other project news and plans were communicated to users via the website, the user forum and by email. We responded to a large number of support requests received via our user support email list. We provided technical support to the NWS in their evaluation of open source software to be run at their GRB and HimawariCast receive stations. We presented briefings and interacted with users at the AMS annual meeting, and began preparations for the fourth CSPP Users' Conference, to be held in Chengdu, China in June 2019.

Dynamic ancillary data required for level 2 product generation such as NWP, OISST and snow mask were acquired, converted, and staged for users on a public-facing server located at SSEC / CIMSS.

Other common tasks included contributions to the ShellB3 portable Python runtime library; maintenance of common facilities such as development and test servers, version control, issue tracking software, collaboration software and the user mailing list; continued distribution of software to process legacy GVAR / GOES-13 and -15 data; formulation of common guidelines for software installation and configuration, versioning, naming conventions, user interfaces, and the appearance of quicklook images.

12. CIMSS Support for ProbSevere Integration into MRMS for Transition to NWS Operations

CIMSS Task Leader: John Cintineo
NOAA Collaborator: Mike Pavolonis
Budget: $95,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Objective

The goal of this project is to transition code and knowledge base of ProbSevere from CIMSS to NCEP Central Operations (NCO).

Project Overview

NOAA/CIMSS ProbSevere is a suite of statistical models for short-term severe weather prediction. ProbSevere fuses together data from geostationary satellites (GOES), numerical weather prediction (NWP) models (e.g., RAP), Multi-Radar, Multi-Sensor products (MRMS) and

Earth Networks (ENI) total lightning information in a storm-centric automated fashion to produce probabilities of severe weather occurrence for thunderstorms CONUS-wide. ProbSevere has been running in real-time at CIMSS since 2013 and has been evaluated at the Hazardous Weather Testbed (HWT) from 2014-2018. This project involves making the ProbSevere code base compatible with MRMS v12, for which ProbSevere will operate as a subsystem. Another goal is to transfer scientific knowledge to the NWS Meteorological Development Laboratory (MDL).

Milestones with Summary of Accomplishments and Findings

Transfer of code and programmatic knowledge base to NSSL and NCO

The National Severe Storms Laboratory hosts the experimental MRMS v12, which ProbSevere will operate under. The ProbSevere code base and knowledge of how to use and troubleshoot the code has been transitioned to NSSL and their experimental MRMS v12 system. The ProbSevere code was modified where necessary to conform to MRMS standards. NSSL has been able to routinely produce ProbSevere end products at NSSL (Figure 74), which compared very well with ProbSevere output from CIMSS. Furthermore, documentation has been created and provided to NSSL and NCO, including documents on how to build, deploy, stop, start, and troubleshoot problems. The code base is available on NOAA's VLAB (https://vlab.ncep.noaa.gov/redmine/projects/probsevere) and the ProbSevere code and MRMS v12 are set to be operational at NCO in August 2019.

Transfer of scientific code and knowledge base to MDL

Codes and data to train and evaluate ProbSevere predictors have been supplied to scientists at MDL. They have been able to synthesize predictor distributions and understand the computation of the naïve Bayesian models in ProbSevere, as well understand the contribution/importance of each predictor in ProbSevere v1.

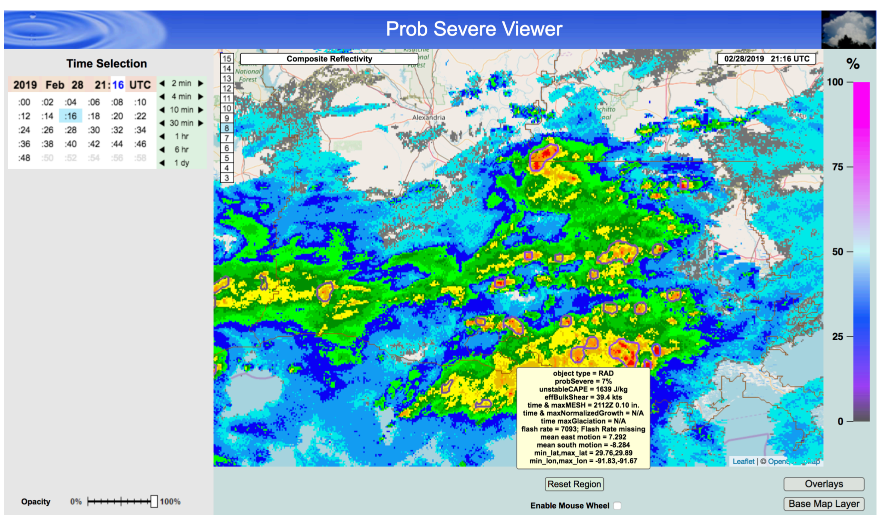


Figure 74. A screenshot from NSSL's internal MRMS viewer of some ProbSevere objects with hover readout.

13. Visiting Scientist Travel Support towards Improving Satellite Products for the GOES-16/17 National Hurricane Center (NHC) Proving Ground

CIMSS Task Leader: Chris Velden
CIMSS Support Scientist:
NOAA Collaborator: Andy Heidinger

Budget: $2,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Support the travel for a visiting scientist to CIMSS for a 1-week period to collaborate with the Tropical Cyclones group.

Project Overview

This project provides travel support for a 1-week visit to CIMSS for a visiting scientist to interact with the CIMSS Tropical Cyclone team and discuss collaborative research ventures. The goals are to leverage outside research efforts and entrain ideas into the GOES-16/17 products supported by the CIMSS TC team towards improving satellite products for use by the National Hurricane Center and Central Pacific Hurricane Center.

Milestones with Summary of Accomplishments and Findings

During this reporting period, the CIMSS TC group hosted a 3-day workshop with invited participants from both the TC research and operational communities. Among the participants was Jeff Hawkins, a long-time TC researcher and NRL scientist, whom this project supported travel to attend. Other attendees included participants from the Joint Typhoon Warning Center, the Office of Naval Research, and several universities. The workshop included fruitful presentations and discussions, and a couple collaborations were formed resulting in joint research proposals.

14. Development of an Archival System for the Integration of High Resolution GOES-R, Radar, and Lightning Data for Improving Severe Weather Forecasting and Warning Capabilities

CIMSS Task Leader: Shane Hubbard
CIMSS Support Scientists: Wayne Feltz and Jun Li
NOAA/NESDIS/STAR Collaborators: Bob Rabin, Lans Rothfusz, Alan Gerard (NOAA/NSSL), Michael Pavolonis (NOAA/STAR)
Collaborators: Anthony Reinhart, Thomas Jones (OU/CIMMS and NOAA/NSSL) and Dave Parsons, Chair, OU/School of Meteorology
Budget: $155,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water

- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications

Project Overview
The Geostationary Operational Environmental Satellite (R-Series; GOES-R) will provide coverage (spatially and temporally) that, particularly when integrated with ground-based systems such as WSR-88D radars, can actively support severe weather forecasting and warnings. With the launch of GOES-R, space-based and ground-based observations will be in cadence with each other, providing the ability to create a top to bottom, linked profile of a severe thunderstorm through direct observation. It is vitally important that stakeholders such as scientists at the National Severe Storms Laboratory (NSSL), developers integrated with the Storm Prediction Center, forecasters at various National Weather Service (NWS) offices, and training entities such as the Warning Decision Training Division (WDTD) have access to the GOES-R data to integrate the data into their current research, algorithm development, and training. All of this integration is critical to GOES-R support of a Weather Ready Nation.

This project will set up and maintain an archive of all of relevant GOES-R data related to severe and hazardous weather. This data will be available through open access and may be used by all interested parties with the goal of integration and development of severe weather applications and algorithms. This proposal not only outlines a plan for data archival, but also supports integration of this initial GOES-R data into these platforms.

Summary of Accomplishments and Findings

Accomplishments
Milestone 1: The CIMSS team has purchased its staging server that intersects with the CIMMS team's archival server.

Milestone 2: Scripts have been developed that grab Level 1 and Level 2 GOES 16 data daily and places those into a FTP staging area whereby scripts developed by CIMMS can grab those datasets seamlessly. The scripts at CIMSS also roll the archive to maintain a 3-4 day storage area and data older than 4-days is then removed. By request, historic GOES 16 data can also be placed onto the server by request. New scripts have been added that will grab missing data whenever the is a data outage. CIMMS can then fill the gaps at a later date.

In Progress
Milestone 2: We are looking at providing additional non-operations Level 2 type products such as cloud top cooling. This is in progress in April 2019.

Milestone 3: We have been working with NOAA scientist Bob Rabin to determine the best algorithm that fits the goals of this project for parallax correction. CIMSS will parallax correct L1 and L2 datasets prior to staging onto the CIMSS server for the ingestion of the CIMMS server.

Milestone 4: Verification of archived datasets, parallax corrections, and completeness will occur by UW-CIMSS.

Milestone 5: Initializing the quantification of the spatiotemporal development, maintenance, and dissipation of cloud top features in relationship to signals of severe weather at the surface (e.g., surface obs, radar detected severe weather)

The linkages between moisture (TPW), rainfall, real-time radar data are being linked together to discover potential relationships between each.

We anticipate additional findings to occur within the next 3 – 4 months. The server is up and running. We are now in the research phase of this project and are developing methodologies and then results.

Publications and Conference Reports
We anticipate conference participation in the fall of 2019 and spring of 2020.

References
We expect peer reviewed publications in 2020.

15. CIMSS Support for Cloud Cover Layers for GOES-R
CIMSS Task Leader: Steve Wanzong
CIMSS Support Scientists: Yue Li, and William Straka III
NOAA Collaborator: Andrew Heidinger
Budget: $65,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
Apply the Cloud Cover Layer (CCL) product to GOES-R (ABI).

Project Overview
Due to budget constraints, several GOES-R ABI products were reclassified from "baseline" to "future capability." Cloud Cover Layer is one such product. In 2014, the NWS Operational Algorithm Team (NOAT) selected five future capability GOES-R ABI products to be transitioned to operations. Included are Cloud Cover Layer (CCL), Aerosol Particle Size, Ice Concentration, Ice Age/Thickness, and Ice Motion.

While this NOAT request was directed for GOES-R as well as the VIIRS instrument on SNPP and NOAA-20. This was accomplished by the development of an enterprise algorithm that is able to run on multiple sensors. This means that the same algorithm that runs on GOES-R also runs on VIIRS and other sensors.

The current NOAT guidance is that CCL should report 6 cloud fractions at predefined flight levels (FLs), including the total cloud fraction. These 5 levels are surface to FL050 (where FL050 stands for 5 kft), FL050 to FL100, FL100 to FL180, FL180 to FL240, and FL240 to the top of the atmosphere (TOA). Additionally, convective and super-cooled cloud fraction needs to be assessed.

Milestones with Summary of Accomplishments and Findings

The baseline CCL products successfully passed the Algorithm Readiness Review (ARR).
In collaboration with ASSISTT, the baseline CCL algorithm was implemented into the GOES-R algorithm test tool (ATT) environment. The output from the ATT was then compared to output generated offline as part of the ARR. Other than cloud layer fraction at a coarser resultion (10km for full disk and CONUS and 4km for mesoscale), bit structure was written to the cloud layer flag to indicate if cloud is detected at the pixel level for each flight layer. This allows users to generate their own CCL products other than those at the provided resolution. After the ARR, the code was delivered to PRO for eventual integration into the GOES-R Ground System.

For the ARR review, one full month of GOES-16 ABI data at hourly resolution were generated from both Framework and offline runs by Clavr-x. Matchups with CALIPSO/CALIOP were conducted to validate CCL products. Figure 75 shows an example of the total cloud fraction and layer cloud fraction between each FL, where layer 1 is the lowest and layer 5 correspond to the highest layer.

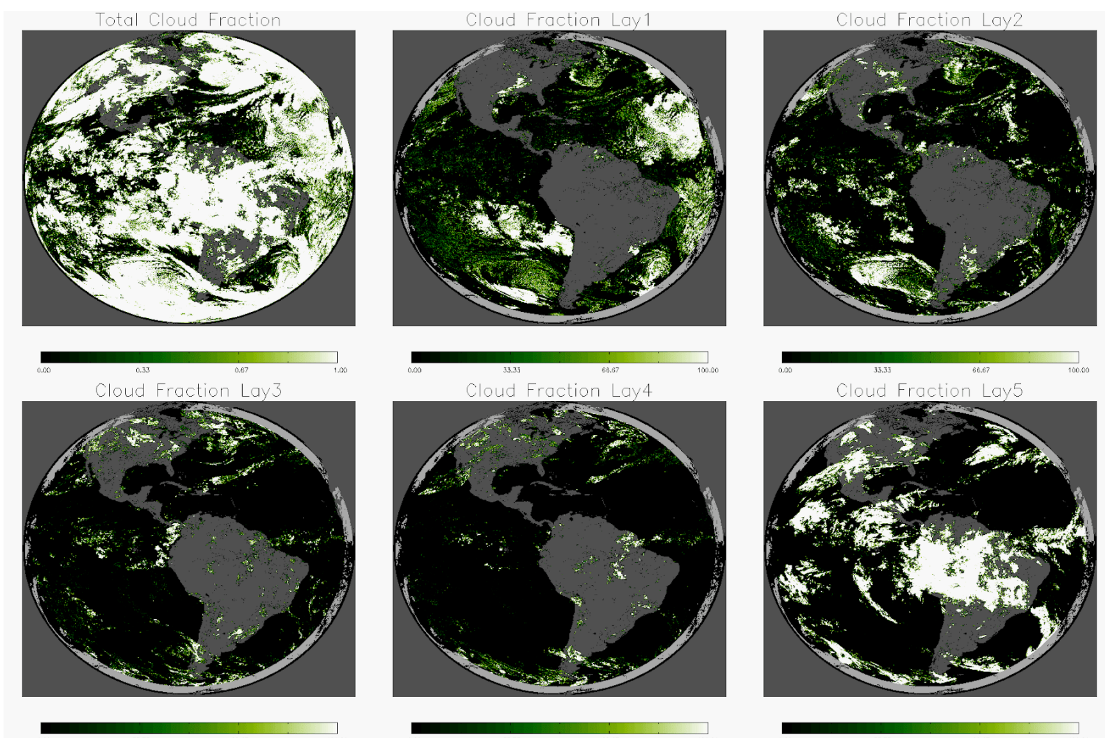


Figure 75. Total cloud fraction and cloud fraction and 5 layer cloud fractions at 0900UTC on 03/17/3018 from FRAMEWORK.

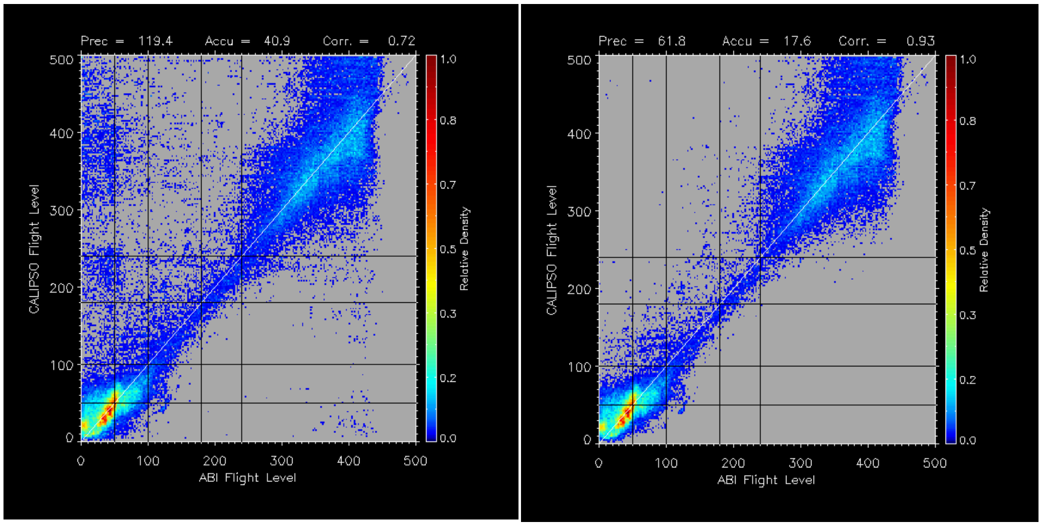


Figure 76. Scatterplots showing temporal and spatially matched CALIPSO/CALIOP and GOES-16 ABI data converted to FLs. The vertical and horizontal lines indicate the predefined FLs and points inside the rectangles along the diagonal line meet the specs requirement. Both original data (left) and with cloud phase matching (right) are shown.

Additionally, the offline codes in CLAVR-x were updated to more flexibly support cloud layer definitions, including both 5 flight levels and 3 pressure levels. Both cloud base height and lower level cloud height can be utilized to increase vertical cloud layer detection. The cloud team will continue to improve CCL products and deliver updates to the ASSISTT.

Publications and Conference Reports

Heidinger, A. K, and coauthors, 2019: Using Sounder Data to Improve Cirrus Cloud Height Estimation from Satellite Imagers. *J. Atmos. Ocean. Tech* (Accepted).

Li. Y., A. K. Heidinger, 2018: GOES-R AWG Cloud Cover Layer Algorithm Theoretical Basis Document, delivered to ASSISTT.

16. SSEC/CIMSS Cloud Research in Support of the SuomiNPP and JPSS Programs

16.1 Algorithm Maintenance/Development (Mask, Height, Base/CCL), CalVal, LTM
CIMSS Task Leader: William Straka III
CIMSS Support Scientists: Corey Calvert, Yue Li, Andi Walther, Pat Heck, Denis Botambekov, Steve Wanzong
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis
Budget: $97,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Project Overview

This project requires that cloud products are maintained to insure that they meet the requirements set in the JPSS L1RD. This includes retuning algorithms using a sufficient amount of data from the operational processing system (the SAPF), delivering updates of the science code as improvements are made, and delivering updated documentation to support NDE operations. In addition, supporting the JPSS EDR monitoring site, JPSS PG, CSPP, and participating in science and user interaction meetings is part of this task.

Milestones with Summary of Accomplishments and Findings

During this time period, the CIMSS Cloud team updated the cloud algorithms (Mask, Type, Height, Base and COMP) twice. As part of this process, the statistics from the algorithm were compared to the truth (ex. CALIOP) as well as to offline (CLAVR-x) processing system. In addition, the Cloud team performed the NOAA-20 beta and provisional reviews for all of the cloud algorithms. While some issues were found, they have been addressed and fixed.

Figure 77 shows the issue discovered during provisional of abnormally low cloud fraction in the cloud mask product at night.

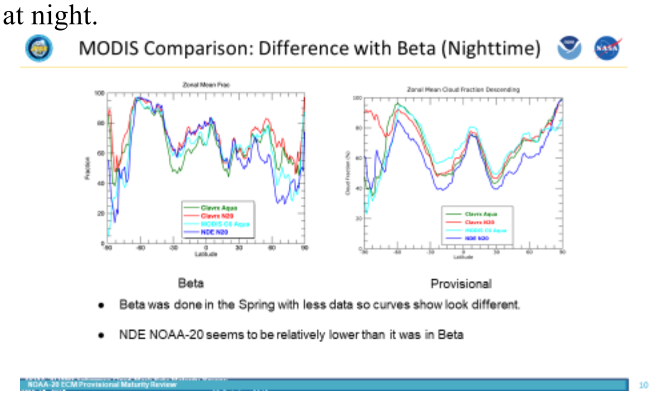


Figure 77. Comparison of the zonal cloud fraction of ECM verses MODIS, which is considered truth for the comparison, from the ECM Provisional review.

This was also seen in the analysis of the clear sky SST temperatures at night, as seen below.

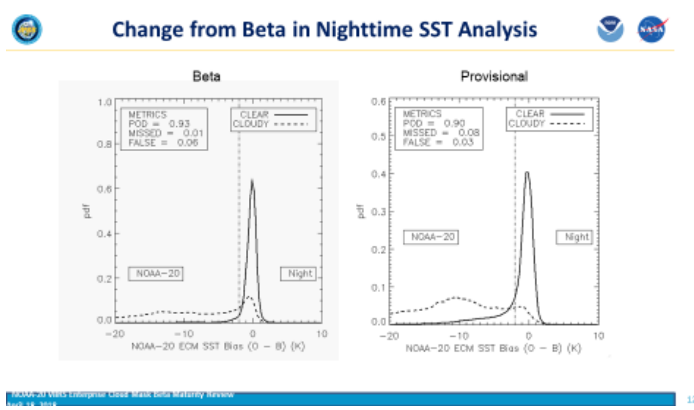


Figure 78. SST analysis from the ECM Provisional review.

This issue was suspected to be in the collocations, which caused several tests to not have proper thresholds. This was addressed and the corrected LUT was applied within NDE in early 2019. As can be seen in the analysis of the nighttime SSTs, the corrected LUT brings the metrics back to expected values.

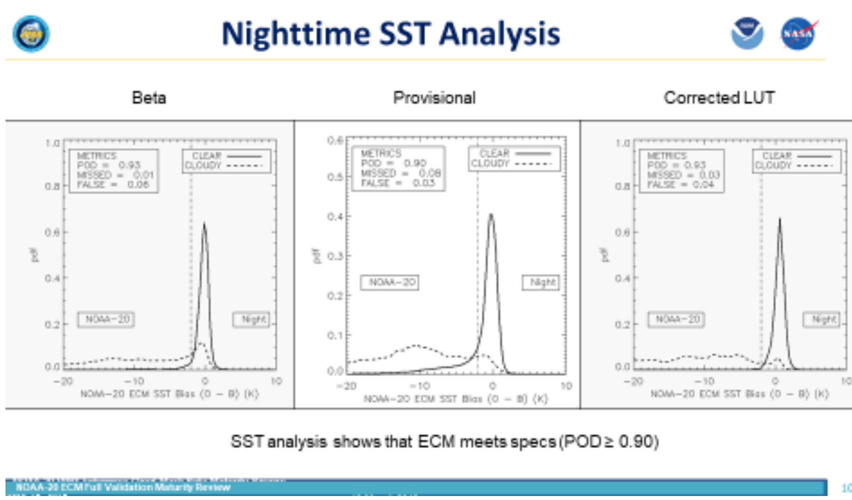


Figure 79. SST analysis from after the corrected LUT was applied in NDE.

As mentioned earlier, the other algorithms also went through provisional and beta reviews. Below shows an example from the ACHA provisional review, showing the consistency between ACHA and NASA MODIS over most latitudes. Over the high latitude regions, NASA MODIS cloud top retrievals are affected by over-detection of clouds by the cloud mask algorithm.

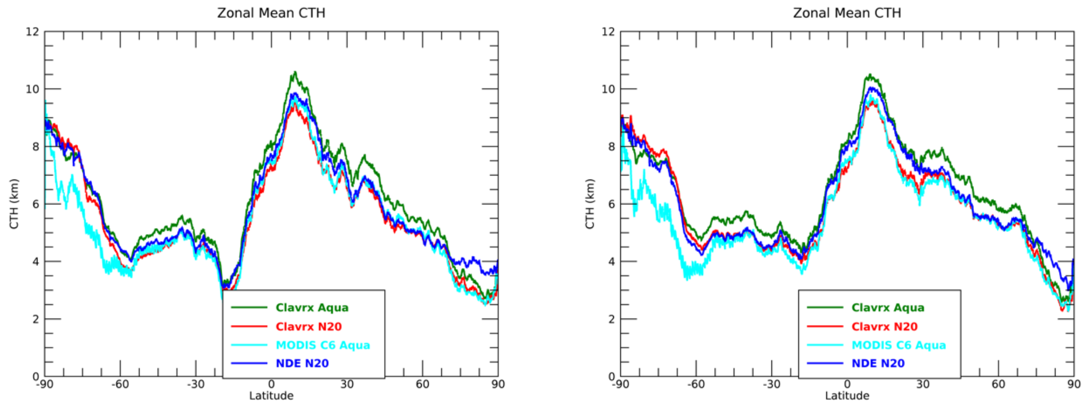


Figure 80. Comparison of the zonal mean cloud top height from the ACHA Provisional review.

A global view of cloud top height from a single day (3/12/2019) demonstrate excellent consistency between NOAA official data and offline runs from CLAVR-x. Additionally, across-sensor consistency between NOAA-20 and Suomi-NPP is observed.

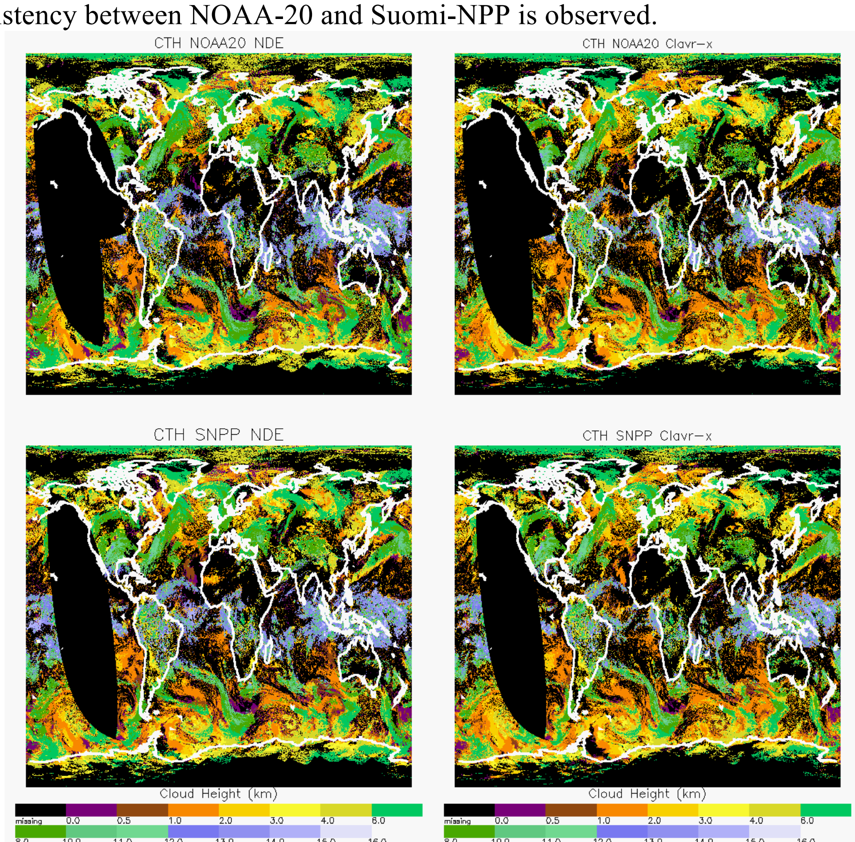
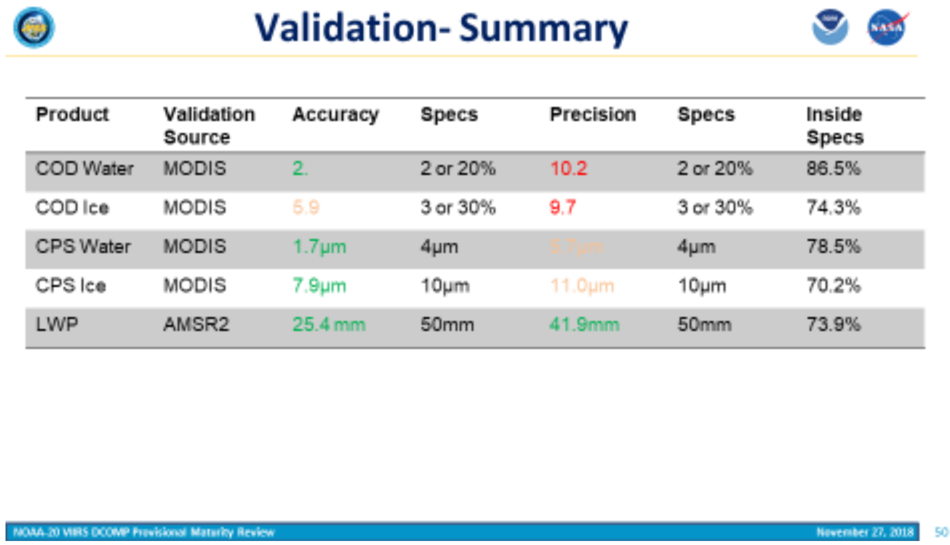


Figure 81. Global composite of the NOAA-20 and SNPP VIIRS Cloud Top Height from NDE and CLAVR-x showing the consistency between satellites and processing systems

And the summary from the DCOMP Provisional review which shows that DCOMP meets the specifications for provisional status. It is anticipated that each algorithm will be fully validated for NOAA-20 by the end of 2019. In addition, it is anticipated that there will be at least one delivery during 2019. NCOMP went through and passed its provisional review in late March 2019.



Product	Validation Source	Accuracy	Specs	Precision	Specs	Inside Specs
COD Water	MODIS	2.	2 or 20%	10.2	2 or 20%	86.5%
COD Ice	MODIS	5.9	3 or 30%	9.7	3 or 30%	74.3%
CPS Water	MODIS	1.7µm	4µm	5.7µm	4µm	78.5%
CPS Ice	MODIS	7.9µm	10µm	11.0µm	10µm	70.2%
LWP	AMSR2	25.4 mm	50mm	41.9mm	50mm	73.9%

Figure 82. Validation summary of DCOMP from the NOAA-20 DCOMP Provisional Review.

16.2 Software/Algorithm Integration and Testing
CIMSS Task Leader: William Straka III
CIMSS Support Scientist: Jay Hoffman
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis
Budget: $68,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
Maintaining and updating cloud algorithms for Suomi-NPP and JPSS.

Project Overview
The NOAA NDE algorithms (enterprise cloud algorithms) are integrated into the STAR Algorithm Processing Framework (SAPF), which is the NDE equivalent of the IDPS. The CIMSS Cloud team views the ability to run the SAPF locally as a critical part of their development and maintenance tasks. The development and maintenance of bridge code allows algorithm tests in both the local processing framework (CLAVR-x) as well as the operational processing framework

(SAPF). Being able to perform algorithm tests in multiple frameworks is a critical step in preserving product performance from research to operations.

Milestones with Summary of Accomplishments and Findings

The focus of the JPSS Cloud AWG this reporting period was maintaining and updating the various cloud algorithms, validating the updated algorithms for Suomi-NPP and JPSS. The tasks for this project were to develop and integrate updated algorithms in to the SAPF and evaluate their integration and their ongoing performance. Each year, the algorithm teams have two standard deliveries, one at the beginning, and the second in middle of each year. Part of the current years projects included ensuring the algorithms were able to run on NOAA-20 as well as updating LUTs and thresholds as quickly as possible. These updates were successfully delivered in the mid and late part of 2018, with an anticipated transition to operations by the end of 2018. During this time, the teams will be validating the algorithms as part of the verification for beta and provisional maturity of the algorithms.

The Cloud team maintains the ability to run the SAPF independently as a way to monitor the output from the operational processing system, to ensure the integrity of the integration of the cloud algorithms, as well as providing output in order to tune and maintain the algorithm. Monitoring is done by calculating some basic metrics (global cloud fraction, average cloud top temperature) on a daily basis and displaying them on a website available for the team (and others) to monitor trends in the data. This allows for the team to see any expected on unexpected changes in algorithm performance, allowing for the team to then diagnose and provide any mitigation efforts to issues that might arise. Figure 83 is a screenshot of the online tool developed by the cloud team for monitoring the cloud algorithms from both the operational and integration and test streams.

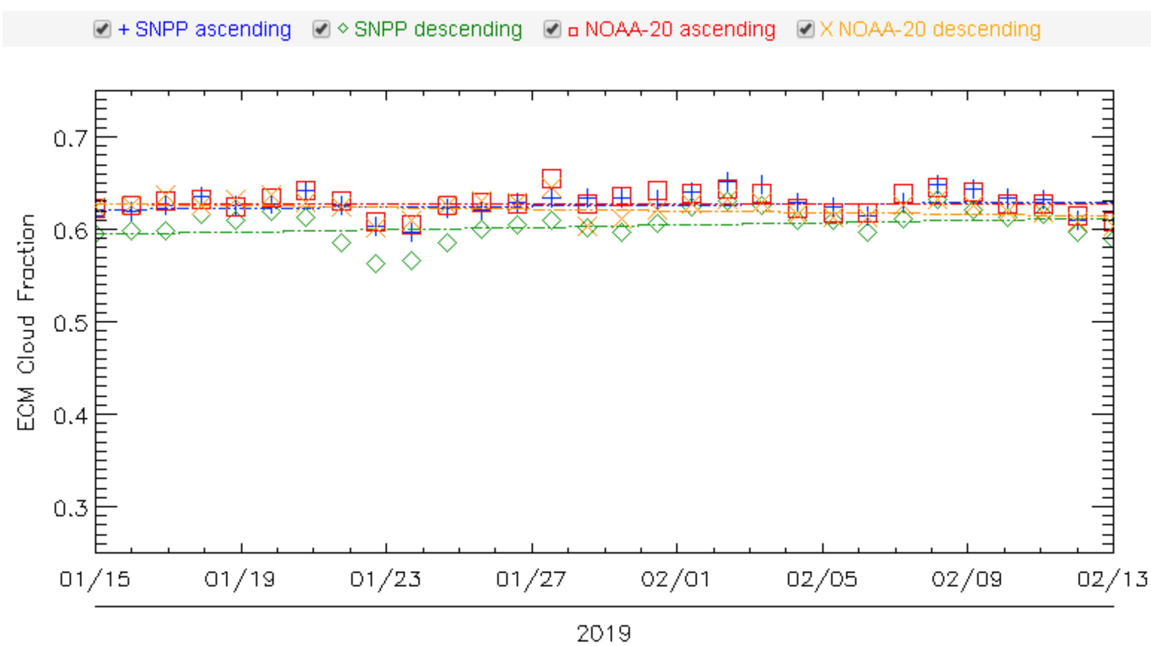


Figure 83. Daily cloud fraction over a month from SNPP and NOAA-20.

16.3 Cloud Phase Algorithm Maintenance
CIMSS Task Leader: Corey Calvert

CIMSS Support Scientists: William Straka and Jason Brunner
NOAA Collaborators: Andy Heidinger and Michael Pavolonis
Budget: $55,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective
To maintain and provide code updates for the NOAA-20 VIIRS Enterprise Cloud Top Phase algorithm.

Project Overview
The Enterprise Cloud Phase (ECP) algorithm was updated to support NOAA-20 VIIRS by modifying the GOES-R ABI cloud phase algorithm specific for VIIRS spectral channels. This was done to ensure that JPSS products benefited from the cutting-edge algorithm development conducted for GOES-R. Since the launch of NOAA-20 the ECP algorithm performance was improved by fine-tuning threshold functions and values used to differentiate between the cloud phase and different cloud types using on-orbit NOAA-20 VIIRS data. Working with the AIT teams (AIT-Midwest and AIT-East), the ECP algorithm has been integrated into the AIT framework and is currently in the review process proceeding towards full operational status.

Milestones with Summary of Accomplishments and Findings
The ECP algorithm has been in the NESDIS Data Exploitation (NDE) system since March of 2018 with additional code updates implemented in September of 2018. An example of the NOAA-20 cloud phase product, along with the GOES-16 cloud phase product, is shown in Figure 84.

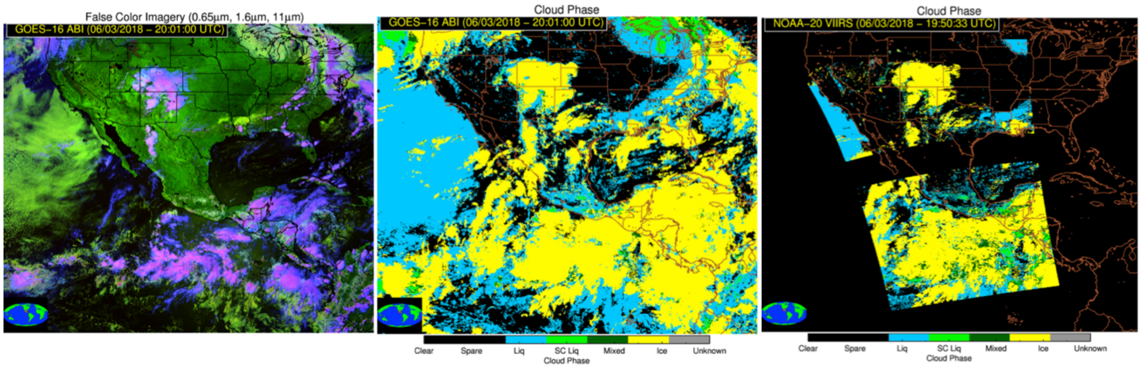


Figure 84. Cloud Top Phase example from June 3, 2018. The left image is a GOES-16 false color image at 20:00 UTC. The center image is the GOES-16 cloud top phase product at 20:00 UTC. The right image is the NOAA-20 cloud top phase product at 19:50 UTC.

The major effort during this reporting period was preparing for the NOAA-20 cloud top phase provisional maturity review. Table 2 contains the result of the provisional review conducted during this period.

Table 2. Cloud Top Phase operational review results.

Maturity Level	Date	Disposition
Provisional	10/2/2018	Passed

The algorithm requirement, specified by JERD-2491, is for 80% correct classification of cloud phase. Using the CALIOP cloud top phase product for validation, we determined the NOAA-20 cloud top phase product meets the accuracy specification. The results of this validation are shown in Figure 85.

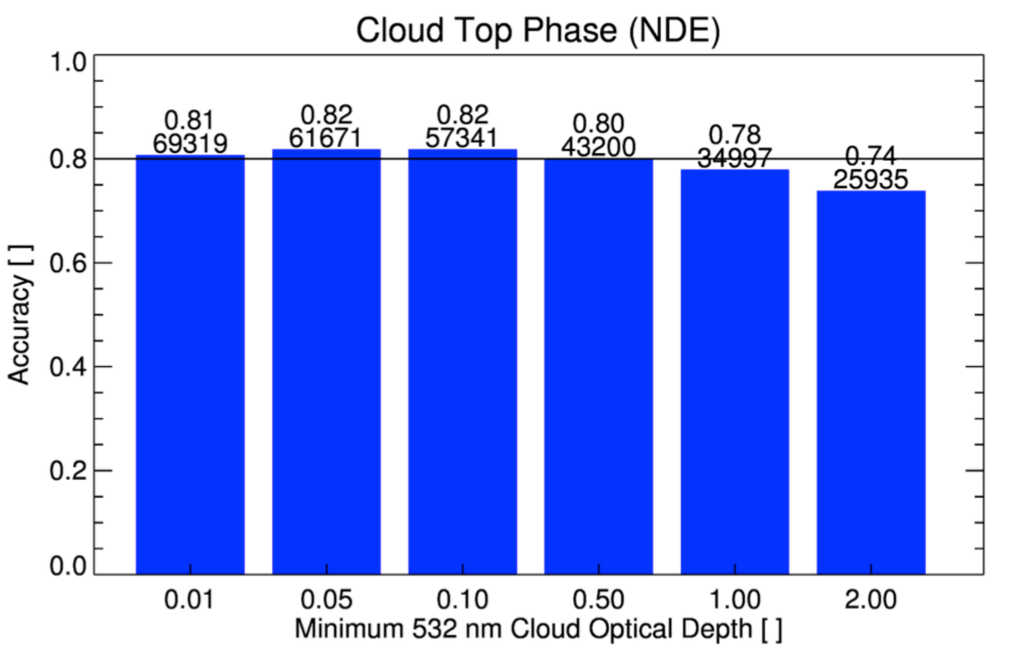


Figure 85. NOAA-20 Cloud Top Phase validation compared to the CALIOP cloud top phase product, as a function of cloud optical depth obtained from CALIOP. The horizontal black line represents the accuracy requirement defined by JERD-2491.

Overall the NOAA-20 cloud phase algorithm performs well and meets the accuracy specification, but classification of optically thick mid level clouds remains a challenge. Additional small situational performance issues were also discovered that may impact downstream user applications. These issues can be addressed by incorporating near-infrared measurements into the ECP algorithm; however, the use of near-infrared measurements is complicated by highly variable surface reflectance and sun geometry. Near-infrared channels are being incorporated into the enterprise cloud phase algorithm for GOES-R, so leveraging those efforts for NOAA-20 VIIRS is possible.

References

Pavolonis, Michael J., Andrew K. Heidinger, Taneil Uttal, 2005: Daytime Global Cloud Typing from AVHRR and VIIRS: Algorithm Description, Validation, and Comparisons. *J. Appl. Meteor.*, **44**, 804–826.

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures. Part I: Theory. *J. Applied Meteorology and Climatology*, **49**, 1992-2012.

16.4 JPSS Cloud EDR Support for Day and Nighttime Cloud Optical Properties

CIMSS Task Leader: Andi Walther
CIMSS Support Scientists: Pat Heck, William Straka III
NOAA Collaborators: Andrew Heidinger, Michael Pavolonis
Budget: $137,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Project Overview

This project requires that cloud optical property products for both Day and Night are maintained to insure that they meet the requirements set in the JPSS L1RD. This includes retuning algorithms using a sufficient amount of data from the operational processing system (the SAPF), delivering updates of the science code as improvements are made, and delivering updated documentation to support NDE operations. In addition, supporting the JPSS EDR monitoring site, JPSS PG, CSPP, and participating in science and user interaction meetings is part of this task.

Milestones with Summary of Accomplishments and Findings

During this time period, the CIMSS Cloud team updated the cloud optical property products algorithms for day and night were updated twice. As part of this process, the statistics from the algorithm were compared to the truth (ex. AMSR2) as well as to offline (CLAVR-x) processing system. In addition, the Cloud team performed the NOAA-20 beta and provisional reviews for all of the cloud algorithms. While some issues were found, they have been addressed and fixed.

Figure 86 shows a comparison of DCOMP LWP to AMSR2 from the DCOMP Provisional review, showing that the NOAA-20 product performs as expected.

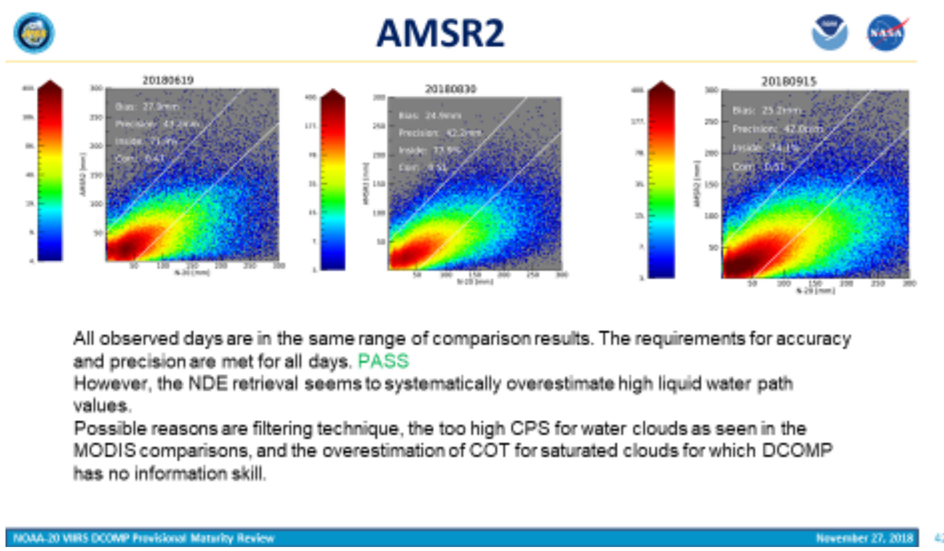
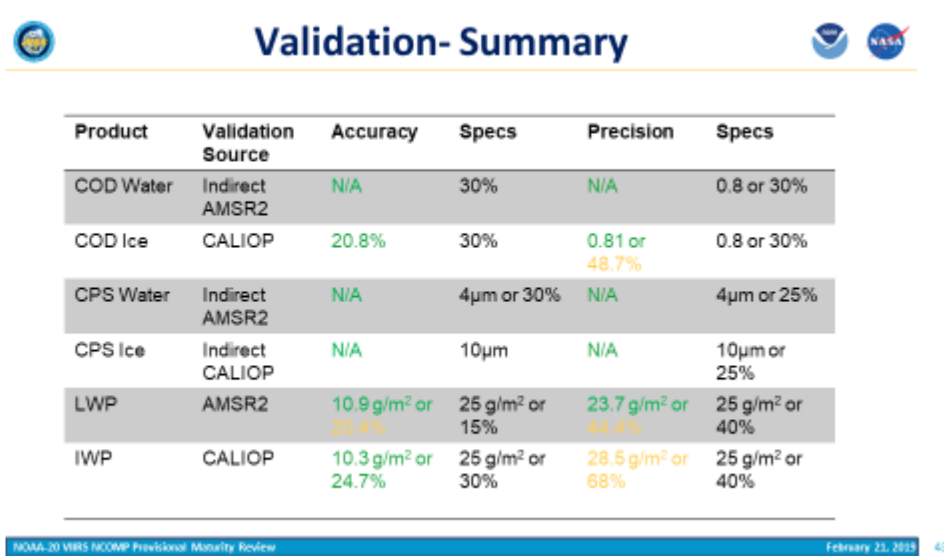


Figure 86. AMSR2 comparison of DCOMP from the NOAA-20 DCOMP Provisional Review.

This helps shows that DCOMP meets the specifications for provisional status. Work progresses on the nighttime visible optical property utilizing the lunar reflectance from the Day Night Band. It is anticipated that this algorithm will be able to be integrated into the NDE processing system within the next couple of years.

Due to an accelerated validation schedule, NCOMP, which is an infrared based nighttime optical property algorithm, held its beta and provisional review in late March 2019. Figure 87 shows the validation summary of NCOMP.


Validation- Summary

Product	Validation Source	Accuracy	Specs	Precision	Specs
COD Water	Indirect AMSR2	N/A	30%	N/A	0.8 or 30%
COD Ice	CALIOP	20.8%	30%	0.81 or 48.7%	0.8 or 30%
CPS Water	Indirect AMSR2	N/A	4μm or 30%	N/A	4μm or 25%
CPS Ice	Indirect CALIOP	N/A	10μm	N/A	10μm or 25%
LWP	AMSR2	10.9 g/m² or 20.4%	25 g/m² or 15%	23.7 g/m² or 44.4%	25 g/m² or 40%
IWP	CALIOP	10.3 g/m² or 24.7%	25 g/m² or 30%	28.5 g/m² or 68%	25 g/m² or 40%

NOAA-20 VIIRS NCOMP Provisional Maturity Review February 21, 2019 43

Figure 87. Validation summary from the NOAA-20 NCOMP Provisional Review.

Like for DCOMP, nighttime LWP results were compared to AMSR-2. The accuracy and precision specifications were met. NCOMP Cloud Optical Depth was also compared to CALIOP for thin ice clouds favorable results. Similarly, NCOMP Cloud Particle Size was compared to CALIOP-derived CPS and results were as expected. Algorithm updates that will further improve performance include usage of a neural net technique to expand the range of COD retrieved for ice clouds and exploration of the usage of a two-habit model for ice cloud emittance parameterizations.

Both algorithms, DCOMP and NCOMP, both passed their Provisional reviews. This means that data is now available to users to use and evaluate. It is anticipated that each algorithm will be fully validated for NOAA-20 by the end of 2019. In addition, it is anticipated that there will be at least one delivery during 2019. NCOMP went through and passed its provisional review in late March 2019.

Publications and Conference Reports

Andi Walther has presented results from JPSS cloud retrievals during the EUMETSAT conference in Tallin, Estonia in September 2018.

16.5 McIDAS Support for VIIRS Imagery and Data Analysis

Task Leaders Tommy Jasmin, Dave Santek
NOAA Collaborator: Don Hillger (RAMMB/CIRA)

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective

To support visualization and analysis of Suomi NPP and JPSS data in McIDAS-V.

Project Overview

Since prior to the launch of Suomi NPP, SSEC/CIMSS has been developing support for the VIIRS, CrIS, and ATMS instruments in McIDAS-V, and for VIIRS in ADDE. Through the dual approach of 1) providing flexible data access via ADDE servers, and 2) developing a user interface in McIDAS-V which allows aggregation of multiple consecutive data granules into a single data selection, we have greatly improved ease of use to these data. The goal of this project is to expand and improve this functionality in support of the VIIRS Imagery Team based at CIRA. These improvements are freely available and benefit the broader atmospheric and Earth science communities.

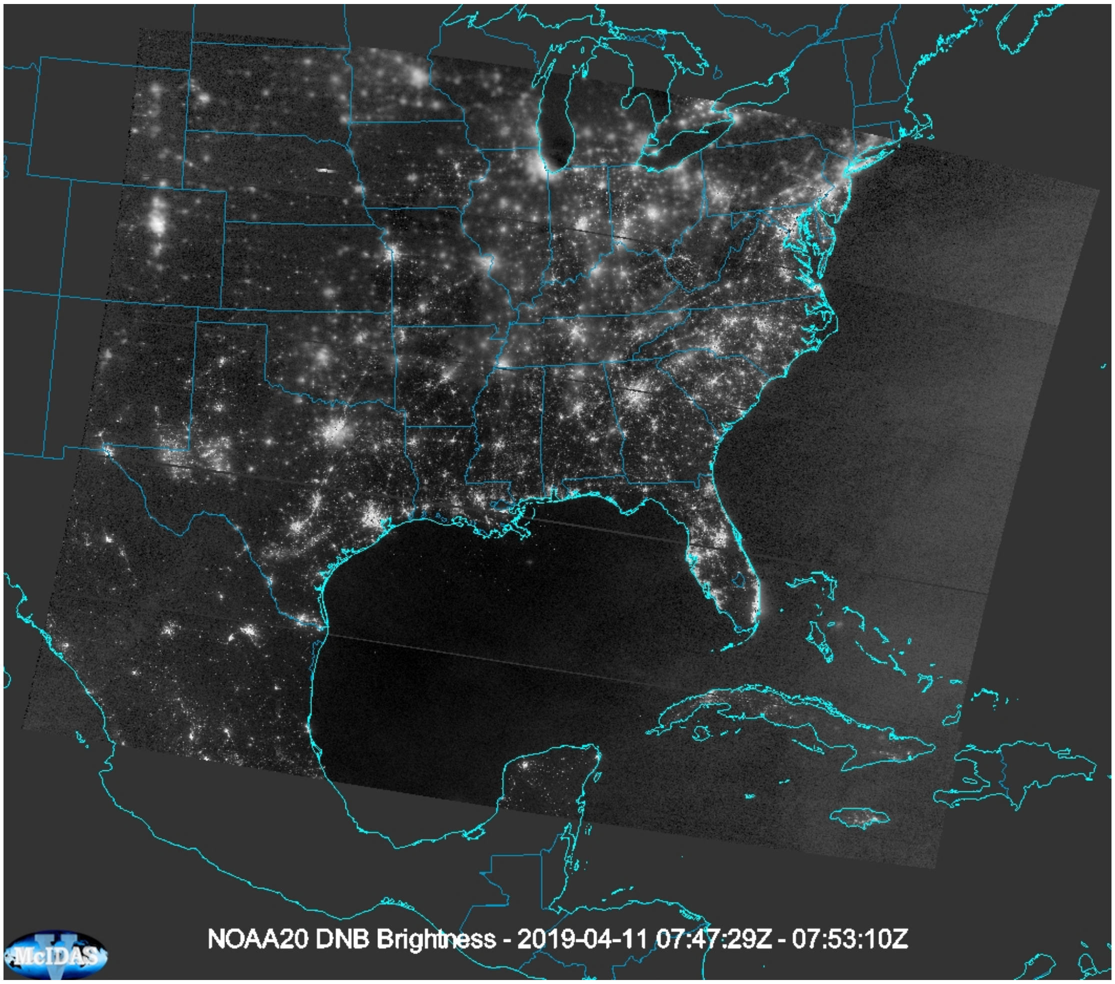


Figure 88. A NOAA-20 VIIRS DNB image, served via ADDE.

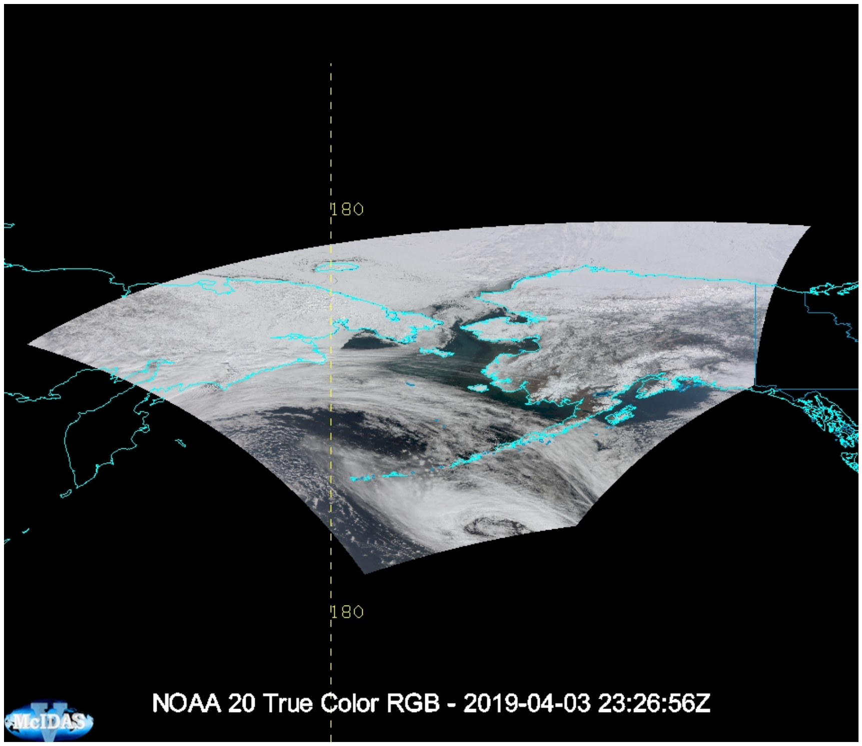


Figure 89. NOAA-20 VIIRS RGB image, rendered seamlessly over the dateline.

Milestones with Summary of Accomplishments and Findings

During 2018, we expanded the ADDE server capabilities to process data from both NOAA's HDF-5 format and NASA's NetCDF-4 format. We also expanded the ADDE servers to support Environmental Data Records (EDRs) and the Day/Night Band (DNB).

Most of the remaining issues with the McIDAS-V JPSS Chooser were resolved utilizing NOAA-20 VIIRS SDR and EDR data. Users can now visualize JPSS data crossing the 180-degree longitude line, and probe data values on either side. Users can also now leverage McIDAS-V JPSS capabilities to create data products entirely in the background, via Jython scripts. The primary VIIRS-related McIDAS-V goals for 2019 will be to resolve any remaining tasks deemed necessary in order to promote this chooser from Under Development to Stable Supported. At this time the primary remaining issue preventing promotion is the 1st task outlined in the Additional Planned Development section following.

Additional Planned Development for 2019

- *Improve data selection user interface for swath data*
  At present, it is very difficult to select an entire data granule or aggregation of data granules, and there is no option to specify a sample/stride for data. We will attempt to add these capabilities in 2019.
- *Expand I/O conversion options.*
  At present, users can load Suomi NPP data and write KMZ (which can be loaded, for example, in Google Earth). Users have expressed interest in being able to write Satellite-CF compliant NetCDF files, and GeoTIFF files. As standards for satellite data are now emerging, swath data can be gridded and output using the current CF standards.
- *Evaluate further ADDE server functionality needs*
  We will discuss with CIRA whether the current McIDAS ADDE servers are meeting their

needs, or if further enhancements/changes are desired. If further development is needed we make it a priority to complete these in 2019.

- *Resolve open JPSS McIDAS-V Inquiries*
  There are a variety of smaller reported problems that, while not serious enough to prevent promotion of the chooser from Under Development, are nonetheless issues which should be addressed. The web inquiry system can be queried to view a prioritized list of these issues. We will address as many of these as budget allows once the higher priority tasks are complete.

17. SSEC/CIMSS Research Tasks in Support of the SuomiNPP and Joint Polar Satellite System (JPSS) Sensor Data Records 2018-2019

17.1 A Broad Scope of Calibration/Validation and Independent Verification and Validation Activities in Support of JPSS, with Emphasis on CrIS SDRs

CIMSS Task Leader: David Tobin
CIMSS Support Scientists: Hank Revercomb, Robert Knuteson, Joe Taylor, Daniel DeSlover, Lori Borg, Michelle Feltz
NOAA Collaborator: Flavio Iturbide-Sanchez (STAR)
Budget: $406,324

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
One objective of this project has been to provide the algorithm description, software, and sample data for the operational CrIS SDR algorithm to include Scene Mirror Induced Polarization correction module, which will improve the accuracy and consistency (across detectors, wavelength, and scan angle) of the data,

Project Overview
For the past period of performance, efforts of this project have focused on following main areas:
1) Support of CrIS SDR related reviews and meetings
2) Continued Cal/Val analyses of the Suomi-NPP and NOAA-20 CrIS data
3) CrIS SDR algorithm assessment and refinement
4) Preparation for the JPSS-2 TVAC and SC level testing
5) Enable the use of CrIS SDRs for atmospheric soundings and data assimilation applications

Milestones with Summary of Accomplishments and Findings

Progress for this project has been provided in quarterly progress reports. Major efforts/milestones include:

- As part of efforts to attain Validated Maturity status for the NOAA-20 CrIS SDRs, various aspects of the radiometric calibrated were investigated and material provided regarding the Radiometric Nonlinearity, Polarization, Predicted ICT radiance, Radiometric Uncertainty, Radiometric Stability, and Cal/Val assessments. A major part of this work was to provide the a2 nonlinearity coefficients that were uploaded as part of Engineering Packet versions 114 and 115.
- Knowledge of the FOV dependence and spectral correlation of the CrIS noise is important for the use CrIS spectra. To help with this issue, we have produced and provided NEDN and noise covariance estimates for unapodized and Hamming apodized data, which characterizes the FOV dependence of the noise and the spectral correlations introduced by the spectral self-apodization corrections and by the Hamming apodization.
- A correction module/algorithm for scene mirror induced polarization effects has been developed and tested. Most recently we have provided two days of SDR and corresponding BUFR data with and without the corrections applied for both SNPP and NOAA-20, and are currently providing three months of the same data. These large datasets are being provided for EDR and Data Assimilation assessments before the algorithm is turned on within the operational IDPS processing.
- SNO-based comparisons of SNPP CrIS and NOAA-20 CrIS have been produced and investigated and in general show very good agreement between the two datasets/sensors. Analysis shows that small changes to the SNPP CrIS calibration can bring it into better agreement with NOAA-20 CrIS. This includes a small change to the LW a2 nonlinearity coefficients values and a change to the modeled component of the SNPP SSM baffle temperature. This is shown in Figure 90.
- Software was developed to produce CrIS noise (NEDN) estimates from TVAC and SC level data, and noise estimates for various NOAA-20 TVAC plateaus have been provided to STAR.
- Analysis was performed to show the responsivity degradation of NOAA-20 CrIS as compared to the degradation of SNPP CrIS.
- Using new cross-talk specification values for JPSS-2 CrIS, which has been found to have high levels of cross-talk due to the wiring of the read-out cables and is now being re-worked to have new flex cables resulting in lower cross-talk, the impact of the cross-talk on Earth view spectra was investigated by applying the effect to in-orbit data. This is shown in Figure 91. Depending on the final cross-talk performance of JPSS-2 CrIS, we can use this same simulation methodology to perform corrections on the spectra to reduce the cross-talk effects to negligible levels.
- The potential artifacts of interferometer double-pass on the CrIS calibration have been diagnosed, and in particular we have investigated if it can help explain the FOV5 artifact. Double pass effects by themselves do no cause an artifact but more subtle second order artifacts may have some effect and this is still under investigation.

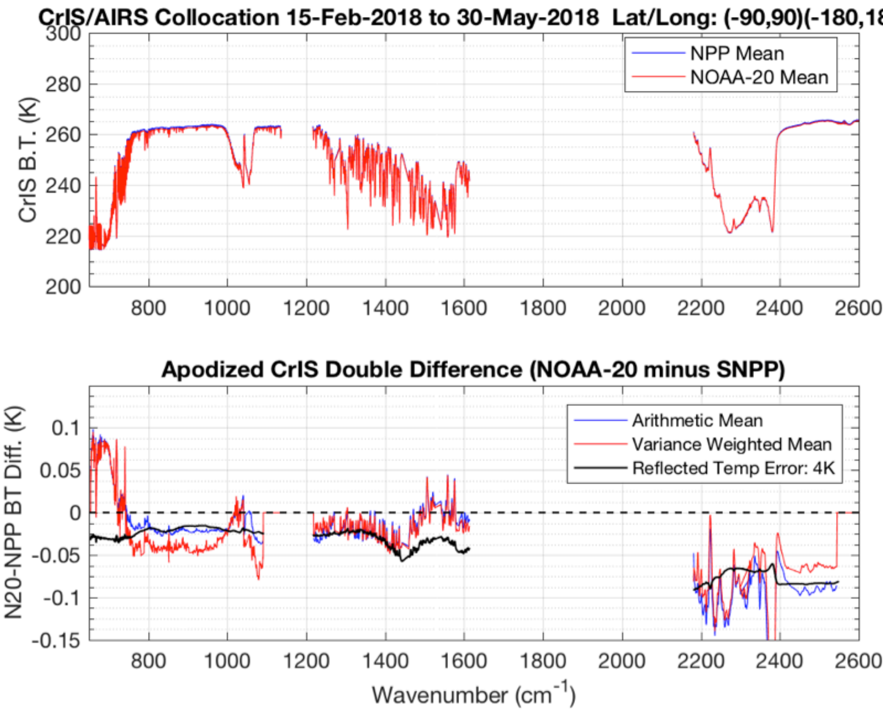


Figure 90. NOAA-20 CrIS minus SNPP CrIS differences (using CrIS/AIRS SNOs), along with the SNPP CrIS calibration difference due to a 4K error in the ICT environmental model reflected temperature. The differences are less than 0.1K, and the remaining differences can be removed with small refinements to the SNPP calibration coefficients.

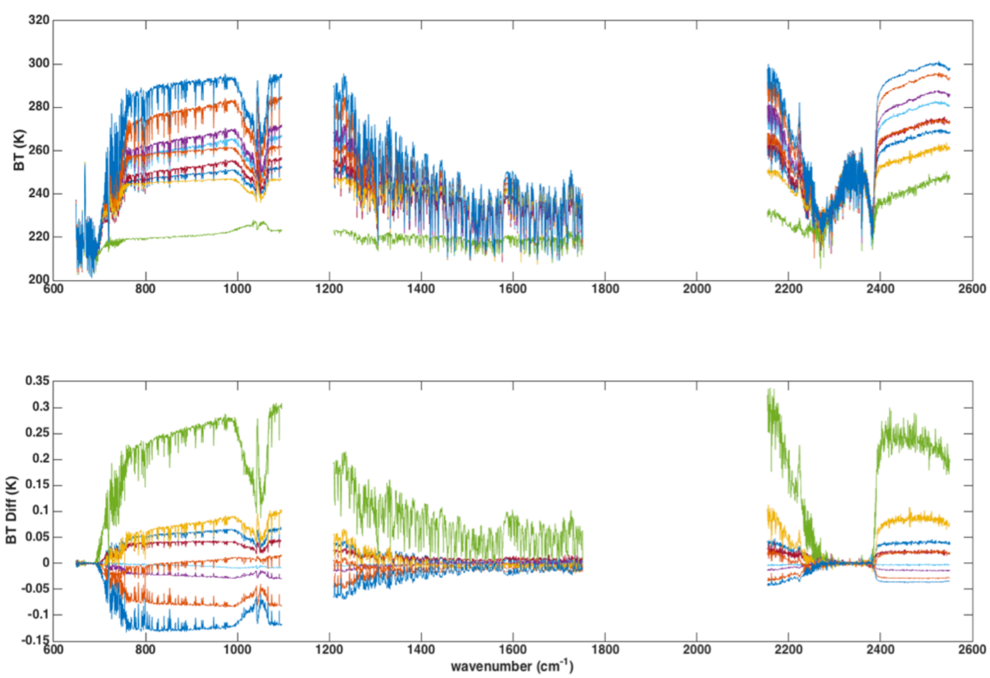


Figure 91. Simulated spectra (top panel) and electrical cross-talk errors (bottom panel) for JPSS-2 CrIS using the new cross-talk specifications. These are worst-case examples from high contrast Field-of-Regards from one orbit of simulated data.

17.2 VIIRS SDR Calibration/Validation
CIMSS Task Leader: Chris Moeller
CIMSS Support Scientist: Jun Li
NOAA Collaborator: Changyong Cao
Budget: $160,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

PART 1

Objective
Establish and maintain instrument performance for all VIIRS sensors, utilizing pre-launch test characterization with on-orbit evaluation to optimize accuracy and precision of the SDR product.

Project Overview
This task includes the subtasks described below.

SNPP and NOAA-20 VIIRS On-Orbit SDR Performance Evaluation
This subtask supports the ongoing application of VIIRS Cal/Val task tools at UW for SDR performance monitoring and review, including VIIRS and CrIS matchups to identify VIIRS SDR bias trends and dependence on scene temperature and scan angle. This subtask contributes to investigations of known and revealed on-orbit performance issues and adjustments to the SDR calibration algorithm.

JPSS-2 VIIRS Pre-launch Performance Characterization
Participation in the JPSS-2 VIIRS pre-launch test program is separately funded under the Flight Project; however pre-launch test data analysis supporting the launch readiness and the post-launch JPSS-2 SDR product performance is partially supported under this subtask

Support STAR and SDR Team Meetings and Activities
UW is continuing participation on the VIIRS SDR Team, providing analyses on VIIRS SDR performance and participating in the review of all VIIRS performance issues.

Milestones with Summary of Accomplishments and Findings

SNPP and NOAA-20 VIIRS On-Orbit SDR Performance Evaluation

- Daily SNPP VIIRS-CrIS radiance comparisons over the SNPP mission lifetime continue to reveal excellent calibration performance for TEB bands M13, M15, M16 and I5 with globally averaged differences within about +/- 0.1 K for typical scenes and trending < 5 mK/year in all bands. A little over a year of trending data for N-20 also shows minimal trending. The scene temperature dependence in N-20 VIIRS-CrIS comparisons shows modest dependence in M15 and M16 (Figure 92); however, for algorithms using both bands together (e.g. SST KPP), the scene temperature dependence will largely cancel. SNPP VIIRS shows similar behavior but with less scene temperature dependence.
- A temperature and scan angle dependence in NOAA-20 VIIRS bands M15 and I5 has been investigated. The dependence is revealed in NOAA-20 VIIRS-CrIS comparisons but is not found in SNPP VIIRS-CrIS comparisons (Figure 93). In subsequent investigation by the VIIRS SDR team, this dependence appears to be related to a 2 degree angle of incidence (AOI) offset in NOAA-20 VIIRS SDR processing. The correction of this behavior will also correct anticipated similar behavior in band M14, which has the largest response versus scan sensitivity of all TEB (M14 cannot be assessed by VIIRS-CrIS comparisons because CrIS doesn't have spectral coverage of the M14 spectral region). Relationships between the AOI offset and the VIIRS-CrIS scene temperature dependence seen in Figure 92 are also likely.
- 90 day composite SNPP VIIRS – MetOpA IASI SNOs confirm trending behavior found in SNPP VIIRS-CrIS comparisons. The VIIRS-IASI comparisons expand the spectral coverage to M12 and M14; these bands are in-family on trending with M13, M15, and M16 indicating that the VIIRS radiometric trending does not contain any meaningful relative spectral bias from band to band. The 7 year ensemble VIIRS-IASI comparisons show less scene temperature dependence for LWIR bands M14-M16 than do the VIIRS-CrIS comparisons. Also, for bands M12 and M13, a more pronounced cold scene bias is present in VIIRS-IASI differences. These behaviors continue to be a point of investigation and suggest that CrIS and IASI may be performing with small radiometric differences, especially for cold scenes. These differences are generally small (~0.1 K) indicating that SNPP VIIRS radiometric performance continues to be exemplary.
- An evaluation of NOAA-20 VIIRS M13 detector striping reveals a similar pattern to that of SNPP VIIRS M13. The evaluation, using VIIRS-CrIS comparisons shows that odd numbered detectors (product order numbering) have a warm bias of 150 – 200 mK compared to even numbered detectors. Using a forward model with a standard Tropical atmosphere shows that odd numbered detectors can be expected to show a warm bias of about 70 mK based solely upon the NOAA-20 M13 spectral performance characterization (caused by the presence of strong CO_2 atmospheric absorption in the wing of the M13 RSR). That explains a portion but not a majority of the warm bias; however, imperfections in the spectral characterization largely due to the influence of CO_2 absorption on the spectral measurements may also be masking response that could further explain the odd numbered detector warm bias. Of interest, if the model assessment is correct, the detector striping in JPSS-2 M13 should be smaller due to a shift of the RSR to shorter wavelengths (further away from the CO_2 absorption region).

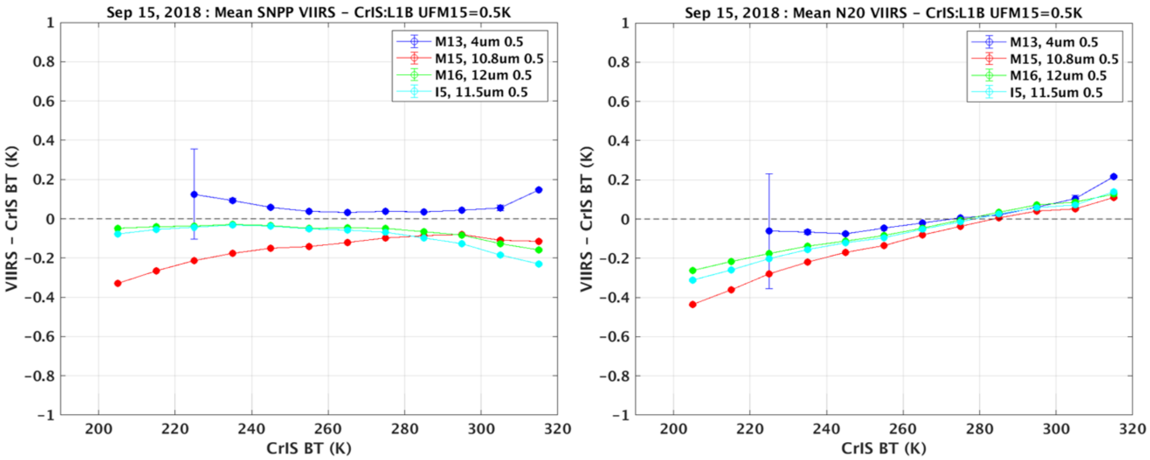


Figure 92. VIIRS-CrIS difference as a function of scene temperature for SNPP (left) and NOAA-20 (right).

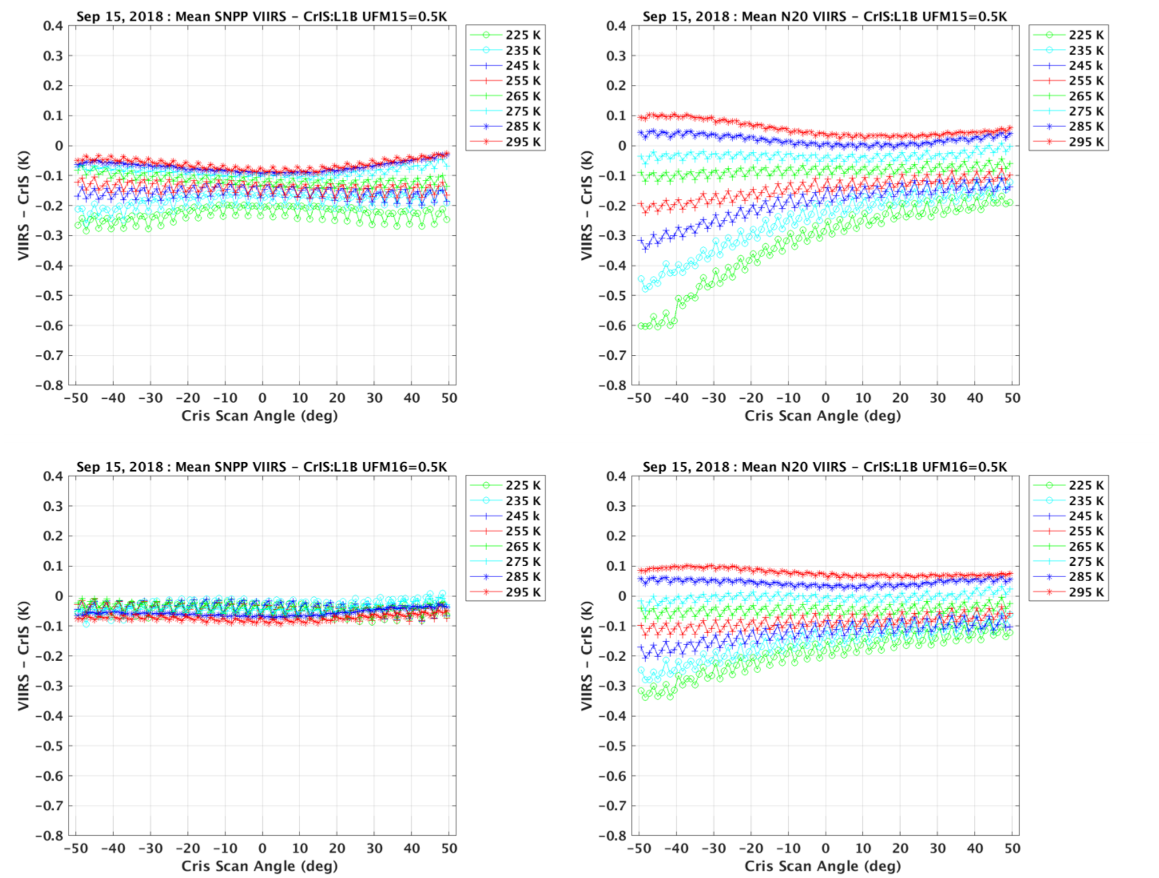


Figure 93. VIIRS-CrIS comparisons as a combined function of scan angle and scene temperature for SNPP (left) and NOAA-20 (right).

JPSS-2 VIIRS Pre-launch Performance Characterization

The JPSS-2 VIIRS V1 relative spectral response release was made in this period of performance. While the effort to generate the data analysis and V1 release is supported under separate funding, the release enables early evaluation of JPSS-2 VIIRS SDR and EDR algorithms by the VIIRS community to anticipate performance changes from SNPP and NOAA-20 VIIRS to JPSS-2

VIIRS. Due primarily to the acquisition of new bandpass filters, modest differences exist in the spectral characterization between JPSS-2 VIIRS and previous VIIRS sensors on SNPP and NOAA-20. The release, along with documentation, has been made available to the EAR99 compliant community via the restricted access NASA eRooms site.

Publications and Conference Reports

Chris Moeller attended the 2018 STAR JPSS Annual Conference remotely and gave a presentation titled "Insight on VIIRS TEB Performance from VIIRS-CrIS Comparisons" at the VIIRS RVS splinter session.

PART 2

Objective

The objective is to understand the impact of CrIS sub-pixel clouds, local zenith angle, and surface types on the inter-comparison between VIIRS and CrIS, and to use CrIS based DCC for monitoring the calibration performance of VIIRS RSBs.

Project Overview

The CrIS and VIIRS instruments fly together on the SNPP and NOAA-20 platform enabling a sample of collocation matchups that cover all times, all weather, and over all surface types. This provides an opportunity for comprehensive inter-comparisons. Previous work has pointed out the advantages of using CrIS to assess VIIRS calibration [Moeller et al., 2013; Wang et al., 2016; Gong et al. 2018]. However, an understanding of how CrIS sub-pixel cloud, surface type and local zenith angle impact the differences between CrIS and VIIRS is needed. In addition, during the unsteady state of quarterly warm up/cool down (WUCD) exercises, the performances of thermal emissive bands (TEBs) [Madhavan et al., 2016; Li et al., 2016; Wang et al., 2016] and effects of correction algorithms [Choi et al., 2016; Cao et al., 2017] need further assessments. Methodologies and tools are needed to process and stratify CrIS and VIIRS matchups to understand the impact of cloudiness and surface types on the VIIRS/CrIS differences.

IDPS VIIRS SDR processing for RSB relies on a solar diffuser based calibration; any unaccounted degradation in the solar diffuser degrades the SDR product accuracy. Unaccounted degradation has been suggested by Lunar observations, especially for bands M1-M4 which impact the ocean color, cloud and aerosol products. To address these issues, there is need to improve the RSB calibration stability using complimentary approaches: Lunar calibration and deep convective clouds (DCC). A preliminary study using DCC has been done by Wang and Cao (2016). However, it was based on monthly/semi-monthly statistics. Weekly statistics are desirable, using better screening with collocated hyperspectral CrIS to support higher quality DCC calibration to enable 0.1% RSB stability.

Milestones with Summary of Accomplishments and Findings

The SSEC near real-time (NRT) VIIRS SRB monitoring using CrIS based DCC technique is online for both SNPP and NOAA-20

The SSEC online monitoring tool is complementary to STAR monitoring, the following link contains the detailed information on near real-time monitoring of SRBs using DCC: www.ssec.wisc.edu/dcc

The SSEC DCC identification is based on the CrIS brightness temperature difference (BTD) between a water vapor absorption channel and an IR window channel to its measurement noise ratio (BTD to noise, or BNR). This DCC is used for monitoring all VIIRS RSB (M01-M11 and I01-I03, M06 is excluded due to saturation over DCC). The angular distribution models (ADMs) are applied to correct the anisotropy effect in the TOA reflectance. This website shows the time series of daily and weekly reflectance of DCCs, along with the mean and mode, their Standard Deviations (STDs and ranges (maximum-minimum). This includes SNPP since 2017/1, NOAA-20 since 2018/2, and most recent one year side by side show for both SNPP and NOAA-20.

Figure 94 shows the daily and weekly time series monitoring for SNPP VIIRS M01, same can be seen for NOAA20 from the webpage. All the SRBs are included in the monitoring tool.

One manuscript is published in JGR-Atmospheres and another manuscript is submitted to JGR-Atmospheres

One manuscript titled "Intercomparison between VIIRS and CrIS by taking into account the CrIS subpixel cloudiness and viewing geometry" is published in Journal of Geophysical Research – Atmospheres. In this manuscript, it is found that CrIS subpixel cloudiness, viewing geometry, and surface types have a weak impact on VIIRS and CrIS radiance differences. This analysis is useful for VIIRS calibration accuracy assessment and product improvement (e.g., SST), and the methodologies and tools developed can be applied to process/reprocess data from imagers and sounders onboard the same satellite.

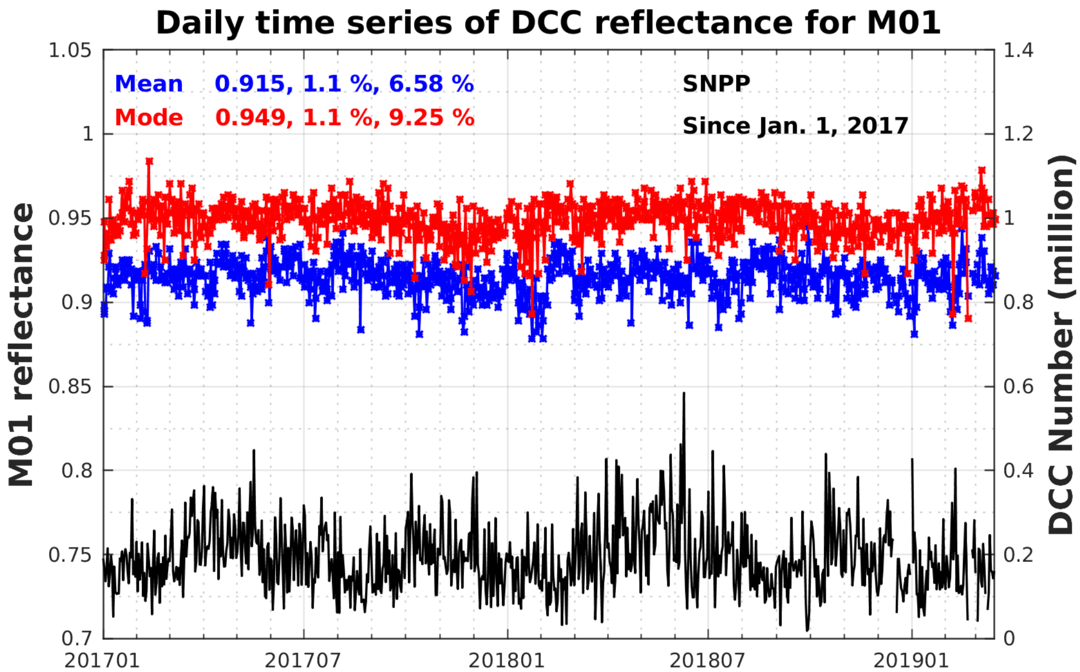
Another manuscript "Monitoring the VIIRS SDR reflective solar band calibrations using DCC with collocated CrIS measurements" was submitted to Journal of Geophysical Research – Atmospheres, and this manuscript is still currently under review, the reviewers' comments are expected in next couple of weeks. In this manuscript, a method of combining CrIS brightness temperature difference to its measurement noise ratio for VIIRS DCC identification is introduced. The methodologies and technical approaches of monitoring VIIRS RSB calibrations using DCC with collocated CrIS measurements are developed and can also be applied to other imagers with collocated advanced infrared sounders to monitor the calibration stabilities of RSBs.

In addition, CIMSS scientists collaborated with STAR scientists (Changyong Cao and Wenhui Wang) on verifying the impact from VIIRS SDR bias correction techniques (Wang et al. 2018).

Publications and Conference Reports

Wang, W., C. Cao, A. Ignatov, X. Liang, Z. Li, L. Wang, B. Zhang, S. Blonski, and Jun Li, 2018: Improving the calibration of Suomi NPP VIIRS thermal emissive bands during blackbody warm-up/cool-down, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2018.2870328.

Gong X., Z. Li, Jun Li, C. Moeller, C. Cao, W. Wang, and W. P. Menzel, 2018: Inter-comparison between VIIRS and CrIS by taking into account the CrIS sub-pixel cloudiness and viewing geometry, Journal of Geophysical Research - Atmospheres, 123 (10), 5335 - 5345.



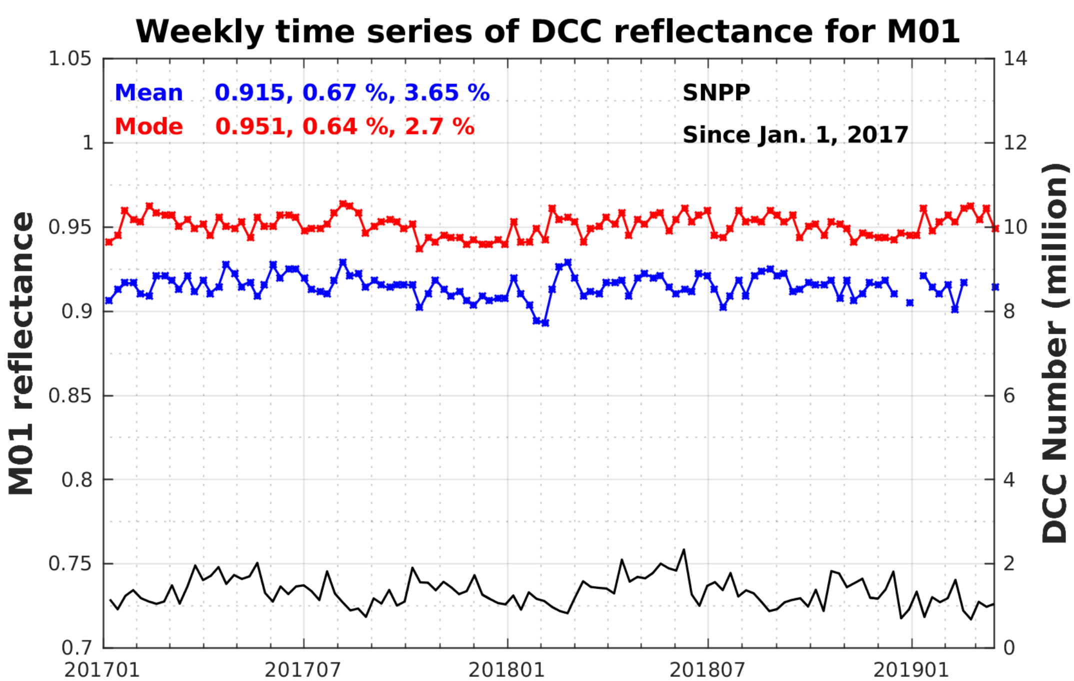


Figure 94. The daily (upper) and weekly (lower) time series monitoring for SNPP VIIRS M01 (from http://www.ssec.wisc.edu/dcc).

18. SSEC/CIMSS Research Tasks in Support of Suomi NPP and the Joint Polar Satellite System (JPSS) Sounding and Cryosphere Environmental Data Records (EDR)

18.1 CrIMSS EDR Cal/Val: ARM Site Support 2018

CIMSS Task Leader: Lori Borg
CIMSS Support Scientist: David Tobin
NOAA Collaborators: Tony Reale, Nicholas Nalli, Lihang Zhou
Budget: $73,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
Coordinate radiosonde launches at the Atmospheric Radiation Measurement (ARM) sites at Eastern North Atlantic (ENA), North Slope Alaska (NSA), & Southern Great Plains (SGP) coincident with NOAA20 overpasses for use in the validation of atmospheric temperature and water vapor retrieved profiles.

Project Overview
Given the high accuracy retrieval goals for the NOAA20 temperature and water vapor profiles, careful and detailed validation using accurate and on-going validation data is required. The ARM program field sites provide such data. In this collaborative effort, radiosondes have been launched coincident with the NOAA20 satellite overpasses of the ARM sites located at ENA, NSA, and SGP. Combined with other ARM data, this validation data set is a well-characterized ensemble of temperature and water vapor profiles, which is essential for assessing the satellite products. Similar collaborative efforts were undertaken for AIRS, IASI, and SNPP and were fundamental, integral, and cost-effective components of the validation effort and provided critical accuracy assessments of the temperature and water vapor soundings. It is anticipated that this effort will be repeated throughout the NOAA20 mission life and will provide data critical for the validation of NOAA20. Further science justification and details of the approach for this effort are described in detail in Tobin et al., 2006 and Nalli et al., 2018.

Milestones with Summary of Accomplishments and Findings
Over the last year, this effort involved the continuing coordination of sonde launches at the ENA, NSA, and SGP ARM sites coincident with overpasses of the NOAA20 satellite. To date, a total of 38/28/74 overpasses have been targeted at the ENA/NSA/SGP sites respectively. Included in these totals are 32/11/50 launches that occurred in collaboration with the RIVAL (Radiosonde

Inter-comparison & VALidation) field campaign. NOAA20 overpasses are typically targeted either with a single radiosonde, launched 15-minutes prior to overpass, or with twin radiosondes, launched one-after-the-other 45- and 5-minutes prior to overpass. During a RIVAL launch, the overpass is targeted with 2-radiosondes (RS92 and RS41 models) on the same balloon. The RIVAL launch may also be followed by a single radiosonde launch, making it a RIVAL twin launch. Details on NOAA20 sonde launch efforts are shown below in Table 3 and Figure 95.

Table 3. NOAA20 sonde launch efforts: Feb 2018 – present. Single launches occur 15-minutes prior to overpass, twin launches occur 45- and 5-min prior to overpass, and RIVAL launches include both a RS41 & RS92 radiosonde on the same balloon.

NOAA20 Radiosonde Launches			
Site	**ENA**	**NSA**	**SGP**
Start Date	22 Feb 2018	13 Feb 2018	13 Feb 2018
Overpasses Targeted	**38**	**28**	**74**
Single Balloon	6	9	0
Twin Balloons	---	8	24
RIVAL Start Date	26 Apr 18	20 Jun 18	13 Feb 18
RIVAL Single Balloon	32	4	18
RIVAL Twin Balloons	---	7	32

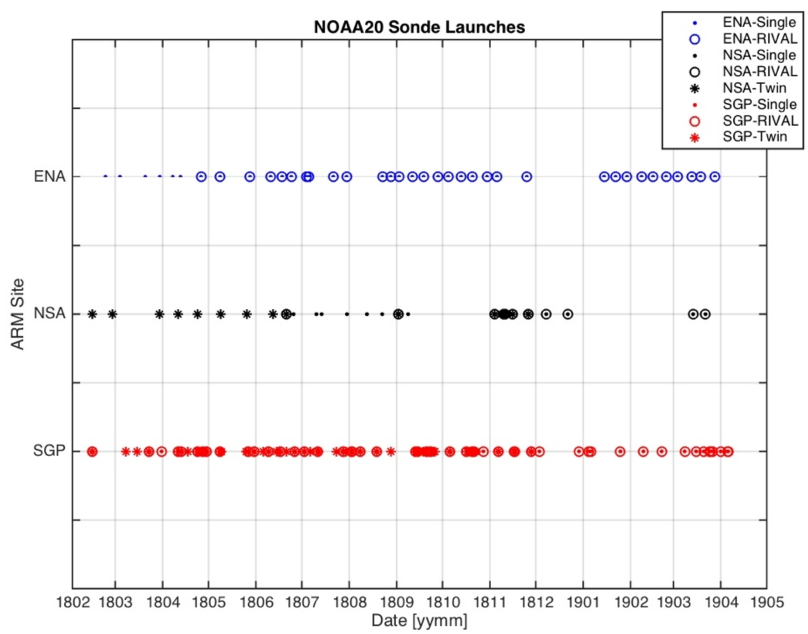


Figure 95. NOAA20 sonde launch timing since Feb 2018. ENA launches are in blue, NSA launches in black, and SGP launches are in red. RIVAL launches are shown with the 'o' symbol.

Radiosonde launches targeting NOAA20 are ongoing, but there is not yet a large enough dataset to be statistically significant for validation of retrievals by site, season, time-of-day, etc. However, preliminary comparisons of CSPP NUCAPS v2p0 retrievals and radiosondes are shown below in Figure 96. It is expected that this analysis will be re-done with an updated NUCAPS algorithm and with additional radiosonde data.

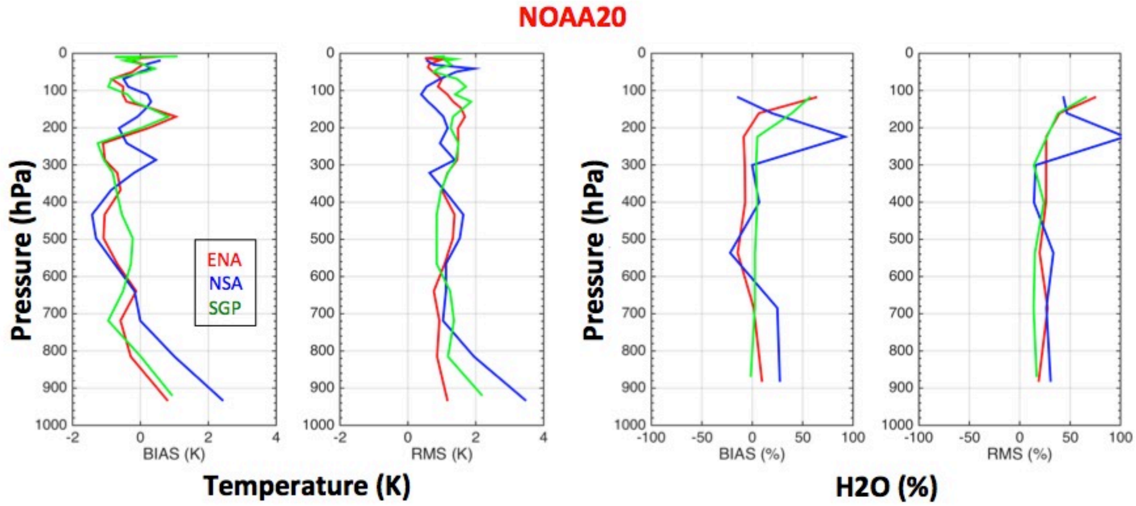


Figure 96. Comparisons of CSPP_NUCAPS v2p0 retrievals with best estimate of atmospheric state using ARM radiosondes and microwave radiometer data. Results consist of a limited number of samples and are preliminary.

It is also important to note, that the pace of launches at each of the ARM sites has slowed significantly compared to the pace in which SNPP was targeted. Launches are now occurring about once per week at each site. This slower pace is due to a funding delay. Phase8 funding for radiosondes was expected to arrive at ARM in October 2018. This has not arrived yet. Currently, the ARM program is loaning radiosondes for launches, in anticipation of funding arriving soon to replenish stock. The hope is that funds will arrive within the month and the pace of launches can be increased.

Oral Presentations

Borg, Lori, Tobin, D. C., Feltz, M., Knuteson, R., Reale, T., Nalli, N., Zhou, L., Holdridge, D., and Mather, J. *ARM Cal/Val Activities for JPSS & MetOp Hyperspectral Sounders.* Oral Presentation in NUCAPS Side Meeting. STAR JPSS Annual Science Team Meeting, 28 August 2018, Greenbelt, MD.

Borg, Lori, Tobin, D. C., Feltz, M., Knuteson, R., Reale, T., Nalli, N., Zhou, L., Holdridge, D., and Mather, J. *JPSS Radiosonde Program - Validation of SNPP CrIS/ATMS temperature and water vapor retrieved profiles using dedicated radiosondes and RO data.* Oral Presentation. Visiting Scientist Talk, 04 May 2018, Darmstadt, Germany

Borg, Lori. *RIVAL Field Campaign at the ENA, NSA, & SGP ARM Sites*. Oral Presentation. GRUAN ICM-10, 24 April 2018, Potsdam, Germany.

References

Tobin, D. C., H. E. Revercomb, R. O. Knuteson, B. M. Lesht, L. L. Strow, S. E. Hannon, W. F. Feltz, L. A. Moy, E. J. Fetzer, and T. S. Cress (2006), Atmospheric Radiation Measurement site atmospheric state best estimates for Atmospheric Infrared Sounder temperature and water vapor retrieval validation, *J. Geophys. Res.*, 111, D09S14, doi:10.1029/2005JD006103.

Nicholas R. Nalli, Gambacorta, A., Liu, Q., Barnet, C., Tan,C., Iturbide-Sanchez, Reale, T., Sun, B., Wilson, M., Borg, L., and Morris, V., Validation of Atmospheric Profile Retrievals From the SNPP NOAA-Unique Combined Atmospheric Processing System. Part 1: Temperature and

Moisture. *IEEE Transactions on Geoscience and Remote Sensing*, Volume: 56, Issue: 1, Jan 2018. DOI: 10.1109/TGRS.2017.2744558.

18.2. Science and Management Support for Suomi NPP VIIRS Snow and Ice EDRs in 2018

CIMSS Task Leader: Richard Dworak
CIMSS Support Scientists: Xuanji Wang, Aaron Letterly
NOAA Collaborators: Jeffrey Key, Yinghui Liu
Budget: $143,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation
- Healthy Oceans

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications

Objective

To provide science and management support for Suomi NPP VIIRS snow and ice EDRs.

Project Overview

The Visible Infrared Imaging Radiometer Suite (VIIRS) provides the majority of the Environmental Data Records (EDR) on the Suomi National Polar-orbiting Partnership (NPP; formerly the NPOESS Preparatory Project) and NOAA-20 satellites. Cryosphere (snow and ice) products are fundamental to weather prediction, hazard detection, transportation, recreation, and climate monitoring, and are therefore an important part of the suite of VIIRS EDRs.

NESDIS/STAR is taking the managerial and technical leadership of NPP and Joint Polar Satellite System (JPSS) cryosphere product development and evaluation activities. The JPSS Cryosphere Team will produce snow and ice Environmental Data Records (EDRs) from visible, infrared, and microwave data. For the purposes of this proposal, however, only those EDRs produced from VIIRS are considered. The VIIRS snow and ice EDRs are sea ice characterization, sea ice concentration, and snow cover/depth. Sea ice characterization includes sea ice thickness and age, and a sea ice surface temperature intermediate product (IP).

The Cryosphere Team is a unified combination of Subject Matter Experts (SMEs) from academia and government. Scientists from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison are an integral part of the team. Research at CIMSS focuses on the sea ice EDRs, in collaboration with colleagues at the Cooperative Institute for Research in the Environmental Sciences (CIRES) at the University of Colorado-Boulder. Snow cover/depth research is being funded, conducted, and reported separately at the

Cooperative Remote Sensing Science and Technology Center (CREST)/City College of New York (CCNY). So this report focus on the sea ice EDRs only.

Milestones with Summary of Accomplishments and Findings

Work at CIMSS continues to obtain VIIRS SDRs, IPs, and EDRs from srelay and snpp ftp sites and CLASS systems, checking the quality of these SDRs and EDRs, and performing comparisons of these IPs and EDRs with all other available datasets, visually and quantitatively.

Sea Ice Surface Temperature

The VIIRS Ice Surface Temperature (IST) EDR provides surface temperatures retrieved at VIIRS moderate resolution (750m), for Arctic and Antarctic sea ice for both day and night. IST is the radiating, or “skin,” temperature at the ice surface. It includes the aggregate temperature of objects comprising the ice surface, including snow and melt water on the ice. The baseline split window algorithm statistical regression method is based on the IST algorithm of Key and Haefliger (1992), and the threshold measurement uncertainty is about 1 K over the measurement range of 213 - 275 K.

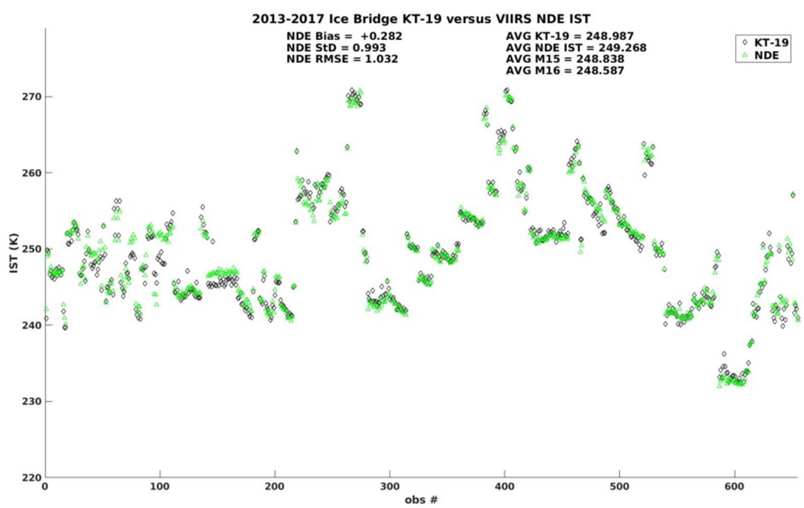


Figure 97. VIIRS IST (green) and KT-19 IST (black) for all coincident IceBridge flights with cloud-free observations over the Arctic (March-May 2013-2017) and Antarctic (October-November 2012-17).

The VIIRS “Enterprise” IST has been validated against and compared with NASA IceBridge KT-19 IR surface temperature, MODIS ice surface temperature, Arctic drifting buoy, and NCEP/NCAR reanalysis. Figure 97 show the VIIRS IST validation and comparison results with IceBridge KT-19, with a bias of 0.282 K and precision of 0.993 K. Comparisons with MODIS show a bias of 0.332 K (0.566 K) and precision of 1.41 K (1.35 K) in Arctic (Antarctic) (Figure not shown). Inter-comparisons between NOAA-20 and S-NPP show a bias of -0.07 K (0.08 K) and precision of 1.08 K (0.84 K) in Arctic (Antarctic) (Figure not shown).

Furthermore, an experimental single I-band IST algorithm has been tested on a small sample size of sea and glacial ice cases with promising validation results. When compared to Ice Bridge KT-19, the calculated bias of 0.32 K and root-mean-square error of 1.03 K (Liu and Dworak 2019).

Sea Ice Concentration

The VIIRS ice concentration is derived using the NOAA's "Enterprise" algorithms. The VIIRS ice concentration algorithm classifies a pixel as ice or no-ice using a threshold method, and calculates the pixel ice concentration using a tie point approach, and generates ice concentration at VIIRS M-band resolution at 750 m at both daytime and nighttime. The Enterprise ice concentration (IC) keeps being validated using ice concentration derived from high-resolution imagery from Landsat 8, and from the Advanced Microwave Scanning Radiometer (AMSR2). The validation with Landsat is restricted to individual cases. Figure 98 shows a Landsat case from 17 February 2019 that shows significant improvement in using VIIRS SIC over AMSR2. The SIC of all March 2019 cases with NOAA-20 compared to AMSR2 show overall bias of -1.50% and precision of 9.28%, which indicates very close agreement between the two products.

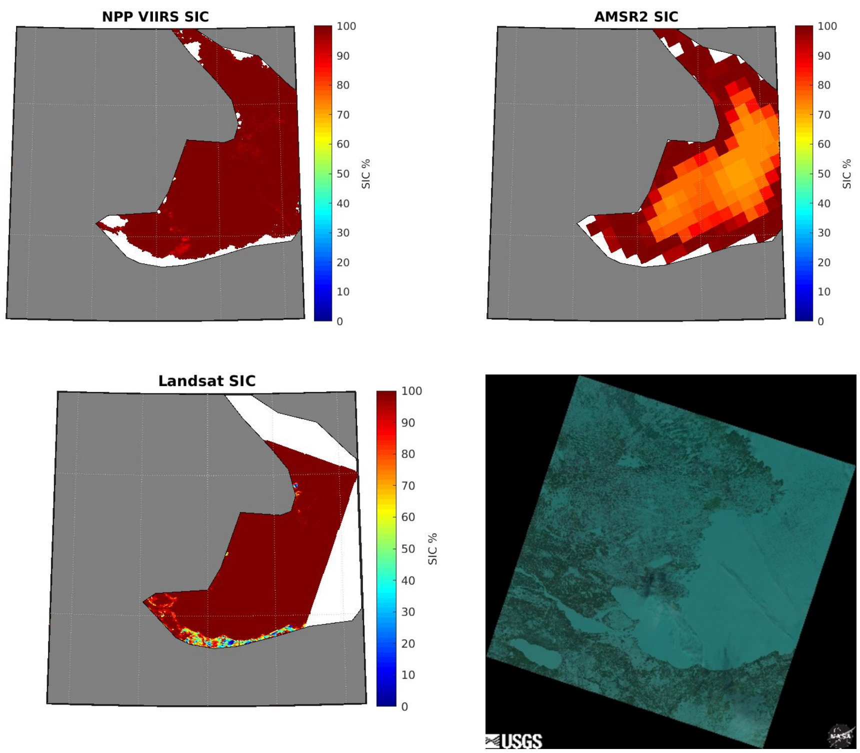


Figure 98. Ice concentration from NPP VIIRS (top-left) AMSR2 (top-right), and Landsat (bottom-left) over a portion of Great Slave Lake on February 17, 2019. At the bottom right is the Landsat Natural Color image from USGS.

The VIIRS Enterprise ice concentration (IC), along with ice surface temperature and ice thickness products, has been generated and monitored routinely, and figures have been archived and shown on CIMSS website at http://stratus.ssec.wisc.edu/ice-products/anibrowser/index.php. In addition, the ice concentration product is available on https://realearth.ssec.wisc.edu/ and is also archived by Naval Research Laboratory for applications in model simulation and Walt Meier of GSFC for comparison with microwave products.

Sea Ice Age and Thickness

The VIIRS Enterprise sea ice thickness is derived with the One-dimensional Thermodynamic Ice Model (OTIM) that is based on the surface energy budget at thermo-equilibrium state initially, and gradually evolved into a physical-statistical hybrid model for both GOES-R ABI and JPSS VIIRS data. The ice thickness algorithm (OTIM) has been improved and updated several times.

The new version of improved OTIM in FORTRAN 95 language has been coded and tested with both NOAA-20 and NPP VIIRS data. This update, version 3.6 has important improvements in cloud contamination and melting ponds on ice. Cloud contamination for assumed clear sky condition, especially in Arctic night during the transitional seasons when cloud detection bears large uncertainty, can cause anomalous sea ice thickness due to lower cloud top temperature interpreted as ice skin temperature. Melting ponds on ice also cause high uncertainty in ice thickness estimation, due to incorrect ice temperature. In this regard, a new nighttime residual heat flux regression has been developed with more in-situ sea ice thickness measurements from buoys, stations, submarines, and field campaigns, along with a surface net flux check to identify cloud contamination and/or melting ponds. The net flux is the net sum of thermal radiation flux, sensible and latent heat flux, and residual heat flux at ice surface. It is found when the net flux is close to zero is usually associated with cloud contamination and/or melting ponds on ice. A threshold is set to identify these cases with no ice thickness retrievals. Many of the old subroutines were revised and optimized, and 11 new subroutines were added to the new version of the OTIM.

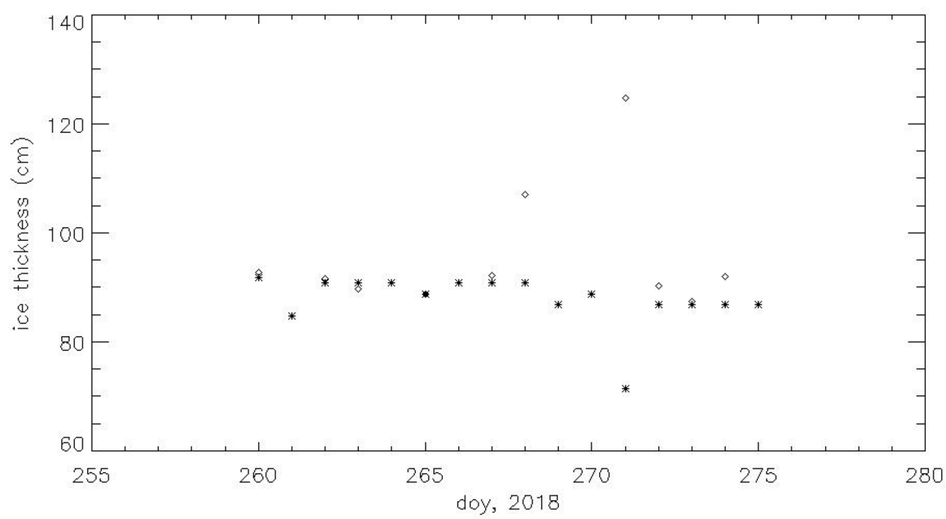


Figure 99. NOAA-20 and CRREL buoy ice thickness, Sep 17 – Oct 2, 2018. Buoy thickness is the * value, NOAA-20 thickness are diamonds.

The Enterprise ice thickness (IC) has been validated using ice thickness products derived from other satellites, aircraft measurements, and in-situ measurements. The most recent validation and comparison of VIIRS ice thickness with CRREL buoy shows close agreement (Figure 99).

Publications and Conference Reports

Yinghui Liu, Richard Dworak and Jeff Key, Ice Surface Temperature from a Single Satellite Imager Band, Remote Sensing, Volume 10, Issue 12, 2018, pp.1909, doi; 10.3390/rs10121909. Reprint # 8318.

Richard Dworak, Yinghui Liu and Jeff Key. Blended VIIRS and AMSR2 Sea Ice Concentration, 2019 AMS Annual meeting, 15th Annual Symposium on New Generation Operational Environmental Satellite Systems, 8 January 2018, Phoenix Convention Center, 100 N 3rd St. Phoenix, AZ 85004.

Yinghui Liu, Jeff Key, Xuanji Wang and Richard Dworak. Status and Validation of S-NPP and NOAA-20 VIIRS Ice Products. 2019 AMS Annual, meeting 15th Annual Symposium on New

Generation Operational Environmental Satellite Systems, 8 January 2018, Phoenix Convention Center, 100 N 3rd St. Phoenix, AZ 85004.

References

Xuanji Wang, Jeffrey Key, Ron Kwok, Jinlun Zhang, 2016, Comparison of Sea Ice Thickness from Satellites, Aircraft, and PIOMAS Data, Remote Sens., Special Issue: Sea Ice Remote Sensing and Analysis, 2016, 8(9), 713; doi:10.3390/rs8090713.

Xuanji Wang, Jeffrey Key, and Yinghui Liu, 2010, A thermodynamic model for estimating sea and lake ice thickness with optical satellite data, J. Geophys. Res., Vol. 115, C12035, 14 PP., doi:10.1029/2009JC005857.

19. CIMSS Participation in the 2018 JPSS Proving Ground/Risk Reduction Research Bundle #1

19.1 Ice Motion from VIIRS, AMSR2, and SAR –Development and Operational Applications

CIMSS Task Leader: Aaron Letterly
CIMSS Support Scientist: Xuanji Wang
NOAA Collaborators: Jeff Key and Yinghui Liu
Budget: 134,550

NOAA Long Term Goals:

- Weather-Ready Nation
- Healthy Oceans
- Resilient Coastal Communities and Economies

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Project Objective

This project will continue the development the ice motion products from individual sensors, create new blended motion products, and implement and test the products in (near-) real-time operations. In addition, we will investigate and prototype a relatively simple short-term ice motion forecast product, based on the derived ice motion vectors and a model surface wind field. The operational environments of primary interest are the National Ice Center (NIC), the Alaska Sea Ice Program (ASIP), and the NOAA Arctic Testbed. The outcome of the project will be routinely-generated, near-operational, individual and blended ice motion products based on VIIRS, AMSR2, and SAR that have been thoroughly tested by users in operational or pseudo-operational applications, and a simple, short-term ice motion forecast product.

Project Overview

Arctic sea ice has changed dramatically in the past few decades. Sea ice extent has been decreasing significantly, associated with changes in sea ice thickness and age. Sea ice in the Antarctic has also been changing, with positive trends in sea ice extent and area. Studies have linked the shrinking of sea ice in the summer and fall to surface warming (Liu et al. 2009), a less stable lower troposphere, increased cloud amount (Liu et al. 2012, Taylor et al. 2015), mid-latitude weather and extreme events through teleconnection between Arctic and mid-latitude, and other impacts (Francis et al. 2009).

The tracking of sea ice from satellites has been done for many years using passive microwave data. For example, Emery et al. (1997) produced maps of sea ice motion from the late-1980s to mid-1990s using standard image processing methods applied to 85.5 GHz Special Sensor Microwave/Imager (SSM/I) data. The original AVHRR Polar Pathfinder (APP) product developed in the early 1990s (in which Co-I J. Key was involved) included an ice motion product. Kwok (2008) found good agreement of sea ice motion derived from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) with drifting buoys. A product that combines passive microwave from multiple satellites, AVHRR, and buoy motions covering the period 1978-2015 has recently been developed (Tschudi et al., 2016). However, these sea ice motion products are usually done over a long time scale (on the order of a couple of days) due to the low resolution of the microwave sensors (approximately 13 km/pixel). Therefore, to make this product available in near real-time, the use of high spatial and temporal imager data is required.

Milestones with Summary of Accomplishments and Findings

Individual VIIRS and AMSR2 sea ice motion products have been developed and are running routinely (daily) at CIMSS. Initially, the VIIRS 11 micron (M15) band was used. A blended VIIRS+AMSR2 product is also being generated. In the blended product, VIIRS provides small- and large-scale motion but only for clear sky areas; AMSR2 provides a more spatially complete but lower resolution motion field. Recently, the VIIRS Day-Night Band (DNB) Near Constant Contrast (NCC) product was tested for ice motion derivation with positive results. An example of AMSR2, VIIRS IR (M15 band), and VIIRS DNB ice motion fields calculated over a 24-hour period is shown in Figure 100. More examples of AMSR2 and AMSR2+VIIRS (M15 only) ice motion are available at http://stratus.ssec.wisc.edu/gcom/rtproducts/.

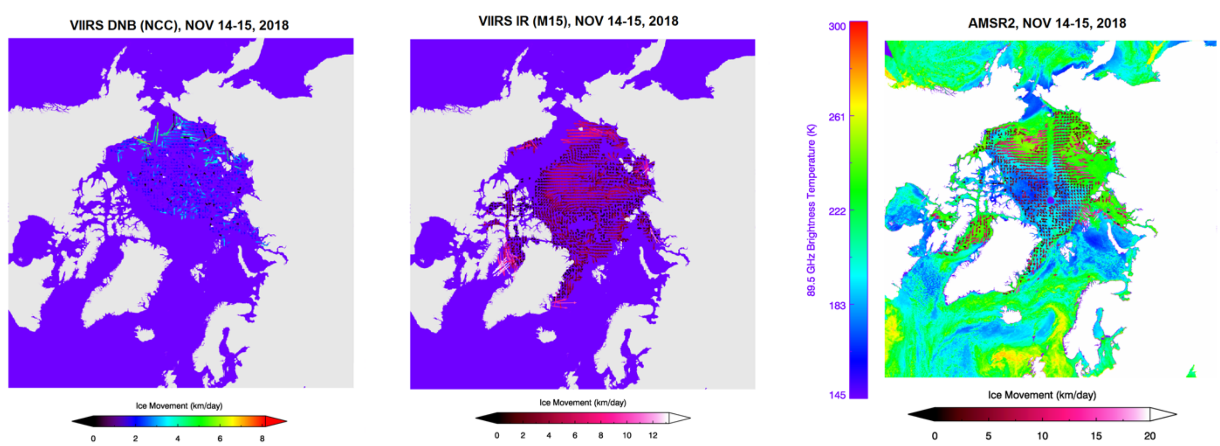


Figure 100. Arctic sea ice motion on November 14-15, 2018 from VIIRS Day/Night Band (top), VIIRS M15 Band (middle), and AMSR2 (right).

During the first year, two demonstrations involving the National Weather Service Alaskan Sea Ice Program (ASIP) were completed. These demonstrations helped determine the capabilities for VIIRS+AMSR2 ice motion for operational use and familiarize ice analysts with the blended product. On one occasion, an ASIP analyst responded to an American mariner that was avoiding drifting ice floes in the Bering Sea, using the VIIRS+AMSR2 ice motion product to assess the direction and speed of the drifting ice.

Synthetic Aperture Radar (SAR) showed promising results during initial ice motion tests. SAR allows for high-resolution, all-weather tracking of sea ice features, and can improve ice motion derived from VIIRS and AMSR2. Blended ice motion quality has also been improved by applying a density-based clustering algorithm to the vector output product, especially in areas of slower ice motion.

Publications and Conference Reports

Aaron Letterly, Jeff Key, Yinghui Liu, A Blended Ice Motion Product from AMSR2, VIIRS, and SAR, 2019 AMS Annual Meeting, January 6-10, 2019, Phoenix, AZ.

Aaron Letterly, Jeff Key, Yinghui Liu, Blended AMSR2+VIIRS Sea Ice Motion, STARR JPSS Annual Science Team Meeting, August 27-30, 2018, College Park, MD.

Aaron Letterly, Richard Dworak, VIIRS+AMSR2 Blended Ice Concentration and Motion Products, 2018 JPSS Arctic Summit Meeting, May 1-8, 2018, Anchorage, AK.

References

Emery, W. J., C. W. Fowler, J. A. Maslanik, 1997. Satellite-derived maps of Arctic and Antarctic sea ice motion: 1988 to 1994, *J. Geophys. Res. Lett.*, **24**(8):897-900.

Francis, J. A., and Coauthors, 2009: An arctic hydrologic system in transition: Feedbacks and impacts on terrestrial, marine, and human life. *Journal of Geophysical Research-Biogeosciences*, **114**.

Kwok, R., 2008. Summer sea ice motion from the 18 GHz channel of AMSR-E and the exchange of sea ice between the Pacific and Atlantic Sectors, *J. Geophys. Res. Lett.*, 35, L03504, doi:10.1029/2007GL032692.

Liu, Y., J. Key, and X. Wang, 2009: Influence of changes in sea ice concentration and cloud cover on recent Arctic surface temperature trends. *Geophysical Research Letters*, **36**.

Liu, Y., J. Key, W. Straka, 2010. *ABI Ice Motion*. NOAA/NESDIS/STAR ATBD v. 1.02.

Liu, Y., J. Key, Z. Liu, X. Wang, and S. Vavrus, 2012: A cloudier Arctic expected with diminishing sea ice. *Geophysical Research Letters*, **39**.

Maslanik, J., C. Fowler, J. Key, T. Scambos, T. Hutchinson, and W. Emery, 1997. AVHRR-based Polar Pathfinder Products for Modeling Applications. *Annals of Glaciology* **25**:388-392.

Miller, S.D., Mills, S.P., Elvidge, C.D., Lindsey, D.T., Lee, T.F., Hawkins, J.D., 2012. Suomi satellite brings to light a unique frontier of nighttime environmental sensing capabilities. *PNAS*, **109**(39), 15706–15711.

Santek, D., D. Parker, R. Dengel, S. Batzli, N. Bearson, T. Jasmin, 2016. RealEarth: Real-time Access to Global Satellite Data and Derived Products. *21st Conference on Satellite Meteorology*. AMS, Madison, Wisconsin.

Scott, C, 2015. NOAA's requirement for an Arctic testbed. Retrieved 01 September 2016. https://ams.confex.com/ams/95Annual/webprogram/Handout/Paper267689/amsfinal.pdf.

Taylor, P. C., S. Kato, K.-M. Xu, and M. C. J. D. Cai, 2015: Covariance between Arctic sea ice and clouds within atmospheric state regimes at the satellite footprint level, **120,** 12656-12678.

Tschudi, M., C. Fowler, J. Maslanik, J. S. Stewart, and W. Meier. 2016. *Polar Pathfinder Daily 25 km EASE-Grid Sea Ice Motion Vectors.*Version 3. [indicate subset used]. Boulder, Colorado USA: National Snow and Ice Data Center. doi: http://dx.doi.org/10.5067/O57VAIT2AYYY.

19.2 Strengthening TPW Visualization in the OCONUS Domain with JPSS Data Products

CIMSS Task Leader: Anthony Wimmers
CIMSS Support Scientist: Chris Velden
NOAA Collaborators: Limin Zhao, Ralph Ferraro, Eric Holloway, Aaron Jacobs, Kennard Kasper
Budget: $71,000

NOAA Long Term Goals:
- Weather-Ready Nation
- Resilient Coastal Communities and Economies

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective
To combine the best features of the CIMSS MIMIC-TPW product with the CIRA Blended TPW/LPW products in order to provide forecasters with accurate, naturalistic and well-calibrated precipitable water imagery.

Project Overview
This project combines CIRA and CIMSS capabilities to develop a new advected TPW product that is ready for a straightforward transition to NOAA operations. NOAA users will be engaged to develop requirements for the advected TPW product. CIRA operational data processing

infrastructure will host the CIMSS advection engine (MIMIC) to create a new hourly advected product. These products will be distributed to NWS collaborators for evaluation and improvement. We will participate in the NOAA Hydrometeorology Testbed to solicit feedback.

The advected blended TPW product will be validated against independent high-accuracy surface and satellite measurements to inform users of product uncertainty. Training modules will be created in this product to prepare users for the improved hydrometeorological products generated by this effort.

At project completion, well-documented, error-characterized blended water vapor products will be ready for transition to NOAA operations. Since the science development will occur in the same CIRA system which is currently operational at NESDIS, the effort required to transition the results of this research will be low. Suomi-NPP and NOAA-20 passive microwave retrievals are foundational inputs for this work.

Milestones with Summary of Accomplishments and Findings

Validation and Sensitivity Testing

In order to optimize the future merged algorithm, we will need verification of the algorithm accuracy against independent observations. We have established a system of verification as follows. Near-real time validation of both the existing blended TPW (without GPS data) and advected TPW are being performed via comparison to surface-based GPS stations. An example for 31 March 2019 is shown in the figure below. Advection reduces RMS and bias errors and improves the correlation with the surface truth GPS data. The GPS sites are essentially all over land, so these statistics apply to land only. Performance over ocean is expected to be better due to the uniform topography and higher quality of microwave retrievals.

Merging the Code of the Blended TPW and MIMIC-TPW Algorithms

We are still in the early stages of merging code by familiarizing ourselves with one another's algorithms and checking the software support required at CIRA. A basic Python program was successfully run on the CIRA machine where the MIMIC / DPEAS integration will be performed. The project team is determining which portions of the task flow will occur in DPEAS (e.g. file gathering, data format reading, remapping) and which portions will occur in MIMIC.

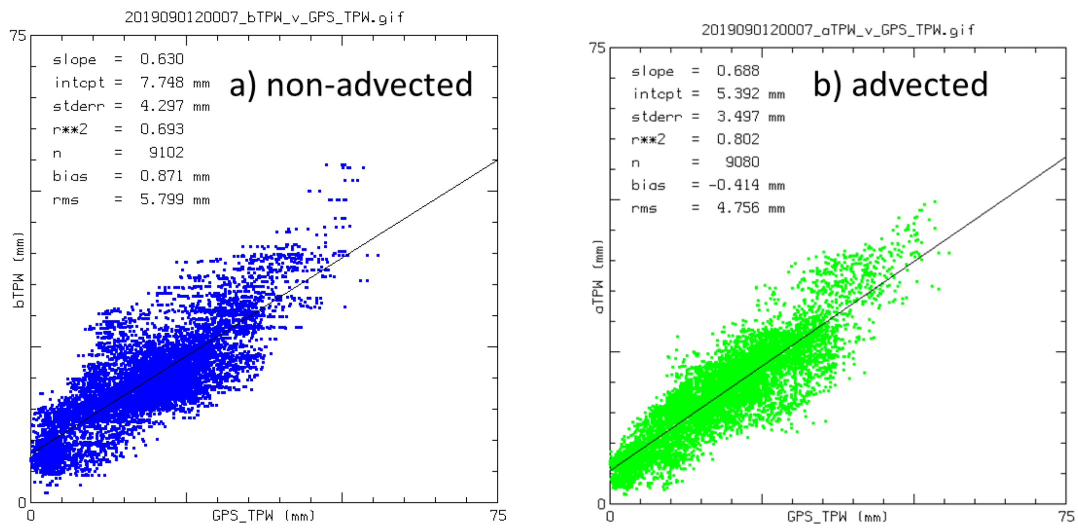


Figure 101. Comparison versus surface-based GPS validation sites of a) non-advected blended TPW using NOAA operational algorithm and b) and advected TPW for 31 March 2019. Advection reduces RMS and bias errors.

Publications and Conference Reports

"Using the New Capabilities of GOES-R to Improve Blended, Multisensor Water Vapor Products for Forecasters" at the 15th Annual Symposium on New Generation Operational Environmental Satellite Systems.

AGU Meeting, December 13 2018: Sheldon Kusselson presented "Advected Layered and Total Precipitable Water Products and Applications to Forecasting Hazardous Precipitation Events: in the IN046 session.

19.3 Development and Impact of Global Winds from Tandem S-NPP and NOAA-20 VIIRS

CIMSS Task Leader: David Santek
CIMSS Support Scientists: Rich Dworak, Steve Wanzong, Sharon Nebuda
NOAA Collaborator: Jeff Key
Budget: $119,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

The VIIRS polar winds product is currently operational for the Suomi National Polar-orbiting Partnership (S-NPP) satellite and provides wind speed, direction, and pressure of cloud-tracked features at high latitudes. With NOAA-20 in a similar orbit as S-NPP but delayed by ½ orbit in time, there is an opportunity to track clouds from the NOAA-20/S-NPP tandem. This will reduce the time interval between images, which will result in reduced latency in product availability, potentially higher quality winds, and global rather than only high-latitude coverage. The outcome of the project will be routinely-generated, NOAA-20/S-NPP dual winds product with assessment of their impact on numerical weather prediction. Also, VIIRS winds from new spectral bands (SWIR and DNB) will be generated.

Project Overview

The VIIRS polar winds product is currently operational for the Suomi National Polar-orbiting Partnership (S-NPP) satellite, providing wind speed, direction, and pressure of cloud-tracked features at high latitudes, both Arctic and Antarctic. The product has been operational since May 2014. The VIIRS winds are being assimilated in the Naval Research Lab's (NRL) Atmospheric Variational Data Assimilation System - Accelerated Representer (NAVDAS-AR) and are currently being monitored in NCEP's pre-operational version of the Global Data Assimilation System/Global Forecast System GDAS/GFS. They are also used by a number of numerical weather prediction centers abroad.

The operational VIIRS wind product use three successive orbits (100-minute time step) from a single satellite to derive cloud motion. Since NOAA-20 is in a similar orbit as S-NPP but delayed by ½ orbit in time, there is an opportunity to track clouds from the NOAA-20/S-NPP tandem. This will reduce the time interval between images to approximately 50 minutes, which will result in reduced latency in product availability, potentially higher quality winds due to the shorter time interval for tracking, and global rather than only high-latitude coverage. If a pair of orbits is used rather than a triplet, global coverage can be achieved, though with some loss of accuracy.

While the goal of this project is to develop a routinely-generated, near-operational unique global wind product from the NOAA-20/S-NPP tandem and evaluate its NWP impact, we will also extend this product and the single-satellite VIIRS polar winds by adding a shortwave infrared (SWIR) band at 2.25 μm and the day-night band (DNB).

Milestones with Summary of Accomplishments and Findings

During this first year, we were able to configure the routine generation of VIIRS AMVs from image pairs using a mix of NOAA-20/S-NPP data. The initial implementation is over only the polar regions, where parallax effects are not significant (due to extensive overlap in the swaths).

By using the CLAVR-x cloud properties (ACHA) and the cluster wind retrieval method developed for GOES-R and used operationally for the VIIRS single-satellite wind product, Atmospheric Motion Vectors (AMVs) are now being generated every 50 minutes over the polar regions using the tandem S-NPP/NOAA-20 configuration. Figure 102 depicts the single-satellite winds (left) and tandem winds (right) from the infrared (IR) window channel over the Arctic. Figure 103 illustrates the winds over the Antarctic. The single-satellite derived AMVs are available at a 100-minute time step; the tandem VIIRS winds have a 50-minute time step. In addition to being available with less latency, the tandem winds have greater spatial coverage because of the large overlap between the orbital swaths of the two satellites.

We have also begun to quantitatively compare the tandem winds to single-satellite S-NPP, NOAA-20, and MODIS winds, and to validate the product with rawinsondes. Initial findings indicate vector differences between single satellites and tandem S-NPP/NOAA-20 winds to be in between 2-3 ms^{-1}.

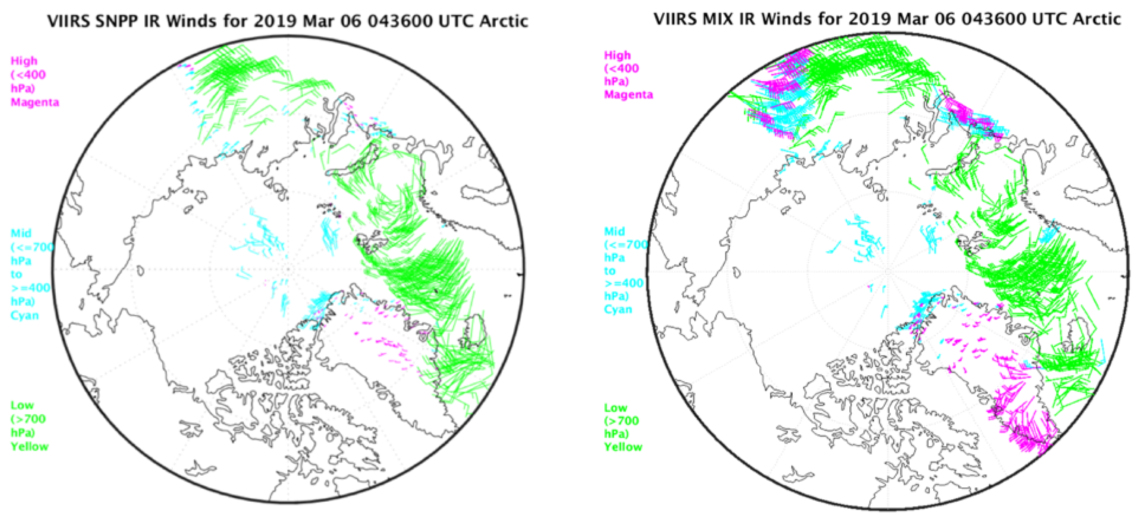


Figure 102. Plots of IR winds at the same date and time over the Arctic, 06 March 2019 at 0436 UTC, from S-NPP alone (left) and from the combination of S-NPP and NOAA-20 (right). Note the increased coverage in the south from the tandem product.

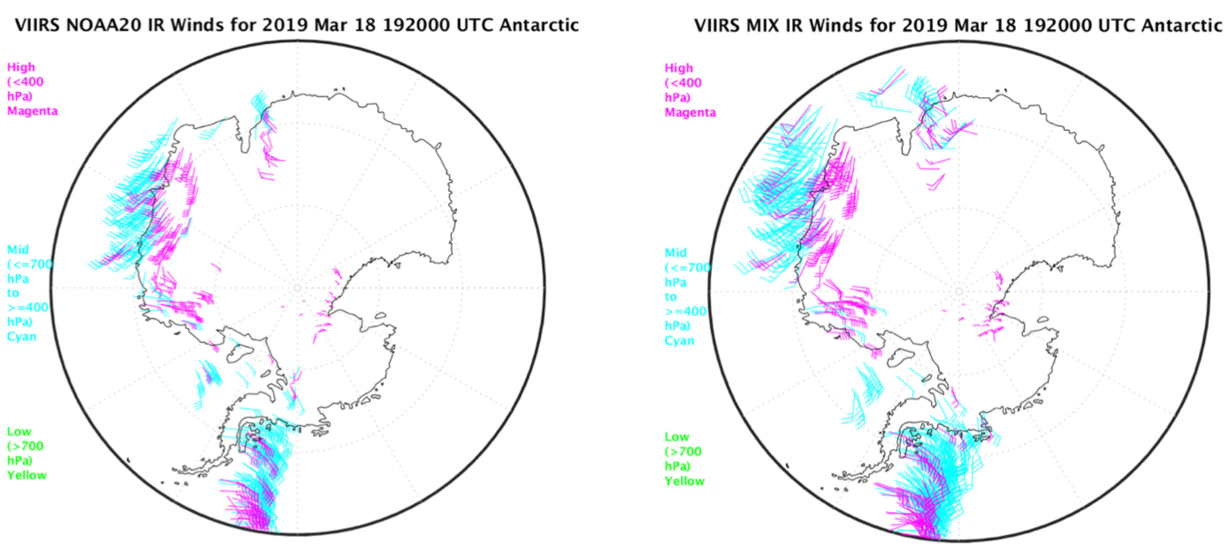


Figure 103. Plots of IR winds at the same date and time over the Antarctic, 18 March 2019 at 1920 UTC, from NOAA-20 alone (left) and from the combination of S-NPP and NOAA-20 (right).

19.4 Visible Applications in Dark Environments, Revisited (VADER): NOAA-20 Joins S-NPP on the 'Dark-Side' to Empower Day/Night Band Research and Operational Capabilities

CIMSS Task Leader: William Straka III

NOAA Collaborator: Dan Lindsey (NOAA/NESDIS/STAR/RAMMB)

Budget: $28,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Integrate 'low-light visible thinking' into the minds of the operational forecaster, providing familiarity with the new technology, and a new empowerment to forecasters as they contend with longstanding challenges of nocturnal environmental characterization.

Project Overview

The overarching goal of this project is to integrate 'low-light visible thinking' into the minds of the operational forecaster, providing familiarity with the new technology, and a new empowerment to forecasters as they contend with longstanding challenges of nocturnal environmental characterization. This research spans essential DNB tool development, novel user applications, instrument stewardship, and foundational research. Key components of this research at CIMSS are listed below:

- DNB Applications
  CIMSS will provide the DNB imagery, along with the information on the location of the imagery to aid in the explorations of new nocturnal applications, focusing on events outside of the CONUS and Alaska regions. These include disaster monitoring, (anthropogenic light changes), Cryospheric Applications (snow cover, sea ice), visibility hazards (fog, fires/smoke, dust, ash), and tropical cyclones (exposed low-level circulation)
- Sensor Performance & Preparation for J1
  Participation in ongoing Cal/Val Team discussions, Technical Interchange Meetings, test/evaluate potential software solutions, and support studies concerning DNB data quality on J1 and beyond.
- Scientific Exploration Studies
  We propose to expand the horizons of science by researching the information content present the DNB nightglow observations. This work will include the analysis and interpretation of gravity waves occurring globally as observed via specially scaled DNB nightglow imagery during the new-moon phase. We will also continue the search for widespread 'milky sea' marine bioluminescent events via strategic monitoring of historically active locations in Southwest Asia and Indonesia.

Milestones with Summary of Accomplishments and Findings

The year of 2018 provided continued examples and real world applications for the Day Night Band and interactions with stakeholders. This included providing imagery of significant weather and natural disaster events. For example, in May 2018, the events of the lower east rift zone of Kīlauea on the island of Hawai‘i as it erupted were monitored by a variety of channels on VIIRS, including the DNB. The DNB could easily see the lava from the various fissures, as seen below.

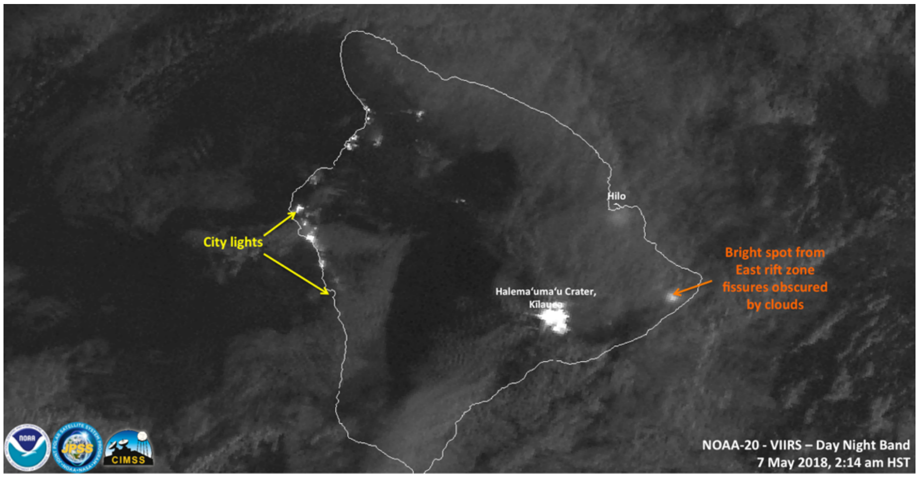


Figure 104. NOAA-20 DNB imagery from, 7 May 2018 over the island of Hawai‘i, showing the bright spot from the Lower east rift zone fissures. Subsequent imagery over the fissures, showing the evolution of the lava flow.

Another event that was the monitored were incidents that were human caused. For example, on 18 April at roughly 11:04am EDT, an excavator working on removing a fallen tower from Maria got too close to an energized line and causing an electrical ground fault near Salinas, Puerto Rico. The result was a cascading failure and island wide power outage, which could be seen by the DNB as seen in the imagery below.

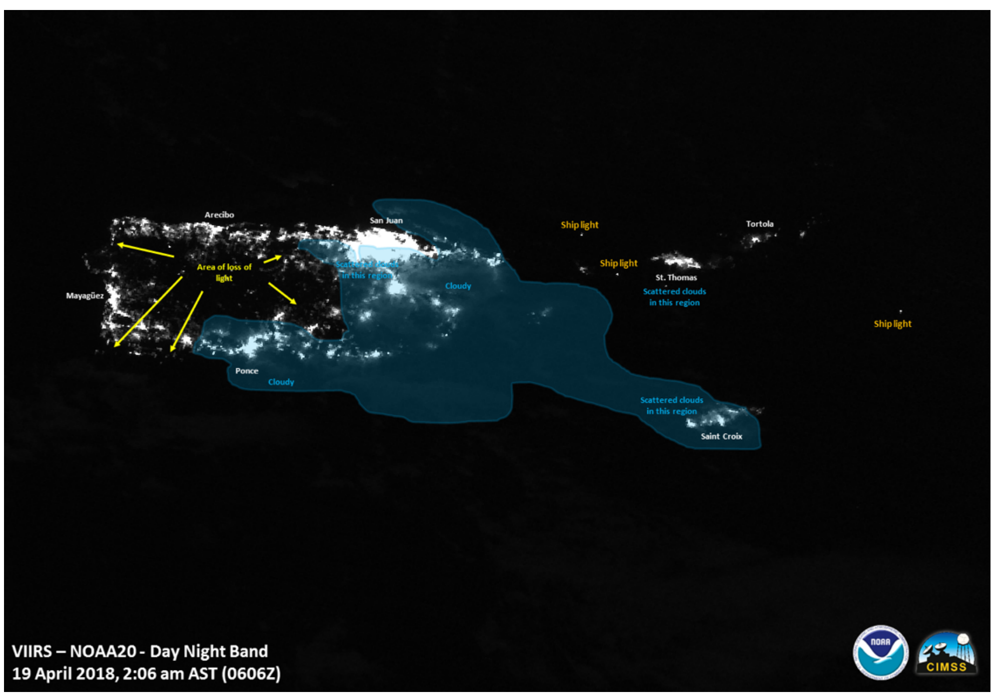


Figure 105. NOAA-20 DNB imagery from, 19 April 2018 over Puerto Rico, showing the loss of light due to an excavator accidentally damaging an energized power line.

DNB imagery from the various tropical cyclones that impacted the United States and its territories were provided both as part of this project and the JPSS Satellite Disaster Outreach Coordinator. An example from the aftermath of Hurricane Michael is shown below.

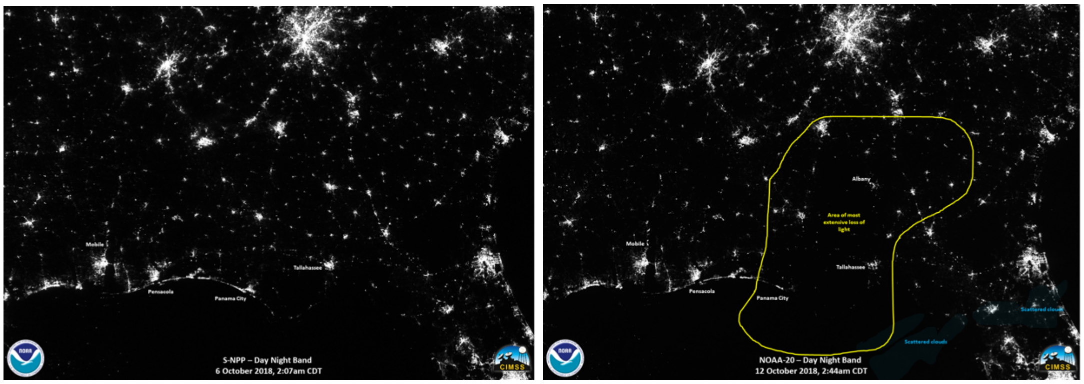


Figure 106. Imagery from 6 October 2018 from SNPP (right), which was used as reference, and 13 October 2018, right after Hurricane Michael made landfall and departed the area, from NOAA-20 (left), as provided to FEMA.

In addition, observations of mesospheric gravity waves continue to be investigated, along with possible cases of bioluminescent.

Publications and Conference Reports

Miller, S. D; Straka, W. C. III; Yue, J.; Seaman, C. J.; Xu, S.; Elvidge, C.D.; Hoffmann, L; Azeem, I. The Dark Side of Hurricane Matthew: Unique Perspectives from the VIIRS Day/Night Band, Bulletin of the American Meteorological Society (BAMS), 2018.

19.5 Concept Study to Extend VIIRS Spectral Coverage Using CrIS Radiance Measurements and to Explore Potential Applications

CIMSS Task Leader: Elisabeth Weisz
CIMSS Support Scientists: W. Paul Menzel, Eva Borbas
NOAA Collaborator: Mitch Goldberg
Budget: $100,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

- Environmental Models and Data Assimilation
- Education and Outreach

Objective

To demonstrate the capabilities of the imager/sounder fusion method for radiances and accurate retrieval products.

Project Overview

Our objective is to demonstrate the ability to construct infrared (IR) absorption narrowband radiances as well as accurate retrieval products using the imager/sounder fusion method while retaining the imager's high spatial resolution. Therefore, temperature and water vapor retrieved from hyperspectral sounder (AIRS, IASI, CrIS) measurements can be provided at the associated imager's (MODIS, AVHRR, VIIRS, ABI) high spatial resolution.

Milestones with Summary of Accomplishments and Findings

Polar-orbiting weather satellite platforms include both a high spatial resolution imager, with pixel spatial resolution on the order of 1 km, and a high spectral resolution (or hyperspectral) infrared (IR) sounder, with fields of view (FOVs) of about 14 km. The Visible Infrared Imaging Radiometer Suit (VIIRS), onboard Suomi-NPP and JPSS platforms, lacks absorbing IR bands that are necessary to sustain continuity of derived cloud and moisture products and associated applications over generations of weather satellite sensors. The "imager plus sounder" (or imager/sounder) data fusion method to construct missing IR bands at high spatial resolution has been demonstrated previously in Weisz et al. (2017). The radiance fusion technique consists of two steps; first, a nearest neighbor search (specifically, a k-d tree algorithm) is performed on both high spatial and low spatial resolution split-window imager radiances, and secondly, convolved sounder radiances (at low spatial resolution) for the nearest neighbors are averaged. With this method any IR absorption band (using any imager/sounder pair) can be constructed. The observed- and fusion-based radiance differences tend to be small (brightness temperature root-mean-square differences are between 0.5 and 1.0 K) and unbiased. Heritage sounding retrieval algorithms can then be used to derive atmospheric profile retrievals from these fusion radiances.

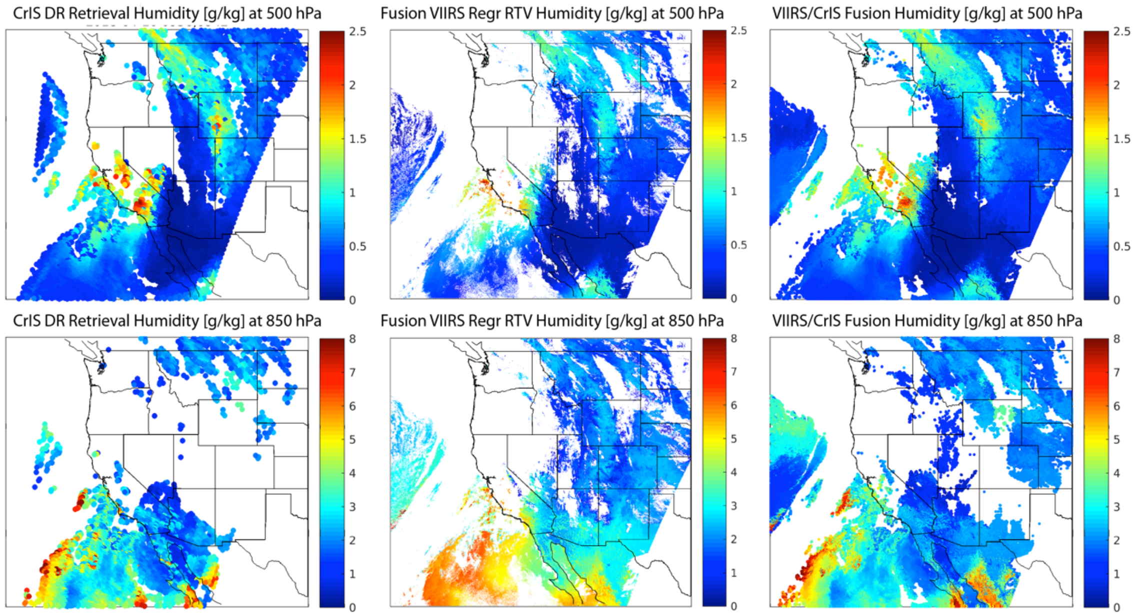


Figure 107. Humidity soundings are shown at the 500 and 850 hPa-pressure level in the top and bottom panels, respectively. CrIS DR retrievals (left), regression retrieval derived from broadband VIIRS/CrIS fusion radiances (middle), and VIIRS/CrIS product fusion results (right). On 10 Apr 2018 (0940 UTC).

Another way to obtain retrieval products is to apply imager/sounder fusion approach directly to the sounder retrievals to infer them at imager pixel resolution. It can be shown that this so-called product fusion approach is capable to produce fine scale features that are similar to those derived with operational broadband sounder retrieval algorithms. Figure 107 shows 500 and 850 hPa water vapor soundings derived from CrIS measurements using the dual-regression method (DR, Smith et al. 2012), MODIS-like retrievals with VIIRS/CrIS fusion radiances, and product fusion retrievals from direct application of the fusion technique to CrIS soundings in panels a-c, respectively. This example illustrates that direct product fusion of CrIS soundings captures more of the information content of the high spectral resolution measurements than retrieving from broadband radiances.

Fusion of sounder products applied to a Geo/Leo instrument pair, such as ABI and CrIS, show similar promising results. Originally split-window bands are used in the k-d tree search, but we found that adding more imager channels (if available, as in the case of ABI) improves the outcome, especially for mid-level moisture products. In Figure 108 we compare fusion results from k-d tree searches with just the ABI split window (11.2, 12.3 µm) to those from k-d tree searches using eight out of the ten ABI IR bands. The center wavelengths of the eight bands range from 6.2 to 13.3 µm. It can be seen that the extra bands, especially the water vapor sensitive 6.2 and 7.0 µm bands, enable better depiction of mid-level dry and moist features.

In summary, applying the nearest neighbor search output directly to hyperspectral sounder retrieval products (rather than to fusion radiances) offers more improved detail in temperature, moisture and cloud features. It should be mentioned that ABI/CrIS fusion is also investigated as a time sequence, which then provides high spectral (which translates to high vertical) resolution retrieval products at high spatial as well as high temporal resolution.

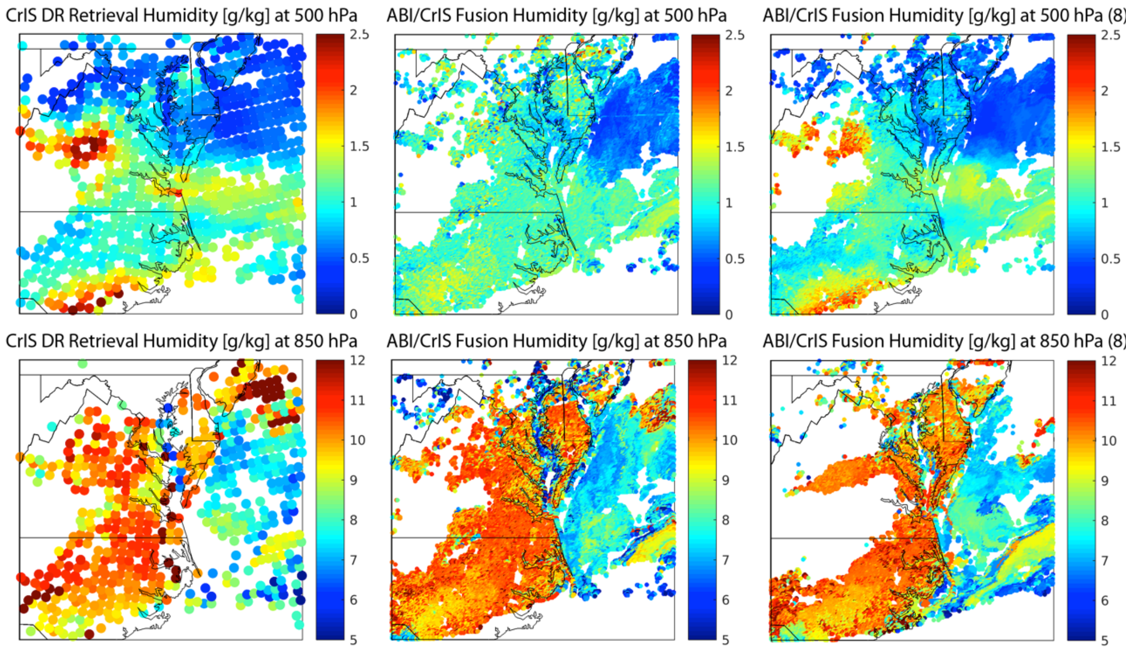


Figure 108. Humidity soundings are shown at the 500 and 850 hPa-pressure levels in the top and bottom panels, respectively. CrIS DR retrievals (left), ABI/CrIS product fusion results using a 2-chnnel k-d tree search, (middle), and ABI/CrIS product fusion results using an 8-channel approach (right). On 19 May 2017 (1800 UTC).

Publications and Conference Reports

P. Menzel, E. Weisz, E. Borbas, R. Frey, B. Baum, "Generating LEO Sounder Products at GEO Imager Spatial and Temporal Resolution", Presentation at EUMETSAT Satellite Users Conference, 19-23 September 2018, Tallinn, Estonia.

E. Weisz, P. Menzel, B. Baum, "Generating Hyperspectral Sounder Products at Imager Spatial and Temporal Resolution", Poster at the International Cloud Working Group (ICWG) meeting, 29-31 October 2018, Madison, WI.

P. Menzel, E. Weisz, E. Borbas, R. Frey, and B. Baum, "Generating LEO Sounder Products at GEO Imager Spatial and Temporal Resolution," Oral Presentation at AMS Annual Conference, 7 Jan 2019, Phoenix, AZ.

E. Weisz and W. Paul Menzel, Imager and Sounder Data Fusion to Generate Sounder Retrieval Products at Improved Spatial and Temporal Resolution", manuscript submitted to SPIE JARS (March 2019).

References

Weisz, E., B. A. Baum, and W. P. Menzel (2017), Fusion of satellite-based imager and sounder data to construct supplementary high spatial resolution narrowband IR radiances, *J. Appl. Remote Sens.* **11**(3), 036022 (2017) [doi: 10.1117/1.JRS.11.036022].

Smith, W. L., E. Weisz, S. V. Kireev, D. K. Zhou, Z. Li, and E. E. Borbas (2012), Dual-regression retrieval algorithm for real-time processing of satellite ultraspectral radiances, *J. Appl. Meteor. Climatol.*, **51**, 1455 – 1476.

19.6 Real-time Acquisition, Processing, Analysis, and Operational Integration of TC-centric Polar Orbiting Data. Part II: Serving Forecasters with Advanced Satellite-based TC Center-fixing and Intensity Information
CIMSS Task Leader: Anthony Wimmers
CIMSS Support Scientists: Derrick Herndon, Chris Velden
NOAA Collaborators: John Beven (NHC), Robert Ballard (CPHC), John Knaff (NESDIS)
Budget: $140K

NOAA Long Term Goals:
- Weather-Ready Nation
- Resilient Coastal Communities and Economies

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

To transition JPSS and other polar-orbiting observations from being a rapidly *viewable* dataset for tropical cyclones (TCs) to a dataset that is rapidly *applied* to quantitative decision-making.

Project Overview

While computational methods to analyze tropical cyclone (TC) characteristics from microwave satellite imagery have become more advanced and necessary for forecasting, the problems inherent in transitioning these algorithms to operations have actually become more acute. As a solution we offer this project as part of a three-pronged effort by NRL, CIMSS and CIRA to adapt a real-time TC satellite data processing platform to the AWIPS2-centered forecasting environments of NHC, CPHC and JTWC.

Our project adapts two root-level algorithms to this TC data processing platform – 'ARCHER' and 'SATCON' – and adds new JPSS imagery to their capabilities. ARCHER is a robust, multi-sensor TC center-finding algorithm, whose results are the starting point of many other TC analysis algorithms. SATCON is a robust TC intensity estimation algorithm that is now outperforming standard Dvorak estimation methods. Together these additions to the TC data processing platform will bring critical, quantitative TC information to the forecaster's analysis environment, and also enable new research to leverage from these newly operational capabilities.

This project redevelops ARCHER and SATCON as JPSS-enabled tools adapted to the proposed TC data processing environment. Subsequently we will test an experimental SHIPS module using these improved TC initialization methods in order to evaluate their improvements to intensity forecasting guidance. Throughout the project we will be engaged with the operational centers

NHC, CPHC and JTWC to evaluate the forecaster experience with the software deliveries and incorporate feedback into the design.

Milestones with Summary of Accomplishments and Findings

Adapt ARCHER into the GeoIPS Environment

ARCHER has been modified to accept GeoIPS-formatted incoming data, but the larger effort of recoding ARCHER into Python for incorporation into GeoIPS is still in beta-testing. The outcome of this work will be an ARCHER module that is finally platform independent.

Adapt SATCON to NOAA-20 ATMS Data

We have completed integrating NOAA-20 ATMS estimates into SATCON. Final calibration of the ATMS channels 7-10 brightness temperatures (Tbs) using limb corrections developed for S-NPP ATMS have yielded no significant issues. Comparisons of limb-corrected Tbs between S-NPP and N-20 for overpasses close in time (< 2 hours) indicate good matchups and performance.

As an additional validation step, tropical cyclone intensity estimates derived from the N-20 data for 22 overpasses were compared to aircraft ground truth for storms in the Atlantic and Eastern Pacific. This evaluation yielded MSLP RMSE of 8.1 hPa, which compares well with the S-NPP RMSE of 7.9 hPa. Maximum sustained wind (Vmax) RMSE for the 22 N-20 cases was 12.8 kts compared with S-NPP RMSE of 11.8 kts. The slightly higher RMSE for N-20 Vmax estimates was due to over-estimation of winds associated with Hurricane Florence and is related to deviations in the pressure-wind relationship for the storm during that time. Evaluation of N-20 estimates outside of the Atlantic/East Pacific shows similar performance in all other ocean basins, with N-20 estimates typically falling within 10 knots/hPa of coincident S-NPP estimates.

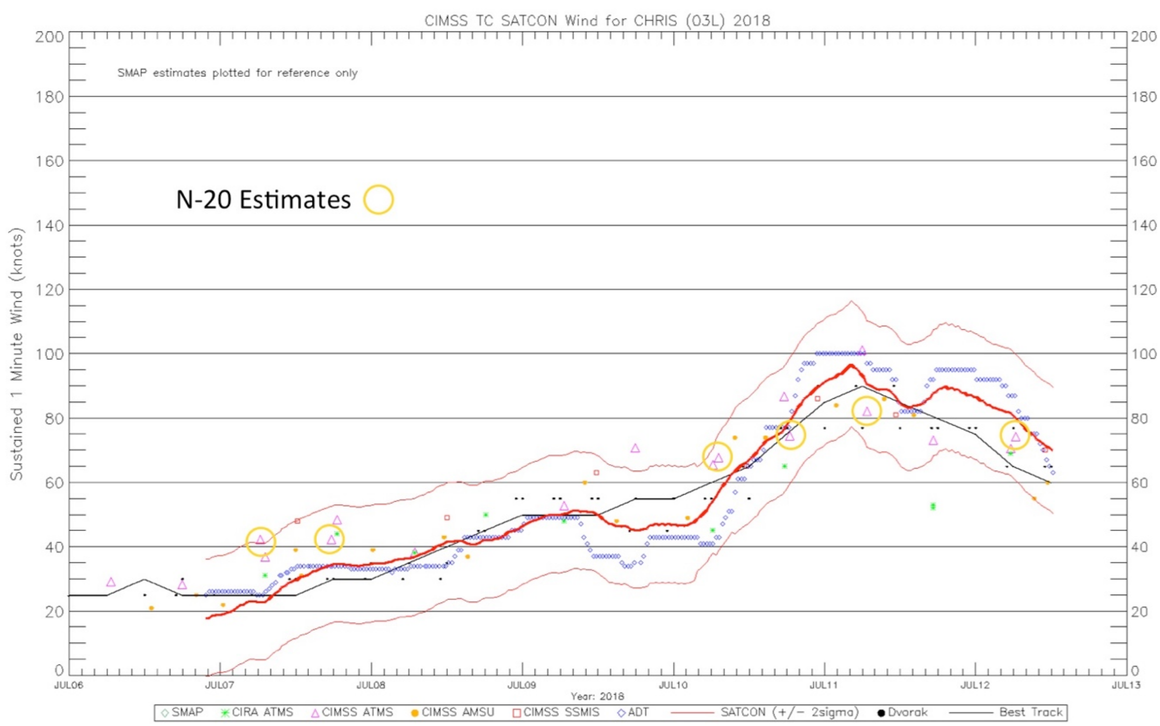


Figure 109. SATCON maximum sustained wind estimates for Hurricane Chris 2018. N-20 ATMS estimates are highighted.

20. CIMSS Participation in the 2018 JPSS Proving Ground/Risk Reduction Research Bundle #2

20.1 Web-based Tool for Rapid Burn Intensity Estimates Using VIIRS NDVI

CIMSS Task Leader: Sam Batzli
CIMSS Support Scientists: Dave Parker, Nick Bearson, Russ Dengel
NOAA Collaborators: Katherine Rowden (NWS/Spokane-WFO), Ivan Csiszar (NOAA/NESDIS-STAR)
Budget: $125,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective

There is a need for timely burn intensity estimates following large wildfires because subsequent rain events can cause life-threatening mud and debris flows. Our objective is to provide timely JPSS satellite-derived burn intensity estimates to enable NWS-WFOs to craft accurate warnings and support their emergency management and response partners

Project Overview

Currently, WFOs often have to wait for Burned Area Emergency Response (BAER) teams to complete on-the-ground assessments of flash flood and debris flow risk before they know which areas are a concern. BAER teams utilize Landsat-derived Burned Area Reflectance Classification (BARC) products from the US Forest Service (USFS) or US Geological Survey (USGS) to begin, or support, their assessment process and development of a final soil burn severity map. However, the BARC product is not intended to be used as an early warning tool. It is a product developed to support BAER teams, and on large fires it can arrive weeks too late for hazard-warning needs of NWS-WFOs. Researchers and programmers will work with an NWS-WFO end-user to design, build, and test a web-based dashboard for rapidly producing post-fire Burn Intensity Delta Greenness Estimation (BRIDGE) maps. The dashboard will help NWS-Weather Forecasting Offices improve their post-fire flash flood and debris flow hazard situational awareness, forecasts, and warnings by integrating SNPP and NOAA-20 VIIRS-derived information into their workflows.

Milestones with Summary of Accomplishments and Findings

Milestone	Planned Completion	Actual Completion	Status
Task 1: Hardware Purchase and Install	Sept 30, 2018	August 1 2018	Completed
Task 2: Begin dashboard design process	Dec 31, 2018	Dec 31, 2018	Completed
Task 3: Code development workflow	Mar 31, 2019	Mar 31, 2019	Completed
Task 4: Initial processing	Jun 30, 2019	n/a	On Track

Initial dashboard design is complete and now being implemented with the code development and workflow. This had involved moving from the desktop environment to the command line server environment to facilitate the semi-automation of the dashboard. Figure 110 shows processing of a difference (or delta) VIIRS dNDVI product over the Thomas Fire near Los Angeles, CA.

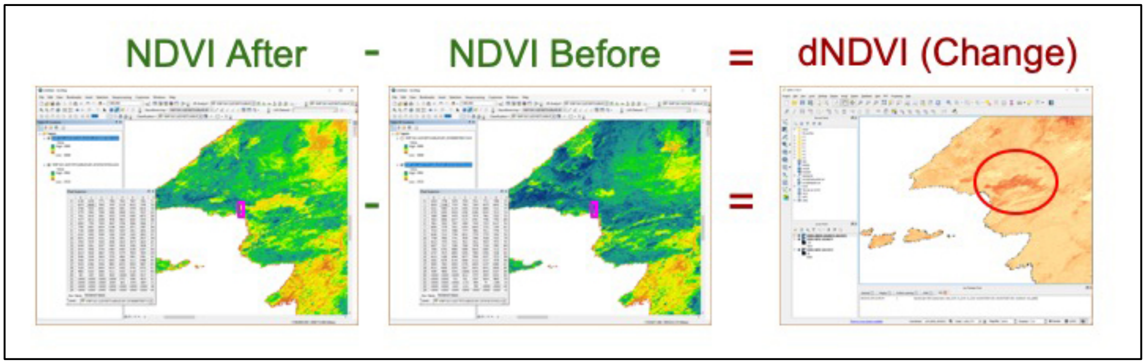


Figure 110. The workflow developed for this product subtracts before NDVI from after NDVI. The difference is highlighted in the VIIRS dNDVI product. This raster image is then transformed to a vector file, shared with NWS-WFOs and integrated into debris flow models to improve situational awareness in a timely manner.

Publications and Conference Reports

AGU 2018, Washington, DC. Presented a poster in the JPSS Fire and Smoke section. Met some important people involved in burn scar work with other sensors and methods.

AMS 2019, Phoenix, AZ. Presented a poster and then also filled in for a missing Federal presentation (because of the shutdown) with this burn scar work in a JPSS session.

After the Flames 2019, Denver, CO. Presented this burn scar mapping work with Bill Sjoberg and Katherine Rowden in the context of JPSS-Fire and Smoke Initiative. Our presentation was very well received, and we established connections with two USGS scientists with whom we had corresponded but not yet met.

20.2 Using JPSS Moisture and Temperature Retrievals to Improve NearCasts of Geostationary Moisture and Temperature Retrievals

CIMSS Task Leader: Lee Cronce
CIMSS Support Scientist: Ralph Petersen
Budget: $40,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society’s needs for weather and water

- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

Improve deficiencies of analyses and projections of infrared-based geostationary (GEO) satellite retrievals of moisture and temperature through fusion with microwave-based low-earth-orbit (LEO) satellite retrievals.

Project Overview

- JPSS (LEO) profiles will be combined with GEO profiles within the NearCast system, which provides short-term projections of satellite moisture and temperature retrievals and derived stability products
- Extend JPSS sounding products both spatially and temporally to address deficiencies in GEO-only datasets
  - In particular, address inconsistencies in cloudy regions apparent in GEO profiles (Figure 111)
- Create more continuous atmospheric analyses and projections for critical weather
  - Most recent JPSS microwave retrievals will be used to fill cloudy, IR-void regions
  - Microwave profiles are preferable since they are 'all-weather' in nature compared to IR profiles
- Enhance use and benefit of JPSS moisture and temperature retrievals in operational forecasting services
  - Provides a means to expose forecasters to the benefits of microwave data, which are infrequently used within WFO operations

Milestones with Summary of Accomplishments and Findings

- Established a new real-time feed of JPSS NUCAPS data via NOAA CLASS for eventual processing and use within a newly-developed hybrid NearCast system
  - Robust data feed with minimum latency of all known data sources
- Hybrid NearCast system has been developed, combining GOES-16 and JPSS NUCAPS retrievals
  - Temperature and moisture data are interpolated to 3-layer nominal resolution of GOES-16 moisture retrievals
  - JPSS NUCAPS retrievals are currently binned every half hour to match temporal resolution of GOES-16 retrievals
  - Simple data weighting currently used for grid points with collocated GOES and JPSS retrievals and initial results show good continuity between data sources (Figure 112)
  - Due to latency differences of retrieval sources (GOES-16 ~5 min, JPSS ~2-3 hr), past runs are reinitialized with new JPSS information and run back to current time (minimal performance lag due to fast run times of NearCast system)
  - Real-time application of system forthcoming

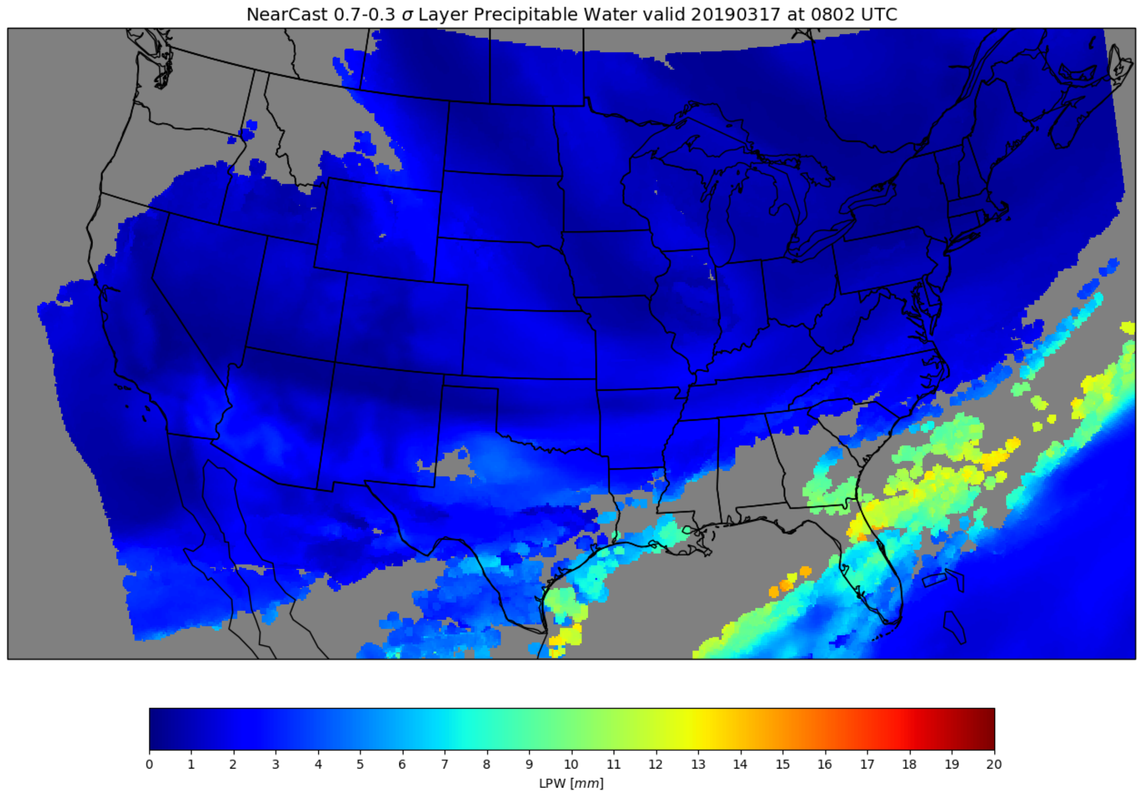


Figure 111. NearCast analysis of GOES-16 0.7-0.3 sigma layer precipitable water valid 17 Mar 2019 at 0802 UTC. Notice the lack of information due to cloud cover from the southeastern U.S. to offshore of the mid-Atlantic coast.

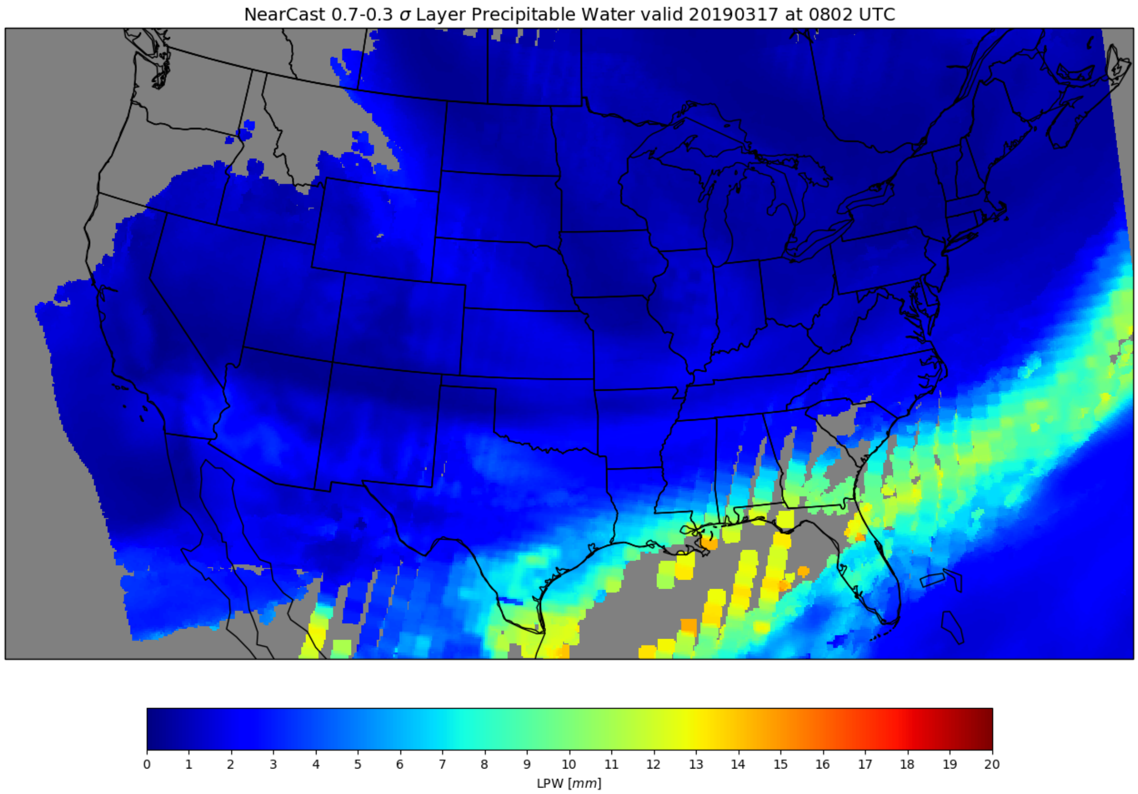


Figure 112. NearCast analysis of combined GOES-16 and JPSS 0.7-0.3 sigma layer precipitable water valid for the same time as Fig. 1. Notice that several cloudy regions apparent in the GOES-16-only analysis have been filled in by the JPSS microwave retrievals. Also, notice the good continuity between the GOES-16 and JPSS data over Mississippi, Alabama, and Georgia where the JPSS microwave profiles have filled in IR-void regions. Even in this case of good GOES-16 coverage, the addition of JPSS microwave retrievals increase data coverage by ~15%.

References

Gravelle, C. M., J. R. Mecikalski, W. E. Line, K. M. Bedka, R. A. Petersen, J. M. Sieglaff, G. T. Stano, and S. J. Goodman, 2016: Demonstration of a GOES-R satellite convective toolkit to "bridge the gap" between severe weather watches and warnings: An example from the 20 May 2013 Moore, Oklahoma, tornado outbreak. *Bull. Amer. Meteor. Soc.*, **97**, 69–84.

Goldberg, M., 2017: The value of polar satellite direct broadcast data for nowcasting and short-range weather forecasting. *2017 EUMETSAT Meteorological Satellite Conf.*, Keynote Address, Rome, Italy, 2-6 October 2017.

20.3. Improving the Assimilation of CrIS Radiances in Operational NWP Models by Using Collocated High Resolution VIIRS Data

CIMSS Task Leader: Jun Li
CIMSS Support Scientists: Kevin Baggett, and Pei Wang
NOAA Collaborators: Mark DeMaria, and John L. Beven, Vijay Tallapragada, Andrew Collard, Ben Ruston
Budget: $130,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

The objective is to improve the assimilation of CrIS radiances in operational NWP models by using collocated high resolution VIIRS data.

Project Overview

Assimilating VIIRS-based CrIS cloud-cleared radiances (CCRs) into the CIMSS near real-time (NRT) Satellite Data Assimilation for Tropical storms (SDAT) system (http://cimss.ssec.wisc.edu/sdat) has resulted in improved tropical cyclone (TC) forecasts (Wang et al. 2017, JGR-Atmospheres). However, because SDAT is a research system for developing and demonstrating prototype data assimilation (DA) methodologies (e.g., VIIRS-based CrIS CCRs), its progress does not necessarily reflect the effectiveness of DA in NOAA's operational numerical weather prediction (NWP) models such as Hurricane Weather Research and Forecast (HWRF) and Global Forecast System (GFS): further work is needed to improve CrIS radiance assimilation in HWRF and GFS, especially in cloudy skies. In collaboration with NOAA users, an initial, short-term demonstration of SNPP VIIRS-based CrIS CCRs in the NOAA operational GFS and Rapid Refresh (RAP) models showed promise (neutral to slightly positive impact), and also indicated that improved CrIS CCRs with quality control (QC) and full spectral resolution (FSR) CrIS CCRs are needed. In addition, both SDAT and GFS/RAP demonstrations showed the need to use the latest versions of NOAA operational NWP models for further experiments and studies. Future work will also include implementing the cloud-clearing algorithm in the community satellite processing package (CSPP) so that VIIRS-based CrIS CCRs can be made available in NRT from multiple direct broadcast (DB) sites over CONUS and adjacent regions for DA applications.

The PI and team propose to continue the science study and develop new approaches for improving CrIS radiance assimilation into NOAA operational NWP models. The team will develop QC steps for VIIRS-based CrIS CCRs based on sub-footprint atmospheric non-homogeneity by using collocated high resolution VIIRS data (IR bands radiances and cloud mask), improve VIIRS-based CrIS CCRs through better error estimation, and apply the VIIRS-based cloud-clearing algorithm to process NOAA-20 FSR CrIS radiances for DA experiments.

There are four steps for the proposed tasks: 1) Develop QC procedures for VIIRS-based CrIS CCRs based on sub-footprint radiance non-homogeneity by using collocated high resolution VIIRS data (cloud mask, IR band radiances), estimate errors on VIIRS-based CrIS CCRs, and apply cloud-clearing technique and QC procedures to process NOAA-20 CrIS FSR radiances; 2) Conduct SDAT demonstrations and further improve VIIRS-based CrIS CCRs; 3) Process

CrIS/VIIRS data and demonstrate the assimilation of VIIRS-based CrIS CCRs in NOAA operational NWP models in collaboration with users (GFS demonstration will be conducted through collaboration with EMC; HWRF demonstration will be conducted mainly by CIMSS scientists using the latest version of HWRF, experiments will be conducted at STAR's supercomputer S4 (Boukabura et al. 2016) physically located at SSEC, both SNPP and NOAA-20 data will be included in the demonstration). NUCAPS-based CrIS CCR assimilation will also be demonstrated and compared with VIIRS-based CCR assimilation in the experiments. In addition to full season hurricane cases over Atlantic Ocean, typical Pacific Ocean typhoon cases will also be included in the offline experiments; and 4) Make VIIRS-based CrIS CCRs available via CSPP over CONUS and adjacent regions in NRT for DA applications.

Milestones with Summary of Accomplishments and Findings

Impacts of Observation Errors of Hyperspectral Infrared Sounder Radiances under Cloudy Skies on Hurricane Forecasts

Hyperspectral infrared sounders provide high vertical resolution atmospheric sounding information that can improve the forecast skill in numerical weather prediction (NWP) models. Usually only radiances not affected by clouds are effectively assimilated in the operational NWP centers due to the challenges in direct assimilating cloudy radiances. Imager based cloud-clearing (CC) technique provides an alternative and effective way to remove the cloud effects from a partially cloudy field-of-view and derive the equivalent clear sky radiances, or the cloud-cleared radiances (CCRs) for assimilation in NWP. Assimilating the CCRs has shown positive impact on hurricane forecasts. Since the observation error is amplified in cloud-clearing process (so called noise amplification), it is therefore necessary to inflate the observation errors in order to achieve the optimal value added impact from assimilating CCRs. The observation error inflation method is developed and discussed; Hurricane Harvey (2017) and Hurricane Maria (2017) are used to demonstrate the impacts of observation error inflation on assimilating CrIS CCRs. The CIMSS Satellite Data Assimilation for Tropical storm forecast (SDAT) is used as testbed in the error inflation study. Three experiments are conducted:

1) CNTRL: assimilates the conventional data from global telecommunication system, AMSU-A, ATMS, and CrIS (operational approach);
2) CCR: CNRTL + CCRs with normal clear observation errors;
3) CCRi : CNTRL + CCRs with inflated observation errors.

It is found that the ETS scores of assimilating CCR and CCRi are much higher than the ETS scores of CNTRL (the operation approaches) for the entire period, which indicates that the assimilation of CCRs can improve the precipitation forecasts. The ETS scores further show that the inflated CCR observation errors can improve the precipitation forecast for both the rainfall location and the intensity.

The assimilation of CCRs with inflated observation errors also improves the hurricane track forecasts. Figure 113 shows the hurricane track (top), and minimum sea level pressure (bottom) RMSE (root mean square error) of three experiments, CNTRL (blue), CCR (red) and CCRi (green), respectively, for the whole 72-hour forecasts of (a) Hurricane Harvey (2017) and (b) Hurricane Maria (2017). The RMSE of the CCRi track is the smallest among the three experiments. These results demonstrate that the noise amplification method for CCRs assimilation could benefit the hurricane forecasts by better represent the observation errors of CCRs data. The CC method for CrIS data will be further applied on the full spectral resolution (FSR) CrIS from SNPP and NOAA-20, and the inflated observation errors will also be used for the full spectral resolution CrIS CCRs assimilation in the future. This method can be applied to other imager/sounder combined observations for improving sounder radiance assimilation in cloudy skies.

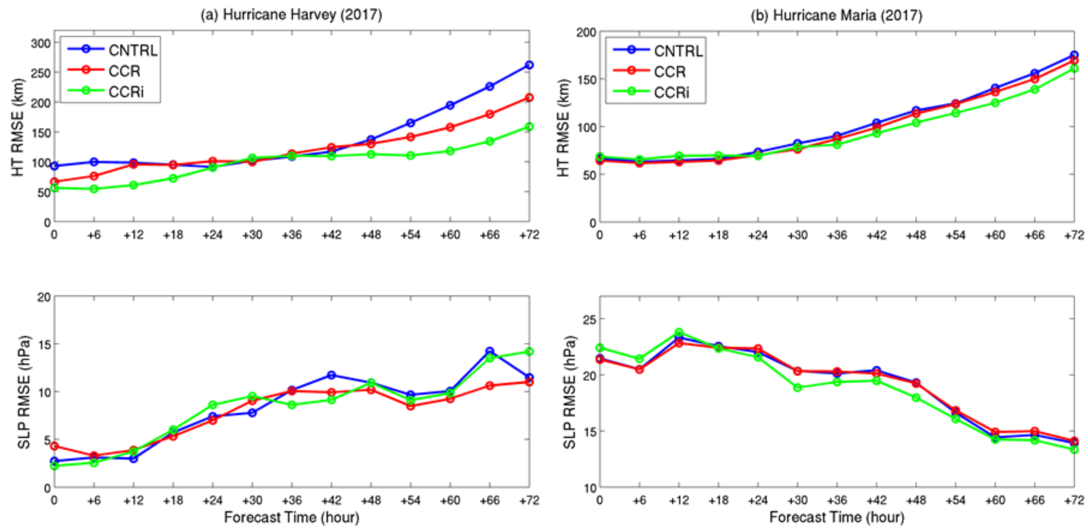


Figure 113. The hurricane track (top), and minimum sea level pressure (bottom) RMSE of three experiments, CNTRL (blue), CCR (red) and CCRi (green), respectively, for the whole 72-hour forecasts of (a) Hurricane Harvey (2017) and (b) Hurricane Maria (2017).

VIIRS-based CrIS full spectral resolution (FSR) cloud-cleared radiances (CCRs) have been successfully developed for experiments with HWRF/S4

Following methodology developed by Li et al. (2005), the imager-based IR sounder cloud-clearing techniques and procedures have been modified to apply to process the collocated VIIRS/CrIS. The VIIRS-based normal spectral resolution (NSR) CrIS CCRs have been successfully tested in SDAT by CIMSS, GFS by EMC and RAP/HRRR by ESRL in FY17. In order to process the CrIS full spectral resolution (FSR) CCRs, the cloud-clearing (CC) algorithm and software have been modified for FSR CrIS/VIIRS cloud-clearing. The NSR CrIS CCRs and FSR CrIS CCRs are compared each other to assure the reliable CrIS CCRs. The spectral differences between NSR and FSR have been taken into account in the cloud-clearing algorithm which is now able to process both NSR and FSR now. The right panel of Figure 114 shows the VIIRS IR BT at CrIS footprint, and the left panel shows the BT difference image between NSR and FSR CCRs. The differences overall are very small, indicating that the cloud-clearing software can produce CCRs from both NSR and FSR with similar quality for data assimilation. The lower panel shows the longwave BT difference (RMS) spectrum from a granule, further assures the similar performance between NSR and FSR CCRs.

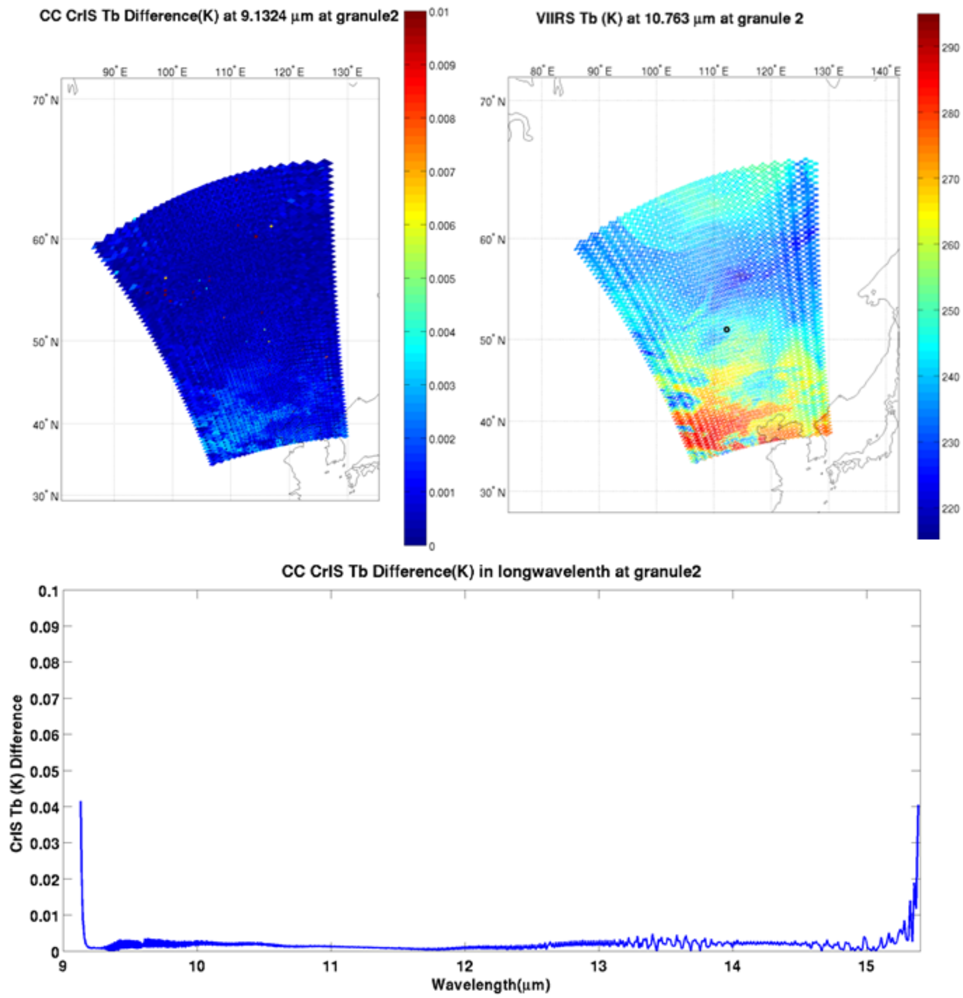


Figure 114. VIIRS IR BT (K) at CrIS footprint (upper right); the BT difference image between NSR and FSR CCRs (converted to BT) (upper left); and the longwave BT difference (RMS) spectrum between NSR and FSR CCRs from the granule in this figure.

The CrIS CC radiances from those footprints can be assimilated as clear in NWP models. The CrIS FSR CCRs for three typical hurricane cases in 2017 (Harvey, Irma and Maria) have been created and the assimilation experiments will be conducted in next couple months.

Related Publications and Conference Presentations

Menzel, W. Paul, Timothy J. Schmit, Peng Zhang, and Jun Li, 2018: Satellite based atmospheric infrared sounder development and applications, Bulletin of American Meteorological Society. 99, 583 - 603.

Pei Wang, Jun Li, Agnes Lim, Zhenglong Li, Jinlong Li, Tim Schmit and Mitchell Goldberg, 2019: Impact study of Observation Errors of Hyperspectral Infrared Sounders under Partially Cloudy Regions on Hurricane Harvey (2017) forecasts, 99th AMS Annual Meeting, 06 – 10, January 2019, Phoenix, ZA.

References

Li, J., C. Y. Liu, H.-L. Huang, T. J. Schmit, W. P. Menzel, and J. Gurka, 2005: Optimal cloud-clearing for AIRS radiances using MODIS. IEEE Trans. On Geoscience and Remote Sensing, 43, 1266 - 1278.

Menzel, W. Paul, Timothy J. Schmit, Peng Zhang, and Jun Li, 2018: Satellite based atmospheric infrared sounder development and applications, Bulletin of American Meteorological Society. 99, 583 - 603.

Wang Pei, Jun Li, Z. Li, A. H. N. Lim, Jinlong Li, T. J. Schmit, and M. D. Goldberg, 2017: The Impact of Cross-track Infrared Sounder (CrIS) Cloud-Cleared Radiances on Hurricane Joaquin (2015) and Matthew (2016) Forecasts, Journal of Geophysical Research - Atmospheres, 122, DOI: 10.1002/2017JD027515.

20.4 Quantifying NCEP's GDAS/GFS Sensitivity to CrIS Detector Differences

CIMSS Task Leader: Agnes Lim
CIMSS Support Scientists: Sharon Nebuda, Dave Tobin and James Jung
Budget: $150,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Objective

Help define the inter-detector design requirements. Instrument providers will need this information to assure that all instrument FOVs are matched well enough to support NWP radiance assimilation.

Project Overview

Design of Infrared (IR) sounding instruments has advanced to use large arrays of detectors to make simultaneous observations. Different bias, noise and correlation properties between detectors within one large array can result in the need to treat observations from each detector differently. This is not desirable for Numerical Weather Prediction (NWP) centers, as observations from each detector have to be treated as independent instruments. The consequence of this is a reduced usage of the observation type if NWP centers choose to select data from one detector to avoid this complication. Current radiometric uncertainty and noise-equivalent change in radiance (NEDN) requirements for IR sounder instruments do not fully address or constrain the noise characteristics between detectors. Detector properties, such as quadratic nonlinearity and detector noise, will contribute to inter-detector bias. No systematic studies have been conducted to determine the degree of match needed between detectors in an array used for IR sounding instruments that support NWP. Understanding what level these inter-detector biases begins to affect NWP analysis and forecast systems is the goal of this research proposal.

This study will help to determine the inter-detector matching requirements of the Cross-track Infrared Sounder (CrIS) necessary to avoid negative impact on the National Centers for Environmental Prediction (NCEP) Global Forecast System Data Assimilation System (GDAS). Inter-detector differences are estimated from real observations for N20 CrIS and applied to simulated N20 CrIS observations. N20 CrIS perfect observations were simulated from NASA GEOS-5 analysis. The areas of focus for this study will be on sensitivity of NCEP GDAS to CrIS Full Spectral Resolution (FSR) detector differences and quantifying the impact of the different amounts of CrIS-FSR detector nonlinearly on model analyses and forecasts.

Milestones with Summary of Accomplishments and Findings

Milestones were generally met with a slight delay in schedule initially on the simulation of perfect CrIS observations. The plan to use clear sky radiances from a JPSS OSSE conducted in a previous project had been dropped, as the time period of the dataset was too old for the version of GFS to be used in this project. In addition, all CrIS channels in band 1 will be needed for this study and are not available in that dataset. The clear sky CrIS radiances were simulated using NASA GEOS-5 analyses for the time period of July to Sept 2018. All 713 longwave bands (band 1) will be simulated and encoded into BUFR. All observations available in the current CrIS FSR BUFR file were simulated. When simulating CrIS observations, an aqua planet was used. Figure 115 shows the comparison of observed against simulated brightness temperature for CrIS channel 89 assuming clear sky conditions. Observed and simulation are in good agreement.

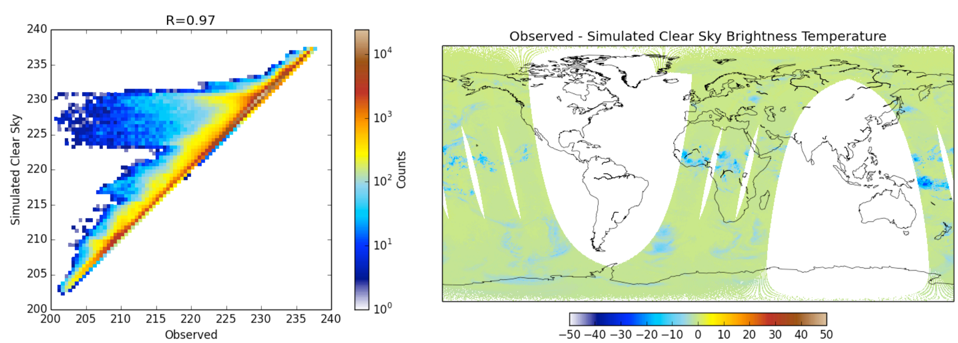


Figure 115. N20 CrIS channel 89 at 705cm-1 (14.1µm). (Left) Observed clear sky brightness temperature verses simulated brightness temperature. (Right) Geographical difference of the difference between observed and simulated brightness

The CrIS detector noise consists of both correlated and random component. The CrJS detector noise was estimated from calibration of Internal Calibration Target (ICT) views using ICT and Deep Space views from that granule. Mean noise values of all estimates/granules from 30 March 2018. Two sets of noise added BUFR files with noise were created from the perfect observations; one had FOV5 noise added while the other set has FOV dependent noise added.

A two-week spin-up period was conducted to allow bias correction to stabilize and any artifacts to dissipate due to the resolution change of the initial condition files. The spin-ups were conducted separately for the two parallel assimilation experiments; cris_n1 assimilates CrIS observations with constant FOV noise and cris_n2 assimilates CrIS observations with FOV dependent noise. Zero bias coefficients and larger observational weights were used for N20 CrIS at the beginning of the experiments. Only CrIS channel 92 has been assimilated. The choice of this channel was based on minimum top of atmosphere and surface contribution as well as the peak of the weighting function located at mid troposphere. System stabilized after 24 cycles (6 days). During this spin up period, the decision was made to include microwave observations (AMSU-A and MHS) from NOAA-15, 18 and 19, METOP-A and B and AQUA in the assimilation experiments to maintain stability in the minimization. From the 25th cycle, the CrIS observation weights were restore to those used in operations. The experiments will run for two months and is currently ongoing. To date, we have completed 50% of the total length of run. Preliminary results (Figure 116) using 20 days of the assimilation diagnostics shows that cris_n2 experiment favors the selection of FOV 7. More experiment days are needed for analysis.

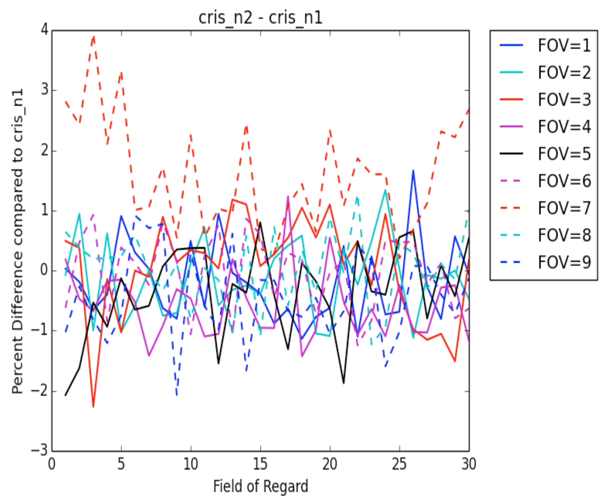


Figure 116. Percent difference in FOV selected between cris_n1 and cris_n2 compared to cris_n1.

20.5 Development of Global Geostationary-JPSS Flood Mapping Software and Products

CIMSS Task Leader: Jay Hoffman
CIMSS Support Scientists: Dave Santek, Shane Hubbard
Budget: $57,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Support GMU in the development of a global flood detection algorithm.

Project Overview

A river flood product was originally developed for VIIRS at George Mason University (GMU). CIMSS has provided support for this product to run routinely using direct broadcast VIIRS data. Through this project the software will expand VIIRS support for NOAA-20 in addition to the SNPP. Flood product coverage will also expand to geostationary satellite platforms including GOES-16/ABI and Himawari-8/AHI.

Milestones with Summary of Accomplishments and Findings

Using project funds, a new computer has been purchased and is dedicated to flood product generation. CIMSS has provided support in acquiring data and computing resources. Using direct broadcast, VIIRS NOAA-20 coverage has been added to SNPP flood product coverage with low latency. The GOES-16/ABI flood product software now runs routinely for every daylight CONUS image.

Data for test cases with Himawari-8 AHI data has been provided to GMU for software testing. An AHI product example in Figure 117 shows results from a large flooding event in Cambodia. Development at CIMSS has begun on software to generate vector flood products in addition to the traditional raster mask products. Concurrently, FEMA has developed a shapefile product that is shows the maximum flood extent over the last five days from the raster satellite flood products (that are delivered via ftp from CIMSS).

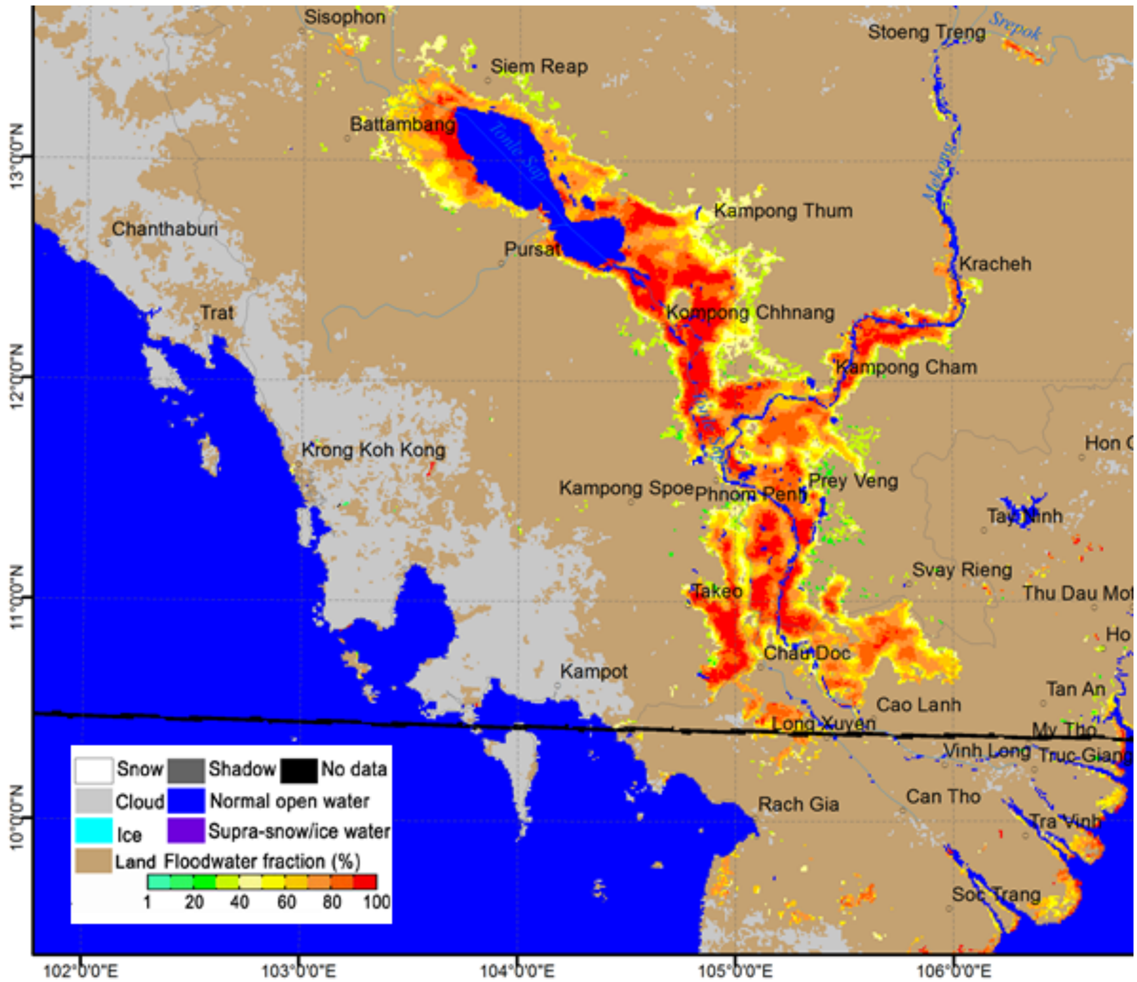


Figure 117. Flood product in Cambodia from 21 August 2018 using Himawari-8/AHI.

20.6 Project Task: The JPSS Advocacy Channel
CIMSS Task Leader: Scott Lindstrom
CIMSS Support Scientists: J. Gerth, W. Straka III
NOAA Collaborators: Nate Eckstein, Eric Lau, Bill Ward, Kevin Scharfenburg
Budget: $48,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective
Create JPSS-Focused training material that clearly shows NWS forecasters (and other forecasters) why JPSS data should be used.

Project Overview
Forecasters and the National Weather Service forecast offices (and elsewhere) require training information on JPSS products if they are expected to use them to their greatest potential. Material created (or linked to) as part of this project will increase the visibility of JPSS data and training to the general meteorological community.

Milestones with Summary of Accomplishments and Findings
This project is just starting. A website that includes JPSS Data Sources and Training sites has been created at https://jpss.ssec.wisc.edu/data/jpssdata.html ; In additions, a YouTube channel 'JPSS Advocacy Channel' now exists that includes, to date, 10 videos that either describe a JPSS Products, show how it can be used, or document how it can be created.

Publications and Conference Reports
Lindstrom, S. S., J. J. Gerth and W. S. Straka III, 2019: **The JPSS Advocacy Channel.** Oral Presentation given at 15th Annual Symposium on New Generation Operational Environmental Satellite Systems, 99th Annual Meeting of the American Meteorological Society, 6-10 January 2019, Phoenix, AZ.

21. CIMSS Participation in the 2018 JPSS Proving Ground/Risk Reduction Bundle #3

21.1 Use of Direct Broadcast POESS and GOES for Localized Convective Weather Forecasting
CIMSS Task Leader: William L. Smith Sr.
CIMSS Support Scientist: E. Weisz, J. Gerth
NOAA Collaborators: M. Dutter, J. Gagan
Budget: $149,131

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

- Environmental Models and Data Assimilation
- Education and Outreach

Objective
To produce soundings from a combination of Direct Broadcast polar soundings and ABI radiances to create products useful to the NWS for forecasting convective initiation.

Project Overview
A joint University of Wisconsin (UW) and the Hampton University (HU) three-year project (FY 2018-2020) was proposed to produce, in real-time, atmospheric soundings derived by combining Direct Broadcast (DB) Polar Hyper-spectral Soundings (PHS) provided by CrIS, AIRS, and IASI (onboard JPSS, Aqua and Metop platforms, respectively) with GOES ABI multi-spectral radiances. These soundings are being used to produce high spatial (i.e., 2-km) and high temporal (i.e., hourly) resolution thermodynamic profile products that can be used by NWS Weather Forecast Office (WFO) personnel to predict the location and time of initiation of convective weather within their region of responsibility. Daily verification of the product accuracy is being conducted using operational radiosonde observations within the regions of DBS data acquisition. Forecasters at the Wakefield VA (AKQ) and Milwaukee/Sullivan WI (MKE) WFOs will assess the operational nowcasting utility of the satellite-sounding product produced using the DBS systems at Hampton University and the University of Wisconsin-Madison.

Milestones with Summary of Accomplishments and Findings
First year milestones met included meetings were held with Michael Dutter and John Gagan, the Science Operations Officers, at the Wakefield VA and the Sullivan Wisconsin WFOs, respectively. Preparations were made for the routine use of the combined GOES ABI and Polar DBS hyperspectral data during the 2019 severe weather season. The PHS and PHS/ABI combined (PHSnABI) satellite retrieval products were made available through the web site: http://dbps.cas.hamptonu.edu/development/ .

The quality of the PHS and PHSnABI retrievals was assessed through comparisons with radiosonde profiles. The individual profile comparisons and validation statistics of the results for the PHS soundings can be seen at the web-site address: ‘ http://cas.hamptonu.edu/dbps_cron/adinorscia/JOBS/ ‘ and for the combined PHS/ABI soundings at: ‘http://cas.hamptonu.edu/~adinorscia/RadiosondesCompare/ ‘. Comparisons between this project’s DBS CrIS retrievals and those produced using the NUCAPS algorithm can be seen at: http://cas.hamptonu.edu/dbps_cron/adinorscia/JOBS/AKQ/Ensemble/ and http://cas.hamptonu.edu/dbps_cron/adinorscia/JOBS/MKE/Ensemble/. It has been found that the model independent NUCAPS comparisons are useful for validating the forecast model vertical resolution de-aliased DBS retrievals when they differ significantly from the Radiosonde measurements and the RAP model forecast profiles.

Significant improvements in the NASA ER-2 aircraft Scanning High-resolution Interferometer Sounding (S-HIS) retrieval algorithms have been made during this quarter as a prelude for their use during the FIREX-AQ 2019. The SHIS code modifications include retrieval of CO, CH4, SO2, N2O, and O3 trace gas, as well as temperature and water vapor profiles. These algorithms were validated using data acquired during the April 2017 GOES-16 validation campaign. During FIREX-AQ, the aircraft retrievals will be used to validate PHSnABI retrievals at locations and times not sampled by conventional radiosondes, as well as provide atmospheric trace gas profile retrievals to the FIREX-AQ database used to accomplish that program’s Air Quality observation and forecast objectives.

Accomplishments during the first year included the development and implementation of the k-d tree search method (see references) for the fusion of clear sky regression retrievals, produced from hourly interval GOES-16 ABI radiances data, together with Dual-Regression (DR) vertically De-Aliased (DA) Polar Hyper-spectral Satellite (PHS) retrievals produced from Direct Broadcast Satellite (DBS) CrIS and IASI radiance measurements. The resulting product is an estimate of hyper-spectral vertical resolution retrievals at the 4-km horizontal resolution of the ABI sensor. Also, a high-resolution (3 to 9-km) RAP-like Weather Research and Forecasting (WRF) model was implemented to assimilate the polar sounding, and the combined geostationary and polar sounding products, to produce numerical forecasts of intense weather conditions. The model was successfully demonstrated using DBS retrievals obtained for both the Hurricane Florence and Hurricane Michael related intense weather occurrences on September 9 and October 10, 2018. Also, the WRF model was used to assimilate the combined geostationary and polar sounding products, to successfully produce improved numerical forecasts of intense weather conditions for the March 3, 2019 Tornado outbreak across the Southeastern US.

Figure 118 and Figure 119 show a few examples of the results obtained from the numerical forecasts conducted for 3 March 2019. They show that for this case there was a significant improvement in the forecasting of the location and timing of severe convective weather and associated tornadoes when the high-resolution (i.e., 2-km, hourly) data are used to initialize the forecast model. Also, the location and intensity of the rainfall associated with these storms was greatly improved.

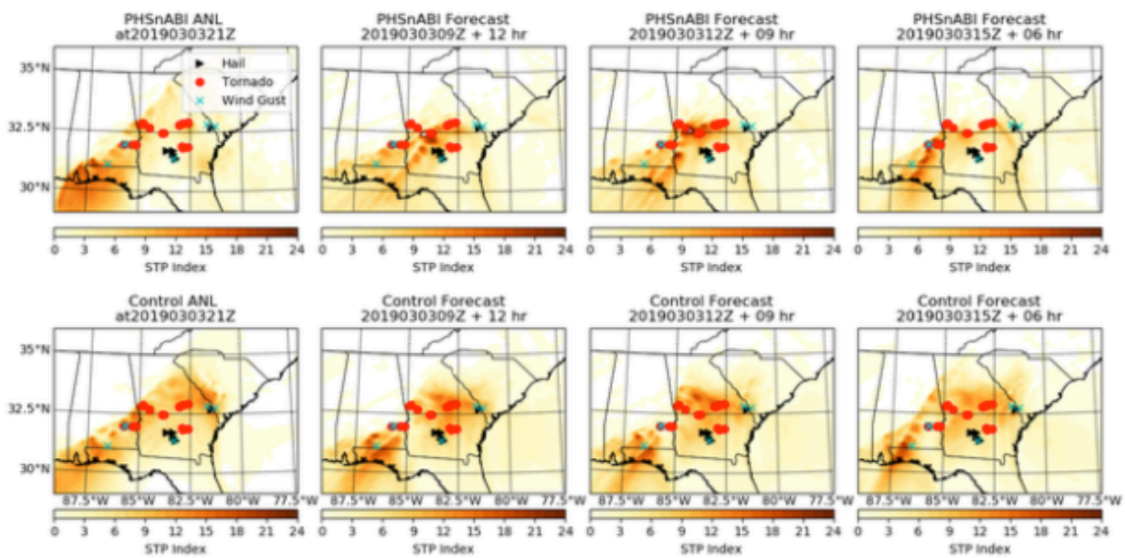


Figure 118. 3, 6, and 12-hr forecasts of the Significant Tornado Parameter (STP) defined as the sum of the CAPE, 0-1 km storm relative helicity/vorticity, 0-6 km bulk wind difference, surface parcel LCL height. Intense convection and tornadoes can be expected where the STP is high. The top row pertains to numerical forecasts made by including the PHSnABI soundings with the operational RAP database whereas the bottom row of forecasts were made excluding the satellite soundings.

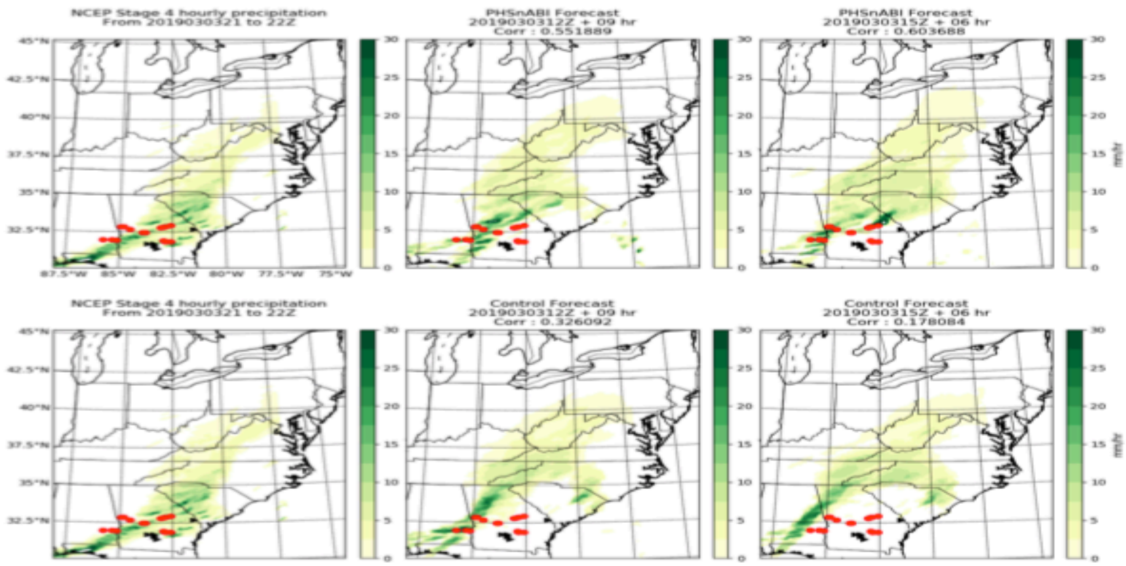


Figure 119. 6 and 9-hour forecasts of the 21-22 UTC hourly precipitation conducted with (PHSnABI) and without (Control) polar plus geostationary satellite radiance derived vertical temperature and moisture soundings. The much higher forecast skill of the satellite sounding initialized precipitation forecast can be seen by their comparison with surface and radar (Stage 4) hourly precipitation measurements shown by the panels on the left side of this figure.

Publications and Conference Reports

DiNorscia, A., W. Smith, and J. McNabb, (2019): Determining the Ability to Use Direct Broadcast System (DBS) Data to Forecast Severe Weather. 23rd Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, 99th Annual Meeting of the American Meteorological Society, Phoenix, AZ.

Shao, M., and W. L. Smith, (2019), Impact of Atmospheric Retrievals on Hurricane Florence/Michael Forecasts in a Regional NWP Model. Accepted for publication in JGR-Atmosphere.

Smith, W. L., E. Weisz, A. DiNorscia, J. McNabb, and M. Shao (2018), On the Combination of polar satellite hyper-spectral and geostationary satellite multi-spectral radiance observations for optimizing the spatial and temporal resolution of atmospheric soundings; SPIE Asia-Pacific Remote Sensing Symposium, 24 - 26 September 2018, Honolulu, Hawaii, United States

Smith, W. L., E. Weisz, J. Gerth, A. DiNorscia, J. McNabb, M. Shao, M. Dutter, J. Gagen (2019), Developing Meteorological Forecast Products in Near Real-time from Hyper-spectral Sounder Radiances; American Meteorological Society 99th Annual Meeting, Phoenix AZ, 6-10 January 2019.

References

Smith, W. L., E. Weisz, S. V. Kireev, D. K. Zhou, Z. Li, and E. E. Borbas (2012), Dual-regression retrieval algorithm for real-time processing of satellite ultraspectral radiances, *J. Appl. Meteor. Climatol.*, **51**, 1455 – 1476.

Smith, W. L., and E. Weisz. (2017) Dual Regression Approach for High Spatial Resolution Infrared Soundings, in *Comprehensive Remote Sensing*, M. Goldberg, Editor, Elsevier Ltd, Langford Lane Oxford, OX5 1GB UK.

Weisz, Elisabeth; Baum, Bryan A. and Menzel, W. Paul, Fusion of satellite-based imager and sounder data to construct supplementary high spatial resolution narrowband IR radiances, Journal of Applied Remote Sensing, Volume 11, Issue 3, 2017.

21.2 Merging NUCAPS with the VIIRS Enterprise Cloud Algorithms for Improved Polar Cloud Detection, Cloud Heights and Polar Winds

CIMSS Task Leader: Steve Wanzong
CIMSS Support Scientists: Yue Li, Sharon Nebuda, Greg Quinn, Nick Bearson
External Support Scientist: Nadia Smith (STC)
NOAA Collaborators: Andrew Heidinger, Jeff Key
Budget: $90,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

To improve cloud detection, cloud heights, and polar winds by combining NUCAPS and VIIRS cloud algorithms.

Project Overview

The Visible Infrared Imaging Radiometer Suite (VIIRS) is the primary sensor for providing cloud products from NOAA-20. These products are both used directly and as critical inputs to the Cross-track Infrared Sounder (CrIS) Radiance Assimilation and Polar Winds Applications. Polar regions provide bright surfaces, deep atmospheric inversions and very cold surfaces. Without absorbing IR bands, the accuracy of the VIIRS cloud detection and cloud heights suffers in Polar Regions. The cloud products from the NOAA-Unique CrIS/ATMS Processing System (NUCAPS) provide cloud fraction and cloud-top pressure at a resolution of 50 km. While the spatial resolution of NUCAPS is much coarser than VIIRS (0.75 km), the hyperspectral retrievals used in NUCAPS should perform well over Polar Regions.

The VIIRS cloud detection and cloud height algorithms use Bayesian (mask) and Optimal Estimation (height) approaches. Both of these techniques allow for the use of prior information. This information can be from climatology, a numerical forecast, or as in this case, retrievals from NUCAPS. Heidinger et al. (2018) demonstrated the use of CrIS-derived cloud heights to improve the accuracy of cirrus cloud heights from VIIRS. This technique with NUCAPS-derived CrIS heights and the NUCAPS cloud fraction will assist the VIIRS cloud detection. The spectral information from CrIS should improve the high horizontal resolution VIIRS cloud products. These improvements should naturally lead to improvements in the Polar Winds and CrIS/VIIRS radiance assimilation.

Milestones with Summary of Accomplishments and Findings

Methodology

The NUCAPS cloud pressures are collocated to VIIRS using tools from UW-Madison SSEC (Greg Quinn software). A gross error check throws NUCAPS pixels away if the cloud fraction is less than 0.2. NUCAPS top layer cloud pressures are converted to temperatures. The VIIRS cloud phase in tandem with the NUCAPS cloud temperatures are used to isolate ice pixels. The NUCAPS ice cloud temperatures are then spatially spread to surrounding VIIRS pixels. Smoothed NUCAPS ice cloud temperatures become an a-priori constraint in the VIIRS Optimal Estimation (OE) cloud height retrieval. The cloud mask, phase, and height pixels are used as input into the GOES-R AWG derived motion wind (DMW) software to height assign wind vectors.

Figure 120 shows an example of the methodology described above. The VIIRS CTT product in the image shows all available cloud pixels. However, only the upper level ice clouds would have been adjusted by this new method.

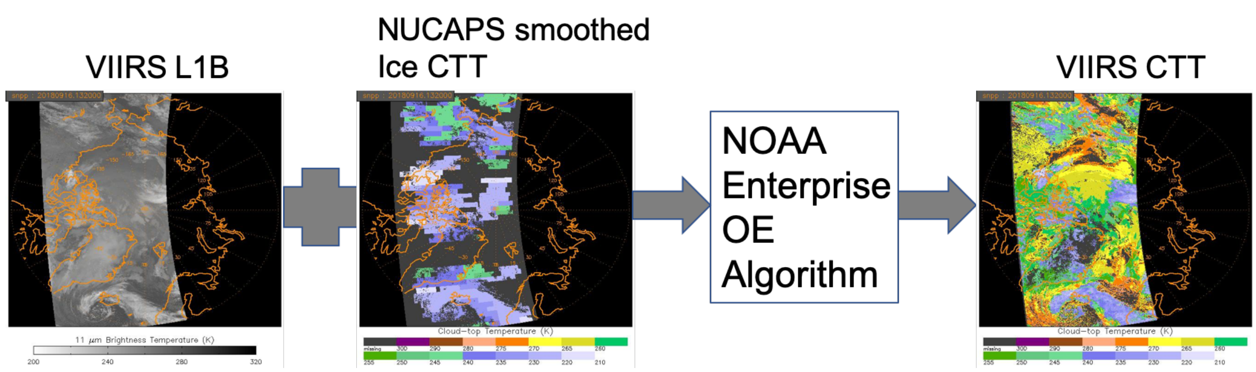


Figure 120. Methodology of the VIIRS+NUCAPS retrievals.

Cloud Top Height Assessment

One day's worth of Arctic VIIRS/CrIS passes from September 11, 2018 were processed using VIIRS only retrievals, and VIIRS+NUCAPS heights. Both were collocated with CALIPSO data. Figure 121 shows the bias between the retrievals and CALIPSO using four different cloud types. Thin (cloud emissivity less than 0.4), moderate (emissivity between 0.4 and 0.8), thick (emissivity greater than 0.8) and all clouds.

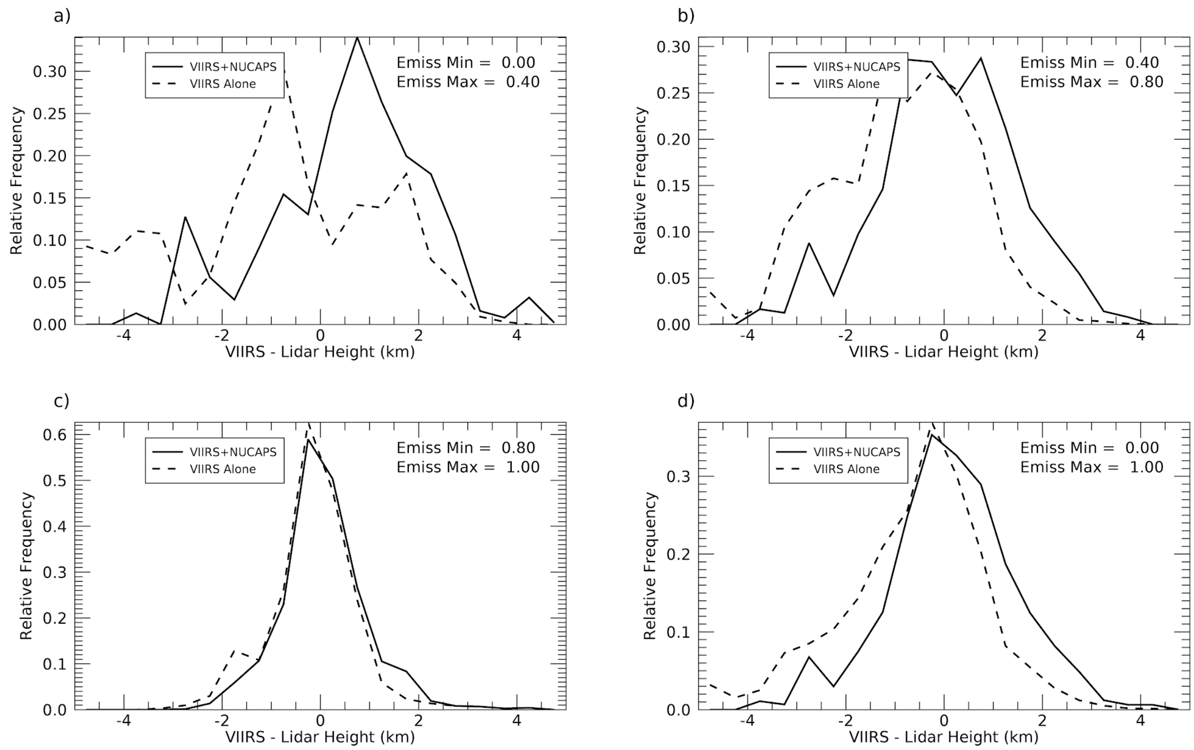


Figure 121. VIIRS+NUCAPS cloud height bias compared to CALIPSO for various cloud emissivites.

The NUCAPS adjusted heights should have the largest impact in thin ice clouds (a), and no impact in the thick clouds (c). Figure 121 indicates that the algorithm with NUCAPS is behaving in the correct manner.

Polar Winds Use

As Figure 121 shows, the NUCAPS adjusted heights have a positive impact on the ice clouds. The hope is that this positive impact translates to the DMW algorithm. Figure 122 is an example DMW set which uses the pixel level cloud heights in the DMW algorithm.

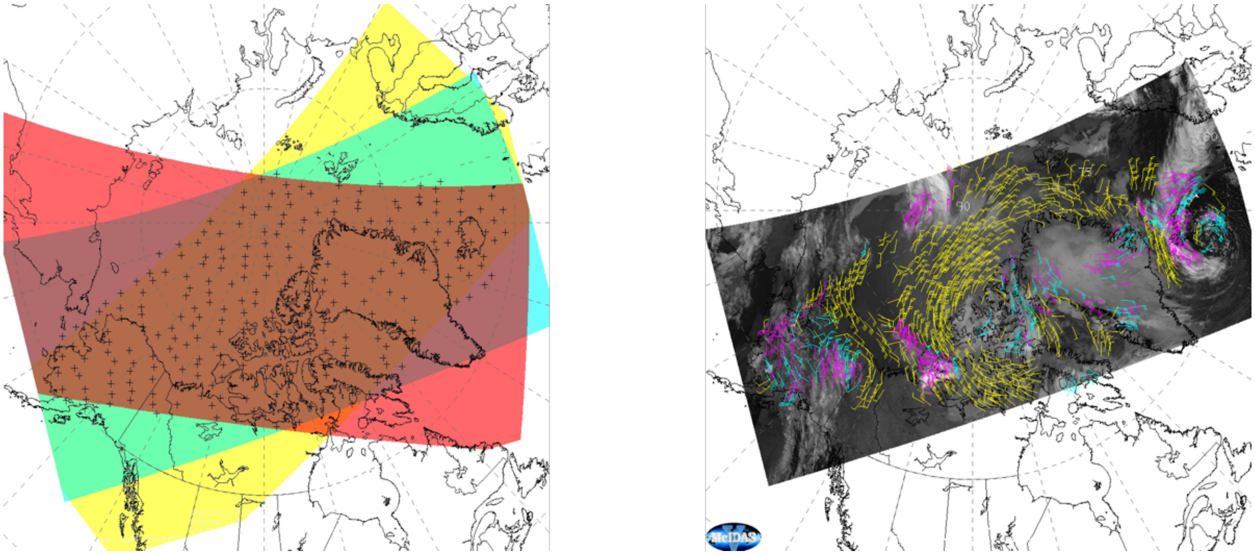


Figure 122. VIIRS Tracking triplet and DMW overlap region in brown (left). Example DMW product (right).

The left image shows the location of 3 VIIRS triplets (each swath may contain up to 13 granules) from September 16, 2018. The center time of the overlap region (in brown) is 1306 UTC. The two tracking images are 101 minutes before and after 1306 UTC. The right image shows the DMW product. Magenta vectors range from 100 - 400 hPa, cyan from 400 - 700 hPa, and yellow from 700 and below.

Figure 123 shows that the NUCAPS adjusted DMWs are pushed higher (lower hPa) in the atmosphere. Again, this is the expected behavior. However, at the time of this report, no validation of the DMWs against RAOBs have been run so it is not possible to assess the impact of the new algorithm.

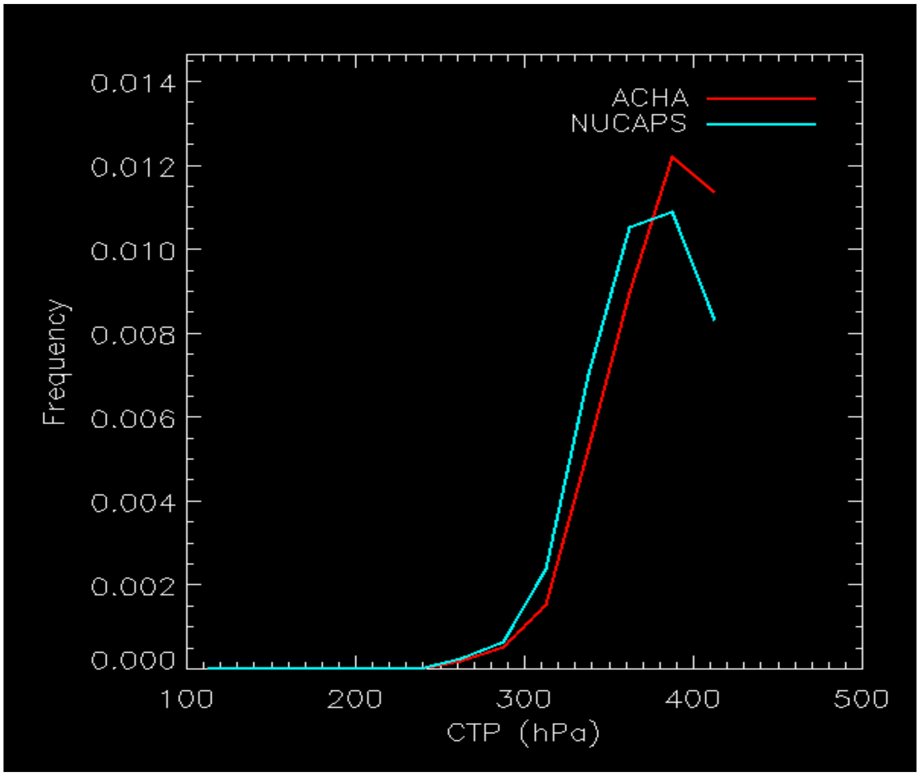


Figure 123. A day's worth of Arctic DMW cloud top pressure from September 16, 2018.

Using NUCAPS provides a beneficial constraint on the cloud heights. The process works and improved pixel level heights (via CALIPSO) are observed. Impacts, good or bad, are seen in the DMWs. The DMW algorithm is moving towards a product which uses Suomi NPP/NOAA-20 data together (50 minute orbit separation) and will allow a global dataset. Bigger impacts in the Tropics (more cirrus) will hopefully be observed.

Publications and Conference Reports

Heidinger, Andrew K.; Bearson, N.; Foster, M. J.; Li, Y.; Wanzong, S.; Ackerman, S.; Holz, R. E.; Platnick, S. and Meyer, K. Using sounder data to improve cirrus cloud height estimation from satellite imagers. Accepted in the Journal of Atmospheric and Oceanic Technology, 2019.

21.3 The Cold Air Aloft Aviation Hazard: Detection Using Observations from the JPSS Satellites and Application to the Visualization of Gridded Soundings in AWIPS II

CIMSS Task Leader: Robert Knuteson
CIMSS Support Scientists: Dave Hoese, Kathy Strabala
NOAA Collaborator: Kristine Nelson (NOAA/CWSU)
Budget: $5,000

NOAA Long Term Goals:

- Weather-Ready Nation
- Resilient Coastal Communities and Economies

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

This proposal is responsive to JPSS Initiative #5 (Sounding Applications; sub-bullet #1) and secondarily responsive to JPSS Initiative #7 (OCONUS and NCEP Service Centers AWIPS; sub-bullet #4). The primary objectives of this proposal are as follows:

1) Develop and disseminate gridded real-time CrIS/ATMS products through DB.
2) Generate new AWIPS II visualization capabilities with gridded products for 3-D visualization of CrIS/ATMS profile data.
3) Transition experimental product to Alaska CWSU and perform targeted assessment to determine operational utility of product for CAA forecast challenge.
4) Identify and investigate other forecast challenges outside of CAA where similar visualizations may be beneficial.

Project Overview

The NOAA/NWS CWSU in Anchorage, Alaska has forecast responsibilities for disseminating text-based products to pilots and airlines, which give guidance on the latitude/longitude bounds and vertical flight levels of these cold air aloft (hereafter CAA) regions where the air temperature is at or below -65^{o}C. Previously, forecasters at the CWSU would rely on a combination of isolated aircraft reports, a sparse network of radiosondes, and global model fields for identifying and characterizing these cold air hazards. However, these current datasets have proven spatially and vertically insufficient for the accurate characterization of the three-dimensional (3-D) nature of these CAA features. Forecasters have expressed an urgent need for additional data to be added to fill observational gaps and/or confirm information that is seen in models (i.e., to build confidence in numerical CAA predictions). One source of observations that has remained largely unused but promises to add great value is temperature soundings from hyperspectral infrared (IR) instruments onboard polar-orbiting satellites. Decision support systems have traditionally been used to visualize observations from space-based imagers as two-dimensional (2-D) surface plots (e.g., a cloud field). Satellite soundings, however, offer 3-D characterization of the atmosphere (latitude, longitude, and height) that can potentially improve forecasting skill in general and the characterization of these CAA regions specifically.

Milestones with Summary of Accomplishments and Findings

Develop and Disseminate Gridded CrIS/ATMS Products through Direct Broadcast

The Dual Regression Retrieval (DR) and Polar2Grid software tools have been available within CSPP for more than two years. At present, the DB site at GINA (U. Alaska) runs CSPP in real-time and disseminates products via File Transfer Protocol (FTP). NUCAPS, the NOAA operational CrIS/ATMS processing algorithm, was released within CSPP at the end of February 2015. GINA receives CrIS/ATMS data from the S-NPP satellite via DB antennas at the University of Alaska campus in Fairbanks and at the NOAA Satellite and Information Service

(NESDIS) Command and Data Acquisition Station at Gilmore Creek, Alaska. We successfully implemented the NUCAPS retrieval products at GINA by using the CSPP software to process the data and generate products depicting the CAA phenomenon in formats ready for ingest into AWIPS II.

UW-CIMSS provided critical support for the adaptation of Polar2Grid software for use with the NUCAPS product. A list of accomplishments from the previous year are provided below:

- This project funded new features, software bug fixes, and software maintenance in the form of testing, documentation, updating third-party libraries, and software packaging of official Polar2Grid releases.
- Initial work added ability to read NUCAPS retrieval NetCDF4 files via a NUCAPS "Reader".
- The Reader could produce Temperature (Temperature) and H2O Mixing Ratio (H2O_MR) data that was then resampled to a uniform grid and written to an HDF5 file via Polar2Grid.
- Resampling was done using a nearest neighbor resampling algorithm.
- HDF5 files were then used by SPORT to view the data in AWIPS and other tools.
- Feature: Ability to mask data below the surface pressure
- Feature: Ability to mask data based on NUCAPS quality flags
- Feature: Ability to specify which pressure levels to produce
- NUCAPS reading was a challenge for Polar2Grid as it was the first pressure-based products it had ever had to read.
- Second round of work added “Skin_Temperature,” “Surface_Pressure,” and “Topography” to produced output.
- The ability to turn off the above-mentioned masking functionality was also added.
- Additional work was done to add fields that may be used in the future.
- The NUCAPS functionality added to Polar2Grid was done so via the open source python library SatPy in collaboration with the PyTroll group. It can be accessed in SatPy using the reader name “nucaps.”
- By adding the NUCAPS Reader to SatPy we benefit from many developers reviewing the code, more testers, more users, and reduced redundancy of code. We also benefit from any features or optimizations that may be contributed to the project; even when it isn't added specifically for the NUCAPS Reader.
- Polar2Grid and SatPy (as well as other PyTroll python packages) are hosted on the online project hosting service GitHub (github.com) and are available to the public.
- Funding was used to add “unit tests” to SatPy and Polar2Grid to help insure that changes to the software keep the NUCAPS functionality working as the software grows and new features get added. Unit tests are run automatically after ever change that is made to the software via the Continuous Integration service TravisCI (travis-ci.org).
- In addition to unit testing the SatPy package takes advantage of the Coveralls service (coveralls.io) to report on how much of the code is being actively tested. It reports this as a percentage of code lines “touched” during testing. This helps to inform the development team and users of the stability of the SatPy project. Since SatPy is a rather new project every new test helps.
- The SatPy python library is available to python developers via the PyPI (Python Package Index) (https://pypi.python.org/pypi/satpy). This allows for easy installation for any developers familiar with the Python programming language.
- SatPy and Polar2Grid are written in the Python programming language with command line helper scripts written in bash. They both take advantage of third-party libraries like

NumPy and SciPy for fast calculations as well as some custom code written in the Cython programming language to produce C/C++ code for the best performance in key areas of the processing.

During the current contract period, the SSEC staff provided technical programming support to the joint project lead by NASA SPORT. The CSPP Polar2Grid software was updated to support additional NUCAPS fields including solar zenith angle and various mixing ratios. Other changes to code were made to keep the NUCAPS-specific software up to date with the rest of Polar2Grid and improve the handling of the NUCAPS quality flags for masking invalid data.

References

Gambacorta, A, 2014: *The NOAA Unique CrIS/ATMS Processing System (NUCAPS): Algorithm Theoretical Basis Documentation*, NOAA/NESDIS/STAR, 72 pp.

21.4 Joint Polar Satellite System Response to Natural and Man-made Disaster Coordinator

CIMSS Task Leader: William Straka III
CIMSS Support Scientist: Bill Bellon
NOAA Collaborator: Mitch Goldberg (NOAA/JPSS)
Budget: $80,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Develop a proof of concept to have a single Disaster Response Team Lead, who will coordinate with various Subject Matter Experts (SMEs) and stakeholders to provide the relevant information requested by these various disaster response agencies.

Project Overview

The goal of this project is to develop a proof of concept to have a single Disaster Response Team Lead, who will coordinate with various Subject Matter Experts (SMEs) and stakeholders to provide the relevant information requested by these various disaster response agencies. The team lead would be a member of working groups of stakeholders that are convened early in the decision process in order to understand what products would be useful for the response to the incident. When a disaster occurs, the lead, in conjunction with the JPSS Program Science and Satellite Analysis Branch (SAB), will coordinate the dissemination of products to stakeholders in the proper formats as well as provide feedback to the relevant teams on improvement to the products that are used.

Milestones with Summary of Accomplishments and Findings

This project began in mid-2018. In that time, the Satellite Disaster Outreach Coordinator (SDOC) has participated in several key JPSS initiatives which deal with natural and man-made disasters, namely the Fire and Smoke as well as the River/Ice Flooding initiatives. For example, there is regular interaction between the SDOC and the GMU flooding group as they provide their products in response to the various flooding incidents.

During this time, several natural disasters have taken place with the SDOC position in place. This have included responses by the JPSS Program to several tropical systems impacting the United States and its territories (Florence, Michael and Yutu), various wildfire both here in the United States (Fall 2018) as well as internationally via the International Charter (Fires in Greece in the summer of 2018), and the flooding in the Midwestern United States. An example of the imagery provided to FEMA during the aftermath of Hurricane Michael is shown below.

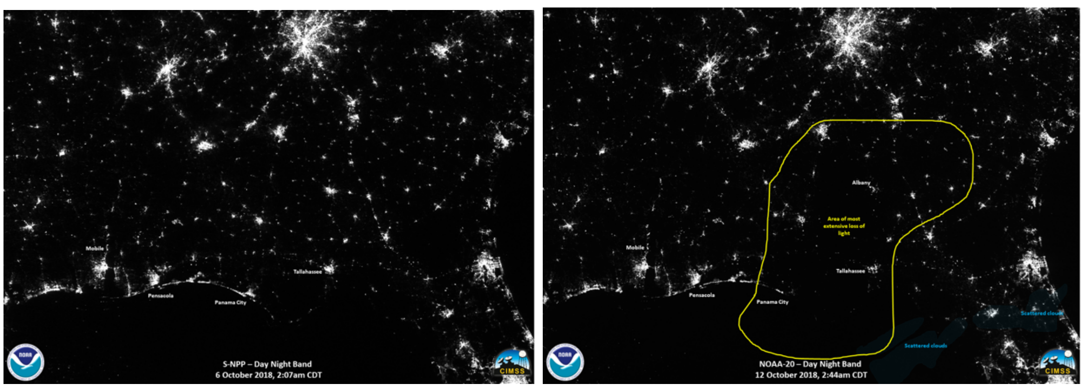


Figure 124. Imagery from 6 October 2018 from SNPP (right), which was used as reference, and 13 October 2018, right after Hurricane Michael made landfall and departed the area, from NOAA-20 (left), as provided to FEMA.

In each case, the SDOC acted as the liaison between the scientists and the stakeholders, providing feedback and requests from the stakeholders as well as communicating the limitations of the products from the scientists. For example, there is communication with CalFires as they begin to use various Fire products as part of their initial intelligence for wildfires. Starting with the California wildfires, an event log was developed to help track and document the response to various incidents. A screenshot of the event catalogue, which is currently hosted at CIMSS, is shown below.

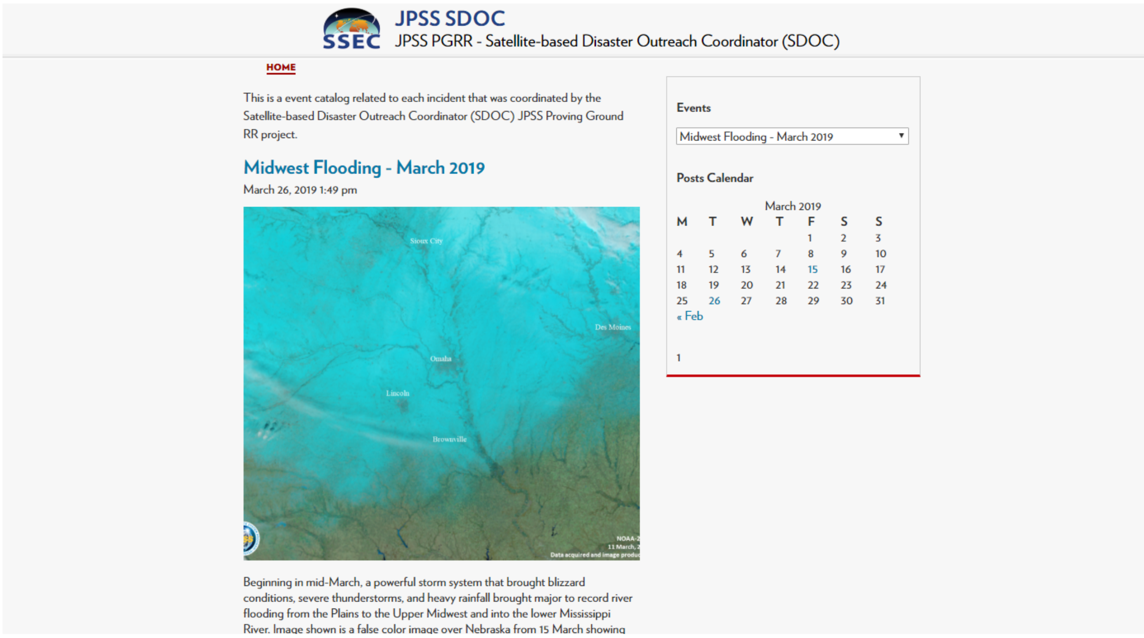


Figure 125. Screen shot of the SDOC event catalogue hosted at CIMSS.

After each incident a review of the response takes place. For these reviews, shortfalls in the response are identified so they can be addressed for future responses. This also involves interacting with the stakeholders to help identify how they used the product and any comments they may have. One example, shown below, of the usage by stakeholders is the 5-day flood extent map from VIIRS which FEMA creates from the daily composites produced at CIMSS via Direct Broadcast.

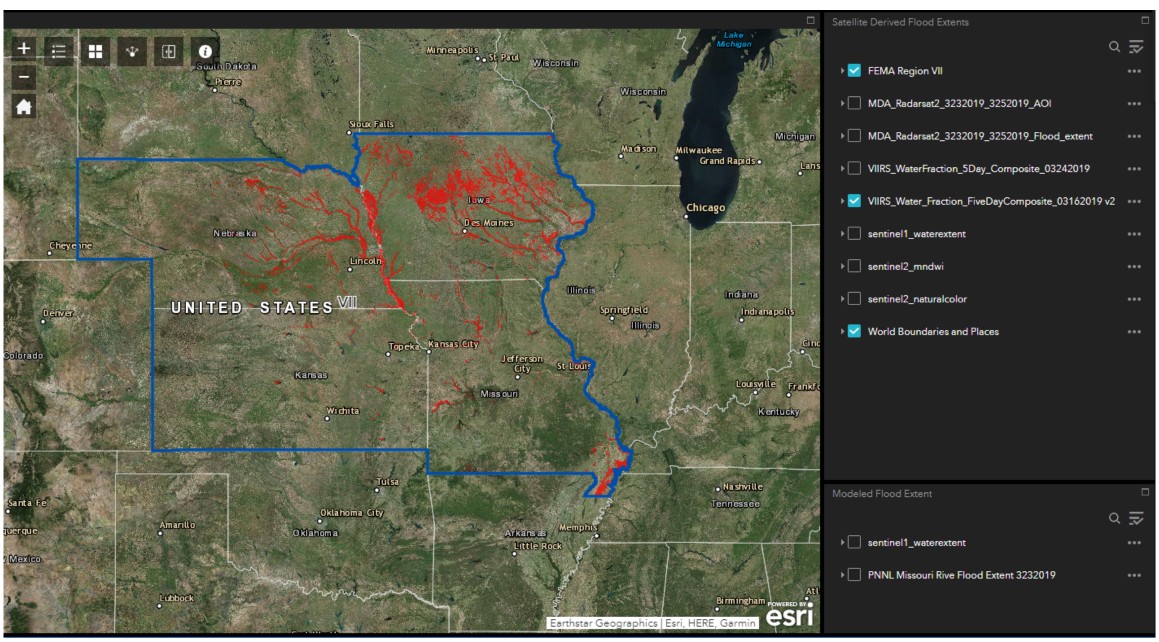


Figure 126. Example web application developed by FEMA, which shows both satellite and modeled flood extents from MDA, VIIRS, and PNNL.

As each incident occurs, the process for responding is refined into a more streamlined method. This includes who the contact is for the particular incident (ex. who the POC at FEMA is for remote sensing data), if routine data flow continues to happen during the incident as well as introducing the concept of the SDOC to stakeholders. It is anticipated that over the next year that the process will continue to be refined.

21.5 Harnessing the Value of NOAA Low Latency LEO DBNet Constellation Satellite Sounder Data – Post Doctoral Education Support

CIMSS Task Leader: Allen Huang
CIMSS Support Scientists: Agnes Lim, Youngchan Noh and Liam Gumley
Budget: $150,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation
- Education and Outreach

Objective

Accessing the forecast impact on global/regional models using reduced latency LEO observations from DBNet and the use of a new CrIS FSR channel subset

Project Overview

A sufficiently accurate knowledge of the atmospheric state at the initial time is important for a good forecast production. This is achieved by combining observations and model prediction through data assimilation. Satellite data, especially from the low earth orbit (LEO) satellites, has become the dominant source of information ingested into Numerical Weather Prediction (NWP) models to reduce errors in the initial-value problem.

Global and regional models that are used to produce forecast prediction run forecast after a predefined data cut off time. Observations that arrive later than the cut off time will not make it into the analysis. The length of allowed cut off times depends on the assimilation frequencies. The more frequent the assimilation system is updated, the less time it has on waiting for observations. In addition, regional models run high resolution forecast at a much smaller coverage compared to the global and due to the orbit configuration of LEO satellites, the amount of data used is dependent on the domain the model covers. For the above two reasons, timely arrival of LEO satellite data at operational NWP centers is very critical to allow for its maximize usage.

With more direct broadcast stations being added to the DBNet and better processing systems, the data latency for timely delivery of LEO satellite data can further be improved. In this study, we proposed to evaluate the forecast impact from ingesting more LEO satellite data by reducing the current 20 minutes' data latency to 10 minutes using global models. Two operational global models that uses different assimilation techniques (4DEnVar and 4DVar), namely the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) and the UK Met Office Unified Model will be used. In addition, we will investigate the forecast benefit from using a new set of CrIS channels selected from Full Spectral Resolution (FSR) using Noh et. al (2017) compared to the 431 channel subset to be distributed to NWP centers in the near future. Global forecast impact assessment would follow the standard verification procedures as used by the respective global models.

Milestones with Summary of Accomplishments and Findings

The first two milestones for year 1 were met despite numerous issues with the version of the GFS used for this study. GFS runs with an early cycle and a late cycle. The late cycle starts 5 hours 50 minutes past the analysis time and thus includes observations that arrived late at NCEP. This cycle is generally not affected by data latency. The early cycle has a cut off time of 2 hours 45 minutes. Currently this cycle includes limited data with a latency of 20 minutes. An improvement in data latency for LEO constellations will have an impact on this cycle. Three different experiments were conducted; (1) a control, which is the current GFS early cycle, (2) the data latency is set at 20 minutes for all LEO satellites that can be transmitted using DBNet and (3) a 5 minutes data latency. The instruments that can be transmitted via the DBNet are AMSU-A and MHS from NOAA-15, 18, 19 and METOP-A/B, AMSU and AIRS from AQUA, CrIS and ATMS from S-NPP and NOAA-20 and IASI from METOP-A/B. The different latency data files are created from the late cycle data files. Observation times made 25 and 40 minutes before the GFS early cycle cutoff times were used to select observations to be included in the data files. Figure 127 shows time series over the 6 w-week assimilation periods for CrIS on S-NPP and NOAA-20. There is increase observation counts with reduced latency. Similar pattern was observed for other LEO satellites assimilated.

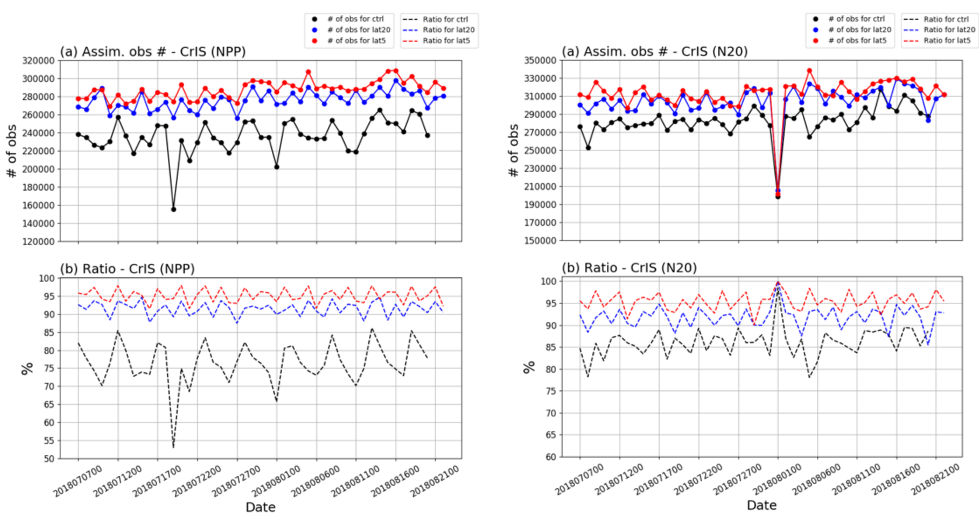


Figure 127. Time series of number of CrIS observations assimilated for S-NPP and NOAA-20 for different data latency.

Figure 128 shows the forecast impact of reduced data latency on GFS verified against self analysis and the final analysis. Improved latency shows forecast with slightly better AC score compared to the control. 20 miniute latency data performs slightly better than the 5 minute latency data. Further analysis needed to understand why.

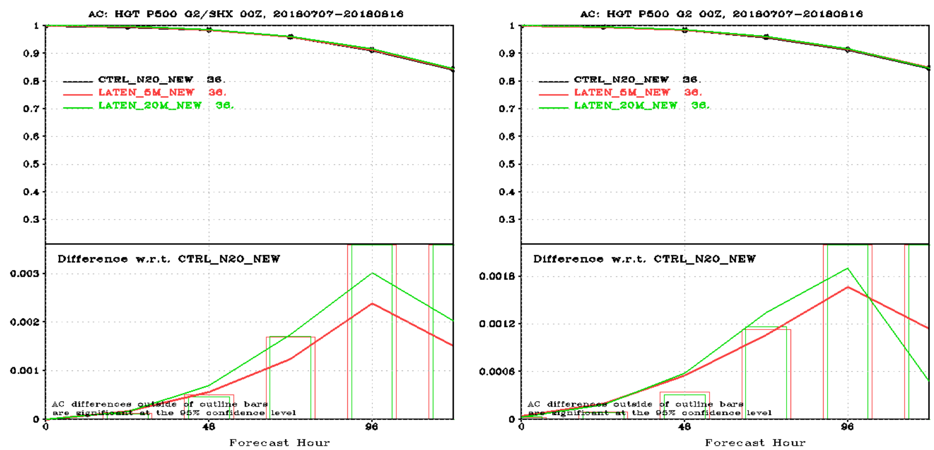


Figure 128. Amorally correlation of 500 hPa geopotential height for all three experiments. Forecast verified against GFS analysis (left) and forecast verified against GDAS analysis (right).

The third milestone has been delayed due to a delay in the availability of the Met Office Unified Model. This milestone will be moved to year 2.

References

Noh, Y.-C., B.-J. Sohn, Y. Kim, S. Joo, W. Bell, and R. Saunders, 2017: A new Infrared Atmospheric Sounding Interferometer channel selection and assessment of its impact on Met Office NWP forecasts. Adv. Atmos. Sci., 34(11), 1265–1281

21.6 JPSS Initiative for Improving Volcanic Hazard Monitoring and Forecasting

CIMSS Task Leaders: Justin Sieglaff, Dave Hyman
NOAA Collaborator: Michael Pavolonis
Budget: $198,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

Utilize multiple JPSS instruments to improve monitoring and characterization of volcanic clouds and integrate the results into dispersion models to improve volcanic cloud forecasting.

Project Overview

NOAA has an operational responsibility to track and forecast volcanic clouds, which are a major aviation hazard with significant economic consequences. We define "volcanic clouds" as clouds that contain volcanic ash and/or sulfur dioxide (SO_2) of a volcanic origin. Through the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO), aviation stakeholders have requested that the science community develop capabilities that will eventually allow for detailed information, such as volcanic ash loading and sulfur dioxide (SO_2) content, to be available for operational decision making. In addition, routine SO_2 monitoring is used to track changes in volcanic activity and inform eruption forecasts, as SO_2 emissions are broadly linked to shallow magma supply in volcanic systems. Finally, quantification of volcanic SO_2 emission rates is needed for volcanic fog (vog) forecasting and for responding to climate-altering volcanic eruptions. This initiative is dedicated to improving volcanic hazard monitoring and forecasting at NOAA's Volcanic Ash Advisory Centers (VAAC's), the NWS Pacific Region, the USGS, and other operational centers (e.g. DoD, international VAAC's and volcano observatories). The JPSS instruments are extremely relevant to volcanic hazard monitoring and forecasting, which encompasses many aspects such as: pre-eruptive monitoring, volcanic ash detection and characterization, SO_2 detection and characterization, and volcanic cloud dispersion and transport forecasting. The initiative builds upon previous JPSS PGRR and GOES-R Risk Reduction research aimed at using multiple JPSS sensors to detect and characterize volcanic ash and SO_2 within the VOLcanic Cloud Analysis Toolkit (VOLCAT). Research under the initiative will initially focus on validating and optimizing the multi-sensor JPSS volcanic ash and SO_2 products, from S-NPP and NOAA-20, for use in NOAA's operational dispersion model, HYSPLIT. A toolkit that will allow the JPSS products to objectively constrain and validate HYSPLIT forecasts will be developed (the toolkit will necessarily include tools for automatically deriving time series of volcanic cloud properties from the JPSS products). Thus, the end goal is improved volcanic cloud analysis and forecasting capabilities, including for vog applications. The research will be performed at NOAA/STAR, UW-CIMSS, NOAA/ARL, UM-CICS, UAF, Michigan Tech, and the USGS over a three-year period (FY18 – FY21). Strong existing end user relationships will ensure proper end user involvement in the initiative. Future potential research topics under this initiative include volcanic thermal anomaly characterization for eruption forecasting, quantitative use of the VIIRS DNB, the development of a S-NPP/JPSS volcanic hazard database, and integration of the JPSS volcanic cloud products with other types of models (climate, Eulerian).

Milestones with Summary of Accomplishments and Findings

During the past year, the primary focus was the development of the CrIS component of the multi-sensor SO_2 detection and characterization algorithm. Significant progress was made, and a prototype CrIS SO_2 algorithm was created. The CrIS SO_2 algorithm, which is based on an approach developed for IASI (Carboni et al. 2012; Clarisse et al. 2014; Carboni et al. 2016), provides information on SO_2 presence and height for every CrIS field, even if clouds and/or volcanic ash is/are present. The ability to retrieve trace gas properties (SO_2 in this case), while accounting for many other variables, including cloud cover, stems from the use of historical CrIS spectra to characterize the mean background (any SO_2 is at or below background levels) spectra and associated covariance. Variables, such as clouds, are accounted for within the historical spectra, so that complex and costly radiative transfer calculations are avoided. Our improvements to the original method, developed for IASI, include the introduction of probabilistic SO_2 height information and the use of refined retrieval model parameters. Figure 129 shows maps of the most probable SO_2 height for several CrIS granules that contain SO_2 emissions from Anak Krakatau (Indonesia) during the 22- 25 December 2018 timeframe. We also generated SO_2 height maps for the 26-29 June 2018 Sierra Negra (Galapagos) eruption (Figure 130). The CrIS SO_2

height is generally consistent with independent assessments of height. Many other cases will be processed and assessed. The first version (v1) of the VOLCAT JPSS SO_2 alerts, which only rely on VIIRS, was also developed. Near real-time testing of v1 of the SO_2 alerts demonstrated the ability to detect moderate to high amounts of SO_2, although false alerts due to stratus and barren land surfaces were also common. The second version (v2) of the alerts, which is currently under development, will include information from CrIS and improved usage of VIIRS. We anticipate that v2 will be suitable for experimental use in operations.

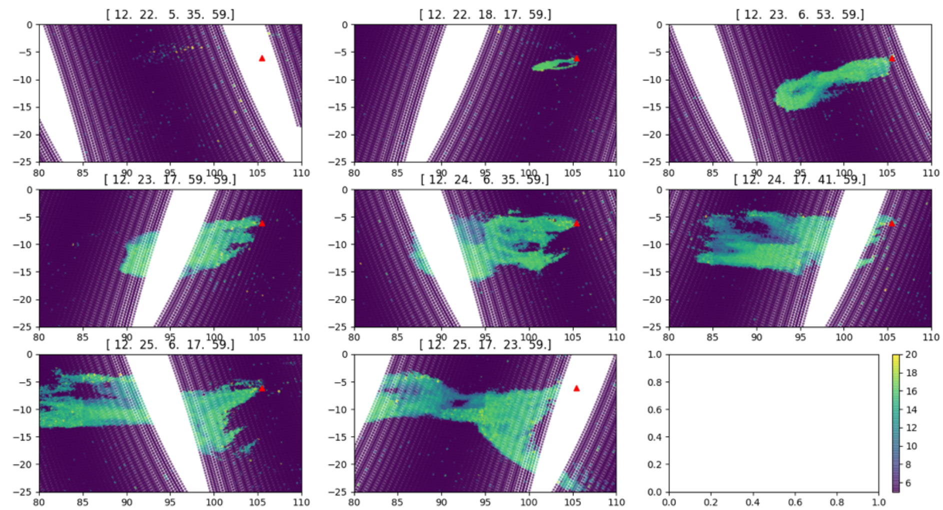


Figure 129. The most probable SO_2 height (km), derived from CrIS measurements, is shown for several S-NPP overpasses of an SO_2 cloud from Anak Krakatau (Indonesia) during the 22- 25 December 2018 timeframe. Longitude is shown on the x-axis and latitude on the y-axis. The red triangle denotes the location of Anak Krakatau. The SO_2 height generally ranges from 12 to 17 km, which is in good agreement with independent assessments.

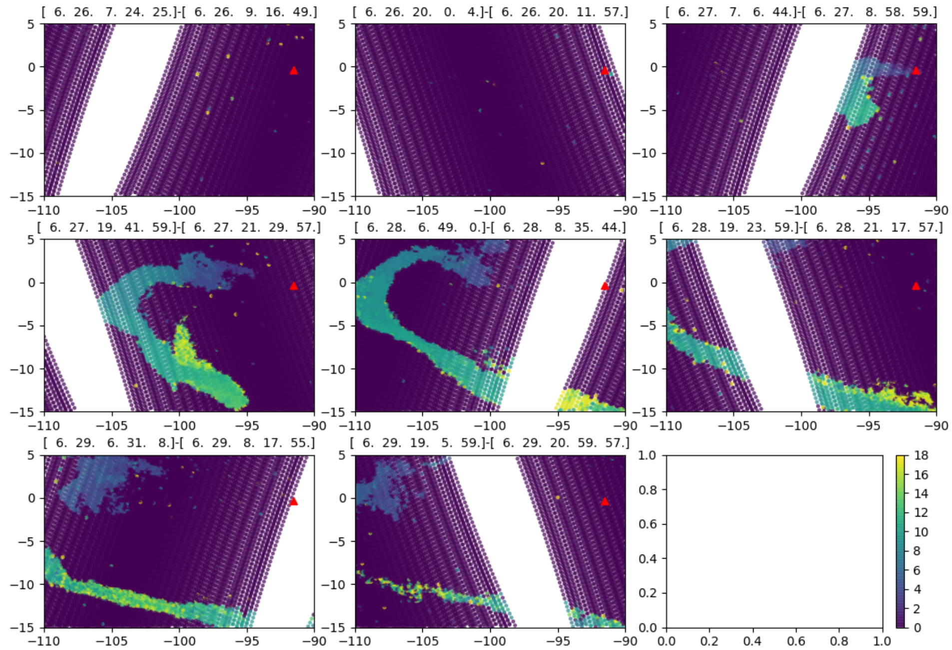


Figure 130. Same as Figure 129, except the SO_2 cloud is from the 26-27 June 2018 Sierra Negra (Galapagos) event.

References

Clarisse, L., Coheur, P.-F., Theys, N., Hurtmans, D., and Clerbaux, C.: The 2011 Nabro eruption, a SO2 plume height analysis using IASI measurements, *Atmos. Chem. Phys.*, **14**, 3095-3111, https://doi.org/10.5194/acp-14-3095-2014, 2014.

Carboni, E., Grainger, R., Walker, J., Dudhia, A., and Siddans, R.: A new scheme for sulphur dioxide retrieval from IASI measurements: application to the Eyjafjallajökull eruption of April and May 2010, *Atmos. Chem. Phys.*, **12**, 11417-11434, https://doi.org/10.5194/acp-12-11417-2012, 2012.

Carboni, E., Grainger, R. G., Mather, T. A., Pyle, D. M., Thomas, G. E., Siddans, R., Smith, A. J. A., Dudhia, A., Koukouli, M. E., and Balis, D.: The vertical distribution of volcanic SO2 plumes measured by IASI, *Atmos. Chem. Phys.*, **16**, 4343-4367, https://doi.org/10.5194/acp-16-4343-2016, 2016.

22. CIMSS Support to the Development of a Community Satellite Processing Package (CSPP) for Suomi NPP/JPSS Real Time Regional Applications for 2018

22.1 CSPP Level 2 Software Enhancement and Support

CIMSS Task Leader: Liam Gumley
CIMSS Support Scientists: Scott Mindock, Kathy Strabala, Geoff Cureton, Nick Bearson, Jim Davies, Graeme Martin, Ray Garcia, Jessica Braun
NOAA Collaborators: Mitch Goldberg
Budget: $405,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
To continue to support and update existing capabilities and add new capabilities of the Community Satellite Processing Package (CSPP) for imager and sounder data received via direct broadcast from polar orbiting satellites including the primary missions NOAA-20 and Suomi NPP, but also the NOAA-18/19, Metop-A/B, and Terra/Aqua satellites. A particular focus is the release of NOAA-developed algorithms and software for creating products from these satellites.

Project Overview
The Community Satellite Processing Package (CSPP) supports the Direct Broadcast (DB) meteorological and environmental satellite community through the packaging and distribution of open source science software. CSPP supports DB users of both polar orbiting and geostationary satellite data processing and regional real-time applications through distribution of free open source software, and through training in local product applications.

Milestones with Summary of Accomplishments and Findings
In the past year a major focus of the CSPP team effort was directed at adding NOAA-20 support to the available software packages. Highlights included:
- VIIRS I-band fire detection for NOAA-20 and SNPP;
- First release of NUCAPS retrieval software for IASI;
- NOAA-20 support and updates to the science and reliability of the MIRS, NUCAPS, and HSRTV packages;
- Image enhancements in Polar2Grid.

The following CSPP Level 2 software releases occurred during the reporting period.

April 1, 2019: CSPP NUCAPS CrIS/ATMS EDR Retrieval Software Version 2.1.1
Updated release of the of the NOAA NESDIS Center for Satellite Applications and Research (STAR) NOAA Unique Combined Atmospheric Processing System (NUCAPS) EDR software providing retrievals of atmospheric temperature, moisture and trace gasses as well as cloud-cleared radiances from input NOAA-20 and S-NPP CrIS and ATMS SDR data files. This version includes the capability to use the GFS .5 degree resolution files as input, matching what NOAA Operations started using in January, 2019.

March 14, 2019: CSPP NOAA VIIRS Active Fire Software Version 1.1
New release of NOAA JPSS Active Fire software supporting the Visible Infrared Imaging Radiometer Suite (VIIRS) imager. The NOAA JPSS fire team at the NOAA NESDIS Center for Satellite Applications and Research (STAR) provided the software which has been adapted and tested for execution in a real-time direct broadcast environment. This version includes support for VIIRS I-Band and M-Band resolution retrievals for both S-NPP and NOAA-20 VIIRS.

February 8, 2019: CSPP Microwave Integrated Retrieval System (MIRS) Software Version 2.2.1
Patched version of CSPP NOAA NESDIS Center for Satellite Applications and Research (STAR) Microwave Integrated Retrieval System (MIRS) Version 2.2 software in support of the ATMS instrument onboard S-NPP and NOAA-20, and the AMSU-A and MHS instruments onboard NOAA-18, NOAA-19, Metop-A and Metop-B satellites. The patch provides a fix for a bug causing malformed file names for Metop-A/B and NOAA-19 (incorrect day of month) and a bug that affected the snowfall rate (SFR) retrieval for AMSUA/MHS instruments onboard NOAA-18, NOAA-19, Metop-A and Metop-B.

November 14, 2018: CSPP VIIRS Flood Detection Software Version 1.1
New release of the VIIRS I-Band resolution (375 m) flood detection software. This version includes support for NOAA-20 VIIRS, as well as improved discrimination of mixed phase surfaces, and cloud/snow_cover/water_surface classifications.

November 9, 2018: CSPP Microwave Integrated Retrieval System (MIRS) Software Version 2.2
Update to the CSPP release of the NOAA NESDIS Center for Satellite Applications and Research (STAR) Microwave Integrated Retrieval System (MIRS) software in support of the ATMS instrument onboard S-NPP and NOAA-20, and the AMSU-A and MHS instruments onboard NOAA-18, NOAA-19, Metop-A and Metop-B satellites. This update includes support for parallel processing and corrects a bug that affected Metop-A and Metop-B AMSU-A/MHS footprint matching.

October 29, 2018: CSPP NUCAPS CrIS/ATMS EDR Retrieval Software Version 2.1
Updated release of the of the NOAA NESDIS Center for Satellite Applications and Research (STAR) NOAA Unique Combined Atmospheric Processing System (NUCAPS) EDR software providing retrievals of atmospheric temperature, moisture and trace gasses as well as cloud-cleared radiances from input NOAA-20 and S-NPP CrIS and ATMS SDR data files. This version includes an updated code base to NOAA DAPv4-3_20180716.

September 10, 2018: CSPP Microwave Integrated Retrieval System (MIRS) Software Version 2.1
Update to the CSPP release of the NOAA NESDIS Center for Satellite Applications and Research (STAR) Microwave Integrated Retrieval System (MIRS) software in support of the ATMS instrument onboard S-NPP and NOAA-20, and the AMSU-A and MHS instruments onboard NOAA-18, NOAA-19, Metop-A and Metop-B satellites. This update includes the base NOAA software upgraded to version 11.3, and the retrieval of Snow Fall Rate (SFR) from ATMS on S-NPP and NOAA-20.

August 3, 2018: CSPP NUCAPS IASI Retrieval Software Version 1.0
First release of NOAA NESDIS Center for Satellite Applications and Research (STAR) NOAA Unique Combined Atmospheric Processing System (NUCAPS) in support of Metop-A and Metop-B satellites. The software produces retrievals of atmospheric temperature, moisture and trace gasses as well as cloud-cleared radiances from input Direct Broadcast IASI, AMSU-A and MHS instrument observations.

June 22, 2018: CSPP CrIS, AIRS and IASI HSRTV Regression Retrieval Software Version 2.0
New version of the multi-instrument hyperspectral retrieval software package that uses CrIS, Aqua AIRS or Metop IASI radiances as inputs and produces vertical profiles of temperature, moisture, ozone as well as cloud and surface properties at single field-of-view resolution. This

software package update includes support for NOAA-20 CrIS as well as Normal Spectral Resolution (NSR) and Full Spectral Resolution (FSR) CrIS retrievals.

May 14, 2018: CSPP NUCAPS CrIS/ATMS EDR Retrieval Software Version 2.0
Updated release of the of the NOAA NESDIS Center for Satellite Applications and Research (STAR) NOAA Unique Combined Atmospheric Processing System (NUCAPS) EDR software providing retrievals of atmospheric temperature, moisture and trace gasses as well as cloud-cleared radiances from input CrIS and ATMS SDR data files. This version provides support for both S-NPP and NOAA-20 missions.

April 27, 2018: CSPP Polar2Grid Reprojection Software Version 2.2.1
Update to the Polar Orbiter Satellite reprojection software tool Polar2Grid. This version consists of bug fixes including improving the sharpness of the false color VIIRS and MODIS image creation, and better handling of spurious negative corrected reflectance values.

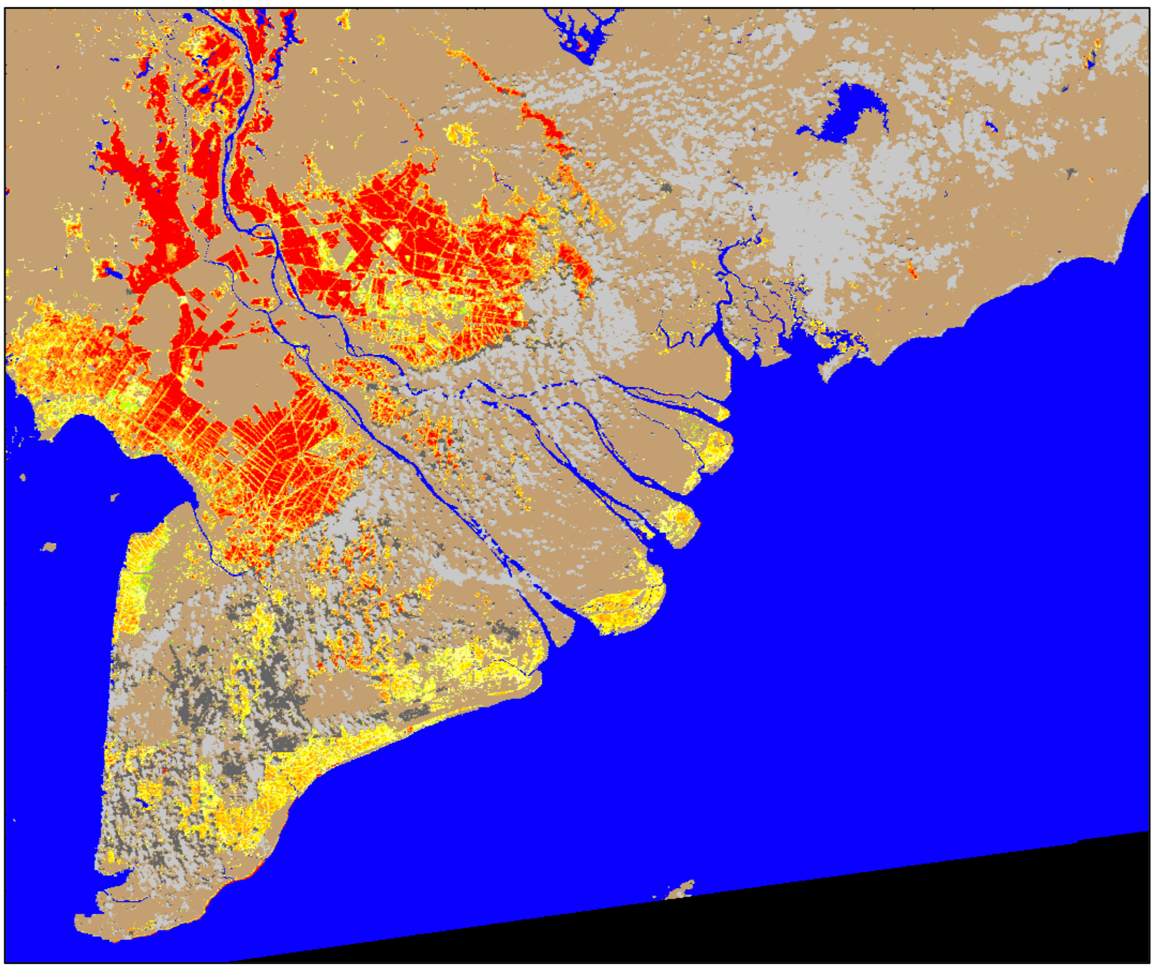


Figure 131. NOAA-20 VIIRS Flood Detection map from 2018/10/30 over the Mekong Delta generated using CSPP VIIRS Flood Detection Software Version 1.1.

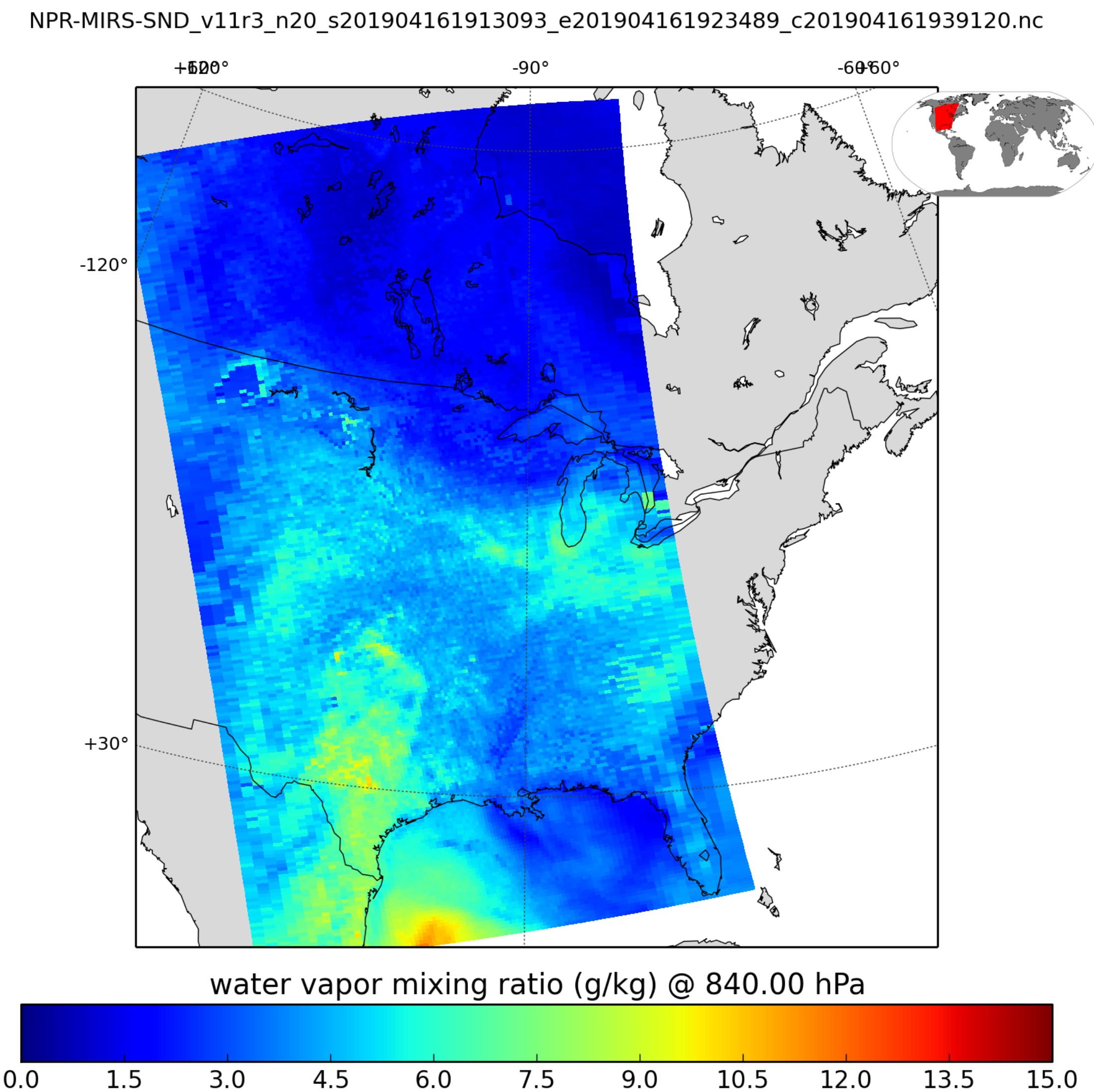


Figure 132. NOAA-20 ATMS retrieval of total column water vapor over CONUS on 2019/04/16 generated using CSPP MIRS v2.1.1.

22.2 NOAA DB Real Time Network Operations, Monitoring, and Processing

CIMSS Task Leader: Liam Gumley
CIMSS Support Scientists: Bruce Flynn, Jessica Braun, Jenny Witt
NOAA Collaborator: Mitch Goldberg
Budget: $48,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

This task supports the continued operation and monitoring of the NOAA direct broadcast real time antenna network and supports the maintenance of real-time processing capability for SNPP, NOAA-20, Metop-A, Metop-B, NOAA-18, NOAA-19, and GCOM-W1. Supported antenna sites include Guam, Honolulu, Madison, Miami, and Mayaguez.

Project Overview

NOAA has funded the deployment of a network of direct readout antennas across the Pacific, North America, and the Caribbean. Data from these antennas, and from other antennas who partner with NOAA, are used for real time applications including NWP assimilation of infrared and microwave sounder data at NOAA/NCEP, and creation of a range of sensor and geophysical products for real time applications. Supported satellites include SNPP, NOAA-20, Metop-A, Metop-B, NOAA-18, and NOAA-19. The network also ingests sounder data from partner antenna sites located in North America, the Pacific Ocean, Africa, and Antarctica. Sounder data from the network are delivered directly to NOAA NCEP for data assimilation, and also to the global NWP community via GTS and EUMETCAST.

Milestones with Summary of Accomplishments and Findings

Highlights in the reporting period included the following accomplishments.

Full support for NOAA-20 CrIS and ATMS was added to the centralized processing at CIMSS/SSEC in July 2018. NOAA-20 CrIS data are processed and distributed in Full Spectral Resolution (FSR) mode.

New antenna sites were added to the NOAA DB Network including Kwajalein Atoll; Edmonton (Canada); Pretoria (South Africa); Kiyose (Japan); Syowa Station (Antarctica); and Easter Island (Chile). These sites are considered partners in the network. At each antenna site, and automated push is configured to send sounder data automatically to the CIMSS/SSEC FTP site. From there it is ingested, processed and delivered by the CIMSS/SSEC central processing server.

The centralized processing system for sounder data at CIMSS/SSEC was updated to use the following software versions:

- CSPP SDR 3.1.1,
- AAPP v8.3 and OPS-LRS 8.0 (implemented in a Singularity container).

The centralized processing server at CIMSS/SSEC was transitioned to dedicated support for the NOAA DB Network: it is no longer shared by other users.

The centralized processing server at CIMSS/SSEC was updated to use the latest operating system (64-bit CentOS 7.6). As part of the OS update, a separate backup server was configured as a DBRTN central processor and it took over routine ingest, processing, and data delivery during the downtime on the primary server. The backup server is still running as a hot backup and can be configured within minutes to take over DBRTN ingest, processing, and distribution.

The centralized processing server at CIMSS/SSEC was instrumented with real-time monitoring software to extract continuous statistics on server health and status, and real-time statuis plots were made available on an internal CIMSS/SSEC website.

CIMSS/SSEC was an active member of the WMO DBNet coordination and operations groups, and participated in the annual DBNet Coordination Group meeting hosted by Meteo France in Paris in October, 2018.

CIMSS/SSEC created a concept and design for a new Cloud-based DBNet processing service. The DBNet Cloud Service will provide low-latency ingest, processing, and delivery for infrared and microwave sounder data from the JPSS, Metop, NOAA, and FY-3 series of polar orbiting satellites. The service is intended to provide an easy and convenient way for polar satellite antenna operators to contribute sounder data to the WMO DBNet without having to install, configure, validate, operate, and maintain the latest versions of the various sounder data processing packages. Initial development and testing of the DBNet Cloud Service commenced with an ingest system deployed in the AWS Cloud, with data ingested from the NOAA DB Network antenna in Puerto Rico.

Publications and Conference Reports

- Liam Gumley attended the WMO DBNet Coordination Group Meeting in Paris, France in October, 2018 and presented the status of the NOAA DB Network.
- Liam Gumley attended the AU Fall Meeting in December and gave an oral presentation on the NOAA DB Network.

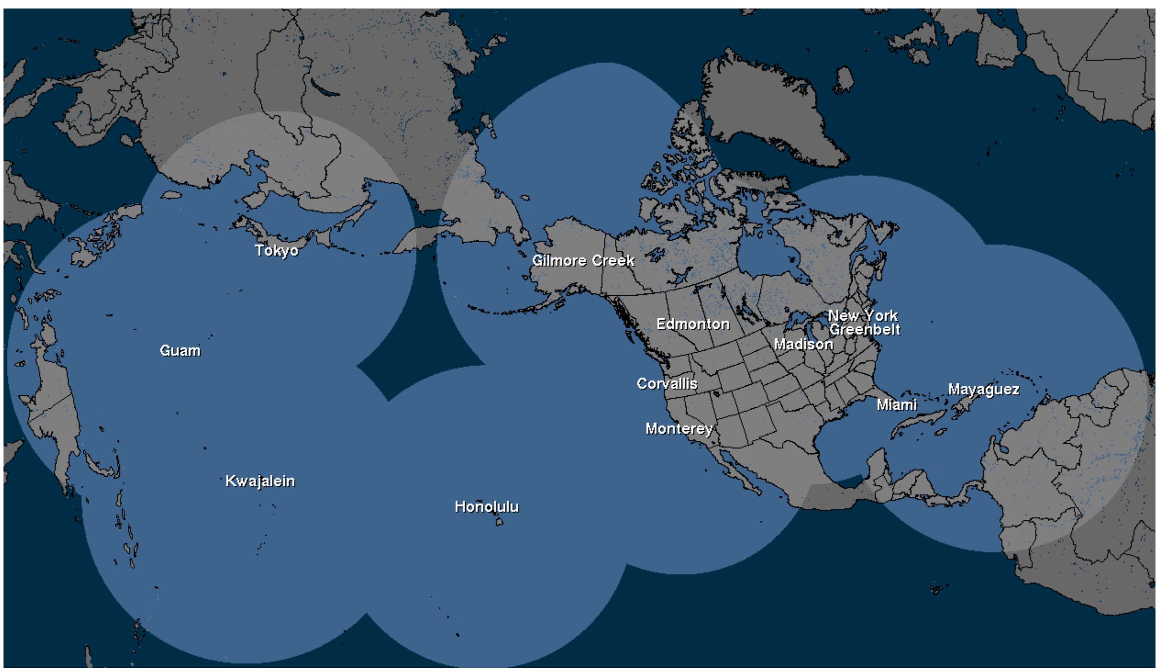


Figure 133. NOAA DB Network coverage in 2019 (not shown are Pretoria, Easter Island, and Syowa Station).

Figure 134. NOAA DB Network central processor monitoring plots for the last 30 days as of 2019/04/16.

22.3 Enhancement of CSPP Polar2Grid Software for Real-Time Imagery Delivery to the National Weather Service

CIMSS Task Leader: Kathleen Strabala
CIMSS Support Scientist: David Hoese
NOAA Collaborator: Mitch Goldberg
Budget: $48,000

NOAA Long Term Goals:

- Resilient Coastal Communities and Economies

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Education and Outreach

Objective

The objective of Polar2Grid is to provide an easy way to create high quality reprojections of Community Satellite Processing Package (CSPP) local direct broadcast data and products for real-time operational support of the US National Weather Service.

Project Overview

The aim of the Community Satellite Processing Package (CSPP) is to facilitate the use of Direct Broadcast (DB) polar orbiter satellite data by global environmental decision makers. Polar2Grid (P2G) is part of the CSPP software suite designed to make it easy for users to make high quality reprojected satellite product images. Polar2Grid is the software that enables delivery of S-NPP and NOAA20 near-real-time products to NWS Forecast Offices and Regional Centers. Polar2Grid allows conversion from swath formats to AWIPS projection grids and formats for display at the NWS in near-real-time. Polar2Grid is used by all of the groups delivering near-real-time data to the NWS, including CIMSS/SSEC, GINA/UAF, Puerto Rico, Guam and SPORT/MSFC.

Milestones with Summary of Accomplishments and Findings

Polar2Grid Version 2.2.1 was prepared for official release as part of the CSPP software suite on 27 April 2019. This version includes:

- Bug fix for true and false color ratio sharpening calculating bad ratios for dark or invalid regions.
- Change the VIIRS and MODIS false color image creation process to use the green band for sharpening.
- Bug fix for the AMSR2 L1B scaling for PNG creation (amsr2_png.ini).

In addition, Pola2Grid supported the installation of the direct broadcast processing stack in Guam for creation of all the images and products that are produced for display in AWIPS. These products include:

- NOAA-20 and S-NPP VIIRS all bands, plus true and false color full resolution.
- Aqua and Terra MODIS subset of bands, plus true and false color full resolution.
- S-NPP ATMS limb correct antenna temperatures – all bands.
- AMSR2 Antenna Temperatures enhanced using NRL color tables
- NOAA-18, NOAA-19, Metop-A and Metop-B AVHRR all bands.
- NOAA-20, S-NPP, NOAA-18, NOAA-19, Metop-A, and Metop-B Microwave Integrated Retrieval System Products – TPW, Rain Rate, and 89 GHz Temperatures.
- S-NPP VIIRS, Aqua and Terra MODIS, NOAA-18, NOAA-19, Metop-A, and Metop-B AVHRR Advanced Clear-Sky Processor for Oceans (ASCPO) SSTS.
- S-NPP and NOAA-20 NOAA Unique Combined Atmospheric Processing System (NUCAPS) Gridded retrievals.

Because CSPP and Polar2Grid software supports many satellite/instrument combinations, the latency between retrievals is significantly reduced. The figure below is a screen capture from a Guam AWIPS terminal that is displaying a composite 24 hours of ACSPO Sea Surface Temperature images created from data acquired and processed at Guam using the CSPP software, including Polar2Grid. There are 21 overpasses in the SST composite from VIIRS, MODIS and AVHRR imagers at greater than 1 km resolution.

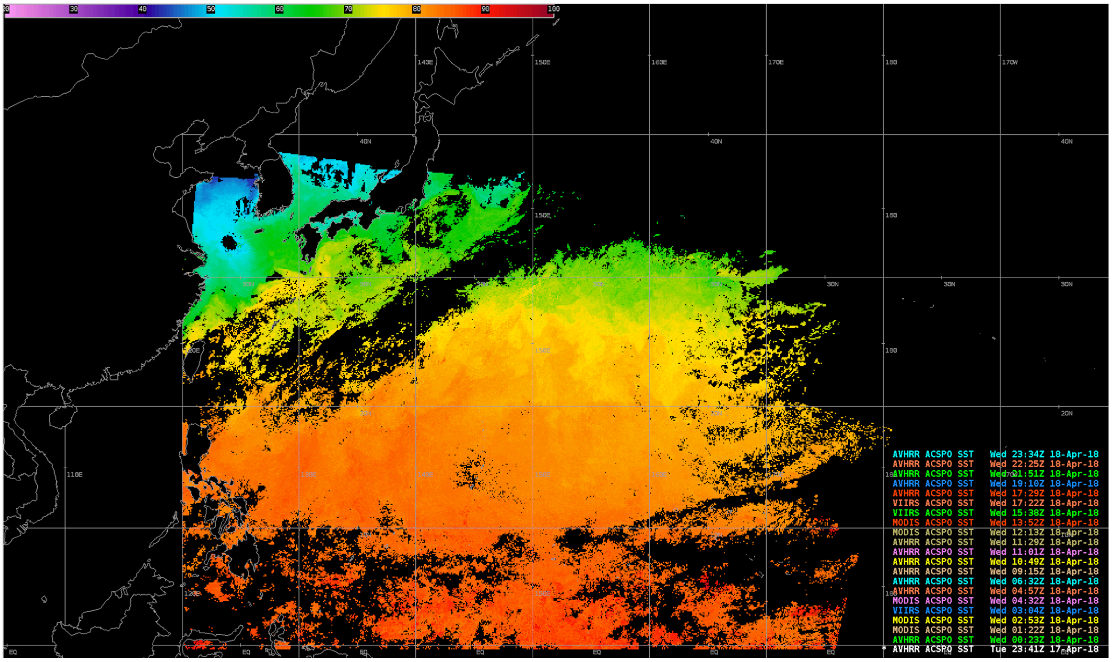


Figure 135. Screen capture from a Guam AWIPS terminal showing a composite 24 hours of ACSPO Sea Surface Temperature images created from data acquired and processed at Guam using the CSPP software, including Polar2Grid.

Conference Reports

David Hoese and Kathleen Strabala: “Shouldn't This Be Easy? NOAA Open Source Software For Creating High Quality Satellite Images”. Oral presentation at the 2019 AMS 99th Annual Meeting, Phoenix, Arizona, 8 January 2019.

22.4 JPSS Science and Innovations

CIMSS Task Leader: Allen Huang
CIMSS Support Scientist: Agnes Lim
NOAA Collaborator: Mitch Goldberg
Budget: $48,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society’s needs for weather and water
- Understand climate variability and change to enhance society’s ability to plan and respond
- Support the nation’s commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

- Continue to maintain OSSE portion of JPSS Analysis Facility for Instrument Impacts on Requirements (JAFIIR)
- Development of innovative processing technique to complement JPSS conventional approaches

Project Overview

JPSS Analysis Facility for Instrument Impacts on Requirements (JAFIIR) - Instrument Wavier Analysis and JPSS OSSE for the Impact Analysis of JPSS Sensor on NWP model performance. This task involves:
- Maintenance of OSSE to refine and support JPSS series sensor configuration change impacts on NWP forecasts especially the data latency that directly or indirectly impact the assimilation and the forecasts.
Development of AI and big data for innovated processing of JPSS data concept and strategy has taken the forms of organizing the society conferences and participating in the NOAA first AI workshop and SPIE and IUGG AI-related events. The concept is developed around the innovations that drive efficiency and sustainability of satellite remote sensing measurements with the initial focus on JPSS ATMS, CrIS and VIIRS sensor suites.

Milestones with Summary of Accomplishments and Findings

Continue to maintain JAFIIR in areas of instrument waiver analysis support and ready to conduct JPSS OSSE for the impact of JPSS sensor on NWP model performance, specifically for any new CrIS sensor specification variations or changes. In addition, by leveraging CSPP processing capability, JAFIIR can be effectively producing any type of simulated measurements that replicates new or modified sensor suites with the impacts not just on level 2 products but also extends to the impacts for the use of measurements or derived products in the subsequent data forecasts.

For the development of AI application to JPSS an abstract entitled "Preparing AI-Enabled Weather and Environment Satellite Big Data" is underway. This conference presentation is to focus on the preparation of the phenomenal volume of complex data, including S-NPP and JPSS satellite data, by exploring the possibility and concept of unified data structure and architecture suitable for the readiness and optimal use for the advanced machine and deep learning AI.

As the conventional, modern, and emerging satellite processing approaches continue to evolve through this innovation study, under the big data conceptual project, we have developed the conceptual diagram which combine the big data analyzer, 4DVAR and deep learning as the integrated processing techniques with the dynamic downscaling as the fusion processing that end with the use of next generation open source RealEarth 4D as the GIS integrator and visualization. Figure 136 depicts the current concept of how conventional, modern, and emerging techniques can be linked for processing innovation. As futuristic and conceptual as it can be it'll require major resource/funding to demonstrate this innovation can deliver unique, efficient and most accurate information from NOAA satellite assets starting from JPSS system.

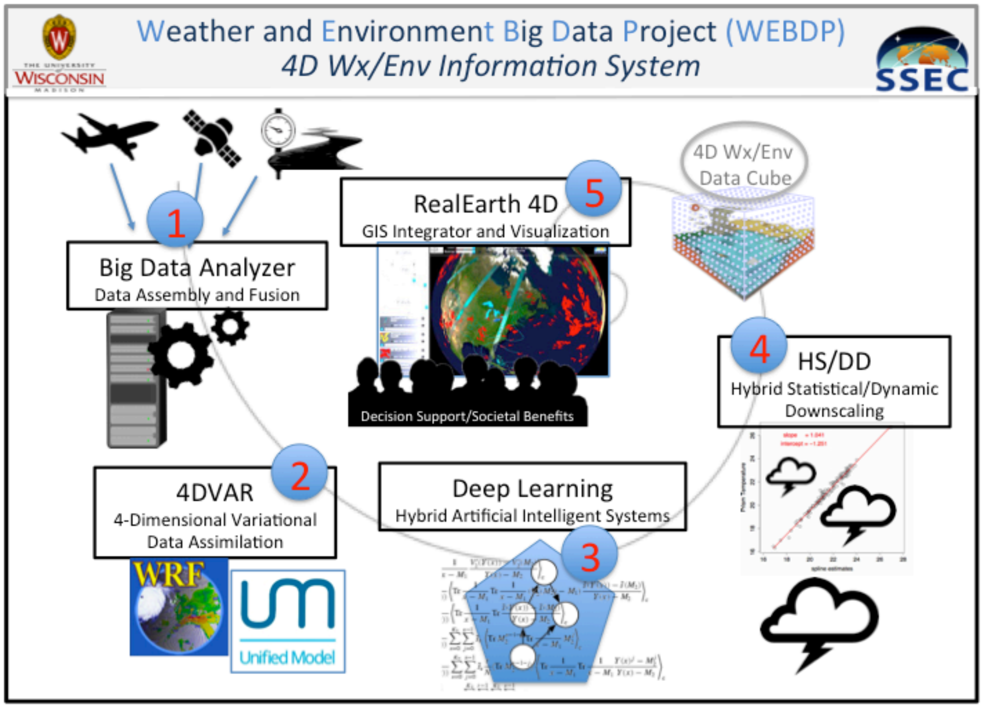


Figure 136. Futuristic/conceptual processing diagram linking conventional, modern, and emerging processing technique for generating 4D weather/environment information cube.

Publications and Conference Reports:

JPSS Direct Readout – Easy Access to Real-Time Data, IGARSS, July 2018

Study of Low Latency LEO Constellation Satellite Sounder Data Impact on Analyses and Forecasts, EUMETSAT Satellite conference, September, 2018

23. CIMSS Support to Participate in JPSS Visiting Scientist Program 2018

CIMSS Task Leader: Andi Walther
CIMSS Support Scientist: Denis Botambekov
NOAA Collaborator: Andrew Heidinger
Budget: $4,284

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Support visit of Dr. Nikos Benas to collaborate on cloud property retrieval research.

Project Overview

Dr. Nikos Benas is a member of the cloud group in the R&D Satellite Observations department of KNMI. This cloud group, led by Dr. Jan Fokke Meirink, has been interacting with Dr. Andy Heidinger's JPSS/GOES-R AWG Cloud Team for a long time. Both groups focus on the development of cloud property retrieval algorithms. At KNMI these activities are aimed at producing climate data records and operational products suitable for nowcasting applications. Climate data records are created in the framework of the EUMETSAT CM SAF, which recently released the second editions of the AVHRR-based CLARA and the MSG-SEVIRI-based CLAAS records. Near-real time cloud retrievals are performed at KNMI and made available via OGC services at http://msgcpp.knmi.nl. The JPSS/GOES-R AWG Cloud Team has been successful in implementing GOES-R AWG Cloud Algorithms on a wide range of sensors including GOES, MSG, POES and JPSS imagers. This proposal would allow Dr. Benas to visit the Advanced Satellite Products Branch at NOAA/NESDIS/STAR/CoRP, Madison (Wisconsin). The host will be Dr. Andi Walther and Dr. Andrew Heidinger.

Milestones with Summary of Accomplishments and Findings

During Nikos' visit we focused on comparisons of cloud optical properties from CLAVR-x and KNMI CPP algorithm. The comparisons focused on specific illumination and viewing geometries that pose challenges in the retrievals, namely cloud glory and bow conditions. Both retrievals were based on SEVIRI measurements over a 5° × 5° region in southeast Atlantic (15°-20° S, 6°-11° E), on March 7, 2017, when the area was almost completely covered with Stratocumulus (Sc) clouds throughout the day. Both algorithms are based on the Nakajima-King physical principle (Nakajima and King, 1990), with their main difference being on the calibration and retrieval process: CPP implements an iterative fitting method, while DCOMP is based on optimal estimation.

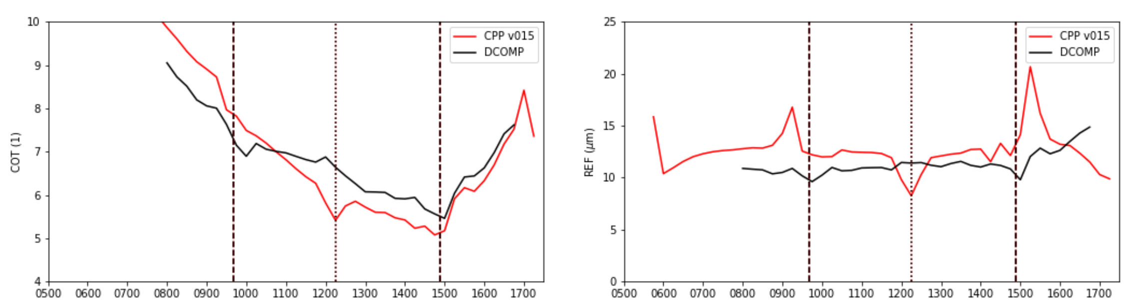


Figure 137. Comparison of DCOMP/CLAVR-x and KNMI CPP optical properties.

Results show overall good agreement between the two algorithms in both spectral pairs used (0.6 µm – 1.6 µm and 0.6 µm – 3.9 µm). Figure 1 shows the diurnal variation in τ and r_e for the 1.6 µm retrievals. Dashed lines correspond to 140° (cloud bow conditions) and dotted lines highlight the maximum scattering angle for this day and region (cloud glory).

Nikos' visit was fruitful and motivating for future collaborations.

24. Implementation of GCOM-W1 AMSR2 Snow Products

CIMSS Task Leader: Yong-Keun Lee (first part of year; now with CICS)

NOAA Collaborator: Jeffrey Key
Budget: $80,000

NOAA Long Term Goals:
- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective
The objectives of this project include continuous testing and validation of the snow algorithm and routine snow product generation with AMSR2 data. The selected heritage algorithms are being modified as necessary.

Project Summary
Snow is one of the most dynamic hydrological variables on the Earth's surface and the cryospheric component with the largest seasonal variation in spatial extent. It also plays a key role in the global energy and water budget. Since microwave radiation is unhindered by darkness and clouds and penetrates a deeper layer of snow cover at certain frequencies, satellite passive microwave measurements have been used to detect snow cover and snow depth globally in nearly all weather conditions. The Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument launched on the Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission 1st – Water "SHIZUKU" (GCOM-W1) satellite. NOAA is supporting work with AMSR2 as part of the Joint Polar Satellite System (JPSS) program.

AMSR2 cryosphere environmental data records (EDRs) include snow products: Snow Cover/Depth, and Snow Water Equivalent (SWE). Snow Cover/Depth includes a binary snow/no snow mask and the depth of snow on land. Snow Water Equivalent is the liquid equivalent depth of the snow cover.

Milestones with Summary of Accomplishments and Findings
The suite of AMSR2 algorithms developed for the retrieval of snow cover and snow depth is now being used operationally by NOAA. The snow cover detection algorithm is based on a brightness temperature-based decision tree approach (Grody, 1991; Grody and Basist, 1996) with additional limatology tests as enhancements. The snow depth algorithm is based on a dynamic empirical approach (Kelly, 2009) blended with a routine for dry/wet snow differentiation.

Accomplishments for this project year include the continued generation of statistics for the AMSR2 snow cover detection by month, forest fraction and elevation. We also investigated "missing" snow in the snow cover products. We have observed that in some cases where the surface temperature is relatively high, AMSR2 snow detection fails. This happens most frequently when the snow is "wet", which is why descending passes often show more snow than ascending passes. A preliminary investigation indicates that the problem may be a temperature constraint in the heritage snow detection algorithm, where all observations (pixels) with 22 GHz brightness temperatures above 258 K are considered to be snow-free. This threshold appears to be based on emissivity that in certain conditions is too low. A solution is currently being tested. An example of the problem is shown in Figure 138.

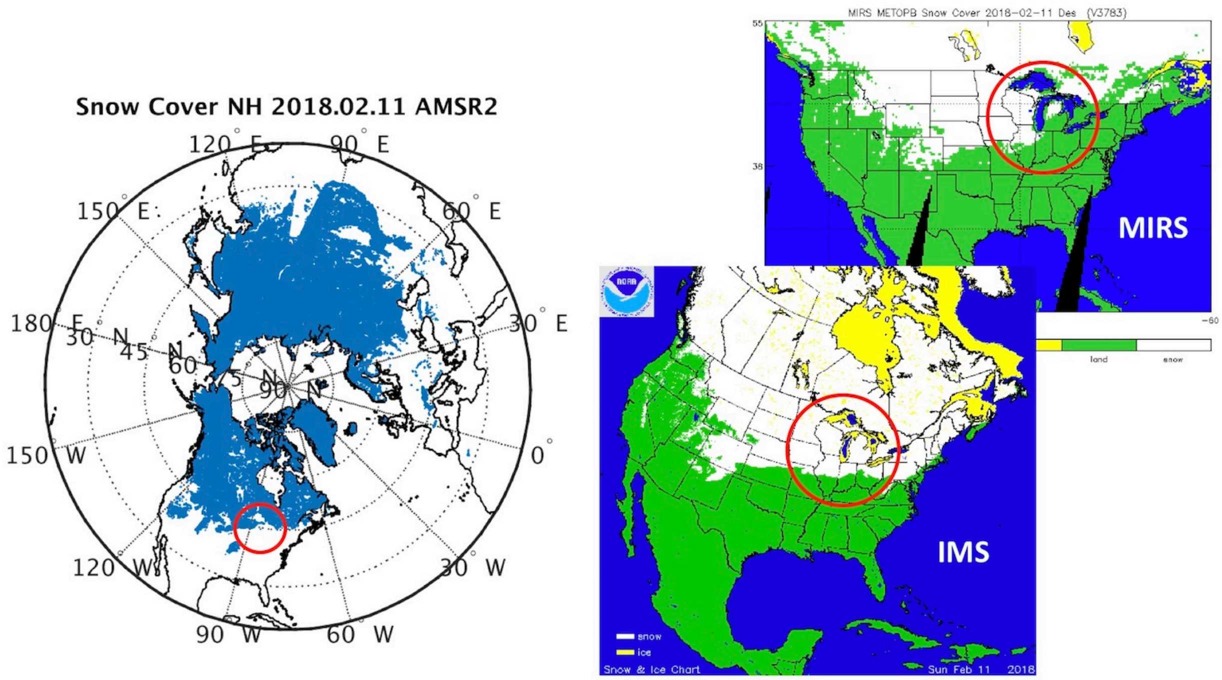


Figure 138. Snow cover on 11 February 2018 from AMSR2 (left), MIRS/ATMS (top right), and the Interactive Multisensor Snow and Ice Mapping System (IMS, bottom right). The Great Lakes area is circled, illustrating missing snow cover in Wisconsin, Michigan, northern Indiana. Note that MIRS also misses some snow in Michigan.

For the longer term, we are investigating the utility of incorporating in situ snow water equivalent data in the AMSR2 product. We have found that a simple correction method using equal weights of the surrounding in-situ snow depth data is fast, improves the satellite retrievals, and can be implemented operationally more easily and at a lower computational cost than Optimal Interpolation methodology. A correction with in-situ data would significantly boost the confidence in AMSR2 retrievals.

Publications and Conference Reports

Lee, Y.-K., C. Kongoli, and J. R. Key, 2017: "NOAA AMSR2 Snow products", NOAA-JAXA AMSR2 Technical Exchange Meeting, Nov. Tokyo, Japan.

References

Grody, N. C., (1991), Classification of snow cover and precipitation using the special sensor microwave imager, J. Geophys. Res., 96 (D4), pp 7423-7435.

Grody, N. C., and A. N. Basist, (1996), Global identification of snowcover using SSM/I measurements, IEEE Trans. Geosci. Remote Sens., 34 (1), pp 237-249.

Kelly, R., (2009), The AMSR-E snow depth algorithm: description and initial results, J. Remote Sensing Soc. Japan, 29 (1), pp 307-317.

Lee, Y.-K., C. Kongoli, and J. R. Key, (2015), An in-depth evaluation of heritage algorithms for snow cover and snow depth using AMSR-E and AMSR2 measurements, J. Atmos. Oceanic Technol., 32, 2319-2336. doi: 10.1175/JTECH-D-15-0100.1.

25. Support CIMSS JPSS and AWIPS II OCONUS Satellite Liaison

CIMSS Task Leader: Jordan Gerth

NOAA Collaborators: Bill Ward and Eric Lau, National Weather Service Pacific Region Headquarters; and Nathan Eckstein, National Weather Service Alaska Region

Budget: $200,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

This project funds a dedicated scientist that improves NOAA's research to operations (R2O) mechanisms and maximizes the operational value of geostationary and polar-orbiting satellite data and research products at National Weather Service (NWS) forecast offices in the Outside CONtiguous United States (OCONUS), particularly Alaska and Hawaii. The scientist serves in a wide array of relevant and related roles: as a satellite liaison, user advocate, R2O consultant, software engineer, subject-matter expert, trainer of operational meteorologists, and atmospheric and oceanic sciences researcher.

Project Overview

The Outside CONtiguous United States (OCONUS) satellite scientist serves four primary functions beyond his capacity as a satellite meteorologist and remote sensing scientist for National Weather Service (NWS) forecast offices in the states of Alaska and Hawaii, and the territories of Guam, American Samoa, and Puerto Rico.

- First, the scientist is a software developer and technical consultant, focusing on the Advanced Weather Interactive Processing System (AWIPS) and the related technical infrastructure, including networking, data flow, and antenna systems, to assure satellite imagery and products are consistently and reliability supplied to the field and meeting the needs of operational meteorologists in the OCONUS and throughout the United States.

- Second, the scientist is a coordinator of regional satellite proving ground and related activities, including the visiting scientist program in NWS Pacific Region. The proving ground introduces new derived satellite products and satellite imagery interpretation techniques to the relevant field offices.
- Third, the scientist is a liaison for meteorologists and office management in NWS Pacific Region and Alaska Region to assist in the development and delivery of training and addressing specific questions about the capabilities of current and future meteorological satellites, particularly the Geostationary Operational Environmental Satellite R-Series (GOES-R, now GOES-16/17) and Joint Polar Satellite System (JPSS, now NOAA-20).
- Fourth, the scientist is a consultant to the Chair of the NWS Operational Advisory Team (NOAT), and coordinates activities with the satellite program leadership as a user advocate, namely recommending and implementing satellite proving ground and training initiatives.

Milestones with Summary of Accomplishments and Findings

The scientist funded under this project:

- Ensures that meteorologists in the OCONUS achieve optimal understanding on the use of satellite imagery and products for the best possible daily operations,
- Conducts scientific investigations and serving as the coordinator for demonstrating JPSS-related science products in NWS Pacific Region and Alaska Region operations,
- Integrates GOES-R/GOES-17, Himawari-8/9, NPP, JPSS/NOAA-20, and GCOM imagery and science products into the AWIPS, and
- Acts as a technical coordinator and AWIPS developer for GOES-R and JPSS proving ground partners.

The major milestones and related accomplishments between 1 April 2018 and 31 March 2019 are indicative of the value of this project. Specifically, the scientist:

- Conducted site visits to NWS forecast offices in Anchorage, Alaska, Fairbanks, Alaska, Juneau, Alaska, Honolulu, Hawaii, and Barrigada, Guam;
- Worked with the Community Satellite Processing Package (CSPP) package development team to establish output formats that are compatible with AWIPS, and conducted related testing and configuration in AWIPS;
- Configured AWIPS at the NWS Pacific Region Headquarters (PRH), Honolulu Forecast Office (HFO), American Samoa field office, and Guam field office to ingest and display Himawari-8/9 and other satellite imagery and derived products at the highest spatial, spectral, and temporal resolution available, with Eric Lau;
- Collected examples of impacts to operational services during GOES-R/GOES-17 image degradation resulting from the malfunctioning loop heat pipe;
- Served as a member of the Satellite Enhancement Team (SET) to ensure satisfactory "day one" visualization of imagery and derived products from GOES-R/GOES-17 and JPSS/NOAA-20;
- Organized international technical interchange teleconferences with the Japan Meteorological Agency (JMA) and Australia Bureau of Meteorology (ABoM);
- Participated on the Satellite Training Advisory Team (STAT) with weekly training teleconferences and planning meetings to recommend and track the development of foundational course content and subsequent applications-centric training materials related to GOES-R/GOES-17 and JPSS/NOAA-20 for all NWS meteorologists;

- Began coordinating nationwide NWS training activities related to JPSS, serving as a subject-matter expert to review some foundational course modules, and developing the charter for the new JPSS program training initiative;
- Contributed to JPSS training events, such as short courses, at the annual meeting of the American Meteorological Society;
- Assisted with planning and executing the 2018 JPSS Alaska Summit;
- Maintained the L/X-band antenna at Honolulu Community College and assured that imagery and products from the antenna system were available to staff at NWS PRH and HFO;
- Maintained the L/X-band antenna at the Guam forecast office and assured that imagery and products from the antenna system were available to the local office staff;
- Arranged and held, with colleagues, a training workshop for operational meteorologists at the Guam forecast office;
- Consulted on best practices to maintain the L/X-band antenna at the NOAA Inouye Regional Center in Pearl Harbor, Hawaii; and
- Supported the JPSS initiatives and other satellite liaisons in NWS Alaska Region.

The scientist attended the following meetings during the award period:

- American Meteorological Society Washington Forum (Washington, District of Columbia)
- American Meteorological Society Summer Community Meeting (Boulder, Colorado)
- National Weather Association Annual Meeting (St. Louis, Missouri)
- Asia-Oceania Meteorological Satellite Users' Conference (Jakarta, Indonesia)
- American Meteorological Society Annual Meeting (Phoenix, Arizona)

Publications and Conference Reports

Publications

Gerth, Jordan J. 2019. "It's not hot air: Using GOES-16 infrared window bands to diagnose adjacent summertime air masses." *Meteorological Applications*. https://doi.org/10.1002/met.1767.

Gerth, Jordan J. 2018. "Shining Light on Sky Cover during a Total Solar Eclipse." *Journal of Applied Remote Sensing* 12 (02): 1. https://doi.org/10.1117/1.JRS.12.020501.

Schmit, Timothy J., Scott S. Lindstrom, Jordan J. Gerth, and Mathew M. Gunshor. 2018. "Applications of the 16 Spectral Bands on the Advanced Baseline Imager (ABI)." *Journal of Operational Meteorology* 06 (04): 33–46. https://doi.org/10.15191/nwajom.2018.0604.

Conference Reports

"Sky Cover during the 2017 Solar Eclipse"
Jordan Gerth, corresponding author/presenter
Talk, American Meteorological Society Annual Meeting—15th Annual Symposium on New Generation Operational Environmental Satellite Systems (Phoenix, Arizona), 9 January 2019

"RMK Satellites ALQDS"
Jordan Gerth, corresponding author/presenter
Poster, National Weather Association Annual Meeting, 28 August 2018

26. CIMSS Support to JPSS Field Terminal Segment (FTS) Tasks 2018

CIMSS Task Leader: Liam Gumley
CIMSS Support Scientists: Scott Mindock, Kathy Strabala, Graeme Martin, Ray Garcia, Jessica Braun, Jenny Witt
NOAA Collaborator: Mitch Goldberg
Budget: $500,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective
This project supports the JPSS High-Rate Data (HRD) direct readout community by providing ATMS, CrIS, and VIIRS Sensor Data Record (SDR) processing software adapted from ADL in a form that is easy to install, operate, and maintain at direct readout antenna sites.

Project Overview
CIMSS/SSEC supports JPSS FTS by providing algorithm and software integration services to enable users to integrate JPSS SDR algorithms into their local processing systems through the development of user-friendly software packages. CIMSS/SSEC provides software packages, supporting ancillary data, documentation and training, end user support, and value-added products and software as part of this effort. CIMSS/SSEC acquires and processes HRD from SNPP and JPSS using its existing 2.4-meter X/L-band antenna system to track the quality of the HRD transmission and monitor the validity of the products created from the HRD broadcast. Products are delivered to the National Weather Service with low latency.

Milestones with Summary of Accomplishments and Findings
In May of 2018, NOAA commanded NOAA-20 to include VIIRS M7 and CrIS FOVs 4 and 6 in the HRD downlink (previously these were deleted in HRD). Shortly after this event, CIMSS/SSEC and other direct readout antenna sites noticed that packets were being dropped in the HRD downlink. This was confirmed by the JPSS project which noted that spacecraft telemetry indicated that due to a buffer overflow, packets were being dropped on the spacecraft. CIMSS/SSEC began studying the impacts of these dropouts on VIIRS, CrIS, and ATMS data. In the case of VIIRS, the impact was missing data (usually over land). In the case of ATMS and CrIS, the impact included both missing data and non-physical radiances and brightness temperatures. After extensive review of the NOAA-20 HRD data CIMSS/SSEC implemented a patch for CSPP SDR 3.0 (released as CSPP SDR patch v3.0.6) that mitigated the data gaps by screening out the corresponding RDR segments from being processed. This patch, in addition to NOAA-20 CrIS LUT updates from JPSS, largely removed the occurrence of non-physical data in NOAA-20 ATMS and CrIS data derived from HRD. The CSPP SDR v3.0.6 was released to operational agencies including EUMETSAT, MeteoFrance, and the Met Office.

Following the release of the CSPP SDR 3.0.6 patch, CIMSS/SSEC continued to investigate and monitor the impact of the NOAA-20 HRD gaps. The monitoring effort included development of a "gapdump" software tool for scanning ATMS, CrIS, and VIIRS RDR files and detecting the presence of packet gaps. These reports were matched with packet drop times noted in the NOAA-20 spacecraft telemetry received by JPSS. CIMSS/SSEC also matched packet gaps in NOAA-20 RDR files obtained via HRD direct readout from multiple antenna sites observing the satellite at the same time.

CIMSS/SSEC also continued daily monitoring of the HRD signal from NOAA-20 and SNPP. The HRD transmissions were received by the Orbital Systems 2.4-meter X/L-band reception system at SSEC. Movies of the received signal characteristics from each pass were captured via a frame grabber attached to an Agilent E4407B spectrum analyzer in line with the down-converted 720 MHz IF output. Plots of signal strength as a function of time, elevation, and azimuth were captured from the antenna control computer for each pass. RT-STPS status logs for each pass were also captured. The monitoring products for both SNPP and JPSS-1 are made available on a website at CIMSS/SSEC and were shared with the JPSS project. The monitoring ended in July 2018 when it became clear that the NOAA-20 data gap issue was well understood.

CSPP SDR Version 3.1 was released to the DB community on 25 September 2018. This software package supports the calibration and geolocation of the Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Technology Microwave Sounder (ATMS), and the Cross-track Infrared Sounder (CrIS) instruments onboard the JPSS Suomi-NPP and NOAA-20 Satellites. The SDR software code base is updated to Block 2.1 Mx2 (ADL5.3_I2.1.02) to correspond with the operational configuration of NOAA-20. New features include:

- Filtering is now performed by default to remove incomplete or partial ATMS and CrIS RDR granules prior to processing. This behavior can be controlled using option -s. This option allowed the SDR software to transparently handle packet drops in the NOAA-20 HRD stream that occurred as a result of the HRD buffer overflows.
- Improved Look-Up-Table (LUT) and ancillary data download and storage.
- Fixed bug that repeated storage of LUT and ancillary data sets into the database.
- New ancillary and LUT distribution site is used: http://jpssdb.ssec.wisc.edu/cspp_v_3_1/ .

CSPP SDR 3.1 is now used by all operational agencies who acquire and process NOAA-20 and SNPP data from HRD direct readout, including the WMO DBNet group who provide infrared and microwave sounder data to NWP centers. Additional patches to CSPP SDR 3.1 were released as follows:

CSPP SDR 3.1.1 was released on **17 October 2018.** This version includes a patch that corrects bugs to improve the granule yields for all ATMS, CrIS, and VIIRS datasets.

CSPP SDR 3.1.2 was released on 29 January 2019. This version includes a patch to fix a problem with incomplete download of S-NPP and NOAA-20 VIIRS SDR Look-Up-Tables (LUTs).

CIMSS/SSEC ingested all required ancillary data for production of the VIIRS, CrIS, and ATMS SDRs and made them available for download to users of the CSPP SDR software. End users are able to run an automated script that will check for new LUTs on the CIMSS/SSEC HTTPS site, and if necessary download, unpack, and install the LUTs without user intervention. CIMSS/SSEC obtained the LUTs from the JPSS FTS website and from the JPSS project for this purpose.

CIMSS/SSEC continued to acquire and process real-time NOAA-20 and SNPP direct broadcast data over CONUS and provide the products to National Weather Service forecast offices for display in AWIPS2. Imagery products visible and infrared single channels, true color and false color imagery, and Day/night band imagery with several enhancements. VIIRS image products were created routinely for both NOAA-20 and SNPP and converted to AWIPS2 compatible format for delivery to NWS forecast offices. In addition, geophysical products from VIIRS, CrIS, and ATMS including cloud mask/phase/height/optical depth, aerosol loading, water vapor, temperature and moisture profiles, sea surface temperature, ocean chlorophyll, land surface temperature, wildfire locations, vegetation index, surface reflectance, and rain rate are created in near real-time and made available to CIMSS/SSEC research partners.

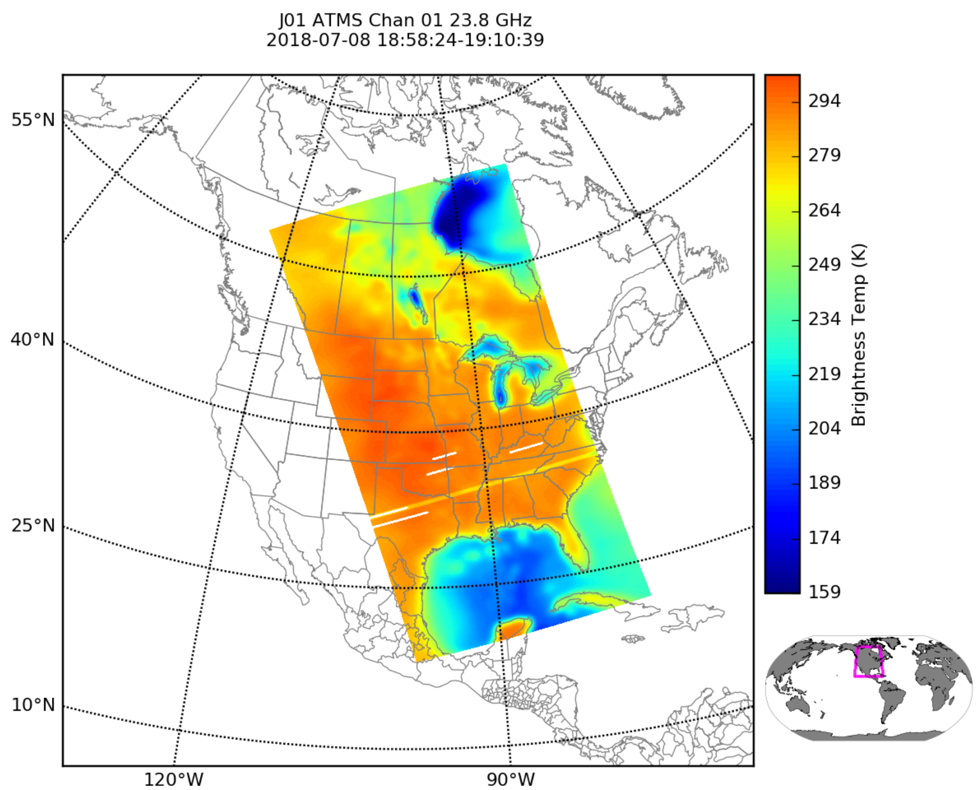


Figure 139. NOAA-20 ATMS SDR quicklook from CIMSS/SSEC HRD where data gaps and non-physical values are present due to packet drops in the HRD transmissions.

27. CIMSS Support of NUCAPS Infrared Surface Emissivity Calibration and Validation

CIMSS Task Leader: Robert Knuteson
CIMSS Support Scientist: Eva Borbas
NOAA Collaborator: Antonia Gambacorta (NOAA STAR)
Budget: $62,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation

- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

Characterize NUCAPS retrieval of the atmospheric boundary layer over land.

Project Overview

The UW CIMSS has a long history of development of global infrared databases leveraging satellite observations from the NASA EOS program and laboratory spectroscopy of terrestrial materials (Seemann et al. 2008). The latest version of this global infrared database is the monthly Combined ASTER/MODIS Emissivity over Land (CAMEL) dataset which spans the time period 2000-2016 at 0.05 deg (5 km) grid spacing. A climatology and covariance has been developed both in the spectral domain and in the space of laboratory principal components. This dataset has been completed as described in Borbas et al. 2018 and validated as described in Feltz et al. 2018. One unique aspect was the estimation of emissivity uncertainty to complement the emissivity estimates. The current CIMSS project was proposed to validate the current version of NOAA NUCAPS and assist in the implementation of the updated surface emissivity database information.

Milestones with Summary of Accomplishments and Findings

- Milestone: Evaluate NUCAPS First Guess and Final IR emissivity for consistency. Finding: NUCAPS first guess IR emissivity is valid but final IR emissivity shown to be non-physical. The figure illustrates the final emissivity as an unphysically large variance and values greater than one which is also unphysical. *The recommended solution is to use the covariance of the CAMEL emissivity to constrain the final emissivity retrieval.*
- Milestone: Acquire aircraft takeoff and landing temperature and water vapor profiles Finding: Daily global profiles available in near-realtime from NOAA MADIS ACAR
- Milestone: Support integration of CAMEL dataset into NUCAPS Finding: The climatology derived from CAMEL 16+ years has been completed.
- Milestone: NUCAPS Boundary Layer Validation Finding: This work is in progress and will be completed during the period of performance. Results to be presented at AMS Joint September 2019, Boston, Mass.

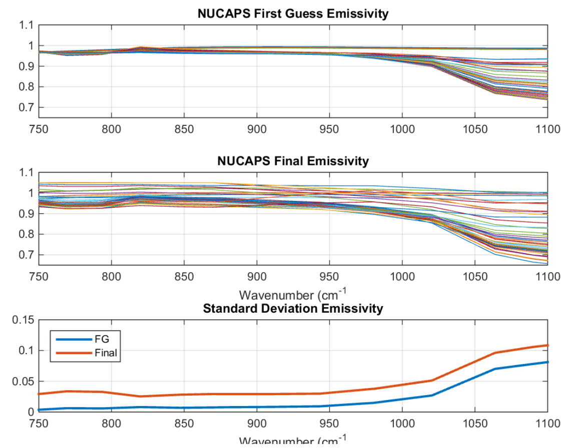


Figure 140. Comparison of NUCAPS First Guess and Final IR emissivity for consistency.

Publications and Conference Reports

Knuteson, et al., (2019). Calibration and Validation of NUCAPS Infrared Surface Emissivity, AMS Annual Meeting, Phoenix, AZ, January 2019, extended abstract. https://ams.confex.com/ams/2019Annual/webprogram/Paper351592.html

Knuteson et al. (2019). Assessment of NOAA NUCAPS Boundary Layer and Surface Retrievals over CONUS and Alaska, AMS/EUMETSAT Joint Meeting, Boston, MA, abstract submitted.

References

Borbas, E. E., Hulley, G., Feltz, M., Knuteson, R., & Hook, S. (2018). The Combined ASTER MODIS Emissivity over Land (CAMEL) Part 1: Methodology and High Spectral Resolution Application. *Remote Sens.* **2018**, *10*(4), 643; https://doi.org/10.3390/rs10040643

Feltz, M., Borbas, E. E., Knuteson, Hulley, G., R., & Hook, S. (2018). The Combined ASTER MODIS Emissivity over Land (CAMEL) Part 2: Uncertainty and Validation. *Remote Sens.* **2018**, *10*(5), 664; https://doi.org/10.3390/rs10050664

Seemann, S.W.; Borbas, E.E.; Knuteson, R.O.; Stephenson, G.R.; Huang, H.L. Development of a global infrared land surface emissivity database for application to clear sky sounding retrievals from multispectral satellite radiance measurements. J. Appl. Meteorol. Climatol. 2008, 47, 108–123.

28. CIMSS Support for the Development of a High-Resolution Quantitative Precipitation Estimate Product over Alaska

CIMSS Task Leader: Jason Otkin
CIMSS Support Scientist: Brett Hoover
NOAA Collaborator: Eugene Petrescu
Budget: $114K

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Objective

Produce and validate a quantitative precipitation estimate for Alaska through combining forecast model and observational data via statistical kriging.

Project Overview

Precipitation observations are sparse over Alaska due to a large expanse of varied terrain, a relatively small population largely confined to the southern coastal regions of the state, and latitudes too far poleward to make use of geostationary satellite data. This project uses the statistical kriging method to combine first-guess and observational precipitation data to produce a quantitative precipitation analysis over Alaska, similar to the method used by the National Operational Hydrologic Remote Sensing Center (NOHRSC) version-2 continental US snowfall product, which combines model forecast data with Stage-IV precipitation analysis for a first-guess and then incorporates snowfall observations through kriging.

Unlike the continental US, Alaska does not have Stage-IV precipitation from which to infer precipitation, so the first-guess is sourced from the High-Resolution Rapid Refresh (HRRR) – Alaska model forecast. Rain gauge data from MesoWest and Alaska's River Forecast Center are incorporated through statistical kriging. Because of the challenges posed by limited observational data, a first-guess entirely sourced from model forecast data, and limited remote sensing from radar and low-Earth orbiting satellites, cross-validation of the analysis product against observations of opportunity and bias correction of the model first-guess are important aspects of this project.

Milestones with Summary of Accomplishments and Findings

Version-1 Kriging Analysis

An initial version of the quantitative precipitation analysis has been produced using basic quality-control of MesoWest observations and HRRR-AK precipitation forecast data, producing 12-hour accumulated precipitation analyses from 0000-1200 UTC and 1200-0000 UTC. Forecast data is accumulated for the 3-9 hour forecast initialized 3 hours prior to the beginning of the analysis and 3 hours after the beginning of the analysis. A small number of observations are withheld from the analysis for cross-validation, demonstrating that the analysis has significantly less impact on the error of the precipitation estimate relative to the HRRR-AK first-guess in regions between observations than in regions where observation data is available – the root mean squared error (RMSE) of the analysis is 47% smaller than the RMSE of the HRRR-AK where observations are assimilated through kriging, but the RMSE of the analysis is only 10% smaller where observations are withheld. Observations that are withheld are often excluded from the analysis because the HRRR-AK errors are outliers at the observation location – thus the cross-validation is taking place explicitly where the HRRR-AK forecast is the least accurate. We believe that improving the first-guess prior to kriging will greatly improve the cross-validation scores.

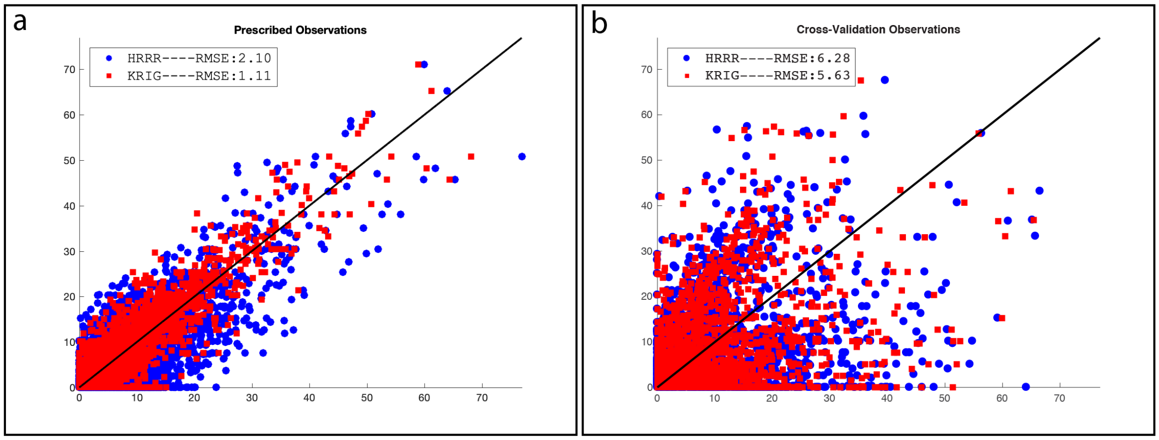


Figure 141. Scatter-plot of 12-hr accumulated precipitation in Alaska, with gridded precipitation estimate interpolated to rain gauge sites on the abscissa and rain gauge observations on the ordinate. Blue circles compare rain gauge observations to the HRRR-AK precipitation estimate and red squares compare rain gauge observations to the QPE analysis combining observations and the HRRR-AK through statistical kriging. Observations are compared for (a) those observations that are assimilated into the QPE analysis, and (b) observations withheld from the QPE analysis, often for violating maximum allowable HRRR-AK errors.

29. CIMSS Support to NPP and JPSS Data Assimilation Improvements and Data Denial Experiments

CIMSS Task Leader: James Jung
CIMSS Support Scientist: Sharon Nebuda
NOAA Collaborators: Mitch Goldberg, Andrew Heidinger, Walter Wolf, John Derber, Dennis Keyser, Lihang Zhao, William McCarty

Budget: $234,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Environmental Models and Data Assimilation

Objective

Increase and improve the use of the Cross-track Infrared Sounder (CrIS) full spectral resolution (FSR) data by the National Centers for Environmental Prediction (NCEP) and other Numerical Weather Prediction Centers.

Project Overview

This year's work continued to help with the transition from the current CrIS configuration to using the higher spectral resolution CrIS-FSR and included: 1) Quantify the detector differences for NOAA-20 and 2) compute the CrIS channel covariance error matrix. We will follow the appropriate protocols to aid in transitioning these changes to NCEP/EMC and National Environmental Satellite, Data and Information Service (NESDIS) Center for Satellite Applications and Research (STAR). While helping with the transition, we reviewed the current CrIS channel selection and tested new channel combinations in the longwave and midwave regions. We also conducted a data addition experiments to quantify the impact of having one and two JPSS satellites available for data assimilation by NWP Centers.

Milestones with Summary of Accomplishments and Findings

Quantify CrIS detector differences on NOAA-20

NWP Centers have had to make software modifications to accommodate infrared field-of-view (FOV) differences in the past. An example of this would be the GOES Sounders. The 4 dissimilar FOVs on these instruments required NCEP to treat each detector as an independent instrument. Specifically, each FOV had its own bias correction routine and fit statistics. The GOES Sounders had 19 channels requiring this approach. The newer hyperspectral instruments like IASI and CrIS have thousands of channels. This significant increase in channels makes treating each detector as an independent instrument in NWP systems difficult. When a FOV is significantly different from the others, NWP Centers now reject that FOV. One example would be ECMWF rejecting an IASI FOV on MetOP-A (Collard and McNally, 2009).

The detector difference tests conducted for the CrIS-FSR data from SNPP showed that FOV 5 in band 1 (longwave) and FOV 7 in band 2 (midwave) have larger errors than the other FOVs. Similar tests of the CrIS-FSR data from NOAA-20 showed FOV 7 in band 1 had larger errors than the other FOVs while FOV 9 in band 2 had larger errors and bias compared to the others. To date, NCEP considers the FOV differences to be less than other errors in the GDAS/GFS system and continue to use all 9 FOVs from both SNPP and NOAA-20

Compute and test channel covariance matrix and develop a CrIS FSR channel selection for NWP

NWP Centers are showing improvements in deriving their analysis and forecasts when incorporating satellite channel error correlation matrices. Some NWP Centers (Navy) have also used these matrices when developing their channel selection (Ben Ruston, Wm. Campbell, personal comm.). NCEP/EMC and NASA/GMAO are currently developing channel error correlation derivation capabilities for various satellite sensors to use in their analysis systems. NCEP/EMC is considering two different techniques to derive satellite channel correlation error, specifically Desroziers et al. (2005) and Hollingsworth and Lönnberg (1986). At this time, the Desroziers et al. (2005) technique is preferred by NCEP/EMC and NASA/GMAO.

We used the Desroziers et al. (2005) technique in deriving the correlation matrices for each of the nine CrIS detectors shown in Figure 142. Data for each detector was allowed to adjust independently for one week in the assimilation system consisting of all currently used observations. Data were collected for the period of 1 month. Consistent with Desroziers et al. (2005), we calculated the covariance and correlation matrices using only cloud free channels over ocean.

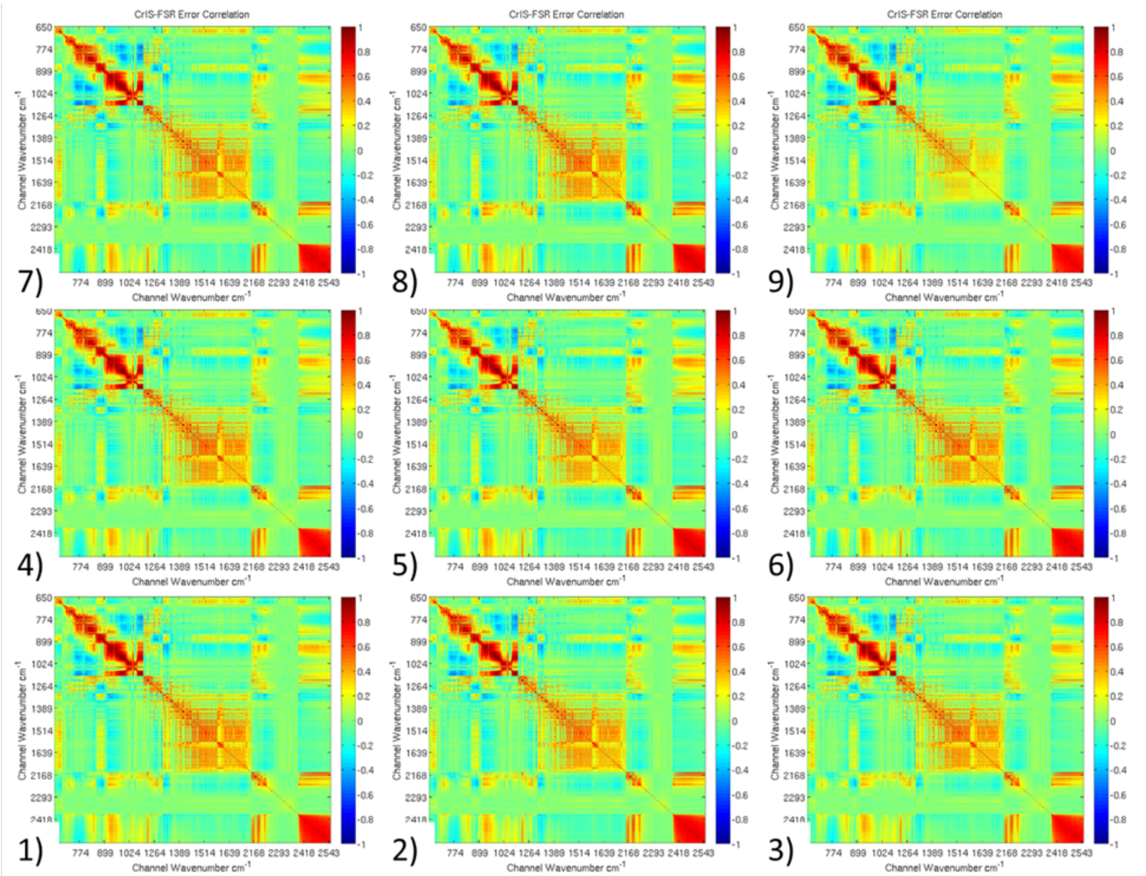


Figure 142. The CrIS-FSR correlation matrix for each of the nine FOVs on NOAA-20. Statistics were derived from clear ocean only profiles during August 2018. FOV #9 in the middle (midwave) is the most dissimilar. Most differences are subtle and probably not significant which suggests consistency between the detectors.

Quantify increased impact of NOAA-20 using data addition experiments

Today's global observing system is composed of a large variety of observing platforms such as: rawinsondes, surface stations, aircraft, buoys, satellite-borne polar-orbiting infrared and microwave radiometers, radio occultation sensors along with geostationary imagers and radiometers. Information from these different sources tends to be complementary as they use different observing techniques, have different horizontal, vertical and temporal resolutions and accuracies. This diversity of observing systems creates a robust assimilation system but can also have a large amount of redundancy.

There are several types of Observing System Experiments (OSE) in use to quantify analysis and forecast impacts of these various observing systems. Forecast sensitivity to observations (FSO), data denial, and data addition are the most common. FSO techniques are based on using the adjoint of a forecast model to provide information on the short term reduction of forecast error from each observation as described in Baker and Daley (2000) and Langland and Baker (2004). Data denial experiments are the most common and measure the forecast impact of removing data from a single sensor or satellite from the entire suite of data (e.g. Zapotocny et al. (2008), Gelaro and Zhu (2009)). A less common approach of adding observing systems to a minimized observation assimilation system, or baseline, is described in Kelly and Thepaut (2007).

By removing as much of the global observing system as possible, the relative information available from the data of each sensor can be measured. As stated by Kelly and Thepaut (2007) "due to a large degree of redundancy of the global observing system, performing impact studies by removing one element of the global observing system can show very limited impact and does not necessarily highlight the intrinsic benefit of the element in question". By using an addition to baseline OSE, it can be determined if the information content of a specific observing system is unique and relevant to NWP.

We used an assimilation system containing all conventional observations, GPS-RO and satellite derived atmospheric motion vectors (baseline). The first experiment added CrIS and ATMS from NPP to this baseline experiment (NPP). The second experiment used all data contained in the NPP experiment and added CrIS and ATMS from NOAA-20 (NPP+N20). The anomaly correlation results (Figure 143) show that adding NPP to the baseline experiment improved the forecast skill by ~50% over the baseline. Adding NOAA-20 improved the forecast skill by ~15% over the NPP experiment.

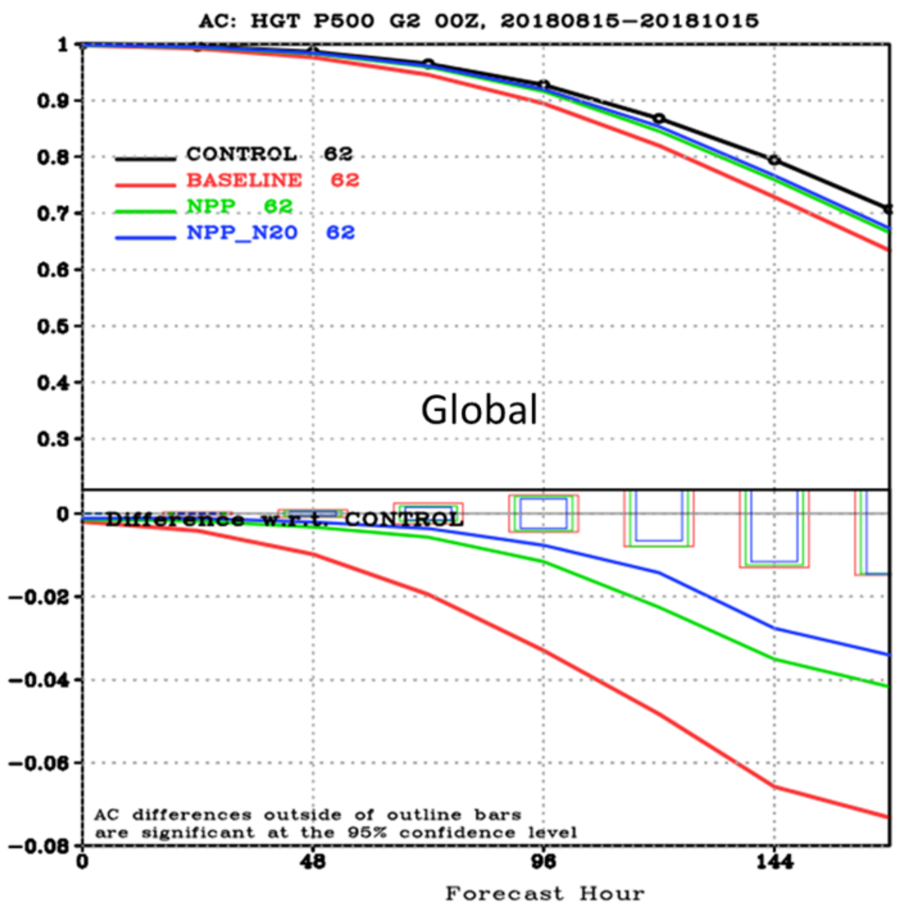


Figure 143. Global 500 hPa anomaly correlation statistics. A ~50% improvement in anomaly correlation scores is observed when SNPP is added to the baseline experiment. An additional ~15% improvement in anomaly correlation scores is observed when N20 is added with SNPP.

Publications and Conference Reports

Jung, J. A., 2018: JPSS Data Assimilation Improvements / Data Denial Experiments, CIMSS Modelling Symposium, Madison WI, 16 May 2018.

Jung, J. A., A. Lim, W. McCarty, Y. Ling, and M. D. Goldberg, 2018: NPP and N20 CrIS Full Spectral Resolution FOV Differences Derived from the NCEP GDAS, 99th AMS Annual Meeting, 6-10 January 2019.

References

Baker, N., and R. Daley, 2000: Observation and background adjoint sensitivity in the adaptive observation-targeting problem. *Quart. J. R. Meteorol. Soc*. 126, 1431-1454.

Collard, A. D. and A. P. McNally, 2009: The Assimilation of Infrared Atmospheric Sounding Interferometer Radiances at ECMWF. *Quart. J. Roy. Meteor. Soc*., **135**, 1044-1058.

Desroziers, Gérald, et al., 2005: "Diagnosis of observation, background and analysis- error statistics in observation space." QJRMS, 131.613, 3385-3396.

Gelaro, R., and Y. Zhu, 2009: Examination of Observation Impacts Derived from Observing System Experiments (OSEs) and adjoint models. *Tellus*, **61A**, 179-193.

Hollingsworth, A., and P. Lönnberg, 1986: "The statistical structure of short- range forecast errors as determined from radiosonde data. Part I: The wind field." Tellus A 38.2, 111-136.

Kelly, G. and J-N. Thepaut, 2006: The Relative Contributions of the Various Space Observing Systems to the ECMWF Forecast System, *15th International TOVS Study Conference, Maratea, Italy,4 – 10 October 2006. Available online at* http://library.ssec.wisc.edu/research_Resources/publications/pdfs/ITSC15/kelly01_ITSC15_2006.pdf

Langland, R. H., and N. L. Baker, 2004: Estimation of observation impact using the NRL atmospheric variational data assimilation adjoint system. *Tellus*, **56A**, 189-201.

Zapotocny, T. H., J. A Jung, J. F. Le Marshall and R. E. Treadon, 2008: A Two-Season Impact Study of Four Satellite Data Types and Rawinsonde Data in the NCEP Global Data Assimilation System. *Wea. Forecasting*, **23**, 80-100.

30. CIMSS Support for Demonstrating Nowcast OSSE Concept

CIMSS Task Leader: Jun Li
CIMSS Support Scientists: Zhenglong Li, Agnes Lim
NOAA Collaborators: Robert Atlas (NOAA/OAR/AOML), Timothy J. Schmit (NOAA/NESDIS/STAR/ASPB)
Budget: $71,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications

Objective

The CIMSS (Cooperative Institute for Meteorological Satellite Studies) at the University of Wisconsin-Madison will conduct studies to demonstrate Nowcast OSSE (Observing System Simulation Experiment) concept, and use Nowcast OSSE to understand the impact of current and planned observing systems on Local Severe Storms (LSS) situation awareness and nowcasting.

Project Overview

In FY18, as part of AOML's Quantitative Observing System Assessment Program (QOSAP), CIMSS conducted studies on nowcasting OSSEs. The purpose of FY18 project is to study the added value for LSS nowcasting from new observing systems such as GEO-IR and TROPICS through inverse procedure, with focus on the added value (both temporal and vertical) for nowcasting products (soundings, TPW, LI, etc.). The satellite observations include existing high spatial/temporal resolution geostationary advanced imaging system (i.e., ABI), current high spectral resolution advanced IR sounding systems from polar orbiting satellites (i.e. CrIS), future high temporal/spectral resolution GEO-IR (i.e. IRS), and the upcoming high temporal Microwave sounding systems (i.e. TROPICS).

Milestones with Summary of Accomplishments and Findings

Nature Run and synthetic observation simulation

From previous OSSE studies, CIMSS has generated a quick regional OSSE (rOSSE) framework, including orbit simulator for LEO and radiance simulator using CRTM. In this nowcast OSSE project, the same high resolution nature run (HRNR) will be used. The HRNR is generated using WRF-NMM v3.6.1, with a spatial resolution of 2 km, a coverage of the whole CONUS and part of the east Pacific Ocean in grid points of 1600 x 1320, 51 vertical layers from surface to model top at 10 hPa. The HRNR initializes at 18 UTC on May 25 2006, and forecasts for 54 hours, ending at 00 UTC on May 28 2006. The storm runs from 00 to 12 UTC on May 27. For more information about the HRNR, please refer to Li et al. (2018 and 2019). Three types of synthetic satellite radiance observations were simulated from the HRNR. For GEO-IR, we put IASI on GOES East (GEO-IASI), with a temporal resolution of 30 minutes and a spatial resolution of 8 km. For polar orbiting hyperspectral IR sounder, we use CrIS onboard Suomi-NPP. And microwave sounders, we use a 6-TROPICS constellation (Blackwell et al 2018). The TROPICS is a microwave CubeSat sounder focusing on tropical precipitation and storms, with an inclination angle of 30 degrees. The 6 TROPCIS are configured as 2-2-2, equally spaced in 3 orbital planes and two satellites in each orbit. This 6-TROPICS constellation provides a median refresh rate better than 60 minutes. For each field of view (FOV) of GEO-IASI, CrIS, or TROPICS, the radiance simulator searches the HRNR to find all grids within the FOV, performs temporal and spatial interpolation, and generate the atmospheric and surface parameters for CRTM inputs.

Experiment design

The purpose of the nowcast OSSE is to study the added value of new observing systems like GEO-IASI and TROPICS. It is therefore needed to collocate the three types of satellite observations. The collocation requires temporal differences less than 15 minutes (half of GEO-IASI refresh rate), and spatial differences less than half of the footprint size of the larger one. Four experiments are designed:

- GEO-IASI only
- GEO-IASI + TROPICS
- CrIS only
- CrIS + TROPICS

For each experiment, satellite observed brightness temperatures (Tbs) are used as predictors along with their quadratic terms. The predictants include temperature/moisture profile and surface skin temperature, from which a number of derived parameters can be calculated, including total precipitable water (TPW), lifted index (LI), convective available potential energy (CAPE) etc. These parameters together with the profiles provide important information for nowcast. Since IASI has a lot more channels than CrIS, we have chosen only those channels that can be found from CrIS, so that GEO-IASI and CrIS will use the same set of channels. For TROPICS, sensitivity tests have been carried out to determine that channels 1-5 are affected by surface, which may pose additional difficulty on the inverse.

The added value from GEO-IASI AND TROPICS

TROPICS alone is not able to provide accurate sounding information because only 7 sounding channels are used. Besides, the microwave channels all have wide weighting functions. So the evaluation of the TROPICS focuses on added value on top of either GEO-IASI or CrIS. Figure 144 shows the RMSE of TPW; for both GEO-IASI and CrIS, TROPICS is able to provide additional value on top of the hyperspectral IR sounder. The overall reduction of TPW RMSE by TROPCIS is 0.03 mm for GEO-IASI and 0.13 mm for CrIS. Note that it is not fair to compare the impact of TROPICS on GEO-IASI and CrIS because they have different samples. In addition, TROPICS, unlike IR, is capable of providing useful sounding information in cloudy region, which is not accounted for in this study.

Figure 145 shows the time series of the TPW RMSE. It again shows that the TROPICS is able to improve the sounding quality on top of GEO-IASI and CrIS for most of the times shown. More importantly, it shows that GEO-IASI + TROPICS provides much more frequent observations than CrIS + TROPICS. GEO-IASI is able to provide nowcasting products with quality similar as CrIS every 30 minutes. The 6-TROPICS constellation has a decent median refresh rate better than 60 minutes. In this case, for most of the times, TROPICS provides observations that can be used to further improve the nowcasting products from GEO-IASI alone.

These results indicate that GEO-IASI can provide nowcasting products with similar quality as CrIS, but much more frequent (every 30 minutes), which can greatly benefit severe storm nowcasting. The TROPICS constellation alone may have difficulty to provide useful nowcasting products. But it can be used to provide added value on nowcasting products from other satellites, such as GEO-IASI and CrIS.

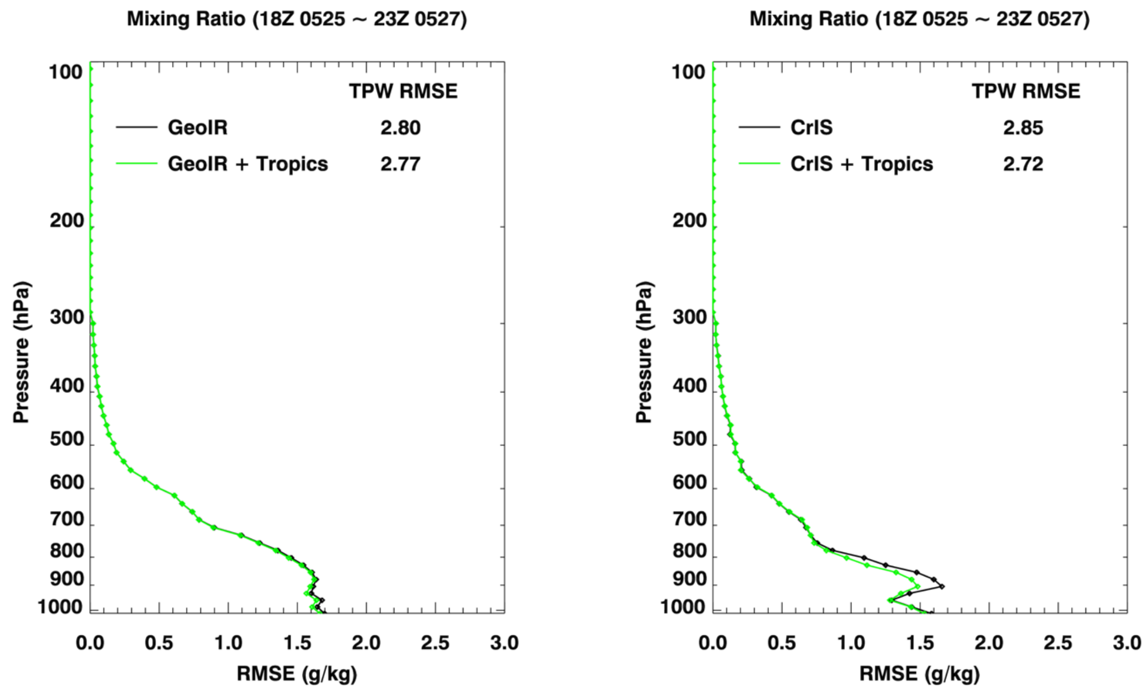


Figure 144. The mixing ratio RMSE from (left) GEO-IASI and GEO-IASI+TROPICS, and (right) CrIS and CrIS+TROPICS. GeoIR = GEO-IASI.

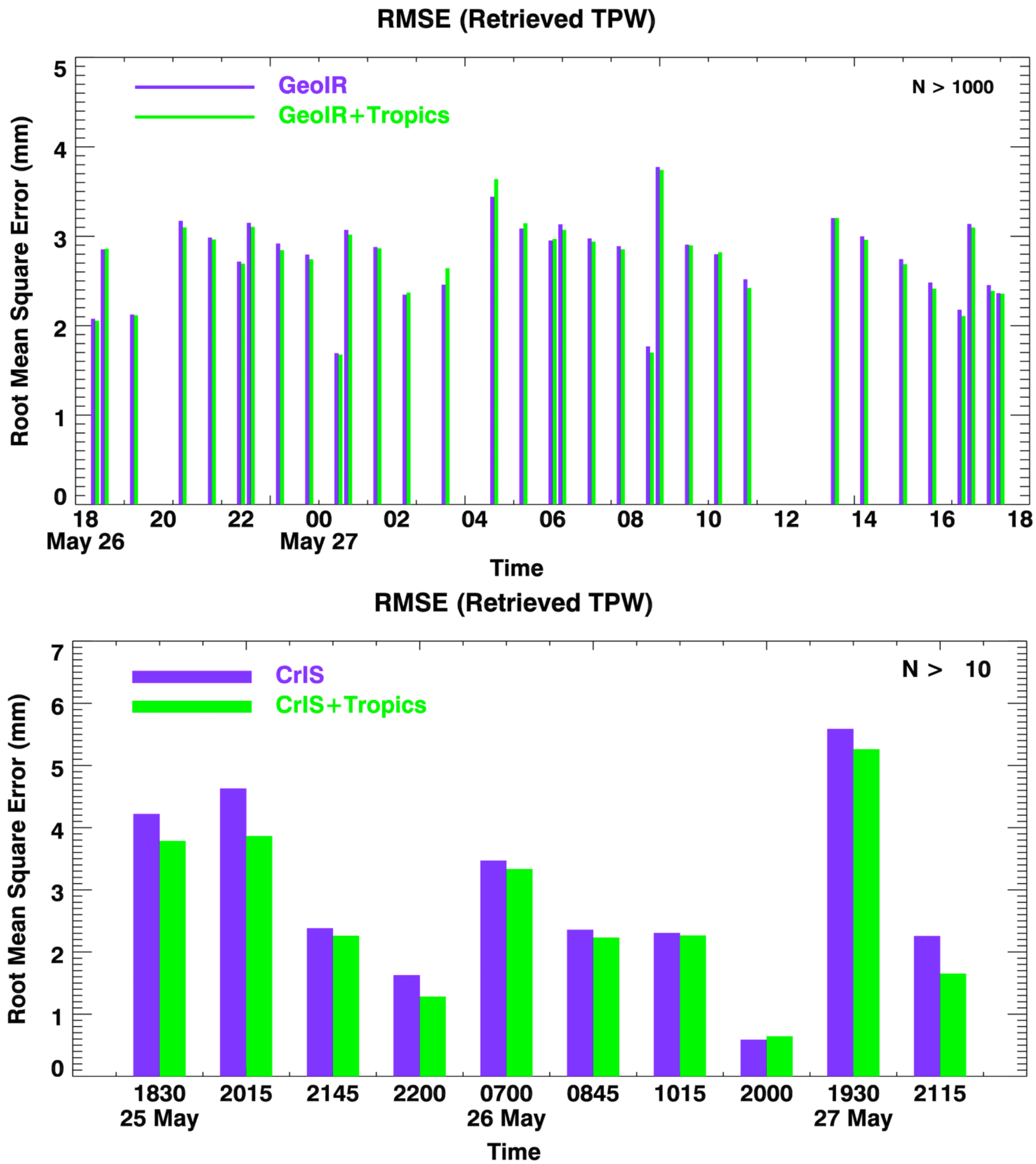


Figure 145. Time series of TPW RMSE by (upper) GEO-IASI and GEO-IASI+TROPICS and (bottom) CrIS and CrIS+TROPICS.

Publications and Conference Reports

Zhenglong Li, Jun Li, Pei Wang, Agnes Lim, Jinlong Li, Fred W. Nagle, Timothy J Schmit, Robert Atlas, R. N. Hoffman, S. A. Boukabara, W. J. Blackwell and T. Pagano, Impacts of Future High Temporal Resolution Advanced Sounding Systems on Local Severe Storm Forecast - regional OSSE Demonstration, 99th AMS Annual Meeting 06 – 11 January 2019, Phoenix, AZ.

Li, Z., Jun Li, T. Schmit, P. Wang, A. Lim, Jinlong Li, F. Nagle, W. Bai, J. Otkin, R. Atlas, R. Hoffman, S. Boukabara, T. Zhu, W. Blackwell, and T. Pagano, 2019: The alternative of CubeSat based advanced infrared and microwave sounders for high impact weather forecasting, Atmospheric and Oceanic Science Letters, Feb 2019, 1 - 11.

Li, Zhenglong, Jun Li, Pei Wang, Agnes Lim, Jinlong Li, Timothy J. Schmit, Robert Atlas, Sid-Ahmed Boukabara, and Ross N. Hoffman, 2018: Value-added Impact of Geostationary Hyperspectral Infrared Sounders on Local Severe Storm Forecasts—via a Quick Regional OSSE, Advances in Atmospheric Sciences, 35(10): 1217-1230.

References

Blackwell, W. J., S. Braun, R. Bennartz, C. Velden, M. DeMaria, R. Atlas, J. Dunion, et al. 2018. "An Overview of the TROPICS NASA Earth Venture Mission." Quarterly Journal of the Royal Meteorological Society (Accepted Author Manuscript). doi:10.1002/qj.3290.

Zhenglong LI, Jun LI, Timothy J. SCHMIT, Pei WANG, Agnes LIM, Jinlong LI, Fredrick W. NAGLE, Wenguang BAI, Jason A. OTKIN, Robert ATLAS, Ross N. HOFFMAN, Sid- Ahmed BOUKABARA, Tong ZHU, William J. BLACKWELL & Thomas S. PAGANO (2019): The alternative of CubeSat-based advanced infrared and microwave sounders for high impact weather forecasting, Atmospheric and Oceanic Science Letters, DOI: 10.1080/16742834.2019.1568816

Zhenglong LI, Jun LI, Pei WANG, Agnes LIM, Jinlong LI, Timothy J. SCHMIT, Robert ATLAS, Sid-Ahmed BOUKABARA, and Ross HOFFMAN (2018). Value-added Impact of Geostationary Hyperspectral Infrared Sounders on Local Severe Storm Forecasts -- via a Quick Regional OSSE. Adv. Atmos. Sci., 10.1007/s00376-018-8036-3

31. CIMSS Participation in the Incorporation of Satellite-derived Atmospheric Motion Vectors into OSSE Studies

CIMSS Task Leader: Chris Velden
CIMSS Support Scientist: Steve Wanzong, Sarah Griffin, Brett Hoover
NOAA Collaborators: Robert Atlas (AOML)
Budget: $200,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

CIMSS will produce simulated AMVs from a basin-scale version nature run of HWRF, characterize their errors, and consult towards the development of new assimilation methodologies that could be applied to future global nature runs and OSSEs that would account for correlated errors in the AMV data.

Project Overview

The UW-SSEC/CIMSS has a strong history of developing automated algorithms to produce AMVs from tracking cloud and moisture features in sequential satellite imagery. The local expertise in this area extends into utilizing these AMVs and associated derived products to support field projects, NWP assimilation experiments, as well as general research analyses. In this project, CIMSS will produce simulated AMVs from a basin-scale nature run of HWRF (HRNR), characterize their errors, and consult towards the development of new assimilation methodologies that could be applied to future global nature runs and OSSEs that would account for correlated errors in the AMV data. We plan to closely coordinate the proposed efforts with Dr. Robert Atlas and Dr. Lidia Cucurull (NOAA/AOML), whom have extensive experience with OSSEs and are interested in the objectives. Colleagues at NASA/JPL are also interested and will be aiding in the characterization of observation errors from the simulated AMV datasets.

Milestones with Summary of Accomplishments and Findings

Collaborators at AOML are in the process of disseminating the needed 2 km HRNR fields to CIMSS for creating simulated GOES images needed to produce simulated AMVs. The simulated AMV datasets will be produced for 10 days during a hurricane in the HRNR. From these, we will characterize the AMV errors including correlated error. To date, one case has been processed, and the correlated errors characterized as shown in the figure below. Collaborators at AOML are assessing the usefulness of this information in their data assimilation and OSSE schemes.

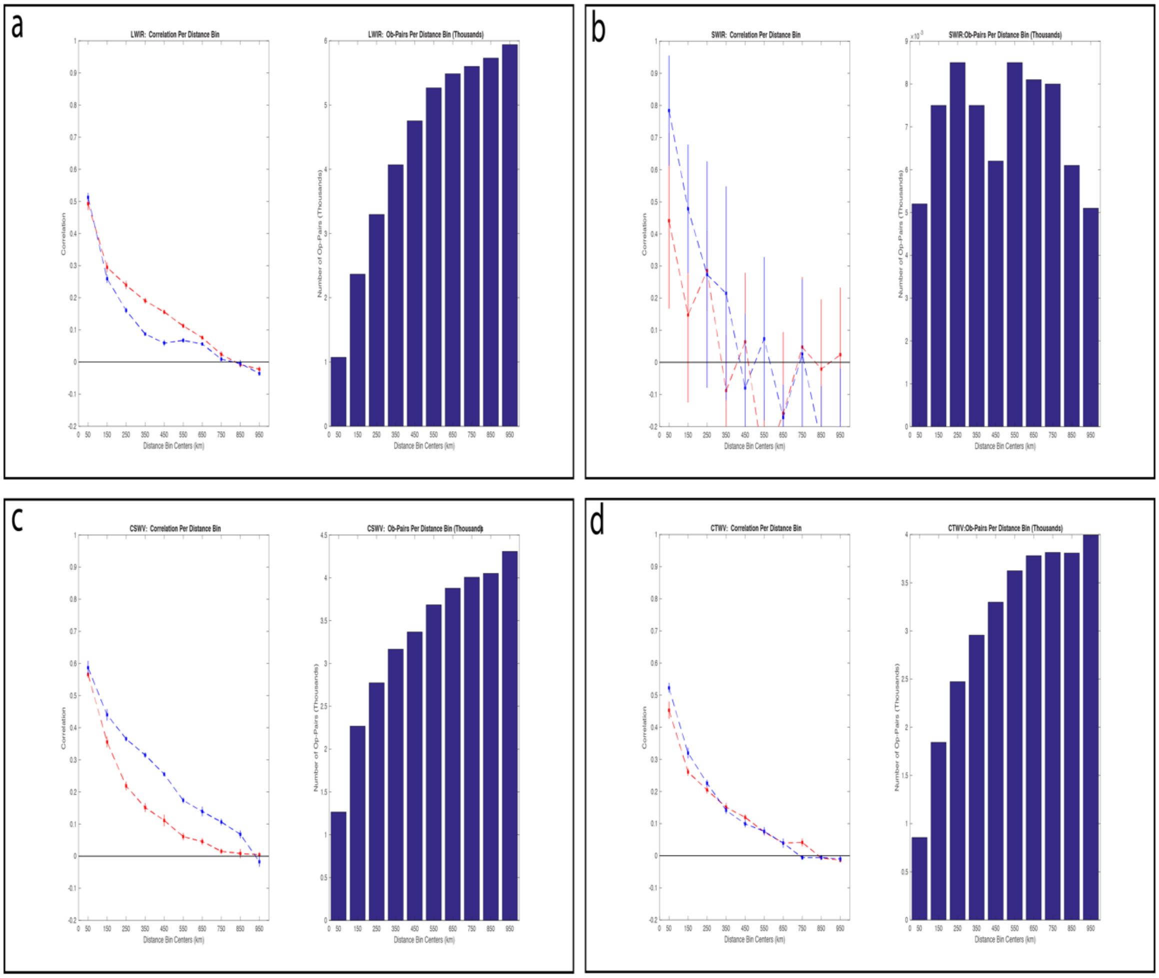


Figure 146. Each panel is the spatial correlation plot as a function of distance for each of the four categories of AMVs (LWIR, SWIR, CSWV, CTWV), for observations between 100 and 400 hPa. The red line is the correlation of the AMV wind speed error relative to the Nature Run (the true spatial error correlation), and the blue line is the AMV wind speed error relative to the first-guess used in the AMV processing. The correlation is computed 10 times from 10 subsets of the data and the sample mean correlation and 05%/95% confidence intervals of the mean correlation are plotted (vertical lines represent the confidence intervals). The SWIR AMV observations are not numerous enough to provide a useful estimate, but the other three categories have worthwhile estimates. The relationship between ob-minus-nature and ob-minus-forecast are pretty different between the AMV types, with LWIR having a higher error correlation relative to the nature run than to the first guess forecast for the majority of sampled distances, while the CSWV AMVs have the opposite behavior. Typically, the spatial correlation drops below 0.20 after 250-300 km.

32. CIMSS Activities on Supporting NESDIS Strategic Planning and Observing Systems Exploitation

32.1 The Impact of Satellite Data Latency on Local Severe Storm Forecasts in Regional NWP

CIMSS Task Leader: Jun Li
CIMSS Support Scientists: Zhenglong Li, Agnes Lim, Kevin Baggett
NOAA Collaborators: Tim Schmit (NOAA/NESDIS/STAR/ASPB), Robert Atlas (NOAA/OAR/AOML) and Sid Boukabara (NOAA/NESDIS/STAR)
Budget: $193,050

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective
The objective is to study the impact of weather satellite data latency on the forecast of high resolution local severe storm (LSS) in regional NWP model.

Project Overview
The forecast of LSS highly depends on how well the pre-convection environment is characterized in the NWP model analysis. The usefulness of the forecast highly depends on how soon the forecast is updated. Therefore, the data latency is critical for assimilation in regional NWP models, to be able to assimilate more data within the data cut-off window. The current polar orbit satellites (i.e. SNPP, JPSS, Metop-A, Metop-B, etc.) have the capability for atmospheric sounding in the pre-convection environment and low latency can be obtained through Direct Broadcast (DB) sites over the contiguous US (CONUS) and adjacent regions. In general, there is a trade-off between the number of observations and latency. Low latency ensures observations closer to model analysis time, which is beneficial to NWP, but may result in less observation available for the model. This work uses the NOAA GSI assimilation system and WRF model to perform observing system experiments (OSE) to study the impact of data latency on LSS forecasts. The experiments assimilate all existing observations, including conventional data (from the GTS) and satellite data (AMSU-A, ATMS, CrIS and IASI), they are carried out in a nested domain with horizontal resolution of 9 km and 3 km, respectively with WRF model. The ETS/FAR/POD scores of the LSS precipitation forecasts are calculated and compared with different data cut-off widows to evaluate the data latency impact. Results indicate that low latency can lead to improved positive impact on precipitation and other forecasts.

Milestones with Summary of Accomplishments and Findings

Case description, model settings and experimental design
To reflect the impacts of the data latency, a typical LSS was selected as case study. The LSS starts from 0000 UTC 24 June to 1800 UTC 24 June 2018. The Stage IV precipitation data combined station observations and radar reflectivity, along with GOES-16 brightness temperature observations both show the processing of this typical LSS. GSI and WRF on S4 are using as the data assimilation system and regional NWP model. All the current existing data are assimilated, including GTS, AMSU-A, ATMS, CrIS and IASI. The horizontal resolution of the simulation model is 9 km and 3 km nested domains. The vertical layers are 50 layers from surface to 10 hPa. The calculation time step is every 20 s. After comparing the different physics schemes in WRF-ARW v3.6 model, Thompson aerosol-arear is used as microphysics scheme to simulate the LSS

precipitation. The RRTMG is used as the longwave and shortwave radiation schemes. Yonesei University scheme (YUS) is used as the PBL scheme. The experiments start at 1800 UTC 23 June with the assimilation of different latency data, and then a 24-hour forecast is carried out.

The following Figure 147 gives the flow chart of the assimilation and forecast experiments. The assimilation time is at 1800 UTC 23 June 2018. To evaluate the impacts of data latency, there are four groups of experiments are carried out: 3-hour data latency, 2-hour data latency, 1-hour data latency, and no data latency.

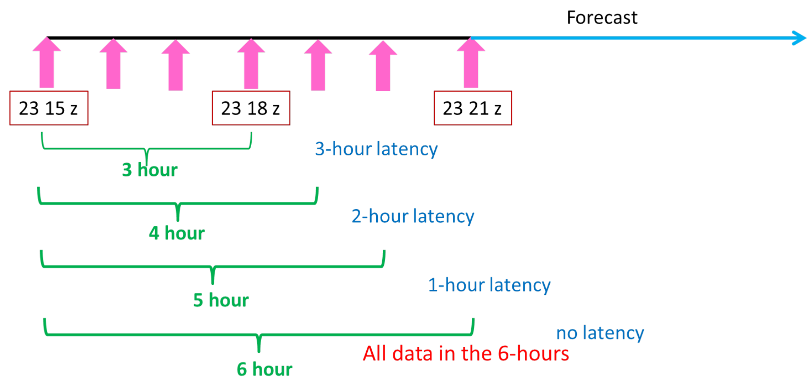


Figure 147. The flow chart of assimilation and forecast experiments. The assimilation time is at 1800 UTC 23 June. The green hours represent the available data time, and the blue represents the latency time.

Analyze the assimilated data with different data latency

Before the evaluation for the precipitation forecasts of LSS, the data coverages with different data latency experiments are analyzed. The figures of the data coverage of AMSU-A, ATMS, CrIS and IASI are shown in the monthly reports. Figure 148 provides the numbers of the observations from each satellite as a summary. The increasing ratios from 3-hour latency to no latency are also listed in the last column. From the increasing ratios and the data coverages, the AMSU-A, ATMS, CrIS and IASI are all have more observations assimilated in no latency experiment, comparing to the observations assimilated in 3-hour latency. Due to the large latency time, the 3-hour latency gives fewer observations to be assimilated in GSI system. The no latency experiments, which can get all observations for the whole 6-hour, provide the largest amount of the observations in GSI system. The additional observations can provide additional information for the regional LSS forecast. Therefore, the forecasts from the four experiments can directly reflect the data impacts from the different latency time.

Satellite	3-hour latency	2-hour latency	1-hour latency	No latency	(no latency – 3-hour latency) / no latency
AMSUA N15 Ch 6	141	141	141	141	-----
AMSUA N18 Ch 6	1385	1383	1383	1384	-----
AMSUA N19 Ch 6	-----	101	101	114	100%
AMSUA MetopA Ch 6	2149	2150	2150	2150	-----
AMSUA MetopB Ch 8	2365	2624	2624	2624	9.9%
ATMS Ch 11	500	500	1076	1075	53.5%
CrIS Ch 96	247	244	874	869	71.6%
IASI MetopA Ch 110	1774	1774	1745	1748	-----
IASI MetopB Ch 110	1879	2210	2177	2175	13.6%

Figure 148. Numbers of assimilated data for each satellite with different data latency, and the increasing rate at analysis field.

Discussion the impacts on LSS forecast

To evaluate the impacts of different latency on LSS forecast, the RMSE of the atmospheric fields and the precipitation between observations and the forecasts are calculated. The forecasts of the temperature (T), moisture (Q), winds (U-wind and V-wind) are compared with the radiosonde observations. There are total 177 stations of radiosonde available during the 24-hour forecast period. The RMSE between the radiosonde observations and the forecast atmospheric fields are calculated for each experiment. For the precipitation forecast, the ETS, POD and FAR are calculated for every 6-hour from 0.1 mm, 1 mm, 5 mm, 10 mm, 15 mm, 20 mm, 50 mm and 75 mm. The details for the ETS, POD and FAR scores can be found from the monthly reports. For all parameters (T/Q/U/V/ETS/POD/FAR), a normalization process is carried out to ensure the sum of the square equals 1 for each parameter, including 1-ETS, 1-POD and FAR. And the final nominalized RMSE is calculated using a weighted average:

- Thermodynamic parameters (T/Q/U/V), 10% for each one
- Precipitation scores (1-ETS/ 1-POD/ FAR), 20% for each one

The calculation is performed at the June 23 1800 UTC, 24 0000 UTC, 24 0600 UTC, 24 1200 UTC and 24 1800 UTC. Using the above method, the final normalized RMSE of the four experiments are calculated (Figure 149). Comparing the four groups of experiments, the improvement from 3-hour latency to 2-hour latency is around 2.3%, from 3-hour latency to 1-hour latency is around 2.9%, and from 3-hour latency to no-latency is around 3.9%. Overall, the no-latency provides the most observations in the assimilation window to the LSS simulation for both the analysis and forecast compared to the other experiments.

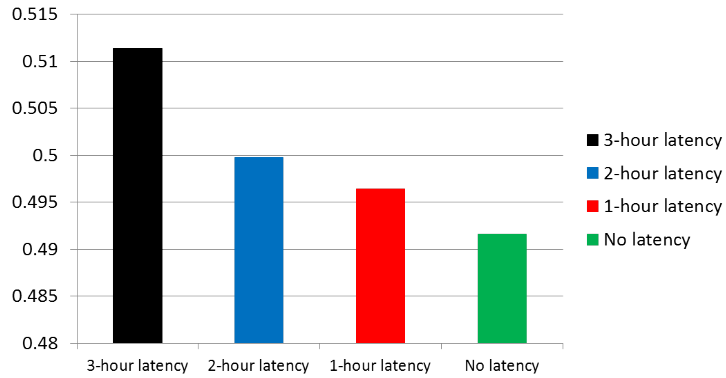


Figure 149. The final normalized RMSE of the four experiments.

32.2 Exploit TROPOMI sensor
CIMSS Task Leader: Allen Lenzen
CIMSS Support Scientist: Tommy Jasmin
SSEC Collaborators: Brad Pierce
NOAA Collaborators: Tim Schmit (NOAA/NESDIS/STAR/ASPB), Sid Boukabara (STAR/NESDIS)
Budget: $135,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications

Objective

This project will study the impact of assimilating TropOMI high spatial resolution NO2 and CO retrievals on pollution prediction, especially the emission of ozone precursors and pollution transport.

Project Overview

TropOMI (Dobber, et al, 2018) provides accurate and timely observations of key atmospheric species, for services on air quality, climate, and the ozone layer. TropOMI provides high spatial resolution carbon monoxide (CO) retrievals, which are uniquely sensitive to boundary layer CO. It is important to understand the impact of those atmospheric chemistry parameters on pollution prediction through data assimilation. The goal of this project is to study the impact of each species on pollution prediction, especially the emissions of ozone precursors and pollution transport. Development of capabilities to assimilate TropOMI nitrogen dioxide (NO2) and formaldehyde (HCHO), which can be used to constrain NOx (nitrogen oxide) VOC (Volatile organic compounds) emissions, provides a means of providing timely updates to emission inventories used to forecast ozone within the NOAA National Air Quality Forecasting Capability

(NAQFC). This project will focus on the development of capabilities to assimilate TROPOMI trace gas retrievals within the NWS National Air Quality Forecast Capability (NAQFC, Stajner et al, 2012).

Milestones with Summary of Accomplishments and Findings

1) Acquired both TropOMI NO2 and CO retrieval products and input files and forecasts for parallel NAM-CMAQ air quality forecasts for the defined study period of June through September 2018.
2) Developed program to read TropOMI NO2 NETCDF files and create BUFR files for input to (National Centers for Environment Prediction) NCEP (Gridpoint Statistical Interpolation) GSI data assimilation system.
3) GSI updated to read TropOMI NO2 bufr files and the TropOMI averaging kernel (AK) was added for use in NO2 TropOMI profile data assimilation.
   This allows for direct comparison between the NAM-CMAQ NO2 profiles and the TropOMI NO2 profiles. For TropOMI, the AK is a simple vector which characterizes the sensitivity of the tropospheric NO2 retrieval to the NO2 mixing ratio at a given altitude.
4) Conducted a baseline and 15% NOx emission perturbation experiments
   These two experiments were used to construct the background error (BE) statistics needed to conduct the NAM-CMAQ/GSI TropOMI NO2 data assimilation experiments. These statistics include standard deviation as well has horizontal and vertical length scales. We have scaled the NO2 standard deviation by a factor of 5 for the TropOMI assimilation experiments based on results from OMI data assimilation experiments conducted during 2017.
5) Conducted NAM_CMAQ/GSI TropOMI NO2 data assimilation experiments.
   NAM-CMAQ/GSI TropOMI NO2 data assimilation experiments were conducted for July-Sept, 2018. Figure 150 shows the mean tropospheric NO2 column differences between the NAM-CMAQ baseline experiment with RAQMS lateral boundary conditions and standard lightning NOX emissions.
   Figure 151 shows the mean GSI analysis increment from the GSI TropOMI tropospheric NO2 data assimilation experiment. The NAM-CMAQ baseline experiment overestimates the tropospheric NO2 columns by 20x1015 mol/cm2 in Denver, near the Four Corners Generating Station, and in Ciudad Acuna, Mexico (across the border from Del Rio, TX). Other major U.S. cities show NAM-CMAQ overestimates range from 5-10x1015 mol/cm2, with 1-2x1015 mol/cm2 underestimates in some rural regions of the western U.S.
6) Developed visualization capabilities for TropOMI data products.
   Added support for TropOMI to the McIDAS-V Visualization and Analysis software package, developed at University of Wisconsin's Space Science and Engineering Center. Added an I/O Service Provider (IOSP) module that allows users to load arbitrary TropOMI NetCDF products into McIDAS-V. The TropOMI IOSP will interrogate the file and make available to users any data within the file that is georeferenced. One significant advantage of being able to work with TropOMI in McIDAS-V is the ability to easily co-locate the data with other data sources.

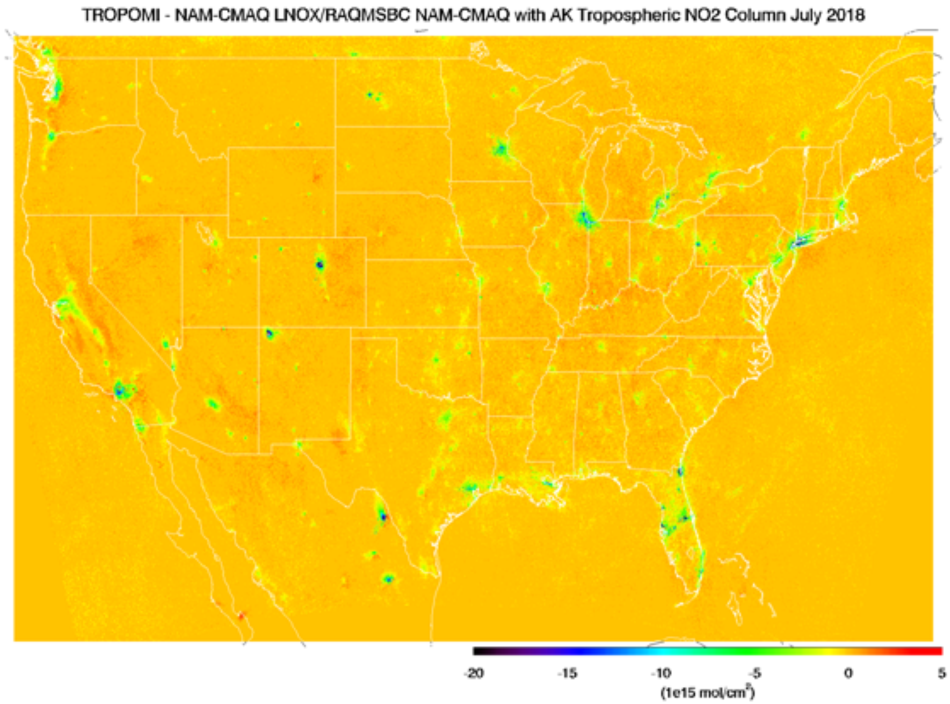


Figure 150. Mean difference (mol/cm2) between TropOMI and NAM-CMAQ tropospheric NO2 column (with TropOMI averaging kernel) for NAM-CMAQ baseline experiment with RAQMS lateral boundary conditions and standard lightning NOX emissions.

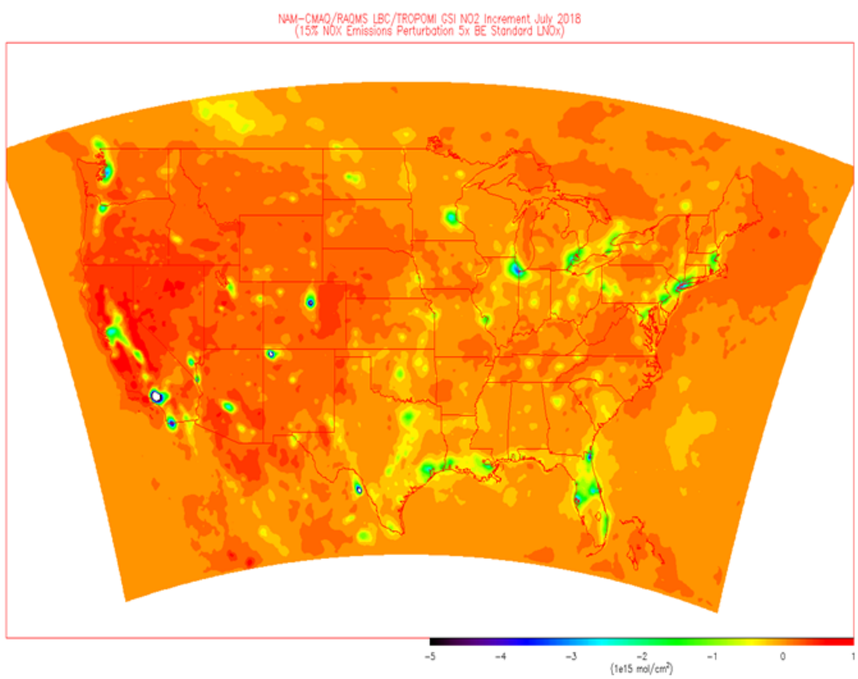


Figure 151. Mean GSI analysis increment (mol/cm2) for NAM-CMAQ/GSI TropOMI NO2 column assimilation during July 2018.

References

Dobber, M. R., et al. (2017), From ozone monitoring instrument (OMI) to tropospheric monitoring instrument (TROPOMI), Proc. of SPIE Vol. 10566, doi: 10.1117/12.2308268

Stajner, I., P. Davidson, D. Byun, J. McQueen, R. Draxler, P. Dickerson, and J. Meagher, 2012: US National Air Quality Forecast Capability: Expanding coverage to include particulate matter. Air Pollution Modeling and Its Application XXI, D. G. Steyn and S. T. Castelli, Eds., NATO Science for Peace and Security Series C: Environmental Security, Springer, 379–384, doi:https://doi.org/10.1007/978-94-007-1359-8_64.

33. Upgrade to the NOAA NESDIS Supercomputer for Satellite Simulations and Data Assimilation Studies (S4) at the Space Science and Engineering Center, University of Wisconsin-Madison

CIMSS Task Leader: Scott Nolin
CIMSS Support Scientists: Allen Lenzen, Jesse Stroik
NOAA Collaborator: Kevin Garrett
Budget: $1,518,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Environmental Models and Data Assimilation

Objective

Upgrade the S4 system to support the FV3GFS and continue the S4 system partnership between NESDSIS/STAR and UW SSEC.

Project Overview

The Space Science and Engineering Center (SSEC) at the University of Wisconsin-Madison hosts a Numerical Weather Prediction (NWP) supercomputer for the NOAA/NESDIS Center for Satellite Applications and Research (STAR). This system allows Data Assimilation experiments as well as Observing System Simulation Experiments (OSSEs) in a research environment using U.S. operational data assimilation and forecast models, at both global and regional scales.

This Project is to upgrade the capabilities of this Supercomputer for Satellite Simulations and Data Assimilation Studies (S4) High Performance Computing (HPC) system. The major impacts of the upgrade will be to run data assimilation experiments with the latest FV3GFS model and continue to serve past the planned lifecycle end date of December 2018 of the existing system.

Milestones with Summary of Accomplishments and Findings

New equipment procurement and installation

The new S4 hardware has been procured and installed, providing:

- 2,560 Intel Xeon Gold 6130 CPU cores in 80 compute nodes with
- 15,360 GB RAM
- 3.2PB of primary storage and 1PB of scratch storage

Software installation, benchmarks, and system testing
Operating system software and all science software and libraries installed. Industry standard system tests including Linpack, IOR, and mdtest complete and show the system meets performance expectations.

Science Code Testing
Initial tests of FV3GFS and WRF-Chem completed and show planned performance improvements compared to the older S4 system. WRF-Chem performance is in the figure below.

User Migration for Routine Operations
Initial migration of users has begun, with ten users now using the new system. Procedures for migrating user data are tested and working appropriately. Detailed user documentation is currently under development. When documentation is complete in the coming days the remaining users will be moved to the system.

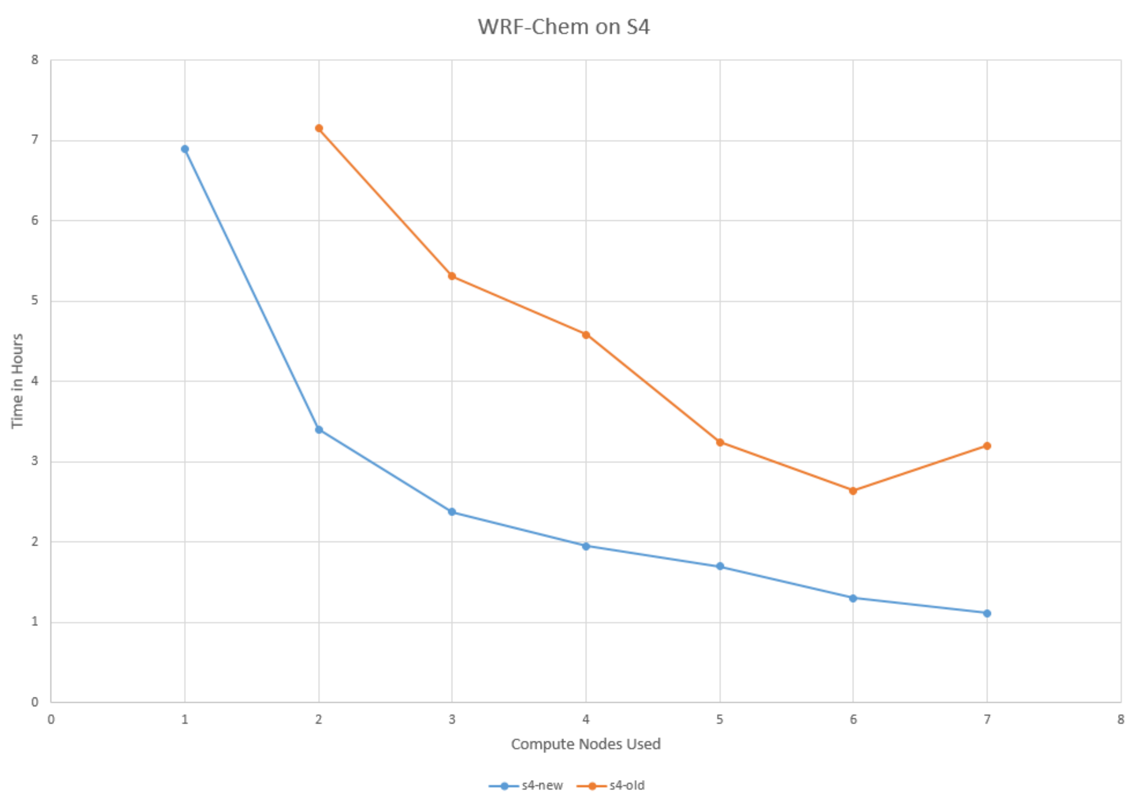


Figure 152. WRF Chem performance.

References
Boukabara, S. A.; S. Lord; S. Goodman; T. Zhu; B. Pierce; R. Atlas; L. Cucurull; M. Zupanski; M. Zhang; I. Moradi; J. A. Otkin; D. Santek; B. Hoover; Z. Pu; X. Zhan; C. Hain; E. Kalnay; D. Hotta; S. Nolin; E.Bayler; A. Mehra; S. Casey; D. Lindsey; K. Kumar; A. Powell; J. Xu; T. Greenwald; J. Zajic; J. Li; J. Li; B.Li; J. Liu; L. Fang; and P. Wang; S4: An O2R/R2O

Infrastructure for Optimizing Satellite Data Utilization in NOAA Numerical Modeling Systems, A Step Toward Bridging the Gap Between Research and Operations. *Bull. Am. Meteorol. Soc*. (December 2016)

34. Demonstration Study Using Artificial Intelligence (AI) for the NowCasting of Tornadoes

CIMSS Task Leader: John Cintineo
CIMSS Support Scientists: Anthony Wimmers, Justin Sieglaff, Bill Bellon
NOAA Collaborator: Mike Pavolonis
Budget: $40,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

This project demonstrates how to use artificial intelligence with satellite imagery to better nowcast severe convective weather.

Project Overview

Severe storm forecasting is a vital component of NOAA's mission to protect life and property. With the increasing resolution, frequency, and information content of data coming into NWS forecast offices, making efficient use of the avalanche of data for timely and accurate warning decisions can be difficult. One way to help capitalize on all of the new information is to use artificial intelligence, which is using computer systems to mimic human tasks, such as complex pattern recognition. One powerful way to do this is using convolutional neural networks (CNNs), or "deep learning". GOES-16 ABI imagery is full of useful information that humans can pick out amid varied and complicated background conditions, but is difficult for explicitly coded algorithms to reliably detect. Because humans have limitations in observing many storms simultaneously and continuously in satellite imagery, CNNs are a good candidate to systematically deduce complex patterns in the evolution of storm-top properties that can inform storm severity. The goal of this project is to train a CNN to accurately detect and possibly predict whether or not a storm is a 'supercell' automatically. Supercell thunderstorms are tied very closely to severe weather at the surface and so such a model may add confidence to warning decisions as well as likely severe weather in areas of North and South America where there is no radar coverage.

Milestones with Summary of Accomplishments and Findings

Building deep learning expertise and toolbox

Using the powerful Keras API and Google TensorFlow backend, we have begun developing tools to train and validate CNNs using a single GPU. Many of these tools provide verification statistics on an independent testing dataset, but some involve model interpretation (see Figure 153). We will use these tools and develop further ones as needed to aid in our CNN training.

Building a truth database

Using mySQL and javascript/PHP APIs, we have developed an online tool for humans to quickly perform storm classification on infrared and visible images (e.g., supercell, ordinary cell, linear). This will allow us to quickly build up a training database of images for the supercell classification task. We anticipate that we can manually classify 10,000 storm images in a matter of 10-20 hours, using infrared and visible imagery, as well as radar imagery.

Trained a CNN for severe weather

As a proof of concept, we used readily available training labels in NCEI severe weather reports and linked them to ProbSevere storm objects (Cintineo et al. 2018). Then we trained a CNN to predict the probability of severe weather using only the 11-µm brightness temperature within a small neighborhood of storms. This is just a test prior to training our supercell classification model (because we need more labeled data), but even this simple CNN demonstrated some skill (see Figure 154). A CNN with skill comparable to human forecasters will likely need to incorporate lightning, radar, NWP, more satellite data, and many more samples, which is outside the scope of this project. However, a supercell identification model with only satellite data could still be useful in the warning process.

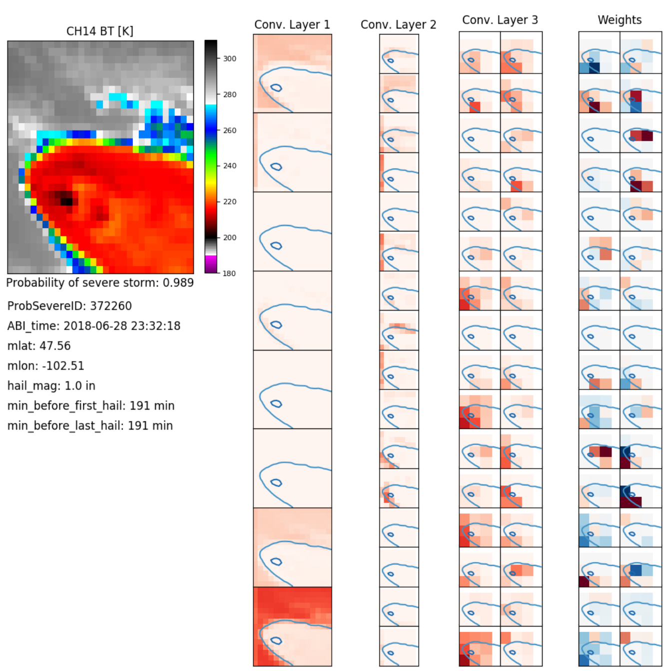


Figure 153. A graphic visualizing feature maps along several layers of a trained convolutional neural network. Snapshots like this may help us see why the model is making the predictions it is, and what features the model says are important. In this case, several feature maps seem to highlight the isolated nature of this storm, strong 11-µm brightness temperature gradients, and the overshooting top.

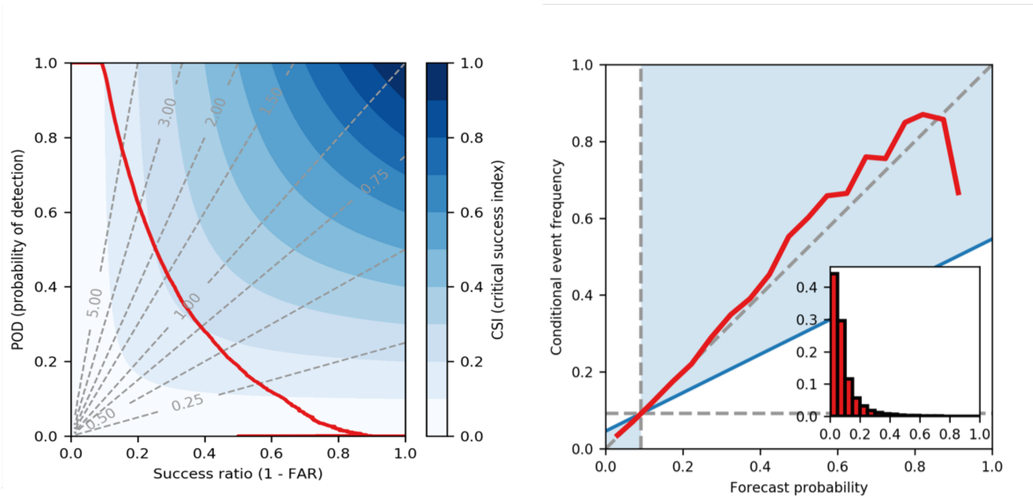


Figure 154. The figure on the left is a performance diagram, plotting the POD vs. success ratio, yielding the CSI (where the red line intersects with shaded blue regions. We can see that the maximum CSI is about 0.22 at a bias (dashed lines) near 1.0. The figure on the right is an attributes diagram, showing the calibration and frequency of the forecasted predictions on independent data samples. This model has very good reliability except for very high predicted probabilities.

Publications and Conference Reports

An abstract was submitted to the 2019 AMS satellite conference.

References

Lagerquist, R., and D.J. Gagne II, 2019: "Interpretation of deep-learning models for predicting thunderstorm rotation: Python tutorial". https://github.com/djgagne/ams-ml-python-course/blob/ryan_branch/module_4/ML_Short_Course_Module_4_Interpretation.ipynb.

Cintineo, J. L., and Coauthors, 2018: The NOAA/CIMSS ProbSevere Model: Incorporation of total lightning and validation. *Wea. Forecasting*, **33**, 331–345.

35. CIMSS Support to Demonstrating the Potential Benefits of a Tundra Orbit

CIMSS Task Leaders: Mat Gunshor, Jun Li
CIMSS Support Scientists: Zhenglong Li, Fred Nagle, Pei Wang
NOAA Collaborators: Tim Schmit, Louis Grasso, Kris Kummerow, Satya Kalluri, Sid Boukabara
Budget: $300,000

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Study the potential added value, along with advantages and disadvantages of a Tundra (highly elliptical) orbit and its impacts on monitoring, nowcasting, and forecasting the high impact weather events such as tropical cyclone, local severe storm and high latitude volcanoes and fires.

Project Overview

The FY18 Tundra project focuses on developing methodologies, software and tools to simulate radiance measurements from a Tundra orbit using NWP field as input, as well as the comparison of spatial coverage, spatial resolution, and observation frequency to the existing geostationary (GEO, i.e. ABI/GOES-16) and LEO (i.e. VIIRS on SNPP and J1) satellites.

Milestones with Summary of Accomplishments and Findings

A Tundra orbit is one type of geosynchronous orbit with an orbital period of 24 hours. The relatively large high eccentricity of 0.2684 makes it spend twice as much time near its apogee (about 16 hours) than perigee (about 8 hours). With an inclination of 90 degrees, a Tundra satellite is capable of providing nearly continuous observations for high latitude regions (Trishchenko and Garand, 2011; PCW, 2010). The main accomplishments include are noted below.

Tundra Orbit Simulator

An orbit simulator was developed to realistically simulate Tundra orbits. From previous OSSE projects, also supported by OPPA, CIMSS has already developed the capability to simulate both existing and future LEO orbits (Li et al. 2019). This study expanded that capability to include the geosynchronous orbits. The simulator allows a user to modify several parameters to configure the orbits, such as eccentricity, inclination angle, right ascension of the ascending node, or RAAN, argument of perigee, and mean anomaly. The orbit simulator predicts the Tundra satellite's nadir location (lat/lon) and altitude for a given time.

Tundra Navigation Simulator

A navigation simulator was developed to simulate the scanning strategy. Due to the similarity between Tundra and GEO, an ABI is assumed to be on-board the Tundra satellite with the same spatial resolution of 56 μrad for infrared bands. The navigation simulator generates the Tundra viewing geometry, including lat/lon and local zenith angle of the observed pixel. The Tundra navigation system is more complicated than both GEO and LEO because the spatial resolution and view geometry vary with time.

Tundra Radiance Simulator

A Tundra radiance simulator is developed to simulate the radiance measurements with CRTM using the GEOS-5 Nature Run (G5NR) from GMAO/GSFC. For a given time and location, the simulator searches G5NR and performs temporal and spatial interpolation, to generate the atmospheric and surface parameters as CRTM inputs. The output radiances are added with Gaussian distributed random noise, generated using GOES-16 ABI's measured in-orbit noise. Also under the support of OPPA, CIMSS has developed capabilities to simulate orbits, navigations, and radiance measurements from both LEO and GEO. This allows us to compare the spatial coverage of Tundra with GEO. Figure 155 shows an example of simulated ABI 11.2 μm brightness temperature (K) at 01:15 UTC on July 1 2018 from a Tundra satellite on the left and

GOES-16 on the right panel using G5NR as input. Similar as ABI/GOES-16, ABI/Tundra has a great spatial coverage as it can scan the full disk of about 1/3 of earth surface every 15 minutes.

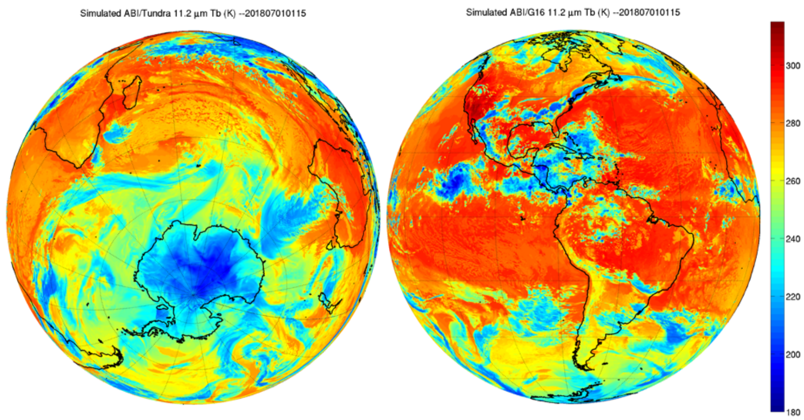


Figure 155. The simulated ABI 11.2 micrometer Tb from (left) Tundra orbit and (right) GOES-16 using G5NR as input at 0115 UTC on July 1, 2018

Comparison of footprint size with ABI/GOES-16 and VIIRS/SNPP

Since Tundra has a polar orbiting geosynchronous orbit, it has some of the advantages from both GEO and LEO, including high temporal resolution, great spatial coverage, and decent spatial resolution. The ABI/Tundra is configured to have the existing technology as ABI/GOES-16, i.e. a refresh rate of 15 minutes for full disk. The inclination angle of 90 degrees allows Tundra to move between the two poles, which greatly improves the spatial coverage compared with a GEO, which has a fixed spatial coverage. The most unique advantage of Tundra is from its relatively large high eccentricity of 0.2684, which allows Tundra to spend twice as much time near its apogee (about 16 out of 24 hours) than perigee (about 8 out of 24 hours). This makes it possible to provide nearly continuous observations for high latitude regions from a single satellite, which will greatly benefit the regional short-term forecasting and nowcasting for NWS.

The ABI/Tundra is compared with ABI/GOES-16 and VIIRS/SNPP for footprint size. Figure 156 shows the footprint size imagery of ABI/Tundra, ABI/GOES-16, and VIIRS/SNPP at 09:00 UTC on July 1 2018 for 15 minutes of scan. For 15 minutes, both Tundra and GOES-16 have much larger coverage (about 1/3 of earth surface) than VIIRS. And Tundra has slightly larger coverage than GOES-16 at this particular time because of higher altitude. This also causes the Tundra to have slight coarser footprint size (2.5 km nadir) than GOES-16 (2 km nadir). The VIIRS/SNPP, with much lower altitude (about 834 km), has much smaller footprint size (750 m nadir) than both Tundra and GOES-16.

Figure 156 also shows 24-hour time series of footprint sizes for nadir and Madison, WI. GOES-16, with a fixed nadir location, has a fixed nadir footprint size of 2 km. That means each location seen by the GOES-16 has a temporally invariable footprint size, including Madison, WI whose footprint size is 3.45 km. The nadir footprint size (750 m) of VIIRS/SNPP does not change temporally much because the variation of satellite altitude is very small. At the latitude of 43.07 degree, Madison, WI is only seen by VIIRS/SNPP twice during the 24 hours. And each time has a different footprint size. The Tundra, on the other hand, neither has a fixed nadir, nor an invariable satellite altitude because of its relatively large eccentricity of 0.2684. That means Tundra's footprint size not just changes with scan angle, but also with time. Figure 156 shows that the ABI/Tundra has a variable nadir spatial resolution of 1.38 km (closest to the earth) to 2.63 km (furthest to the earth). For about 1/3 of the time (near perigee) Tundra has finer footprint size than

GOES-16, and coarser footprint size for the remaining 2/3 of the time (near apogee). Madison, WI, although not very high latitude, is covered by Tundra for 15 consecutive hours, with a wide range of footprint size (4 – 12 km). Note the footprint size can be improved with an optimal orbit for CONUS.

All of these advantages are demonstrated with one day of simulated ABI/Tundra radiances for July 1, 2018. Animations of simulated radiances (show spatial coverage), footprint size, observation frequencies, are generated, and can be viewed from the following PPT: ftp://ftp.ssec.wisc.edu/ABS/zli/tundra/STAR_CIMSS_Tundra_demonstration_28Feb2019_update.pptx

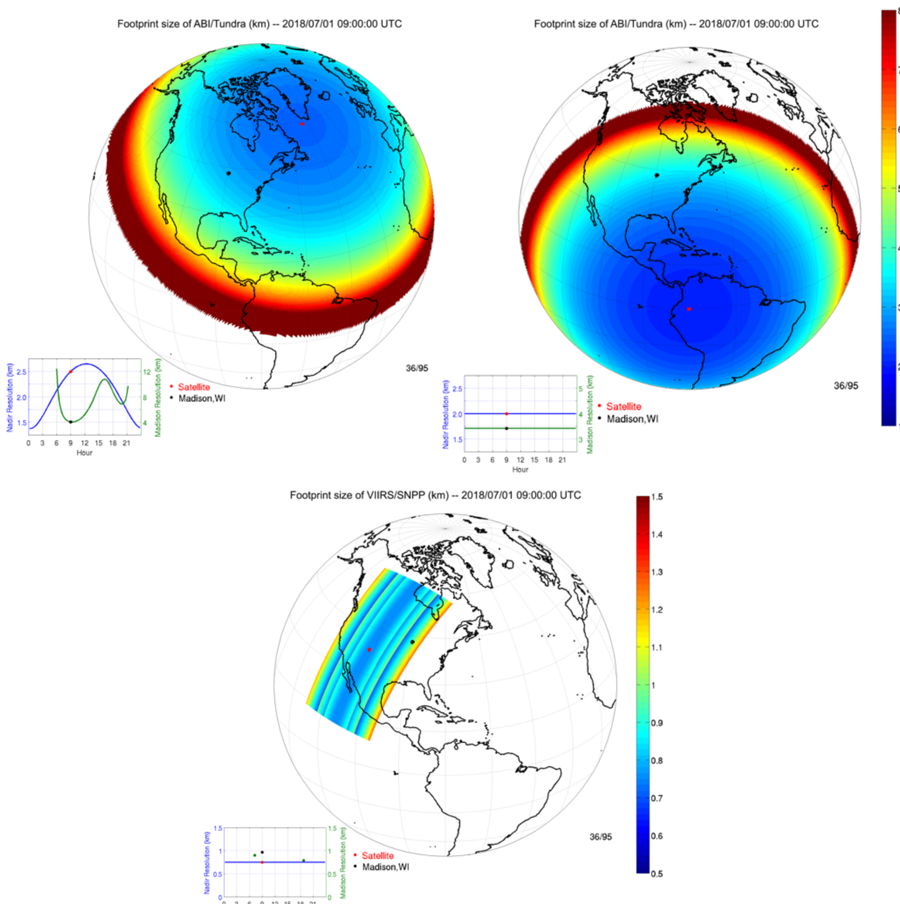


Figure 156. The simulated ABI footprint size in km from (upper left) Tundra orbit, (upper right) GOES-16, and (bottom) VIIRS/SNPP at 09:00 UTC on 01 July 2018 for 15 minutes of scan. The upper two panels use the same color bar. Note that the figure has animation format as well for one day with 15-minute interval (resolution). Also shown are the temporal variation of footprint size of satellite nadir in red dot and Madison, WI in black dot. Note Tundra does not have fixed footprint size.

References

Trishchenko, A.P. and L. Garand, 2011: Spatial and Temporal Sampling of Polar Regions from Two-Satellite System on Molniya Orbit. J. Atmos. Oceanic Technol., 28, 977–992, https://doi.org/10.1175/JTECH-D-10-05013.1

Zhenglong LI, Jun LI, Timothy J. SCHMIT, Pei WANG, Agnes LIM, Jinlong LI, Fredrick W. NAGLE, Wenguang BAI, Jason A. OTKIN, Robert ATLAS, Ross N. HOFFMAN, Sid- Ahmed BOUKABARA, Tong ZHU, William J. BLACKWELL & Thomas S. PAGANO (2019): The alternative of CubeSat-based advanced infrared and microwave sounders for high impact weather forecasting, Atmospheric and Oceanic Science Letters, DOI: 10.1080/16742834.2019.1568816

PCW, 2010: Polar Communication and Weather mission: User requirement document. Version 5.1, 111 pp.

36. CIMSS Cal/Val Activities in Support of the Calibration Work Group

CIMSS Task Leader: Mat Gunshor
CIMSS Support Scientist: Jim Nelson
NOAA Collaborator: Tim Schmit (NESDIS/STAR/ASPB)
Budget: $100,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques

Objective

Support the GOES-R Calibration Working Group (CWG) in post-launch test activities for GOES-R series Advanced Baseline Imager (ABI) data, especially in the area of serving user's needs and best interests.

Project Overview

CIMSS assists the GOES-R CWG in preparing NOAA and users for the GOES-R era. Experience with the legacy GOES-series on science checkouts and radiance quality assurance, as well as involvement on the GOES-R AWG developing a system for analyzing ABI product output, have been be valuable to the CWG's mission of providing the most accurate data possible.

Milestones with Summary of Accomplishments and Findings

Specific tasks proposed:

1. Assist CWG in analysis of calibration issues and their effects on products
    a. Supporting L1b calibration and ensuring ABI data quality.
    b. Analyzing the impact of L1b issues on users.
    c. Assisting CWG through GOES-S PLT/PLPT.
2. Assist CWG in analysis of calibration and navigation on JMA's AHI.
    a. Support GOES CVCT INR efforts.
3. Report on issues addressed by CIMSS that affect GOES radiance quality.
4. Attend regular CWG telecons, reporting on findings when appropriate.
    a. Report pertinent activities to the CWG weeklies.

Issues addressed and reported by CIMSS to CWG:

- GOES-16 PLT
  - Supported CWG efforts on achieving Full Maturity status for GOES-16 ABI L1b radiances.
- GOES-17 PLT
  - Supported CWG efforts on achieving first Beta and then Provisional status for the GOES-17 ABI L1b radiances.
- GOES-17 Loop Heat Pipe Analysis & Mitigation
  - Developed a website to monitor GEO-GEO comparisons (GOES-17 – GOES-16 mean brightness temperature differences over a central comparison area) for Full Disk and CONUS/PACUS sectors.
    - Includes GOES-17 Longwave IR (LWIR) Focal Plane Module (FPM) Temperature so users can see the impact of instrument heating on data quality.
    - http://cimss.ssec.wisc.edu/goes-r/abi-/band_statistics_imagery.html
- GOES-17 Periodic Infrared Calibration Anomaly (PICA)
  - Seen in CONUS and Mesoscale sector data, particularly noticeable to users when animating a series of images. Was seen on GOES-16 as well.
  - This is fixed in MODE-6 for GOES-17
  - There was also a PICA-like effect seen in the GOES-17 Full Disk data which was corrected in August 2018.
- GOES-17 Predictive Calibration
  - The ABI vendor is working on what has been called "predictive calibration" for GOES-17 to help mitigate the heating issue. Initial results are promising and show that while it cannot bring back data when the instrument is so hot that images are totally saturated or unusable, it can make the calibration before and after those times better even when the instrument's temperature is elevated from its nominal state. See Figure 157 for early sample results from February 26, 2019.
- GOES-16 & GOES-17 Stray Light / Solar Intrusion to Calibration
  - The ABI is designed to not directly scan the sun and avoids scanning areas around the edge of the earth when the sun is too close to the region scanned. But it was discovered on GOES-16 that "leaked" stray light can still impact the shortwave IR band (3.9um).
  - The GEO-GEO comparison website developed to monitor FPM temperature impacts on data quality also highlighted this issue.
  - All IR bands were impacted by stray light during the spring equinox period near satellite midnight, which suggests stray light is getting into the calibration data (such as space looks), but this issue is still being investigated as to the root cause.
- GOES-17 Lunar Intrusion to Space Look
  - Lunar intrusion on space looks was causing striping to occur in band 11 on GOES-17. This was addressed by CWG with an ADR submitted before the time of Provisional status.

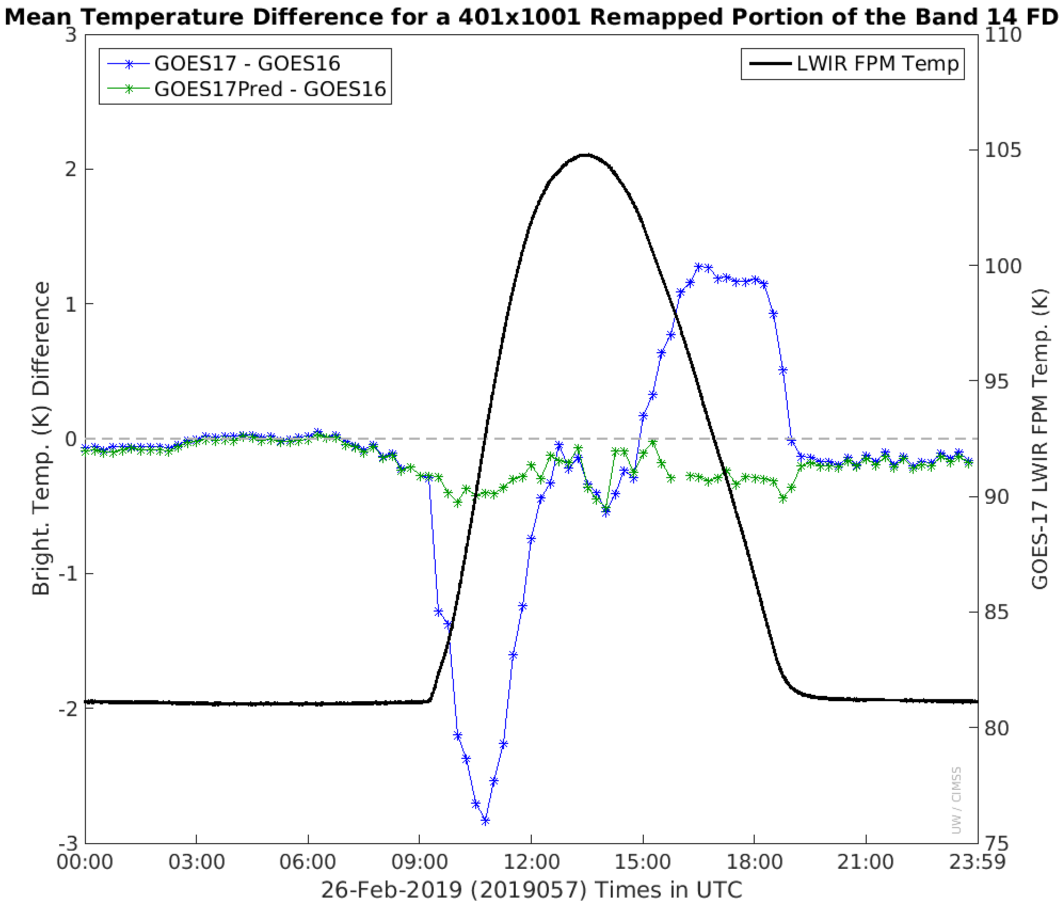


Figure 157. ABI GEO-GEO comparisons (GOES-17 minus GOES-16) for band 14 (11um) Infrared Window on February 26, 2019, one of the hottest days of the year for the instrument. The solid black curve is the GOES-17 Longwave Infrared (LWIR) Focal Plane Module (FPM) temperature, corresponding to the scale on the right axis. The blue line shows the results in the comparison area of mean brightness temperature differences for operational GOES-17 minus GOES-16; note the large temperature swing of approximately 4K during the times of elevated FPM temperature. The green line shows the results in the comparison area of mean brightness temperature differences for GOES-17 minus GOES-16 where GOES-17 was a test of Predictive Calibration.

Publications and Conference Reports

Fangfang Yu, Xiangqian Wu, Haifeng Qian, John Van Naarden, Michael Ramirez, Dan Lindsey, Chad Gravelle, Mathew Gunshor, Tim Schmit, Xi Shao, Zhipeng Wang, Hyelim Yoo, Bob Iacovazzi, Vladimir Kondratovich, "Validation of GOES-16 ABI infrared spatial response uniformity," Proc. SPIE 10764, Earth Observing Systems XXIII, 107640F (7 September 2018); doi: 10.1117/12.2322147

37. CIMSS Support to GOES-R Calibration/Validation Deployment Support for Scanning HIS 2018 (S-HIS)

CIMSS Task Leaders: Joe Taylor, David Tobin

CIMSS Support Scientists: Hank Revercomb, Robert Knuteson, Ray Garcia, David Hoese, Dan DeSlover

NOAA Collaborators: Dan Lindsey, Steve Goodman, Frank Padula, Aaron Pearlman
Budget: $103,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Education and Outreach

Objective
The primary objective of this project is radiometric calibration validation of the GOES-16 ABI instrument via intercomparison with the high-altitude airborne S-HIS sensor. The S-HIS was deployed on the NASA ER-2 in 2017 for this project, and full analysis was completed following the deployment.

Project Overview
GOES-16 conducted a calibration and validation field campaign in 2017. The FY17 (Year 2) funding was used to deploy the UW-Madison SSEC Scanning High-resolution Infrared Sounder (S-HIS) on the ER-2 aircraft, conduct preliminary analyses, and conduct post-mission end-to-end laboratory calibration verification of the S-HIS. The FY18 (Year 3) funds were used to provide further support for the final analyses, publications, and continue post-deployment laboratory characterization of the S-HIS instrument. Routine instrument maintenance and field deployment preparation were the primary activities in FY16 (Year 1).

Milestones with Summary of Accomplishments and Findings
- Post-mission end-to-end radiometric calibration verification of the S-HIS was completed at SSEC. All results were well within the predicted radiometric uncertainty and in good agreement with pre-mission results.
- Observation to observation (ABI – S-HIS) analyses for ABI North-South-Scan and Mesoscale data collects for the ABI calibration validation focus days (2017-03-23, 2017-03-28, 2017-04-13) has been completed. All comparison results are within the expected radiometric uncertainty.
- The complete Double Observation Minus Calculation (DOMC) calibration-validation analyses of the GOES-16 ABI instrument using co-located S-HIS data has been completed for ABI North-South-Scan data collects for the ABI calibration validation focus days (2017-03-23, 2017-03-28, 2017-04-13). At this time, all comparison results are within the expected radiometric uncertainty. An example of the result for 2017-04-13 flight (Gulf of Mexico, ABI TEB cal-val primary flight) is provided in Figure 158.
- Results of the DOMC based calibration-validation were presented at the 2019 AMS Annual Meeting. A paper is in preparation.

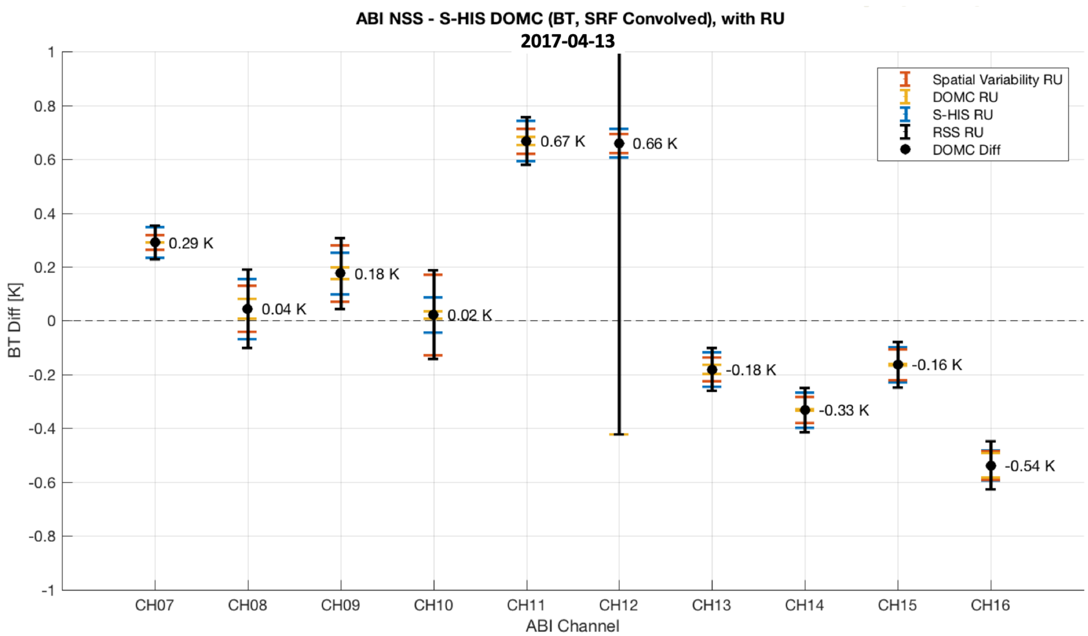


Figure 158. DOMC result for 2017-04-13. The ABI 1-sigma radiometric accuracy requirement is +/- 1K at 300K scene equivalent brightness temperature.

Publications and Conference Reports

Joe Taylor, D.C. Tobin, H.E. Revercomb, F.A Best, R.K. Garcia, R.O. Knuteson, M. Feltz, F.P. Padula, S.J. Goodman, " Calibration Validation of GOES-16 Advanced Baseline Imager (ABI) with the Airborne Scanning High-Resolution Interferometer Sounder (S-HIS)," AMS Annual Meeting (10 January 2019)

References

Brent Bartlett, Jason Casey, Francis Padula, Aaron Pearlman, Dave Pogorzala, Changyong Cao, "Independent validation of the advanced baseline imager (ABI) on NOAA's GOES-16: post-launch ABI airborne science field campaign results," Proc. SPIE 10764, Earth Observing Systems XXIII, 107640H (7 September 2018)

38. Evaluation and Inter-validation of 3D Winds from Independent Platforms: A Synergistic Approach

CIMSS Task Leader: David Santek
CIMSS Support Scientists: Hong Zhang, Sharon Nebuda, Brett Hoover
NOAA Collaborator: Sid Boukabara
Budget: $150,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society’s needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective
The objectives of the proposed work are to quantify the quality of 3D AMVs as derived from Aeolus and hyperspectral retrievals through intercomparison of the winds, comparison to rawinsondes, and deviation from model background fields. Also, to determine if there are preferred locations where the quality of the AMVs are better or worse than in other locations, that could be related to atmospheric conditions or geographic location.

Project Overview
A recognized deficiency in the global observing system is an accurate depiction of the 3D structure of the global wind field. The first mission to directly measure wind profiles throughout the troposphere and lower stratosphere will be the ADM/Aeolus mission using ALADIN, a Doppler wind lidar (DWL) instrument. This is a single line-of-sight instrument, which results in the component of the wind along the instrument Horizontal Line of Sight (HLOS) in clear-sky and above clouds.

An alternate method for deriving 3D winds has been the focus of NASA-sponsored research at the Space Science and Engineering Center (SSEC) using retrievals from the IR hyperspectral instrument, the Atmospheric Infrared Sounder (AIRS). In two previous NASA ROSES awards, we developed a 3D winds product by tracking moisture features (troposphere) and ozone gradients (stratosphere) from AIRS retrieved vertical profiles of temperature, humidity, and ozone in clear-sky and above cloud.

Although, the goal of both of these projects is to determine 3D winds from space-based platforms, the resulting products are quite different in terms spatial and vertical distribution, errors, and the definition of the AMV, itself.

A quantitative assessment of the AMVs will be accomplished through several types of comparisons, based on scripts used in previous winds intercomparison projects:
- Bulk statistics: This will provide statistics and distributions for each AMV type independently, in terms of vertical distribution, spatial coverage, and statistics discretized by height, latitude bands, and wind speed, for example.
- Co-located comparisons: Co-located AMVs (in 3D) between the data types will be compared in terms of wind speed difference, including a measure of statistical significance using a paired t-test.
- Rawinsonde comparison: A comparison of all AMVs to nearby rawinsondes will provide an independent measure of the quality of the winds.
- Model grid comparison: This is an analysis similar to the rawinsonde comparisons, using both all and co-located winds.
- Best fit height: A Best Fit height analysis is computed for each AMV type according to the method described by Salonen (ECMWF). This technique finds the background model best fit pressure associated with the AMV, which is where the vector difference between the observed AMV and model background is at a minimum.

Milestones with Summary of Accomplishments and Findings

The Aeolus satellite successfully launched in August 2018; however, the wind product was not available until January 2018. Therefore, only an initial comparison of the DWL product to the AIRS retrieval winds is described below.

The Aeolus wind data is available in Earth Explorer (EE) and BUFR formats. We chose the EE format and used the Common Data Access (CODA) code provided by ESA to read the data using MATLAB, which facilitated the conversion to text format for subsequent analysis.

For this initial comparison one day was selected: 13 January 2019. In this one day of data over the polar regions (restricted to poleward of 60º latitude), there are nearly 75,000 Aeolus Rayleigh and 2350 AIRS quality-controlled winds. Since the orbits of Aqua and Aeolus are quite different, there are only 302 co-located AMVs for this one day. Co-location is defined as within 150 km, +/- 50 minutes, and +/- 50 hPa. Note: Each AIRS wind is matched only to the closest Aeolus wind in distance, that also meet the other 2 criteria. This results in 156 matches in the Arctic and 146 over Antarctic. In addition, the speed and direction of the AIRS AMVs are converted to an equivalent Aeolus-viewed HLOS speed.

The results of this preliminary comparison are very reasonable, considering the small sample size. Figure 159 depicts a scatter plot of the Aeolus HLOS speed vs. AIRS equivalent HLOS speed, where the correlation coefficient is 0.78. Figure 160 is a frequency plot of Aeolus HLOS speed minus the AIRS equivalent HLOS speed. The mean difference is +1.8 ms^{-1} (Aeolus has a fast bias, compared to the AIRS winds), with an RMS difference of 8.7 ms^{-1}. These results are similar to other satellite-derived wind-to-wind or wind-to-rawinsonde comparisons.

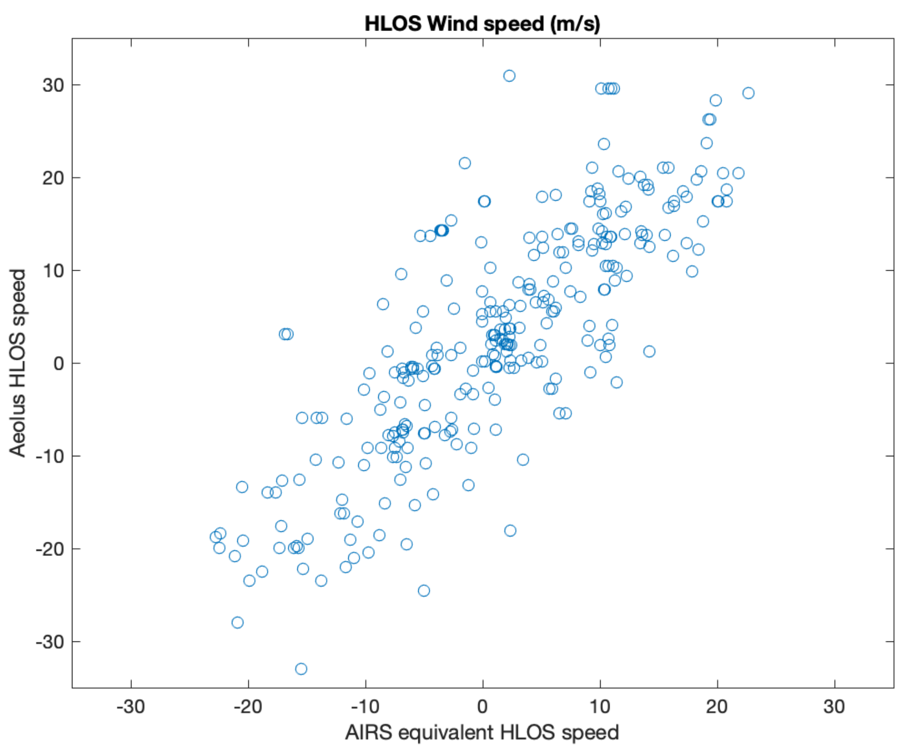


Figure 159. Scatter plot of Rayleigh HLOS wind speed vs. co-located equivalent HLOS wind speed from AIRS 3D winds over the polar regions 13 January 2019.

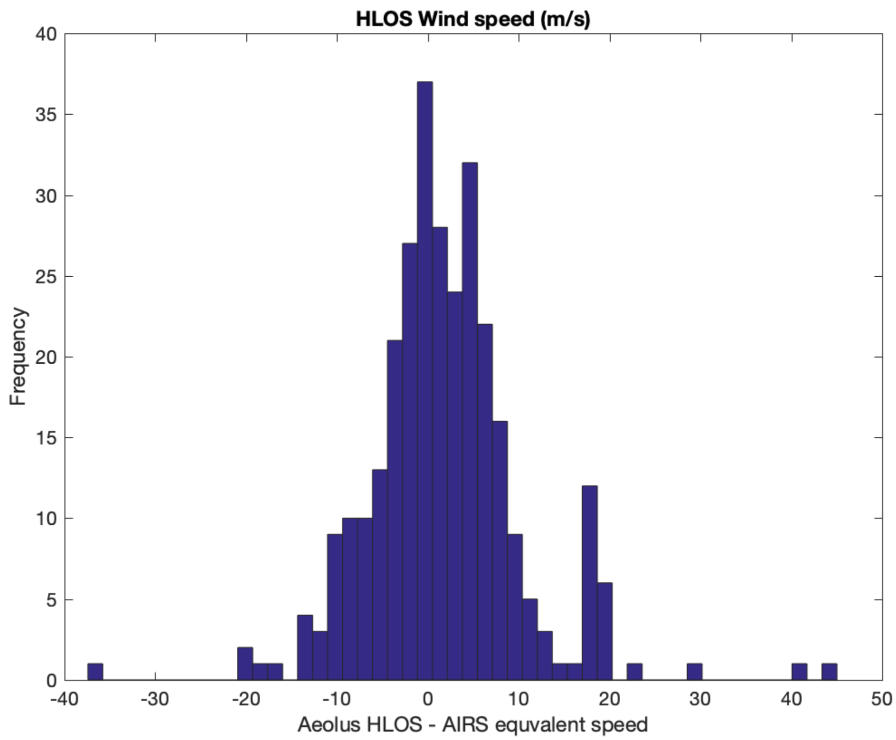


Figure 160. Difference of Rayleigh HLOS wind speed and co-located equivalent HLOS winds speed from AIRS 3D winds over the polar regions on 13 January 2019.

39. CIMSS Support to VortexSE Training
CIMSS Task Leader: Denny Hackel
CIMSS Support Scientists: Jonathan Gero, Mark Mulligan, William Roberts
NOAA Collaborator: Erik Rasmussen NOAA/NSSL
Budget: $10,681

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Education and Outreach

Objective
To train the Oklahoma University personnel AERI maintenance, calibration, and verification activities while performing them on AERI-113 (CLAMPS-1) and AERI-116 (CLAMPS-2) in support of the VORTEX-SE field experiment.

Project Overview
Denny Hackel, Jon Gero and William Roberts were on site in Norman, Oklahoma June 25-26, 2018. Doug Kennedy and Matt Carney were provided training in: Keysight digital multimeter

calibration and installation/removal, resistance validation test performance and analysis, 3rd Blackbody test setup and analysis, scene mirror cleaning and replacement, stirling cooler control setting inspection and modification, laser replacement, field-of-view mapping, and general preventative maintenance. Procedures used for the training are available on the AERI knowledge base: https://www.ssec.wisc.edu/aeri.

Milestones with Summary of Accomplishments and Findings

The initial 3rd Body tests revealed that AERI-113 met certification verification requirements and AERI-116 did not. Field-of-view mapping showed the AERI-116 interferometer's view was partially obstructed by the hex structure instead of a clear view of the target. Re-alignment of the interferometer by adjusting the kinematic mount and mirror angles was needed. After maintenance, calibration and verification was complete both AERIs were passed 3rd Blackbody certification verification tests.

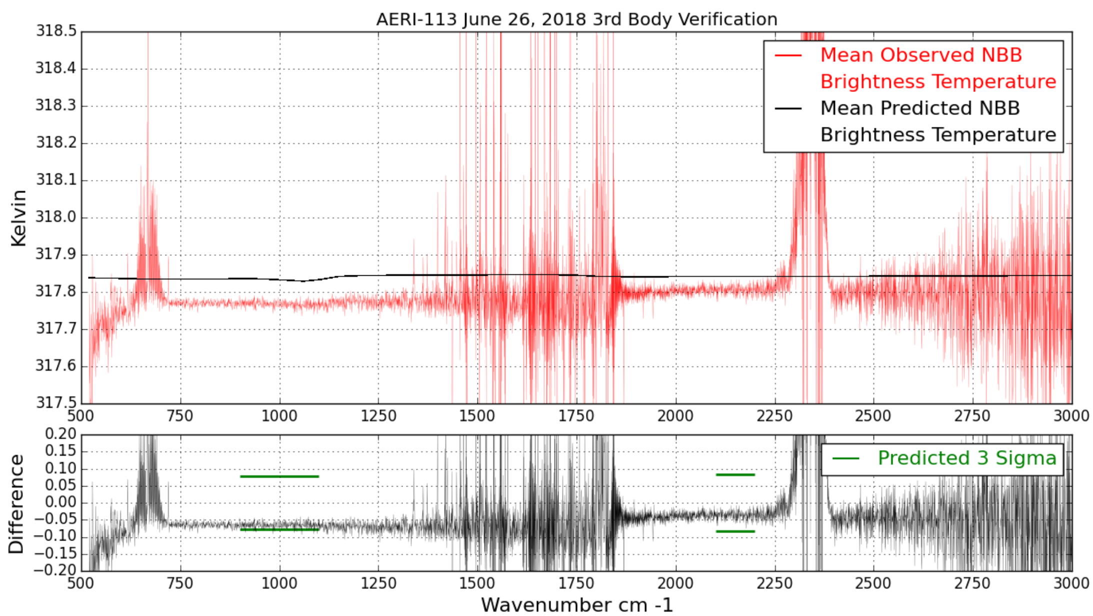


Figure 161. AERI-113 observed blackbody brightness temperature for intermediate temperature body compared to predicted value. Green bars indicate the certification test criteria.

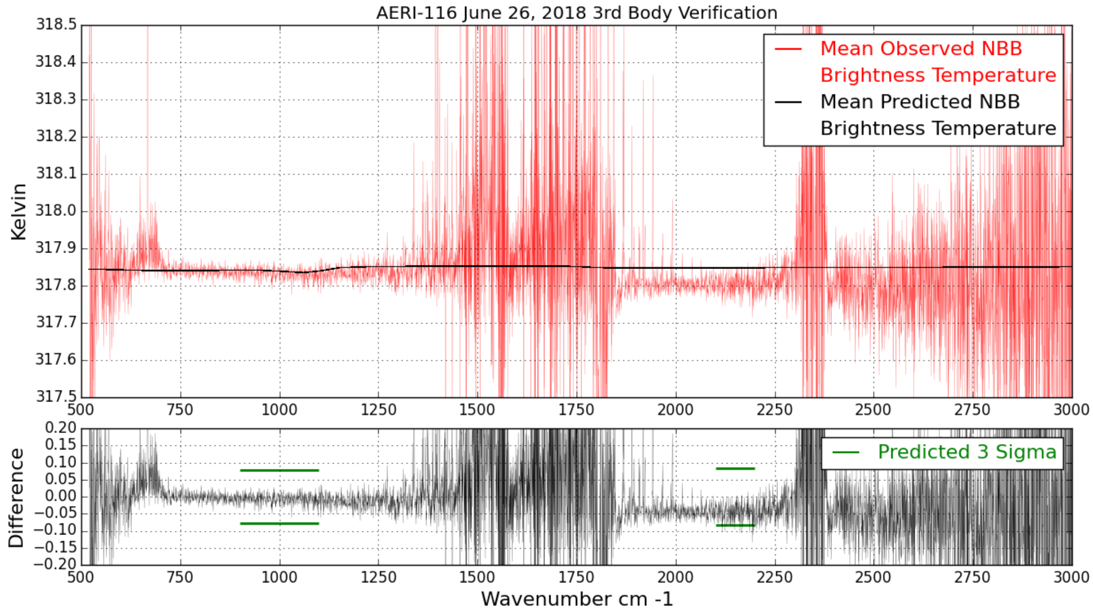


Figure 162. AERI-116 observed blackbody brightness temperature for intermediate temperature body compared to predicted value. Green bars indicate the certification test criteria.

40. CIMSS Support to Improving the Characterization and Evaluating the Impact of Assimilated Meteorological Observations from Commercial Aircraft

CIMSS Task Leader: Tim Wagner
CIMSS Support Scientists: Ralph Petersen, Brett Hoover
NOAA Collaborator: Curtis Marshall, NOAA NWS Office of Observations
Budget: $47,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Environmental Models and Data Assimilation

Objective
Evaluate the accuracy and impact of the private sector airborne data streams purchased by NOAA and assimilated into operational NWP models.

Project Overview
The Tropospheric Airborne Meteorological Relay (TAMDAR) is a private sector data feed consisting of observations from specially-equipped commercial aircraft. NOAA purchases these

observations for assimilation into NWP as well as use by local NWS WFOs. This project evaluates the accuracy of these data by conducting a nationwide validation against the operational radiosonde network as well as a plane-to-plane validation. From that, the impact of these data in NWP will be tested by doing data-denial tests using the GFS installation on CIMSS's S4 supercomputer.

Milestones with Summary of Accomplishments and Findings

TAMDAR exhibits a warm and moist bias throughout the depth of the atmosphere that generally increases with increasing altitude. There is little hysteresis, as both ascending and descending profiles demonstrate the same response; there is also little variation in the performance in different regions of CONUS. As long as the bias is well-characterized, this makes it well-suited for NWP assimilation.

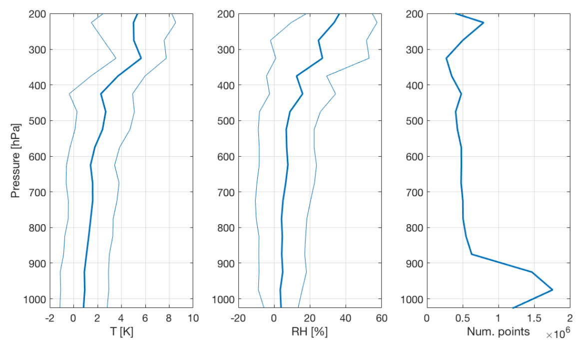


Figure 163. Profiles of TAMDAR temperature bias (thick line) and standard deviation (thin line) for temperature (left) and relative humidity (center). The number of observations at each level is on the right.

41. CrIS/OMPS and TES Ozone Retrievals in Support of the FIREX Intensive Campaign

CIMSS Task Leader: Allen Lenzen
CIMSS Support Scientist: Hong Zang
NOAA Collaborator: Brad Pierce
Budget: $49,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation

Objective

Collaborate with JPL in support NOAA FIREX field campaign by providing near-real-time joint CrIS/OMPS tropospheric ozone and CrIS carbon monoxide products and assimilate these products within the Real-time Air Quality Modeling System (RAQMS).

Project Overview

The project focuses on joint tropospheric ozone products from CrIS/OMPS and their assimilation within a nested global to regional air quality modeling system in support of the NOAA FIREX campaign. The spectral resolution of infrared hyperspectral CrIS measurements restricts the sensitivity of inferred ozone to the upper troposphere. OMPS measurements are designed for total column ozone only. The JPL team has demonstrated that the combination of radiances from these two instruments provides lower tropospheric ozone sensitivity. This sensitivity permits quantification of ozone in the outflow regions of biomass burning. We will compare these retrieved ozone profiles with the NOAA operational CrIS/ATMS NUCAPS retrieval algorithm. The CrIS/OMPS and NUCAPS ozone, along with full spectral resolution CrIS CO retrievals will be assimilated into the RAQMS/GSI analysis/forecast system. The FIREX campaign was originally scheduled for the summer of 2018 but has now been combined with NASA as the FIREX-AQ campaign which will occur during the summer of 2019. This has resulted in a revision of the original milestones for the project.

Milestones with Summary of Accomplishments and Findings

Milestone 1: Provide low latency CrIS and OMPS UV radiances for multi-spectral ozone (O3) and carbon monoxide (CO) retrievals at JPL and NUCAPS products for validation activities utilizing the CIMSS Direct Broadcast (DB) Community Satellite Processing Package (CSPP) capabilities

Generation of the CrIS Full Spectral Resolution (FSR) SNPP and JPSS-1 and OMPS SNPP SDR's in real-time for all the CONUS direct broadcast sites for both SNPP and JPSS-1 has been completed. The CrIS SDR data is posted at ftp://ftp.ssec.wisc.edu/pub/eosdb and the OMPS SDR data is posted at ftp://ftp.ssec.wisc.edu/pub/firex, and is used

The NOAA IDPS is currently producing S-NPP CrIS SDR produce output files with the midwave (1208.75–1751.25 cm^{-1}) channels set to missing. This should not interfere with the proposed CrIS/OMPS multi-spectral ozone (Fu et al, 2013) or CrIS carbon monoxide (Fu et al, 2016) retrievals.

Milestone 2: Perform 3D-var global retrospective ozone and CO assimilation (1.0° x 1.0°) using CONUS CrIS/OMPS O3 and CrIS CO in addition to NASA MLS and OMI ozone columns for July-August 2015 during the exceptional Western US fire events

JPL is continuing to work on development and testing of CrIS/OMI O3 and CrIS CO retrievals and so we have not been able to conduct the proposed July-August 2015 ozone and carbon monoxide assimilation experiments. Instead, we have focused on assimilation of global multi-spectral AIRS/OMI O3 retrievals that were conducted during the NASA KORUS-AQ field campaign (April-June, 2016). Figure 164 shows the resulting zonal mean ozone analysis for combined MLS, OMI and multi-spectral (MUSES) AIRS/OMI retrieval assimilation. Assimilation of MLS stratospheric profile measurements results in the largest analysis increments (note different color scale for MLS) with positive adjustments in the middle and upper stratosphere (10-1mb). Assimilation of OMI total column ozone results in small positive adjustments throughout the depth of the stratosphere (100-1mb). Assimilation of the MUSES AIRS/OMI ozone retrieval results in small negative adjustments that oppose the MLS adjustments. Figure 165 shows the mean (left) MUSES AIRS/OMI and RAQMS (with MUSES averaging kernel) and bias (right) in percent for Southern Hemisphere profiles during April-May-June, 2016. Biases are generally less than 10% between 1000-1mb. This is less than the reported

10-30% uncertainty in the MUSES AIRS/OMI retrieval and demonstrates that the assimilation of the MUSES AIRS/OMI ozone retrievals was successful. The overall adjustment from assimilating the MUSES AIRS/OMI ozone retrievals is small because the assimilation of MLS and OMI result in small differences between the resulting background and observation. We are currently preparing to assimilate the MUSES AIRS carbon monoxide retrievals during July-August 2018 to investigate the impact of MUSES carbon monoxide assimilation on western wild fire analyses.

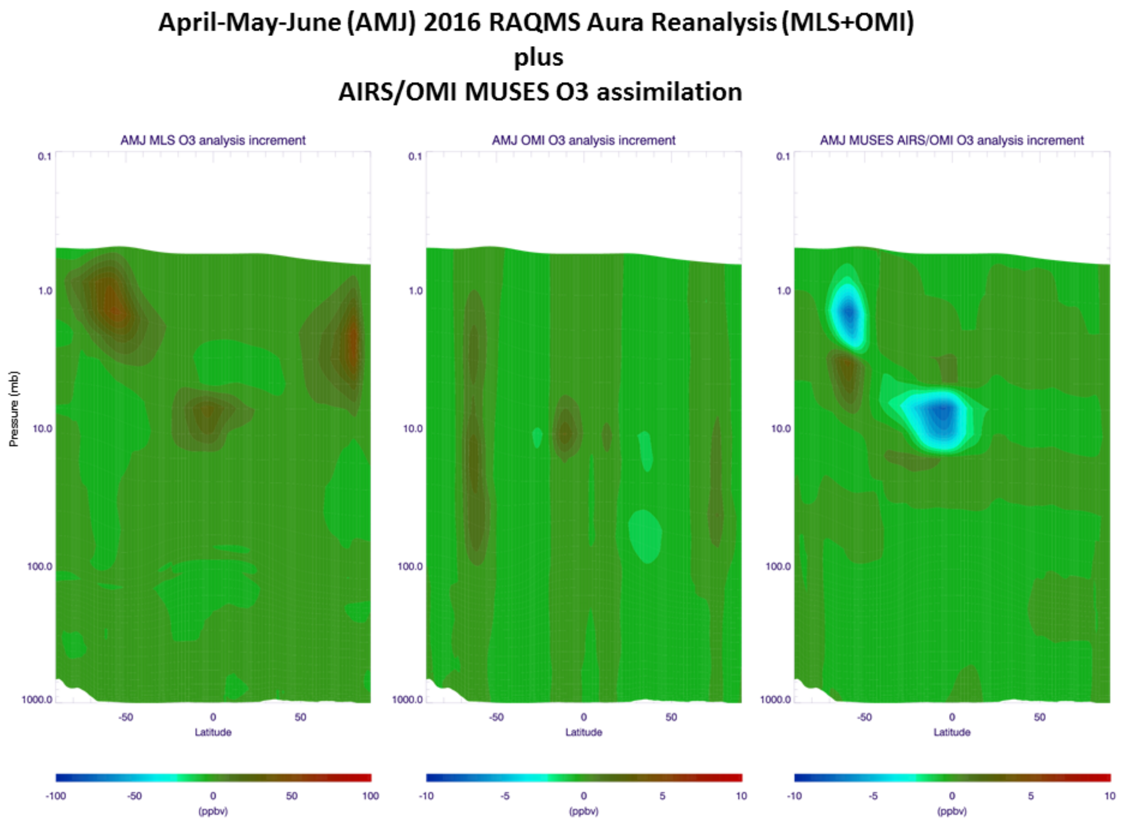


Figure 164. MLS (left), OMI (middle), and MUSES AIRS/OMI (right) zonal mean ozone analysis increments (ppbv) during April-June 2016.

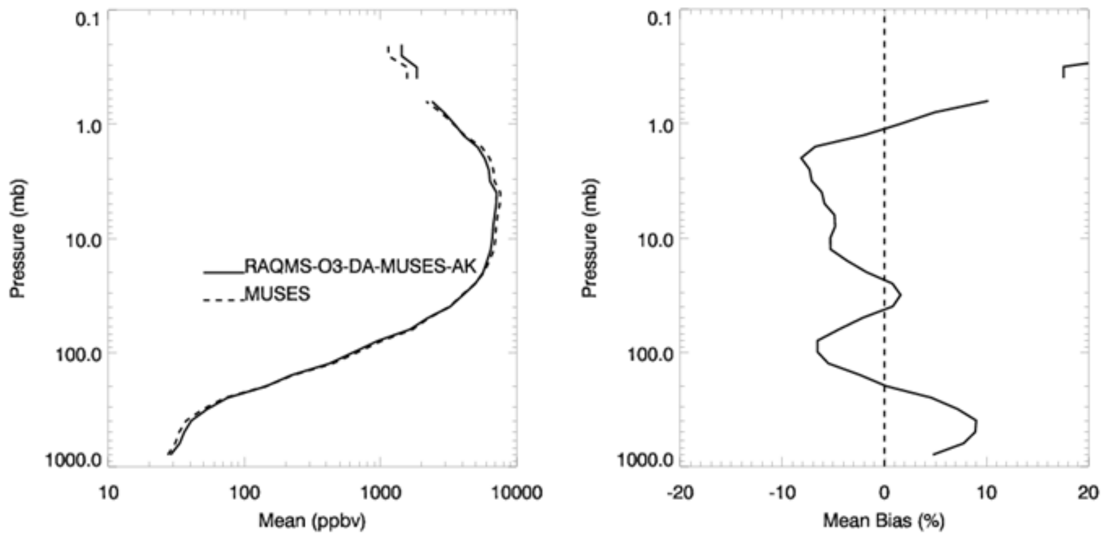


Figure 165. Southern Hemisphere mean ozone profiles (left) and biases (percent) for RAQMS analysis (solid) and MUSES (dashed) during April-June, 2016. The MUSES averaging kernel has been applied to RAQMS for these comparisons.

References

Fu, D., Worden, J. R., Liu, X., Kulawik, S. S., Bowman, K. W., and Natraj, V., 2013: Characterization of ozone profiles derived from Aura TES and OMI radiances, Atmos. Chem. Phys., 13, 3445–3462, doi:10.5194/acp-13-3445-2013.

Fu, D. K. W. Bowman, H. M. Worden, V. Natraj, J. R. Worden, S. Yu, P. Veefkind, I. Aben, J. Landgraf, L. Strow, and Y. Han, 2016: High-resolution tropospheric carbon monoxide profiles retrieved from CrIS and TROPOMI, Atmos. Meas. Tech., 9, 2567–2579, doi:10.5194/amt-9-2567-2016

42. CIMSS Support for GOES-16/17 Education Proving Ground and ABI short-Course Training

42.1 CIMSS Task GOES-R Education Proving Ground

CIMSS Task Leader: Margaret Mooney
CIMSS Support Scientist: Scott Lindstrom
NOAA Collaborators: Tim Schmit and Dan Lindsey

NOAA Long Term Goals:

- Climate Adaptation and Mitigation
- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Understand climate variability and change to enhance society's ability to plan and respond

CIMSS Research Themes:

- Education and Outreach

Objective

Prepare the education community for the imagery and products from the next generation of satellite and encourage the involvement of students in using the new data.

Project Overview

The GOES-R Education Proving Ground (http://cimss.ssec.wisc.edu/education/goesr/) was established to ensure that the education community was "launch ready" for new satellite imagery and improved products available in the GOES-R era. Now that data is flowing from GOES-16 and GOES-17, the focus of the project has expanded from teacher preparation to include students and encouraging them to use the new data.

A key element of the Education Proving Ground has always been working closely with educators in close coordination with NOAA scientists at the Advanced Satellite Products Branch (ASPB).

Milestones with Summary of Accomplishments and Findings

With an eye toward the 2020 American Meteorological Society (AMS) Centennial meeting, the GOES-R Education Proving Ground purposely recruited New England educators in 2018 to participate and help develop guidelines for a spring 2019 Virtual Science Fair requiring students from grades 6-14 to use data from GOES-16 or GOES-17 to investigate weather and natural hazards. Three winning teams will be announced this summer: middle school, high school and grades 13/14 (community college or university). Students from the winning teams will receive $25 gift cards AND official GOES-T launch viewing invitations to KSC (but no travel support). Teachers coaching the winning teams will garner launch invites (no travel support) and conference travel support to attend and present at the AMS Centennial meeting in Boston.

GOES-16/17 Virtual Science Fair (http://cimss.ssec.wisc.edu/education/goesr/vsf)

A team of six educators from New Jersey to California began participating in monthly telecoms in autumn 2018 to develop guidelines for the Virtual Science Fair (VSF) devised by Margaret Mooney (CIMSS) Tim Schmit, (NOAA/ASPB) and Vicky Gorman, our lead educator from Medford, NJ. Additional teachers working on the project include Tara Alcorn, a High School teacher from Tyngsborough, MA; Karin Loach, a Middle School teacher from Auburn, MA; Patrick Rowley, a Community College instructor from Norfolk VA; Jon Roth, a Middle School teacher from Madison, WI; and Peg Kozick-Kingston, a High School teacher from Mission Viejo, CA. Numerous resources were developed and made available on-line, including detailed grading rubrics that will make judging fair and fairly seamless, and should also serve to aid science fair applicants.

Extensive promotion has been underway starting with a workshop session at AGU GIFT (Geophysical Information for Teachers) in 2018 and a poster at AMS 2019, CIMSS social media and an invited post to the AMS Front Page blog. More recently, Tim Schmit and Scott Lindstrom (CIMSS) presented a 2-hour session at the Wisconsin Society of Science Teachers meeting in Madison, WI and the Space Science and Engineering Center (SSEC) published an on-line story promoting the science fair.

Figure 166. Scott Lindstrom and Margaret Mooney at AGU GIFT, December 2018.

The main requirement for every VSF submission is a scientific poster detailing which ABI channels the student use for their investigation. This requirement mirrors real world college and career expectations. Students also need to upload a video where they describe the poster in detail, similar to a poster session at a professional conference. By requiring students to use multiple ABI channels in an investigation of weather or natural hazards and share results via a scientific poster, this VSF offers the perfect blend of STEM (science, technology, engineering and math) enrichment and GOES-R series promotion.

Publications, Reports, Presentations

Mooney, Margaret. GOES-16/17 Virtual Science Fair, Symposium on Education, 28th, Phoenix, AZ 6-10 January 2019. American Meteorological Society, Boston, MA, 2018, Abstract 107.

42.2 CIMSS Support for GOES-16/17 Short Courses and Other GOES-R Program Trainings

CIMSS Task Leader: Mat Gunshor
CIMSS Support Scientists: Jordan Gerth, Scott Lindstrom, Chris Schmidt
NOAA Collaborator: Tim Schmit (NESDIS/STAR/ASPB)
Budget: $53,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Education and Outreach

Objective
To provide support to the GOES-R Program's training efforts to reach a wide audience of users, including international users, and at day-long AMS short courses.

Project Overview
This report covers two multi-year projects for CIMSS to support the GOES-R program's plan to attend multiple American Meteorological Society (AMS), and other, conferences to provide training on uses of GOES-R, primarily the Advanced Baseline Imager (ABI). The first project is specifically tailored for AMS Short Courses and the second project was to facilitate trainings at other events, such as international conferences, that are less-well-attended by NOAA. In preparation for each short course, the instructors prepare presentations and engaging hands-on material to present to the students. Whenever possible, material is tailored to the audience. While AMS annual meetings have a fairly general meteorological audience, others such as a broadcaster meeting, or fire and forest meteorology meeting, have audiences with a more specific focus. Presentations are also tailored for region and the instructors try to make use of case studies that are recent and had a local impact when possible.

Milestones with Summary of Accomplishments and Findings
- Helped to organize and presented GOES-R Short Courses:
  - January 6, 2019 preceding the 99th AMS Annual Meeting in Phoenix, AZ.
  - The 46th conference on Broadcast Meteorology was joint with the annual meeting in Phoenix and hence did not have a separate short course.
- Helped to organize and presented trainings at non-AMS meetings:
  - 2018 NWS IMET Continuity of Excellence Exercise
  - AMS 12th Fire and Forest Meteorology Symposium
  - Canadian Met. and Ocean. Society's 2018 Congress
  - A NOAA GOES-16 workshop at the National Autonomous University of Mexico in Mexico City
  - AMS 10th International Conf. on Urban Climate
  - Ahead of RELAMPAGO field campaign (Argentina).
- Typical preparation for a short course includes:
  - Preparing hands-on and presentation material that includes audience-specific (or site-specific) case studies with recent data.
  - Inviting and/or coordinating with a lunch-time speaker.
  - Setting up a course web site so participants have easy access to hands-on web app material and can later download presentations.
- During a short course:
  - Presenting an introduction to The GOES-R Advanced Baseline Imager (ABI): Capabilities, products, and concept of operations
  - Hands-on exercises showcasing ABI's 16 channels with improved spatial resolution, temporal refresh rate, and RGB products.
  - Hands-on exercises highlighting GOES-R derived products used in the Proving Ground
  - Hands-on exercises using operational GOES-R derived products.

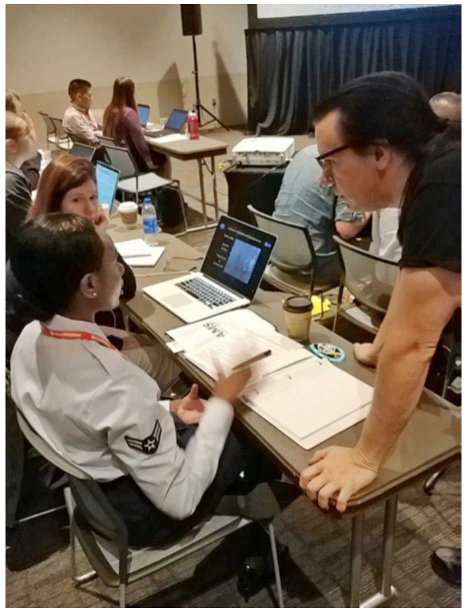


Figure 167. Chris Schmidt of CIMSS (right, standing) talking with one of the students at the GOES-R Short Course held prior to the AMS 2019 Annual Meeting in Phoenix, AZ.

43. Weighting Function Training
CIMSS Task Leader: Mat Gunshor
CIMSS Support Scientist: Chia Moeller
NOAA Collaborator: Tim Schmit (NESDIS/STAR/ASPB)
Budget: $105,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Education and Outreach

Objective
To provide near-real-time weighting functions for GOES infrared bands that can be used for training and educating researchers and users, including forecasters, with an enhanced, modernized website that can also be used operationally.

Project Overview
Weighting functions calculated using a fast forward radiative transfer model (RTM) are a tool forecasters and scientists can use to understand the vertical extent of a spectral band on satellite instruments such as the Advanced Baseline Imager (ABI) on GOES-16. The weighting function is a two dimensional plot which illustrates the contribution layer of the spectral band given the

temperature, moisture, and ozone profile as inputs. View angle, skin temperature, and surface emissivity also contribute to the variability observed. Given that these parameters change across satellite image scene and time, weighting functions are critical to understanding what is being sensed by individual bands and can be used to compare different bands, such as the three water vapor bands on ABI for a given scene. Of particular interest to scientists, forecasters, and others is the peak pressure of the contribution, which can be used to derive a height in the atmosphere. The peak pressure, and calculated brightness temperature, can vary with temperature, moisture content, view angle, surface emissivity, skin temperature, and the presence of other absorbing gasses such as carbon dioxide, sulfur dioxide, and more.

The CIMSS GOES "Realtime" Weighting Functions webpage has been online for approximately 10 years. This page gives users the ability to view weighting functions calculated from a fast forward radiative transfer model for RAOBs at 00 and 12 UTC daily. RAOB stations include those in CONUS, non-CONUS stations in Alaska, Hawaii, and Puerto Rico, and some South American stations. The calculations are done for both GOES-East and GOES-West and the page is updated twice a day. In addition, there are static versions of the page for the Advanced Baseline Imager (ABI), the ABI's sister instrument which is called the Advanced Himawari Imager (AHI), GOES-10, and GOES-13. These static versions allow a user to alter view angle, surface temperature, total column moisture, and between 4 standard/canned atmospheres. This website has been used for training of National Weather Service (NWS) personnel, in satellite meteorology classes and workshops both national and international, in COMET modules, and occasionally operationally by NWS forecasters.

CIMSS proposed a 3 year project to update this website, enhance its capabilities, and work toward providing this information in AWIPS. In addition to this, CIMSS personnel would include these data in NWS training, working with forecast offices to better understand the ABI, and demonstrating how the data can be used to better understand the atmosphere. Feedback from forecasters and trainers would be implemented when possible.

Milestones with Summary of Accomplishments and Findings

Year 2

- Add GOES-17 ABI to realtime page
- Add Himawari-8 AHI to realtime page
- Add peak pressure of the weighting function to each plot
- Add forecast model analyses as input to fast forward model, increasing number of locations to model grid (e.g. GFS model)

The GOES-17 weighting functions were on the real-time webpage before in time for it to become operational GOES-West. Additionally, peak pressure of the weighting function for each band was added to the plots. Work is under way to add forecast model analyses as input and the team is experimenting with different ways to visualize the full disk and use a full disk image to pull up the weighting function data. As part of the process to incorporate model data, the team is also experimenting with the possibility of having web-based plotting to generate the plots so that they can be more dynamic. When the model data are added, the AHI weighting functions will be added as well. Access to RAOB data in Asia is less reliable for us, so using global model output will make transitioning to Himawari more workable. There will still be weighting functions produced via RAOB.

The weighting function web page continues to be highlighted at the GOES-R Short Courses at the AMS Meetings and in other training venues. CIMSS personnel Jordan Gerth and Scott

Lindstrom, along with NOAA/ASPB partner Tim Schmit, have participated in many trainings in the past year where they include the website as part of the training material. These trainings leverage other training projects and will continue throughout the year.

The current layout of the website includes GOES-16, GOES-15, and GOES-17. GOES-15 will be removed from the site when it stops operating, but will remain available until then while users are still able to access the GVAR data.

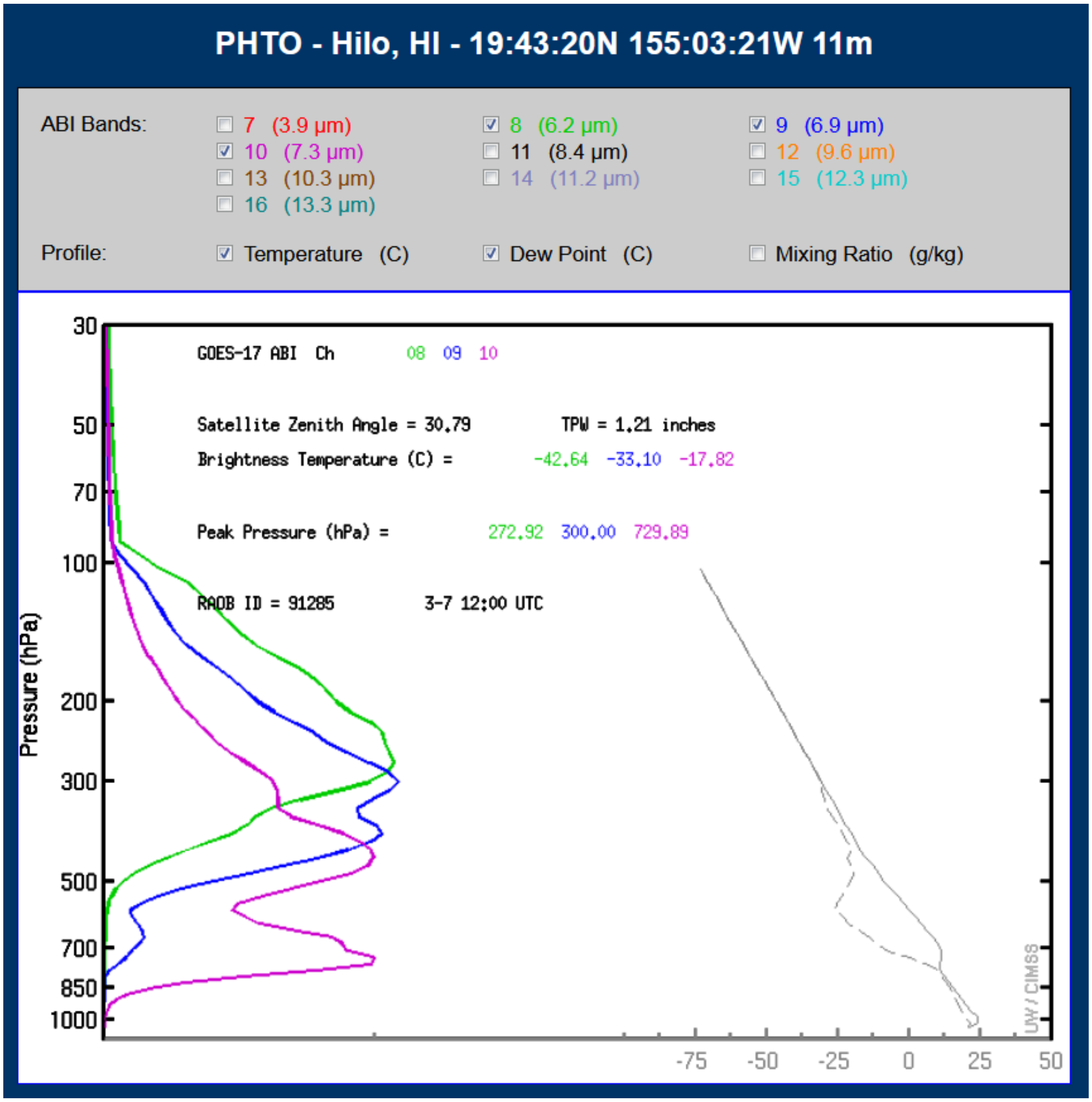


Figure 168. GOES-17 ABI water vapor bands weighting functions over Hilo, HI on March 7, 2019 from the 12UTC RAOB.

44. CIMSS Support for Satellite Training Activities for the VISIT Program in 2018-2019

44.1 CIMSS Support for Satellite Training Activities for the VISIT Program in 2018-2019

CIMSS Task Leader: Scott Lindstrom
CIMSS Support Scientists: Scott Bachmeier, Lee Cronce
NOAA Collaborators: Brian Motta, Leroy Spayd, Kevin Scharfenberg, Ross van Til
Budget: $164,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

Create training material for GOES-R and JPSS following the guidance of FDTD and the SOO Training and Advisory Team (STAT).

Project Overview

VISIT (the Virtual Institute for Satellite Integration Training) has a nearly 20-year history of creating training material with a focus on satellite imagery for the National Weather Service. Originally this was remote training using VISITview software, and that is still occasionally done. The scope has broadened to include shorter videos (Quick Briefs) and documents (Quick Guides, Job Aids) to help broaden satellite knowledge in NWS forecast offices.

Milestones with Summary of Accomplishments and Findings

The Satellite Foundational Course for GOES-R (SatFC-G) has been updated. It was originally created using AHI imagery from Himawari-8 and VIIRS imagery from Suomi-NPP. In the past year, all of the CIMSS-created modules have been changed to include data from GOES-16/GOES-17, and these updated modules have been uploaded into the Department of Commerce's Learning Management System. In addition, Quick Guides (short 2-page documents), Quick Briefs (5-minute videos) and Job Aids (Forms that are useful for Science and Operations Officers (SOOs) in Weather/Forecast Offices (WFOs) for one-on-one training) have been created for different channels, channel differences, and products. Some of these are available here: http://cimss.ssec.wisc.edu/goes/GOESR_QuickGuides.html. That link also points to Quick Guides and Quick Briefs created for JPSS products, as this project has funded training material for the Satellite Foundational Course for JPSS (SatFC-J).

VISIT training has also continued, with training sessions delivered on GOES-16 IFR Probability, NOAA/CIMSS ProbSevere, NUCAPS (NOAA-Unique Combines Atmospheric Processing System) Soundings, TROWAL (Trough of Warm Air ALoft) Formation and MCVs (Mesoscale Convective Vortices). VISIT Funding helped support, partially, more than 100 blog posts at http://cimss.ssec.wisc.edu/goes/blog as well.

44.2 CIMSS Support to Develop the Satellite Information Familiarization Tool for the National Weather Service Training Program
CIMSS Task Leader: Jordan Gerth
CIMSS Support Scientists: Ray Garcia, Dave Hoese, and Scott Lindstrom
NOAA Collaborators: Tim Schmit, National Environmental Satellite, Data, and Information Service Advanced Satellite Products Branch; and Bill Ward, National Weather Service Pacific Region Headquarters
Budget: $77,000

NOAA Long Term Goals:
- Weather-Ready Nation

NOAA Strategic Goals:
- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Education and Outreach

Objective
This project continues the development of the Satellite Information Familiarization Tool (SIFT), open-source software that is freely available and used by the National Weather Service (NWS) and others for training and post-event geostationary satellite data review. Releases and new features align with the NWS operational meteorologist training program.

Project Overview
The Satellite Information Familiarization Tool, or SIFT, is a Python-based meteorological satellite imagery visualization software application with a graphical user interface designed at the University of Wisconsin to run on modern mid-range consumer-grade computers and notebooks. Windows, Mac, and some Linux-based operating systems are supported. SIFT is open source and freely available for all interested.

The National Weather Service (NWS) originally funded the development of SIFT for use as a training application for Himawari-8 imagery at the forecast offices in Guam and Honolulu, but SIFT's capabilities have expanded to handle imagery from the Geostationary Operational Environmental Satellite R-Series (GOES-R) Advanced Baseline Imager (ABI) and numerical weather prediction model Gridded Binary (GRIB2) output.

SIFT is the primary learning software for the foundational and applications training exercises on the new-generation geostationary weather satellites as part of the formal NWS training program. SIFT, used during seven preparatory courses offered to nearly all NWS Science and Operations Officers (SOOs) on the GOES-R in late 2016 and early 2017, is familiar to the NWS and actively used for the review of meteorological satellite data following events.

Milestones with Summary of Accomplishments and Findings
The current release of SIFT is version 1.0.6. Current capabilities of SIFT allow users to: visualize Japan Himawari-8 Advanced Himawari Imager (AHI) and GOES-R ABI imagery at full bit depth, loop through multiple bands for a single time, or multiple times for a single band; load

GRIB2 fields; change the color enhancement by band; modify color enhancements; control the color-value mapping for each enhancement; seamlessly pan and zoom across entire full disk images, even while looping; probe a point/pixel to determine the reflectance or brightness temperature for all loaded bands at that location; produce Red-Green-Blue (RGB) spectral composites; create histograms (single band) and density maps (two bands) based on a user-defined polygon on an image; save images and animations; and perform basic arithmetic involving spectral bands captured at the same time. An example of the SIFT graphical user interface (GUI) is shown in
Figure 169.

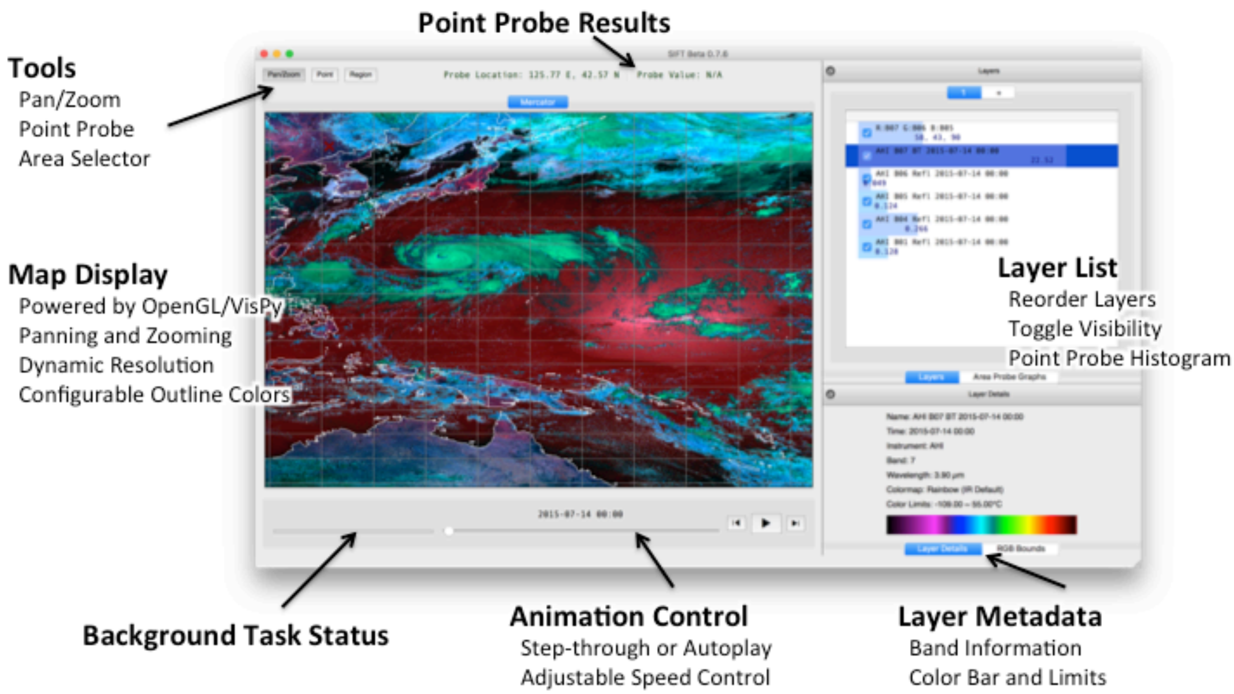


Figure 169. This SIFT screen capture shows the graphical user interface (GUI) with annotated capabilities: tools, point probe results, layer list, layer metadata, animation control, background task status, and map display.

SIFT was designed to maximize performance and nearly eliminate crashes. There are ongoing efforts to modernize and modularize the code to improve performance and make it inviting for community contributions. It presently reads network Common Data Format (netCDF) files of satellite imagery containing the requisite geospatial information, with *SatPy* integration for handling other formats in progress.

The SIFT developers submitted 259 code changes, or "commits", with 83,349 new lines of code in the year preceding 1 April 2019, at which time there were 64 open support tickets that address discrepancies (i.e., "bugs"), enhancements, and optimizations of varying priority. As part of the testing procedure for SIFT, alpha and beta releases incorporating discrepancy fixes, new enhancements, and optimized code are made available online prior to the announcement of a new formal release. Installers for past and the most recent version of SIFT are available to download on the SIFT project web page, https://sift.ssec.wisc.edu/, and the code is available for advanced developers and users on GitHub, https://github.com/ssec/sift/.

In addition to development activities, this project provides assistance to NWS SOOs, NWS training divisions, and funded partners who have incorporated SIFT, or plan to, into training exercises so that there is no degradation in user experience. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) works closely with the NWS to ensure SIFT ably functions on NWS hardware of sufficient grade. The SIFT project web page has details for users seeking to learn how to retrieve data and use the software.

SIFT continues to be used in support of training activities at various levels, including beyond the NWS, and has been introduced to the international community in recent presentations and other interactions. Recent presentations have sought to engage the broader meteorological enterprise on prospective user applications and future directions for the software.

Publications and Conference Reports

"SIFT: An OpenGL-powered Python GUI for Training NWS Forecasters"
Dave Hoese, corresponding author/presenter
Poster, SciPy Conference (Austin, Texas), 11 July 2018

"Visualizing Himawari and GOES-R imagery with the Satellite Imagery Familiarization Tool"
Jordan Gerth, corresponding author/presenter
Talk, Asia/Oceania Meteorological Satellite Users' Conference—Facilitation of data access and utilization (Jakarta, Indonesia), 9 October 2018

"SIFT: A Python-Based User Interface for Visualizing Meteorological Satellite Imagery"
Jordan Gerth, corresponding author/presenter
Talk, American Meteorological Society Annual Meeting—Ninth Symposium on Advances in Modeling and Analysis Using Python (Phoenix, Arizona), 8 January 2019

45. CIMSS Participtation in SHyMet for 2018

CIMSS Task Leader: Scott Lindstrom
CIMSS Support Scientists: Scott Bachmeier, Lee Cronce, Kaba Bah
NOAA Collaborator: Tim Schmit
Budget: $165,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective

Create Training material that is relevant to GOES-R.

Project Overview
The Satellite Hydrology and Meteorology training courses are designed to introduce forecasters and interns to some of the capabilities of Geostationary Satellites. Recent work on training modules has focused on updating the modules that included legacy GOES information to information more pertinent to the GOES-R Era.

Milestones with Summary of Accomplishments and Findings
Short Training Videos were created for all 16 ABI Bands. They are available here: https://www.ssec.wisc.edu/~scottl/SHyMet/ Note that there is also a training video on Channel Differences.

Training videos were created for the Hazardous Weather Testbed to familiarize forecasters with NOAA/CIMSS ProbSevere, Legacy Atmospheric Profiles and NUCAPS vertical profiles Training material in the form of oosts on the CIMSS satellite blog describe how GOES-16/GOES-17 data can be used in certain situations to augment situational awareness at a variety of spatial scales.

Creation of a Users' Guide for the Satellite Information Familiarization Tool (SIFT) (This was a supplemental $10K award to this proposal at the request of D. Lindsey) at this url: https://github.com/ssec/sift/wiki/The-SIFT-User's-Guide There are also training videos relate to SIFT: Getting GOES-16 and GOES-17 data from NOAA CLASS, which data can be used in SIFT: https://www.youtube.com/watch?v=yMBcMixACX4 ; Using SIFT to make an Airmass RGB: https://www.youtube.com/watch?v=bn12KwnpFto ; Using SIFT to detect dust: https://www.youtube.com/watch?v=vHE4eQHmpL4

Publications and Conference Reports
Abstracts submitted to both CMOS and SatMet in Boston. (Pending)

46. CIMSS Support for AquaWatch, the Group on Earth Observations (GEO) Initiative
CIMSS Task Leader: Timothy Wagner
CIMSS Support Scientist: Steven Greb
NOAA Collaborator: Paul DiGiacomo NOAA/NESDIS

NOAA's Long-Term Goals:
- Weather-Ready Nation

NOAA Strategic Plan-Mission Goals:
- Serve society's needs for weather and water
- Support the nation's commerce with information for safe, efficient and environmentally sound transportation
- Provide critical support for the NOAA mission

CIMSS Research Themes:
- Satellite Meteorology Research and Applications
- Satellite Sensors and Techniques
- Environmental Models and Data Assimilation
- Education and Outreach

Objective
To support GEO AquaWatch and associated activities.

Project Overview
This funding supported the establishment of the director of GEO AquaWatch for approximately 1/3 time in the FY. This position was responsible for the overall management of this initiative. More specifically, this position provided overall leadership and strategic direction for Secretariat activities, support the AquaWatch Steering Committee and Working Groups in identifying priority activities and appropriate partners, provide guidance to the Steering Committee on scientific and technical activities, work to expand and maintain GEO AquaWatch partnerships, represent GEO AquaWatch at domestic and international Earth observation meetings, identify and pursue funding opportunities to support GEO AquaWatch activities, provide expert guidance to NOAA on the provision and utilization of NOAA et al. observations in support of inland and coastal water quality assessments and management.

Milestones with Summary of Accomplishments and Findings

AquaWatch/GloboLakes Workshop Planning, Hosting and Workshop Report Writing
A joint workshop between the UK GloboLakes project and GEO AquaWatch Initiative was held in Stirling Scotland 29-31 August 2018. This workshop marked the culmination of the six-year GloboLakes project as well as featured the latest applications of EO to inland and near-shore coastal waters at local, regional and global scales and contributions to improved water management, climate studies, and achieving SDGs. We engaged in community discussions of data and technology challenges, linkages between EO data providers and stakeholders, community-based water monitoring, and finally, we identified the future Group on Earth Observation (GEO) AquaWatch Initiative activities. The workshop planning and organization occupied much of my time in the summer of 2018. The workshop report can be found at https://www.geoaquawatch.org/

IOCCG Report Chair and Editor
The International Ocean Colour Coordinating Group published the report titled Earth Observations in Support of Global Water Quality Monitoring. A working group had been formed in 2014 to support the implementation of a global water quality monitoring service that contributes to the broader implementation of the Global Earth Observation System of Systems (GEOSS) under the auspices of the Group on Earth Observations (GEO). The goal of the working group was to provide a strategic plan that incorporates current and future Earth Observation (EO) information into national and international near-coastal and inland water quality monitoring efforts. This report provides an overview, as well as background and detailed information needed to support the development of an EO-based global water quality monitoring service. The report can be accessed at http://ioccg.org/what-we-do/ioccg-publications/ioccg-reports/

Coordinate AquaWatch Webinar Series
AquaWatch has run an ongoing webinar series for the past 10 years. This has been a good way to generate interest and engage the community. They have been quite successful. Recent webinars include:

- GEMS/Water: Evolving a Global Long-term Water Quality Data Repository UNEnvironmental Programs 27 September 2018

- Sustainability of Future Environmental Observation Networks Panel Discussion. Plymouth Marine Lab, UK 24 October 2018
- CyanoAlert – Space based cyanobacteria information & services Brockmann Geomatics 27 November 2018
- Why a new generation of EO sensors for water quality needs a new generation of in situ validation instruments? Water Insight Inc. 31 January 2019

NASA Post-Doc proposal

A proposal was written to fund a post-doctoral position in support of AquaWatch. This position will be stationed at NASA Goddard and applications are now open through June 30th. The new candidate will work closely with AquaWatch, as well as Goddard labs that process and validate aquatic satellite data and develop a near-real time information system to monitor water quality using current multi-spectral satellite data and future hyperspectral data from PACE and any field campaigns associated with a potential mission on Surface Biology and Geology, currently an architecture study. Prospective candidates will work closely with AquaWatch to grow Earth Observation-derived water quality products to support effective monitoring, management and decision-making.

Additional Funding and Support

In an effort to further establish and grow AquaWatch as an organization serving the water quality community, additional support funding and financial have been pursued. These include a round 1 application to the Global Innovation Fund, the World Bank, and internal SSEC2025 grants. In addition, AquaWatch has established a fiscal sponsorship with the Meridian Institute, a 501(c)3 nonprofit. This relationship is critical because AquaWatch currently has no legal status and does not qualify to pursue a number of grant opportunities.

Publications and Conference Reports

IOCCG (2018). Earth Observations in Support of Global Water Quality Monitoring. Greb, S., Dekker, A. and Binding, C. (eds.), IOCCG Report Series, No. 18, International Ocean Colour Coordinating Group, Dartmouth, Canada.

47. A Satellite Conversations Roadshow for the National Weather Service Alaska Region

CIMSS Task Leader: Jordan Gerth
CIMSS Support Scientist: Scott Lindstrom
NOAA Collaborators: Nathan Eckstein, National Weather Service Alaska Region
Budget: $29,000

NOAA Long Term Goals:

- Weather-Ready Nation

NOAA Strategic Goals:

- Serve society's needs for weather and water
- Provide critical support for the NOAA mission

CIMSS Research Themes:

- Satellite Meteorology Research and Applications
- Education and Outreach

Objective
Satellite applications training, in the form of three-hour conversations with small groups of operational meteorologists, was conducted at the National Weather Service (NWS) Alaska Region forecast offices. The primary purpose of the training was to build capabilities and increase retention of satellite meteorology approaches in operational weather analysis and forecasting procedures. The satellite conversations at the three forecast offices in the region, Anchorage, Fairbanks, and Juneau, were completed as part of a "roadshow" within two weeks, where subject-matter experts (SMEs) travelled between offices by airplane.

Project Overview
Scientists from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) visited the three National Weather Service (NWS) Alaska Region weather forecast offices over a ten-day period to conduct discussions with small groups of meteorologists about the imagery and products from the new Geostationary Operational Environmental Satellite (GOES) in the West position (GOES-17). The discussions increased awareness of GOES-17, its loop heat pipe issues, and other non-GOES satellite capabilities for routine weather analysis and forecasting duties. Participants learned about the spectral bands, multi-spectral composites, and baseline products, and when they should be applied to assist with common forecast decisions required of Alaska operational meteorologists.

Milestones with Summary of Accomplishments and Findings
With the second satellite in the Geostationary Operational Environmental Satellite R-Series (GOES-R) becoming operational, tailored GOES-17 training was desired in the Outside of the CONtiguous United States (OCONUS). To satisfy the need for short and impactful training in Alaska, scientists from CIMSS with subject-matter expertise provided in-person though informal training on new-generation weather satellites called satellite conversations at NWS Alaska Region forecast offices in Anchorage, Fairbanks, and Juneau. These non-traditional training sessions involved small groups of 1340-series operational meteorologists sitting with a CIMSS subject-matter expert (SME) at an Advanced Weather Interactive Processing System (AWIPS) workstation in the office, stepping through the Advanced Baseline Imager (ABI) spectral bands, band differences, Red-Green-Blue (RGB) spectral composites, and baseline products. An overview of useful AWIPS features for viewing satellite imagery and products was also provided.

As part of these conversations, there were no PowerPoint presentations or formal training exercises such as job sheets or quizzes. Each conversation was unique to participants, lasted about three hours in length, and mainly focused on how the different ABI bands and products could be applied within and around Alaska for daily decision support and routine weather forecasting tasks, considering the time of day and day of the year. The success of the effort was predicated on the imagery and products in AWIPS on the days of the conversation, and forecaster participants spending time immediately after the discussion preparing new procedures to use on subsequent shifts.

The conversations occurred in succession, up to four per day with two SMEs, in March 2019, after live GOES-17 data was available in AWIPS from the operational position at 137 degrees West longitude. They could not occur before that time because live AWIPS imagery and products from GOES-17 were paramount to the success of the conversations and their applicability to operational tasks. Meteorologists from the Alaska Aviation Weather Unit (AAWU), Center Weather Service Unit (CWSU), and River Forecast Center (RFC) also attended the discussions in Anchorage, leading to larger groups there, as well as sessions on the weekend.

The format and content for the conversations was well received. Doug Wesley, the Science and Operations Officer (SOO) at the AAWU, wrote: "(I) [w]anted to let you know from the AAWU that the sessions were great, operationally-focused, and excellent tools for continuing our evolution into the [GOES-17] era. I've received nothing but positive feedback from attendees. ... From an internal standpoint, I cannot stress enough how important 1-1 training is to all of us."

The SMEs also fielded questions on the Joint Polar Satellite System (JPSS) imagery and products, and discussed how JPSS mission data can complement the GOES-17 imagery in certain situations. JPSS has certain advantages for Alaska, particularly resulting from the difference in spatial resolution compared to GOES-17 at high latitudes. The SMEs found that the NWS meteorologists in Alaska Region generally outperformed their CONUS colleagues on knowledge of satellite imagery and product availability and utility, though the training closed small gaps for some participants. No further training in Alaska is planned as part of this project.

Appendix 1: List of Awards to Staff Members

2019

Margaret Mooney: Earth Science Information Partners (ESIP) 2019 Catalyst Award
Timothy Schmit: AMS Fellow

2018

Kelton Halbert: Best Student Poster, AMS Conference on Severe Local Storms
Bob Holz: Permanent Principal Investigator, UW-Madison
Allen Huang: Chair, Asia-Oceania Meteorological Satellite Users Conference (AOMSUC)
Jun Li: Permanent Principal Investigator, UW-Madison
Margaret Mooney: UW-Madison Robert and Carroll Heideman Award for Excellence in Public Service and Outreach
Tim Schmit: Finalist, Samuel J. Heyman Service to America Award
Tim Schmit: Fellow of the American Meteorological Society, 2019
Dave Tobin: Permanent Principal Investigator, UW-Madison
Christopher Velden: American Meteorological Society Banner I. Miller Award
Charles White: Best Oral Presentation, NOAA/NESDIS Cooperative Research Program Annual Science Symposium
Tom Whittaker: STAC Distinguished Scientific/Technological Accomplishment and Outstanding Service Award

Appendix 2: Publications Summary

Table 1 below indicates the number of reviewed and non-reviewed papers that include a CIMSS or ASPB scientist as first author during the period 2016-2018. Two additional columns show lead authorship of NOAA scientists outside of ASPB or lead authors from other institutions or organizations. When summed, peer reviewed totals for each year (in Table 1) will equal peer reviewed totals in Table 3, a longitudinal graphic.

Table 2 below shows collaborations on papers between or among Institute, ASPB, and NOAA authors outside of ASPB. Because there may be many collaborators on a given paper, the by-year totals in Table 2 will not match the actual published paper totals in Table 1 (or in Table 3); they will be greater.

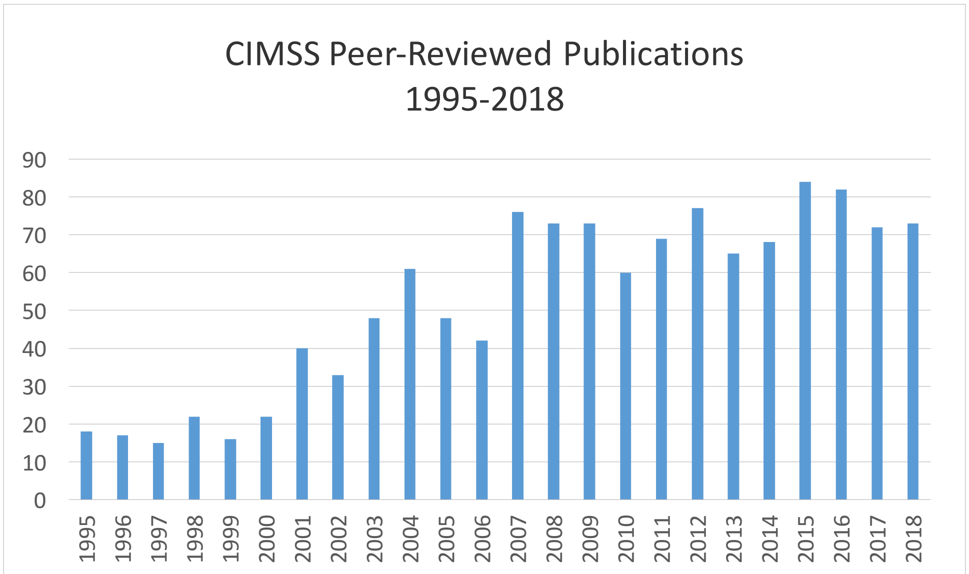
Table 1. Totals of Peer Reviewed and Non Peer Reviewed journal articles having CIMSS, ASPB, NOAA, or Other lead authors, 2016-2018.

	Inst Lead			ASPB Lead			NOAA Lead			Other Lead		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
Peer Reviewed	17	21	20	2	2	2	13	5	11	50	44	40
Non Peer Reviewed	0	0	0	0	0	0	0	0	1	0	0	1

Table 2. Peer Reviewed and Non Peer Reviewed journal articles having one or more CIMSS, ASPB, or NOAA co-authors, 2016-2018.

	Institute Co-Author			ASPB Co-Author			NOAA Co-Author		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
Peer Reviewed	121	94	79	24	20	20	54	31	53
Non Peer Reviewed	0	5	0	0	0	0	0	0	0

Table 3. CIMSS publishing history showing peer-reviewed publications for the period 1995-2018.



Notes:

1. A more detailed analysis of CIMSS publishing is available in the report, "A Bibliometric Analysis of Peer-Reviewed Articles by Cooperative Institute for Meteorological Satellite Studies Authors for the Period 2015-2017: https://infogram.com/1pn9qqzdqm3kd7bzdlpx302v1msmvdrglyj?live
2. Additionally, a bibliography of Advanced Satellite Products Branch (ASPB) publications is available at: http://library.ssec.wisc.edu/research_Resources/bibliographies/aspb

Appendix 3: Employee Support Documentation

Personnel				
Category	Number	B.S.	M.S.	Ph.D.
Research Scientist	11	0	2	9
Visiting Scientist	0	0	0	0
Postdoctoral Fellow	1	0	0	1
Research Support Staff	40	3	28	9
Administrative	0	0	0	0
Total (≥ 50% Support)	52	3	30	19
Undergraduate Students	9			
Graduate Students	4	4	0	
Employees that received <50% NOAA Funding (not including students)	73	19	23	29
Located at Lab (include name of lab)	1 - JCSDA			
Obtained NOAA employment within the last year	2			

Appendix 4: Research Topics of Current CIMSS Graduate Students and Post-Doctors

NOAA Funded Graduate Students

James Anheuser
Ph.D. research focus: Working on a Low Earth Orbit Sounder and Geostationary Earth Orbit Imager data fusion process enabling the downscaling of sounder data to imager spatial and temporal scale. Intention is to find interesting applications of this fusion to weather and climate applications in order to form thesis.

Margaret Bruckner
Ph.D. topic: "Indirect Validation of Ozone Mapping Profiler Suite (OMPS) Limb Retrievals." Chemical re-analyses are used in investigation of ozone interannual variability and trends associated with ozone recovery. The Real-time Air Quality Modeling System (RAQMS) reanalysis has been developed using retrievals from the NASA Ozone Monitoring Instrument and Microwave Limb Sounder. These satellites are being replaced by the next generation of instruments, including OMPS. To continue this re-analysis, the re-analysis must be able to assimilate OMPS limb retrievals. In order to assimilate this data, a good estimate of the observation error is necessary. We are obtaining an estimate of observation error through indirect validation. Indirect validation does not require coincident measurements, which increases the number of data points included in the intercomparison of datasets and reduces the error in comparing the datasets. This indirect validation bias-corrects the existing RAQMS re-analysis with Atmospheric Chemistry Experiment (ACE) retrievals, validates this correction with ozonesonde observations, and evaluates the observation error in OMPS utilizing the bias-corrected re-analysis.

Charles White
Ph.D. focus: "Applications of Machine Learning to Remotely Sensed Cloud Products and Satellite Climate Records." This work focuses on the use of supervised learning methods to improve cloud property retrievals from satellite imagers. These techniques have recently demonstrated substantial ability to increase the accuracy of cloud masking, cloud top height, and cloud top phase. In particular, we have noted very large improvements in cloud masking over ice and snow, where cloud masks have traditionally struggled. Unsupervised methods will also be used to analyze variability in satellite climate records.

Students Funded on other projects than NOAA

Kai-Wei Chang
PhD Title: "Processes and features of temperature, water vapor, and cirrus clouds in the tropical tropopause layer" The tropical tropopause layer controls the amount of water vapor entering the lower stratosphere. It is recognized that as air encounters cold temperatures at the tropical tropopause it is dehydrated by cirrus formation. This research explores the processes, such as tropical convection and equatorial wave dynamics, which modulate temperature and water vapor at the tropopause, as well as the relation of water vapor to cirrus cloud properties observed by satellites.

Austin Dixon
The streamwise vorticity current (SVC) is a persistent tube of streamwise vorticity located along the FFDB that flows rearward along the FFDB and eventually upward into the updraft. In our 30m isotropic simulation of the 24 May, 2011 El Reno, OK tornadic supercell, the SVC appears to create non-linear dynamic pressure perturbations near its intersection with the low-level updraft, which likely enhances and lowers this region of the updraft. This enhancement of the low level updraft is precursory to tornado genesis. A radar emulator has been developed to view the simulation data in a similar presentation to NEXRAD and X-band research radars. The ultimate goal of the study is to analyze radar characteristics of the SVC in order to inform field researchers on ways to identify it. (NSF funding)

Alyson Douglas
Ph.D. focus: Understanding Aerosol-Cloud Interactions using Satellite Observations. Our research uses NASA A-Train observations to discern aerosol-cloud interactions. Cloud brightening, and darkening, is a regime dependent process that is important estimates of the climate sensitivity. Cloud extent can also increase, or decrease, in size depending on the local meteorological conditions. Aerosol can suppress precipitation, leading to invigoration depending on the cloud state and stability of the boundary layer. Our results indicate that aerosol-cloud interactions must be inferred using a holistic method, otherwise important buffering or invigoration processes can be missed. (NASA funding)

Andrew Dzambo
Research topic: We recently completed the 3rd deployment to São Tomé for the ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) experiment. Over 10 million W-band radar profiles were collected from the Advanced Precipitation Radar - 3rd Generation, with several million more collected in 2018 and are currently undergoing post processing. Radar data from 2016 and 2017 were utilized in an adapted version of CloudSat's 2C-RAIN-PROFILE algorithm to retrieve precipitation rate from each (valid) W-band radar profile taken during the experiment. This new dataset has been made available to NASA's ESPO archive and is described in a journal paper presently undergoing revisions. (NASA funding)

Kelton Halbert
Ph.D. focus: "Maintenance of Violent Tornadoes in Simulated Supercell Thunderstorms." This research uses high-resolution large-eddy simulations of supercell thunderstorms and tornadoes to understand the storm-scale dynamics of what creates and maintains long-lived violent tornadoes. Of particular interest is the role of horizontal streamwise vorticity in the cold pool and how it relates to tornado maintenance, particularly in how the lower surface boundary acts to create this vorticity. Results from this research hope to improve our understanding of the most violent and deadly storms in order to better predict their occurrence. (NSF funding)

April Hang
Ph.D. focus: "The Effect of Cloud Type on Earth's Energy Budget." This research leverages measurements made by satellites CloudSat, CALIPSO, and MODIS to analyze spatial and temporal distributions of individual cloud types and their radiative characteristics. Of particular interest are multi-layered cloud systems and their large impact on the atmospheric heating. Results of our observational analysis are used to develop benchmarks for evaluating the representation of individual cloud types in global climate models. (NASA funding)

David Loveless
PhD Focus: “Combining space-based infrared sounders with ground-based interferometers.” This work aims to combine space-based infrared sounders with a ground-based interferometer in order to improve thermodynamic retrievals of the boundary layer. A clear-sky information content study reveals that combining the radiances from both sets of instruments into a single retrieval results in the greatest improvement in the boundary layer, compared to an a posteriori combination of the products in a single-instrument retrieval. Further work is required to understand the improvements of this synergy in cloudy sky conditions.

Ashtin Massie
M.S. topic: "Developing an algorithm for retrieving ice cloud properties from NASA A-Train satellites." This research involves improving the retrieval of ice cloud properties in the mid-latitudes using NASA A-Train satellites. By conducting an information content analysis of various cloud regimes in the mid-latitudes, we can see the optimal combination of AIRS and MODIS observations that can yield the most information about the properties of ice clouds in the atmosphere, both in single-layer and multi-layer cloud regimes. (NASA funding)

Elin McIlhattan
Ph.D. focus: “Polar Cloud Behavior and Impact on Surface Energy Balance” This research leverages measurements made by instruments aboard the NASA A-Train satellite constellation to analyze spatial and temporal distributions of polar clouds and their characteristics. Of particular interest are supercooled liquid containing clouds and their large impact on the surface radiation balance relative to fully glaciated clouds. Results of our observational analysis are used to develop benchmarks for evaluating the representation of polar clouds in global climate models. (This work is supported by a NASA Earth and Space Science Fellowship.)

Coda Phillips
M.S. focus "Optical Properties of Aerosol in Seoul using the High Spectral Resolution Lidar." Aerosol concentrations have large variation over time and space, which necessitates intensive observations like those performed during KORUS-AQ in South Korea. In East Asia, air quality is a real problem in which policies are informed by aerosol science. Observations of the vertical profile of aerosol concentration afforded by a lidar like the HSRL can aid understanding of aerosol processes and transport in the region. An information-dense aerosol climatology is developed from one year of observations. (NASA funding)

Julie Pilewskie
M.S. Title: "The Precipitation and Radiative Responses to Convective Organization in the Tropical North Atlantic". This research blends NASA A-Train's low-Earth Orbit and geostationary satellite observations to assess the relationships between characteristics of convection under different environmental conditions. We are particularly interested in understanding convective organization’s role in influencing Earth’s water cycle and radiative energy budget, and the link between the two. This work provides observational constraints for improving numerical weather prediction models and assessing the influence of convection on Earth’s energy imbalance. (NASA funding)

Julia Shates
M.S.: "High–Latitude Precipitation: Characterizing Snowfall Regimes and Identifying Key Processes". This research combines observations from in-situ and ground-based remote sensing instrumentation and reanalysis data at two high latitude sites: Haukeliseter, Norway and Kiruna, Sweden. Specifically, I am using observations from a 24GHz Micro Rain Radar (MRR), particle

imaging package (PIP)/custom video disdrometer, weather stations, and reanalysis products (ECMWF ERA5) to characterize snowfall properties associated with meteorological events. After characterizing the microphysical properties in a synoptic scale context, I will attempt to define distinct snowfall regimes. Snowfall regimes will allow us to improve accumulation estimates and potentially work on satellite snowfall validation. (NASA funding)

Anne Sledd
PhD focus: "Arctic energy balance and sea ice variability." This research focuses on the two-way relationship between radiative fluxes and sea ice in the Arctic and the role of clouds. Satellite observations are used to investigate the importance of clouds in modulating the effect of sea ice decline on the planetary albedo and compare with reanalysis datasets. Of current interest is the role of longwave radiation and how models can be used to complement observations in studying sea ice variability. (NASA funding)

Appendix 5: Visitors at CIMSS 2017-2019 (visits of 3 days or more and key visitors)

Nikos **Benas**	Royal Netherlands Meteorological Institute, De Bilt (KNMI), The Netherlands
Alejandra **Castrodad-Rodríguez**	Strategic Planning & Resilience, Puerto Rico
Su **Chen**	Beijing Institute of Technology, China
John **Crockett**	NWS Office of Science and Technology Integration, Silver Spring, MD
Cathy **Finley**	St. Louis University, U.S.
Donatello **Gallucci**	Italian National Research Council: CNR/IMAA, Italy
Xinya **Gong**	Institute of Atmospheric Physics, Chinese Academy of Sciences, China
Ed **Grigsby**	NASA GOES-R Program Office
David **Hyman**	University of Buffalo, Buffalo, NY
Jung-Sun **Im**	NWS Office of Science and Technology Integration, Silver Spring, MD
Neil **Jacobs**	NOAA Deputy Director
Benjamin **Johnson**	Joint Center for Satellite Data Assimilation/NOAA/CWCP, College Park, MD
Jung-Rim **Lee**	Korea Meteorological Administration, Korea
SuJeong **Lee**	Ewha Womans University, Republic of Korea
Pieternel **Levelt**	Royal Netherlands Meteorological Institute, Delft University of Technology
Yu-Ching **Liu**	Central Weather Bureau, Taiwan
Dr. Bing **Lu**	Institute of Urban Meteorology of China Meteorology Administration, China
Qingqing **Lyu**	National Satellite Meteorology Center, China
Leon **Majewski**	Australian Bureau of Meteorology, Australia
Deming **Meng**	Nanjing University of Information Science & Technology, China
Youngchan **Noh**	Seoul National University, Republic of Korea
Matyas **Rada**	Eötvös Loránd University, Hungary
Pam **Sullivan**	NOAA/NESDIS GOES-R Program Office
Hiroshi **Suzue**	Meteorological Satellite Center of Japan Meteorological Agency, Japan
Xiaoping **Xie**	Jiangsu Meteorological Bureau, China
Yunheng **Xue**	Chinese Academy of Sciences, China
Zhiyu **Zhou**	North China Electric Power University, China

Appendix 6: List of Staff/Students hired by NOAA in the past years

Mark Kulie (Ph.D. 2010): NOAA/NESDIS/STAR/ASPB, Physical Scientist: 2018

Yinghui Liu (Ph.D. 2006): NOAA/NESDIS/STAR/ASPB, Physical Scientist: 2019

2019 Hollings Scholar at CIMSS: Daniel Hueholt

Appendix 7: CIMSS Board of Directors and Science Council

CIMSS Board of Directors

The Board of Directors will consist of senior employees from NOAA and UW-Madison. The Board of Directors shall review the policies, research themes, and priorities of CIMSS, including budget and scientific activities and will also provide for the periodic external review of the scientific activities of CIMSS. The Director of CIMSS or his/her designee shall serve as a non-voting member of the Board of Directors. The NESDIS Cooperative Research Program Director will serve as a special advisor to the Council in an *ex officio* status. Current Board of Directors members include:

Norman Drinkwater	Interim Vice Chancellor for Research and Graduate Education, UW–Madison
Tristan L'Ecuyer	Director, CIMSS, UW–Madison
Brad Pierce	Director, SSEC, UW–Madison
Greg Tripoli	Chair, Department of Atmospheric and Oceanic Sciences, UW-Madison
Steven Volz	Assistant Administrator for Satellite and Information Services, NOAA/NESDIS
Harry Cikanek	Director, Center for Satellite Applications and Research, NOAA/NESDIS
Jeff Key	Chief, Advanced Satellite Products Branch, NOAA/NESDIS
Jack A. Kaye	Associate Director for Research, NASA
Peter Hildebrand	Director, Earth-Sun Exploration Division of the Sciences and Exploration Directorate, NASA Goddard Space Flight Center
David F. Young	Director, Science Directorate, NASA Langley Research Center

CIMSS Science Advisory Council

The Science Council will advise the CIMSS Director in establishing the broad scientific content of CIMSS programs, promoting cooperation among CIMSS, NOAA, NASA and other agencies, maintaining high scientific and professional standards, and preparing reports of CIMSS activities. All Science Advisory Council members shall be recommended and selected by the Director of CIMSS, in consultation with the Board of Directors. In addition, the Executive Director of SSEC or designee shall be a Council member. Council members shall serve three-year terms. Reappointment is possible for additional three-year terms pending approval by the Board. The number of Council members shall be set by the Board, provided the number of University members equal the total number of agency members. The Director of CIMSS will serve as the Chairperson of the Council. The NESDIS Cooperative Research Program Director will serve as a special advisor to the Council in an *ex officio* status. Science Council members include:

Tristan L'Ecuyer	Director, CIMSS; Professor, UW-Madison Atmospheric and Oceanic Sciences
Jun Li	Distinguished Scientist, CIMSS, UW–Madison
Chris Velden	Senior Scientist, CIMSS, UW–Madison
Trina McMahon	Professor, College of Engineering, UW–Madison
Annemarie Schneider	Professor, SAGE, UW–Madison
Chris Kummerow	Professor, Department of Atmospheric Science, Colorado State University
Mitch Goldberg	GOES-R Program Scientist, NOAA/NESDIS/ORA

Satya Kalluri	Chief, Satellite Meteorology and Climate Division, NOAA/NESDIS/STAR
Steve Platnick	Aqua Deputy Project Scientist, EOS Senior Project Scientist (acting), NASA Goddard Space Flight Center
Bill Smith Jr.	Senior Research Scientist, NASA Langley Research Center

Appendix 8: CIMSS Publications, 2016-2019

CIMSS Peer-Reviewed Publications, 2016-2019

2019

Peer-Reviewed Journal Articles

Bhatia, K. T., G. A. Vecchi, T. R. Knutson, H. Murakami, J. Kossin, K. W. Dixon, and C. E. Whitlock, 2019: Recent increases in tropical cyclone intensification rates. Nature communications 10.

Cesana, G., D. E. Waliser, D. Henderson, T. S. L'Ecuyer, X. Jiang, and J. L. F. Li, 2019: The vertical structure of radiative heating rates: a multimodel evaluation using A-train satellite observations. Journal of Climate 32:1573-1590.

Ferre, I. M., S. Negron, H. Pantin, S. J. Schwartz, J. P. Kossin, and J. M. Shultz, 2019: Hurricane Maria's landfall near Punta Santiago, Puerto Rico: Community needs and mental health assessment 6 months post-impact. Disaster Medicine and Public Health Preparedness 13:18-23.

Hoffman, J. P., S. A. Ackerman, Y. Liu, and J. R. Key, 2019: The detection and characterization of Arctic sea ice leads with satellite imagers. Remote sensing 11:521.

Lemonnier, F., J.-B. Madeleine, C. Claud, C. Genthon, C. Duran-Alarcon, C. Palerme, A. Berne, N. Souverijns, N. van Lipzig, I. V. Gorodetskaya, T. L'Ecuyer, and N. Wood, 2019: Evaluation of CloudSat snowfall rate profiles by a comparison with in situ micro-rain radar observations in East Antarctica. Cryosphere 13:943-954.

Li, J.-L. F., M. Richardson, W.-L. Lee, E. Fetzer, G. Stephens, J. Jiang, Y. Hong, Y.-H. Wang, J.-Y. Yu, and Y. Liu, 2019: Potential faster Arctic sea ice retreat triggered by snowflakes' greenhouse effect. Cryosphere 13:969-980.

Li, Z., J. Li, T. J. Schmit, P. Wang, A. Lim, J. Li, F. W. Nagle, W. Bai, J. A. Otkin, R. Atlas, R. N. Hoffman, S.-A. Boukabara, T. Zhu, W. J. Blackwell, and T. S. Pagano, 2019: The alternative of CubSat-based advanced infrared and microwave sounders for high impact weather forecasting. Atmospheric and Oceanic Science Letters 12:80-90.

Lim, A. H. N., J. A. Jung, S. E. Nebuda, J. M. Daniels, W. Bresky, M. Tong, and V. Tallapragada, 2019: Tropical cyclone forecasts impact assessment from the assimilation of hourly visible, shortwave, and clear-air water vapor atmospheric motion vectors in HWRF. Weather and Forecasting 34:177-198, DOI: 10.1175/WAF-D-18-0072.1.

Liu, Z., M. Min, J. Li, F. Sun, D. Di, Y. Ai, Z. Li, D. Qin, G. Li, Y. Lin, and X. Zhang, 2019: Local severe storm tracking and warning in pre-convection stage from the new generation geostationary weather satellite measurements. Remote sensing 11:383.

Merrelli, A., M. C. Turnbull, and T. S. L'Ecuyer, 2019: Terran World Spectral Simulator. Publications of the Astronomical Society of the Pacific 131.

Palerme, C., C. Claud, N. B. Wood, T. L'Ecuyer, and C. Genthon, 2019: How Does Ground Clutter Affect CloudSat Snowfall Retrievals Over Ice Sheets? IEEE Geoscience and Remote Sensing Letters 16:342-346.

Schroeder, M., M. Lockhoff, L. Shi, T. August, R. Bennartz, H. Brogniez, X. Calbet, F. Fell, J. Forsythe, A. Gambacorta, S. Ho, E. R. Kursinski, A. Reale, T. Trent, and Q. Yang, 2019: The GEWEX water vapor assessment: overview and introduction to results and recommendations. Remote Sensing 11.

Shultz, J. M., J. P. Kossin, J. M. Shepherd, J. M. Ransdell, R. Walshe, I. Kelman, and S. Galea, 2019: Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Disaster Medicine and Public Health Preparedness 13:5-17.

Wagner, T. J., P. M. Klein, and D. D. Turner, 2019: A new generation of ground-based mobile platforms for active and passive profiling of the boundary layer. Bulletin of the American Meteorological Society 100:137-153.

Wang, W., C. Cao, A. Ignatov, X. Liang, Z. Li, L. Wang, B. Zhang, S. Blonski, and J. Li, 2019: Improving the calibration of Suomi NPP VIIRS thermal emissive bands during blackbody warm-up/cool-down. IEEE Transactions on Geoscience and Remote Sensing 57:1977-1994.

Xu, Shuang, Jia Yue, Xianghuui Xue, Sharaon L. Vadas, Steven D. Miller, Irfan Azeem, William Straka III, Lars Hoffmann, and Simin Zhang, 2019: Dynamical coupling between Hurricane Matthew and the middle to upper atmosphere via gravity waves. J. Geophys. Res.: Space Phys., doi:10.1029/2018JA026453.

2018

Books and Book Chapters

Ackerman, S. A., S. Platnick, P. K. Bhartia, B. Duncan, T. L'Ecuyer, A. Heidinger, G. Skofronick-Jackson, N. Loeb, T. Schmit, and N. Smith, 2018: Satellites see the world's atmosphere. Meteorological Monographs 59:4.1-4.53.

Lewis, John M.; Jean M. Phillips; W. Paul Menzel; Thomas H. Vonder Haar; Hans Moosmüller; Frederick B. House, and Matthew G. Fearon, 2018: Verner Suomi: the life and work of the founder of satellite meteorology. American Meteorological Society, xiii, 189p.

Peer-Reviewed Journal Articles

Alessandrini, S., L. Delle Monache, C. M. Rozoff, and W. E. Lewis, 2018: Probabilistic prediction of tropical cyclone intensity with an analog ensemble. Monthly Weather Review 146:1723-1744.

Bah, M. K., M. M. Gunshor, and T. J. Schmit, 2018: Generation of GOES-16 true color imagery without a green band. Earth and Space Science 5:549-558.

Bhatia, K., G. Vecchi, H. Murakami, S. Underwood, and J. Kossin, 2018: Projected response of tropical cyclone intensity and intensification in a global climate model. Journal of Climate 31:8281-8303.

Blackwell, W. J., S. Braun, R. Bennartz, C. Velden, M. DeMaria, R. Atlas, J. Dunion, F. Marks, R. Rogers, B. Annane, and R. V. Leslie, 2018: An overview of the TROPICS NASA Earth Venture mission. Quarterly Journal of the Royal Meteorological Society 144:16-26, DOI: 10.1002/qj.3290.

Borbas, E. E., G. Hulley, M. Feltz, R. Knuteson, and S. Hook, 2018: The Combined ASTER MODIS Emissivity over Land (CAMEL) part 1: Methodology and high spectral resolution appliation. Remote Sensing 10:doi:10.3390/rs10040643.

Cintineo, J. L., M. J. Pavolonis, J. M. Sieglaff, D. T. Lindsey, L. Cronce, J. Gerth, B. Rodenkirch, J.

Brunner, and C. Gravelle, 2018: The NOAA/CIMSS ProbSevere Model: Incorporation of total lightning and validation. Weather and Forecasting 331-345.

Costa, S. M. S., R. G. Negri, N. J. Ferreira, T. J. Schmit, N. Arai, W. Flauber, J. Ceballos, D. Vila, J. Rodrigues, L. A. Machado, S. Pereira, M. J. Bottino, R. A. Sismanoglu, and P. Langden, 2018: A successful practical experience with dedicated Geostationary Operational Environmental Satellites GOES-10 and -12 supporting Brazil. Bulletin of the American Meteorological Society 99:33-47.

Di, D., J. Li, W. Han, W. Bai, C. Wu, and W. P. Menzel, 2018: Enhancing the fast radiative transfer model for FengYun-4 GIIRS by using local training profiles. Journal of Geophysical Research-Atmospheres 123.

Dougherty, E. M., J. Molinari, R. F. Rogers, J. A. Zhang, and J. P. Kossin, 2018: Hurricane Bonnie (1998): maintaining intensity during high vertical wind shear and an eyewall replacement cycle. Monthly Weather Review 146:3383-3399.

Elsberry, R. L., E. A. Hendricks, C. S. Velden, M. M. Bell, M. Peng, E. Casas, and Q. Zhao, 2018: Demonstration with special TCI-15 datasets of potential impacts of new-generation satellite atmospheric motion vectors on Navy regional and global models. Weather and Forecasting 33:1617-1637.

Emanuel, K., P. Caroff, S. Delgado, C. C. Guard, M. Guishard, C. Hennon, J. Knaff, K. R. Knapp, J. Kossin, C. Schreck, C. Velden, and J. Vigh, 2018: On the desirability and feasibility of a global reanalysis of tropical cyclones. Bulletin of the American Meteorological Society 99:427-429.

Famiglietti, C. A., J. B. Fisher, G. Halverson, and E. E. Borbas. 2018. Global validation of MODIS near-surface air and dew point temperatures. Geophysical Research Letters 45:7772-7780.

Feltz, M., E. Borbas, R. Knuteson, G. Hulley, and S. Hook, 2018: The combined ASTER and MODIS emissivity over land (CAMEL) global broadband infrared emissivity product. Remote Sensing 10:1027, doi: 10.3390/rs10071027.

Feltz, M., E. Borbas, R. Knuteson, G. Hulley, and S. Hook, 2018: The Combined ASTER MODIS Emissivity over Land (CAMEL) part 2: Uncertainty and validation. Remote Sensing 10:doi:10.3390/rs10050664.

Fierro, A. O., S. N. Stevenson, and R. M. Rabin, 2018: Evolution of GLM-observed total lightning in Hurricane Maria (2017) during the period of maximum intensity. Monthly Weather Review 146:1641-1666.

Gao, L., L. Chen, J. Li, A. K. Heidinger, X. Xu, and S. Qin, 2018: A long-term historical aerosol optical depth data record (1982-2011) over China from AVHRR. IEEE Transactions on Geoscience and Remote Sensing .

Gerth, J, 2018: It's not hot air: GOES-16 infrared window bands to diagnose adjacent summertime air masses. Meteorological Applications doi: 10.1002/met.1767.

Gerth, J. J., 2018: Shining light on sky cover during a total solar eclipse. Journal of Applied Remote Sensing `12:020501.

Gong, X., Z. Li, J. Li, C. C. Moeller, C. Cao, W. Wang, and W. P. Menzel, 2018: Intercomparison between VIIRS and CrIS by taking into account the CrIS subpixel cloudiness and viewing geometry. Journal of Geophysical Research-Atmospheres 123:5335-5346.

Grabow, M., T. Bryan, M. M. Checovich, A. K. Converse, C. Middlecamp, M. Mooney, E. R. Torres, S. G. Younkin, and B. Barrett, 2018: Mindfulness and climate change action: A feasibility study. Sustainability

10.

Greenwald, T. J., R. Bennartz, M. Lebsock, and J. Teixeira, 2018: An uncertainty data set for passive microwave satellite observations of warm cloud liquid water path. Journal of Geophysical Research-Atmospheres 123:3668-3687.

Griffin, S. M. and C. S. Velden, 2018: Hazard avoidance products for convectively-induced turbulence in support of high-altitude Global Hawk aircraft missions. Pure and Applied Geophysics 1420-9136.

Hendricks, E. A., R. L. Elsberry, C. S. Velden, A. C. Jorgensen, M. S. Jordan, and R. L. Creasey, 2018: Environmental factors and internal processes contributing to the interrupted rapid decay of Hurricane Joaquin (2015). Weather and Forecasting 33:1251-1262.

Herring, S. C., N. Christidis, A. Hoell, J. P. Kossin, C. J. I. Schreck, and P. A. Stott, 2018: Explaining extreme events of 2016 from a climate perspective: Introduction to Explaining extreme events of 2016 from a climate perspective. Bulletin of the American Meteorological Society S1-S6.

Judd, L. M., J. A. Al-Saadi, L. C. Valin, R. B. Pierce, K. Yang, S. J. Janz, M. G. Kowalewski, J. J. Szykman, M. Tiefengraber, and M. Mueller, 2018: The dawn of geostationary air quality monitoring: case studies from Seoul and Los Angeles. Frontiers in Environmental Science 6.

Kabatas, B., R. B. Pierce, A. Unal, M. J. Rogal, and A. Lenzen, 2018: April 2008 Saharan dust event: its contribution to PM10 concentrations over the Anatolian Peninsula and relation with synoptic conditions. Science of the Total Environment 633:317-328.

Kaku, K. C., J. S. Reid, J. L. Hand, E. S. Edgerton, B. N. Holben, J. Zhang, and R. E. Holz, 2018: Assessing the challenges of surface-level aerosol mass estimates from remote sensing during the SEAC(4)RS and SEARCH campaigns: baseline surface observations and remote sensing in the Southeastern United States. Journal of Geophysical Research-Atmospheres 123:7530-7562.

Karstens, C. D., J. Jr. Correia, D. S. LaDue, J. Wolfe, T. C. Meyer, D. R. Harrison, J. L. Cintineo, K. M. Calhoun, T. M. Smith, A. E. Gerard, and L. P. Rothfusz, 2018: Development of a human-machine mix for forecasting severe convective events. Weather and Forecasting 33:715-737.

Knapp, K. R., C. S. Velden, and A. J. Wimmers, 2018: A global climatology of tropical cyclone eyes. Monthly Weather Review 146:2089–2101.

Kossin, J., 2018: Comment on "Spatial and temporal trends in the location of the lifetime maximum intensity of tropical cyclones" by Tennille and Ellis. Atmosphere 9:241-244.

Kossin, J. P., 2018: A global slowdown of tropical-cyclone translation speed. Nature 558:104-107.

Kurzrock, F., S. Cros, F. Chane-Ming, J. A. Otkin, L. Linguet, A. Hutt, G. Lajoie, and R. Potthast, 2018: The assimilation of geostationary meteorological satellite observations in regional NWP for cloudiness forecasting. Meteorologische Zeitschrift 27:277-298.

Langford, A. O., R. J. I. Alvarez, J. Brioude, S. Evan, L. T. Iraci, G. Kirgis, S. Kuang, T. Leblanc, Newchurch. M. J., R. B. Pierce, C. J. Senff, and E. L. Yates, 2018: Coordinated profiling of stratospheric intrusions and transported pollution by the Tropospheric Ozone Lidar Network (TOLNet) and NASA Alpha Jet experiment (AJAX): Observations and comparison to FYSPLIT, RAQMS, and FLEXPART. Atmospheric Environment 174:1-14.

Letterly, A., J. Key, and Y. Liu, 2018: Arctic climate: changes in sea ice extent outweigh changes in snow cover. The Cryosphere 12:3373-3382.

Levizzani, V., C. Kidd, K. Aonashi, R. Bennartz, R. R. Ferraro, G. J. Huffman, R. Roca, F. J. Turk, and N. Y. Wang, 2018: The activities of the international precipitation working group. Quarterly Journal of the Royal Meteorological Society 144:3-15, DOI: 10.1002/qj.3214.

Li, S., D. Sun, M. D. Goldberg , B. Sjobrg, D. Santek, J. P. Hoffman, M. DeWeese, P. Restrepo, S. Lindsey, and E. Holloway, 2018: Automatic near real-time flood detection using Suomi-NPP/VIIRS data. Remote Sensing of Environment 204:672-689.

Li, Z., J. Li, P. Wang, A. Lim, J. Li, T. J. Schmit, R. Atlas, S.-A. Boukabara, and R. N. Hoffman, 2018: Value-added impact of geostationary hyperspectral infrared sounders on local severe storm forecasts--via a quick regional OSSE. Advances in Atmospheric Sciences 35:1217-1230, doi: 10.1007/s00376-018-8036-3.

Liang, C. K., J. J. West, R. A. Silva, H. S. Bian, M. Chin, Y. Davila, F. J. Dentener, L. Emmons, J. Flemming, G. Folberth, D. Henze, U. Im, J. E. Jonson, T. J. Keating, T. Kucsera, A. Lenzen, M. Y. Lin, M. T. Lund, X. H. Pan, R. J. Park, R. B. Pierce, T. Sekiya, K. Sudo, and T. Takemura, 2018: HTAP2 multi-model estimates of premature human mortality due to intercontinental transport of air pollution and emission sectors. Atmospheric Chemistry and Physics 18:10497-10520.

Liu, Y.-A., H.-L. A. Huang, A. H. N. Lim, and W. Gao, 2018: Adaptive bias correction of advanced infrared sounding radiance assimilation in a regional model and its impact on typhoon forecast. Journal of Applied Remote Sensing 12:doi: 10.1117/1.JRS.12.026012.

Liu, Y., R. Dworak, and J. Key, 2018: Ice surface temperature retrieval from a single satellite imager band. Remote Sensing 10:1909, doi: 10.3390/rs10121909.

Liu, Y., J. R. Key, S. Vavrus, and C. Woods, 2018: Time evolution of the cloud response to moisture intrusions into the Arctic during winter. Journal of Climate 31:9389-9405, doi: 10.1175/JCLI-D-17-0896.1.

Lorenz, D. J., J. A. Otkin, M. Svoboda, C. R. Hain, and Y. Zhong, 2018: Forecasting rapid drought intensification using the climate forecasting system (CFS). Journal of Geophysical Research-Atmospheres 123:8365-8373.

Manninen, T., A. Riihela, A. Heidinger, C. Schaaf, A. Lattanzio, and J. Key, 2018: Intercalibration of polar-orbiting spectral radiometers without simultaneous observations. IEEE Transactions on Geoscience and remote sensing 56:1507-1519.

Mapes, B. E., E. S. Chung, W. M. Hannah, H. Masunaga, A. J. Wimmers, and C. S. Velden, 2018: The meandering margin of the meteorological moist tropics. Geophysical Research Letters 45:1177-1184.

Menzel, W. P., T. J. Schmit, P. Zhang, and J. Li, 2018: Satellite-based atmospheric infrared sounder development and applications. Bulletin of the American Meteorological Society 99:583-603.

Milani, L., M. S. Kulie, D. Casella, S. Dietrich, T. S. L'Ecuyer, G. Panegrossi, F. Porcu, P. Sano, and N. B. Wood, 2018: CloudSat snowfall estimates over Antarctica and the Southern Ocean: an assessment of independent retrieval methodologies and multi-year snowfall analysis. Atmospheric Research 213:121-135, doi: 10.1016/j.atmosres.2018.05.015.

Miller, N. B., M. E. Shupe, J. T. M. Lenaerts, J. E. Kay, G. de Boer, and R. Bennartz, 2018: Process-based model evaluation using surface energy budget observations in central Greenland. Journal of Geophysical Research-Atmospheres 123:4777-4796.

Miller, S. D., M. A. Rogers, J. M. Haynes, M. Sengupta, and A. K. Heidinger, 2018: Short-term irradiance forecasting via satellite/model coupling. Solar Energy 168:102-117.

Miller, S. D., W. C. I. Straka, J. Yue, C. J. Seaman, S. Xu, C. D. Elvidge, L. Hoffmann, and I. Azeem, 2018: The dark side of Hurricane Matthew: unique perspectives from the VIIRS Day/Night Band. Bulletin of the American Meteorological Soceity 99:2561-2574.

Min, M., C. Bai, J. Guo, F. Sun, C. Liu, F. Wang, H. Xu, S. Tang, B. Li, D. Di, L. Dong, and J. Li, 2018: Estimating summertime precipitation from Himawari-8 and global forecast system based on machine learning. IEEE Transactions on Geoscience and Remote Sensing .

Oreskovic, C., L. G. Orf, and Savory Eric, 2018: A parametric study of downbursts using a full-scale cooling source model. Journal of Wind Engineering and Industrial Aerodynamics 180:168-181.

Oreskovic, C., E. Savory, J. Porto, and L. G. Orf, 2018: Evolution and scaling of a simulated downbust-producing thunderstorm outflow. Wind and Structures 26:147-161.

Otkin, J. A., T. Haigh, A. Mucia, M. C. Anderson, and C. Hain, 2018: Comparison of agricultural stakeholder survey results and drought monitoring datasets during the 2016 U.S. Northern Plains flash drought. Weather Climate and Society 10:867-883, doi: 10.1175/WCAS-D-18-0051.1.

Otkin, J. A., R. Potthast, and A. S. Lawless, 2018: Nonlinear bias correction for satellite data assimilation using Taylor series polynomials. Monthly Weather Review 146:263-285.

Otkin, J. A., M. Svoboda, E. D. Hunt, T. W. Ford, M. C. Anderson, C. Hain, and J. B. Basara, 2018: Flash droughts: A review and assessment of the challenges imposed by rapid-onset droughts in the United States. Bulletin of the American Meteorological Society 99:911-919.

Otkin, J. A., Y. Zhong, D. Lorenz, M. C. Anderson, and C. Hain, 2018: Exploring seasonal and regional relationships between the Evaporative Stress Index and surface weather and soil moisture anomalies across the United States. Hydrology and Earth System Sciences 22:5373-5386.

Pavolonis, M. J., J. Sieglaff, and J. Cintineo, 2018: Automated detection explosive volcanic eruptions using satellite-derived cloud vertical growth rates. Earth and Space Science 5:903-928.

Pettersen, C., R. Bennartz, A. J. Merrelli, M. D. Shupe, D. D. Turner, and V. P. Walden, 2018: Precipitation regimes over central Greenland inferred from 5 years of ICECAPS observations. Atmospheric Chemistry and Physics 18:4715-4735.

Riihela, A., T. Manninen, J. Key, Q. Sun, M. Sutterlin, A. Lattanzio, and C. Schaaf, 2018: A multisensor approach to global retrievals of land surface albedo. Remote Sensing 10.

Ross, A. D., R. E. Holz, G. Quinn, J. S. Reid, P. Xian, F. J. Turk, and D. J. Posselt, 2018: Exploring the first aerosol indirect effect over Southeast Asia using a 10-year collocated MODIS, CALIOP, and model dataset. Atmospheric Chemistry and Physics 18:12747-12764.

Schmit, T. J., S. S. Lindstrom, J. J. Gerth, and M. M. Gunshor, 2018: Applications of the 16 spectral bands on the Advanced Baseline Imager (ABI). Journal of Operational Meteorology 6:33-46.

Schroder, M., M. Lockhoff, F. Fell, J. Forsythe, T. Trent, R. Bennartz, E. Borbas, M. G. Bosilovich, E. Castelli, H. Hersbach, M. Kachi, S. Kobayashi, E. R. Kursinski, D. Loyola, c. Mears, R. Preusker, W. B. Rossow, and S. Saha, 2018: The GEWEX Water Vapor Assessment archive of water vapour products from satellite observations and reanalyses. Earth System Science Data 10:1093-1117.

Serio, C., G. Masiello, C. Camy-Peyret, E. Jacquette, O. Vandermarcq, F. Bermudo, D. Coppens, and D. Tobin, 2018: PCA determination of the radiometric noise of high spectral resolution infrared observations from spectral residuals: Application to IASI. Journal of Quantitative Spectroscopy and Radiative Transfer 206:8-21.

Shultz, J. M., J. P. Kossin, C. Ettman, P. L. Kinney, and S. Galea, 2018: The 2017 perfect storm season, climate change, and environmental injustice. The Lancet Planetary Health 2.

Shultz, J. M., J. P. Kossin, and S. Galea, 2018: The need to integrate climate science into public health preparedness for hurricanes and tropical cyclones. JAMA-Journal of the American Medical Association 320:1637-1638.

Stott, P. A., N. Christidis, S. C. Herring, A. Hoell, J. P. Kossin, and C. J. I. Schreck, 2018: Explaining extreme events of 2016 from a climate perspective: Future challenges in event attribution methodologies. Bulletin of the American Meteorological Society S155-S157.

Su, Y., J. Yue, X. Liu, S. D. Miller, W. C. Straka, S. M. Smith, D. Guo, and S. Guo, 2018: Mesospheric bore observations using Suomi-NPP VIIRS DNB during 2013-2017 . Remote Sensing 10:DOI: 10.3390/rs10121935.

Wang, P., J. Li, B. Lu, T. J. Schmit, J. Lu, Y.-K. Lee, J. Li, and Z. Liu, 2018: Impact of moisture information from Advanced Himawari Imager measurements on heavy precipitation forecasts in a regional NWP model. Journal of Geophysical Research-Atmospheres 123:6022-6038, DOI: 10.1029/2017JD028012.

White, C. H., A. K. Heidinger, S. A. Ackerman, and P. B. McIntyre, 2018: A long-term fine-resolution record of AVHRR surface temperatures for the Laurentian Great Lakes. Remote Sensing 10.

Wimmers, A., S. Griffin, J. Gerth, S. Bachmeier, and S. Lindstrom, 2018: Observations of gravity waves with high-pass filtering in the new generation of geostationary imagers and their relation to aircraft turbulence. Weather and Forecasting 139-144.

Yang, Y., M. C. Anderson, F. Gao, B. Wardlow, C. R. Hain, J. A. Otkin, J. Alfieri, Y. Yang, L. Sun, and W. Dulaney, 2018: Field-scale mapping of evaporative stress indicators of crop yield: an application over Mead, NE, USA. Remote Sensing of Environment 210:387-402.

Zhang, S., Z. Pu, and C. Velden, 2018: Impact of enhanced Atmospheric Motion Vectors in HWRF hurricane analyses and forecasts with different data assimilation configurations. Monthly Weather Review 146:1549-1569.

Zhao, X., Y. Liu, F. Yu, and A. K. Heidinger, 2018: Using long-term satellite observations to identify sensitive regimes and active regions of aerosol indirect effects for liquid clouds over global oceans. Journal of Geophysical Research-Atmospheres 123:457-472.

2017

Books and Book Chapters

Knutson, T., J.P. Kossin, C. Mears, J. Perlwitz, and M.F. Wehner, 2017: Detection and attribution of climate change. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program, Washington, DC, 114-132, doi: 10.7930/J01834ND.

Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program, Washington, DC, 257-276, doi: 10.7930/J0S7KXX.

Perlwitz, J., T. Knutson, J.P. Kossin, and A.N. LeGrande, 2017: Large-scale circulation and climate variability. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program, Washington, DC, 161-184, doi: 10.7930/J0RV0KVQ.

Wardlow, B.D., M.C. Anderson, C. Hain, W. Crow, J.A. Otkin, T. Tadesse, and A. Aghakouchak, 2017: Advancements in Satellite Remote Sensing for Drought Monitoring. In: Drought and Water Crises: Integrating Science, Management, and Policy. CRC Press, 542p.

Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waptle, and C.P. Weaver, 2017: Executive summary. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program, Washington, DC, 12-34, doi: 10.7930/J0DJ5CTG.

Wuebbles, D.J., D.R. Easterlin, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, A.N. LeGrande, C. Mears, W.V. Sweet, P.C. Taylor, R.S. Vose, and M.F. Wehner, 2017: Our globally changing climate. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program, Washington, DC, 35-72, doi: 10.7930/J08S4N35.

Peer-Reviewed Journal Articles

Ai, Y., Li, J., Shi, W., Schmit, T.J., Cao, C., and Li, W., 2017: Deep convective cloud characterizations from both broadband imager and hyperspectral infrared sounder measurements. Journal of Geophysical Research-Atmospheres, 122(3): 1700-1712.

Anderson, M.C., Hain, C.R., Jurecka, F., Trnka, M., Hlavinka, P., Dulaney, W., Otkin, J.A., Johnson, D., and Gao, F., 2017: Relationships between the evaporative stress index and winter wheat and spring barley yield anomalies in the Czech Republic. Climate Research, 70(2-3): 215-230.

Bennartz, R., Hoschen, H., Picard, B., Schroder, M., Stengel, M., Sus, O., Bojkov, B., Casadio, S., Diedrich, H., Eliasson, S., Fell, F., Fischer, J., Hollmann, R., Preusker, R., and Willen, U., 2017: An intercalibrated dataset of total column water vapour and wet tropospheric correction based on MWR on board ERS-1, ERS-2, and Envisat. Atmospheric Measurement Techniques, 10(4): 1387-1402.

Chai, T., Crawford, A., Stunder, B., Pavolonis, M.J., Draxler, R., and Stein, A., 2017: Improving volcanic ash predictions with the HYSPLIT dispersion model by assimilating MODIS satellite retrievals. Atmospheric Chemistry and Physics, 17(4): 2865-2879.

Cooper, S.J., Wood, N.B., and L'Ecuyer, T.S., 2017: A variational technique to estimate snowfall rate from coincident radar, snowflake, and fall-speed observations. Atmospheric Measurement Techniques, 10(7): 2571-2571.

Diak, G.R., 2017: Investigations of improvements to an operational GOES-satellite-data-based insolation system using pyranometer data from the US Climate Reference Network (USCRN). Remote Sensing of Environment, 195: 79-95.

Ding, J., Bi, L., Yang, P., Kattawar, G.W., Weng, F., Liu, Q., and Greenwald, T., 2017: Single-scattering properties of ice particles in the microwave regime: Temperature effect on the ice refractive index with implications in remote sensing. Journal of Quantitative Spectroscopy and Radiative Transfer, 190: 26-37.

Doyle, J.D., Moskaitis, J.R., Feldmeier, J.W., Ferek, R.J., Beaubien, M., Bell, M.M., Cecil, D.L., Creasey, R.L., Duran, P., Elsberry, R.L., Komaromi, W.A., Molinari, J., Ryglicki, D.R., Stern, D.P., Velden, C.S., Wang, X., Allen, T., Barrett, B.S., Black, P.G., Dunion, J.P., Emanuel, K.A., Harr, P.A., Harrison, L., Hendricks, E.A., Herndon, D., Jeffries, W.Q., Majumdar, S.J., Morre, J.A., Pu, Z., Rogers, R.F., Sanabia, E.R., Tripoli, G.J., and Zhang, D.-L., 2017: A view of tropical cyclones from above: The Tropical Cyclone Intensity experiment. Bulletin of the American Meteorological Society, 98(10): 2113-2134.

Elsaesser, G.S., O'Dell, C.W., Lebsock, M.D., Bennartz, R., Greenwald, T.J., and Wentz, F.J., 2017: The Multisensor Advanced Climatology of Liquid Water Path (MAC-LWP). Journal of Climate, 30(24): 10193-10210.

Feltz, M.L., Borg, L., Knuteson, R.O., Tobin, D., Revercomb, H., and Gambacorta, A., 2017: Assessment of NOAA NUCAPS upper air temperature profiles using COSMIC GPS radio occultation and ARM radiosondes. Journal of Geophysical Research-Atmospheres, 122(17): 9130-9153.

Feltz, M.L., Knuteson, R.O., and Revercomb, H.E., 2017: Assessment of COSMIC radio occultation and AIRS hyperspectral IR sounder temperature products in the stratosphere using observed radiances. Journal of Geophysical Research-Atmospheres, 122(16): 8593-8616.

Feng, L., Hu, C., Barnes, B.B., Mannino, A., Heidinger, A.K., Strabala, K., and Iraci, L.T., 2017: Cloud and sun-glint statistics derived from GOES and MODIS observations over the Intra-Americas Sea for GEO-CAPE mission planning. Journal of Geophysical Research-Atmospheres, 122(3): 1725-1745.

Foster, M.J., Ackerman, S.A., Bedka, K., Di Girolamo, L., Frey, R.A., Heidinger, A.K., Sun-Mack, S., Philips, C., Menzel, W.P., Minnis, P., and Zhao, G., 2017: State of the Climate in 2016: Cloudiness. Bulletin of the American Meteorological Society, 98(8): S27-S28.

Gartzke, J., Knuteson, R., Przybyl, G., Ackerman, S., and Revercomb, H., 2017: Comparison of satellite-, model-, and radiosonde-derived convective available potential energy in the Southern Great Plains region. Journal of Applied Meteorology and Climatology, 56(5): 1499-1513.

Griffin, S.M., 2017: Climatology of tropical overshooting tops in North Atlantic tropical cyclones. Journal of Applied Meteorology and Climatology, 56(6): 1783-1796.

Griffin, S.M., Otkin, J.A., Rozoff, C.M., Sieglaff, J.M., Cronce, L.M., and Alexander, C.R., 2017. Methods for comparing simulated and observed satellite infrared brightness temperatures and what do they tell us? Weather and Forecasting , 32(1): 5-25.

Griffin, S.M., Otkin, J.A., Rozoff, C.M., Sieglaff, J.M., Cronce, L.M., Alexander, C.R., Jensen, T.L., and Wolff, J.K., 2017: Seasonal analysis of cloud objects in the High-Resolution Rapid Refresh (HRRR) model using object-based verification. Journal of Applied Meteorology and Climatology, 56(8): 2317-2334.

Gumber, A. and Foster, M.J., 2017. A MODIS-derived value-added climatology of maritime cloud liquid water path that conserves solar reflectance. Journal of Applied Meteorology and Climatology, 56(6): 1767-1781.

Heymsfield, A., Kramer, M., Wood, N.B., Gettelman, A., Field, P.R., and Liu, G., 2017: Dependence of the ice water content and snowfall rate on temperature, globally: Comparison of in situ observations, satellite active remote sensing retrievals, and global climate model simulations. Journal of Applied Meteorology and Climatology, 56(1): 189–215.

Hoover, B.T., and R.H. Langland, 2017: NAVGEM forecast and observation impact experiments with assimilation of ECMWF analysis data in the global domain. Journal of the Meteorological Society of Japan, 95, 369-389.

Hoover, B.T., Santek, D.A., Daloz, A.-S., Zhong, Y., Dworak, R., Petersen, R.A., and Collard, A., 2017: Forecast impact of assimilating aircraft WVSS-II water vapor mixing radio observations in the Global Data Assimilation System (GDAS). Weather and Forecasting, 32(4): 1603-1611.

Huang, M., Huang, B., and Huang, H.-L.A., 2017: Acceleration of the WRF Monin-Obukhov-Janjic surface layer parameterization scheme on an MIC-based platform for weather forecast. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(10): 4399-4408.

Huang, M., Huang, B., and Huang, H.-L.A., 2017: Parallel construction of the WRF Pleim-Xiu land surface scheme with Intel Many Integrated Core (MIC) architecture. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(4): 1239-1246.

Huang, M., Carmichael, G.R., Pierce, R.B., Jo, D.S., Park, R.J., Flemming, J., Emmons, L.K., Bowman, K.W., Henze, D.K., Davila, Y., Sudo, K., Jonson, J.E., Lund, M.T., Janssens-Maenhut, G., Dentener, F.J., Keating, T.J., Oetjen, H., and Payne, V.H., 2017: Impact of intercontinental pollution transport on North American ozone air pollution: An HTAP phase 2 multi-model study. Atmospheric Chemistry and Physics, 17(9): 5721-5750.

Jang, H.-S., Sohn, B.-J., Chun, H.-W., Li, J., and Weisz, E., 2017: Improved AIRS temperature and moisture soundings with local a priori information for the 1DVAR method. Journal of Atmospheric and Oceanic Technology, 34(5): 1083-1095.

Jones, T.A., Koch, S., and Li, Z., 2017: Assimilating synthetic hyperspectral sounder temperature and humidity retrievals to improve severe weather forecasts. Atmospheric Research, 186(1): 9-25.

Kaldunski, B., Pierce, B., and Holloway, T., 2017: When stratospheric ozone hits ground-level regulation: Exceptional events in Wyoming. Bulletin of the American Meteorological Society, 98(5): 889-892.

Kim, M., Kim, H.M., Kim, J.W., Ki, S.-M., Velden, C., and Hoover, B., 2017: Effect of enhanced satellite-derived Atmospheric Motion Vectors on numerical weather prediction in East Asia using an adjoint-based observation impact method. Weather and Forecasting, 32(2): 579–594.

Kossin, J.P., 2017: Hurricane intensification along United States coast suppressed during active hurricane periods. Nature , 541(7637): 390-393.

Kuang, S., Newchurch, M.J., Johnson, M.S., Wang, L., Burris, J., Pierce, R.B., Eloranta, E.W., Pollack, I.B., Graus, M., de Gouw, J., Warneke, C., Ryerson, T.B., Markovic, M.Z., Holloway, J.S., Pour-Blazar, A., Huang, G., Liu, X., and Feng, N., 2017: Summertime tropospheric ozone enhancement associated with a cold front passage due to stratosphere-to-troposphere transport and biomass burning: Simultaneous ground-based lidar and airborne measurements. Journal of Geophysical Research-Atmospheres , 122(2): 1293-1311.

Lai, C., Yue, J., Xu, J., Straka, W.C.I., Miller, S.D., and Liu, X., 2017: Suomi NPP VIIRS/DNB imagery of nightglow gravity waves from various sources over China. Advances in Space Research, 59(8): 1951-1961.

Langford, A.O., Alvarex, R.J.I., Brioude, J., Fine, R., Gustin, M.S., Lin, M.Y. , Marchbanks, R.D., Pierce, R.B., Sandberg, S.P., Senff, C.J., Weickmann, A.M., and Williams, E.J., 2017: Entrainment of stratospheric air and Asian pollution by the convective boundary layer in the southwestern US. Journal of Geophysical Research-Atmospheres, 122(2): 1312-1337.

Le Marshall, J., Howard, D., Xiao, Y., Daniels, J., Wanzong, S., Jung, J., Bresky, W., Bailey, A., Tingwell, C., Le, T., and Margetic, D., 2017: Himawari-8 Atmospheric Motion Vectors - Operational generation and assimilation. Journal of Southern Hemisphere Earth Systems Science, 67(1): 12-24.

Lee, Y.-K., Li, J., Li, Z., and Schmit, T., 2017: Atmospheric temporal variations in the pre-landfall environment of Typoon Nangka (2015) observed by the Himawari-8 AHI. Asia-Pacific Journal of Atmospheric Sciences, 53(4): 431-443.

Li, J. and Han, W., 2017: A step forward toward effectively using hyperspectral IR sounding information in NWP. Advances in Atmospheric Sciences, 34: 1263-1264.

Li, J., Li, Z., Wang, P., Schmit, T.J., Bai, W., and Atlas, R., 2017: An efficient radiative transfer model for hyperspectral IR radiance simulation and applications under cloudy-sky conditions. Journal of Geophysical Research-Atmospheres, 122(14): 7600-7613.

Lin, H., Weygandt, S.S., Lim, A.H.N., Hu, M., Brown, J.M., and Benjamin, S.G., 2017: Radiance preprocessing for assimilation in the hourly updating rapid refresh mesoscale model: A study using AIRS data. Weather and Forecasting, 32(5): 1781–1800.

Lorenz, D.J., Otkin, J.A., Svoboda, M., Hain, C.R., Anderson, M.C., and Zhong, Y., 2017: Predicting US drought monitor states using precipitation, soil moisture, and evapotranspiration anomalies. Part I: Development of a nondiscrete USDM index. Journal of Hydrometeorology, 18(7): 1943–1962.

Lorenz, D.J., Otkin, J.A., Svoboda, M., Hain, C.R., Anderson, M.C., and Zhong, Y., 2017: Predicting US drought monitor states using precipitation, soil moisture, and evapotranspiration anomalies. Part II: Intraseasonal drought intensification forecasts. Journal of Hydrometeorology, 18(7): 1963-1982.

Meier, W.N., Stewart, J.S., Liu, Y., Key, J., and Miller, J.A., 2017: Operational implementation of sea ice concentration estimates from the AMSR2 sensor. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(9): 3904-3911.

Mueller, K.J., Wu, D.L., Lorvath, A., Jovanovic, V.M., Muller, J.-P., De Girolamo, L., Garay, M.J., Diner, D.J., Moroney, C.M., and Wanzong, S., 2017: Assessment of MISR Cloud Motion Vectors (CMVs) relative to GOES and MODIS Atmospheric Motion Vectors (AMVs). Journal of Applied Meteorology and Climatology, 56(3): 555-572.

Noh, Y.-J., Forsythe, J.M., Miller, S.D., Seaman, C.J., Li, Y., Heidinger, A.W., Lindsey, D.T., Rogers, M.A., and Partain, P.T., 2017: Cloud-base height estimation from VIIRS. Part I I: A statistical algorithm based on A-train satellite data. Journal of Atmospheric and Oceanic Technology, 34(3): 585-598.

Otkin, J.A., Lewis, W.E., Lenzen, A.J., McNoldy, B.D., and Majumdar, S.J., 2017: Assessing the accuracy of the cloud and water vapor fields in the hurricane WRF (HWRD) model using satellite infrared brightness temperatures. Monthly Weather Review, 145(5): 2027-2046.

Palerme, C., Claud, C., Dufour, A., Genthon, C., Wood, N.B., and L'Ecuyer, T., 2017: Evaluation of Antarctic snowfall in global meteorological reanalyses. Atmospheric Research, 190: 104-112.

Palerme, C., Genthon, C., Claud, C., Kay, J.E., Wood, N.B., and L'Ecuyer, T., 2017: Evaluation of current and projected Antarctic precipitation in CMIP5 models. Climate Dynamics, 48(1): 225-239.

Pan, L.L., Atlas, E.L., Salawitch, R.J., Honomichl, S.B., Bresch, J.F., Randel, W.J., Apel, E.C., Hornbrook, R.S., Weinheimer, A.J., Anderson, C.D., Andrews, S.J., Baidar, S., Beaton, S.P., Campos, T.L., Carpenter, L.J., Chen, D., Dix, B., Donets, V., Hall, S.R., Hanisco, T.F., Homeyer, C.R., Huey, L.G., Jensen, J.B., Kaser, L., Kinnison, D.E., Koenig, T.K., Lamarque, J.-F., Liu, C., Luo, J., Luo, Z.J., Montzka, D.D., Nicely, J.M., Pierce, R.B., Riemer, D.D., Robinson, T., Romashkin, P., Saiz-Lopez, A., Schauffler, S., Shieh, O., Stell, M.H., Ullmann, K., Vaughan, G., Volkamer, R., and Wolfe, G., 2017: The Convective Transport of Active Species in the Tropics (CONTRAST) experiment. Bulletin of the American Meteorological Society, 90(1): 106–128.

Platnick, S., Meyer, K.G., King, M.D., Wind, G., Amarasinghe, Marchant, B., Arnold, G.T., Zhang, Z., Hubanks, P.A., Holz, R.E., Yang, P., Ridgway, W.L., and Riedi, J., 2017: The MODIS cloud optical and microphysical products: Collection 6 updates and examples from Terra and Aqua. IEEE Transactions on Geoscience and Remote Sensing, 55(1): 502-525.

Plokhenko, Y., Menzel, W.P., Knuteson, R., and Revercomb, H.E., 2017: Mathematical aspects in the meteorological interpretation of satellite hyperspectral infrared measurements part II: Estimates of the cloud absorption vertical profile of Hurricane Ioke on 28 August 2006. International Journal of Remote Sensing, 38(51): 57-79.

Poli, P., Dee, D.P., Saunders, R., John, V.O., Rayer, P., Schulz, J., Holmlund, K., Coppens, D., Klaes, D., Johnson, J.E., Esfandiari, A.E., Gerasimov, I.V. , Zamkoff, E.B., Al-Jazrawi, A.F., Santek, D., Albani, M., Brunel, P., Fennig, K., Schroder, M., Kobayashi, S., Oertel, D., Dohler, W., Spankuch, D., and Bojinski, S., 2017: Recent advances in satellite data rescue. Bulletin of the American Meteorological Society, 98(7): 1471-1484.

Rausch, J., Meyer, K., Bennartz, R., and Platnick, S., 2017. Differences in liquid cloud droplet effective radius and number concentration estimates between MODIS collections 5.1 and 6 over global oceans. Atmospheric Measurement Techniques, 10(6): 2105-2116.

Reid, J.S., Kuehn, R., Holz, R.E., Eloranta, E.W., Kaku, K.C., Kuang, S., Newchurch, M.J., Thompson, A.M., Trepte, C.R., Zhang, J., Atwood, S.A., Hand, J.L., Holben, B.N., Minnis, P., and Posselt, D.J., 2017: Ground-based high spectral resolution lidar observation of aerosol vertical distribution in the summertime Southeast United States. Journal of Geophysical Research-Atmospheres, 122(5): 2970-3004.

Riihela, A., Key, J.R., Meirink, J.F., Munneke, P.K., Palo, T., and Karisson, K.-G., 2017: An intercomparison and validation of satellite-based surface radiative energy flux estimates over the Arctic. Journal of Geophysical Research-Atmospheres, 122(9): 4829-4848.

Rogers, R.F., Aberson, S., Bell, M.M., Cecil, D.J., Doyle, J.D., Kimerlain, T.B., Morgerman, J., Shay, L.K., and Velden, C., 2017: Rewriting the tropical record books: The extraordinary intensification of Hurricane Patricia (2015). Bulletin of the American Meteorological Society, 98(10): 2091-2112.

Ross, A., Holz, R.E., and Ackerman, S.A., 2017: Correlations of oriented ice and precipitation in marine midlatitude low clouds using collocated CloudSat, CALIOP, and MODIS observations. Journal of Geophysical Research-Atmospheres, 122(18): 8056-8070.

Schmit, T.J., Griffith, P., Gunshor, M.M., Daniels, J.M., Goodman, S.J., and Lebair, W.J., 2017: A closer look at the ABI on the GOES-R series: Supplement. Bulletin of the American Meteorological Society, 98(4).

Schmit, T.J., Griffith, P., Gunshor, M.M., Daniels, J.M., Goodman, S.J., and Lebair, W.J., 2017: A closer look at the ABI on the GOES-R series. Bulletin of the American Meteorological Society, 98(4): 681-698.

Seaman, C.J., Noh, Y.-J., Miller, S.D., Heidinger, A.K., and Lindsey, D.T., 2017: Cloud-base height estimation from VIIRS. Part I: Operational algorithm validation against CloudSat. Journal of Atmospheric and Oceanic Technology, 34(3): 567-583.

Sieron, S.B., Clothiaux, E.E., Zhang, F., Lu, Y., and Otkin, J.A., 2017: Comparison of using distribution-specific versus effective radius methods for hydrometeor single-scattering properties for all-sky microwave satellite radiance simulations with different microphysics parameterization schemes. Journal of Geophysical Research-Atmospheres, 122(13): 7027-7046.

Taghavi, F., Owlad, E., and Ackerman, S.A., 2017: Enhancement and identification of dust events in the south-west region of Iran using satellite observations. Journal of Earth System Science, 126(2):

doi:10.1007/s12040-017-0808-0.

Velden, C., Lewis, W.E., Bresky, W., Stettner, D., Daniels, J., and Wanzong, S., 2017: Assimilation of high-resolution satellite-derived Atmospheric Motion Vectors: Impact on HWRF forecasts of tropical cyclone track and intensity. Monthly Weather Review, 145(3): 1107-1125.

Velden, C., Olander, T., Herndon, D., and Kossin, J.P., 2017: Reprocessing the most intense historical tropical cyclones in the satellite era using the Advanced Dvorak Technique. Monthly Weather Review, 145(3): 971-983.

Wang, P., Li, J., Li, Z., Lim, A.H.N., Li, J., Schmit, T.J., and Goldberg, M.D., 2017: The impact of Cross-track Infrared Sounder (CrIS) cloud-cleared radiances on Hurricane Joaquin (2015) and Matthew (2016) forecasts. Journal of Geophysical Research-Atmospheres, 122(24): 13201-13218.

Weisz, E., Baum, B.A., and Menzel, W.P., 2017: Fusion of satellite-based imager and sounder data to construct supplementary high spatial resolution narrowband IR radiances. Journal of Applied Remote Sensing, 11(3): doi:10.1117/1.JRS.11.036022.

Wu, D.L., Baum, B.A., Choi, Y.-S., Foster, M.J.K.K.-G., Heidinger, A., Poulsen, C., Pavolonis, M., Riedi, J., Roebeling, R., Sherwood, S., Thoss, A., and Watts, P., 2017: Toward global harmonization of derived cloud products. Bulletin of the American Meteorological Society, 98(2): ES49-ES52.

Yang, Y., Anderson, M., Gao, F., Hain, C., Kustas, W., Meyers, T., Crow, W., Finocchiaro, R., Otkin, J., Sun, L., and Yang, Y., 2017: Impact of tile drainage on evapotranspiration in South Dakota, USA, based on high spatiotemporal resolution evapotranspiration time series from a multisatellite data fusion system. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(6): 2550-2564.

Yates, E.L., Johnson, M.S., Iraci, L.T., Ryoo, J.-M., Pierce, R.B., Cullis, P.D., Gore, W., Ives, M.A., Johnson, B.J., Leblanc, T., Marreo, J.E., Sterling, C.W., and Tanaka, T., 2017: An assessment of ground level and free tropospheric ozone over California and Nevada. Journal of Geophysical Research-Atmospheres, 122(8): 10,089-10,102.

Yue, Q., Kahn, B.H., Fetzer, E.J., Wong, S., Frey, R., and Meyer, K.G., 2017: On the response of MODIS cloud coverage to global mean surface air temperature. Journal of Geophysical Research-Atmospheres, 122(2): 966-979.

Zhang, L., Rechtman, T., Karnauskas, K.B., Li, L., Donnelly, J.P., and Kossin, J.P., 2017: Longwave emission trends over Africa and implications for Atlantic hurricanes. Geophysical Research Letters, 44(17): 9075-9083.

Zhou, Y., Xiao, X., Zhang, G., Wangle, P., Bajgain, R., Dong, J., Jin, C., Basara, J.B., Anderson, M.C., Hain, C., and Otkin, J.A., 2017: Quantifying agricultural drought in tallgrass prairie region in the US Southern Great Plains through analysis of a water-related vegetation index from MODIS images. Agricultural and Forest Meteorology, 246: 111-112.

Zhu, L., Li, J., Zhao, Y., Gong, H., and Li, W., 2017: Retrieval of volcanic ash height from satellite-based infrared measurements. Journal of Geophysical Research-Atmospheres, 122(10): 5384-5379.

Zoogman, P., Liu, X., Suleiman, R.M., Pennington, W.F., Flittner, D.E., Al-Saadi, J.A., Hilton, B.B., Nicks, D.K., Newchurch, M.J., Carr, J.L., Janz, S.J., Andraschko, M.R., Arola, A., Baker, B.D., Canova, B.P., Chan Miller, C., Cohen, R.C., Davis, J.E., Dussault, M.E., Edwards, D.P., Fishman, J., Ghulam, A., Gonzalez Abad, G., Grutter, M., Herman, J.R., Houck, J., Jacob, D.J., Joiner, J., Kerridge, B.J., Kim, J., Krotkov, N.A., Lamsal, L., Li, C., Lindfors, A., Martin, R.V., McElroy, C.T., McLinden, C., Nattaj, V., Neil, D.O., Nowlan, C.R., O'Sullivan, E.J., Palmer, P.I., Pierce, R.B., Pippin, M.R., Saiz-Lopez, A.S.R.J.D., Szykman, J.J., Torres, O., Veefkind, J.P., Veihelmann, B., Wang, H., Wang, J., and Chance, K., 2017: Tropospheric emissions: Monitoring of pollution (TEMPO). Journal of Quantitative Spectroscopy and Radiative Transfer, 186: 17-39.

Wilson, T., Wu, A., Shrestha, A., Geng, X., Wang, Z., Moeller, C., Frey, R., and Xiong, X., 2017: Development and implementation of an electronic crosstalk correction for bands 27-30 in Terra MODIS collection 6. Remote Sensing, 9(6), article 569.

2016

Peer-Reviewed Journal Articles

Anderson, D.C., Nicely, J.M., Salawitch, R.J., Canty, T.P., Dickerson, R.R., Hanisco, T.F., Wolfe, G.M., Apel, E.C., Atlas, E., Bannan, T., Bauguitte, S., Blake, N.J., Bresch, J.F., Campos, T.L., Carpenter, L.J., Cohen, M.D., Evans, M., Fernandex, R.P., Kahn, B.H., Kinnison, D.E., Hall, S.R., Harris, N.R.P., Hornbrook, R.S., Lamarque, J.-F., Le Breton, M., Lee, J.D., Percival, C., Pfister, L., Pierce, R.B., Piemer, D.D., Saiz-Lopez, A., Stunder, B.J.B., Thompson, A.M., Ullmann, K., Vaughan, A., and Weinheimer, A.J., 2016: A pervasive role for biomass burning in tropical high ozone/low water structures. Nature Communications, doi:10.1038/ncomms10267.

Anderson, M.C., Hain, C.R., Jurecka, F., Trnka, M., Hlavinka, P., Dulaney, W., Otkin, J.A., Johnson, D., and Gao, F., 2016: An energy balance approach for mapping crop water stress and yield impacts over the Czech Republic. Climate Research, 70, 215-230.

Anderson, M.C., Zolin, C.A., Sentelhas, P.C., Hain, C.R., Semmens, K., Yilmaz, M.T., Gao, F., Otkin, J.A., and Tetrault, R., 2016: The Evaporative Stress Index as an indicator of agricultural drought in Brazil: An assessment based on crop yield impacts. Remote Sensing of Environment, 174(1): 82-99.

Arvani, B., Pierce, R.B., Lyapustin, A.I., Wang, Y., Ghermandi, G., and Teggi, S., 2016: Seasonal monitoring and estimation of regional aerosol distribution over Po valley, northern Italy, using a high-resolution MAIAC product. Atmospheric Environment, 141: 106-121.

Baukabara, S.A., Zhu, T., Tolman, H.L., Lord, S., Goodman, S., Atlas, R., Goldberg, M., Auligne, T., Pierce, B., Cucurull, L., Zupanski, M., Zhang, M., Moradi, I., Otkin, J., Santek, D., Hoover, B., Pu, Z., Zhan, X., Hain, C., Kalnay, E., Hotta, D., Nolin, S., Bayler, E., Mehra, A., Casey, S.P.F., Lindsey, D., Grasso, L., Kumar, V.K., Powell, A., Xu, J., Greenwald, T., Zajic, J., Li, J., Li, J., Li, B., Liu, H., Fang, L., Wang, P., and Chen, T.-C., 2016: S4: An O2R/R2O infrastructure for optimizing satellite data utilzation in NOAA numerical modeling systems. A step toward bridging the gap between research and operations. Bulletin of the American Meteorological Society, 97(12): 2359–2378.

Baylon, P.M., Jeffe, D.A., Pierce, R.B., and Gustin, M.S., 2016: Interannual variability in baseline ozone and its relationship to surface ozone in the western US. Environmental Science and Technology, 50(6): 2994-3001.

Boukabara, S.-A., Moradi, I., Atlas, R., Casey, S.P.F., Cucurull, L., Hoffman, R.N., Ide, K., Kumar, V.K., Li, R., Li, Z., Masutani, M., Shahroudi, N., Woollen, J., and Zhou, Y., 2016: Community Global Observing System Simulation Experiment (OSSE) Package (CGOP): Description and usage. Journal of Atmospheric and Oceanic Technology, 33(8): 1759–1777.

Brunner, J., Pierce, R.B., and Lenzen, A., 2016: Development and validation of satellite-based estimates of surface visibility. Atmospheric Measurement Techniques, 9(2): 409-422.

Cassano, J.J., Nigro, M.A., and Lazzara, M.A., 2016: Characteristics of the near-surface atmosphere over the Ross Ice Shelf, Antarctica. Journal of Geophysical Research-Atmospheres, 121(7): 3339-3362.

Christensen, M.W., Behrangi, A., L'Ecuyer, T.S., Wood, N.B., Lebsock, M.D., and Stephens, G.L., 2016: Arctic observation and reanalysis integrated system: A new data product for validation and climate study. Bulletin of the American Meteorological Society, 97(6): 907-915.

Cintineo, R.M., Otkin, J.A., Jones, T.A., Koch, S., and Stensrud, D.J., 2016: Assimilation of synthetic GOES-R ABI infrared brightness temperatures and WSR-88D radar observations in a high-resolution OSSE. Monthly Weather Review, 144(9): 3159-3180.

Crawford, A.M., Stunder, B.J.B., Ngan, F., and Pavolonis, M.J., 2016: Initializing HYSPLIT with satellite observations of volcanic ash: A case study of the 2008 Kasatochi eruption. Journal of Geophysical Research-Atmospheres, 121(18): 10786-10803.

Di, D., Ai, Y., Li, J., Shi, W., and Lu, N., 2016: Geostationary satellite-based 6.7 micron band best water vapor information layer analysis over the Tibetan Plateau. Journal of Geophysical Research-Atmospheres, 121(9): 4600–4613.

Ding, J., Yang, P., Holz, R.E., Platnick, S., Meyer, K.G., Vaughan, M.A., Hu, Y., and King, M.D., 2016: Ice cloud backscatter study and comparison with CALIPSO and MODIS satellite data. Optics Express, 24(1): 620-636.

Foster, M.H., Ackerman, S.A., Bedka, K., Frey, R.A., Di Girolamo, L., Heidinger, A.K., Sun-Mack, S., Maddux, B.C., Menzel, W.P., Minnis, P., Stegel, M., and Zhao, G., 2016: State of the climate in 2015: Cloudiness. Bulletin of the American Meteorological Society, 97(8, supplement): S28-S29.

Foster, M.J., Heidinger, A., Hiley, M., Wanzong, S., Walther, A., and Botambekov, D., 2016: PATMOS-x cloud climate record trend sensitivity to reanalysis products. Remote Sensing, 8(5): doi:10.3390/rs8050424.

Gao, L., Li, J., Chen, L., Zhang, L., and Heidinger, A.K., 2016: Retrieval and validation of atmospheric aerosol optical depth from AVHRR over China. IEEE Transactions on Geoscience and Remote Sensing, 54(11): 6280-6291.

Grasso, L., Lindsey, D.T., Seaman, C.J., Stocks, B., and Rabin, R.M., 2016: Satellite observations of plume-like streaks in a cloud field in Canada. Pure and Applied Geophysics, 173(9): 3103-3110.

Gravelle, C.M., Mecikalski, J.R., Line, W.E., Bedka, K.M., Petersen, R.A., Sieglaff, J.M., Stano, G.T., and Goodman, S.J., 2016: Demonstration of a GOES-R satellite convective toolkit to "bridge the gap" between severe weather watches and warnings: An example from the 20 May 2013 Moore, Oklahoma, tornado outbreak. Bulletin of the American Meteorological Society, 97(1): 69-84.

Greenwald, T.J., Pierce, R.B., Schaack, T. , Otkin, J., Rogal, M., Bah, K., Lenzen, A., Nelson, J., Li, J., and Huang, H.-L., 2016: Real-time simulation of the GOES-R ABI for user readiness and product evaluation. Bulletin of the American Meteorological Society, 97(2): 245-261.

Griffin, S.M., Bedka, K.M., and Velden, C.S., 2016: A method for calculating the height of overshooting convective cloud tops using satellite-based IR imager and CloudSat cloud profiling radar observations. Journal of Applied Meteorology and Climatology, 55(2): 479-491.

Gultepe, I., Rabin, R., Ware, R., and Pavolonis, M., 2016: Chapter Three: Light snow precipitation and effects on weather and climate. Advances in Geophysics, 57: 147-210.

Han, H., Li, J., Goldberg, M., Wang, P., Li, J., Li, Z., Sohn, B.-J., and Li, J., 2016: Microwave sounder cloud detection using a collocated high-resolution imager and its impact on radiance assimilation in tropical cyclone forecasts. Monthly Weather Review, 144(10): 3937-3959.

Heidinger, A., Foster, M., Botambekov, D., Hiley, M., Walther, A., and Li, Y., 2016: Using the NASA EOS A-train to probe the performance of the NOAA PATMOS-x cloud fraction CDR. Remote Sensing, 8(6): doi:10.3390/rs8060511.

Herring, S.C., Hoell, A., Hoerling, M.P., Kossin, J.P., Schreck, C.J.I., and Stott, P.A., 2016: Explaining extreme events of 2015 from a climate perspective: Introduction to explaining extreme events of 2015 from a climate perspective. Bulletin of the American Meteorological Society, 97(12): S1-S3.

Herring, S.C., Hoell, A., Hoerling, M.P., Kossin, J.P., Schreck, C.J.I., and Stott, P.A., 2016: Explaining extreme events of 2015 from a climate perspective: Summary and broader context. Bulletin of the American Meteorological Society, 97(12): S141-S145.

Heymsfield, A.J., Matrosov, S.Y., and Wood, N.B., 2016: Toward improving ice water content and snow-rate retrievals from radars, part I: X and W bands, emphasizing CloudSat. Journal of Applied Meteorology and Climatology, 55(9): 2063–2090.

Hillger, D., Kopp, T., Seaman, C., Miller, S., Lindsey, D., Stevens, E., Solbrig, J., Straka, W.I., Kreller, M., Kuciauskas, A., and Terborg, A., 2016: User validation of VIIRS satellite imagery. Remote Sensing, 8(1): doi:10.3390/rs8010011.

Hioki, S., Yang, P., Baum, B.A., Platnick, S., Meyer, K.G., King, M.D., and Riedi, J., 2016. Degree of ice particle surface roughness inferred from polarimetric observations. Atmospheric Chemistry and Physics, 16(12): 7545-7558.

Holz, R.E., Platnick, S., Meyer, K., Vaughan, M., Heidinger, A., Yang, P., Wing, G., Dutcher, S., Ackerman, S., Amarasinghe, N., Nagle, F., and Wang, C., 2016: Resolving ice cloud optical thickness biases between CALIOP and MODIS using infrared retrievals. Atmospheric Chemistry and Physics, 16(8): 5075-5090.

Key, J., Wang, X., Liu, Y., Dworak, R., and Letterly, A., 2016: The AVHRR Polar Pathfinder climate data records. Remote Sensing, 8(3): doi:10.3390/rs8030167 .

Knapp, K.R., Matthews, J.L., Kossin, J.P., and Hennon, C.C., 2016: Identification of tropical cyclone storm types using crowdsourcing. Monthly Weather Review, 144(10): 3783-3798.

Kossin, J.P. and DeMaria, M., 2016: Reducing operational hurricane intensity forecast errors during eyewall replacement cycles. Weather and Forecasting, 31(2): 601-608.

Kossin, J.P., Emanuel, K.A., and Camargo, S.J., 2016: Past and projected changes in Western North Pacific tropical cyclone exposure. Journal of Climate, 29(16): 5725–5739.

Kossin, J.P., Emanuel, K.A., and Vecchi, G.A., 2016: Comment on 'Roles of interbasin frequency changes in the poleward shifts of the maximum intensity location of tropical cyclones'. Environmental Research Letters, 11: doi:10.1088/1748-9326/6/068001.

Kulie, M.S., Milani, L., Wood, N.B., Tushaus, S.A., Bennartz, R., and L'Ecuyer, T., 2016: A shallow cumuliform snowfall census using spaceborne radar. Journal of Hydrometeorology, 17(4): 1261-1279.

Le Marshall, J., Xiao, Y., Howard, D., Tingwell, C., Freeman, J., Gregory, P., Le, T., Margetic, D., Morrow, T., Daniels, J., Jung, J., Bresky, W., Bailey, A., and Wanzong, S., 2016: First results from the generation and assimilation of 10-minute atmospheric motion vectors in the Australian region. Journal of

Southern Hemisphere Earth System Science, 66(1): 12-18.

Letterly, A., Key, J., and Liu, Y., 2016: The influence of winter cloud on summer sea ice in the Arctic, 1983-2013. Journal of Geophysical Research-Atmospheres, 121(5): 2178-2187.

Li, J., Li, X., Huang, B., and Zhao, L., 2016: Hopfield neural network approach for supervised nonlinear spectral unmixing. IEEE Geoscience and Remote Sensing Letters, 13(7): 1002-1006.

Li, J., Wang, P., Han, H., Li, K., and Zheng, J., 2016: On the assimilation of satellite sounder data in cloudy skies in numerical weather prediction models. Journal of Meteorological Research, 30(2): 169-182.

Line, W.E., Schmit, T.J., Lindsey, D.T., and Goodman, S.J., 2016: Use of geostationary super rapid scan satellite imagery by the Storm Prediction Center. Weather and Forecasting, 31(4): 483–494.

Liu, C.-Y., Li, J., Ho, S.-P., Liu, G.-R., Lin, T.-H., and Young, C.-C., 2016: Retrieval of atmospheric thermodynamic state from synergistic use of radio occultation and hyperspectral infrared radiances. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(2): 744-756.

Liu, Y., Key, J., and Mahoney, R., 2016: Sea and freshwater ice concentration from VIIRS on Suomi NPP and the future JPSS satellites. Remote Sensing, 8(6): doi:3390/rs8060523.

Liu, Y. and Key, J.R., 2016: Assessment of Arctic cloud cover anomalies in atmospheric reanalysis products using satellite data. Journal of Climate, 29(17): 6065–6083.

Marais, W.J., Holz, R.E., Hu, Y.H., Kuehn, R.E., Eloranta, E.E., and Willett, R.M., 2016: Approach to simultaneously denoise and invert backscatter and extinction from photon-limited atmospheric lidar observations. Applied Optics, 55(29): 8314-8334.

Menzel, W.P., Tobin, D.C., and Revercomb, H.E., 2016: Infrared remote sensing with meteorological satellites. Advances in Atomic, Molecular and Optical Physics, 65: 193-264.

Menzel, W.P., Frey, R.A., Borbas, E.E., Baum, B.A., Cureton, G., and Bearson, N., 2016: Reprocessing of HIRS satellite measurements from 1980 to 2015: Development toward a consistent decadal cloud record. Journal of Applied Meteorology and Climatology, 55(11): 2397-2410.

Meyer, K., Platnick, S., Arnold, G.T., Holz, R.E., Veglio, P., Yorks, J., and Wang, C., 2016: Cirrus cloud optical and microphysical property retrievals from eMAS during SEAC4RS using bi-spectral reflectance measurements within the 1.88 micron water vapor absorption band. Atmospheric Measurement Techniques, 9: 1743-1753.

Mielikainen, J., Huang, B., and Huang, H.-L.A., 2016: Optimizing Purdue-Lin microphysics scheme for Intel Xeon Phi coprocessor. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(1): 425-438.

Mielikainen, J., Price, E., Huang, B., Huang, H.-L.A., and Lee, T., 2016: GPU Compute Unified Device Architecture (CUDA)-based parallelization of the RRTMG shortwave rapid radiative transfer model. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(2): 921-931.

Miller, D.J., Zhang, Z., Ackerman, A.S., Platnick, S., and Baum, B.A., 2016: The impact of cloud vertical profile on liquid water path retrieval based on the bispectral method: A theoretical study based on large-eddy simulations of shallow marine boundary layer clouds. Journal of Geophysical Research-Atmospheres, 121(8): 4122-4141.

Miller, S.D., Schmit, T., Seaman, C.J., Lindsey, D.T., Gunshor, M.M., Kohrs, R.A., Sumida, Y., and

Hillger, D., 2016: A sight for sore eyes: The return of true color to geostationary satellites. Bulletin of the American Meteorological Society, 97(10): 1803-1816.

Miyazaki, Y., Coburn, S., Oho, K., Ho, D.T., Pierce, R.B., Kawamura, K., and Volkamer, R., 2016: Contribution of dissolved organic matter to submicron water-soluble organic aerosols in the marine boundary layer over the eastern equatorial Pacific. Atmospheric Chemistry and Physics, 16(12): 7695-7707.

Nalli, N.R., Smith, W.L., and Liu, Q., 2016: Angular effect of undetected clouds in infrared window radiance observations: Aircraft experimental analyses. Journal of the Atmospheric Sciences, 73(5): 1987-2010.

Neely, H.L., Morgan, C.L.S., Hallmark, C.T., McInnes, K.J., and Molling, C.C., 2016: Apparent electrical conductivity response to spatially variable vertisol properties. Geoderma, 263: 168-175.

Otkin, J.A., Anderson, M.C., Hain, C., Svoboda, M., Johnson, D., Mueller, R., Tadesse, T., Wardlow, B., and Brown, J., 2016: Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought. Agricultural and Forest Meteorology, 218-219: 230-242.

Painemal, D., Greenwald, T., Cadeddu, M., and Minnis, P., 2016: First extended validation of satellite microwave liquid water path with ship-based observations of marine low clouds. Geophysical Research Letters, 43(12): 6563–6570.

Petersen, R.A., 2016: On the impact and benefits of AMDAR observations in operational forecasting, part 1: A review of the impact of automated aircraft wind and temperature reports. Bulletin of the American Meteorological Society, 97(4): 585–602.

Petersen, R.A., Cronce, L., Mamrosh, R., Baker, R., and Pauley, P., 2016: On the impact and future benefits of AMDAR observations in operational forecasting, part II: Water vapor observations. Bulletin of the American Meteorological Society, 97(11): 2117–2133.

Pettersen, C., Bennartz, R., Kulie, M.S., Merrelli, A.J., Shupe, M.D., and Turner, D.D., 2016: Microwave signatures of ice hydrometeors from ground-based observations above Summit, Greenland. Atmospheric Chemistry and Physics, 16(7): 4743-4756.

Plokhenko, Y., Menzel, W.P., Knuteson, R., and Revercomb, H.E., 2016: Mathematical aspects of the meteorological interpretation of satellite hyperspectral infrared measurement part 1: Statement of the inverse problem for estimation of the cloud absorption vertical profile. International Journal of Remote Sensing, 37(7): 1601-1619.

Rabin, R.M., Gultepe, I., Kuligowski, R.J., and Heidinger, A.K., 2016: Monitoring snow using geostationary satellite retrievals during the SAAWSO Project. Pure and Applied Geophysics, 173(9): 3085-3102.

Reid, J.S., Lagrosas, N.D., Jonsson, H.H., Reid, E.A., Atwood, S.A., Boyd, T.J., Ghate, V.P., Xian, P., Posselt, D.J., Simpas, J.B., Uy, S.N., Zaiger, K., Blake, D.R., Bucholtz, A., Campbell, J.R., Chew, B.N., Cliff, S.S., Holben, B.N., Holz, R.E., Hyer, E.J., Kreidenweis, S.M. , Kuciauskas, A.P., Lolli, S., Oo, M., Perry, K.D., Salinas, S.V., Sessions, W.R., Smirnov, A., Walker, A.L., Wang, Q., Yu, L., Zhang, J., and Zhao, Y., 2016: Aerosol meteorology of Maritime Continent for the 2012 7SEAS southwest monsoon intensive study - part 2: Philippine receptor observations of fine-scale aerosol behavior. Atmospheric Chemistry and Physics, 16(22): 14057-14078.

Reid, J.S., Xian, P., Holben, B.N., Hyer, E.J., Reid, E.A., Salinas, S.V., Zhang, J., Campbell, J.R., Chew, B.N., Holz, R.E., Kuciauskas, A.P., Lagrosas, N., Posselt, D.J., Sampson, C.R., Walker, A.L., Welton, E.J., and Zhang, C., 2016: Aerosol meteorology of the Maritime Continent for the 2012 7SEAS southwest monsoon intensive study - part 1: Regional-scale phenomena. Atmospheric Chemistry and Physics, 16(22): 1441-14056.

Rink, T., Menzel, W.P., Gumley, L., and Strabala, K., 2016: HYDRA2: A multispectral data analysis toolkit for sensors on Suomi-NPP and other current satellite platforms. Bulletin of the American Meteorological Society, 97(7): 1283–1294.

Roman, J., Knuteson, R., Ackerman, S., and Revercomb, H., 2016: Estimating minimum detection times for satellite remote sensing of trends in mean and extreme precipitable water vapor. Journal of Climate, 29(22): 8211-8230.

Roman, J., Knuteson, R., August, T., Hultberg, T., Ackerman, S., and Revercomb, H., 2016: A global assessment of NASA AIRS v6 and EUMETSAT IASI v6 precipitable water vapor using ground-based GPS SuomiNet stations. Journal of Geophysical Research-Atmospheres, 121(15): 8925–8948.

Saide, P.E., Thompson, G., Eidhammer, T., da Silva, A.M., Pierce, R.B., and Carmichael, G.R., 2016: Assessment of biomass burning smoke influence on environmental conditions for multiyear tornado outbreaks by combining aerosol-aware microphysics and fire emission constraints. Journal of Geophysical Research-Atmospheres , 121(17): 10294-10311.

Song, S., Schmidt, K.S., Pilewskie, P., King, M.D., Heidinger, A.K., Walther, A., Iwabuchi, H., Wind, G., and Coddington, O.M., 2016: The spectral signature of cloud spatial structure in shortwave irradiance. Atmospheric Chemistry and Physics, 16(21): 13791-13806.

Staten, P.W., Kahn, B.H., Schreier, M.M., and Heidinger, A.K., 2016: Subpixel characterization of HIRS spectral radiances using cloud properties from AVHRR. Journal of Atmospheric and Oceanic Technology, 33(7): 1519-1538.

Thompson, G., Tewari, M., Ikeda, K., Tessendorf, S., Weeks, C., Otkin, J., and Kong, F., 2016: Explicitly-coupled cloud physics and radiation parameterizations and subsequent evaluation in WFR high-resolution convective forecasts. Atmospheric Research, 168(1): 92-104.

Tobin, D., Holz, R., Nagle, F., and Revercomb, H., 2016: Characterization of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) ability to serve as an infrared satellite intercalibration reference. Journal of Geophysical Research-Atmospheres, 121(8): 4258-4271.

Veglio, P., Tobin, D.C., Dutcher, S., Quinn, G., and Moeller, C.C., 2016: Long-term assessment of Aqua MODIS radiance observation using comparisons with AIRS and IASI. Journal of Geophysical Research-Atmospheres, 121(14): 8460–8471.

Wagner, T.J. and Kleiss, J.M., 2016: Error characteristics of ceilometer-based observations of cloud amount. Journal of Atmospheric and Oceanic Technology, 33(7): 1557-1567.

Walsh, K.J.E., McBride, J.L., Klotzbach, P.J., Balachandran, S., Camargo, S.J., Holland, G., Knutson, T.R., Kossin, J.P., Lee, T., Sobel, A., and Sugi, M., 2016: Tropical cyclones and climate change. Wiley Interdisciplinary Reviews-Climate Change, 7(1): 65-89.

Wang, X., Key, J., Kwok, R., and Zhang, J., 2016: Comparison of Arctic sea ice thickness from satellites, aircraft, and PIOMAS data. Remote Sensing, 8(9): doi:10.3390/rs8090713.

Wimmers, A.J. and Velden, C.S., 2016: Advancements in objective multisatellite tropical cyclone center fixing. Journal of Applied Meteorology and Climatology, 55(1): 197–212.

Wu, X., Huang, B., Wang, L., and Zhang, J., 2016: GPU-based parallel design of the hyperspectral signal subspace identification by minimum error (HySime). IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(9): 4400-4406.

Yan, Q., Wei, T., Korty, R.L., Kossin, J.P., Zhang, Z., and Wang, H., 2016: Enhanced intensity of global tropical cyclones during the mid-Pliocene warm period. Proceedings of the National Academy of Sciences of the United States of American (PNAS), 113(46): 12963-12967.

Zhang, K., Wu, C., and Li, J., 2016: Retrieval of atmospheric temperature and moisture vertical profiles from satellite advanced infrared sounder radiances with a new regularization parameter selecting method. Journal of Meteorological Research, 30(3): 356-370.

Zhao, X., Heidinger, A.K., and Walther, A., 2016: Climatology analysis of aerosol effect on marine water cloud from long-term satellite climate data records. Remote Sensing, 8(4): doi:10.3390/rs8040300.

Zheng, X., Ackerman, S., Ferraro, R.D., Lee, T.J., Hurray, J.J., Pawson, S., Reynolds, C., and Teixeira, J., 2016: Challenges and opportunities in NASA weather research. Bulletin of the American Meteorological Society, 97(7): ES137-ES140.

Zhou, D.K., Liu, X., Larar, A.M., Tian, J., Smith, W.L., Kizer, S.H., Wu, W., Liu, Q., and Goldberg, M.D., 2016: First Suomi NPP Cal/Val campaign: Intercomparison of satellite and aircraft sounding retrievals. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(9): 4037-4046.