CLIMCAPS: Use of AIRS/AMSU and CrIS/ATMS Continuity Product for Cloud Feedback Studies

Thursday, Nov. 1, 2018

ICWG-2, Session 6: 4:30 pm EDT

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Creating a hyperspectral sounding continuity product

- We have 5 operational thermal sounder suites at this time

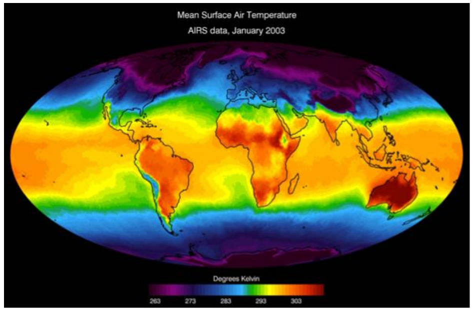
Satellite	Instruments	Overpass	Launch dates
Aqua	AIRS, AMSU	1:30	2002
Metop	IASI, AMSU, MHS	9:30	2008, 2012, …
S-NPP, JPSS	CrIS, ATMS	1:30	2011, 2017, …

- There are numerous differences in these sounding suites
  - Instruments are different
    - Spectra resolution, sampling and noise
    - Spatial sampling
    - Degradation over time
  - Algorithm differences
    - NOAA algorithms became operational ~1 year after launch and have asynchronous maintenance schedules (e.g., training datasets are different)
    - 9:30/1:30 orbits co-location w/ insitu is different (affects regression training and makes validation more difficult)
  - Sensitivity to a-priori assumptions
    - Sensitivity to meteorology (e.g., clouds at 9:30 vs 1:30 am/pm)
    - Sensitivity to seasonal and climate changes (e.g., 8% increase in CO_2, 2002-2017)

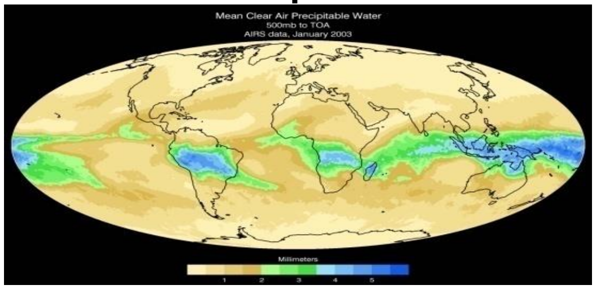
Continuity was not the primary design criteria of the modern satellite sounding suite

Example of retrieval products (AIRS v.5 & 6 products are shown)

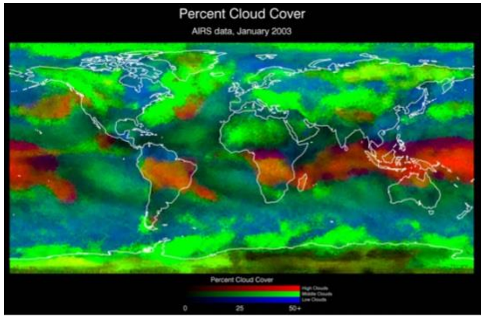
Temperature Profiles



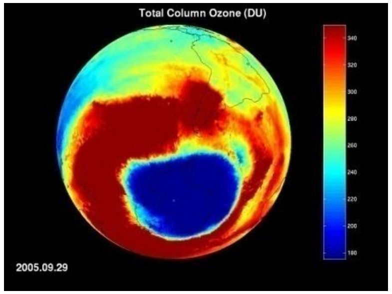
Water Vapor Profiles



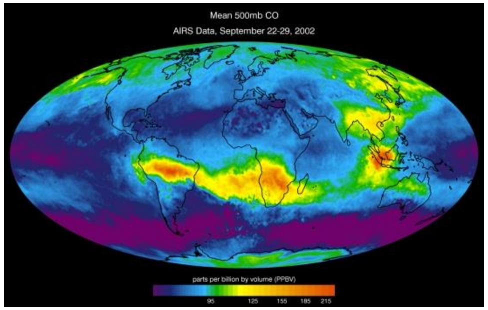
Clouds



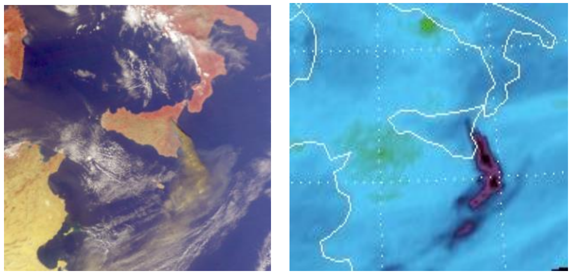
Ozone



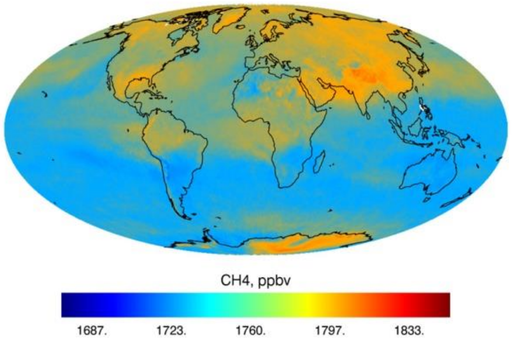
CO



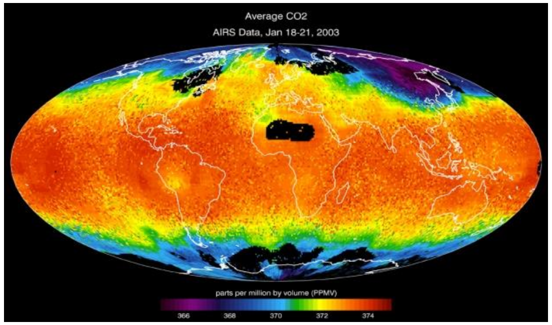
SO2



Methane

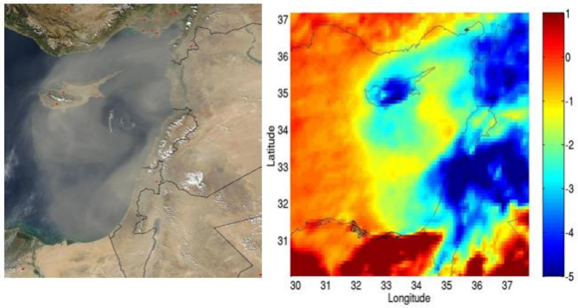


CO2

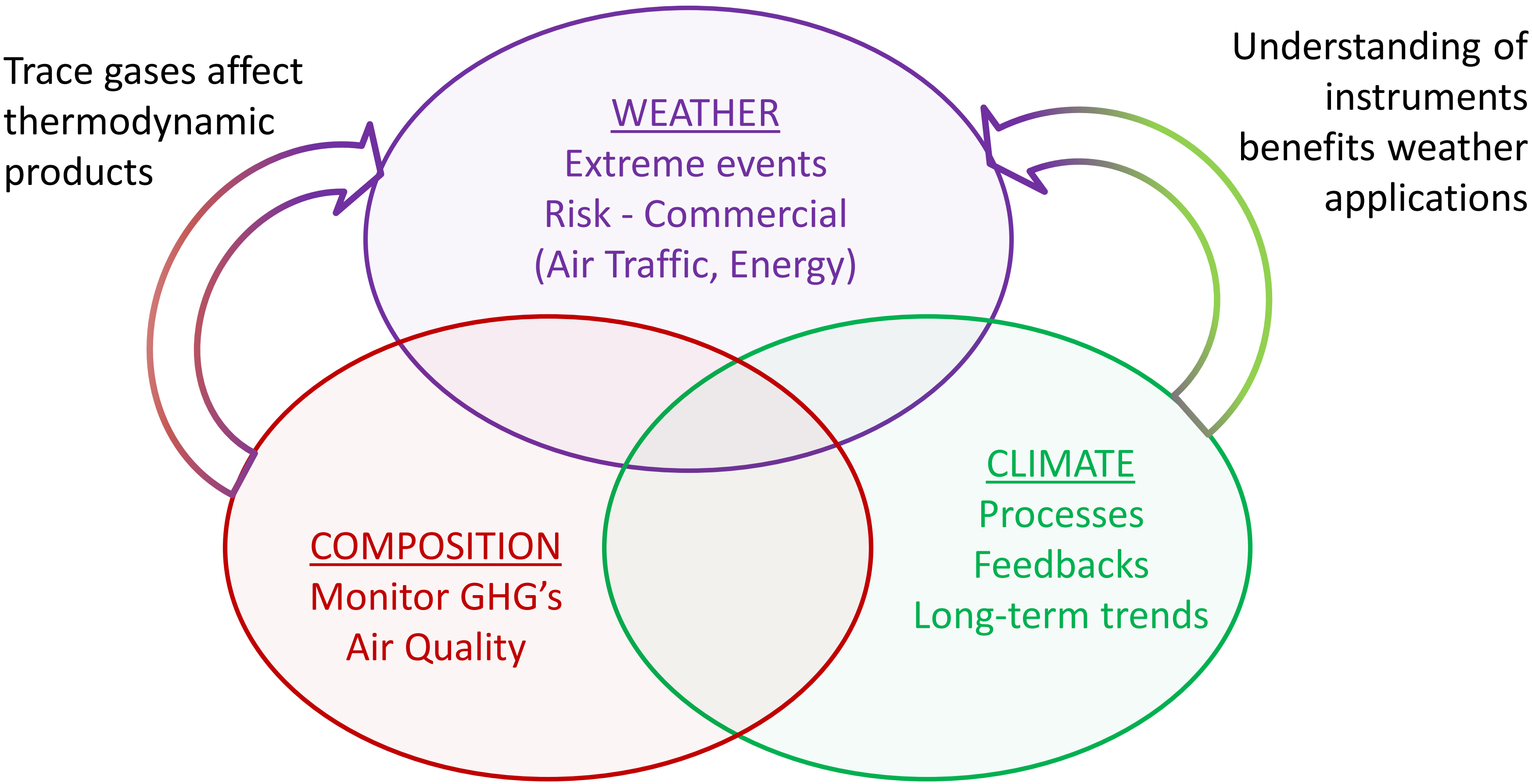


Dust

AIRS vs MODIS AEROSOLS
Eastern Mediterranean Dust Storm



We are attempting to meet the needs of 3 communities

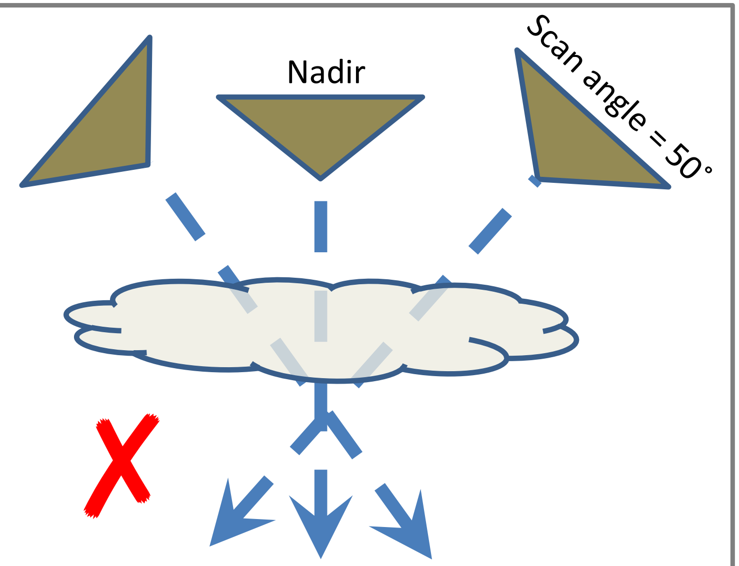


How do we deal with clouds for these microwave + infrared systems?

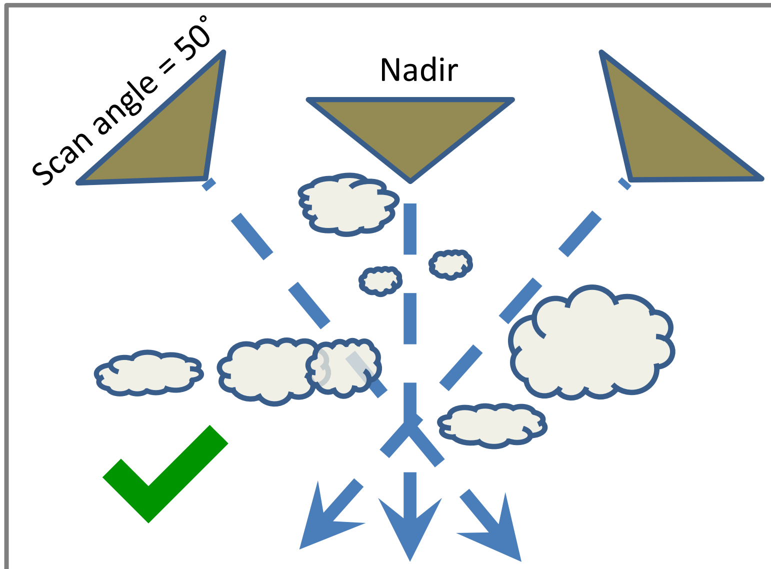
For infrared sounder system (AIRS, IASI or CrIS) even a small amount of cloud can be an obstacle.

The goal is to provide soundings in difficult meteorological situations ..... and ..... as close to the surface as possible

We want to minimize the impact of instrumental information content differences on downstream thermodynamic and trace gas products



We do NOT retrieve the thermodynamic environment THROUGH uniform clouds



We can retrieve cloud-cleared thermodynamic environment AROUND transparent holes in clouds

Cloud clearing eliminates the need to model the cloud microphysics.

- Assumption: Each FOV, j, is a mixture of a clear spectrum, $R_{clr}(n)$, and cloudy spectra, $R_{cld}(n,k)$.

$$R(n,j) = [1-\Sigma\alpha(j,k)]\cdot R_{clr}(n) + \Sigma\, \alpha(j,k)\cdot R_{cld}(n,k)$$

Σ's for k=1, K cloud types

  - Assume only cloud amounts, $\alpha(j,k)$, vary spatially.
    - Reject scenes with excessive surface & moisture variability (in the infrared or microwave).
  - Assume within FOR (set of J FOVs) there is variability of cloud amount
    - Reject scenes with uniform cloud amount
    - This is where microwave information is valuable.
- Roughly 70-80% of any given day satisfies these assumptions.

- ***Cloud clearing solves for $R_{clr}(n)$ by eliminating $R_{cld}(n,k)$ from the set of J equations.***

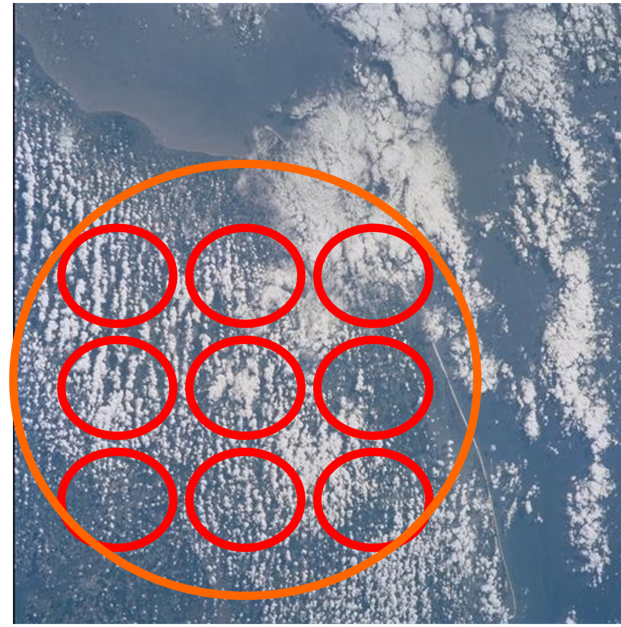


Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov). STS104-724-50 on right (July 20, 2001). Delaware bay is at top and Ocean City is right-center part of the images.

Spatial variability is used to remove the cloud radiance.

- In general, the set of J equations can be solved for R_{clr} using a sub-set (≈ 50 chl's) of computed radiances, $R_{clr}(n) = R(n, X)$, from a clear estimate, X, and J sets of cloudy infrared radiances, $R_{n,j}$ (n) to determine a constrained set of J parameters, $\eta(j)$.

$$R_{clr}(n) = R_{avg}(n) + (R_{avg}(n) - R(n,j))\cdot\eta(j)$$

$$R_{avg}(n) \equiv \mathit{average}(R(n,j)) \quad \text{over} \quad j = 1, J$$

- Thus, a small number of *linear* parameters, $\eta(j)$, can remove cloud contamination from thousands of channels.
  - Does not require a model of clouds and is not sensitive to cloud spectral structure
    - this is implicitly contained in radiances, R(n,j)
  - We are using spatial information to derive cloud corrections.
  - Reserve spectral information for everything else (T, q, trace gases).

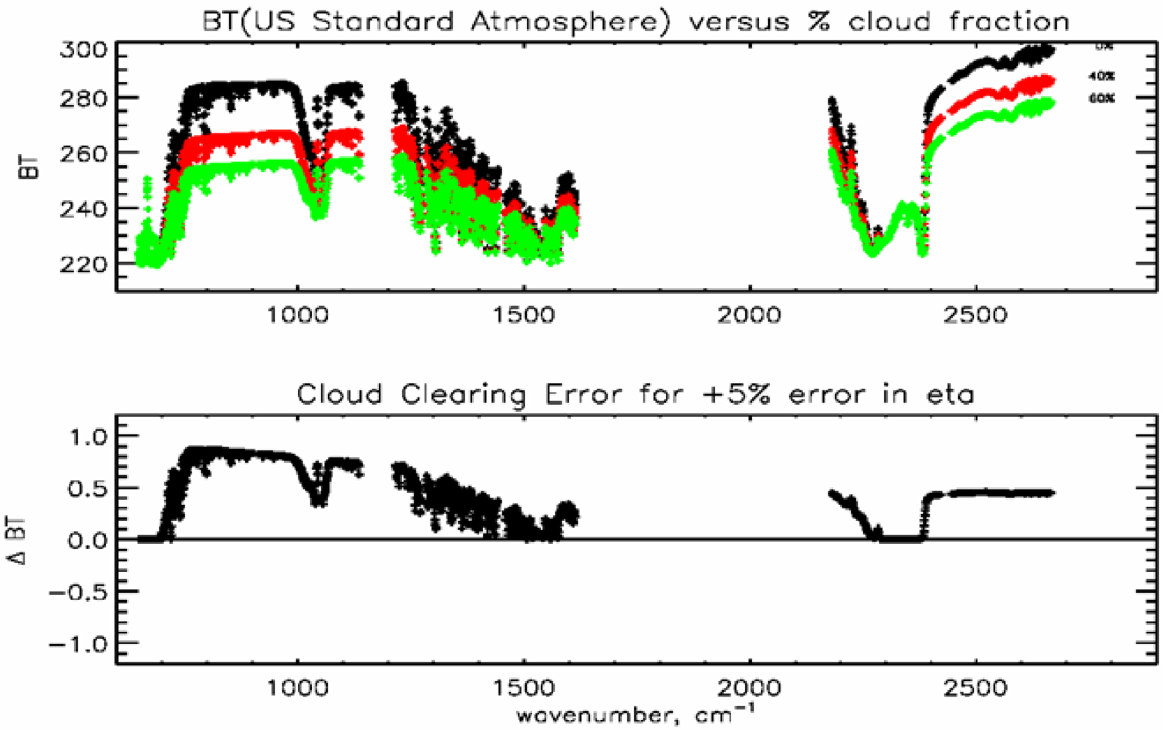
Cloud cleared radiances create spectrally correlated errors.

Example AIRS spectra, at right, for a scene with α_1=40% clouds (red) and α_2=60% clouds (green)

Extrapolate to clear scene (black curve, α=0%).

Can use many channels and FOVs to determine the parameters, $\eta(j)$.

Note that cloud clearing produces a spectrally correlated error that is well estimated with $\delta\eta\delta\eta^T$.



In this 2 FOV example, the cloud clearing parameters, $\eta(j)$ is equal to $\frac{1}{2}\langle\alpha\rangle/(\alpha_j-\langle\alpha\rangle)$

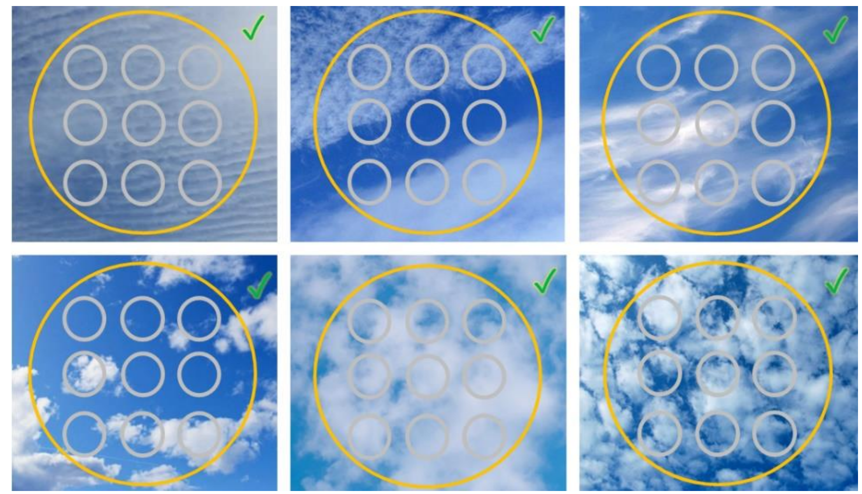
Cloud clearing allows retrievals in partially cloudy scenes

NUCAPS field of regard (FOR) =
set of 9 CrIS field of view (FOV)

Cloud Clearing **succeeds** when **a** FOR has **cloud variability**; i.e. when the CrIS FOV have different cloud fractions

~5% probability a CrIS FOV is clear
~2% probability a CrIS FOR is clear

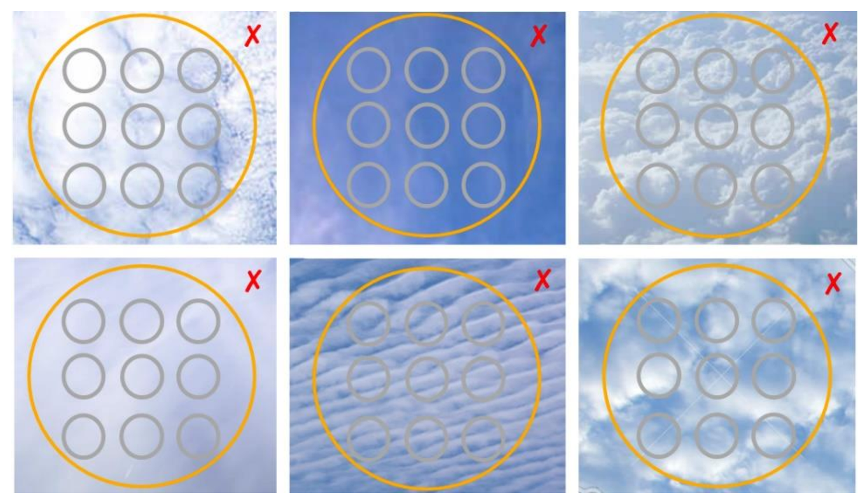
~70-80% of scenes can be cloud cleared
→ even if no single FOV is clear



Cloud Clearing **FAILS** when a FOR is **uniformly cloudy**, *i.e*. when each CrIS FOV has the same cloud fraction

Scene does not have to be overcast

Even a small amount of *uniform* clouds needs to be rejected



Pro's and Con's Of Cloud Clearing versus solving for cloud parameters

(in the context of atmospheric state retrievals)

Pro's/Con's of cloud clearing	Pro's/Con's of parameter retrieval
Pro: Does not require a radiative transfer model for clouds.	Pro: Derives cloud particle types, optical depth, and other cloud information.
Pro: ~4 linear parameters can remove complex cloud formations (multiple cloud types, strong scattering, etc.)	Pro: Does not modify the instrument radiance. Theoretically can fit radiances to level of the instrument noise.
Con: Does not work when clouds are uniform on the ~50 km scale. Must use microwave to reject these cases	Con: Infrared does not constrain the plethora of parameters necessary to describe clouds.
Con: Sacrifices spatial resolution, but … Pro: retain spectral information for all other geophysical parameters.	Pro: can operate at full spatial resolution (~15 km for AIRS, IASI, CrIS)
Con: Radiances have highly variable noise that can be spectrally correlated. Pro: Error is well characterized.	Con: Cloud forward model errors are still very large and induce large and unknown errors into the clear radiance component.

Together, *x*CAPS meets the needs of a diverse community

- NOAA-Unique Combined Atmospheric Processing System (NUCAPS) is supporting *real-time weather and air quality* applications.

  (Metop-A to -C 9:30 and S-NPP/JPSS-1 to -4 1:30 orbits)
  - Air traffic safety.
  - Pre-convective forecasting
  - Wildfire management and air quality.
  - Hurricane forecasting.
  - Ozone recovery and use of ozone at STE indicator.
- Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS) will focus on a *long-term (2002-2040's) record* for Aqua/AIRS+AMSU and S-NPP/JPSS CrIS+ATMS
  - Study how to build *and document* continuity records.
    - Transparent, instrument agnostic approaches.
    - Choose the appropriate a-priori for NASA applications.
  - Create a baseline global product suite for EOS-era.
    - Can support targeted regional studies with cloud parameter retrievals.
  - Communicate the strengths and caveats of the product.
    - Guidance for future algorithm development.

CLIMCAPS differs from AIRS Science Team and NUCAPS

- For 20+ years the sounder community has attempted to make a model-independent system.
  - NUCAPS and AIRS v.6 use static statistical ***models*** as the a-priori.
- CLIMCAPS uses Merra-2 reanalysis for T(p), q(p) and O_3(p).
  - Hypothesis: the statistical step in AIRS Science Team methodology does not provide a stable or well characterized a-priori for continuity.
  - Merra-2 is a data driven system, does an incredible job with T(p).
  - Retrieval can benefit from the stability provided by the reanalysis.
  - For water vapor, hyperspectral infrared information content (IC) is high → departs strongly from the re-analysis.
  - Merra-2 O_3(p) implicitly brings in MLS and OMPS O_3(p) information.
- CLIMCAPS uses the Combined ASTER & MODIS Emissivity over Land (CAMEL) as a-priori over land
  - CAMEL database has scene dependent uncertainties
  - ***Effectively brings in imager IC*** and high spectral resolution lab. data
- Significant improvements in the *estimate of geophysical errors and their propagation* through the retrieval process.

CLIMCAPS retains many components of the NUCAPS Methodology

- Employs cloud clearing
  - Allows other state components (SST/LST, T(p), q(p), $\varepsilon(\upsilon)$, O_3(p), CO(p), CO_2, CH4, SO_2, HNO_3, N_2O etc.) to be derived *independently* of clouds from spectral information.
  - A-priori used for cloud clearing is extremely important.
    - Iteration of cloud clearing causes biases and confounds error characterization … **CLIMCAPS does not iterate cloud clearing**
- Uses all space sounding assets
  - Microwave radiances used for both for T(p) & q(p) information content and quality control of cloud clearing.
  - Imager data is implicitly used via IR emissivity a-priori
- Retains the embedded information content (IC) analysis.
  - Maximizes the weight of observations.
    - Enables diverging from Merra-2 if we have high IC.
- Retain the sequential retrieval approach.
  - Extremely fast and stable global retrieval product.

What about cloud products?

- We use the clear state (derived from cloud cleared radiances + microwave radiances) to derive cloud parameters from the J cloudy observed spectra, R(n,j).
  - Solve for two cloud top pressures, $P_{cldtop}(k)$, and effective cloud fraction, $\alpha(j,k)$, k=1,2.
- Cloud cleared parameters and radiances are also a useful "cloud" product from xCAPS.
  - Cloud clearing parameters are independently derived cloud contrast indicators.
  - Quality control parameters and error estimates allow separation of cloud derived (P_{cldtop}, α) and spectral derived quantities (thermodynamic, trace gas).
- Downstream algorithms can use xCAPS products to derive cloud microphysical parameters for targeted domains.

*x*CAPS is both an R2O and an O2R engine

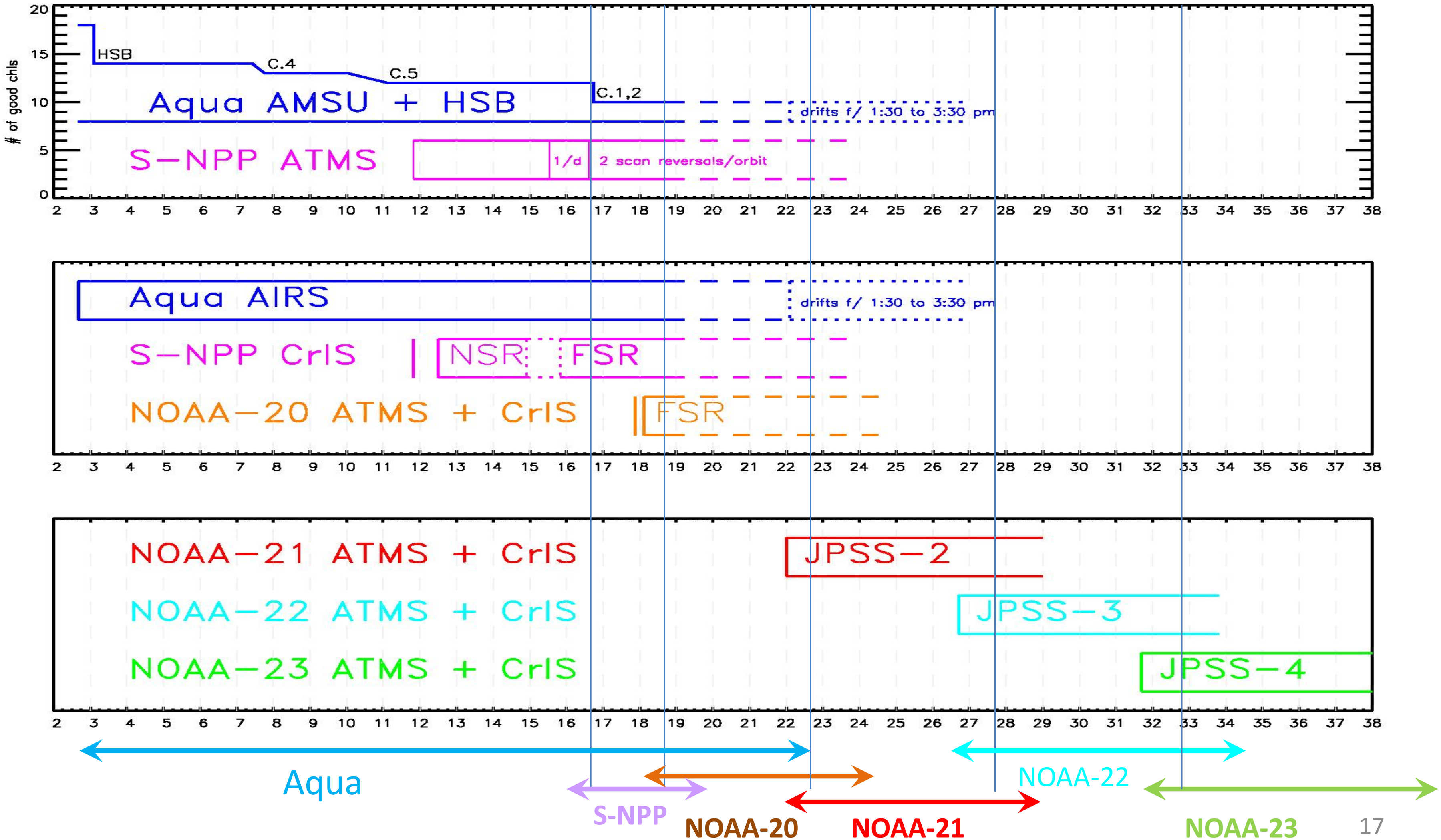
- NUCAPS is based on AIRS Science Team (AST) methodology (version 5.9) and leverages a NASA research investment to support NOAA operations (R2O)
  - NUCAPS-Metop has been operational since 2008
    - 2008 to present Metop-A/IASI+AMSU+MHS + AVHRR
    - 2012 to present Metop-B/IASI+AMSU+MHS
  - 2/2013 to present, NUCAPS/S-NPP operational
  - 7/2018 to present, NUCAPS/NOAA-20 operational (in DB)
  - *NUCAPS is fully capable of running AIRS+AMSU (but doesn't)*
  - NUCAPS has many operational users (T, q, O_3, CO, and CH_4)
- CLIMCAPS leverages NUCAPS & AST development (O2R)
  - Continuity benefits diurnal Metop/NOAA-2x continuity

CLIMCAPS has benefited from NUCAPS O2R investment
NUCAPS can benefit from CLIMCAPS R2O investment

Choosing the cross-over point for Aqua to S-NPP

- Nominal or Full spectral resolution (NSR or FSR)
  - Dec. 4, 2014 S-NPP/CrIS was put into FSR mode
  - Nov. 2, 2015 S-NPP/CrIS FSR extended spectral mode
- Transition from AMSU+HSB to ATMS
  - Aqua/AMSU Chl.7 has never been used
  - Aqua/HSB was lost on Feb. 5, 2003
  - Aqua/AMSU degradation: Chl.4 (2007) and Chl.5 (2009-2011)
  - Aqua/AMSU Chl.1 and 2 lost in 10/2016
  - ATMS scan reversals: began 7/14/15 (1/day), 8/9/16 (2x/orbit)
- ***Recommendation*** (based on discussions w/ L. Strow):
  - Use AIRS+AMSU from 9/1/2002 to 8/31/2016
    - Use “pristine” AIRS channels that were well behaved
    - Use AMSU 1, 2, 3, 6, 8, 9, 10, 11, 12, 13, 14, 15
  - Use S-NPP CrIS.FSR+ATMS from 9/1/2016 to 8/31/2018
    - 12/10/2015-9/31/2016 overlap periods of Aqua/S-NPP
  - Use NOAA-20 CrIS.FSR+ATMS from 9/1/2018 to …
    - Adequate overlap periods of S-NPP and NOAA-20 exist

Choosing the cross-over points for Aqua, S-NPP, and beyond



CLIMCAPS supports building a continuity dataset *NOW*

- Provide an archive of these measurements as a baseline for the future.
  - Reasonable mitigation of instrument artifacts.
  - Characterization with error covariance propagation and averaging kernels.
  - Full suite of trace gases (O_3(p), CO(p), CO_2, CH_4, HNO_3, N_2O, SO_2).
- Build a long-term record so that researchers can:
  - Use the record for understanding climate processes and change.
  - Document our best understanding of the information content.
- Future work (next ROSES cycle?).
  - Reprocess CLIMCAPS Level-2 using the Common Hyperspectral InfraRed Product (CHIRP) homogenized radiance dataset.
    - CHIRP transform AIRS, IASI, CrIS to common spectrum.
  - Create a Metop long-term dataset: 2008 to 2040's.
    - Metop-A, -B, -C at 9:30 am/pm with IASI, AMSU, MHS.
    - Follow-on (EPS-SG/IASI-NG) has been approved for 2021-2040.

Questions?

1. *x*CAPS is a robust product system
   - NUCAPS uses a static statistical regression and supports real-time.
   - CLIMCAPS uses Merra-2 as a-priori for T(p) and q(p), CAMEL for $\varepsilon(\nu)$, static climatologies for trace gases.
2. *x*CAPS retrieves soundings in clear and partly cloudy scenes.
   - CLIMCAPS has better diurnal, seasonal and inter-annual and inter-satellite stability.
   - CLIMCAPS provides a-priori and retrieval error estimates.
3. *x*CAPS is designed to support **community needs.**
4. **So …. How can *x*CAPS support your research?**

Recent Terra-Aqua-S-NPP ROSES Cycle: 2018-2021

- The TASNPP ROSES solicitation focused primarily on the continuity of the EOS mission. In addition, the solicitation cited
  - Improvements to estimates of information content (e.g. error covariance matrix and averaging kernels).
  - Improvements in the boundary layer.
  - "*All data products must be focused on an application that can be justified as meeting NASA's applied science goals or a unique unmet operational data need that fits within the NASA program objectives and mission. For Suomi NPP, to* ***<u>prevent duplication of efforts pursued by NOAA</u>****, NASA will only support the upgrade, refresh and operation and maintenance of EOS Continuity algorithms and supporting systems*." ROSES A.37 solicitation p.9-10.
- The Panel Review selected CLIMCAPS as the "core" algorithm.
  - Numerous science applications that will be dependent on the upstream level-1 or level-2 products were selected.

Summary of the Algorithms Selected by the ROSES S-NPP Panel in 2018

PI, last name	PI, first name	affiliation	instruments	summary of topic
Barnet	Chris	STC	Aqua AIRS/AMSU & S-NPP and NOAA-20 CrIS/ATMS	Continuity products for T(p), q(p), O3(p), other trace gases, surface and cloud top pressure and fraction.
Cady-Pereira	Karen	AER	CrIS Level-1	CrIS Single FOV NH3 Product
Elsaesser	Gregory	Columbia	AIRS Level-2 T/q at high spatial resolution	Convective transition in storms.
Henze	Daven	U.Colo.	CrIS NH3 product	NH3 Inversion Model
Huang	Xianglei	U.Mich.	AIRS, CrIS Level-1 CERES, CrIS, Merra(T,q)	cloud radiative effect
Lambrigtsen	Bjorn	JPL	AMSU, ATMS Level.1	ATMS Level-1 and Level-2 T, q
Liu	Xu	LaRC	AIRS/AMSU Level.1 CrIS/ATMS Level.1	S-FOV T,q,trace gas, surf, cloud CLARREO Climate Fingerprint
Milstein	Adam	MIT/LL	AIRS, CrIS, Level.1	NN L2 alg tailored for PBL
Payne	Vivienne	JPL	CrIS Level.1	Single FOV PAN Product
Reale	Oreste	USRA	AIRS, CrIS Level.1 and CCR's	Radiance DA: cloudy and cloud cleared targeted obs study
Ruston	Benjamin	NRL	AIRS, CrIS, CALIOP, MODIS, MISR	dust correction within radiance DA
Santek	David	U.Wisc	AIRS, CrIS Dual Regress (q, O3)	H2O,O3 winds
Soden	Brian	U.Miami	AIRS, CERES, MODIS	Radiative kernels to quantify CMIP6 fluxes
Strow	Larrabee	UMBC	AIRS, CrIS, IASI	Climate trends derived from delta radiances.
Tan	Ivy	UMBC	MODIS, AIRS, CERES, AMSR	cloud feedback
Tian	Baijun	JPL	AIRS/AMSU	CMIP5/6, compare w/ Merra
Wilcox	Eric	DRI	MODIS, AMSE-R, CloudSat, CALIPSO, OMI, AIRS, IASI	study of radiative heating by black carbon
Worden	Helen	UCAR	MOPITT, CrIS	Single FOV Carbon Monoxide retrieval product

Applications we are targeting for the NASA continuity product.

Topic	Potential applications for thermal sounding products
Fingerprinting (e.g., Santer 2018 Science, Pierrehumbert 2011 Phys. Today)	Improved stratosphere/troposphere allows better separate of O3 hole from GHG's, N.H./S.H. gradients, polar amplification (downwelling thermal), Arctic moisture budget (Boisvert 2015 JGR)
PBL (Fetzer 2004 GRL, Hoogewind 2017 J.Clim)	Capping layer inversions, convection and stability. Most important for a thermal sounder is knowledge of when we have skill (i.e., averaging kernels).
UTH, double ITCZ (Tian 2015 GRL), ENSO, MJO	Stable and seasonally consistent T(p) will stabilize cloud clearing and q(p). Departures from Merra-2 will be more valuable than a derived state.
Ozone	Ozone hole; Intrusions and mid-trop O3 (Langford 2018 Atmos. Env); LS O3 trends (Ball 2018 ACP, Wargan 2018 GRL); CO/O3 ratio (Anderson 2016 Nat.Comm)
Carbon Dioxide (CO2)	Contribute to discussion of seasonal cycle amplitude (Barnes 2016 JGR), clear bias of OCO (Corbin 2008 JGR)., and stratospheric/troposphere CO2 gradient. (Separability of T/CO2 is improved with use of Merra-2 and AMSU/ATMS.
Carbon Monoxide	Long-term trends of CO (Worden 2013 ACP). Impact on OH (Gaubert 2017 GRL), Seasonal cycle (Park 2015 JGR) and CO/CO2 emission factors (Wang 2009 ACP)
Methane (CH4)	Monitoring of Amazon CH4 (Bloom 2016 ACP), Changes to Arctic emissions (Shakhova 2010 Science, Thornton 2016 GRL)
Other trace gases	Nitric Acid, Nitrous Oxide, Sulfur Dioxide, Isoprene, PAN, Acetylene, Methanol, etc – all benefit from stable cloud clearing and upstream derived T(p), q(p), etc.

How we collaborate with the sounding community

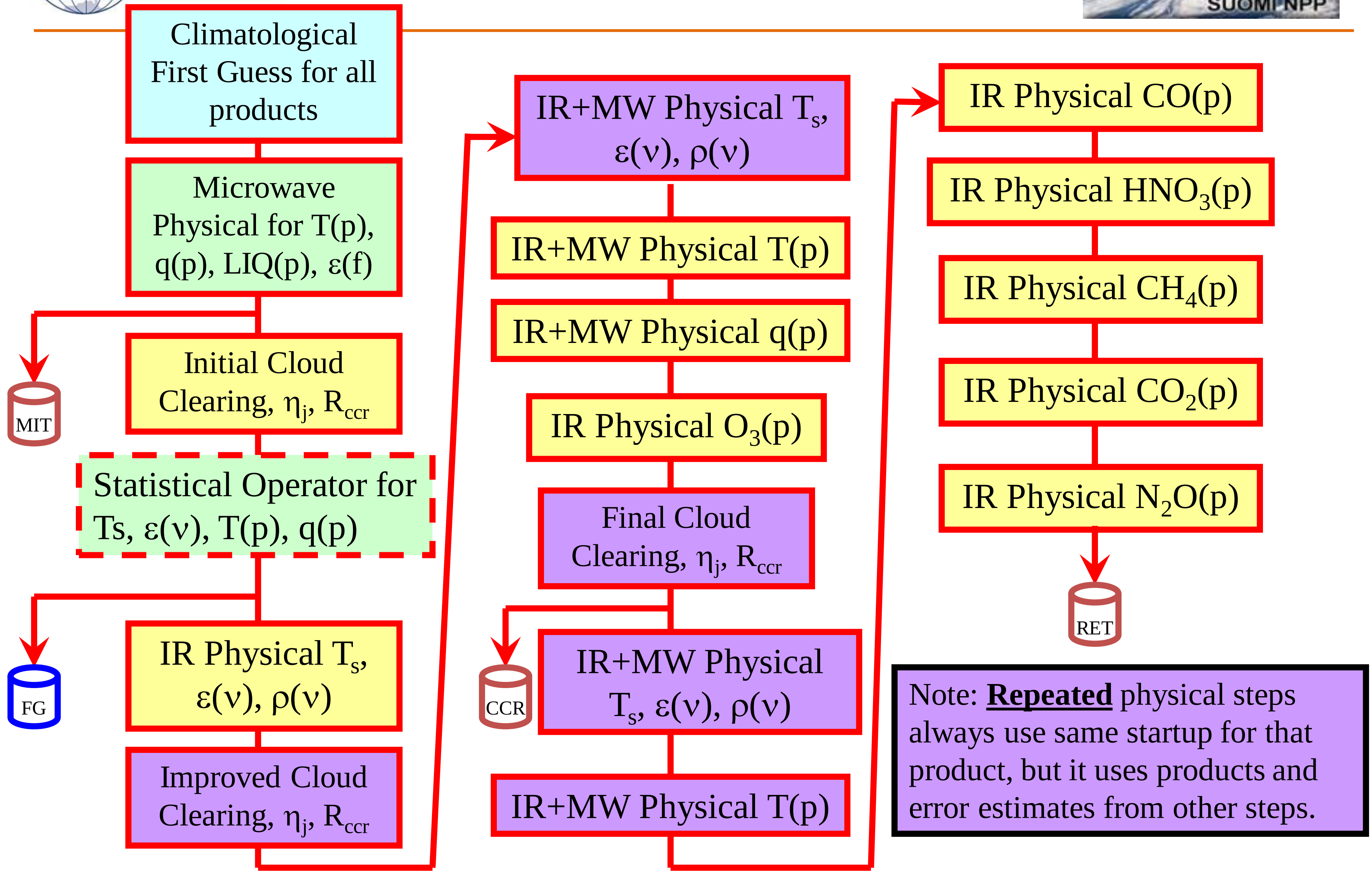
- Aqua/AIRS/AMSU is a project.
  - AIRS Version.6 used a neural network a-priori
- S-NPP/NOAA-20 is a ROSES competed SIPS.
- With the Terra-Aqua-Suomi-NPP (TASNPP) selection these two worlds have been intertwined
  - Joao Teixeira is the AIRS Project Lead
  - Bryan Baum is the S-NPP Science Team Lead
  - Chris Barnet is the S-NPP Sounder Discipline Lead
- We are now working towards a common goal of producing a EOS/S-NPP/JPSS continuity product.
  - AIRS v.6.x will be maintained for use by science community.
  - AIRS Science Team is evaluating CLIMCAPS as a candidate for Version.7.

We are working towards having a GLOBAL baseline (CLIMCAPS) sounding product begin production at GES-DSIC by Oct. 2019 for Aqua, S-NPP, and NOAA-20

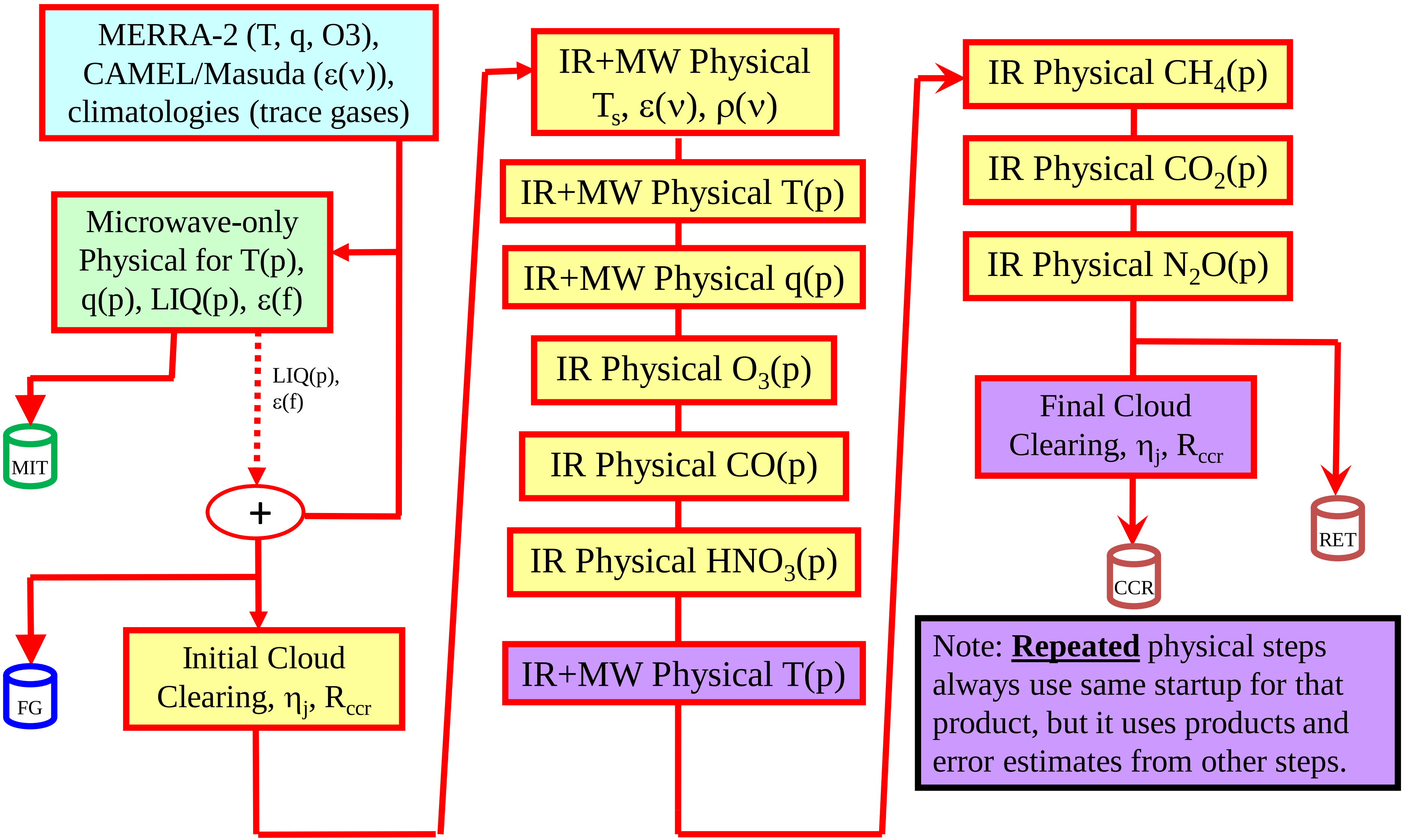
What about trends?

- Any trend in temperature in the a-priori will leave an imprint on the final thermal sounder product trend.
  - Infrared has cross-talk between CO_2 and T has been mitigated within CLIMCAPS (use of microwave, CO2 is solved for)
  - Uncorrected, a 3 ppm change in CO_2 will cause ~0.1 K in T(p)
- Statistical operators extrapolate trends from their training
  - Induces a tendency to under-estimate trends.
- CLIMCAPS has been optimized to move away from a-priori
  - Error estimates quantify IC added by sounder observations.
  - Measurements will depart if AIRS or CrIS disagrees with Merra.
- TASNPP funded investigation of the derivation of trends from radiance differences (PI, Larrabee Strow)
  - Simplifies the a-priori assumptions.
  - Does not require solving for the full atmospheric state.

Simplified Flow Diagram of the NUCAPS Algorithm



Simplified Flow Diagram of the CLIMCAPS Algorithm



CLIMCAPS differs in the choice of a-priori for T, q, O3

Concern	Statistical Model	Re-analysis model
Satellite data is used twice	YES: All channels are used in NN and regressions. Subset of the same exact channels are re-used.	→zero Weight of obs is extremely small w.r.t. 6 hour window and all other instruments.
Vertical sub-structure	Derived from ECMWF statistics and only our obs. The a-priori contribution in the solution cannot be quantified.	Derived from ensemble of many instruments and model dynamics. Contribution is partitioned via error propagation, $dXdX^T$
Latency	Zero – it is a static training	Re-analysis: ~1 month GMAO FP: ~4 to 7 hours
Spatial consistency	Clouds and other signals cause “spatial speckle” that can induce large gradients at 100 km scale.	Constrained by model dynamics (including thermal wind) and is spatially consistent.
Temporal consistency (NOTE NN and regressions are “trained” from specific instruments within specific year(s).)	Non-graceful response to instrument changes (e.g. , degradation, AIRS/CrIS transition) and state changes (climate, volcanoes, or anything outside the domain of its training)	Stated goal is to mitigate obs. discontinuities. Can have artifacts due to instrument changes: O3: MLS in 10/2004; T/q: Metop 2009, 2013, S-NPP 2012, etc.

Preliminary assessment of using Merra-2 as a-priori

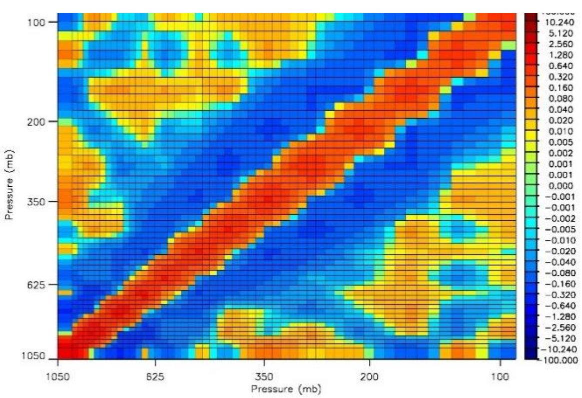
Product	How much does Merra-2 help?
CCR's	Merra-2 T(p) stabilizes cloud clearing.
T(p)	Merra-2 ≈50-75% of IC, CLIMCAPS $dXdX^T(H_2O, CO_2, O_3, \ldots)$
q(p)	Merra-2 contributes ≈25% of IC, CLIMCAPS $dXdX^T(T, CH_4, \ldots)$
O3(p)	≈1.5 d.o.f. in LS/UT Merra-2 O3(p) provides shape
CO	≈1 d.o.f. in mid-trop, Merra-2 T(p) adds stability
CH4, CO2, N2O	≈0.5 d.o.f. in mid-trop, Merra-2 T(p) adds stability
HNO3	≈1 d.o.f. in LS, MERRA-T(p) stabilizes the solution

A-priori is necessary because our solution is under-determined
Merra-2 is more stable than statistical operators
Merra-2 has less discontinuities than forecast models
Retrieval departures from Merra-2 are valuable in the context of continuity because we are exploiting more of the IC of the Aqua/S-NPP/NOAA-20 infrared/microwave satellites and account for $dXdX^T$ of trace gases

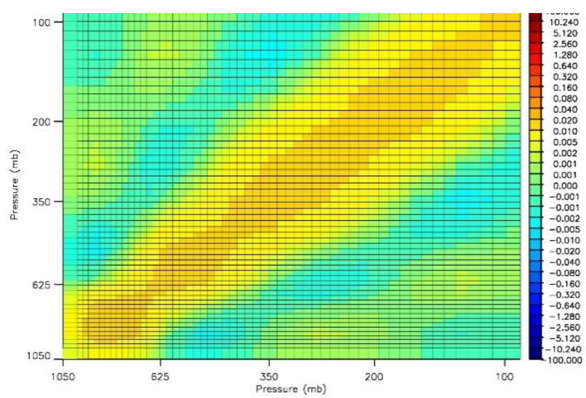
Error covariance of the T(p) retrieval, $\delta T \delta T^T$

- Error covariance & averaging kernels are related through the a-priori covariance
- Error can be mapped through our physical retrieval such that the amount of the a-priori in our solution can be known and analyzed
  - The left panel is how much of the a-priori leaks through (~50% in this case)
  - Middle panel is the error covariance of the measurements
  - Right panel is the total error covariance of the temperature retrieval
- Most of the scene-to-scene variability in the error will be from the fraction of the a-priori that leaks through – ***and that is a strong function of cloud homogeneity***

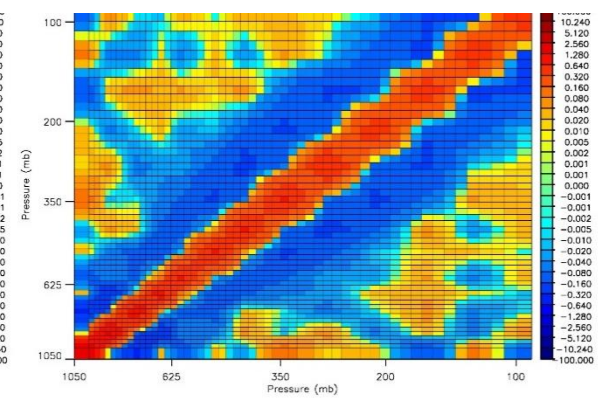
Merra2 error in solution, $(\delta T \delta T^T)^A$



Error in solution, from radiances $(\delta T \delta T^T)^O$



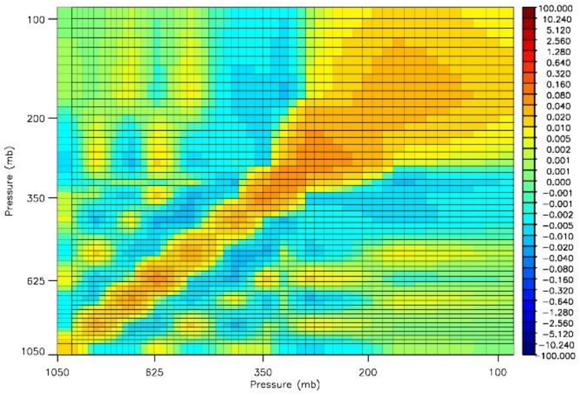
Retrieval error: $\delta T \delta T^T = (\delta T \delta T^T)^A + (\delta T \delta T^T)^O$



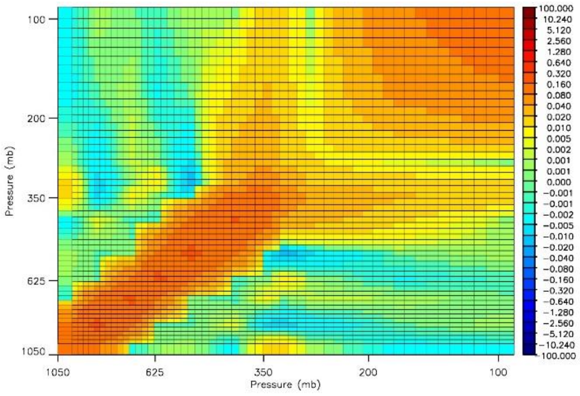
Error covariance of the q(p) retrieval, $\delta q \delta q^T$

- The error from T(p) retrieval, $\delta T \delta T^T$, is used as error source when solving for water vapor, q(p)
  - In the case of water vapor, a greater fraction of the measurements are believed (i.e., ~25% of a-priori error propagates to solution)
  - Higher errors (e.g., cloud clearing or $\delta T \delta T^T$) will cause more of the water a-priori to leak through, especially near the surface
- With CLIMCAPS we can quantify the sources of error in our retrieval.

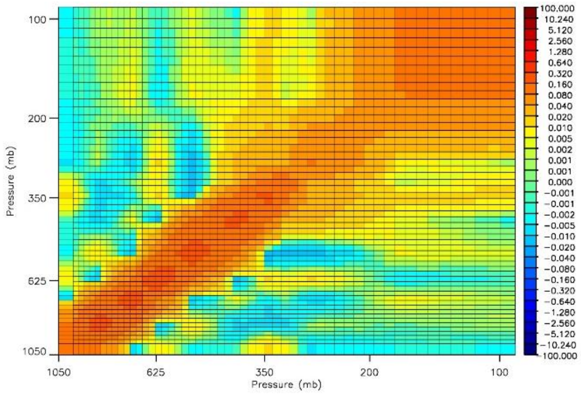
Merra2 error in solution, $(\delta q \delta q^T)^A$



Error in solution, from radiances $(\delta q \delta q^T)^O$



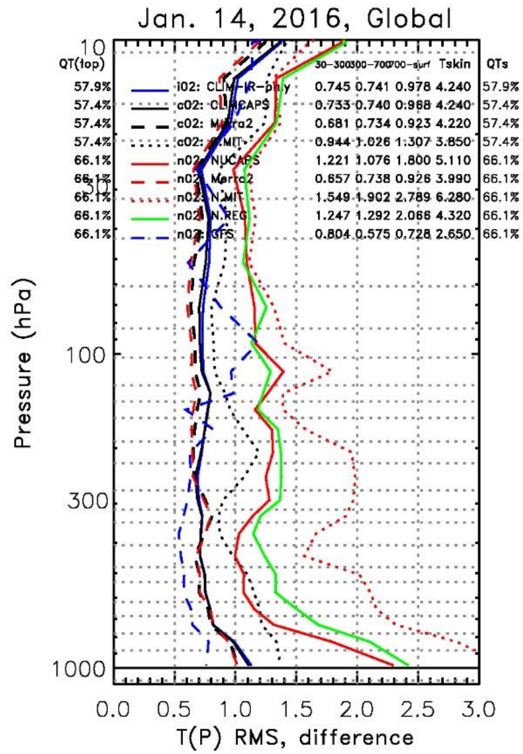
Total retrieval error: $\delta q \delta q^T = (\delta q \delta q^T)^A + (\delta q \delta q^T)^O$

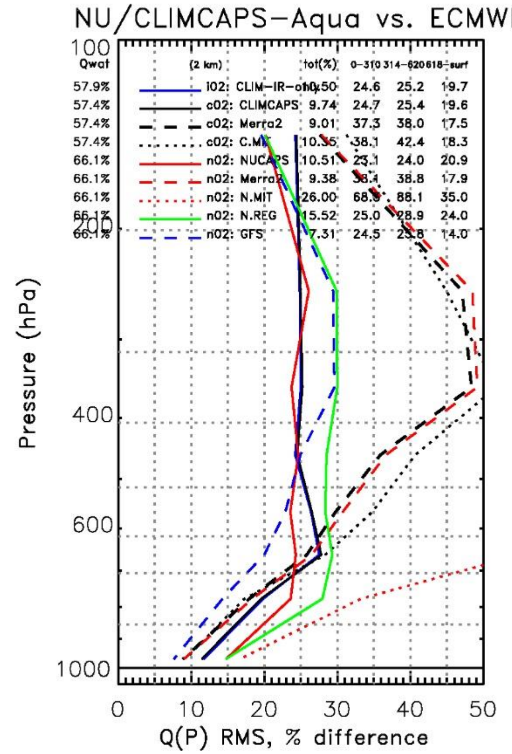


We must be able to interrogate our scene dependent information content in order to understand it impact on level-3 or averaged products.

How much do we improve over Merra-2?

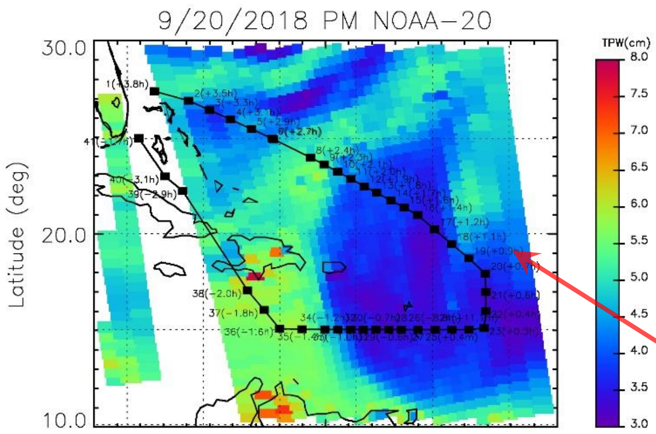
- Statistics for the Jan. 14, 2016 focus day
- CLIMCAPS T(p) is ~= MERRA T(p)
- But CLIMCAPS q(p) ends up in same place as NUCAPS q(p) even though Merra-2 start-up significantly worse than NUCAPS regression.
- **AIRS (and S-NPP) DOES NOT add significant information content to T(p)**
- **AIRS (and S-NPP) DOES add significant IC to q(p)**





Black: CLIMCAPS-Aqua, Solid = AIRS+AMSU dotted: AMSU-only
Blue: CLIMCAPS-Aqua, Solid = AIRS-only
Red: NUCAPS-Aqua, Solid = AIRS+AMSU, dotted: AMSU-only
Green: NUCAPS-Aqua, Solid = AIRS+AMSU LINEAR regression
Dashed Black: Merra-2 for CLIMCAPS-Aqua QC
Dashed Red: Merra-2 / Blue: GFS for NUCAPS-Aqua QC

Saharan Air Layer field
Sep. 20, 2018

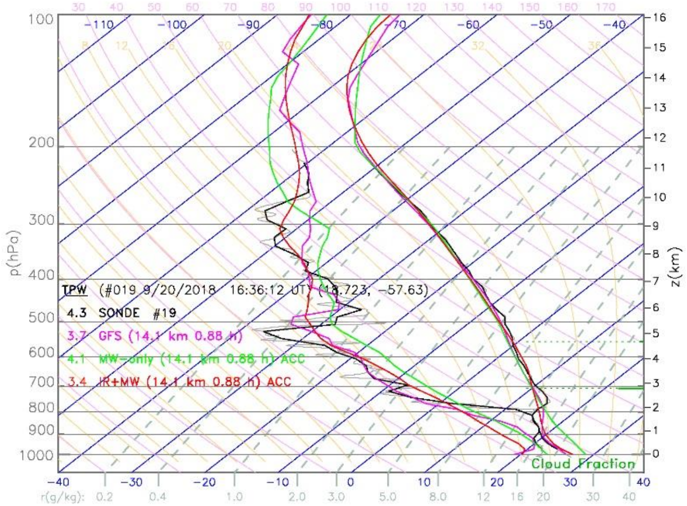


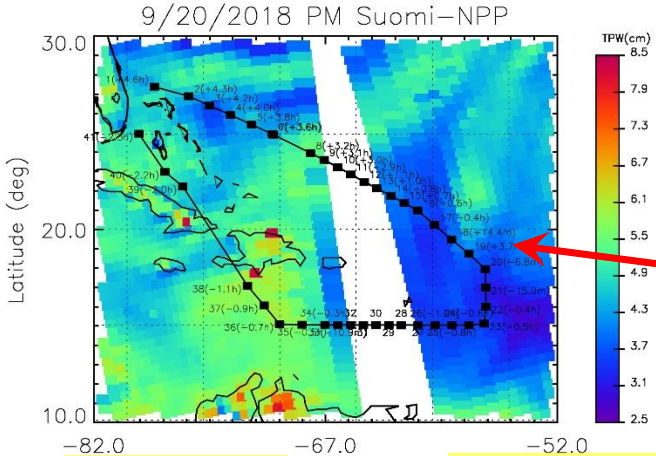
19:10 UT

17:30 UT

Sonde
#19/41
16:36 UT

NOAA-20
NUCAPS
14.1 km
+54 min

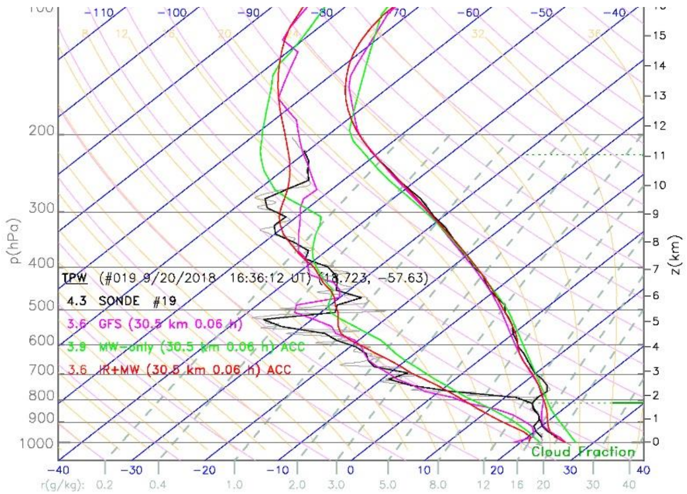




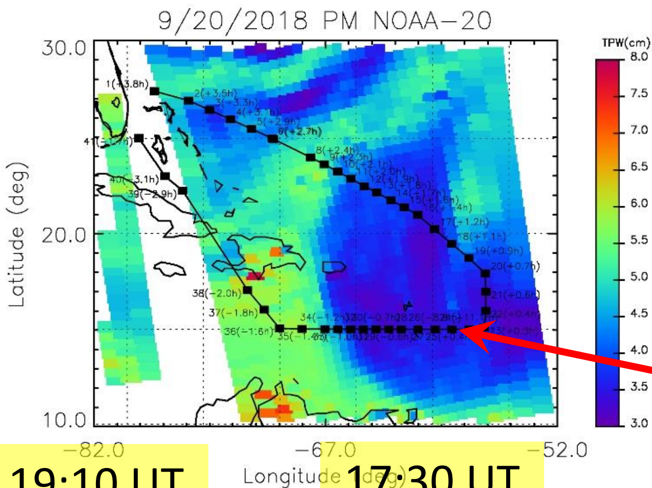
18:20 UT

16:40 UT

S-NPP
NUCAPS
30.5 km
+3.7 min



Saharan Air Layer field Sep. 20, 2018

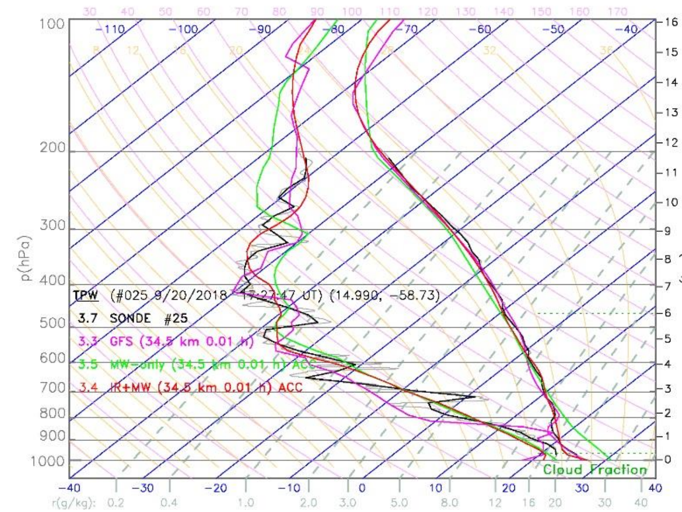


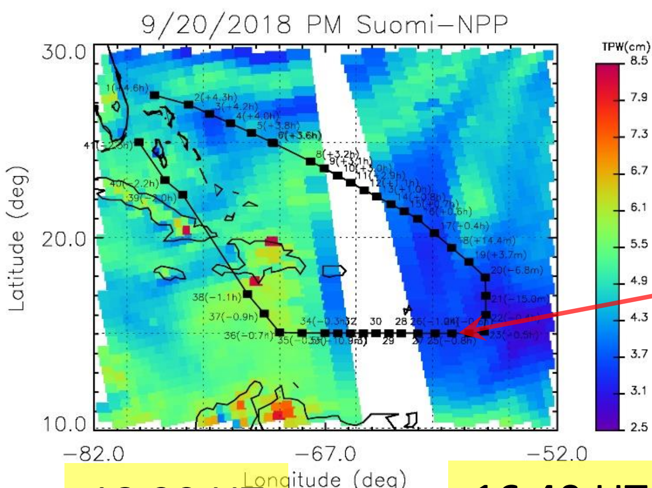
19:10 UT

17:30 UT

Sonde #25/41 17:28 UT

NOAA-20 NUCAPS 34.8 km +0.4 min

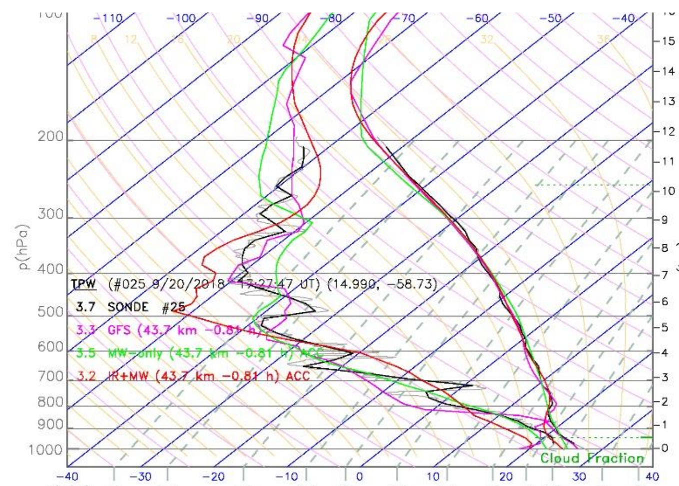




18:20 UT

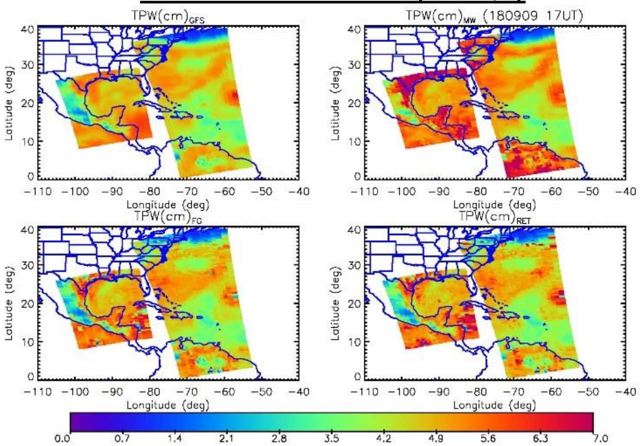
16:40 UT

S-NPP NUCAPS 43.7 km -49 min

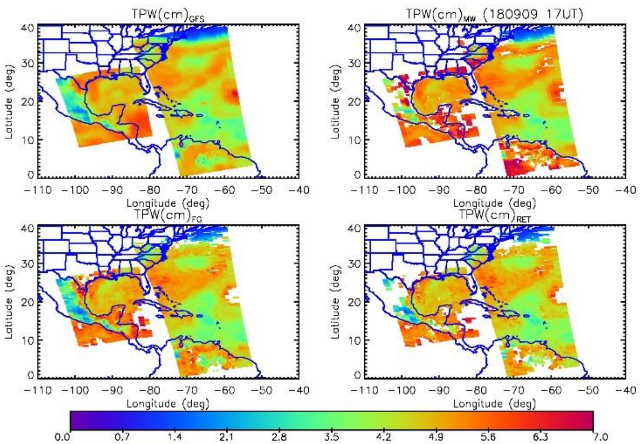


Hurricane Florence campaign, Sep. 9, 2018

NOAA-20 NUCAPS (no QC)



NOAA-20 NUCAPS (with QC)



Here is all the NUCAPS data that was available by direct broadcast (DB) on Sep. 9th.

We could go back and process from archive but I think it is important to show what we would have had in DB

Top is all data bottom is accepted only.

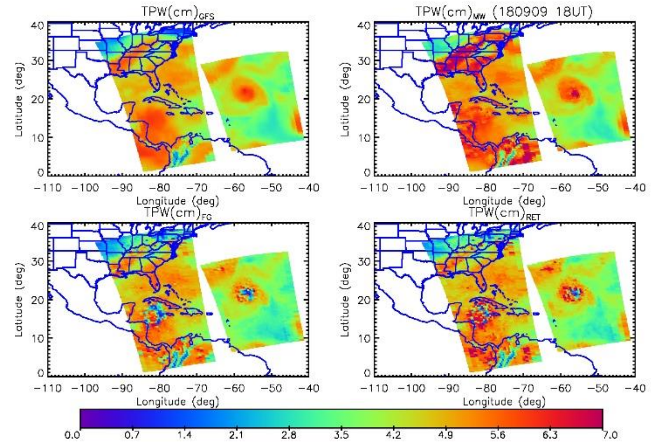
NOAA-20 (left) and S-NPP right)

At a given longitude NOAA-20 goes over 50 minutes before NPP.

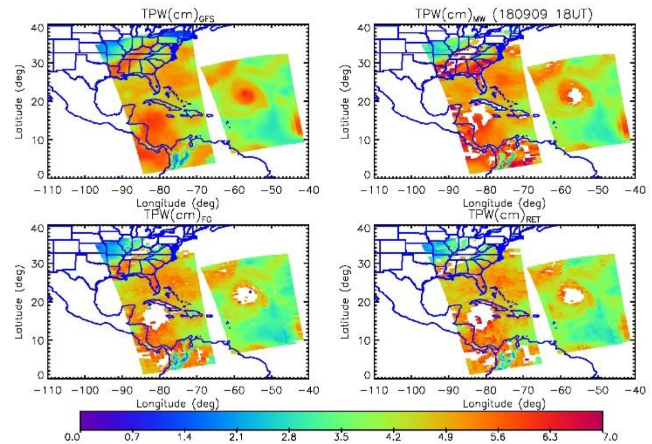
4 panels are GFS (interpolated to satellite), microwave only (MIT), first guess (FG), and final retrieval (RET).

I have these plots from Sep. 9 to Sep. 20th.

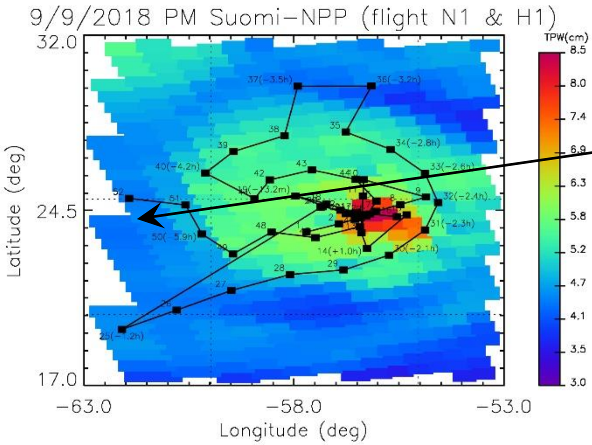
S-NPP NUCAPS (no QC)

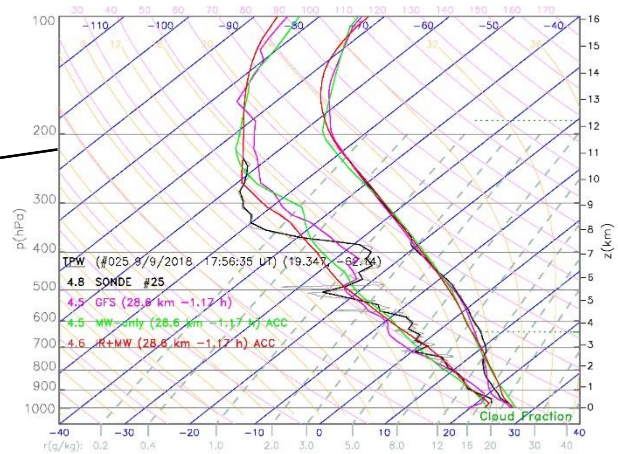


S-NPP NUCAPS (with QC)



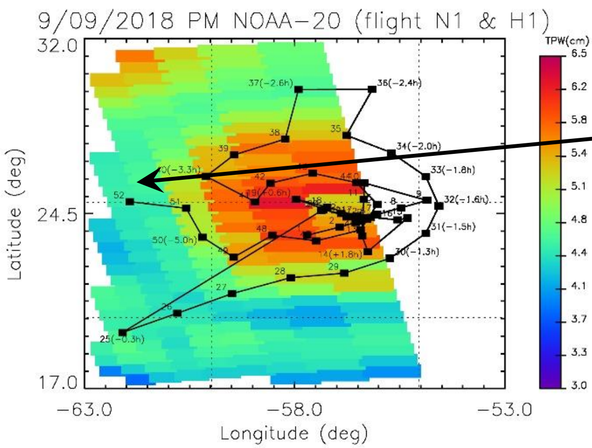
Hurricane Florence campaign, Sep. 9, 2018

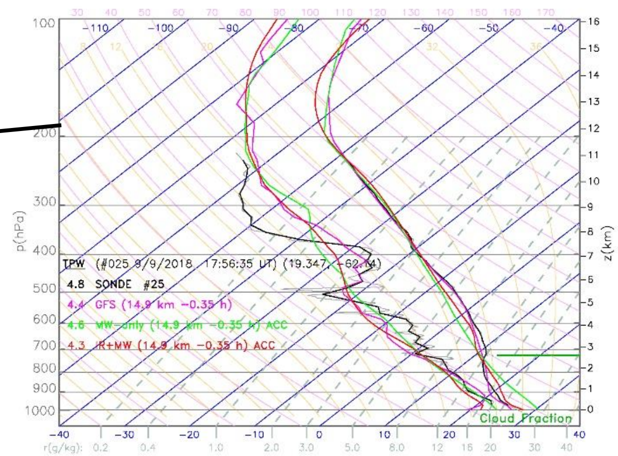




Sonde #25 is shown here. This is from the "N1" flight which is a ***G-IV aircraft***.

For both S-NPP and NOAA-20 in this case the closest matchup was an accepted NUCAPS retrieval



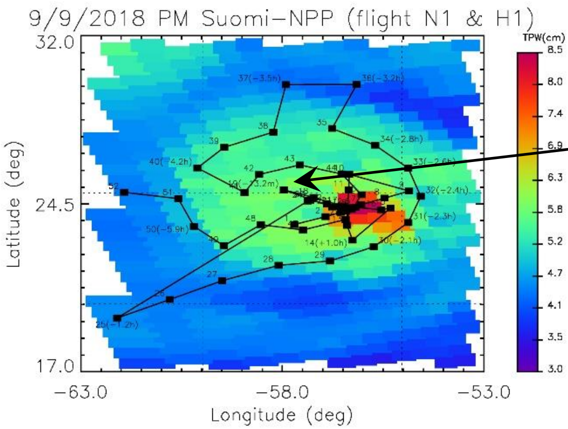


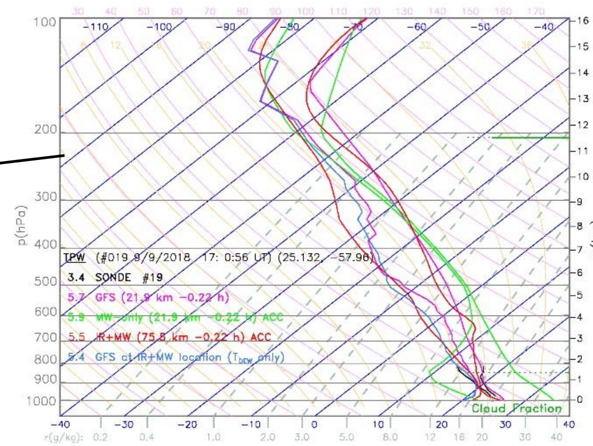
NPP is well centered spatially but the orbit occurred about 1.1 hour before sonde #25 was dropped. Therefore, we can look at all the sondes up to #24.

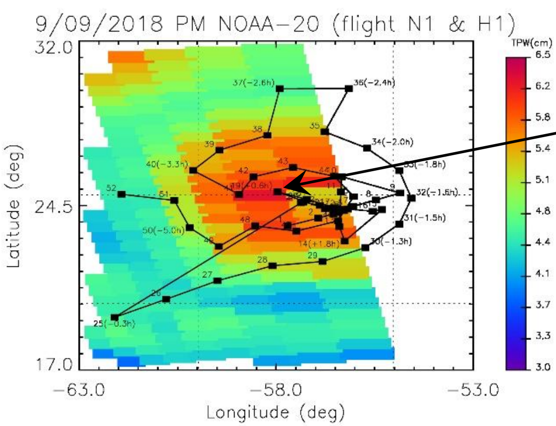
NOAA-20 overpass is closer in time (0.35 hour before sonde #25) but many sondes are in the gap of NOAA-20 and should be ignored.

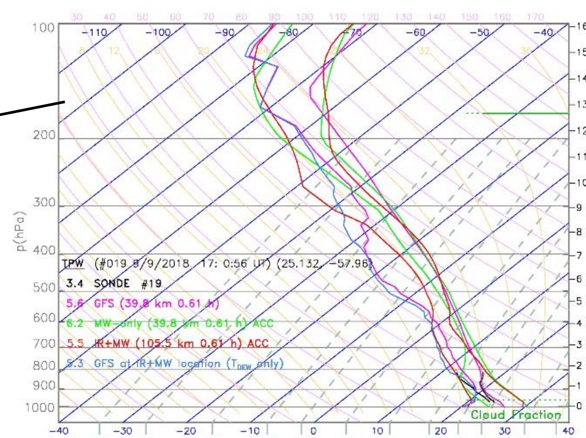
This shows the value of having 2 satellites

Hurricane Florence campaign, Sep. 9, 2018









Sonde #19 is shown here. This is from the “H1” flight which is a ***P-3 aircraft***

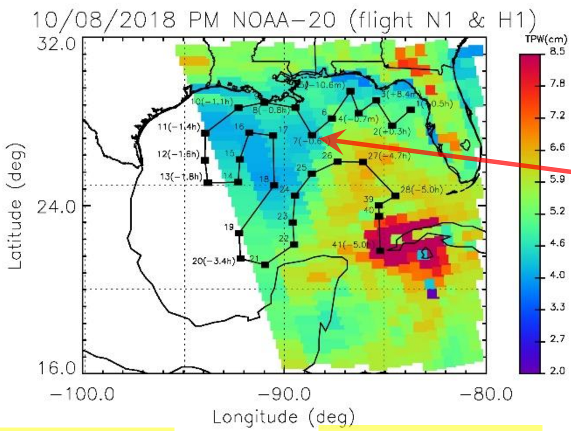
S-NPP is well centered and the orbit occurred about 13 minutes before sonde #19 was dropped. For S-NPP the closest MIT was accepted but the closest accepted RET is 75 km away. GFS is plotted for both.

NOAA-20 overpass is also close in time (36 minutes after sonde #19). Again, closest RET was rejected, so one shown is ~100 km away.

Again, shows value of 2 satellites. In this case 2 views of same scene are both within ½ h.

Hurricane Michael campaign, Oct. 8, 2018

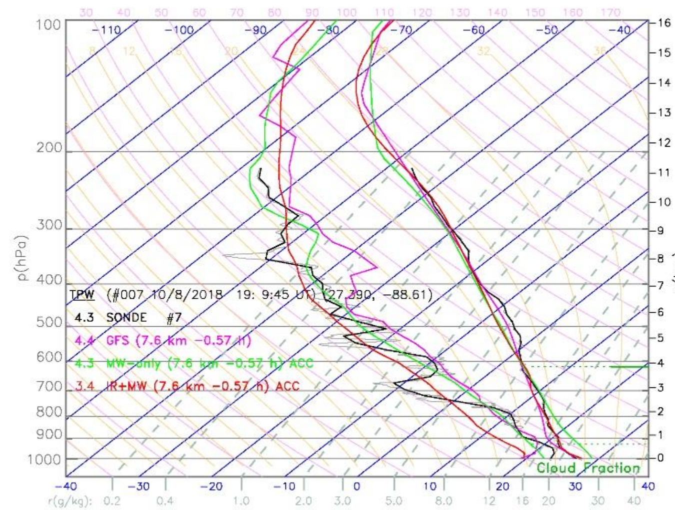
Sonde #7
19:10 UT

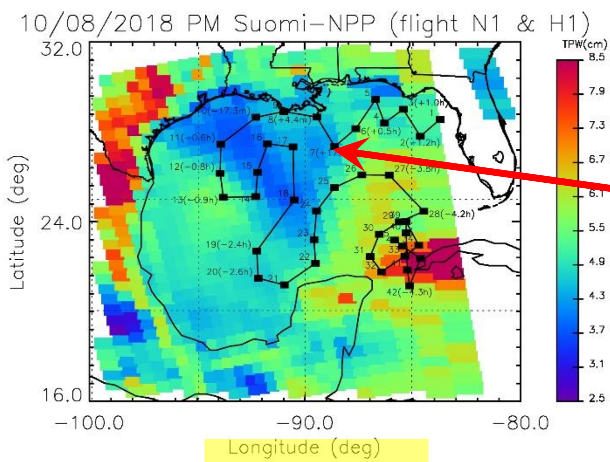


NOAA-20
NUCAPS
7 km
-34 min

20:15 UT

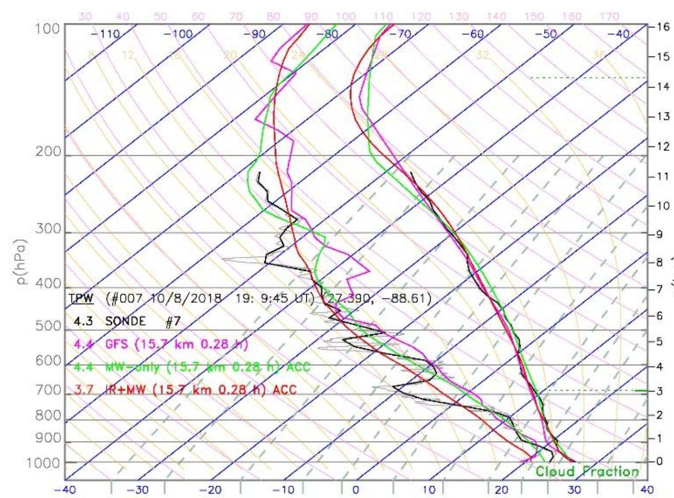
18:35 UT



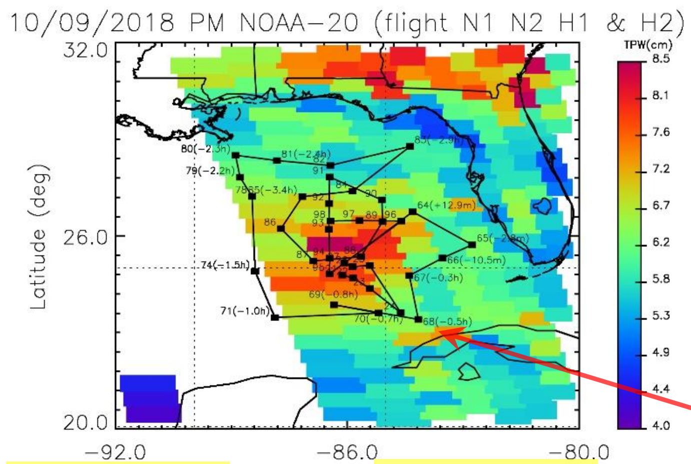


19:25 UT

S-NPP
NUCAPS
15 km
+17 min



Hurricane Michael campaign, Oct. 9, 2018

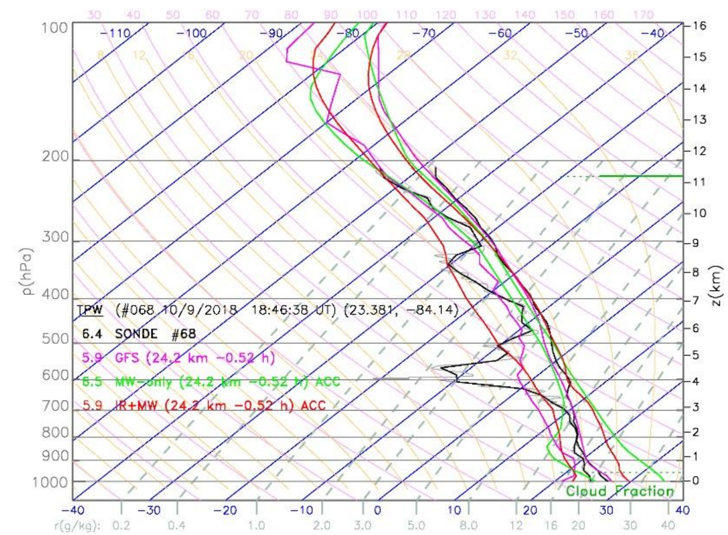


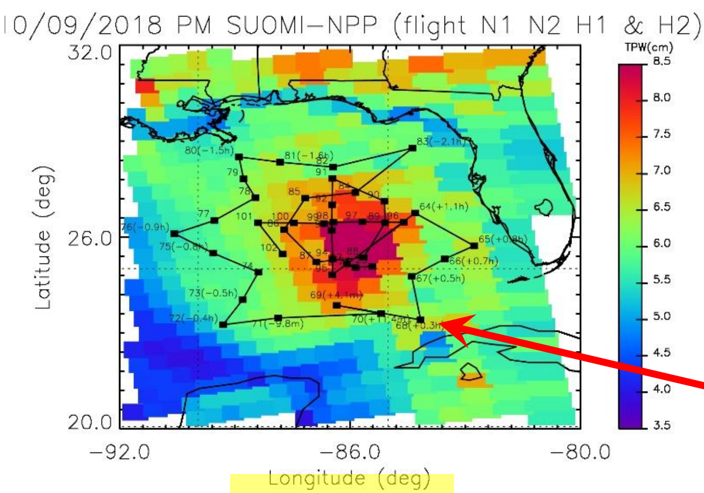
19:55 UT

18:15 UT

Sonde #68 18:47 UT

NOAA-20 NUCAPS 24 km -31 min





19:07 UT

S-NPP NUCAPS 34 km +20 min