2009 IEEE International Geoscience and Remote Sensing Symposium
Earth Observation – Origins to Applications
July 12-17, 2009 • Cape Town, South Africa

MODIS Applications

MODIS direct broadcast data for enhanced forecasting and real-time environmental decision making

CIMSS

NASA

8 July 2009

Kathleen Strabala

Part 2

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison USA

Aviation Applications Continued

- Clouds
  - Composition
  - Cloud Top Properties
  - Cloud Phase

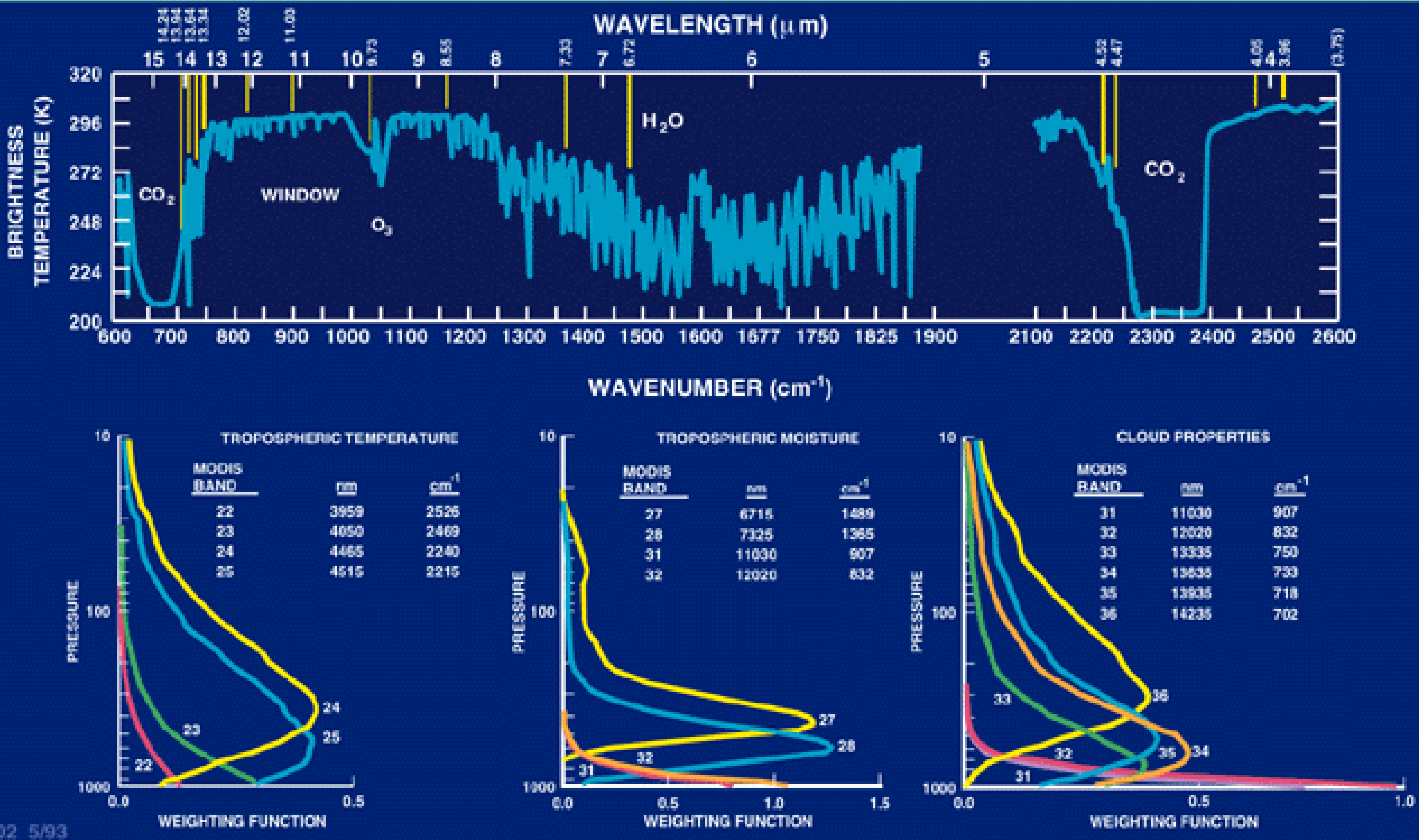
Clouds

- MOD06 Cloud Product contains
  - Cloud Top Properties at 5km
    - Cloud Top Pressure, Cloud Top Temperature, Cloud Fraction, Cloud Emissivity
  - Cloud Phase at 5 km
  - Cloud Optical Properties at 1 km (Daytime only)
    - Cloud Effective Radius
    - Cloud Optical Thickness
    - Not part of current IMAPP – soon to come

Cloud Top Property Algorithm

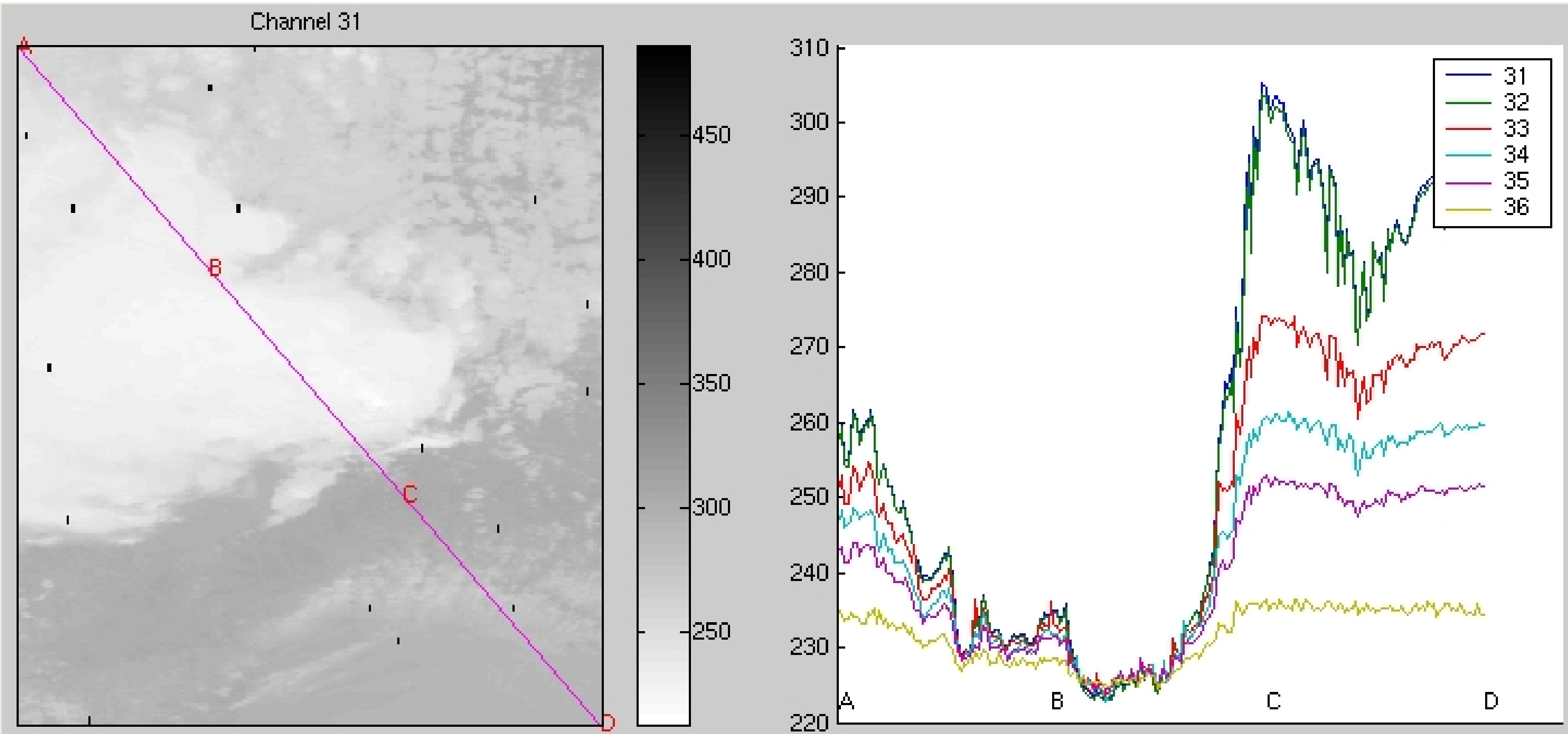
- Cloud Top Pressure, Temperature, Emissivity derived using CO_2 “slicing”
- MODIS product utilizes 4 spectral channels in the 13 – 14 μm region.
- 5x5 1 km pixel retrievals where at least 5 of the 1 km pixels are cloudy as determined by the cloud mask
- Cloud properties retrieved both day and night

ATMOSPHERE - THERMAL RADIATION

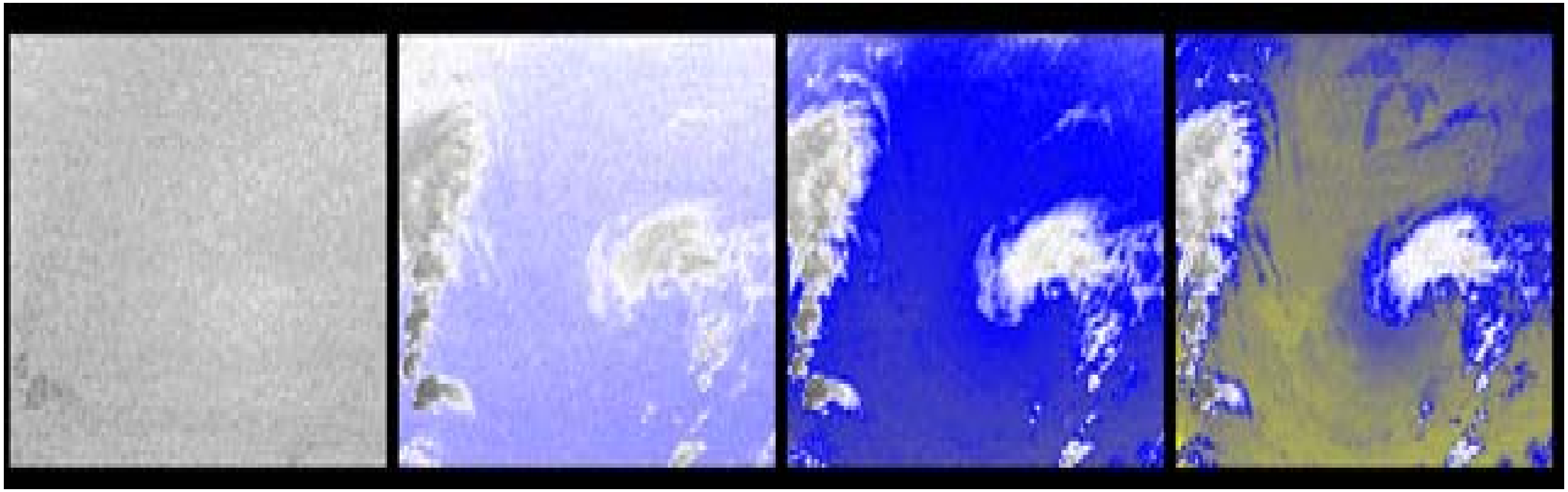


BT in and out of clouds for MODIS CO_2 bands

- demonstrate weighting functions and cloud top algorithm



CO2 channels see to different levels in the atmosphere

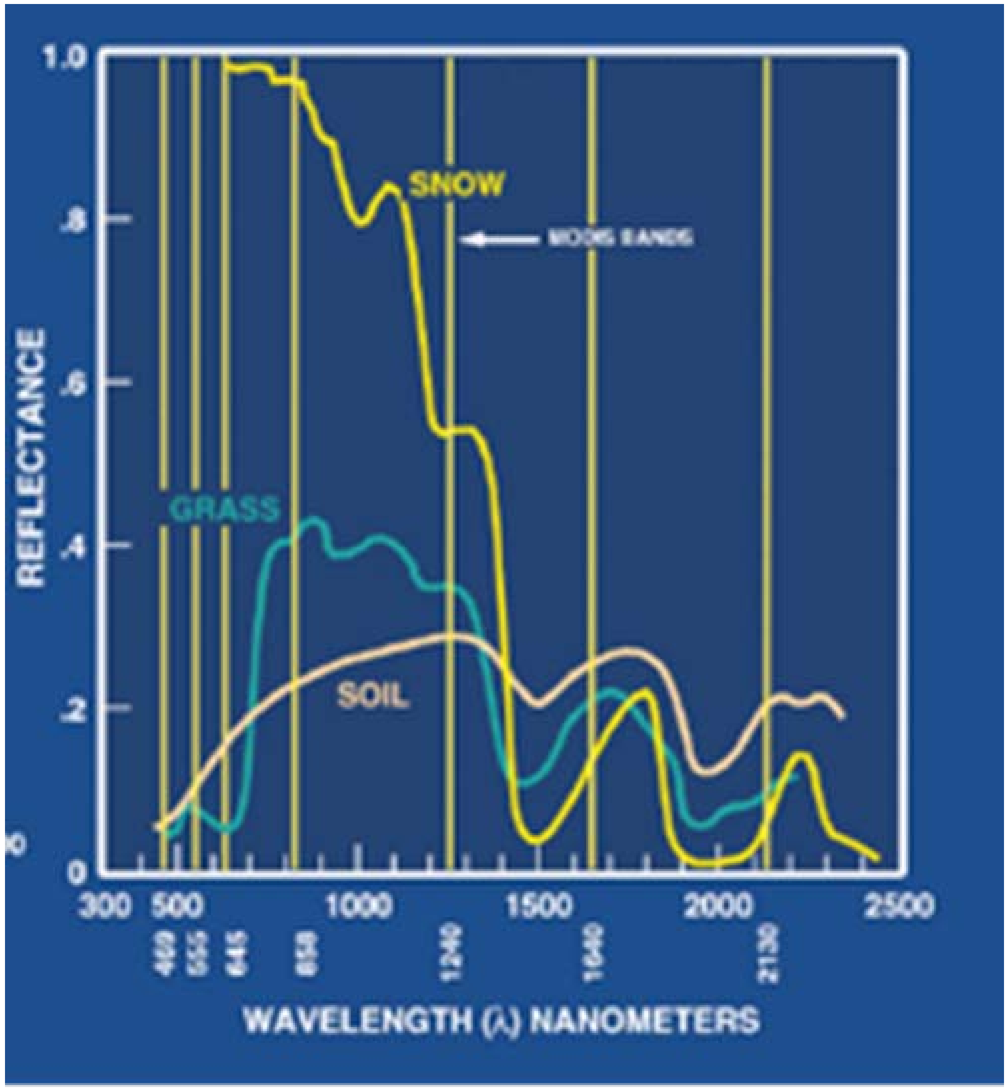


14.2 um 13.9 um 13.6 um 13.3 um

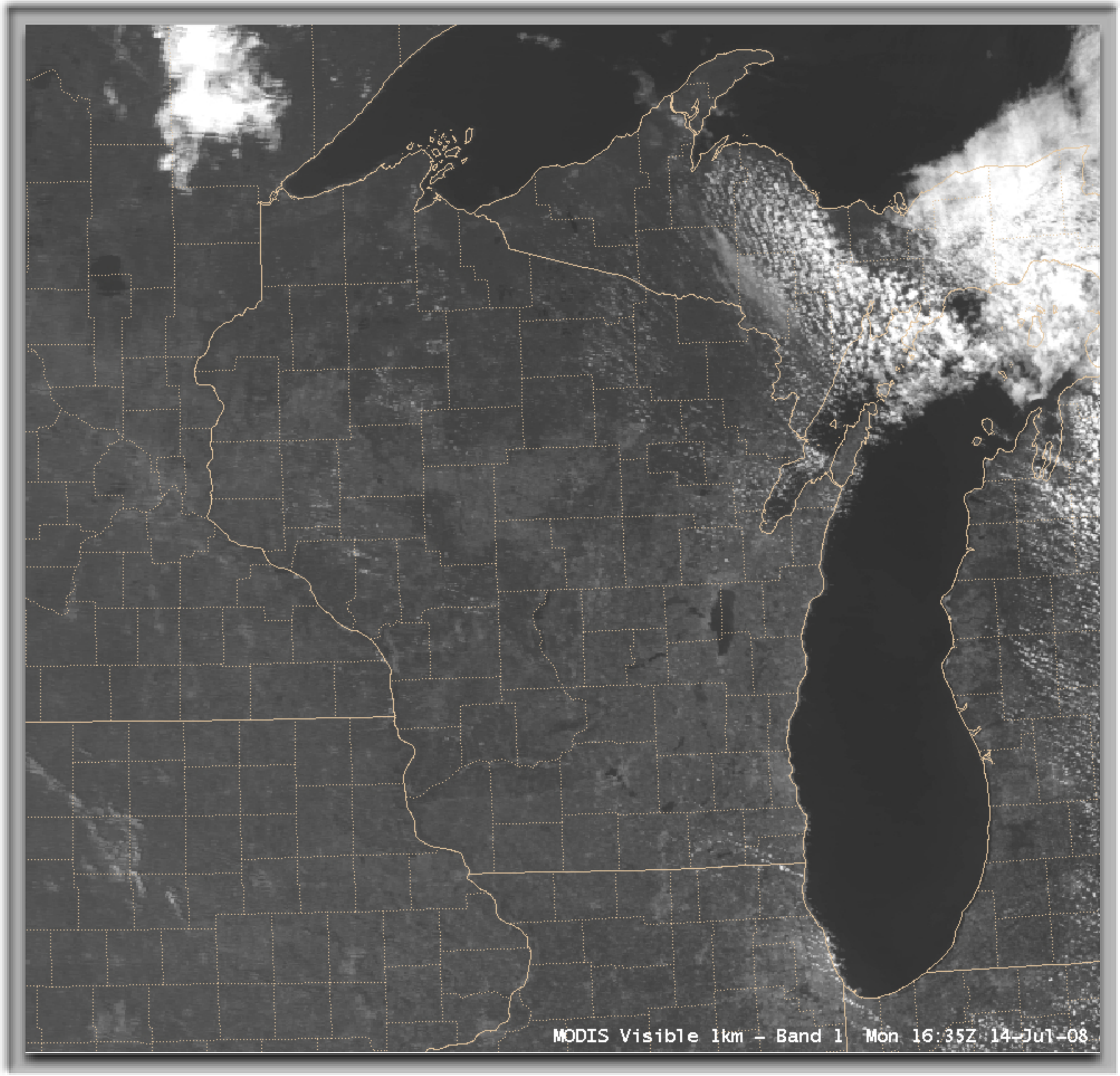
Cloud Phase

- IR Brightness Temperature Difference Product
  - Band 29 (8.6μm) – Band 31 (11μm)
  - Takes advantage of difference in water/ice cloud absorption in this spectral region
- Near Infrared Bands (1.6 and 2.1μm)
- Short Wave Infrared Bands (4μm region)

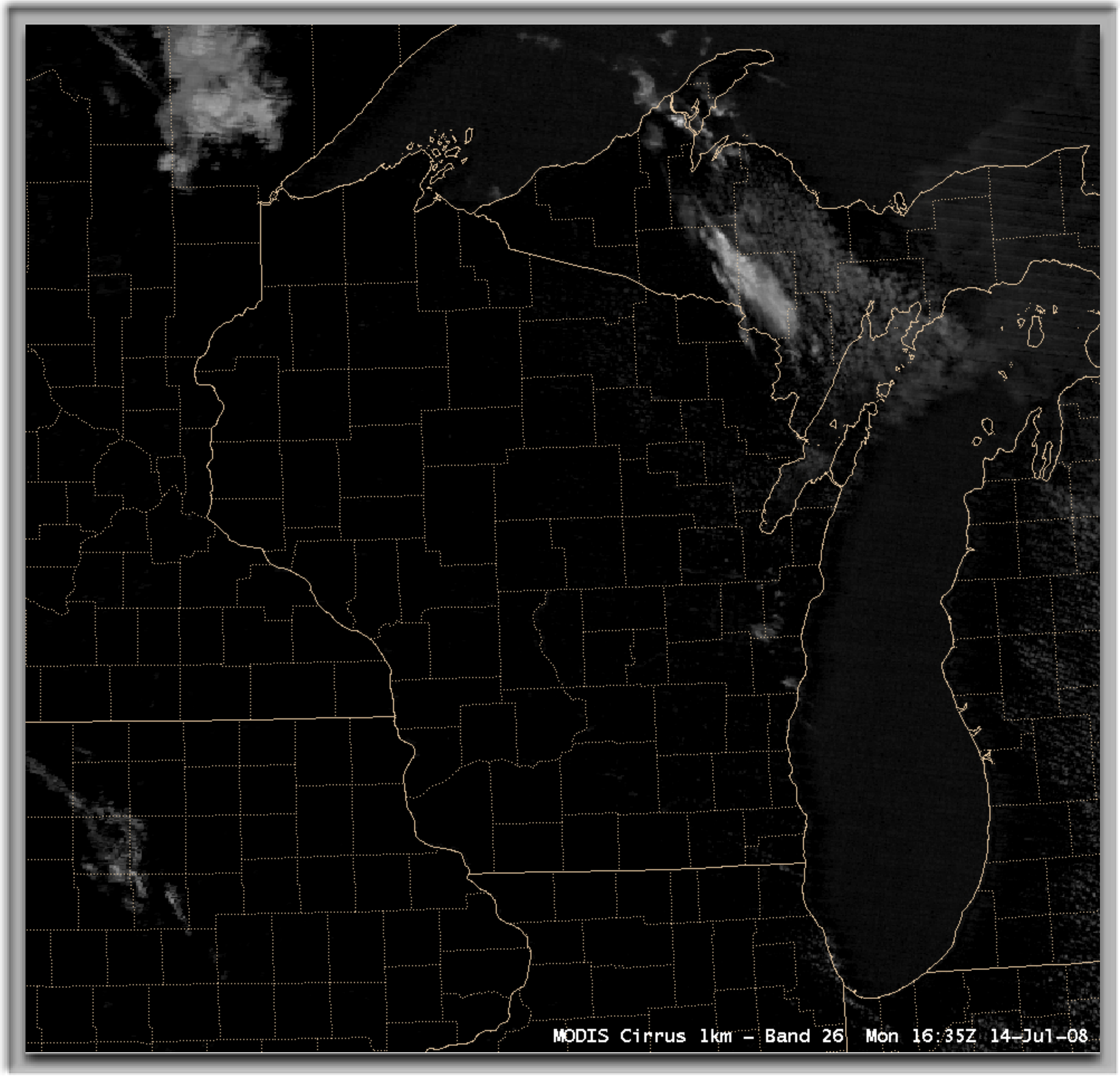
MODIS – Snow/Ice and Ice Clouds



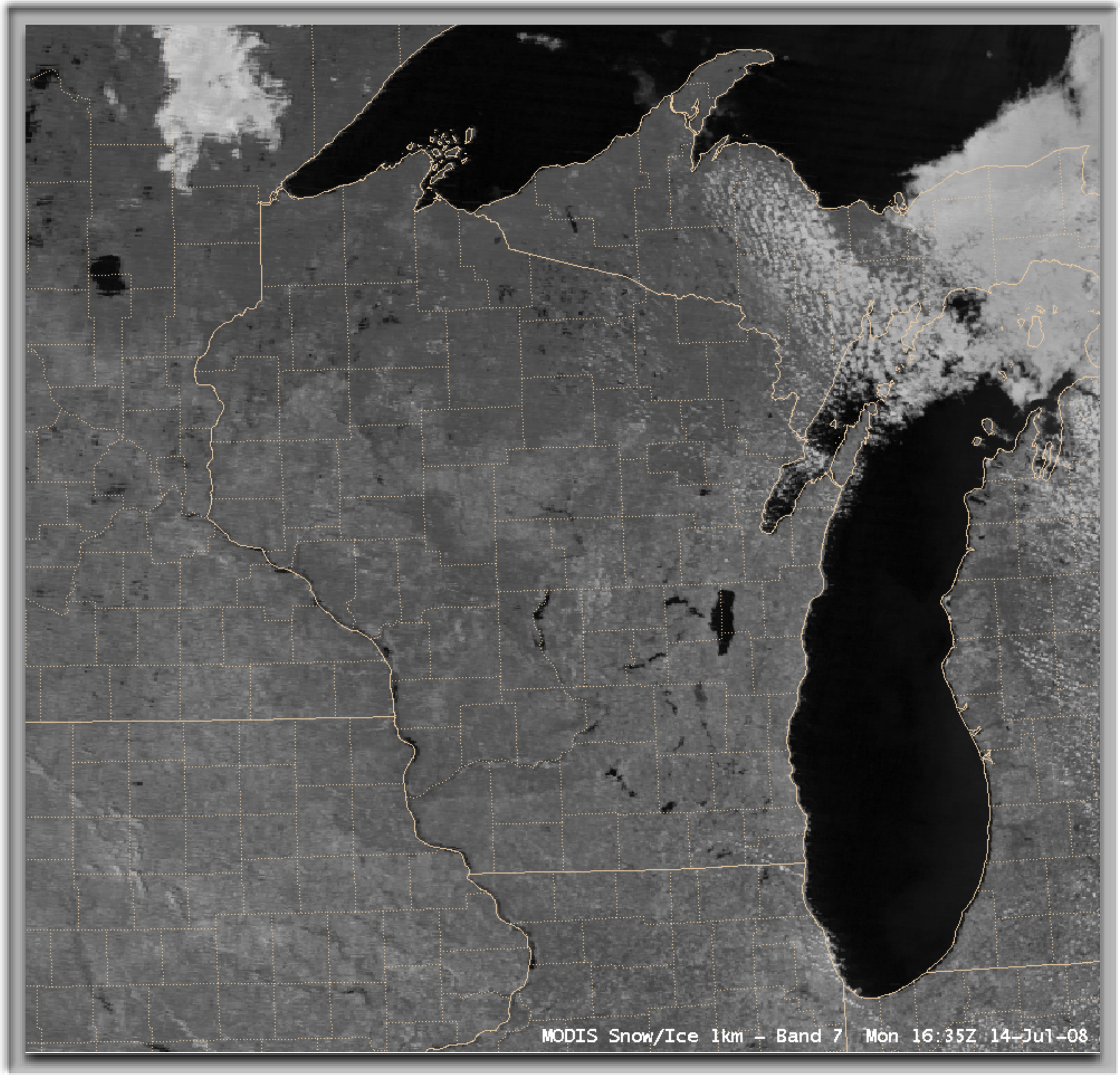
MODIS Products in AWIPS



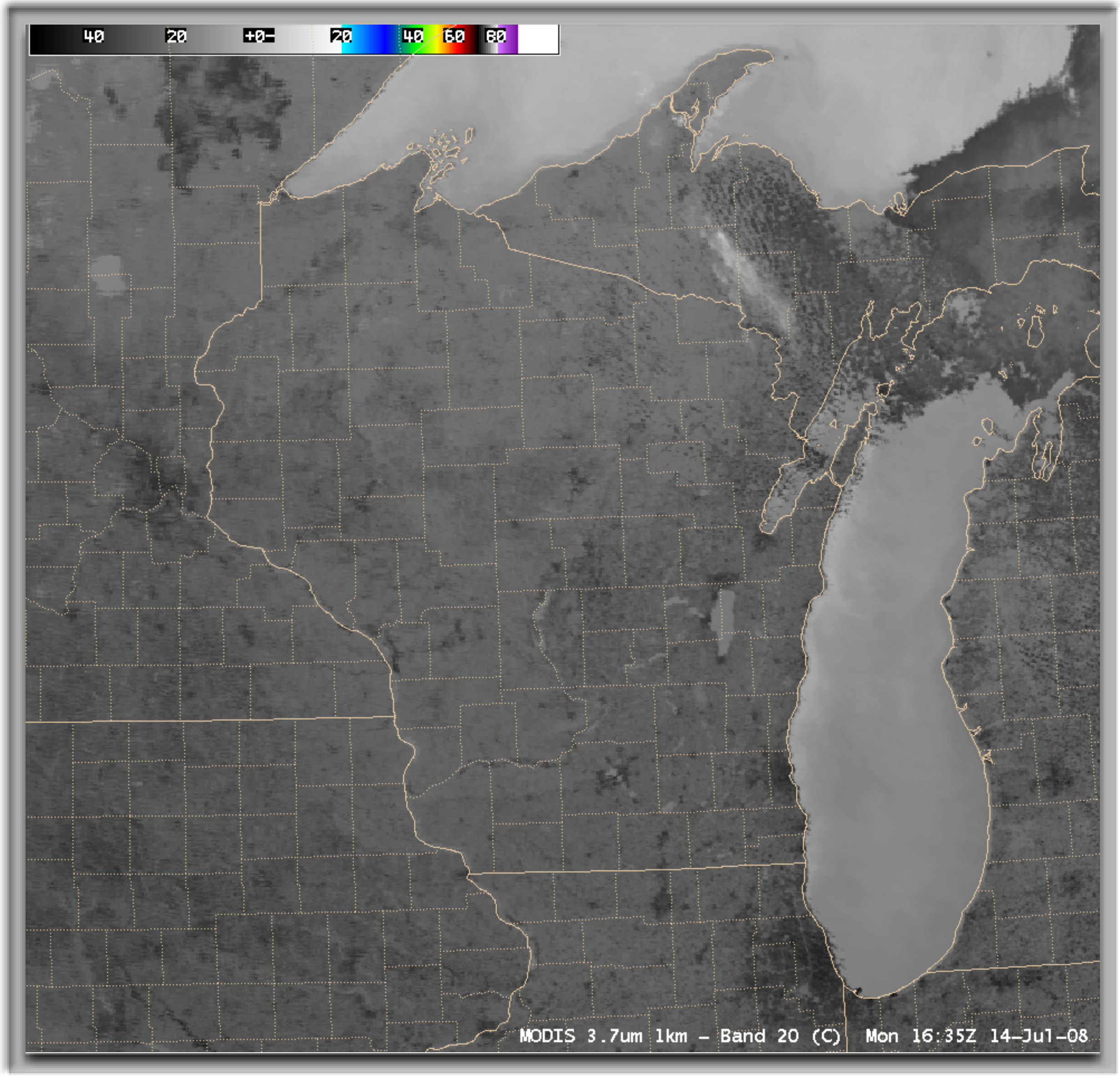
Visible (0.65 µm): 1-km resolution



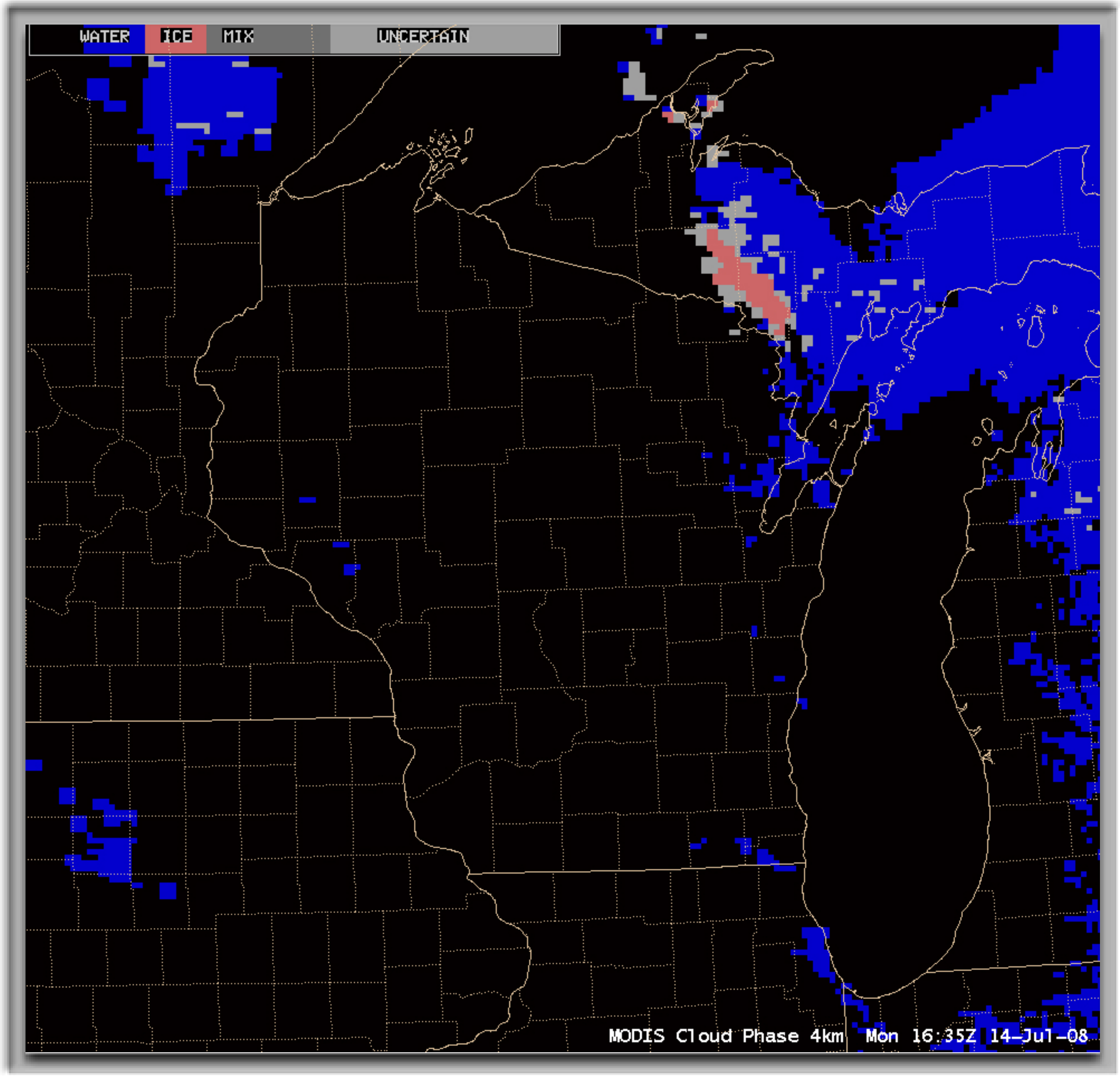
Cirrus detection (1.3 µm): 1-km resolution



Snow/ice discrimination (2.1 µm): 1-km resolution

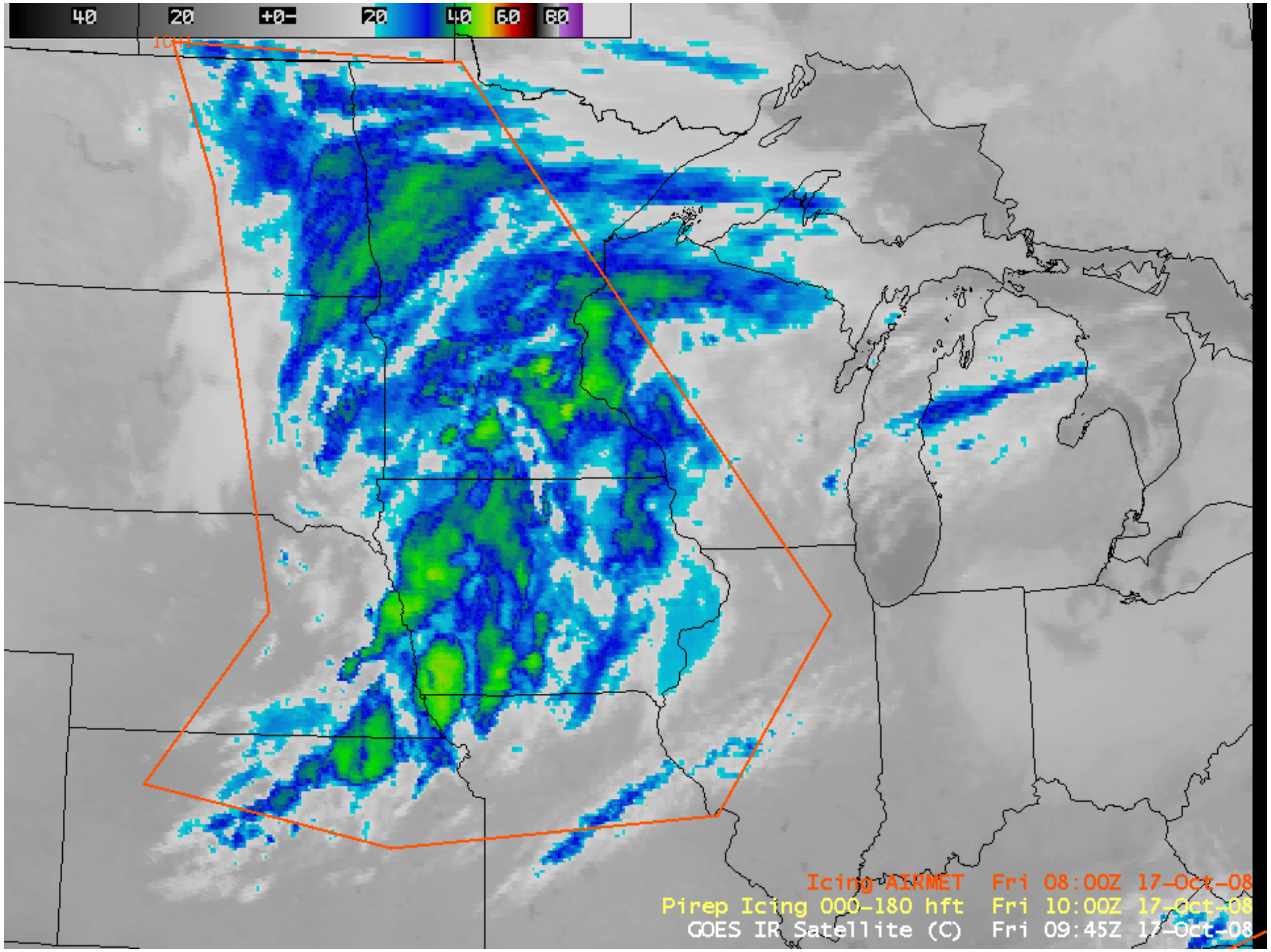


Shortwave IR (3.7 µm): 1-km resolution



Cloud Phase: 4-km resolution

Using Satellite Imagery to Help Diagnose Areas of Aircraft Icing Potential



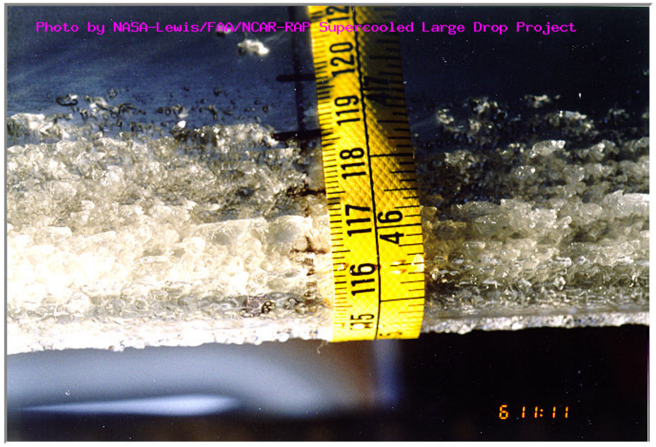
GOES IR window animation 17 October 2008

Icing

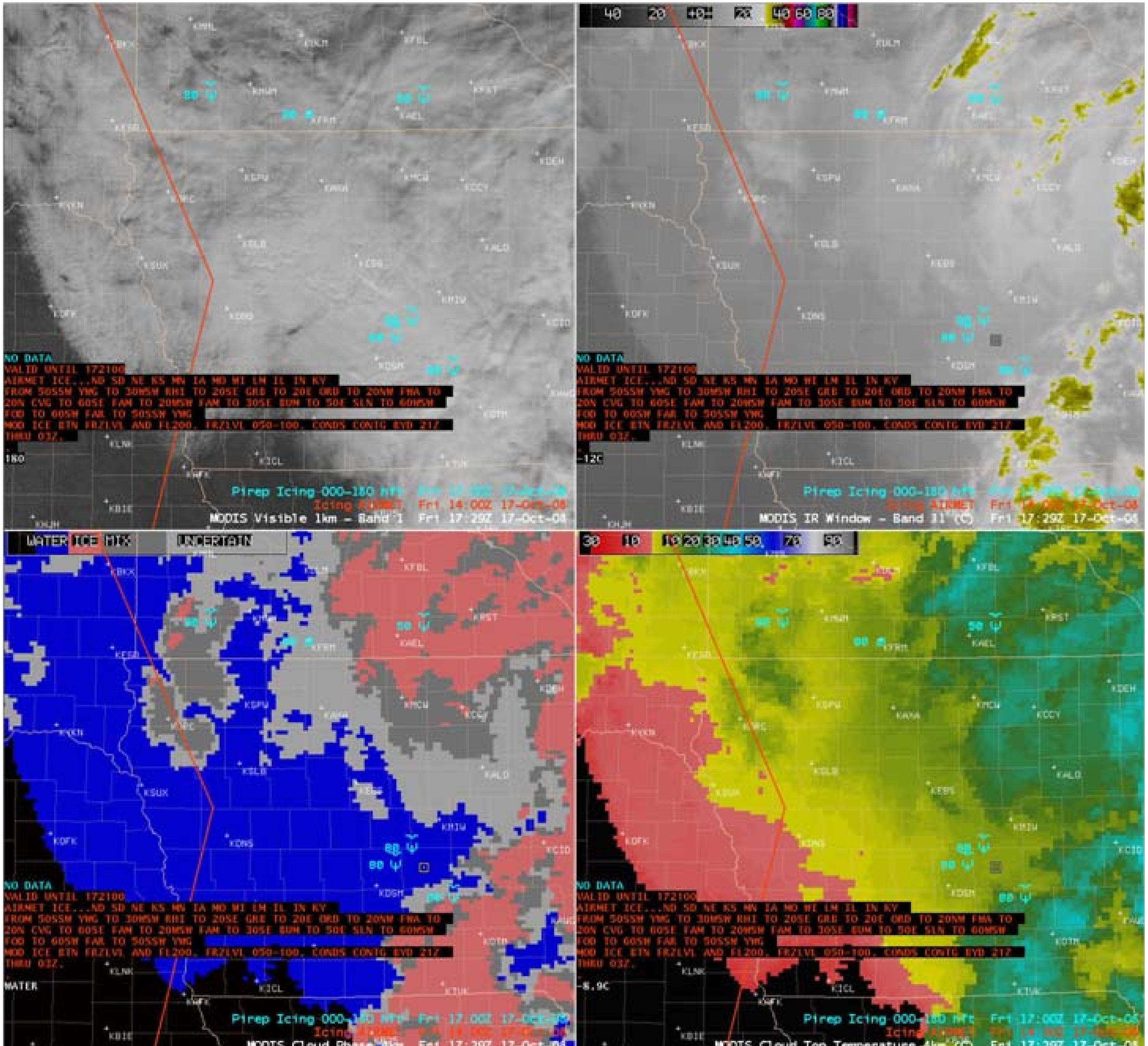
- Freezing Level
  - Altitude at which the temperature is 0 degrees C
  - Above this level the temperature is < 0 C
- Water Can Exist at Temperatures Well Below Freezing
  - Supercooled Water
- An airplane whose temperature is < freezing in this environment can accrue ice

Why is This Important?

- We worry about icing because it can adversely affect the flight characteristics of an aircraft. Icing can increase drag, decrease lift, and cause control problems. The added weight of the accreted ice is generally only a factor in light aircraft.



Ice Accumulation On
The Wing of a Small Aircraft
NASA



NO DATA
VALID UNTIL 172100
AIRMET ICE...ND SD NE KS MN IA MO WI LM IL IN KY
FROM 50SSW YWG TO 30WSW RHI TO 20SE GRB TO 20E ORD TO 20NW FWA TO
20N CVG TO 60SE FAM TO 20WSW FAM TO 30SE BUM TO 50E SLN TO 60WSW
FOD TO 60SW FAR TO 50SSW YWG
MOD ICE BTN FRZLVL AND FL200. FRZLVL 050-100. CONDS CONTG BYD 21Z
THRU 03Z.
Pirep Icing 000-180 hft Fri 17:00Z 17-Oct-08
Icing AIRMET Fri 14:00Z 17-Oct-08
MODIS Visible 1km - Band 1 Fri 17:29Z 17-Oct-08
MODIS IR Window - Band 31 (C) Fri 17:29Z 17-Oct-08
WATER ICE MIX UNCERTAIN
MODIS Cloud Phase 4km Fri 17:29Z 17-Oct-08
MODIS Cloud Top Temperature 4km (C) Fri 17:29Z 17-Oct-08

Other Cloud Applications Too

- Identification of mature T-storms
  - Must glaciate, meaning tops of cell must be ice
- Accurate height of "thin" high clouds
  - Energy transmitted from below the cloud in the IR window. Can't get accurate level from window BT.
  - Important for pilots. Clouds mean more moisture, dry entrainment and potential for turbulence.

Ash Detection

Why is this important?

- Ash particles can clog airline engines
- One such event caused a commercial airliner to make an emergency landing

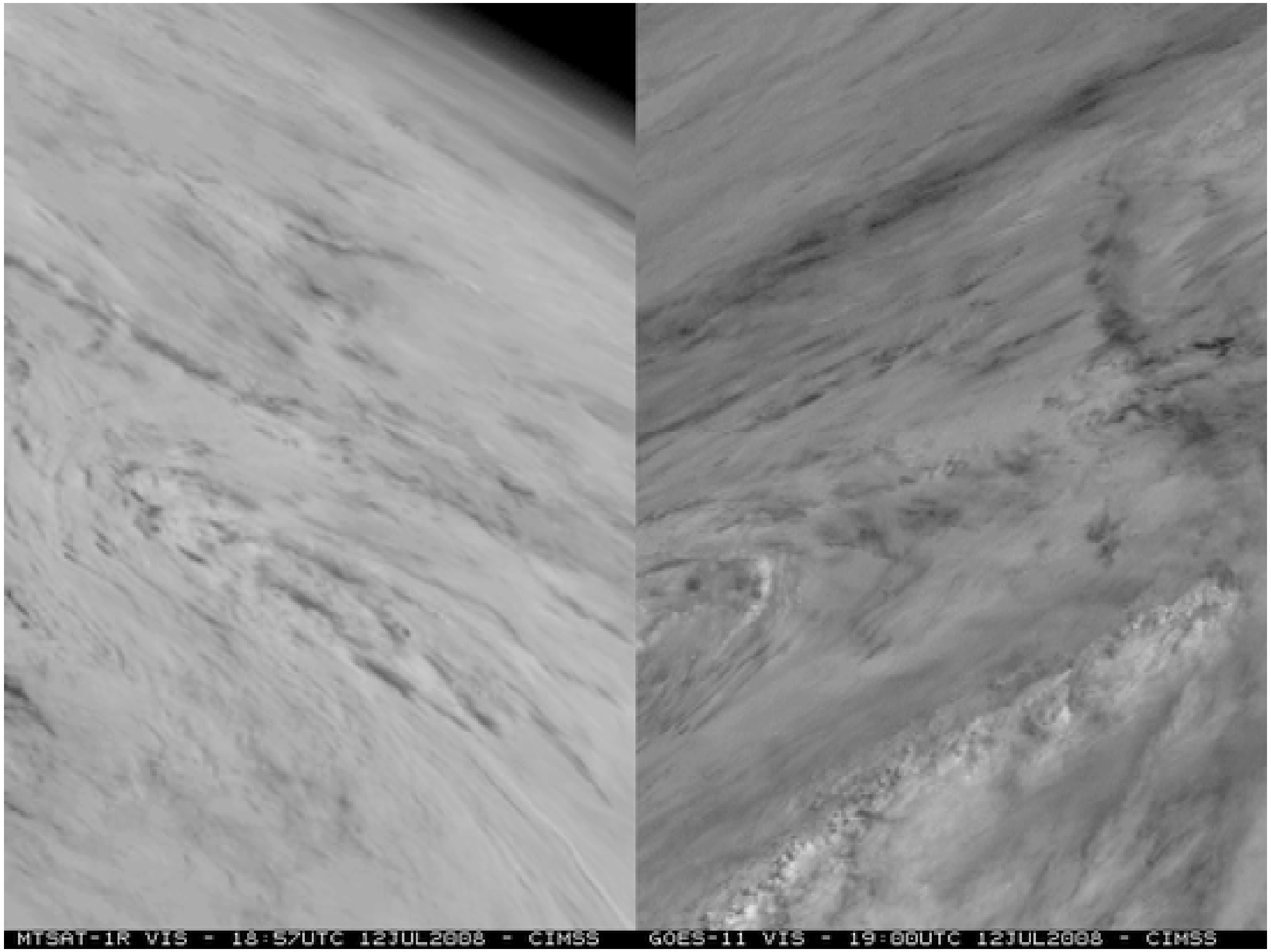
Okmok Volcano

Okmok Volcano Eruption

13 July 2008

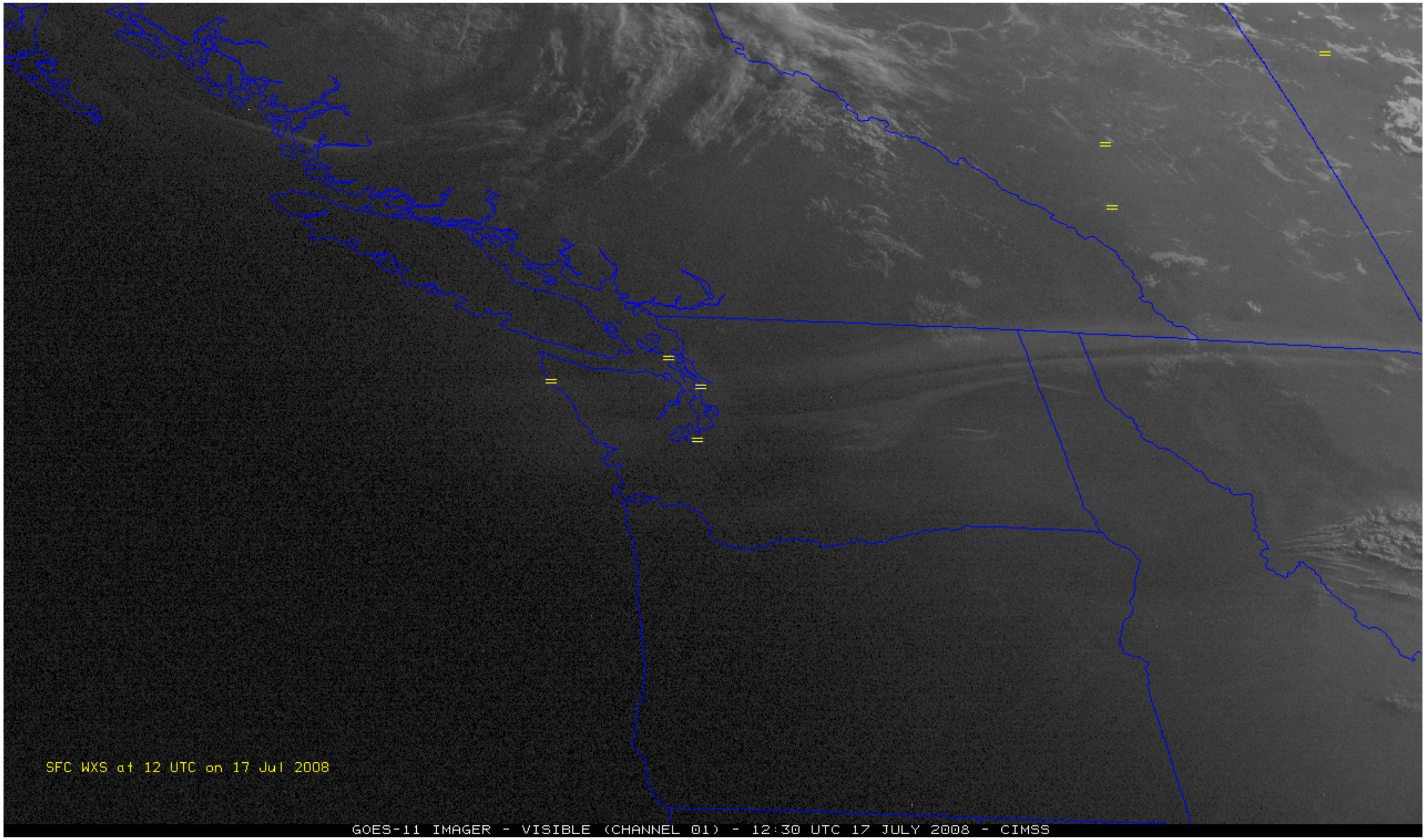
Okmok Eruption

12 July 2008



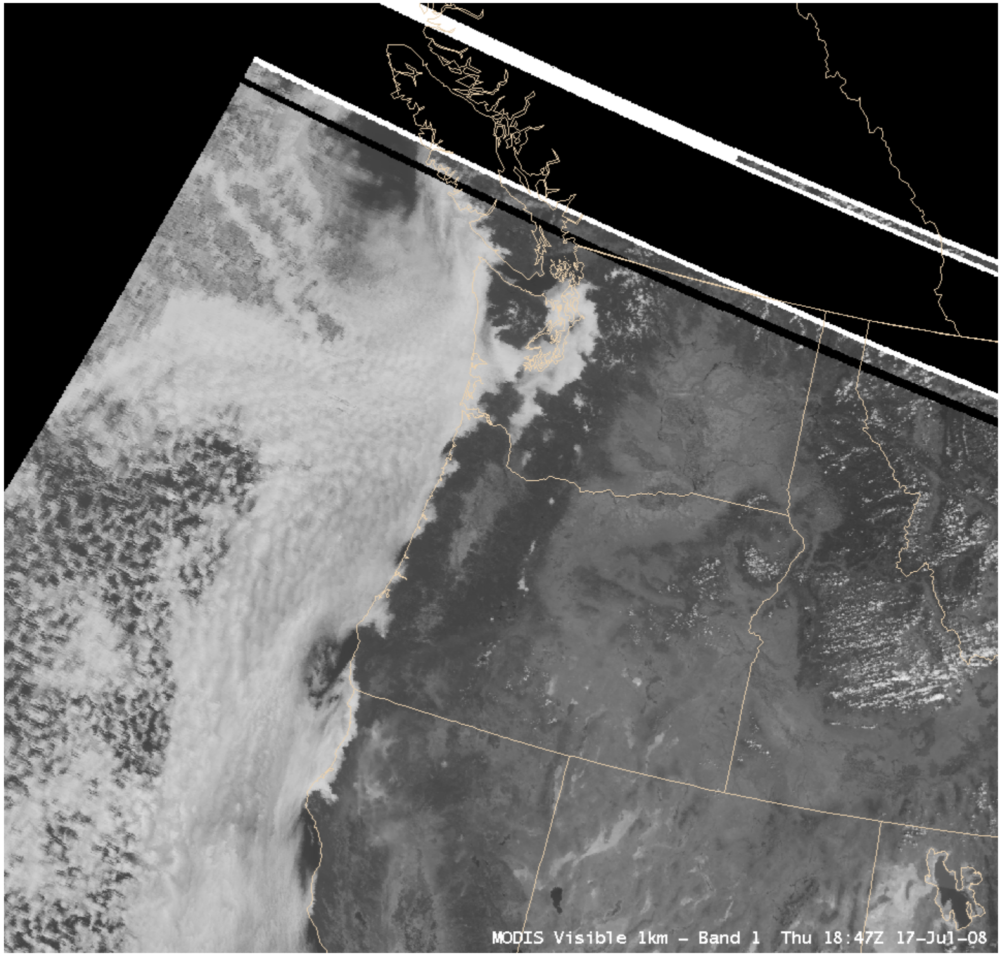
GOES Visible Image Loop

17 July 2008



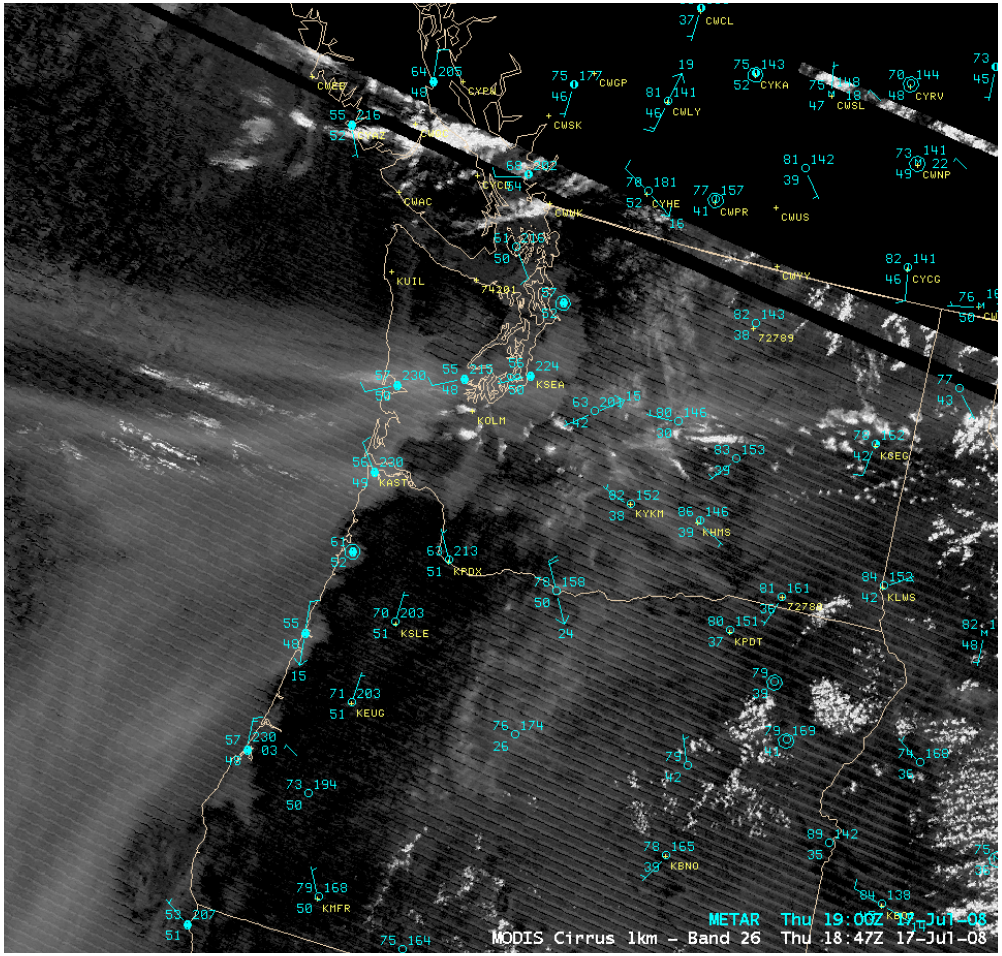
Terra MODIS Band Comparison

17 July 2008

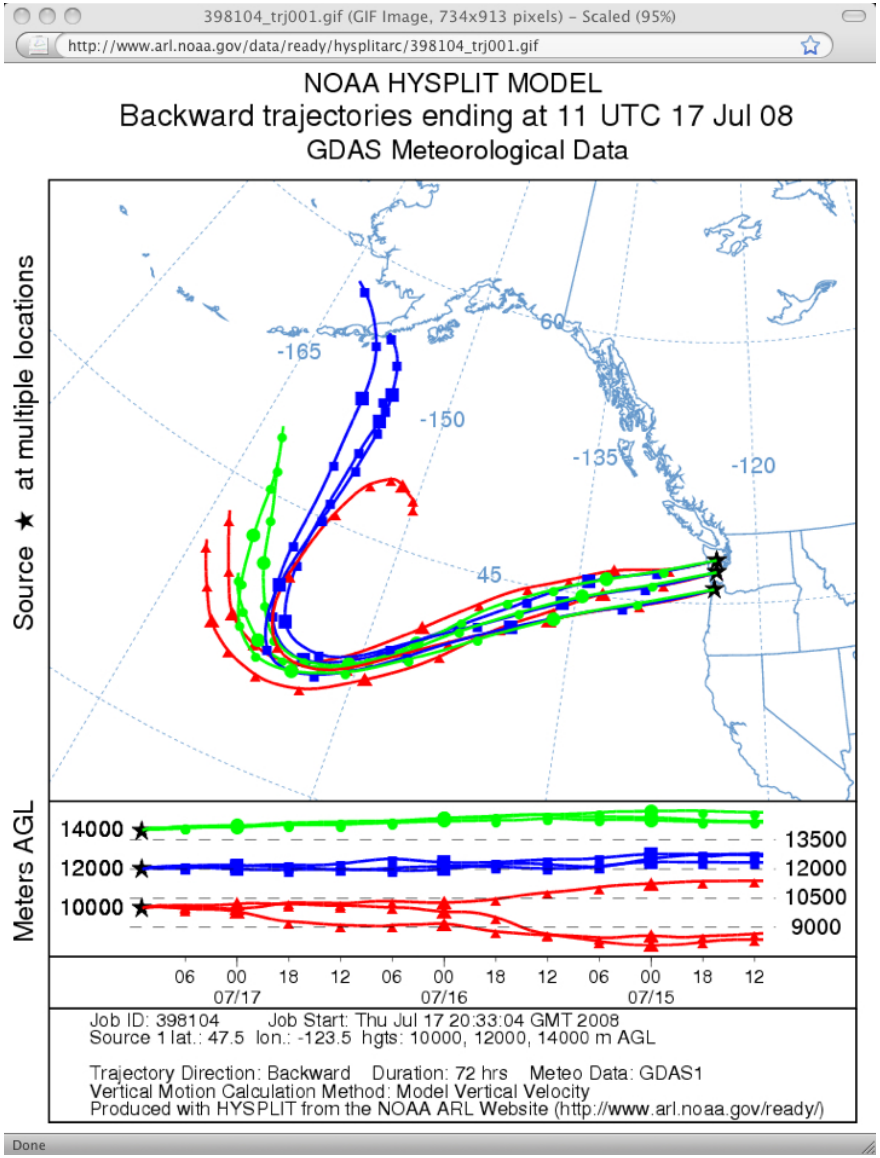


MODIS 1.38 μm Reflectances

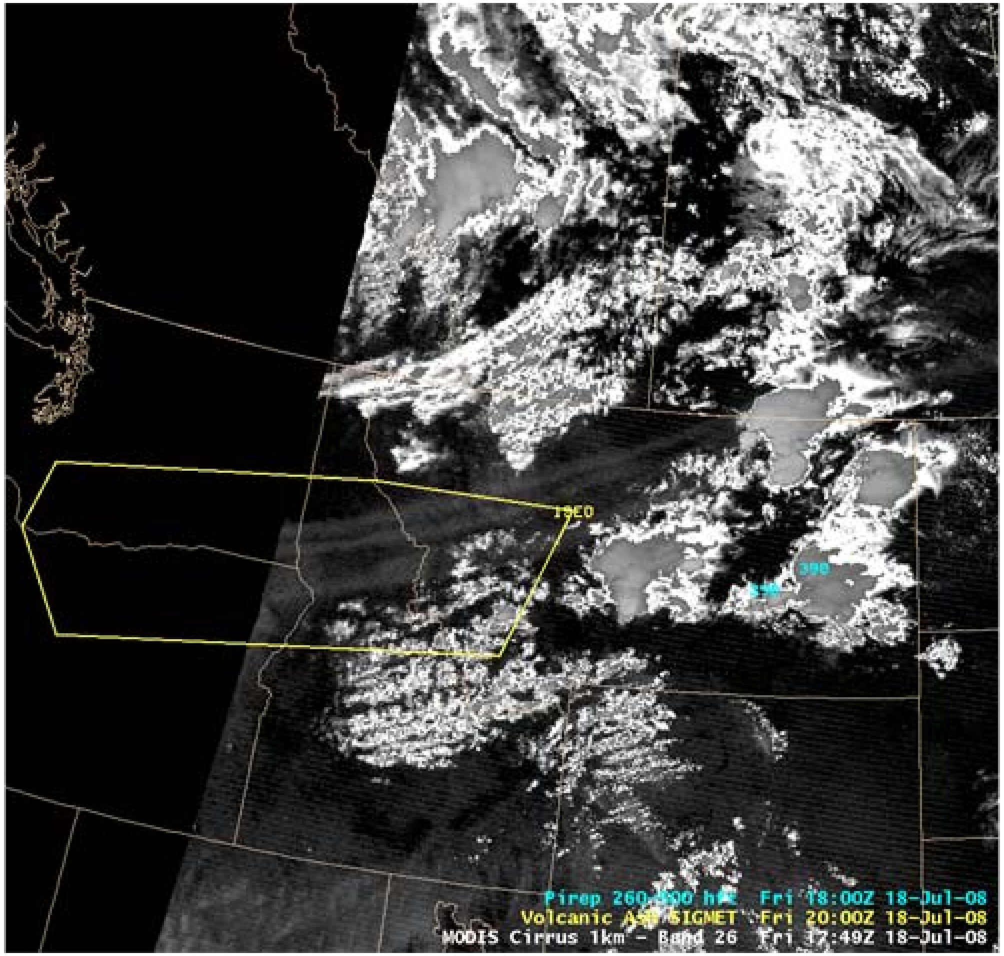
17 July 2008



NOAA Aerosol Trajectory Model



MODIS 1.38 μm Reflectances



18 July 2008

Pilot Reports

18-19 July 2008

Pilot reports (PIREPS) from aircraft encountering the Okmok volcanic plume over the northwestern and northcentral continental US on 18-19 July 2008:

DLN UA /OV DLN 270080/TM 1900/FL320/TP MD80/RM ORANGE CLOUD ASSOCIATED WITH VOLCANIC ACTIVITY. NO SMELL, CLR ABV/BLW FL320/ZLC

RDM UUA /OV DSD280030/TM 1909/FL310/TP B737/RM LGT ASH CLOUD FL320 -ZSE

PDX UUA /OV BTG180060/TM 1912/FL330/TP B738/RM FL330-310 ASH CLOUD CLR AT FL300 -ZSE

SLE UA /OV BTG180060/TM 1921/FL300/TP B733/RM BAND OF SULFER DIOXIDE WEST TO EAST FL300-340 AWC-WEBSWA

PDT UA /OV PDT/TM 1937/FL380/TP NUMEROUS/SK ORANGE HAZE/RM VOG 320-380 SMELLS THROAT IRRATATION -ZSE

PDX UUA /OV KPDX/TM 2018/FL320/TP B739/RM VERY THIN PROB ASH CLOUD VISIBLE E-W OVER PDX AND MT HOOD AT APPROX FL320 AWC-WEBASA

LWS UUA /OV MQG130050/TM 2051/FL350/TP B737/RM VOLCANIC ASH CLOUD 320-380 –ZSE

LWS UUA /OV MQG 135060/TM 2053/FL320/TP SVRL ACFT/RM VOLCANIC ASH CLOUD 320-386 CLIMBING/DESCENDING TO AVOID ZLC

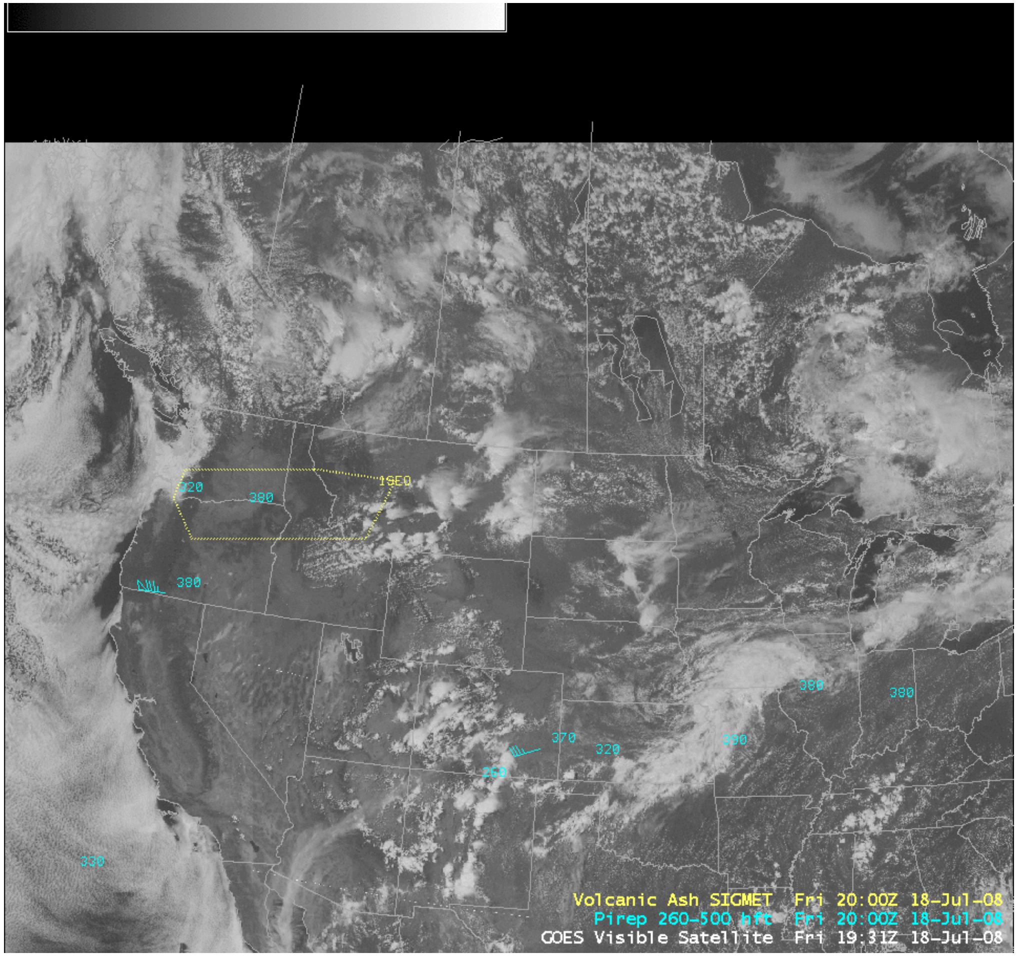
MSO UA /OV MLP143070/TM 2053/FLUNKN/TP B737/RM BAND OF CLOUDS W/ ORANGE TINT FL300-FL350 AWC-WEBSWA

PDT UA /OV PDT200020/TM 2100/FL290/TP B737/WV 275039KT/TB SMOOTH/RM ASH CLOUD APPEARS TO BE DISPERSED IN SEVERAL AREAS.MAIN CLOUD LOCATED FURTHER NORTH RUNS W-E AWC-WEBSWA

MSO UUA /OV MSO 120030/TM 2115/FL320/TP CL60/RM ASH CLOUD FL320-395 ZLC

SIGMET eventually extended

18 July 2008

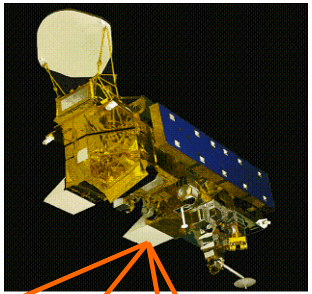


Numerical Weather Prediction

Good Grief, what is this doing here?

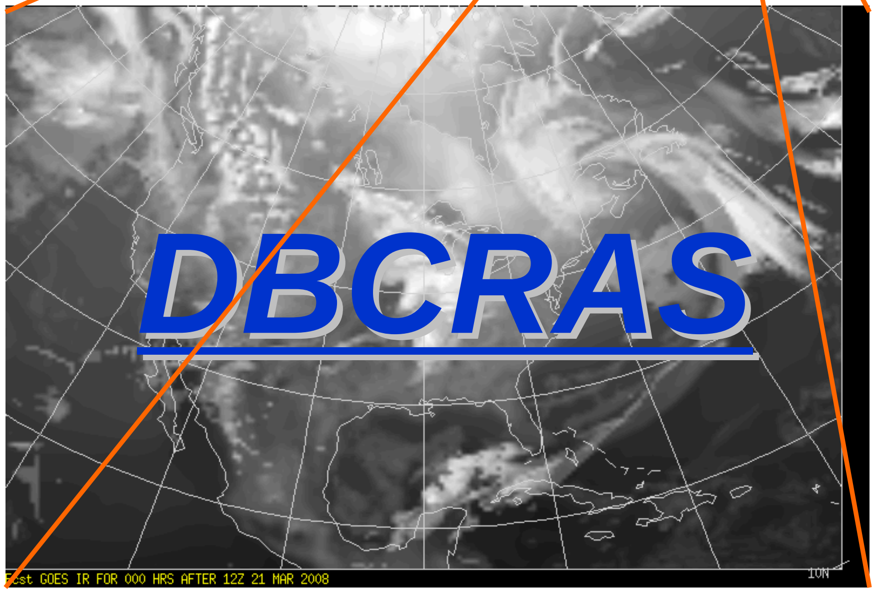
The Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin, Madison

The Direct Broadcast Version of the CIMSS Regional Assimilation System for Global Users



Bob Aune

Advanced Satellite Products Branch,
Cooperative Research Program
Center for Satellite Applications and Research
DOC/NOAA/NESDIS



What is Numerical Weather Prediction?

- Describing the Atmosphere mathematically
  - Equations of motion
- Taking the Derivative with respect to time
  - Delta T is time step
- Need good representation of the atmosphere in 3 dimensions to start with
  - Assimilation
    - Gathering all surface observations (METARS)
    - Radiosondes – Balloon launches that provide vertical profiles of the temperature, moisture and winds
  - Satellite observations

Why should I care about DBCRAS?

- It’s FREE!
- Configurable anywhere in the world
  - One time initial domain set-up. You provide central latitude/longitude
- Can run on any modest linux platform
- Produces standard meteorological products
  - Temperature, Moisture, Precipitation, Winds
- Provides unique products
  - Forecast water vapor and IR window satellite imagery

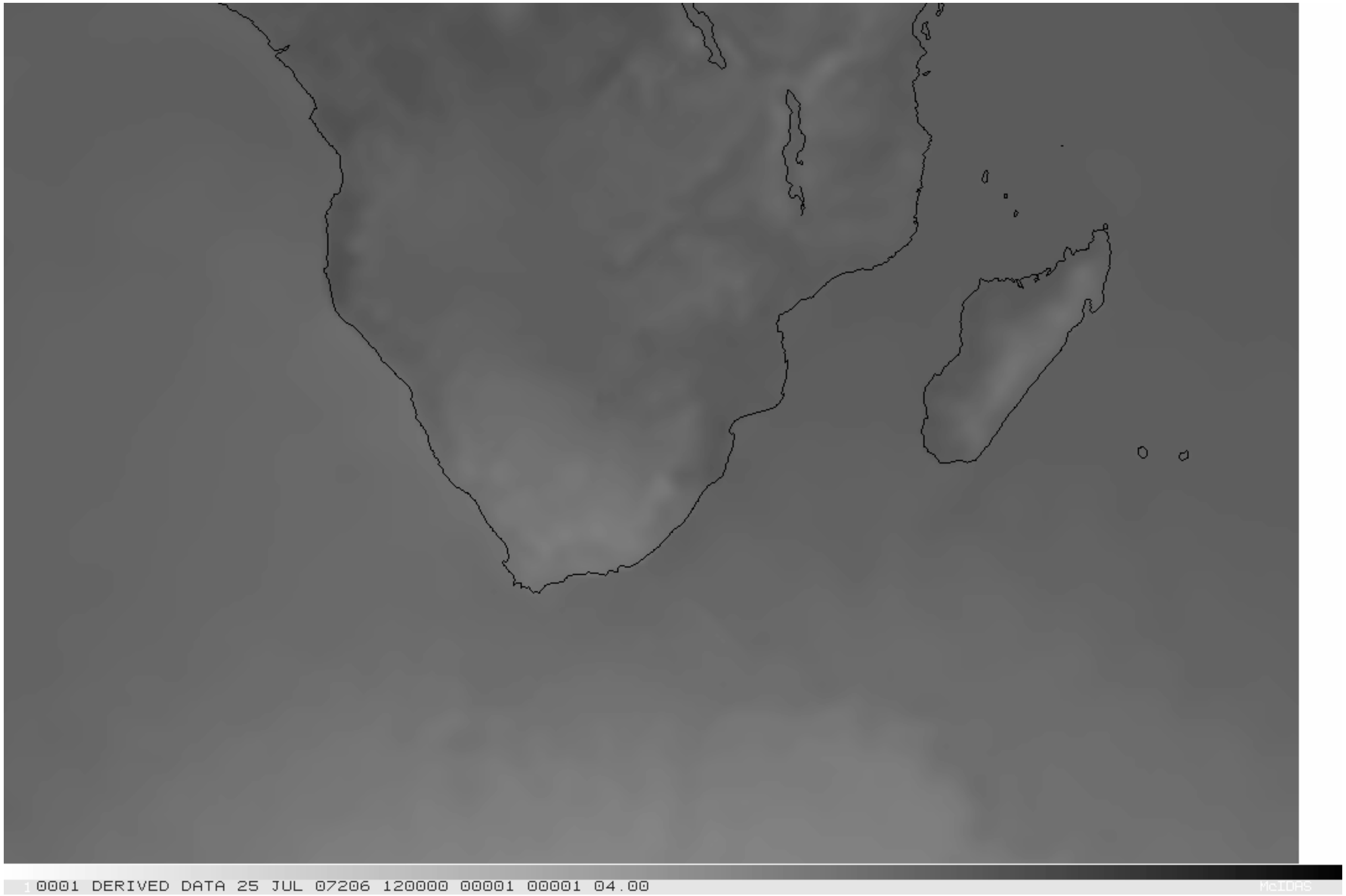
Why should I care about DBCRAS?

- Uses MODIS Products to improve the depiction of clouds and moisture in the initial model conditions
  - MOD07 Total Precipitable Water Vapor
  - MOD06 Cloud Top Pressure, Cloud Emissivity
- Others only assimilate satellite clear radiances
- Requires efficient and reliable internet connection
  - ≈500MB of ancillary data required per model run

Why should I care about DBCRAS?

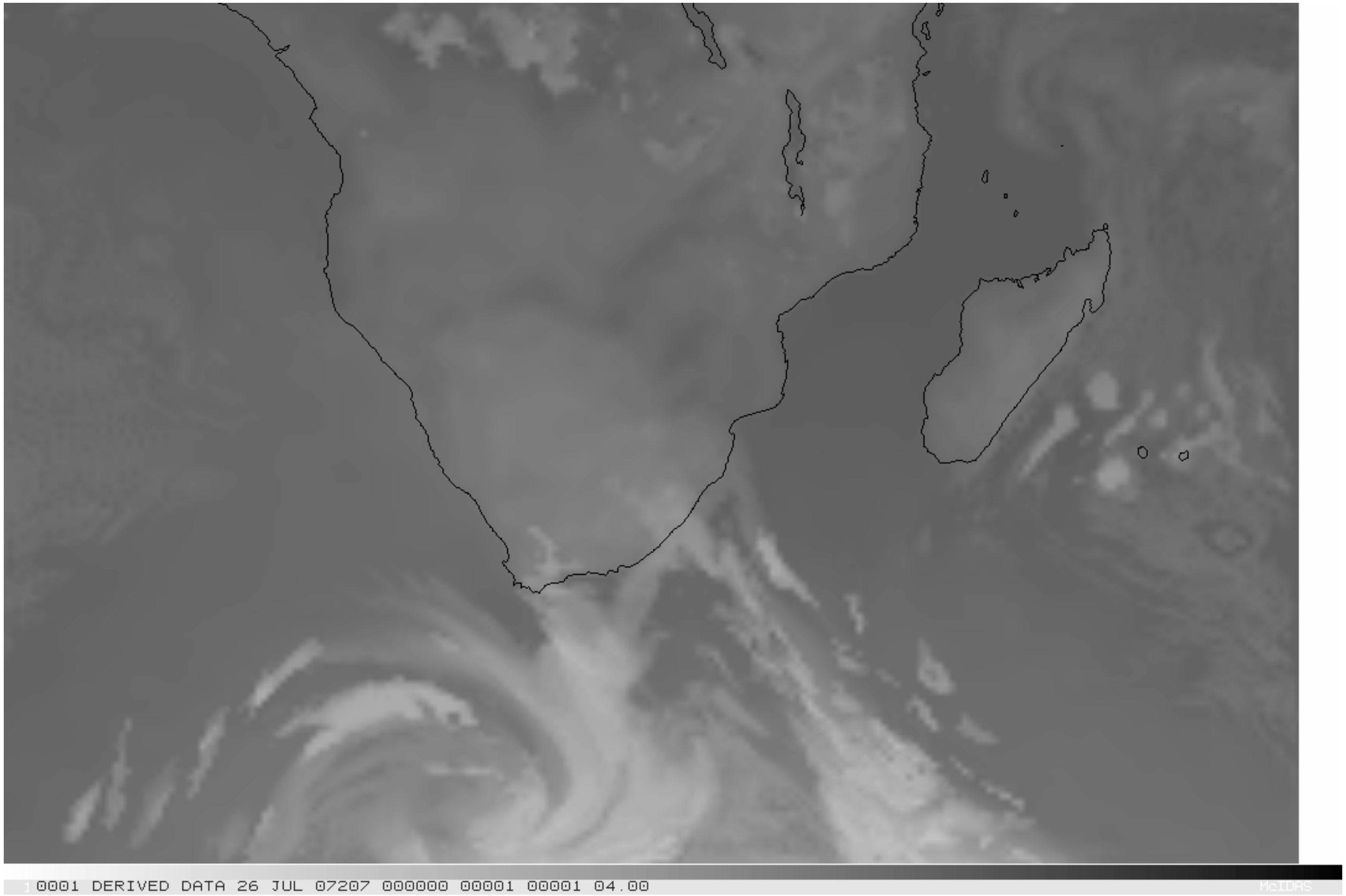
- Products created at 48 km resolution out to 72 hours
- Automatically creates forecast imagery

DBCRAS IR window



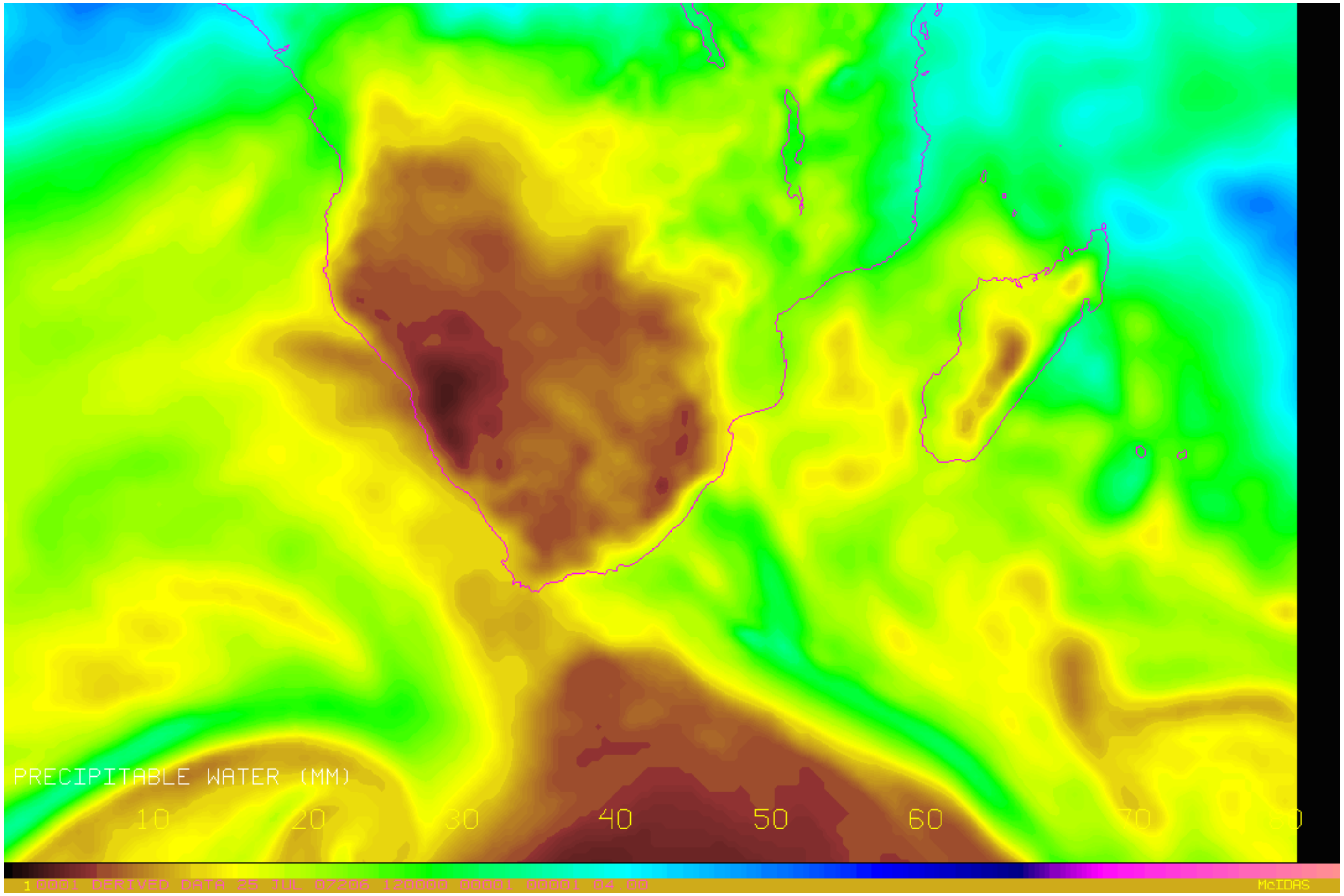
DBCRAS 12 hour Pre-forecast 11 μm Brightness Temperatures 12 UTC 25 July 2007

DBCRAS IR Window



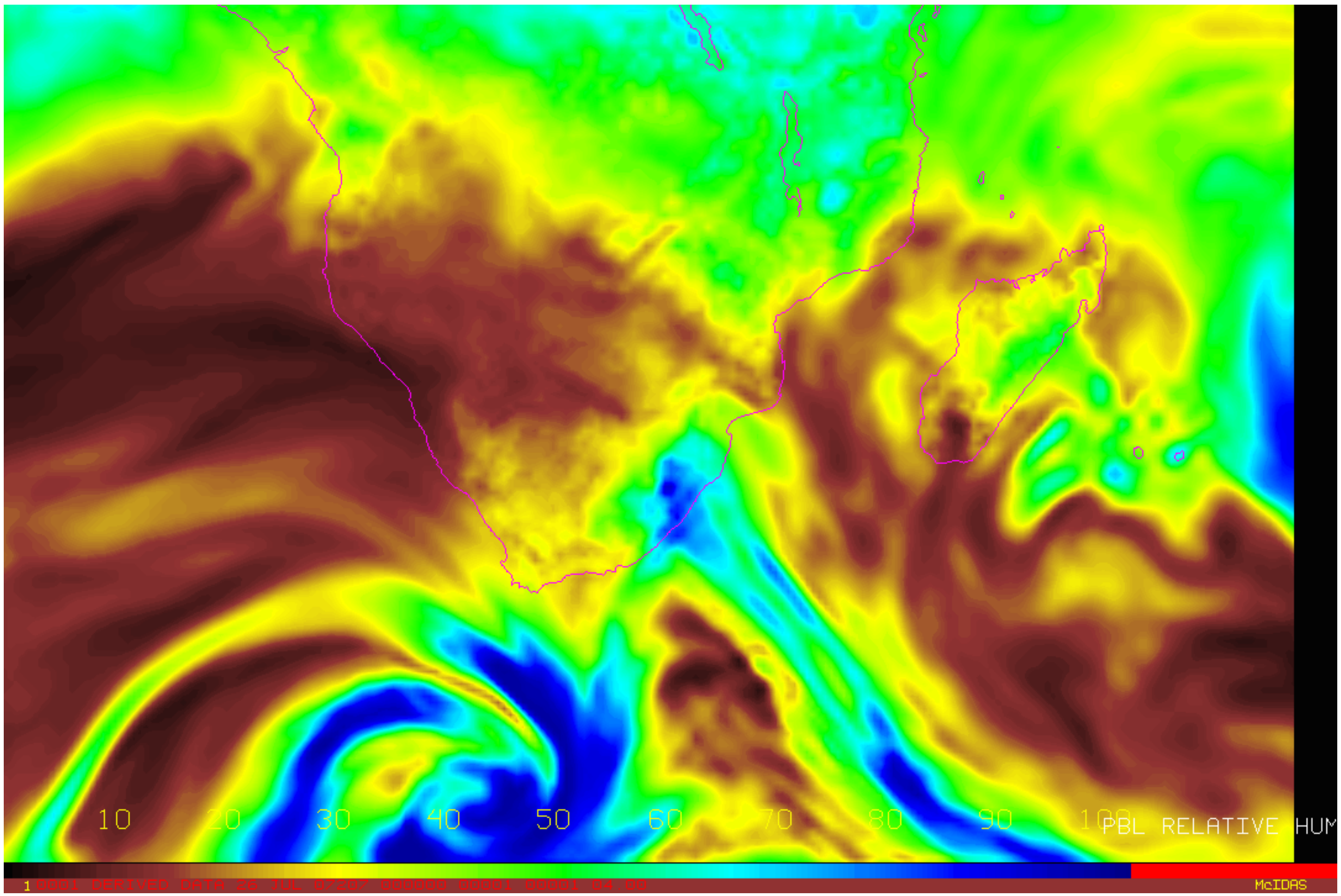
DBCRAS 72 hour Forecast 11 µm Brightness Temperatures 00 UTC 26 July 2007

DBCRAS Moisture (TPW)



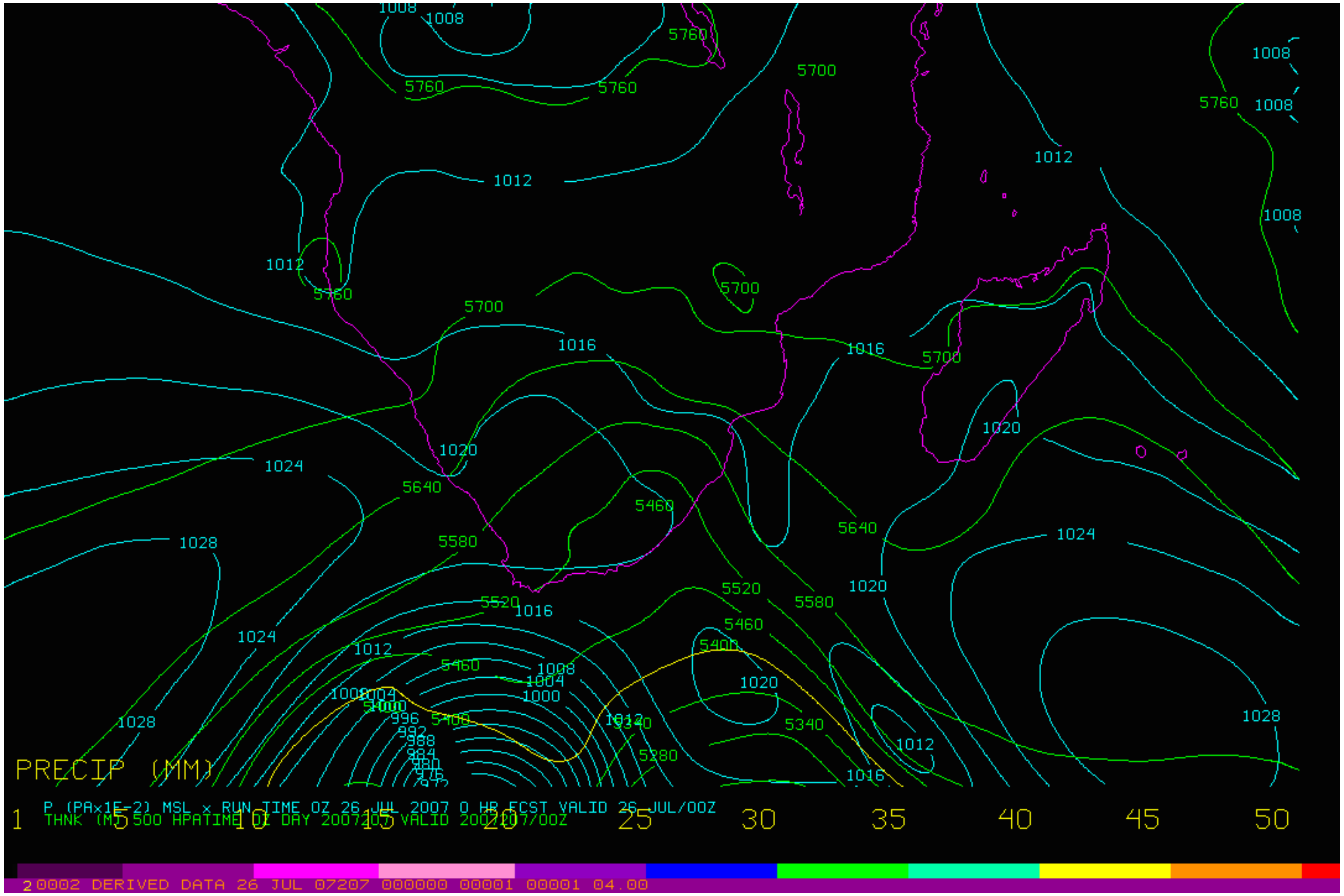
DBCRAS 12 hour Pre-forecast Total Precipitable Water Vapor 12 UTC   25 July 2007

DBCRAS Moisture (Humidity)



DBCRAS 72 hour Forecast Relative Humidity 00 UTC 26 July 2007

DBCRAS Sea Level Pressure, Precipitation



DBCRAS 72 hour Forecast SLP, Precipitation 00 UTC 26 July 2007

Applications

- Weather Forecasting
  - CRAS is used by some US Forecasters in the US
  - DBCRAS was installed at Taiwan Central Weather Bureau in November 2008
- Aerosol transport
- Fire hazard
- Others?

DBCRAS can be downloaded from the IMAPP web page at: http://cimss.ssec.wisc.edu/imapp/dbcras_v1.0.shtml

References

- Bayler, G., R. M. Aune and W. H. Raymond, 2000: NWP cloud initialization using GOES sounder data and improved modeling of nonprecipitating clouds. Mon. Wea. Rev. 128, 3911-3920.
- Raymond, W. H., and R. M. Aune, 1998: Improved precipitation forecasts using parameterized feedbacks in a hydrostatic forecast model. Mon. Wea. Rev., 126, 693-710.
- Raymond, W. H., 1999: Non-local turbulent mixing based on convective adjustment concepts (NTAC). Bound-layer Meteor, 92, 263-291.

How accurate is the CRAS model?

AREA FORECAST DISCUSSION

NATIONAL WEATHER SERVICE TWIN CITIES/CHANHASSEN MN

224 PM CDT WED OCT 29 2008

.DISCUSSION...

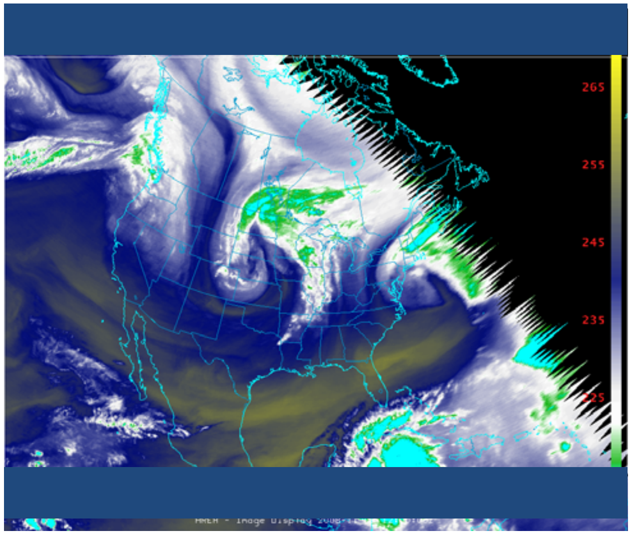
NEXT COLD FRONT EXPECTED TO COME THROUGH DRY...WITH LIMITED MOISTURE...LITTLE CLOUD WILL BE ASSOCIATED...AS INDICATED BY MODEL BUFKIT TIME/HGT OVERVIEWS AND CRAS IR SATELLITE FCST. SOME CONCERN HOW FAR SOUTH CURRENT STRONG LOOKING SHORT WAVE MOVING THROUGH MT/ID/WY REGION. MODELS DIVE THIS FEATURE FAR ENOUGH SOUTH TO LIMIT THREAT OF SIGNIFICANT CLOUDS OVER THE CWA. FRONT SHOULD EXIT TO THE SOUTHEAST OF THE AREA BY FRIDAY MORNING. SHOULD SEE SOME MARGINAL COOLING BEHIND THIS FRONT. AGREE WITH MAV GUIDANCE NUMBERS FOR THE MOST PART.

How accurate is the CRAS model??

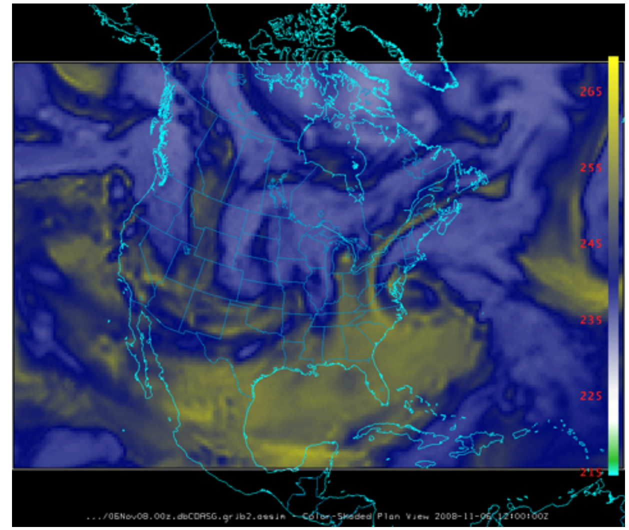
Comparison from 5 November 2008

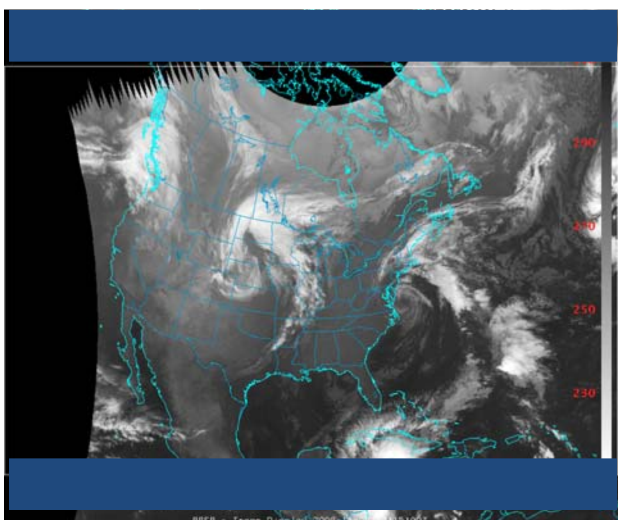
GOES Observations

CRAS 12 Hour forecast

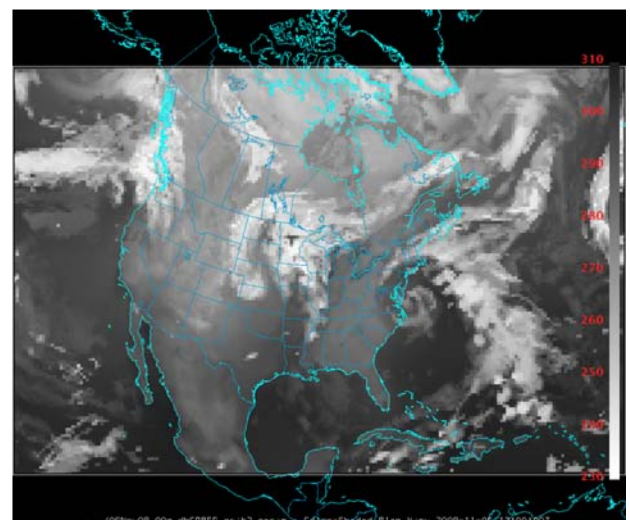


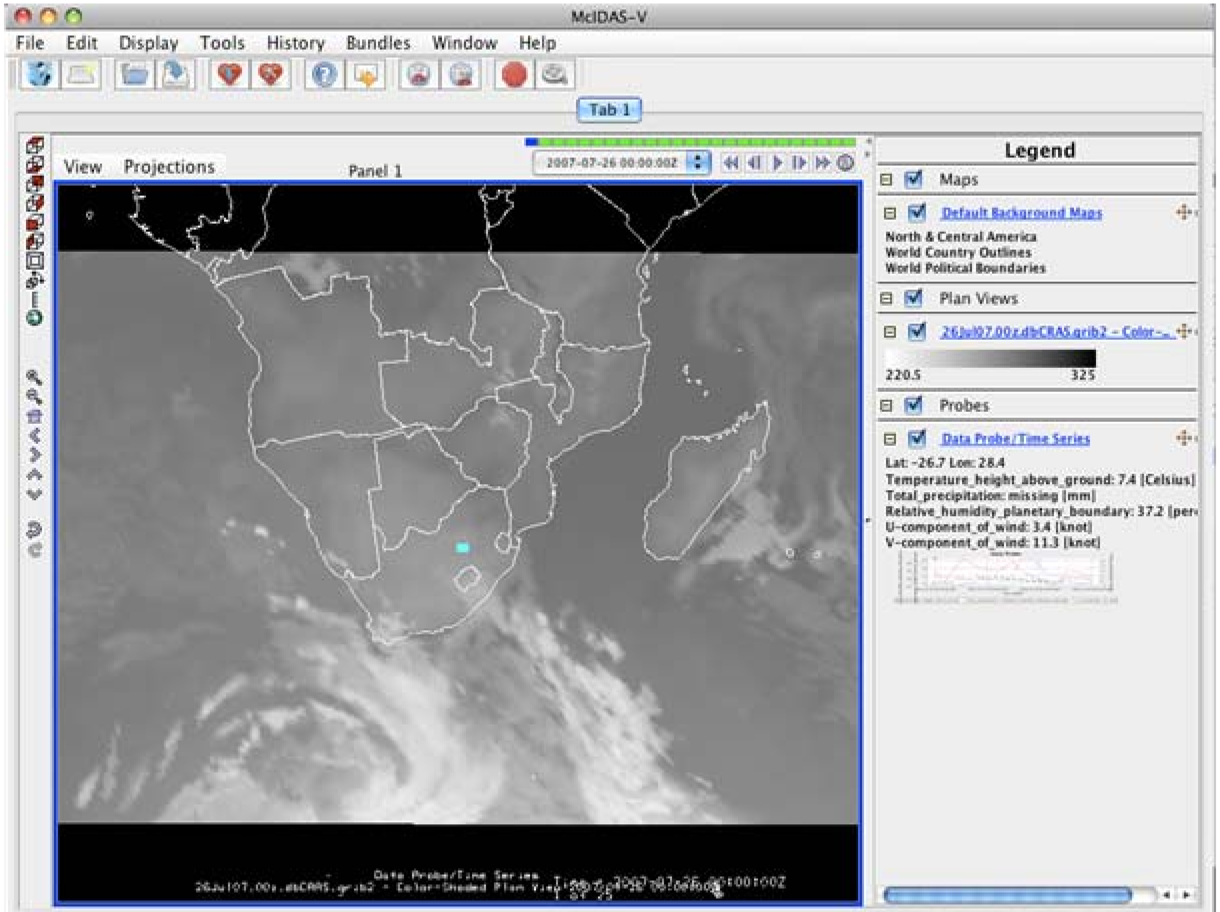
6.7 micron (CRAS no Clouds)

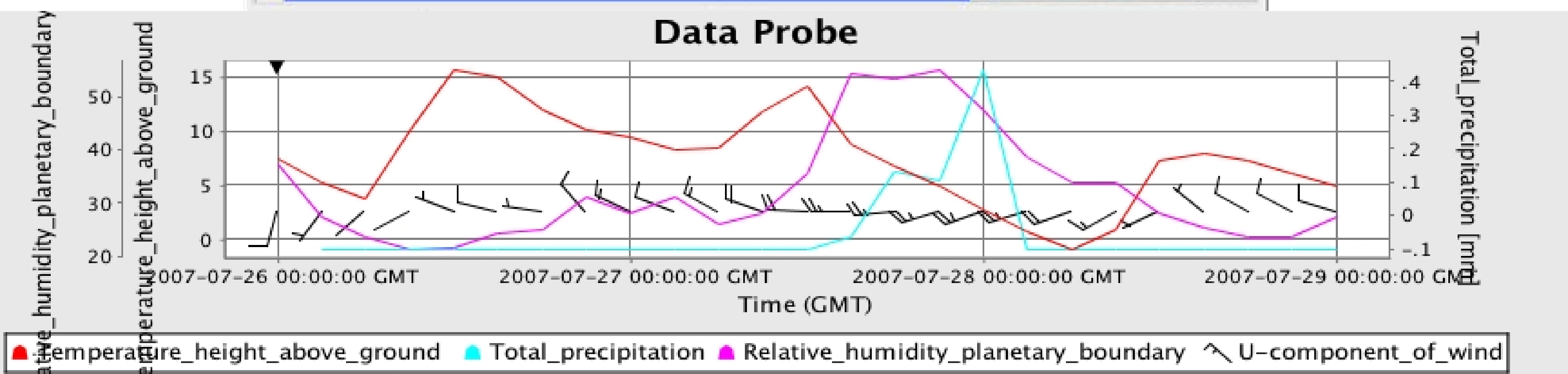




11 micron



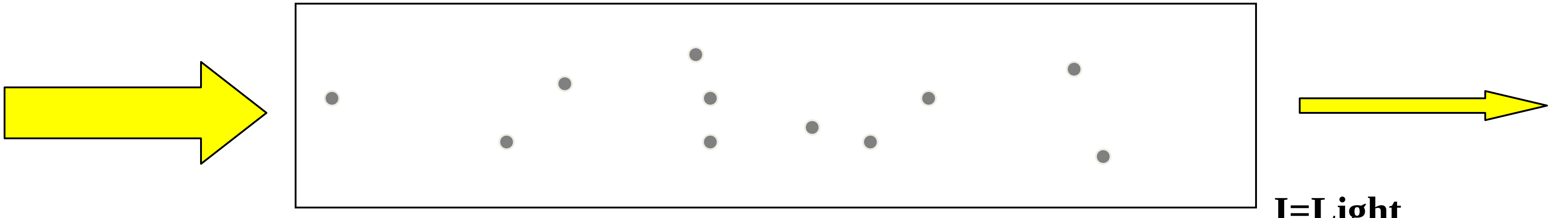

McIDAS-V
File Edit Display Tools History Bundles Window Help
Tab 1
View Projections
Panel 1
2007-07-26 00:00:00Z
Legend
Maps
Default Background Maps
North & Central America
World Country Outlines
World Political Boundaries
Plan Views
26Jul07.00z.dbCRAS.grib2 - Color-...
220.5
325
Probes
Data Probe/Time Series
Lat: -26.7 Lon: 28.4
Temperature_height_above_ground: 7.4 [Celsius]
Total_precipitation: missing [mm]
Relative_humidity_planetary_boundary: 37.2 [per
U-component_of_wind: 3.4 [knot]
V-component_of_wind: 11.3 [knot]


Data Probe
Relative_humidity_planetary_boundary
Temperature_height_above_ground
Total_precipitation [mm]
2007-07-26 00:00:00 GMT
2007-07-27 00:00:00 GMT
2007-07-28 00:00:00 GMT
2007-07-29 00:00:00 GMT
Time (GMT)
Temperature_height_above_ground
Total_precipitation
Relative_humidity_planetary_boundary
U-component_of_wind

Air Quality Applications

Aerosol Detection

Scattering and Absorption of Light by Aerosols



$$\frac{I}{I_0} = e^{-\sigma_{ext} L} = e^{-(\sigma_{sp} + \sigma_{ap}) L}$$

$$\tau = (\sigma_{sp} + \sigma_{ap}) * L \qquad \varpi = \sigma_{sp} / (\sigma_{sp} + \sigma_{ap})$$

The quantity L is called the density weighted path length. $\sigma_{ext(\lambda)}$ L is a measure of the cumulative depletion that the beam of radiation has experienced as a result of its passage through the layer and is often called the optical depth τ_λ.

Wide Spectral Range makes land retrieval possible

- **Mid-IR is used to observe the surface brightness**

- **Then aerosol is derived from estimated surface reflectance in the visible and actual reflectance**

$$\tau_{0.66} \sim [\rho^*_{0.66} - 0.5\rho^*_{2.1}]$$

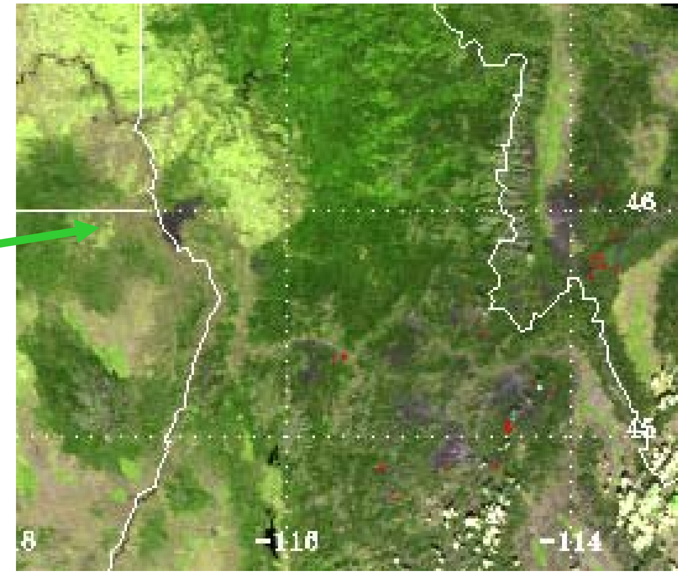
$$\tau_{0.47} \sim [\rho^*_{0.47} - 0.25\rho^*_{2.1}]$$

λ(μm)

1.2

1.6

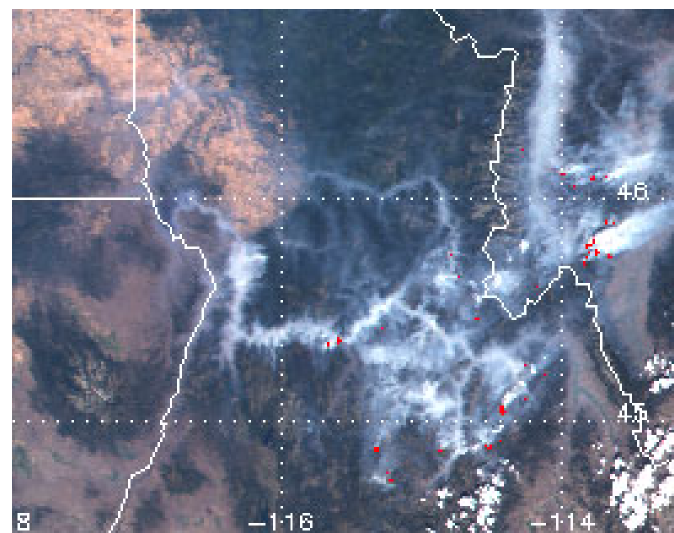
2.1



0.47

0.55

0.66

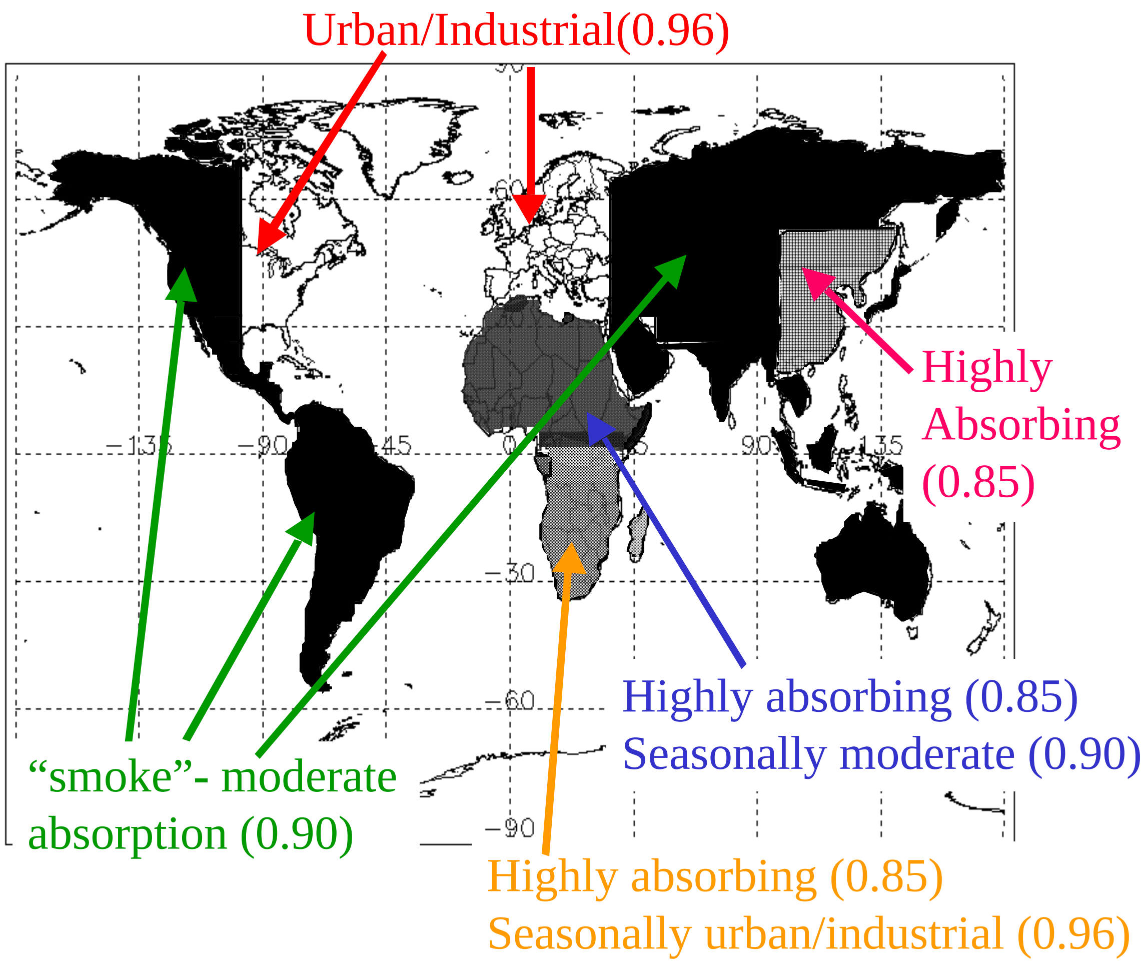


Yoram Kaufman

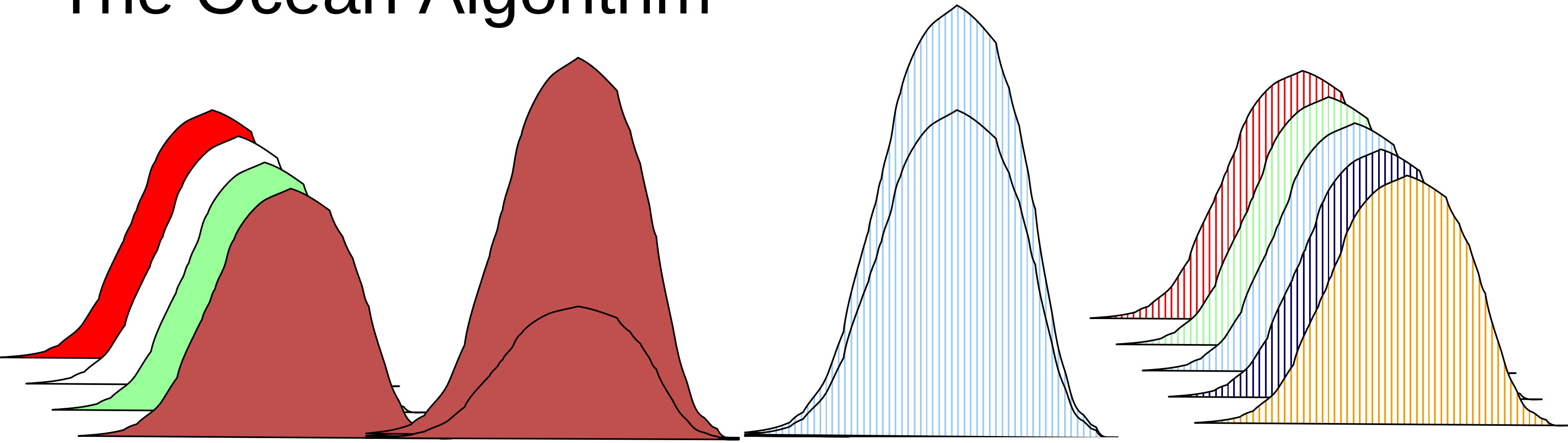
3 non-dust models plus dust

Set by geography and season

Models are dynamic f(τ)

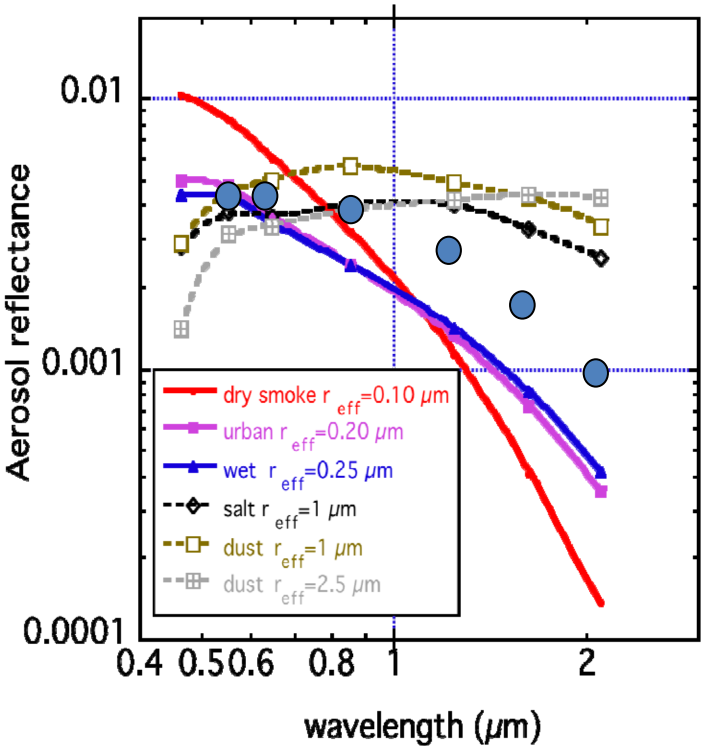


The Ocean Algorithm

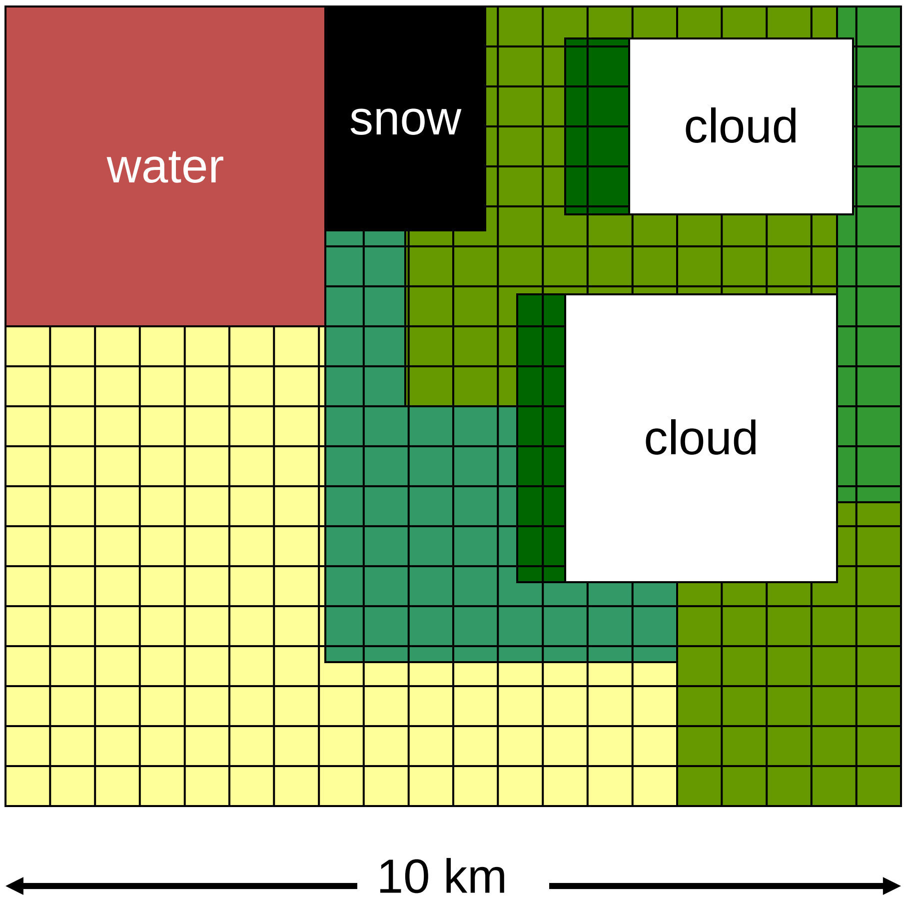


Choice of 4 fine modes
and 5 coarse modes

In order to minimize
(ρ_{meas} - ρ_{LUT}) over 6 wavelengths



MODIS Over Land Algorithm
20 x 20 pixels at 500 m resolution
(10 km at nadir)



400 total
- 56 water

344
- 24 snow

320
- 55 cloud

265
-116 "bright"

149 "good"

Discard brightest 50% and darkest 20% of the 149 good pixels.

44 pixels

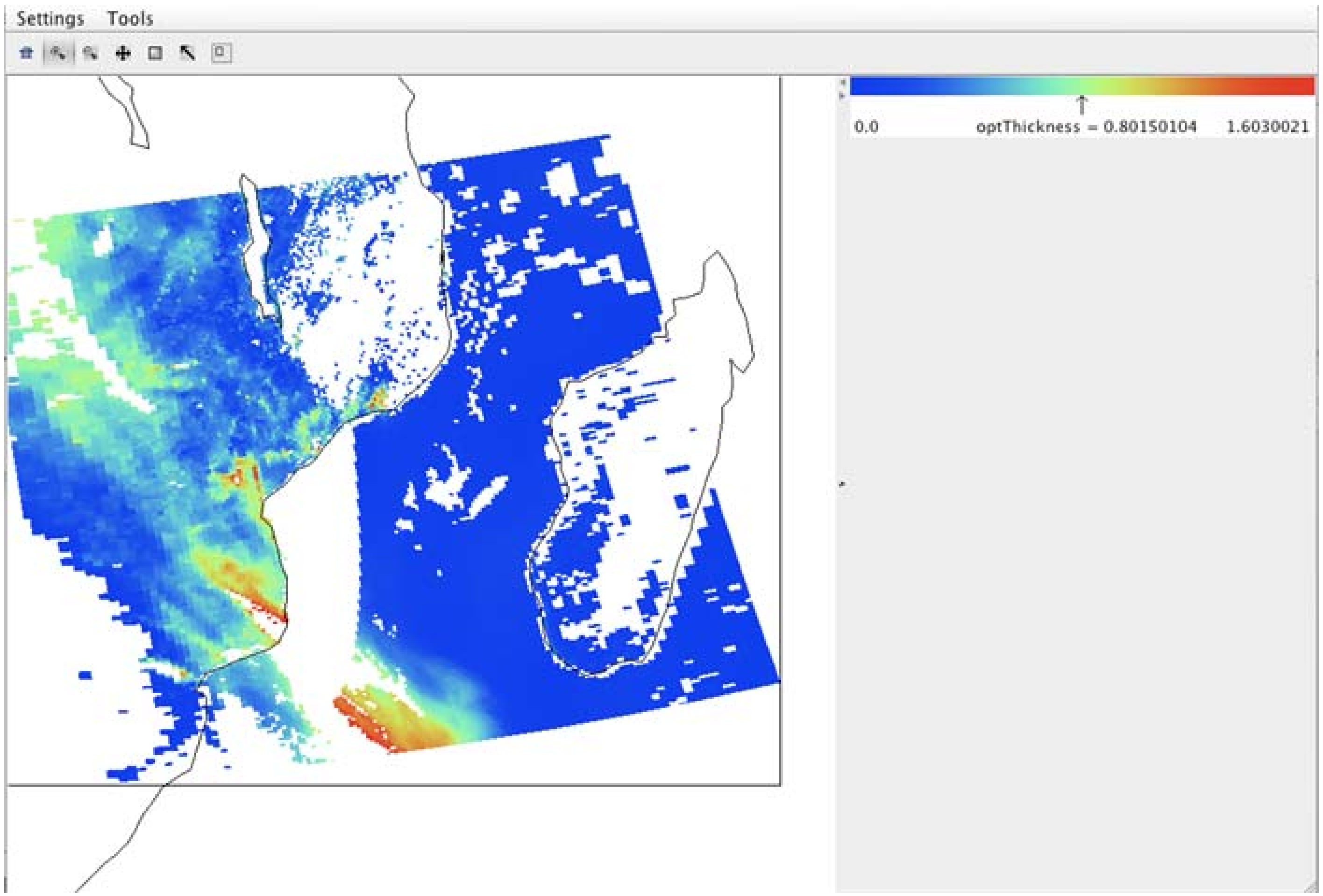
References

Levy, R. C., L. A. Remer, and O. Dubovik, 2007: Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land. J. Geophys. Res., 112, D13210

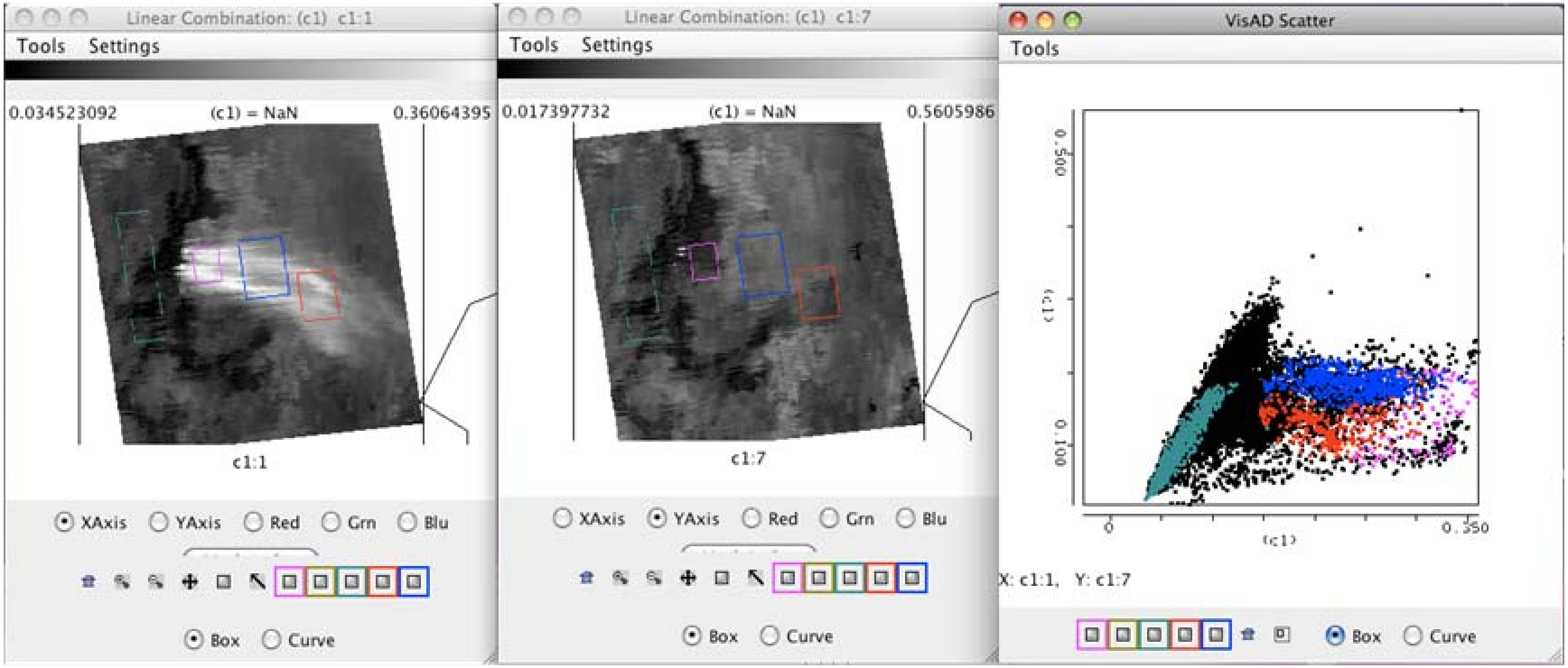
Levy, R. C., L. Remer, S. Mattoo, E. Vermote, and Y. J. Kaufman, 2007: Second-generation algorithm for retrieving aerosol properties over land from MODIS spectral reflectance. J. Geophys. Res., 112, D13211, 22 pages.

Remer, L. A., Y. J. Kaufman, D. Tanre, S. Mattoo, D. A. Chu, J. V. Martins, R-R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, E. Vermote, & B. N. Holben, 2004: The MODIS Aerosol Algorithm, Products and Validation. Journal of Atmospheric Sciences, 64, 4, 947-973.

MODIS AOD product



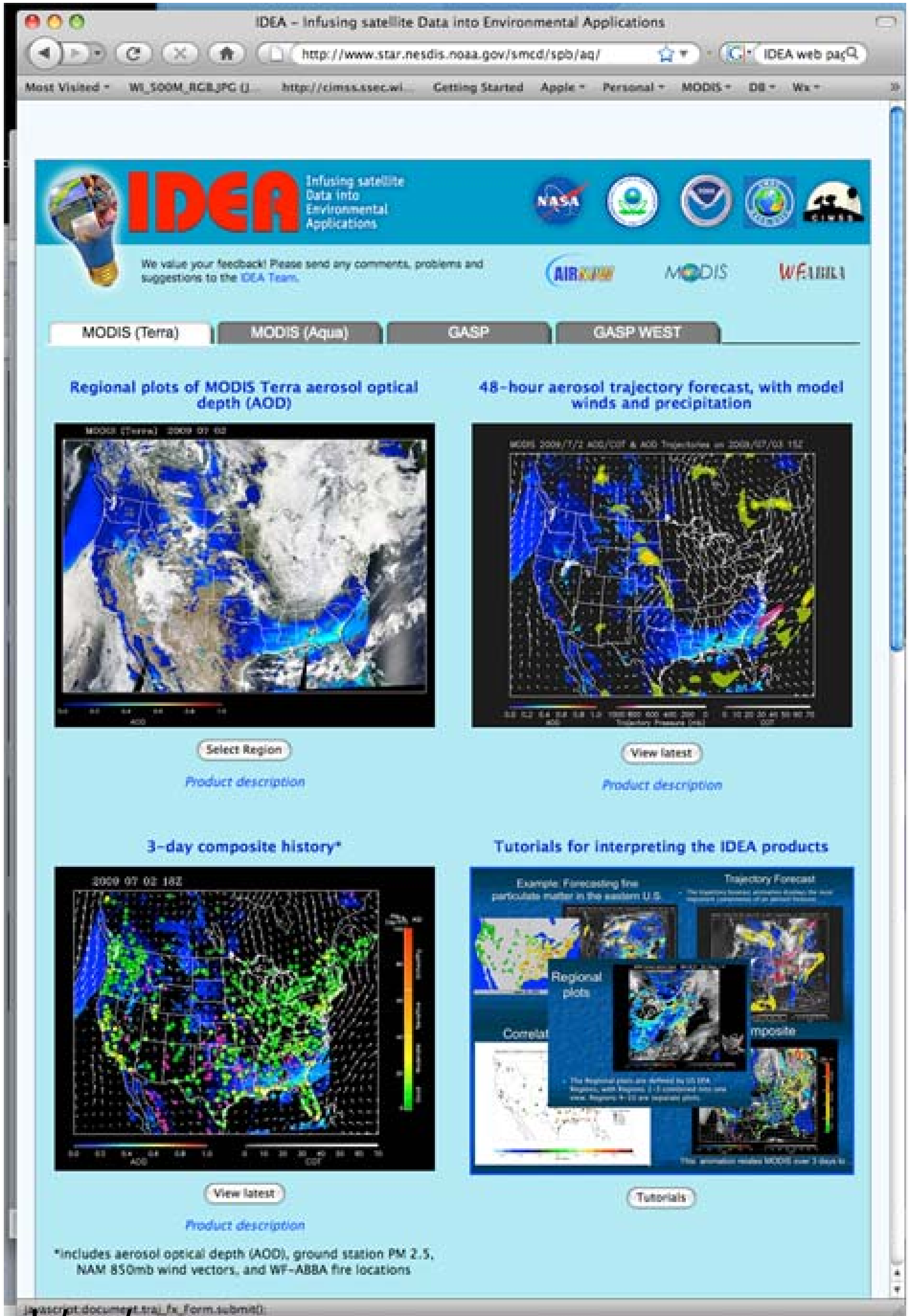
MODIS Aerosol Bands



Band 1, Band 7 and scatter diagram

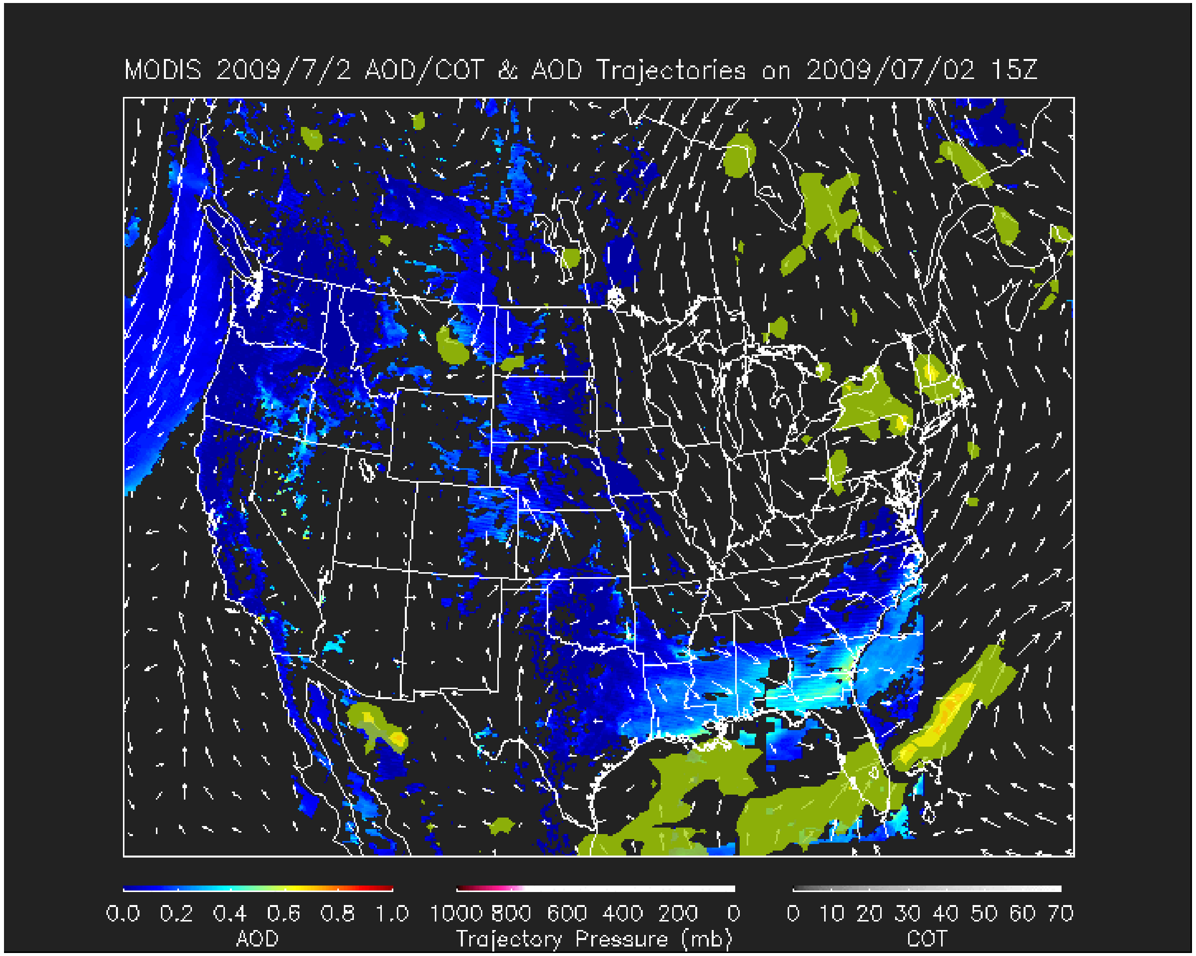
Infusing Satellite Data into Environmental Applications

Used by the US Environmental Protection Agency to Monitor and Forecast Air Quality in the United States

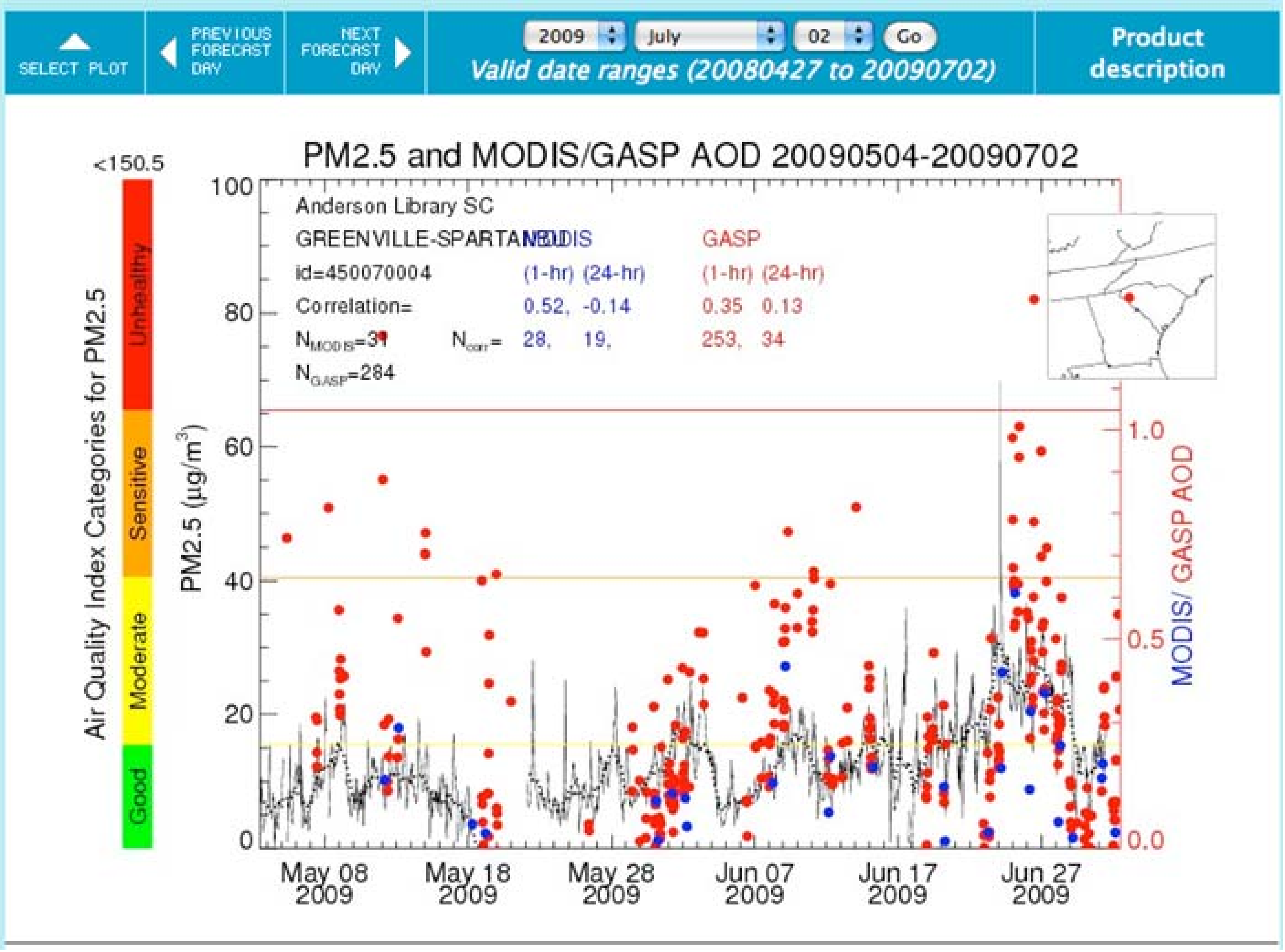


http://www.star.nesdis.noaa.gov/smcd/spb/aq/

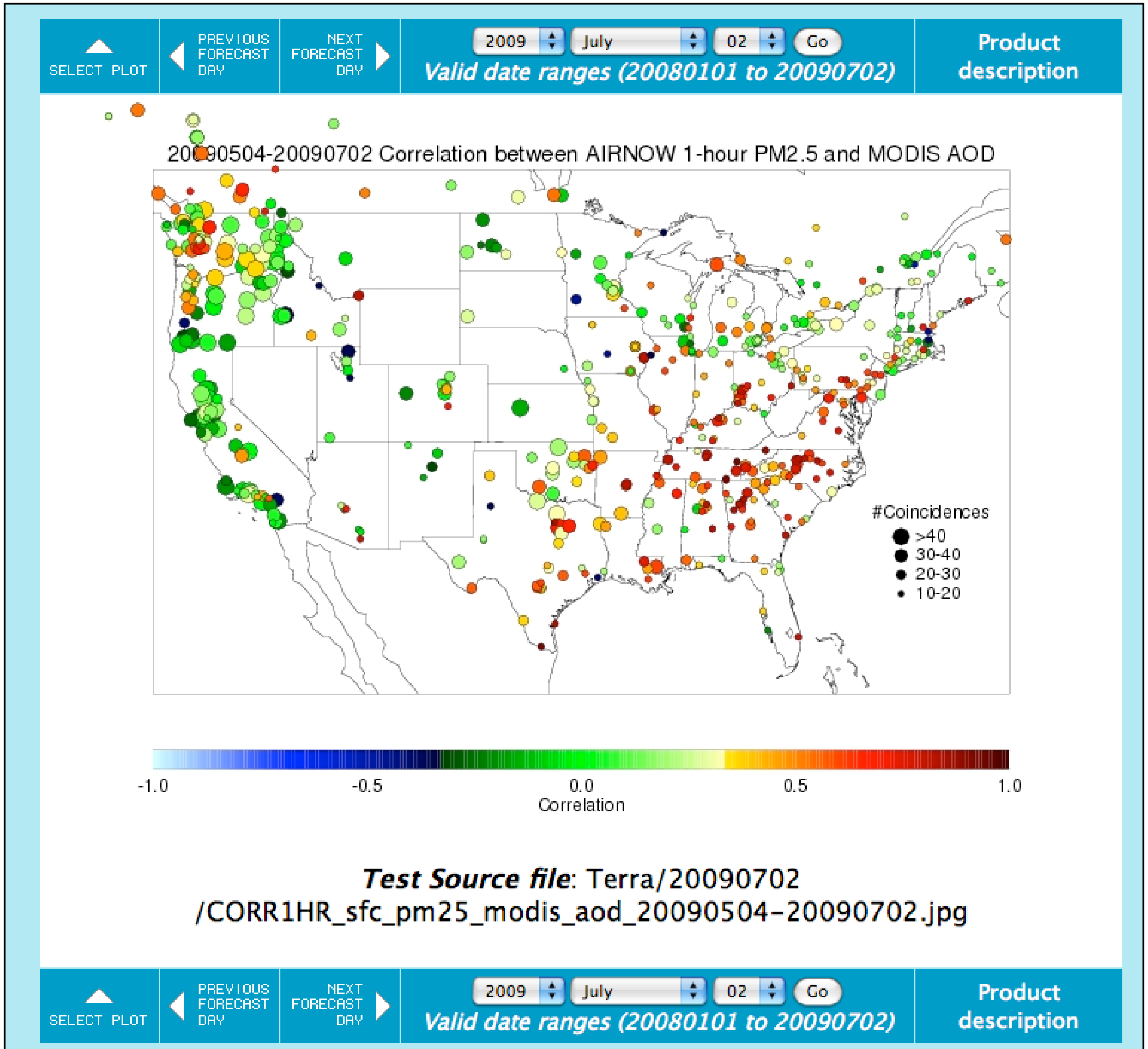
48 Hour Trajectory Forecast



PM Observations, MODIS AOD and GOES AOD retrieval Time Series



Correlation Between MODIS AOD and PM Observations



References

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Doreen Neil, James J. Szykman, Jack Fishman, R. Bradley Pierce, Jassim A. Al-Saadi, Chieko Kittaka, A good IDEA (Infusing satellite Data into Environmental Applications), American Meteorological Society, 13the Conference on Satellite Meteorology, Society, Norfolk, VA Sept. 21, 2004.

James J. Szykman, Chieko Kittaka, R. Bradley Pierce, Jassim Al-Saadi, Doreen O. Neil, John White, D. Allen Chu, and Lorraine A. Remer, Use of MODIS Satellite Observations in Near-Real-Time to Improve Forecast of Fina Particulate Matter (PM2.5): An Experimental Forecast Tool. 2004 National Air Quality, Baltimore, MD, February 22-25, 2004

Other Applications

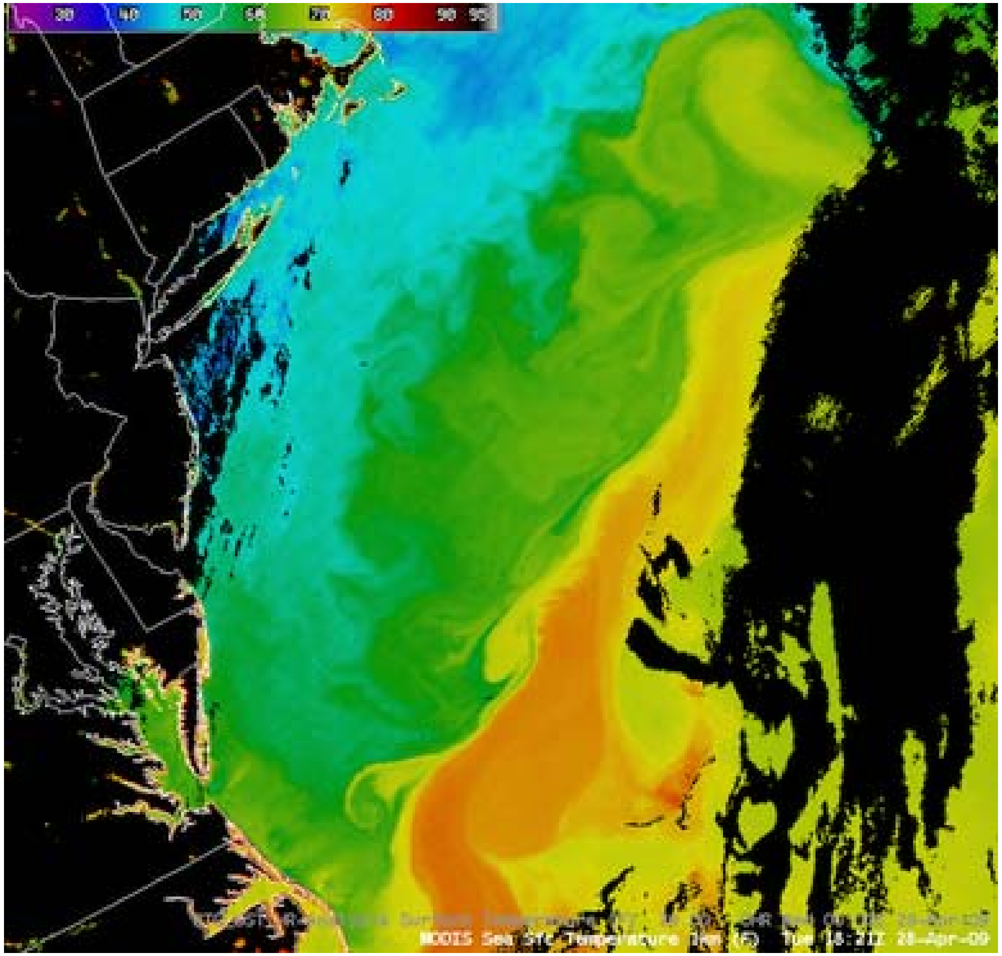
Sea Surface Temperatures

- Simple Brightness Temperature Difference Algorithm
- "Split Window" technique
- Regression between
  - 11-12 μm BTDIF (MODIS bands 31 and 32)
  - 4 – 11 μm BTDIF (MODIS bands 31 and 32)
    - Must be careful in sunglint regions because of solar contamination

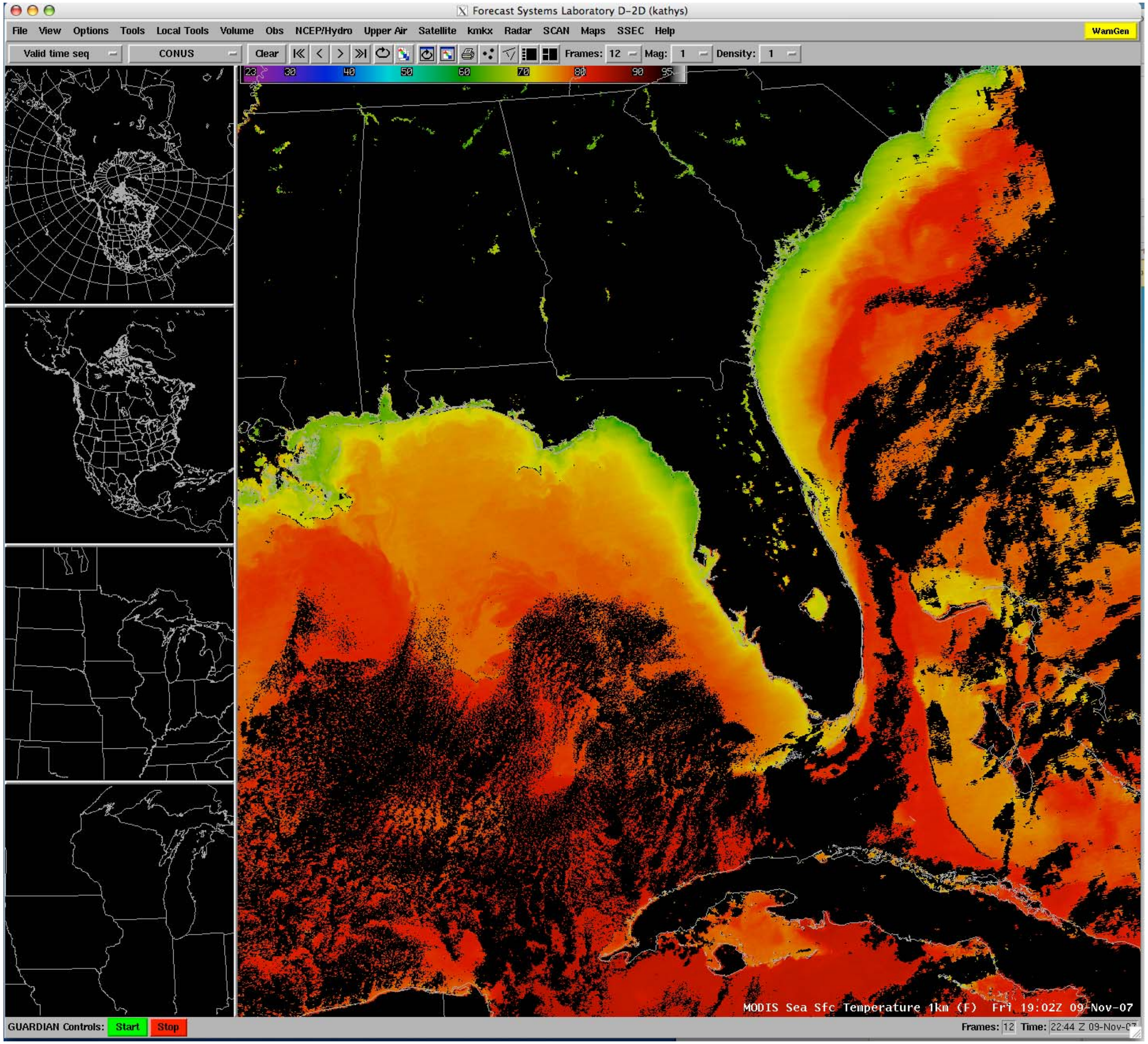
Applications

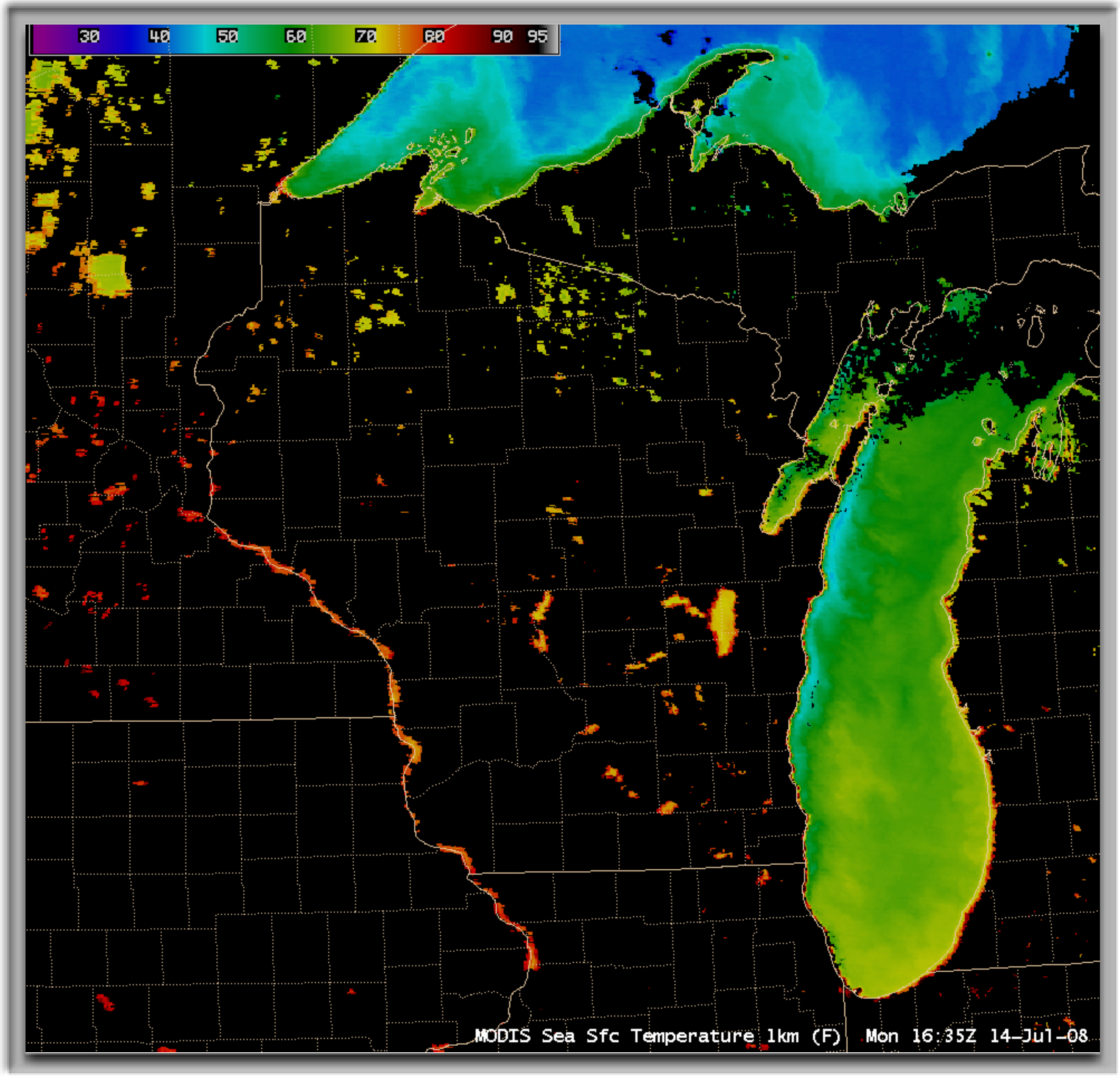
- Weather Forecasting
- Fishing
- Numerical Weather Prediction Assimilation
- Marine Biology

MODIS SST Comparison To Model



MODIS Sea Surface Temperature viewed in AWIPS





Sea Surface Temperature: 1-km resolution

MODIS Sea Surface Temperature used by Forecasters

FXUS63 KMKX 142114

AFDMKX

AREA FORECAST DISCUSSION

NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI

313 PM CST WED NOV 14 2007

FORECAST FOCUS ON GUSTY WEST WINDS SPREADING COLDER AIR OVER SRN WI

TONIGHT. …….

QUIET SUNDAY AS HIGH PRESSURE SETTLES OVER WRN GREAT LAKES…WITH TEMPS A BIT HIGHER THAN MEX GUIDANCE AS SRLY FLOW SETS UP IN THE AFTERNOON OVER THE CWA...AND SE FLOW OFF RELATIVELY WARMER WATERS OF LAKE MICHIGAN (MID 40S TO AROUND 50 PER LATEST MODIS SEA-SFC TEMPERATURE IMAGE) HOLD TEMPS UP IN LAKE SHORE COUNTIES.

ASSIMILATION OF MULTI-SATELLITE HIGH-RESOLUTION SEA SURFACE TEMPERATURES FOR A REAL-TIME LOCAL ANALYSIS AND FORECASTING SYSTEM

Dr. Steven Lazarus, Corey G. Calvert

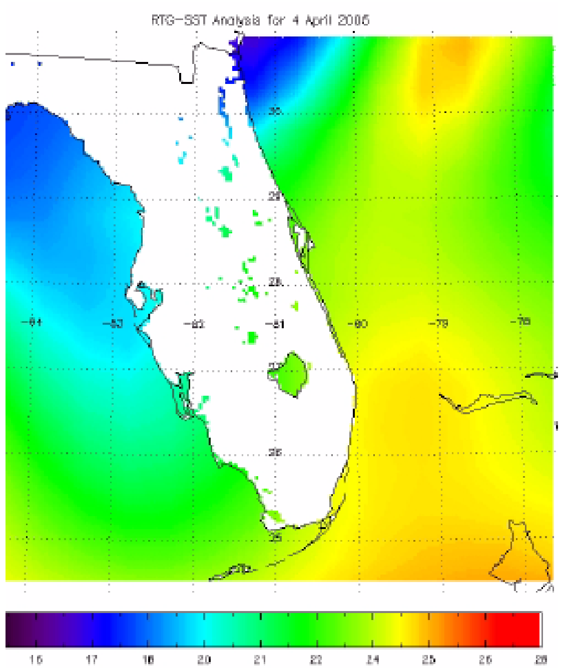
Florida Institute of Technology

- The NWS in Melbourne Florida runs a combined analysis and forecasting system called ARPS/ADAS (Advanced Regional Prediction System) (ARPS) Data Analysis System) (ADAS)

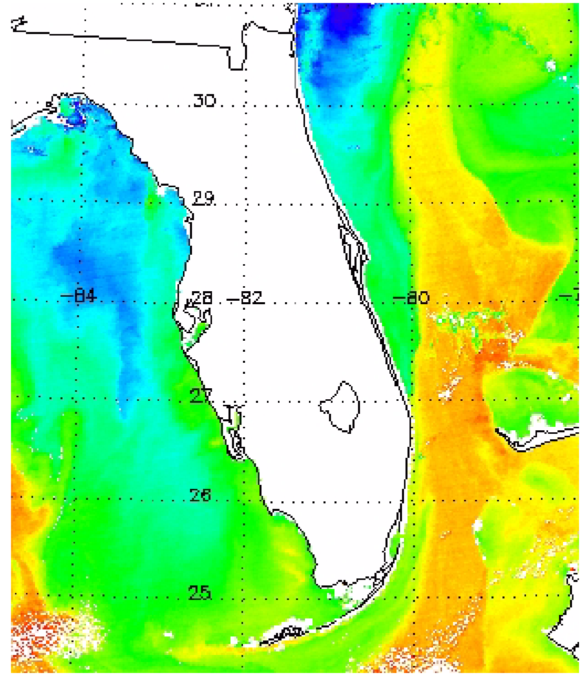
- The model SSTs are initialized using NCEP's Real-Time Global Sea Surface Temperature (RTG-SST) analysis which has a horizontal resolution of approximately 50 km

(10 times more coarse than model it is initializing!)

Global .5 degree SST

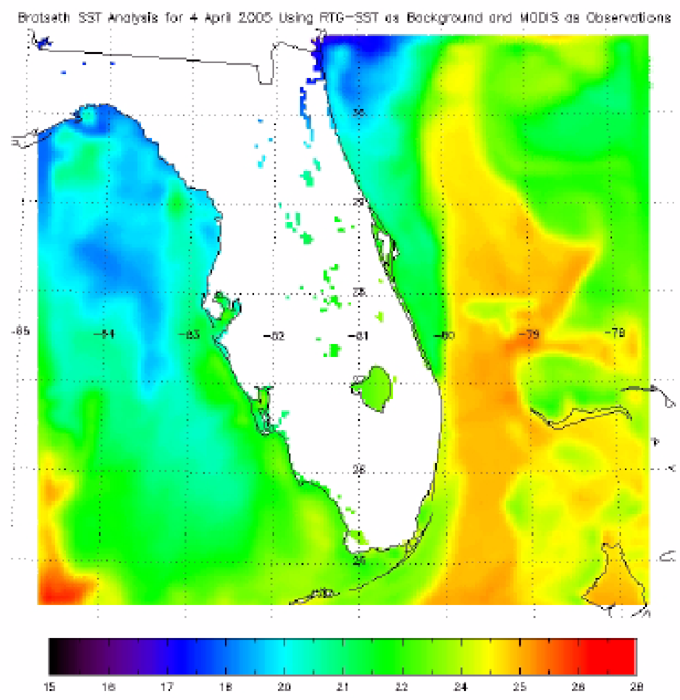


MODIS 1842 UTC SST



Sea Surface Temperatures

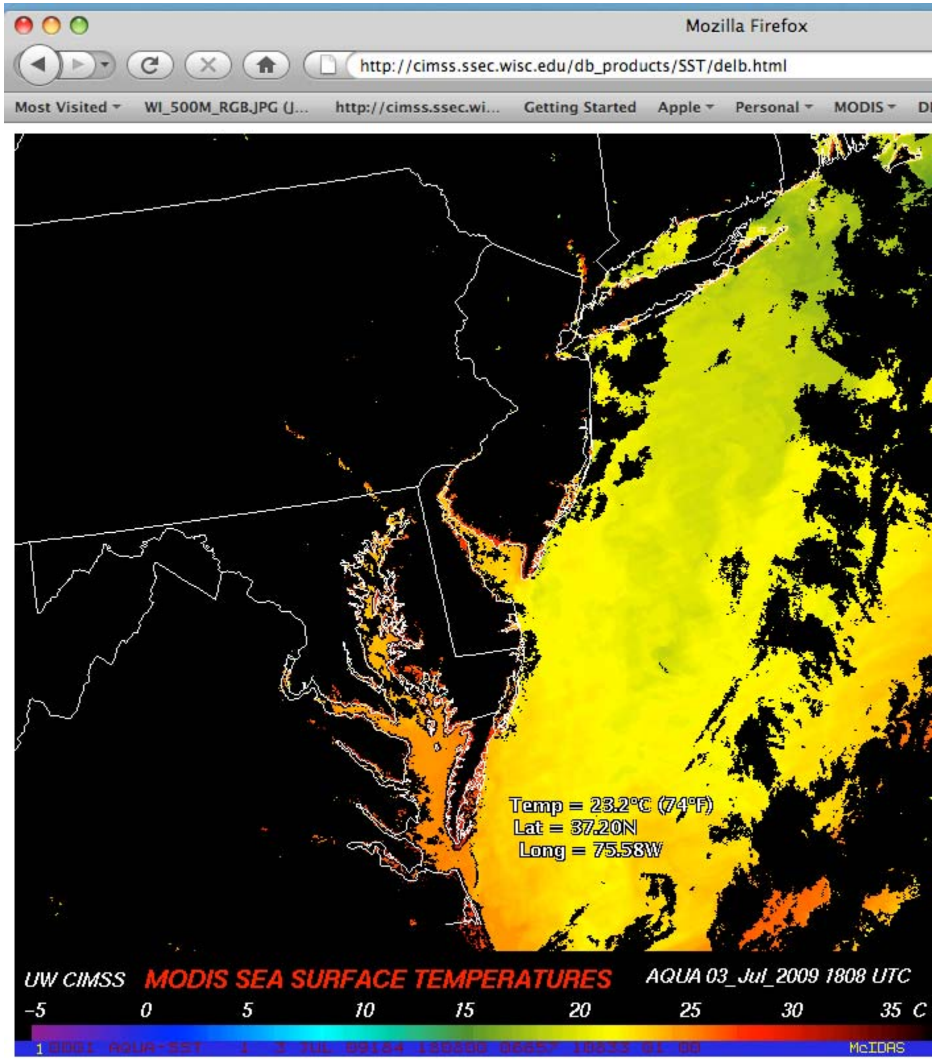
4 April 2005



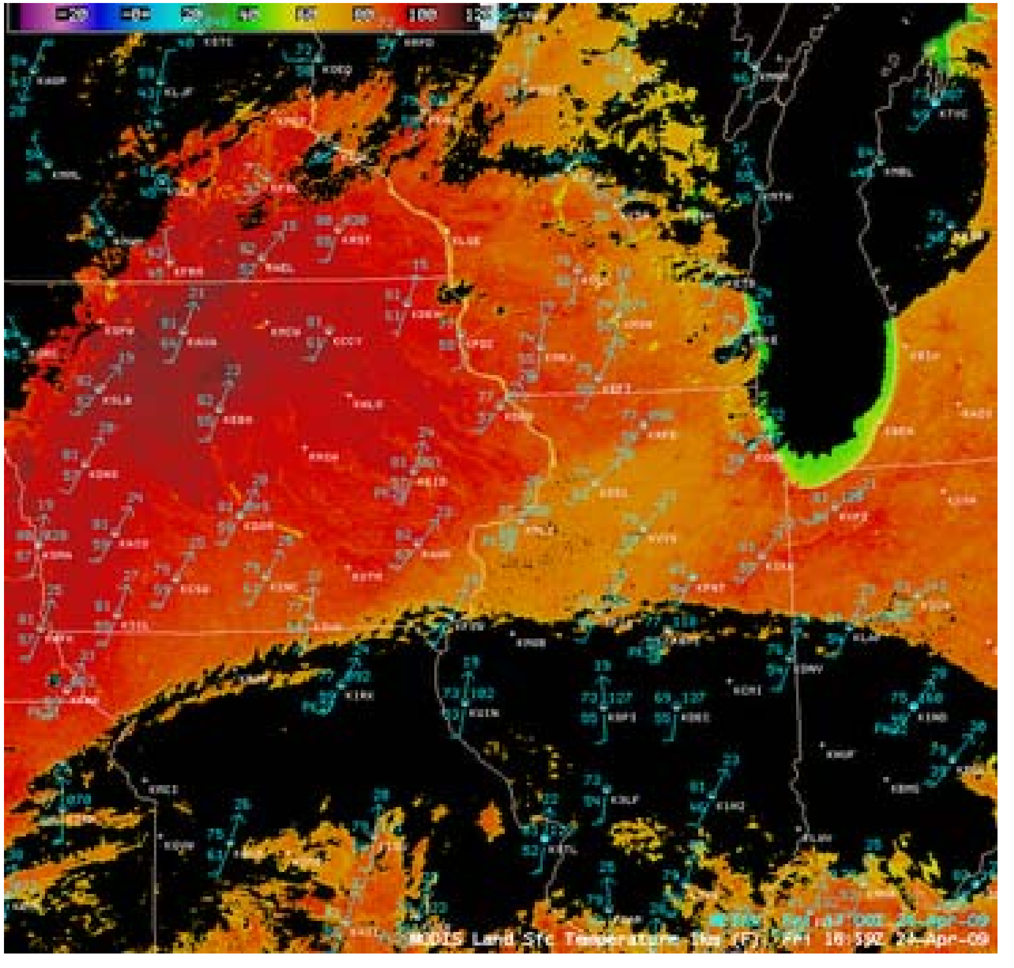
Bratseth analysis combining the RTG-SST and MODIS data.

Supports Turtle Migration Studies in Delaware Bay

http://whale.wheelock.edu/whalenet-stuff/stop_cover

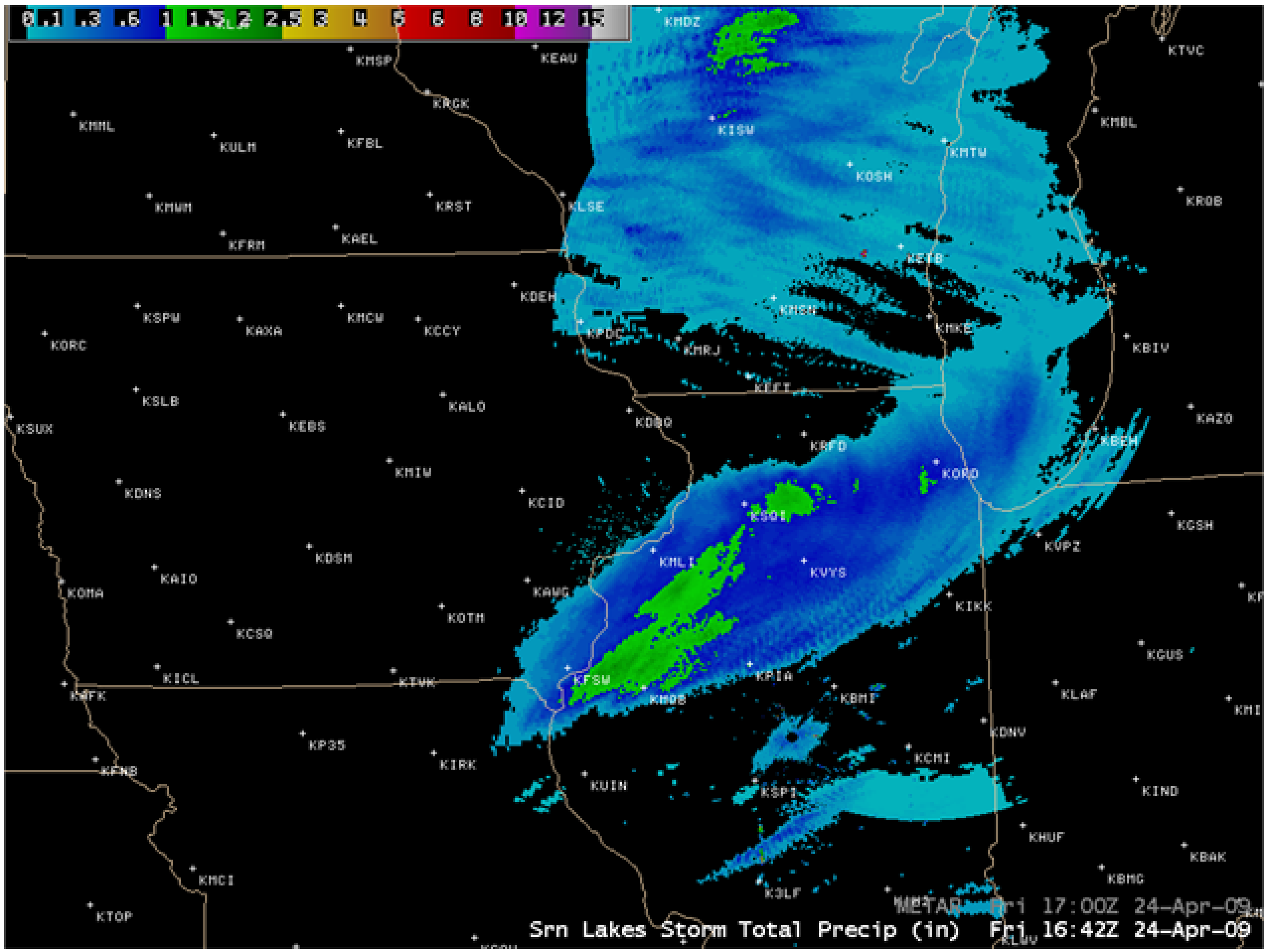


Soil Moisture



MODIS Land Surface Temperatures and NDVI 16:59 UTC 24 April 2009

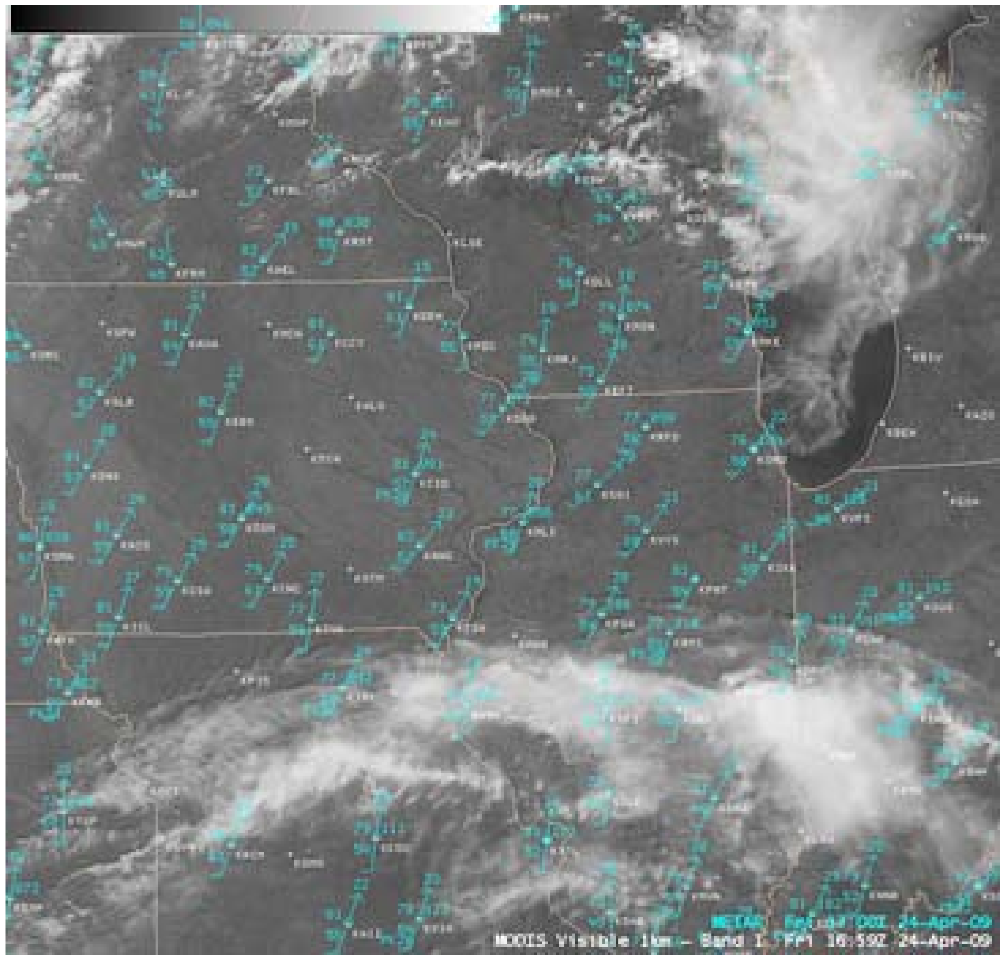
Precipitation Totals



NWS Radar Estimate
17 UTC
24 April 2009

MODIS Vis, IR and LST comparison

MODIS .68 µm reflectances, 4 µm Brightness Temperatures and Land Surface Temperatures Overlaid by METARS 16:59 UTC 24 April 2009



MODIS LST and buggers

1064 Journal of Medical Entomology Vol. 43, no. 5

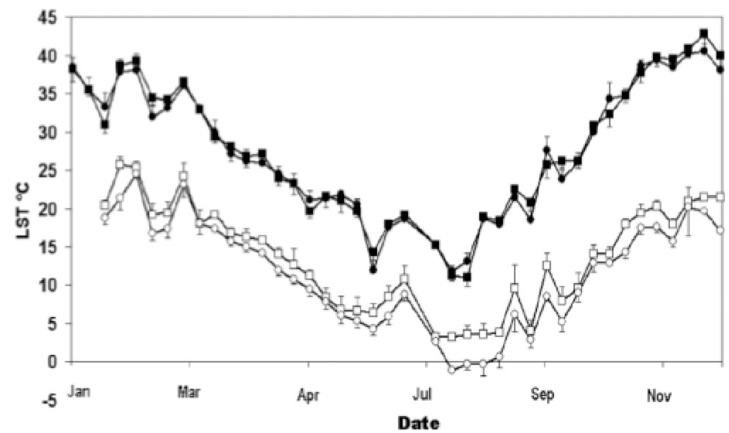


Fig. 4. Annual variation (2003) of diurnal land surface temperature (LST day) produced by the MODIS sensor (closed symbols) and LST night (open symbols) in locality groups of high (squares) and low (circles) house infestation rate. LST values are 8-d composites.

Reference: X. Porcasi, , S. S. Catala, H. Hrellac, M. C. Scavuzzo, D. E. Gorla, 2006: Infestation of Rural Houses by Triatoma Infestans (Hemiptera: Reduviidae) in Southern Area of Gran Chaco in Argentina, J. Med. Entomol. 43(5): 1060-1067.

Using MODIS Sun Glint Patterns

- What is sun glint?
- Application
  - Identifying regions of calm waters
  - Relationship of calm waters and sea surface temperatures

"Mirror" reflection of sunlight off calm water.

Sun Glint

Simple example where your eye is the sensor

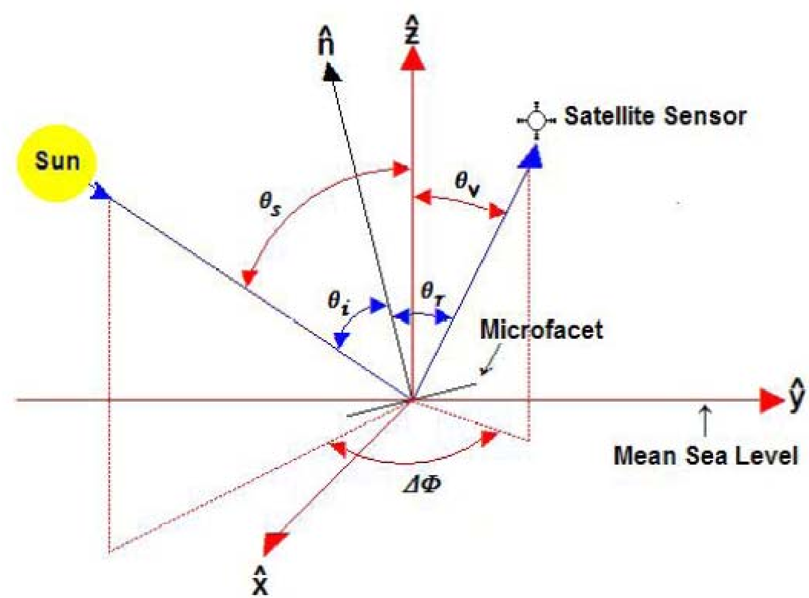
Sun Glint Ellipse Defined by: $\theta_r < 36$

$\cos\theta_r = \sin\theta_v \cos\theta_s \cos\Delta\Phi + \sin\theta_v \cos\theta_s$

Where θ_v = Viewing Zenith Angle

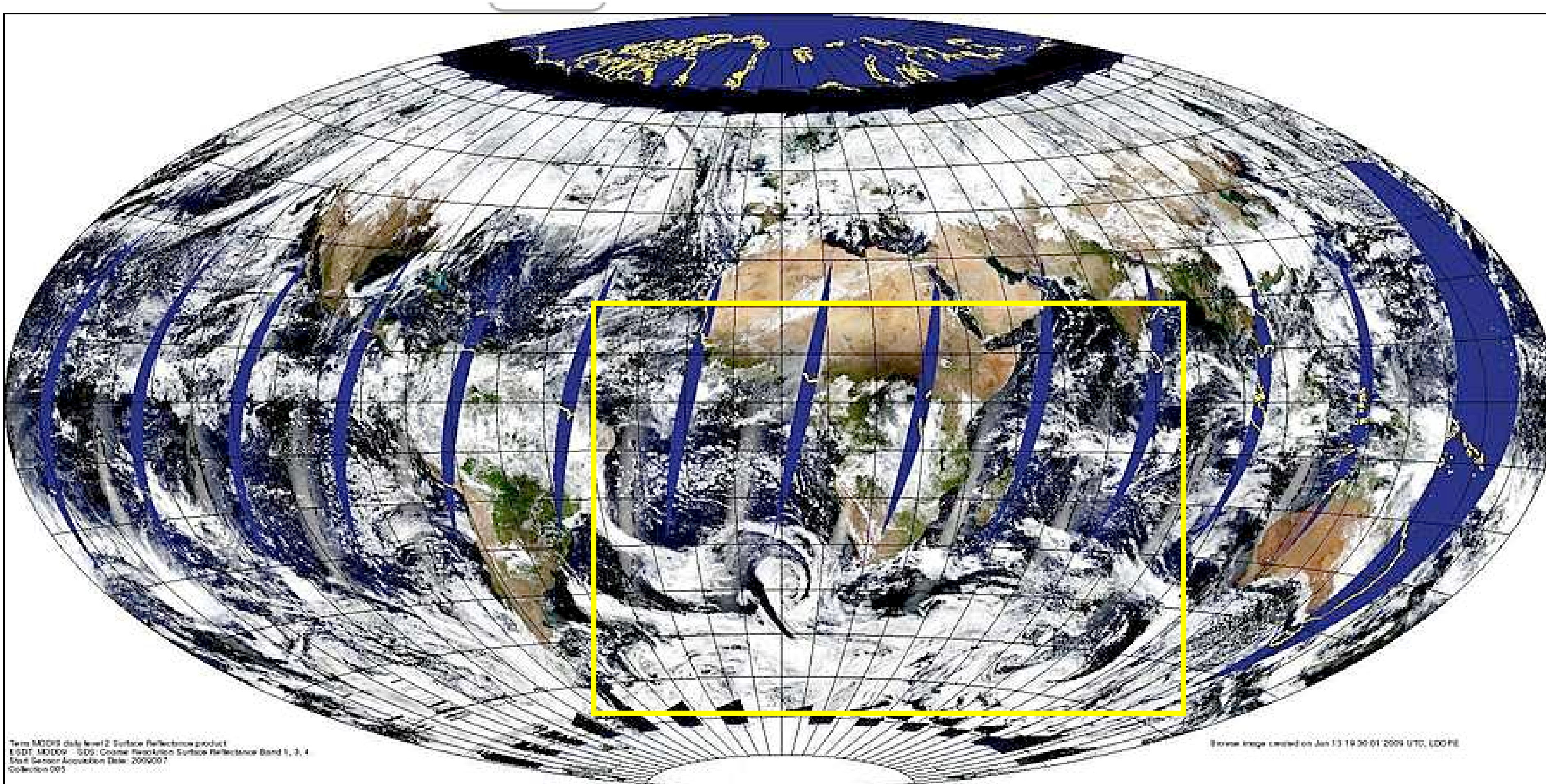
θ_s = Solar Zenith Angle

$\Delta\Phi$ = Relative Angle – difference between the Solar and Viewing azimuth angles.

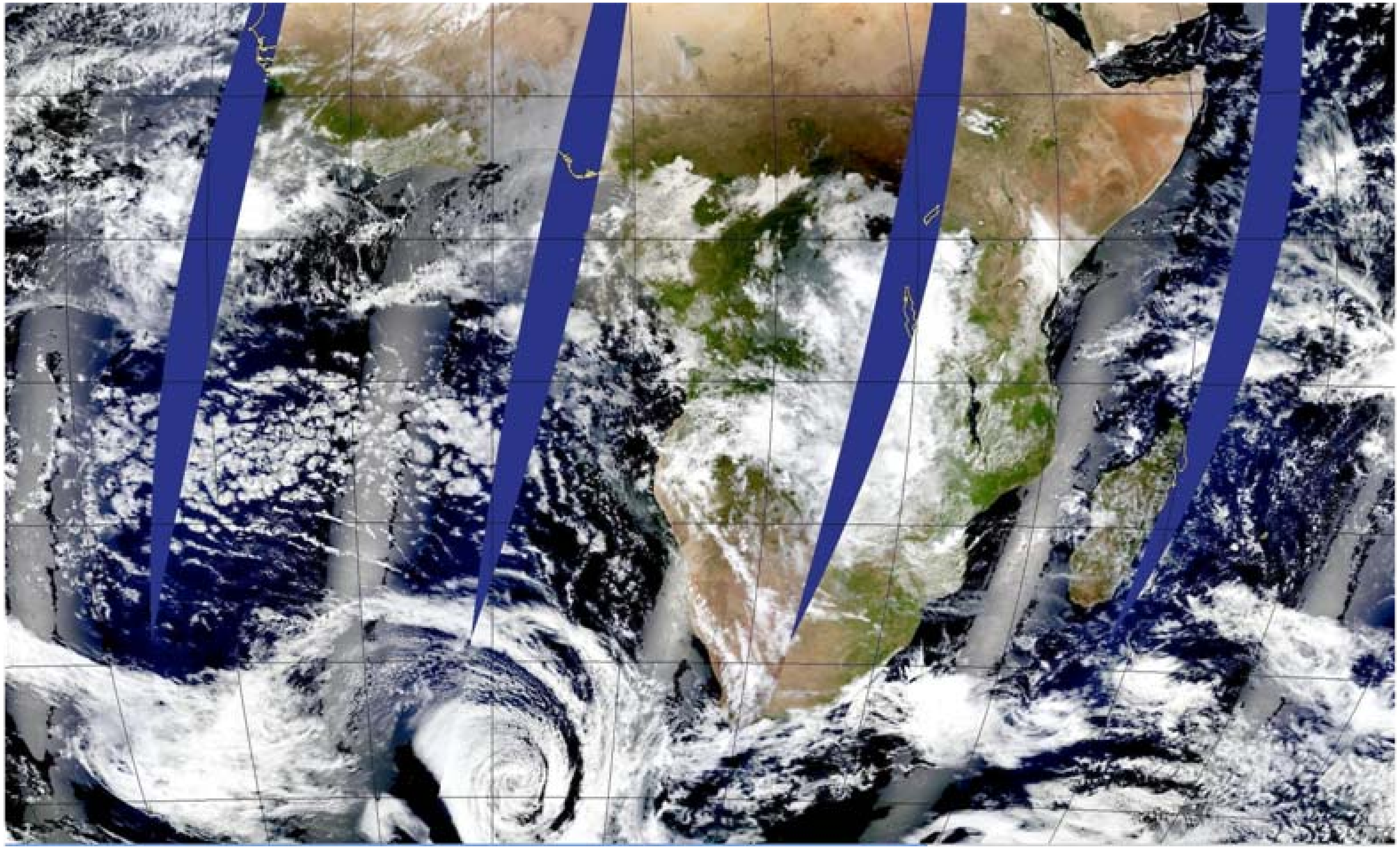


Aqua MODIS Sun Glint Example

7 January 2009

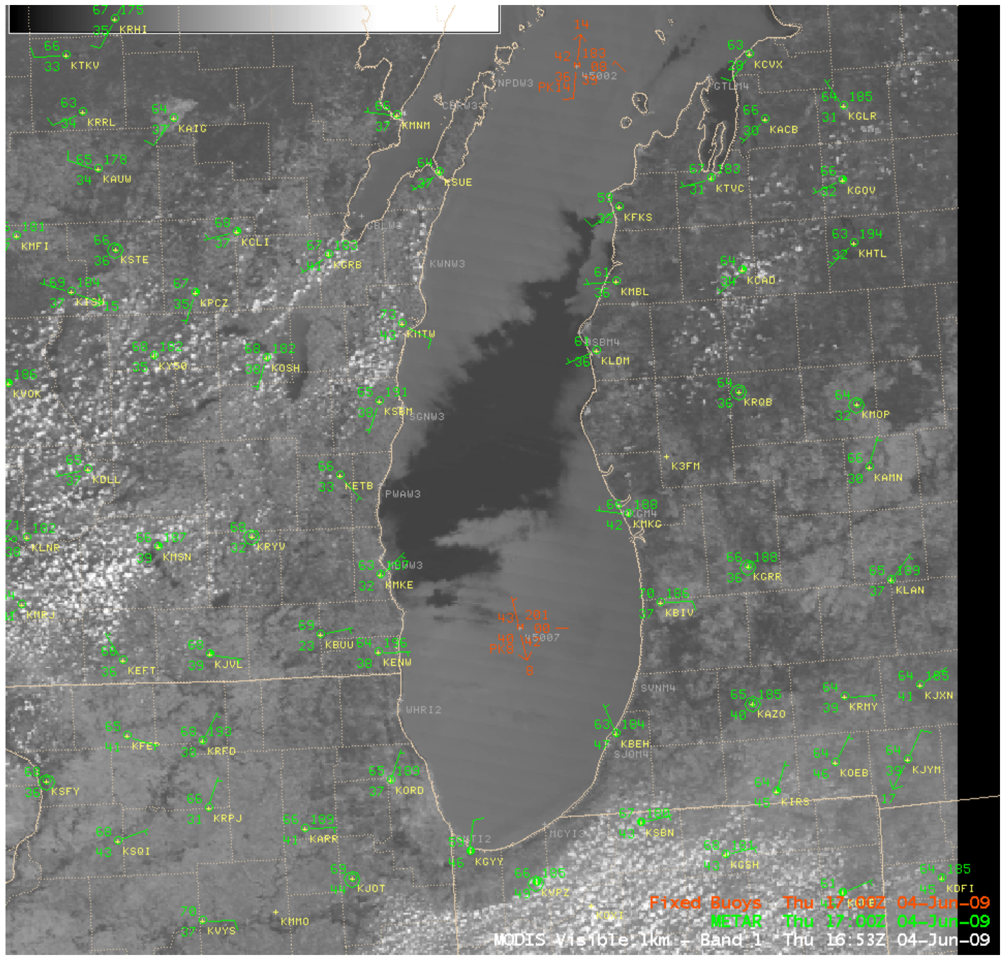


Sun Glint Patterns



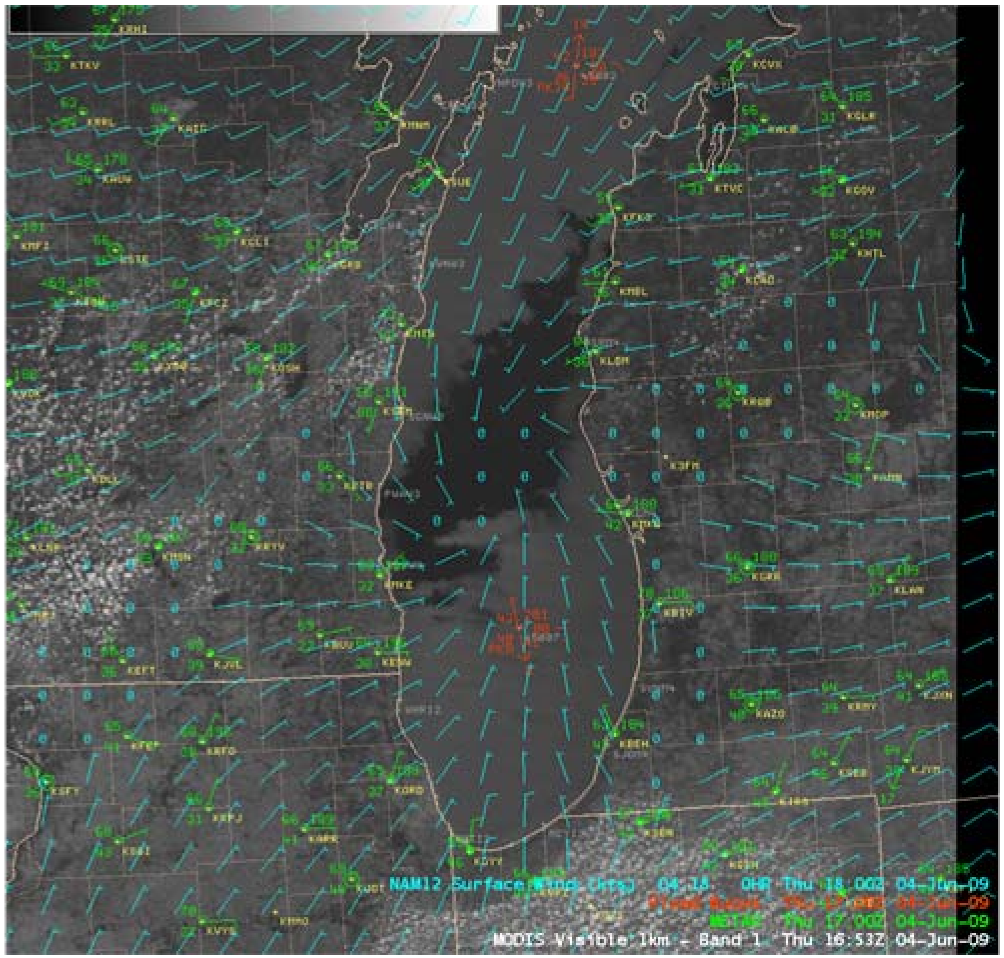
Example From Lake Michigan

4 June 2009



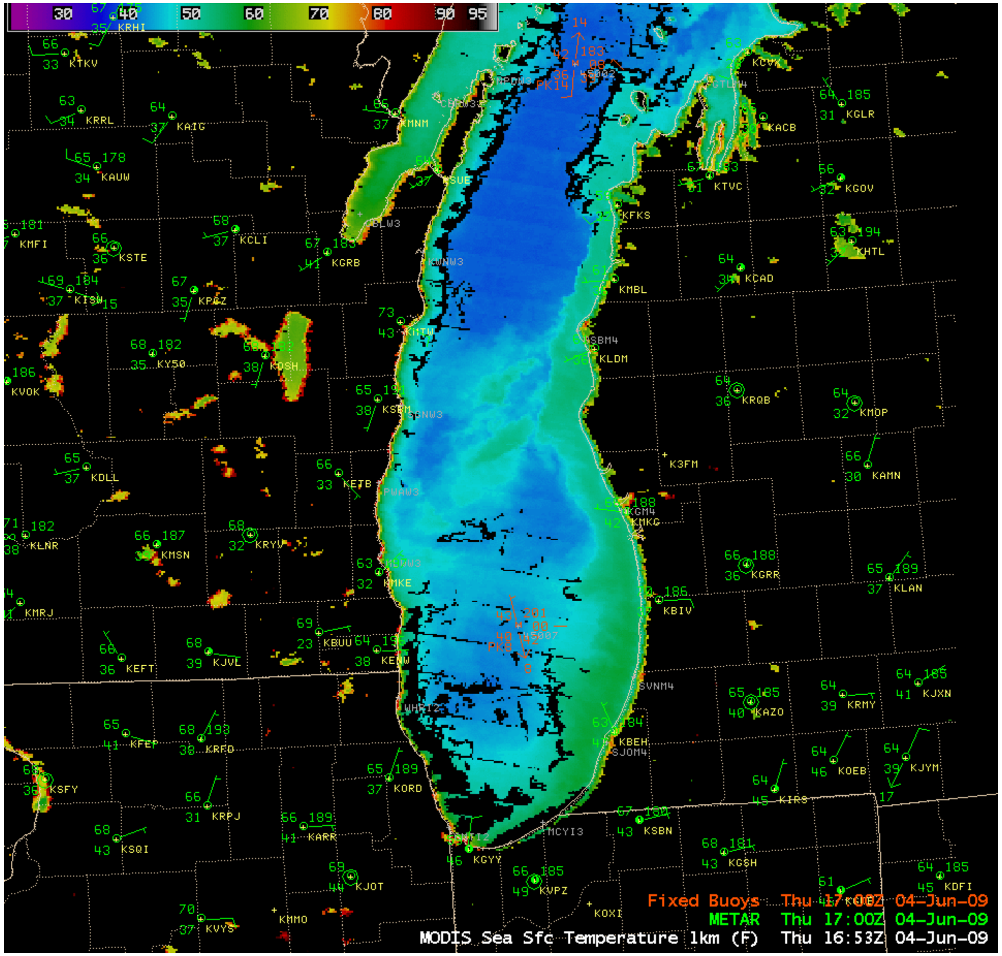
Numerical Weather Prediction

Wind analysis 18 UTC 4 June 2009

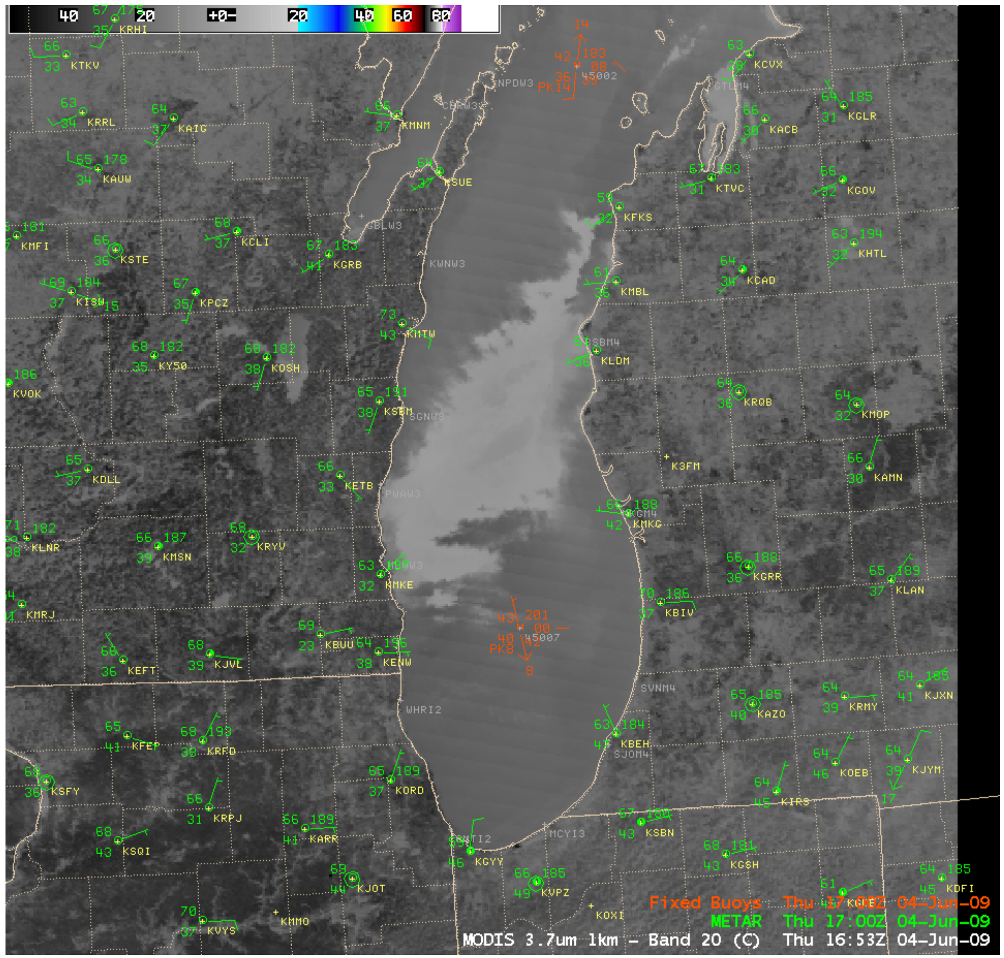


MODIS Sea Surface Temperatures

4 June 2009

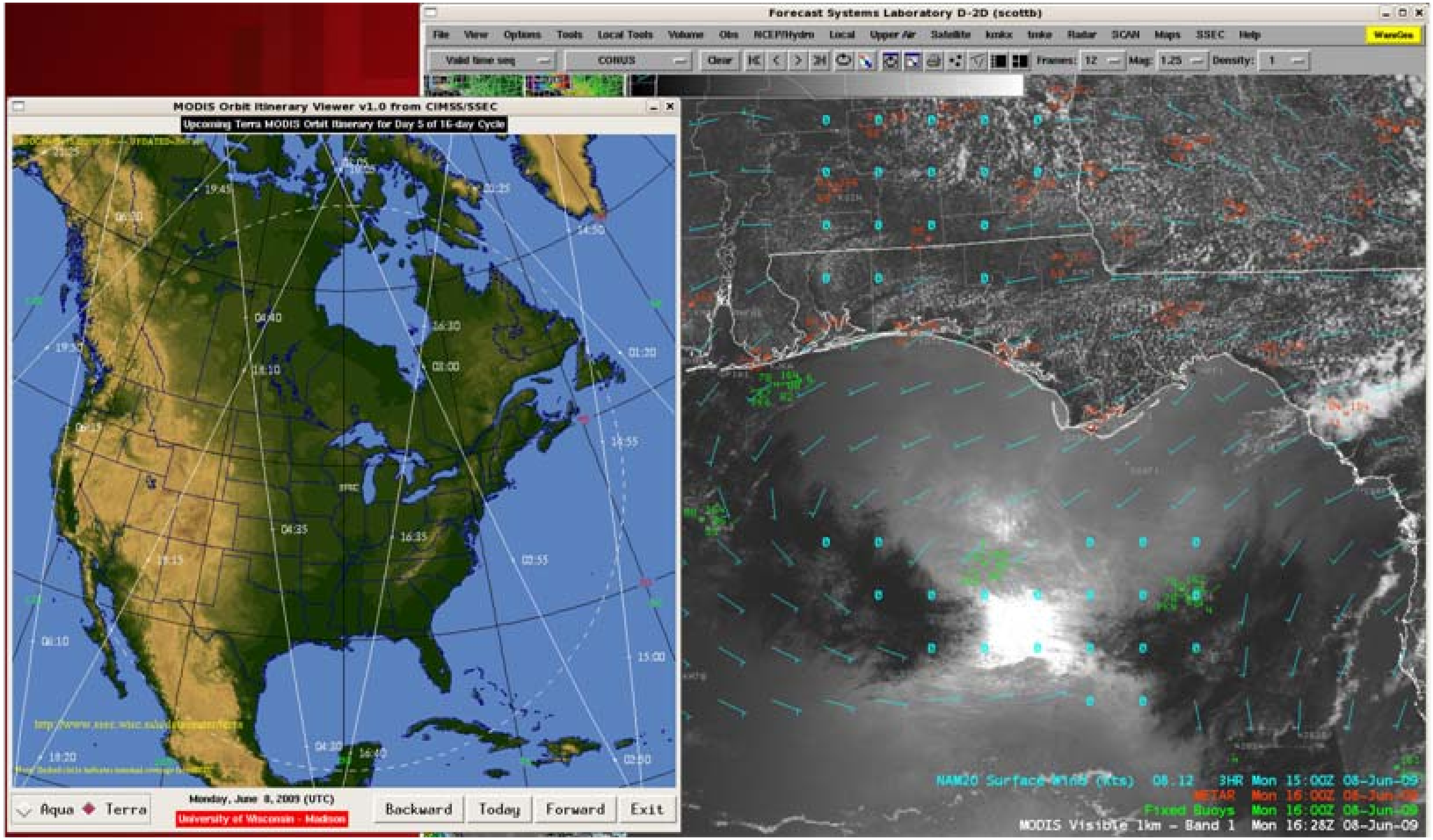


MODIS 4 μm Brightness Temperatures



MODIS Sunglint Pattern

8 June 2009



MODIS Polar Wind Vectors can be derived automatically

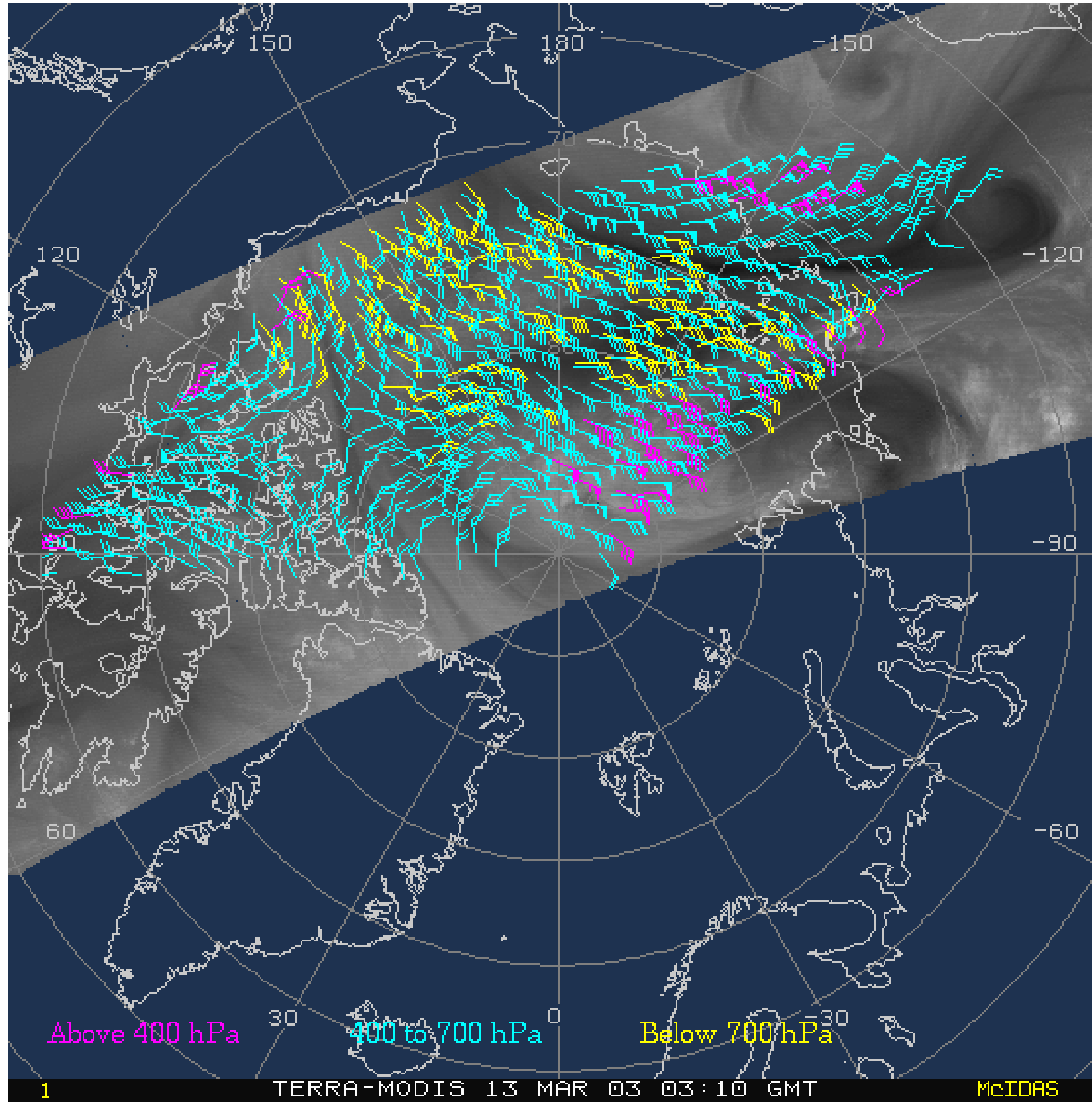
Jeff Key, Chris Velden, Dave Santek

Wind vectors are generated using automatic feature tracking software developed for GOES.

6.7 µm heights are assigned based on forecast atmospheric profile.

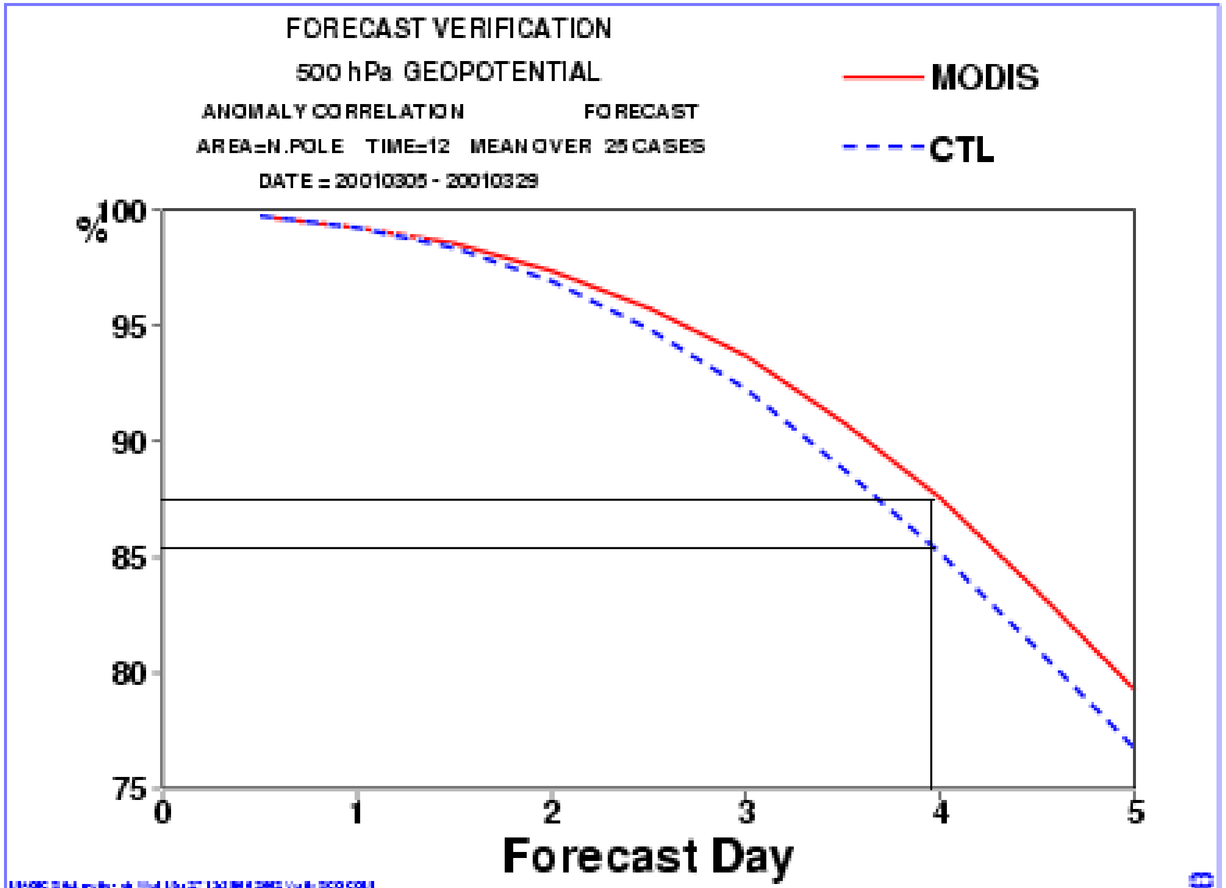
11.0 µm heights are assigned based on window brightness temperature or CO_2 cloud height.

Winds are automatically quality controlled.



Terra MODIS 6.7 µm (band 27) 2003/03/13

Positive impact on forecast demonstrated by ECMWF



NWP Centers using MODIS Polar Winds Operationally:

ECMWF, GMAO, JMA, CMC, FNMOC, UKMO, DWD, NCEP/EMC

Key, J. R., D. Santek, C. S. Velden, N. Bormann, J.-N. Thépaut, L. P. Riishojgaard, Y. Zhu, and W. P. Menzel, 2003. Cloud-Drift and Water Vapor Winds in the Polar Regions from MODIS. *IEEE Transactions on Geoscience and Remote Sensing, 41, 482-492.*