Early MODIS Atmospheric Science Products: Radiances, Cloud Detection, Cloud Properties, and Atmospheric Profiles

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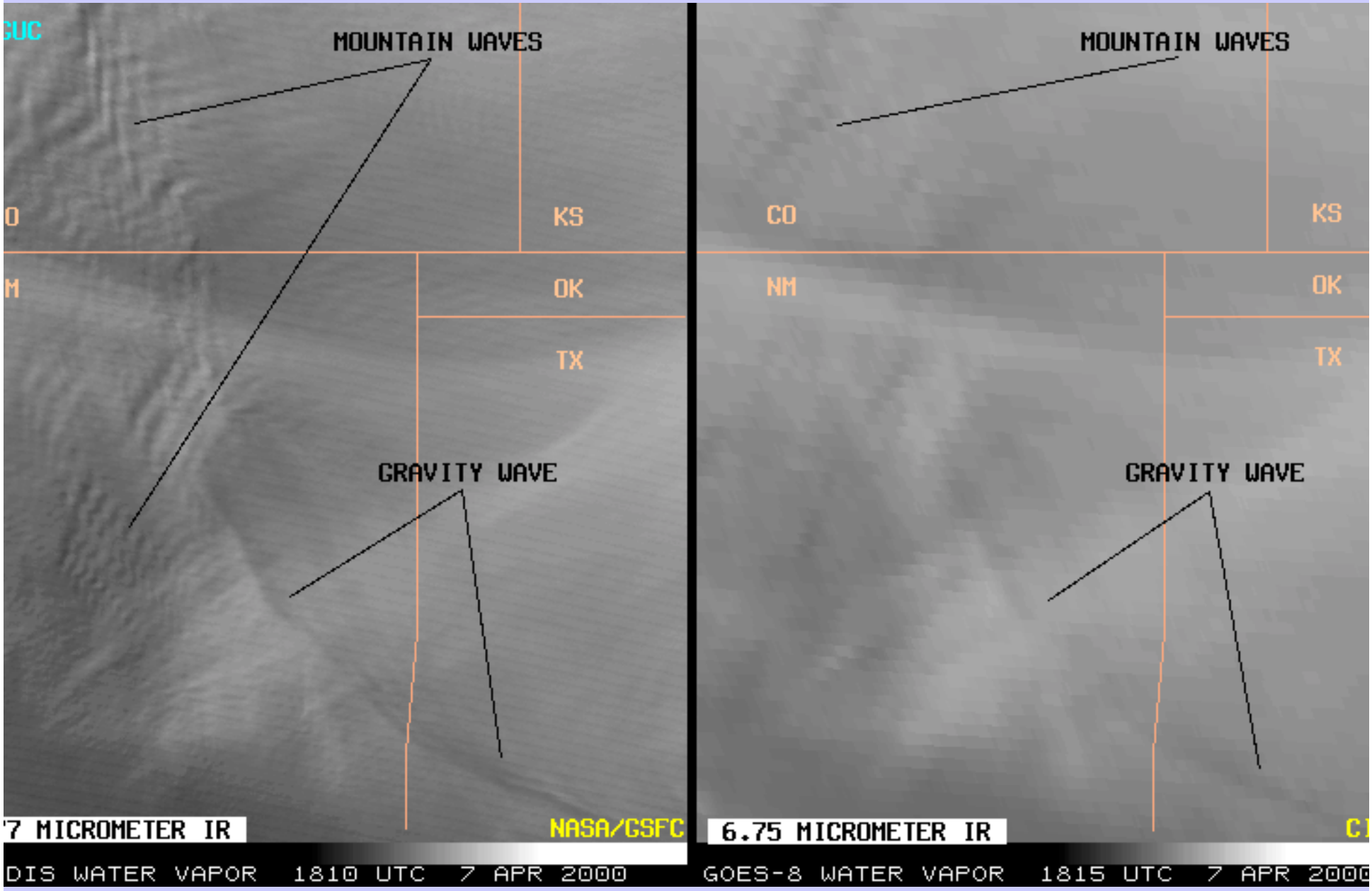
University of Wisconsin
CIMSS

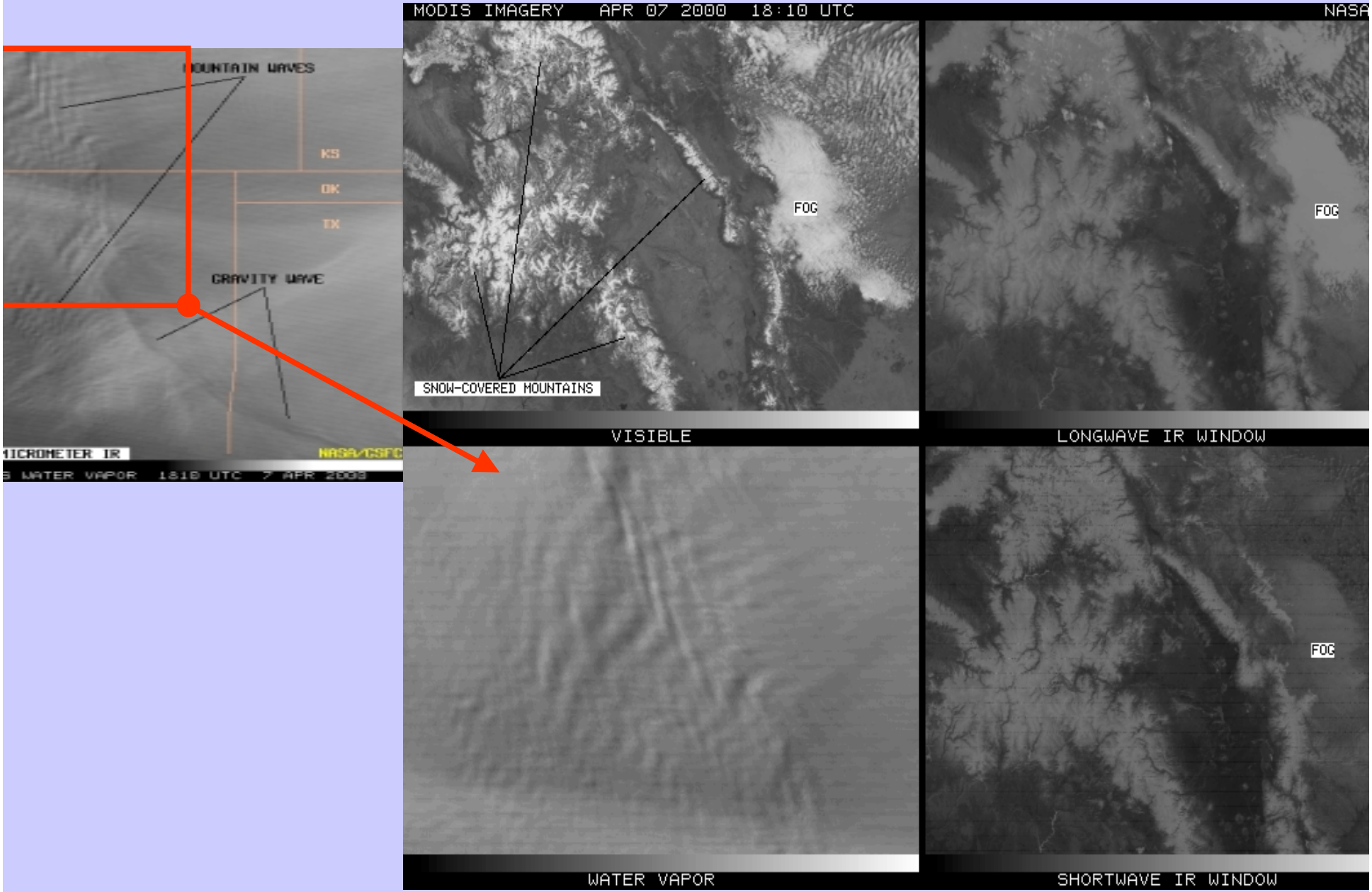
1 km WV
inter-calibration
cloud mask
cloud and atm properties
cal/val

MODIS revealing atmospheric moisture details as never befor

1 km MODIS WV (left) & 4x8 km GOES WV (right)



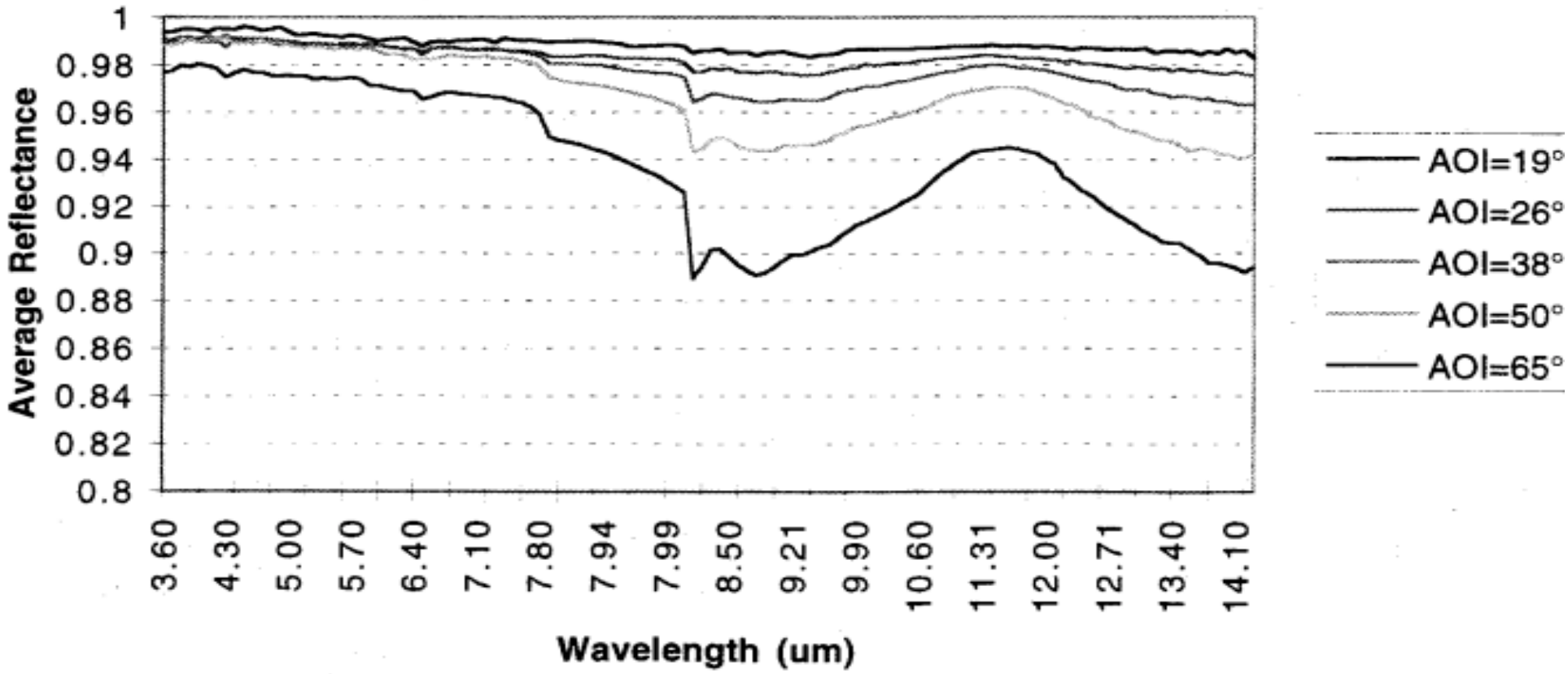
Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery



MODIS (PFM) Performance Issues
University Wisconsin; June 2000

PERFORMANCE ISSUE	IMPACT	REMEDIATION
Scan Mirror RVS in PC Bands	Confounds CO2 high cloud test in Cloud Mask	Adjust RVS LUT
SWIR/MWIR Electronic Xtalk	Snow, thin cirrus detection in Cloud Mask	Minimize Xtalk; apply influence coefficients
PC Band Optical Crosstalk	Cloud mask, cloud top pressure	Adjust PC_XT LUT
5um Thermal Leak into SWIR	Thin cirrus detection in Cloud Mask	Determine on-orbit correction coeffs LUT
3.9um and 11um radiometric accuracy	Cloud Mask is missing low cloud, esp at night	?
Polarization Effects in Band 29(?)	Cloud Phase becomes less certain	?
1.6um “dead” detectors and detector striping	“Imager” Quality	Flag “dead” detectors; apply detector correction

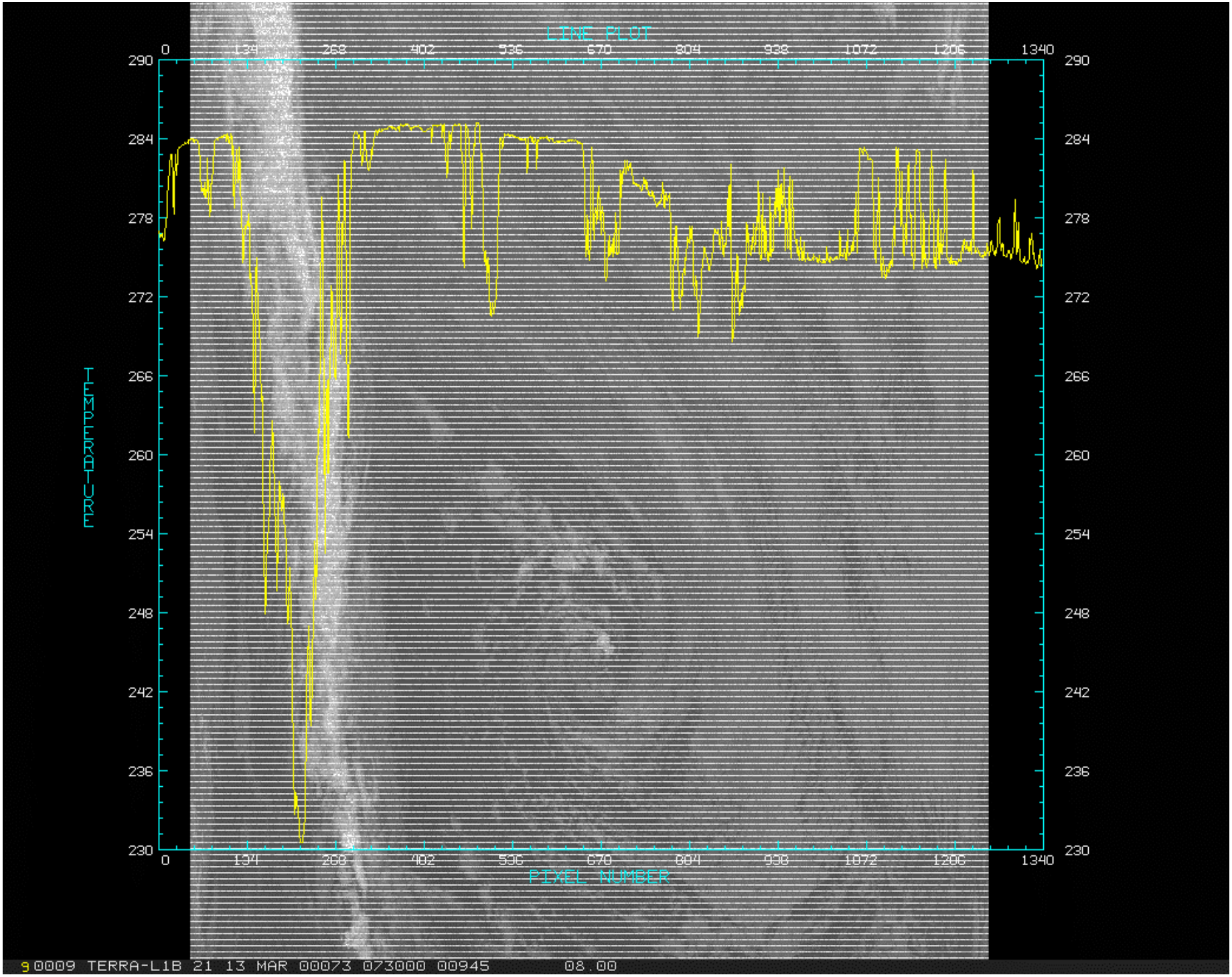
PFM Scan Mirror Reflectance Measurement



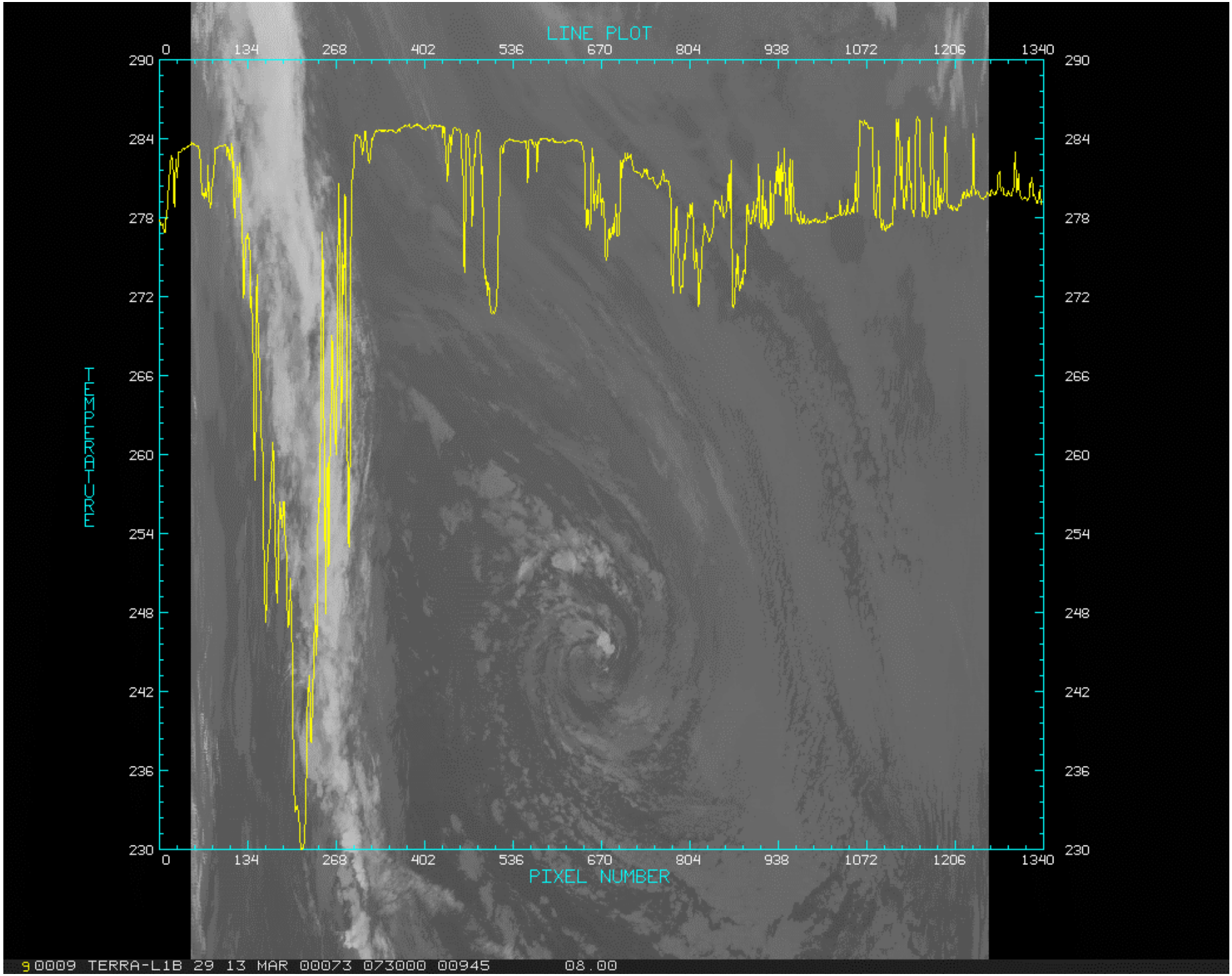
Average of SN03 and SN04 Samples; Measurement #1

Scan Mirror RVS in PC Bands

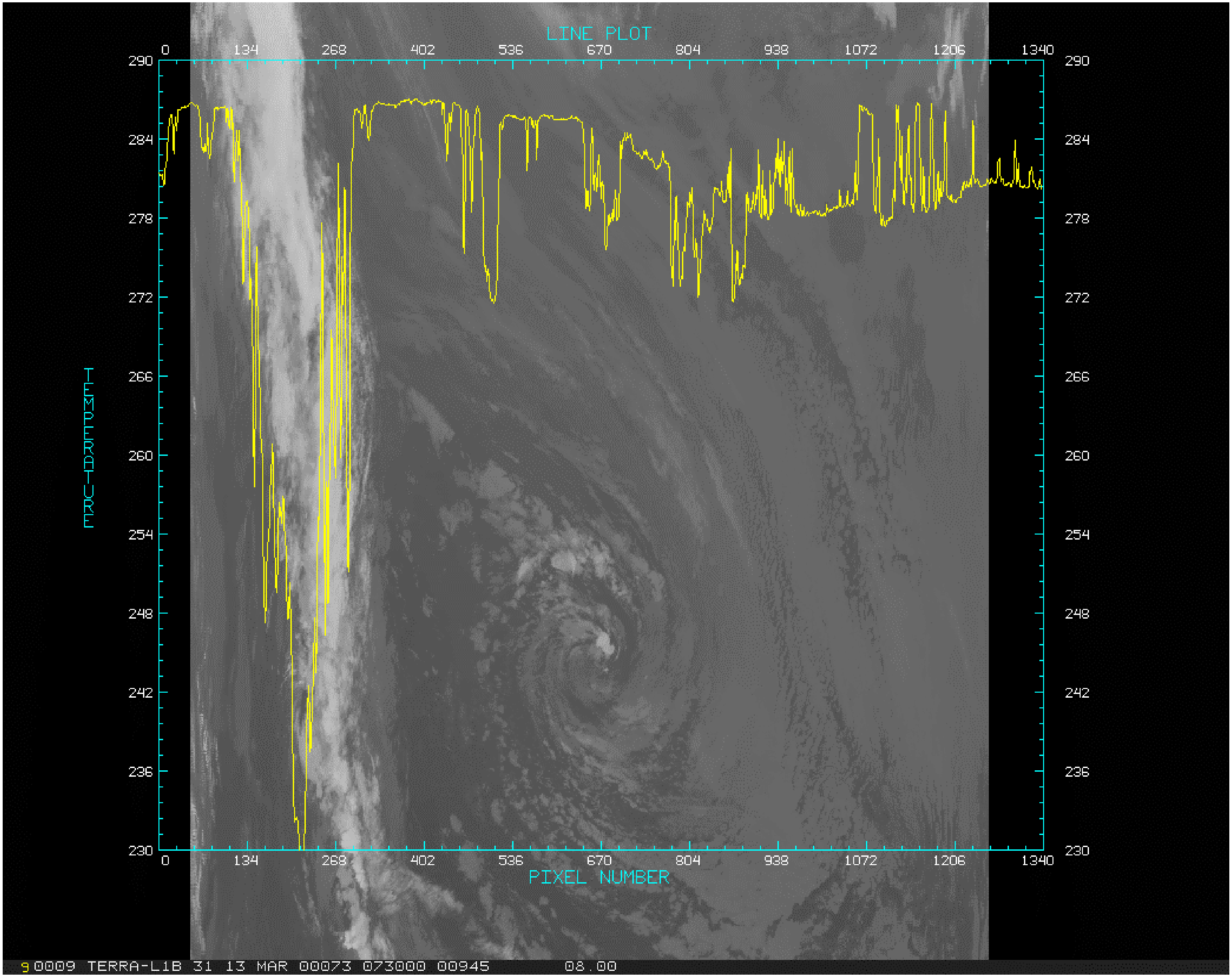
Band 21 (3.9um)


LINE PLOT
TEMPERATURE
PIXEL NUMBER
290
284
278
272
266
260
254
248
242
236
230
0
134
268
402
536
670
804
938
1072
1206
1340
9 0009 TERRA-L1B 21 13 MAR 00073 073000 00945 08.00

Band 29 (8.6um)

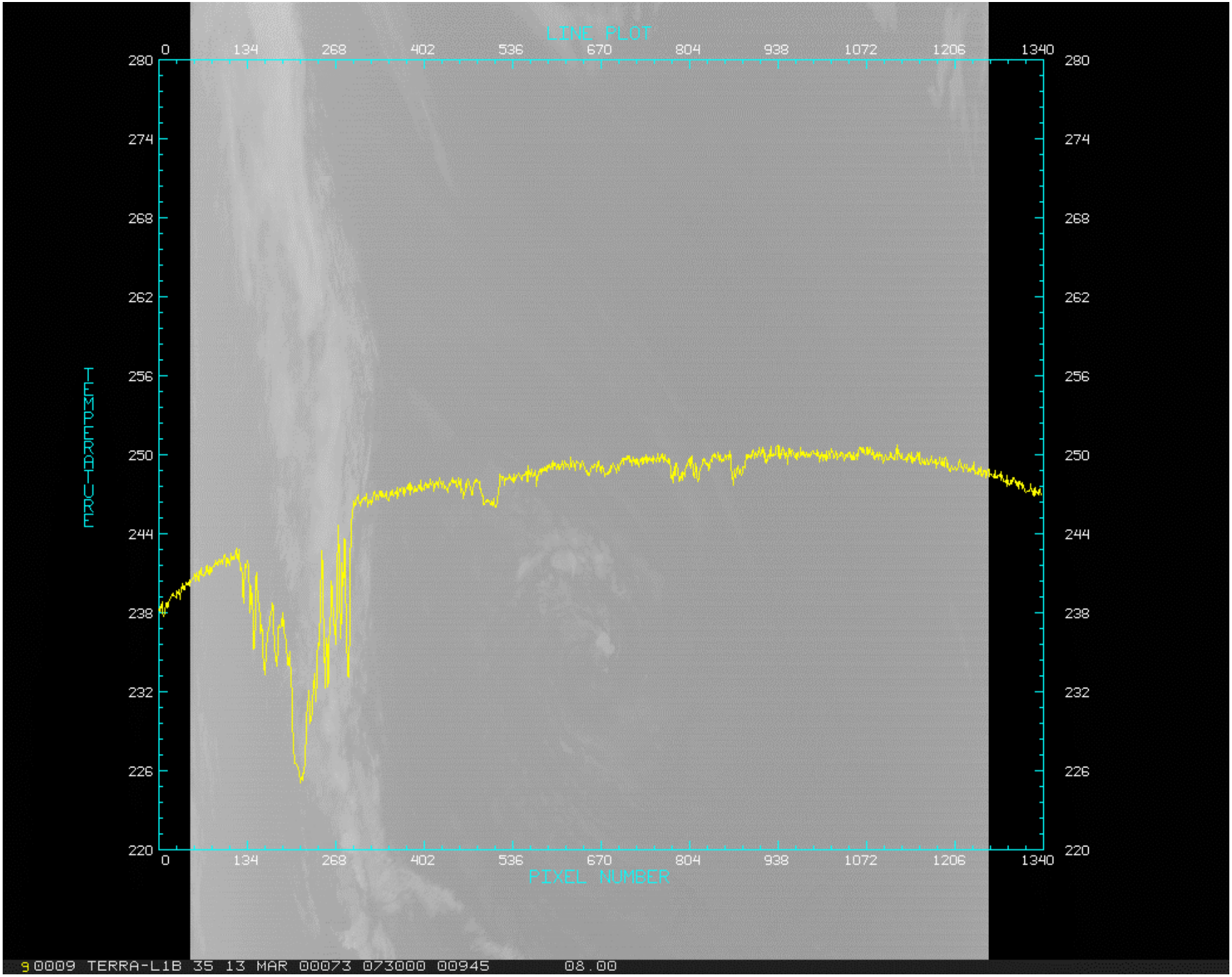

LINE PLOT
0
134
268
402
536
670
804
938
1072
1206
1340
290
284
278
272
266
260
254
248
242
236
230
BRIGHTNESS TEMPERATURE
PIXEL NUMBER
9 0009 TERRA-L1B 29 13 MAR 00073 073000 00945 08.00

Band 31 (11um)



LINE PLOT
0 134 268 402 536 670 804 938 1072 1206 1340
290 284 278 272 266 260 254 248 242 236 230
TEMPERATURE
PIXEL NUMBER
9 0009 TERRA-L1B 31 13 MAR 00073 073000 00945 08.00

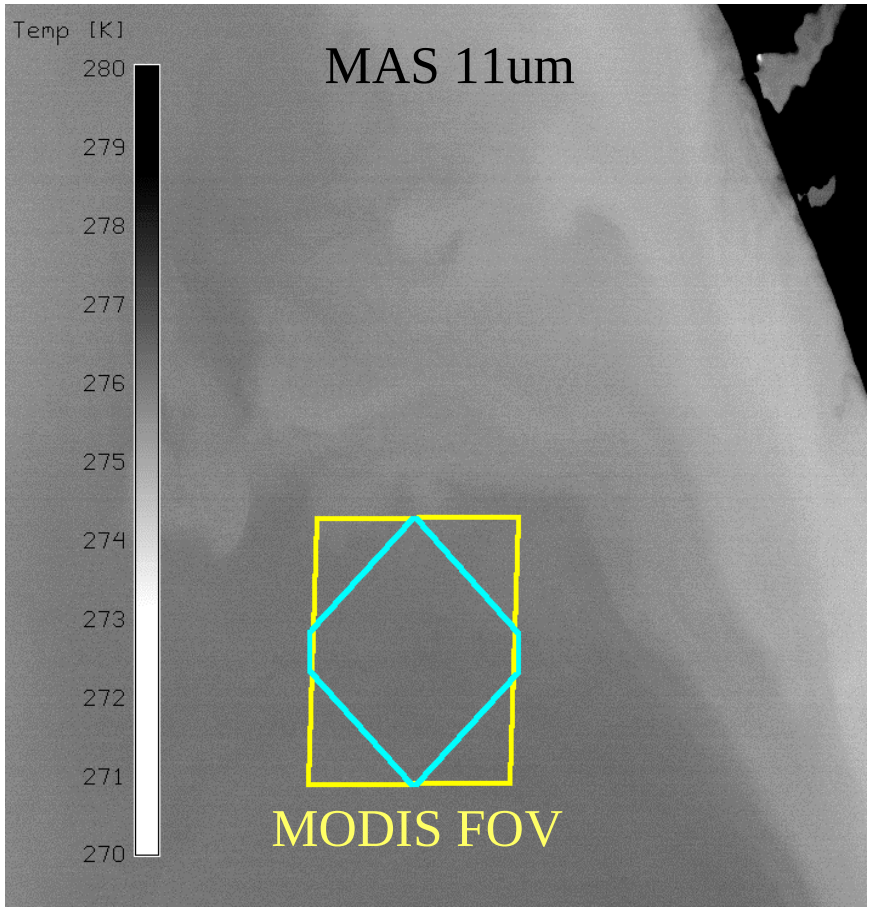
Band 35 (13.9um)



MODIS IR Cal/Val from ER-2 Feb - Mar 2000

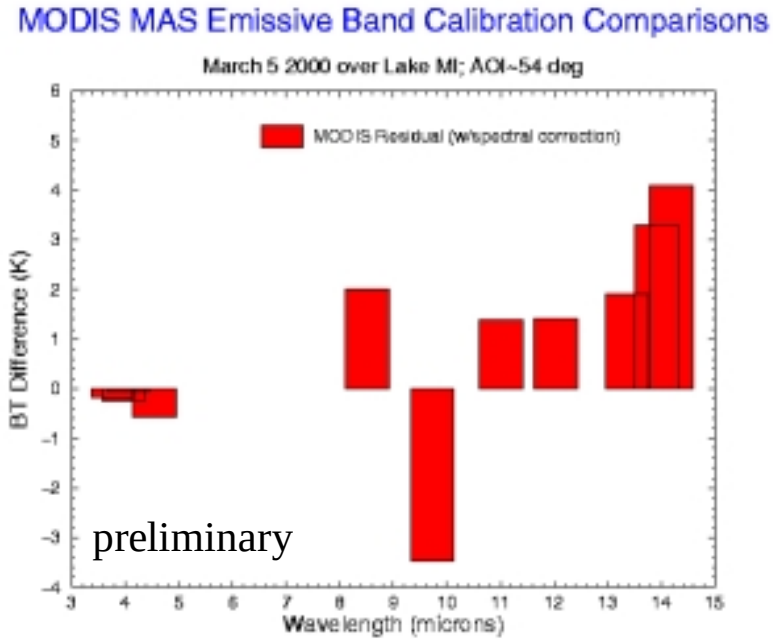
MODIS

MAS
S-HIS

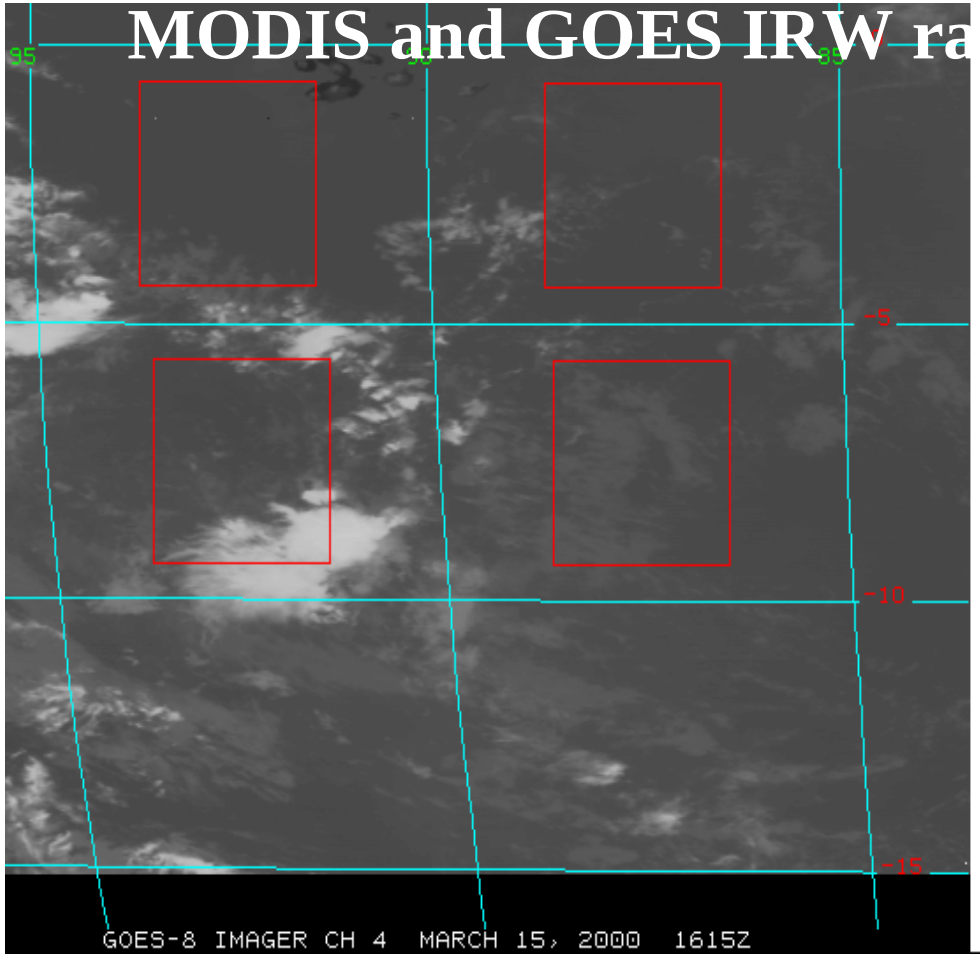


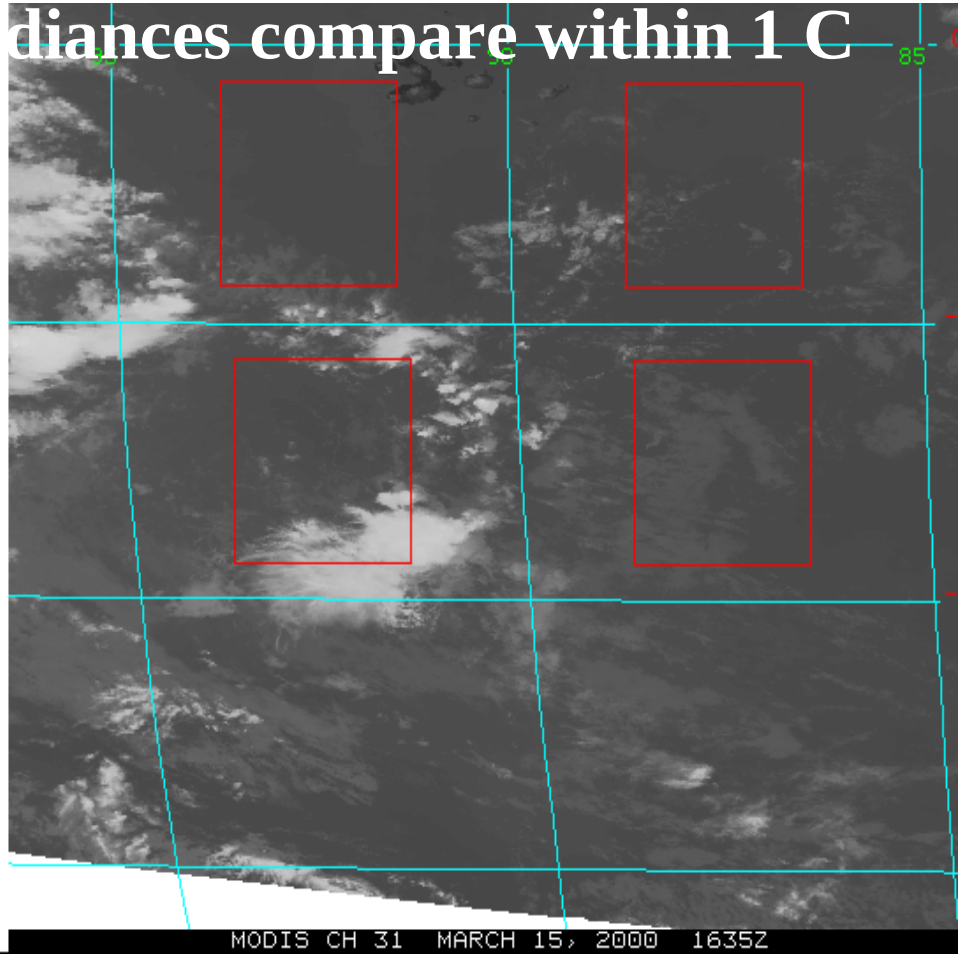
Purpose: Validate MODIS L1E

- Transfer S-HIS cal to MAS
- Collocate MODIS FOV on MAS
- Remove spatial, spectral and viewing geometry dependencies



MODIS and GOES IRW radiances compare within 1 C





Lon	Satellite	Pixels	Minimum	Maximum	Mean	Stn. Dev.
/ 92.5	GOES-8 Ch 4	10201	53.804 = 258.49 K	138.341 = 315.25 K	100.947 = 293.79 K	3.524
	MODIS Ch 31	10201	65.755 = 265.69 K	127.012 = 306.29 K	103.660 = 292.53 K	3.612
/ 87.5	GOES-8 Ch 4	10201	77.903 = 278.17 K	103.532 = 295.41 K	100.873 = 293.74 K	2.120
	MODIS Ch 31	10201	67.991 = 267.50 K	108.405 = 295.46 K	105.558 = 293.71 K	2.731
/ 87.5	GOES-8 Ch 4	10201	81.919 = 281.07 K	102.575 = 294.81 K	96.805 = 291.15 K	3.849
	MODIS Ch 31	10201	87.851 = 282.18 K	107.27 = 294.77 K	101.823 = 291.38 K	4.112
/ 92.5	GOES-8 Ch 4	10201	20.142 = 217.50 K	102.766 = 294.93 K	85.643 = 283.69 K	23.516
	MODIS Ch 31	10201	20.086 = 214.221 K	105.899 = 293.92 K	87.879 = 282.20 K	25.055

Detecting Clouds (IR)

IR Window Brightness Temperature Threshold and Difference Tests

IR tests sensitive to sfc emissivity and atm PW, dust, and aerosols
BT11 < 270
BT11 + aPW * (BT11 - BT12) < SST
BT11 + bPW * (BT11 - BT8.6) < SST
  aPW and bPW determined from lookup table as a function of PW
BT3.9 - BT11 > 8 indicates daytime low cloud cover
BT11 - BT12 > 2 (rel for scene temp) indicates high cloud
BT11 - BT6.7 large neg diff for clr sky over Antarctic Plateau winter

CO2 Channel Test for High Clouds

BT13.9 < threshold (problems at high scan angle or high terrain)

Detecting Clouds (vis)

Reflectance Threshold Test

r3.9 > 6% considered to be cloudy and < 3% considered to be snow/
problems in bright deserts

Near IR Thin Cirrus Test

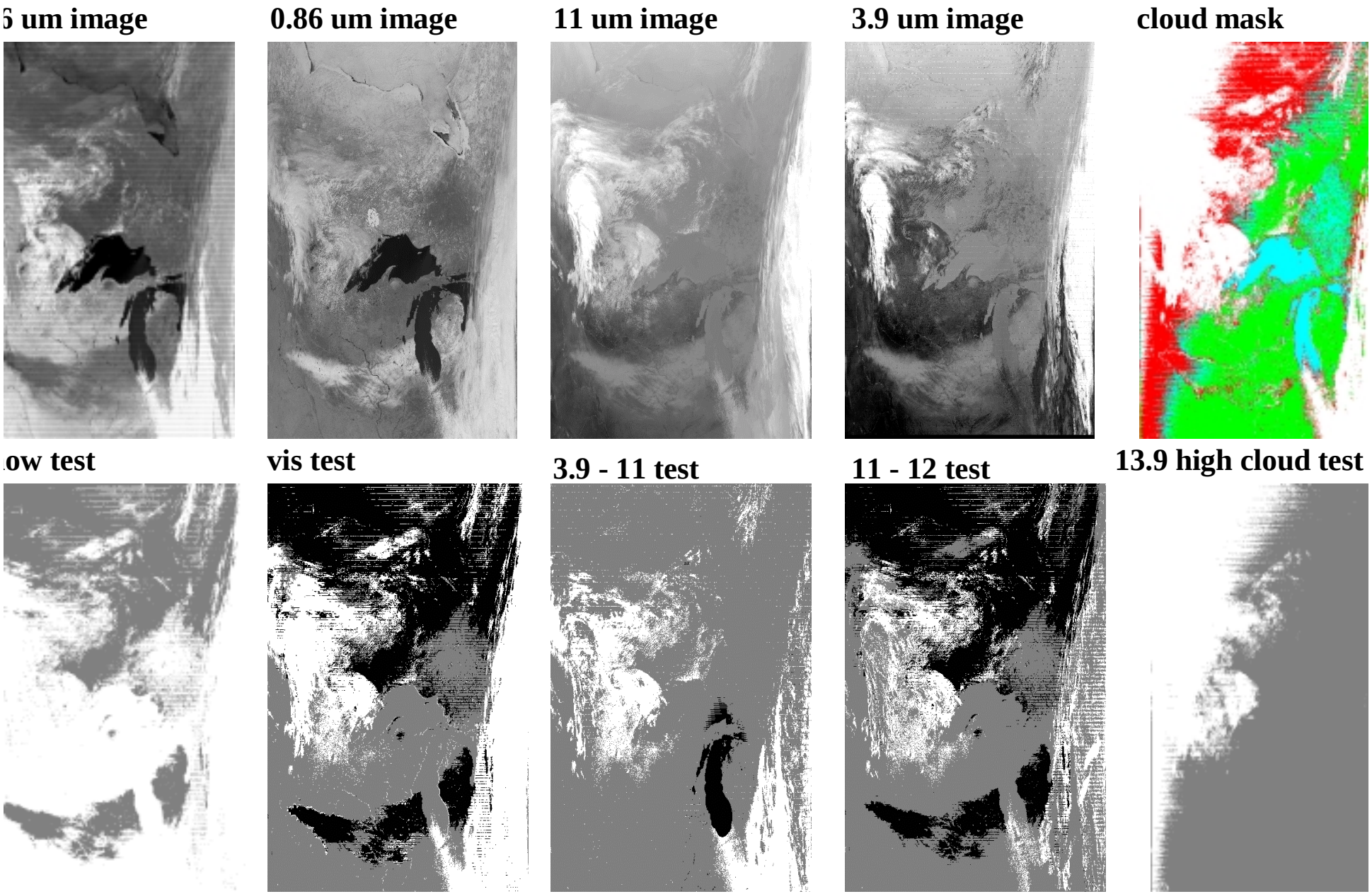
r1.38 > threshold indicates presence of thin cirrus cloud
ambiguity of high thin versus low thick cloud (resolved with BT13.
problems in high terrain

Reflectance Ratio Test

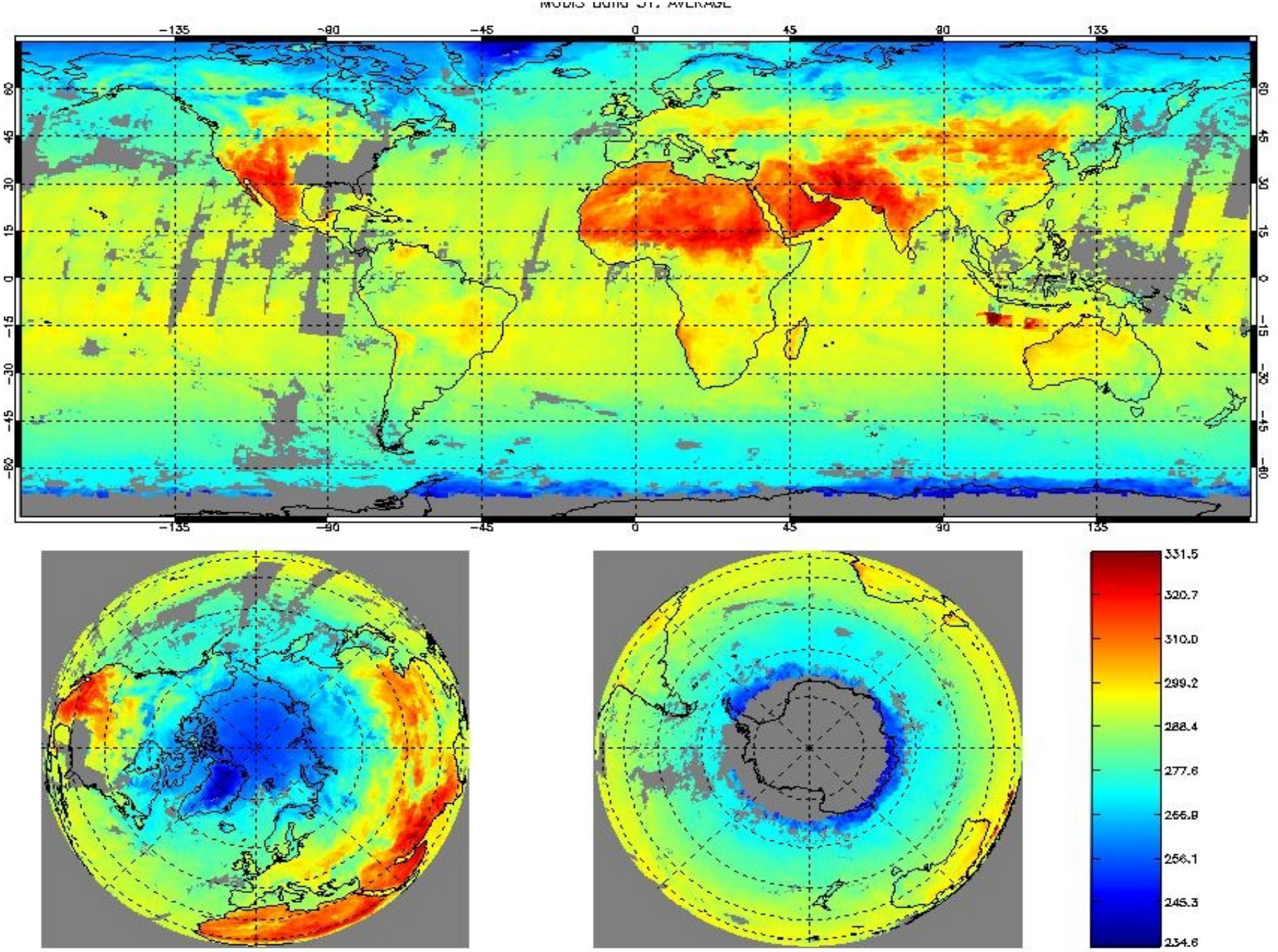
r.87/r.66 between 0.9 and 1.1 for cloudy regions
must be ecosystem specific

Snow Test

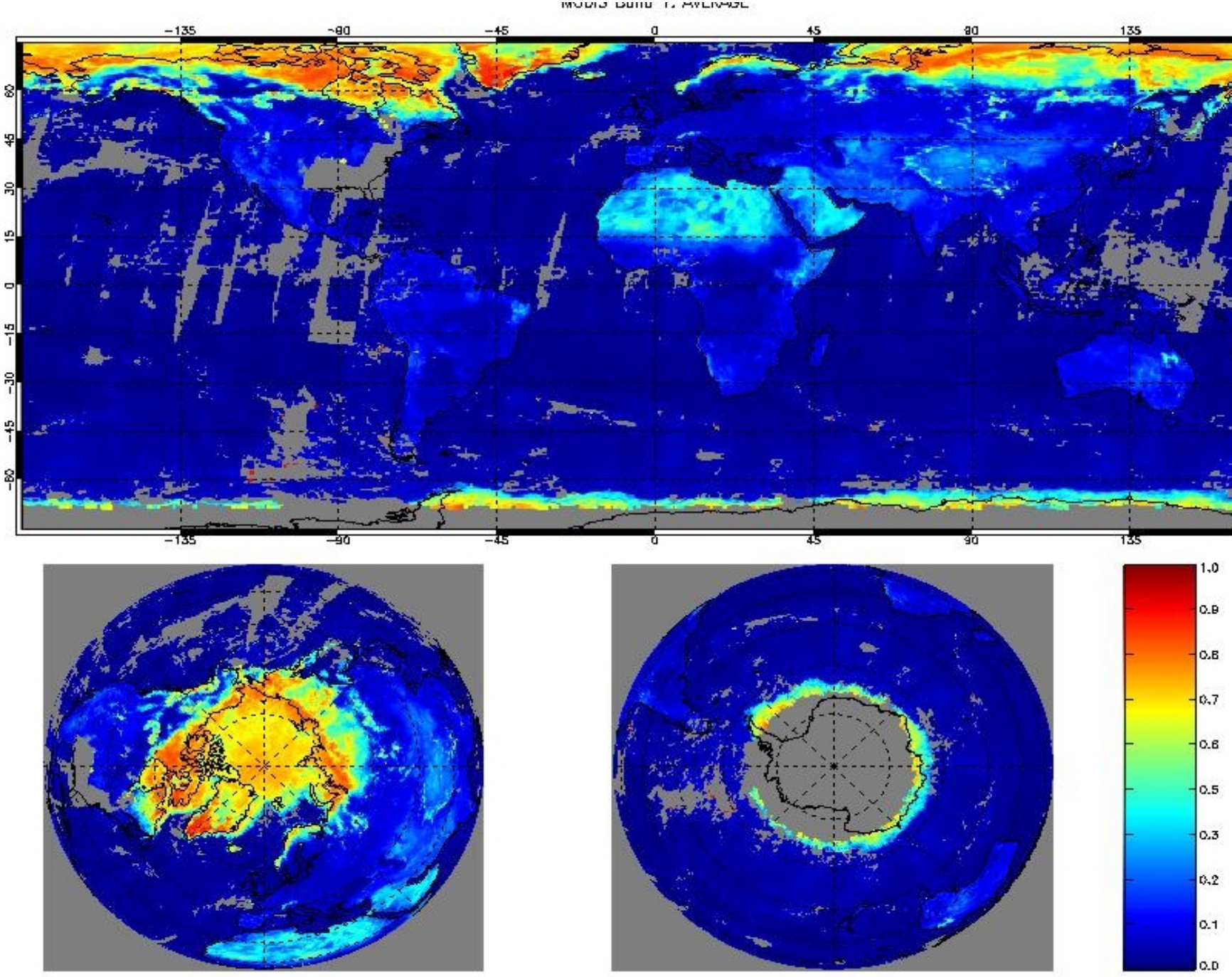
NDSI = [r.55-r1.6]/ [r.55+r1.6] > 0.4 and r.88 > 0.1 then snow



ODIS Cloud Mask (high confidence clear is green, confident is blue, uncertain is red, cloudy is whit
ow test determines which spectral tests / thresholds are used. Vis test is not used over snow-covered
as (shown as black). 3.9-11 µm test finds primarily low clouds. 11-12 µm test primarily finds high
uds. 13.9 µm test is causing uncertainty in colder regions (should improve with stable calibration).



IR Window Tb Composite Clear-sky Values for 4-7 May 2000
Derived from the MODIS Cloud Mask



Visible Composite Clear-sky Values for 4-7 May 2000
Derived from the MODIS Cloud Mask

Changes and/or fixes to MODIS Cloud Mask code through 6/1/2000 at UW SCF

1. Land/snow/sun-glint bug
2. Added call to set_qa_bit for test bit #25 (allows result of test #25 to be seen)
3. Added 11-12 μm thin cirrus test to night land and ocean
4. Added spatial variability test to daytime oceans poleward of 60)
5. Modified NDSI test processing:
   must have positive NDSI *and* ancillary snow/ice for all oceans
   same for land between –60 and +25 latitude
6. Output clear-sky radiance data for day, land, (geometric) sun-glint regions
7. Turned off CO_2 test poleward of 60 degrees latitude

Upcoming Cloud Mask Investigations/Modifications

1. Sun-glint regions
2. Warm cloud scenes in arid ecosystems, day and night
3. Antarctica
4. Low-level clouds on land at night
5. Snow/ice surfaces at night

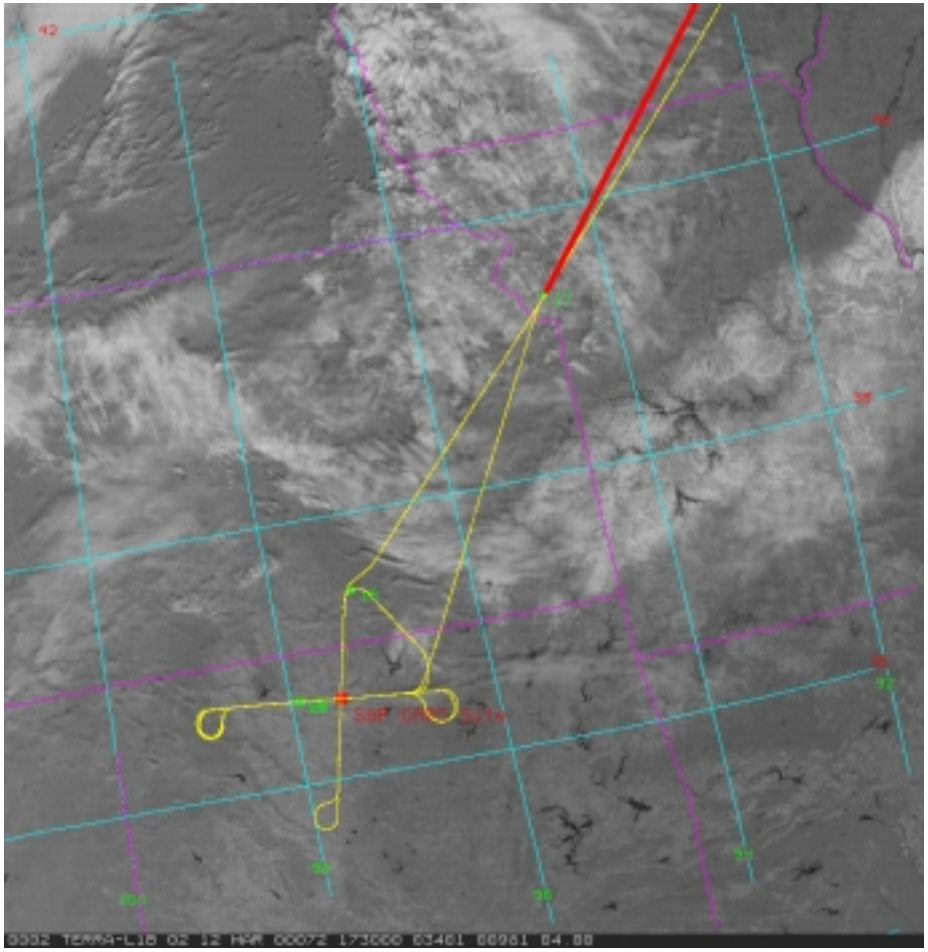
   Items 3-5 very subject to calibration changes

CLS, HIRS, and Raob cal/val of MODIS cloud properties

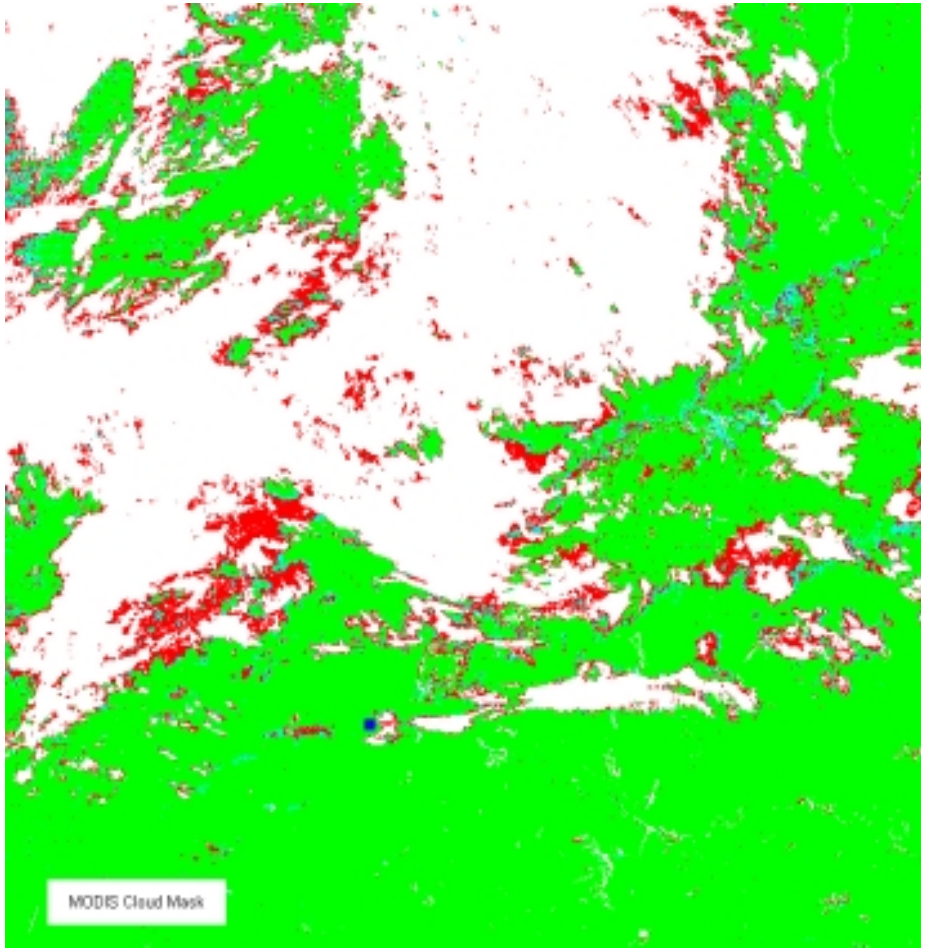
On March 12, a high-altitude research aircraft (ER-2) flew under the Terra spacecraft as it traversed central North America from north to south. Part of the ER-2 flight track (yellow line) is shown, superimposed on the MODIS 0.86 μm image from 17:10Z. This scene is the same one as shown in the cloud top properties examples. The cloud mask result is important input to the MODIS cloud top properties algorithm. Note that the mask properly discriminates snow from cloud in almost all cases. Aircraft nadir-viewing LIDAR cloud top pressures from the CLS (Cloud Lidar System) on board the ER-2 are compared to MODIS retrievals. LIDAR cloud top pressure values are shown in the histogram. The red line in the above image shows the approximate coverage area of the CLS data. Histograms of MODIS cloud top pressure retrievals are compared with NOAA-14 HIRS (CHAPS) values from the same region. The CHAPS (Collocated HIRS and AVHRR ProductS) data were collected about 3 hours later in the day.

There is generally good agreement between LIDAR and MODIS results but note that the LIDAR covers a much smaller area than MODIS. The LIDAR is capable of sensing very thin cirrus clouds shown by the solid bar at 300-399 mb which is largely missing from the MODIS results. Good agreement is also seen between MODIS and CHAPS, where the smaller FOV of the MODIS leads to more clear-sky values. A comparison between CHAPS and MODIS cloud effective emissivities reveals good agreement between the two, with MODIS finding more clear-sky scenes due to higher spatial resolution.

A sounding taken at the CART Site beginning at 17:29Z reveals a rapid increase in dew point depression at approximately 450 mb. This agrees with the peak frequency of cloud top pressures in both the MODIS and CHAPS histogram.

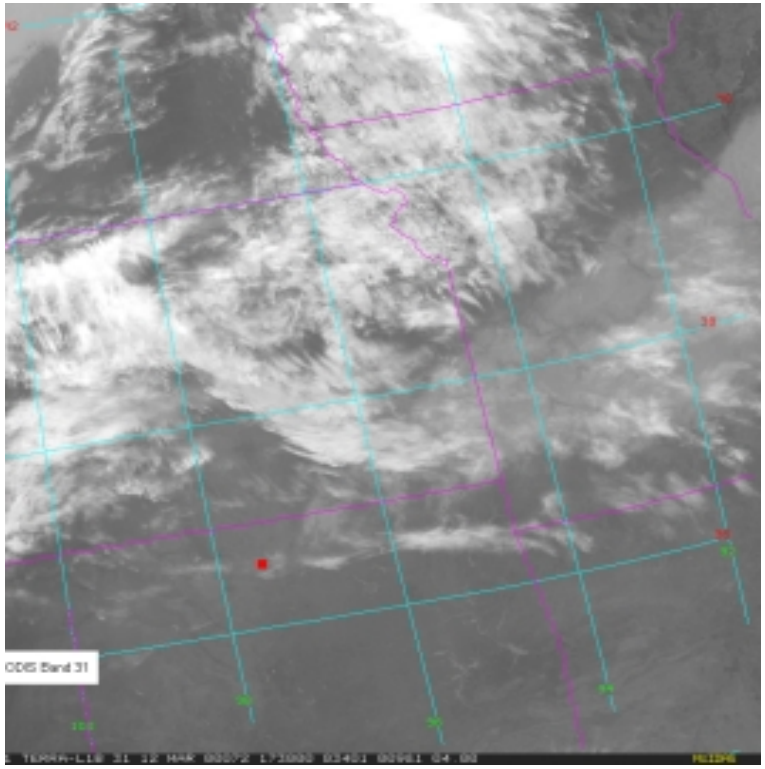


ER-2 flight track on
MODIS 0.86 um image from 1710 UTC



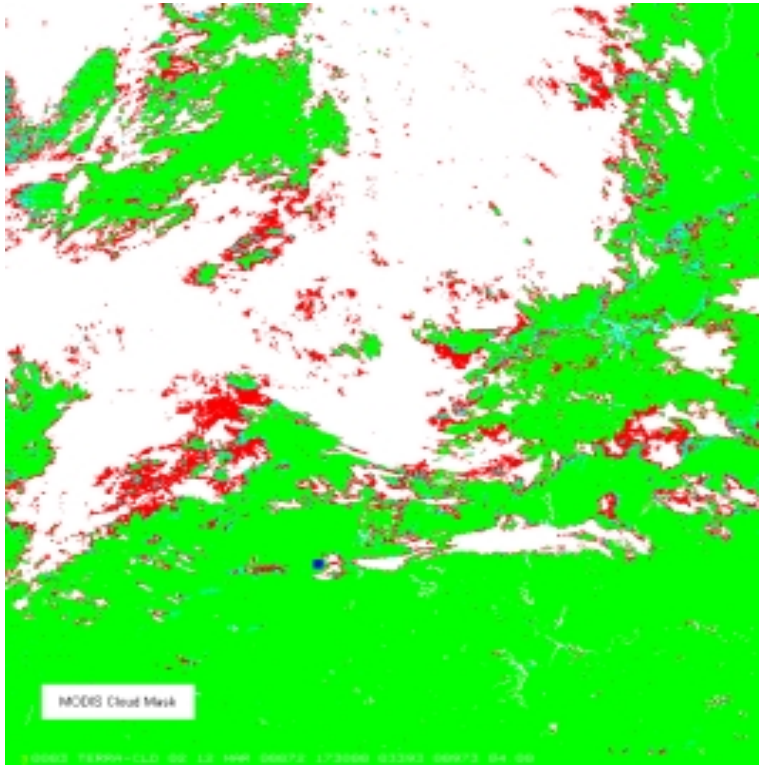
Associated cloud mask

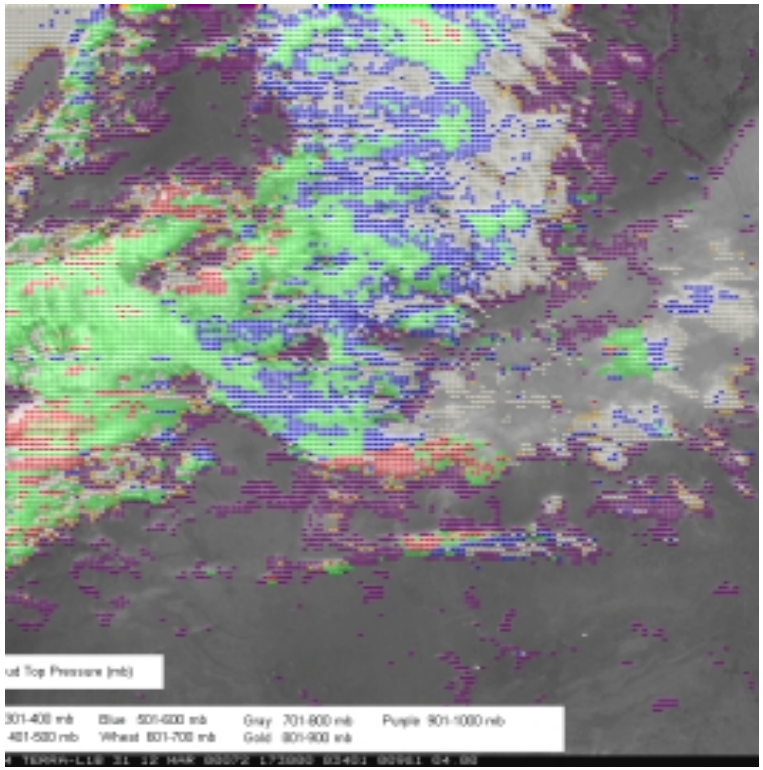
(ER-2) flew under the Terra on March 12, 2000 (WISC-T2000 Field Experiment)



VIS CM

MODIS
Cloud
Mask



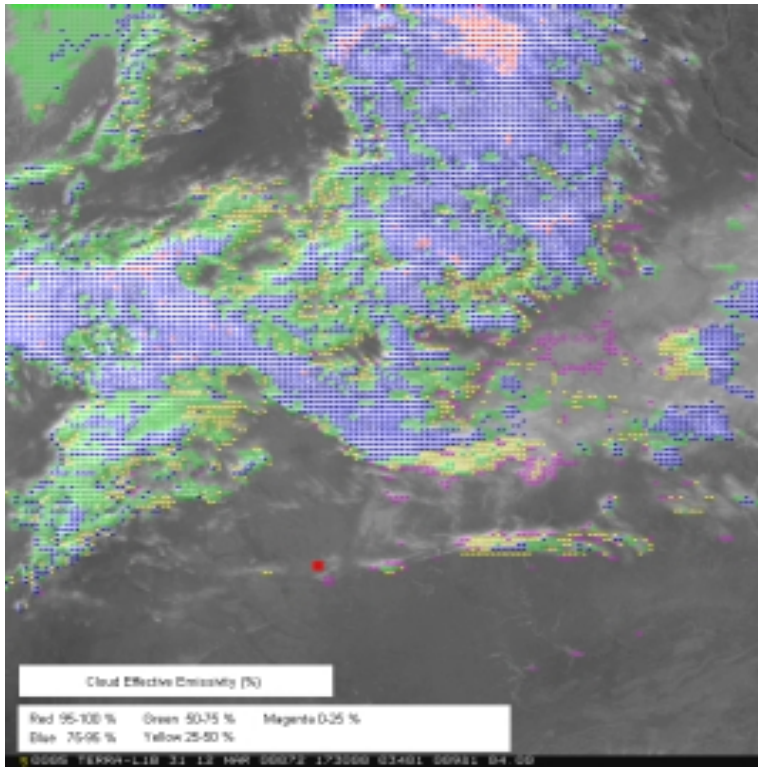


CTP Nε

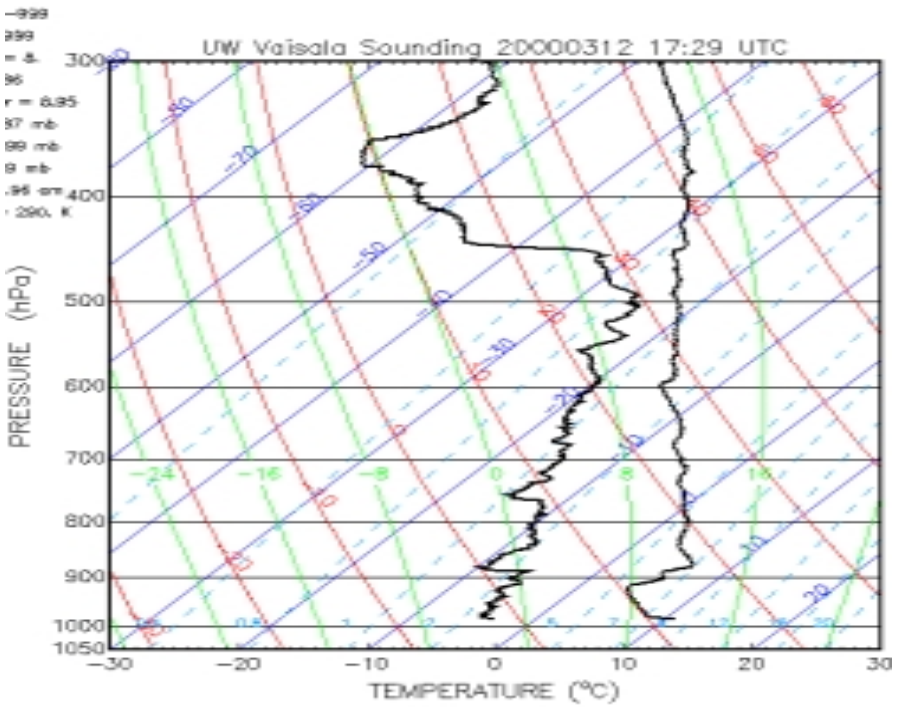
MODIS
Cloud
Properties

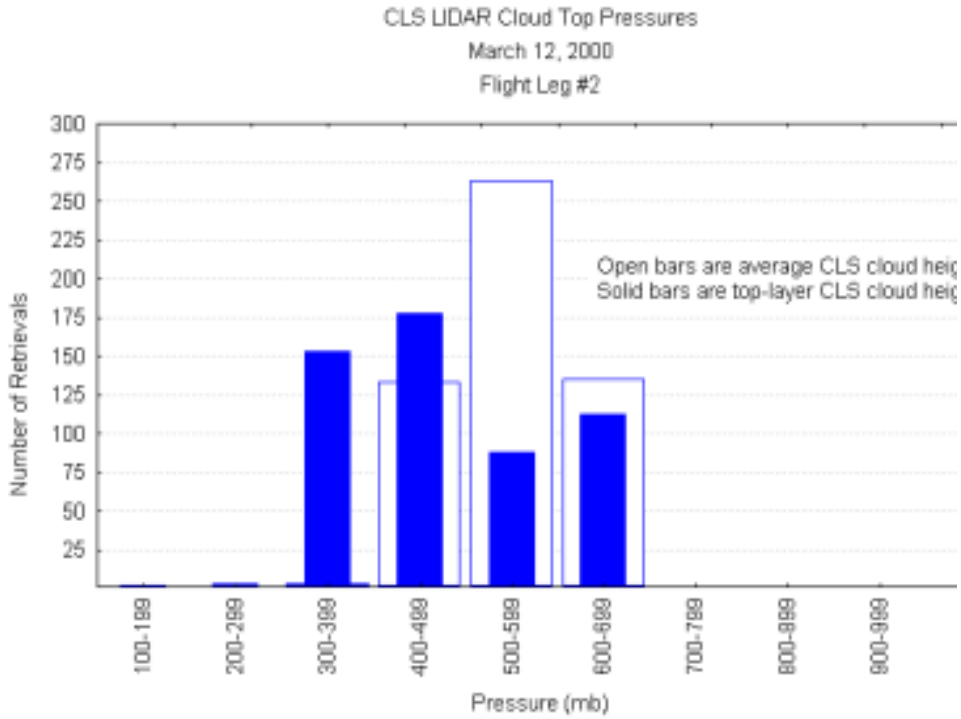
r 3-4
g 4-5
b 5-6

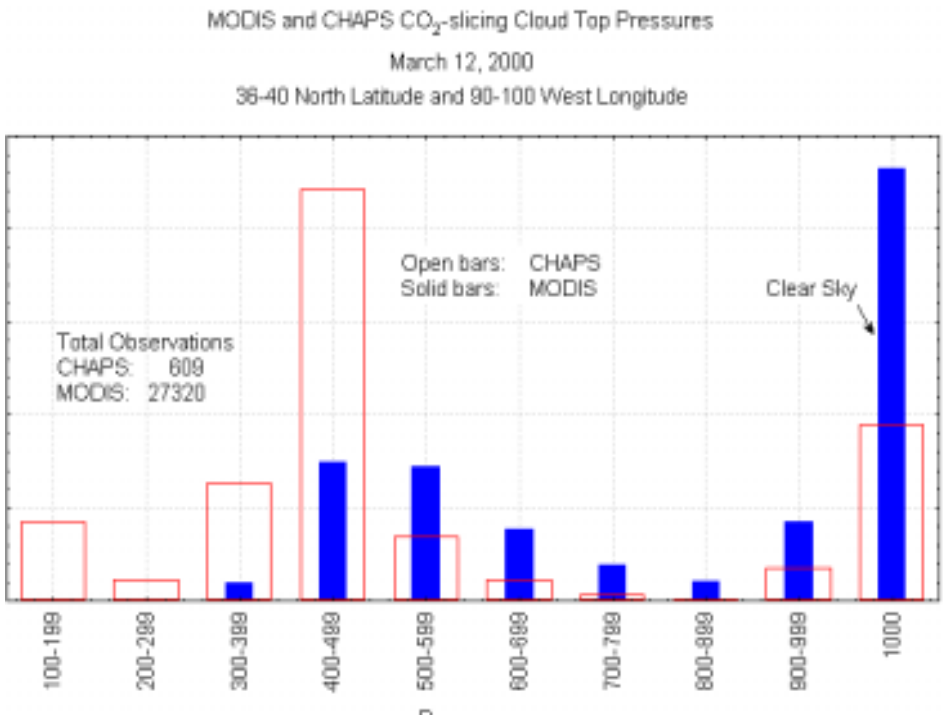
r>95
b>75
g>50
y>25

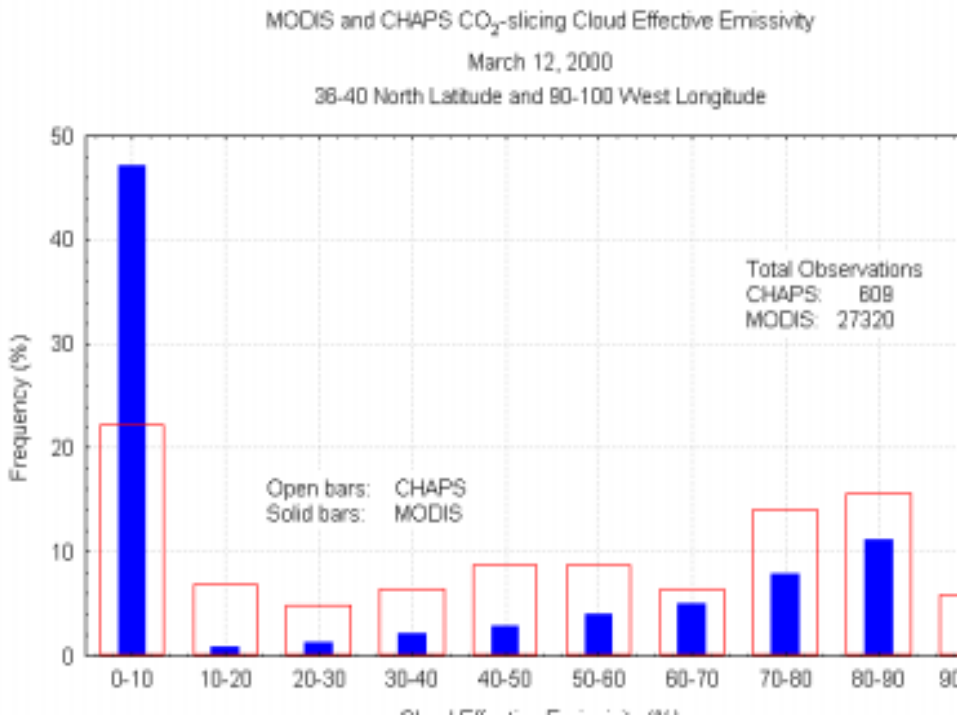


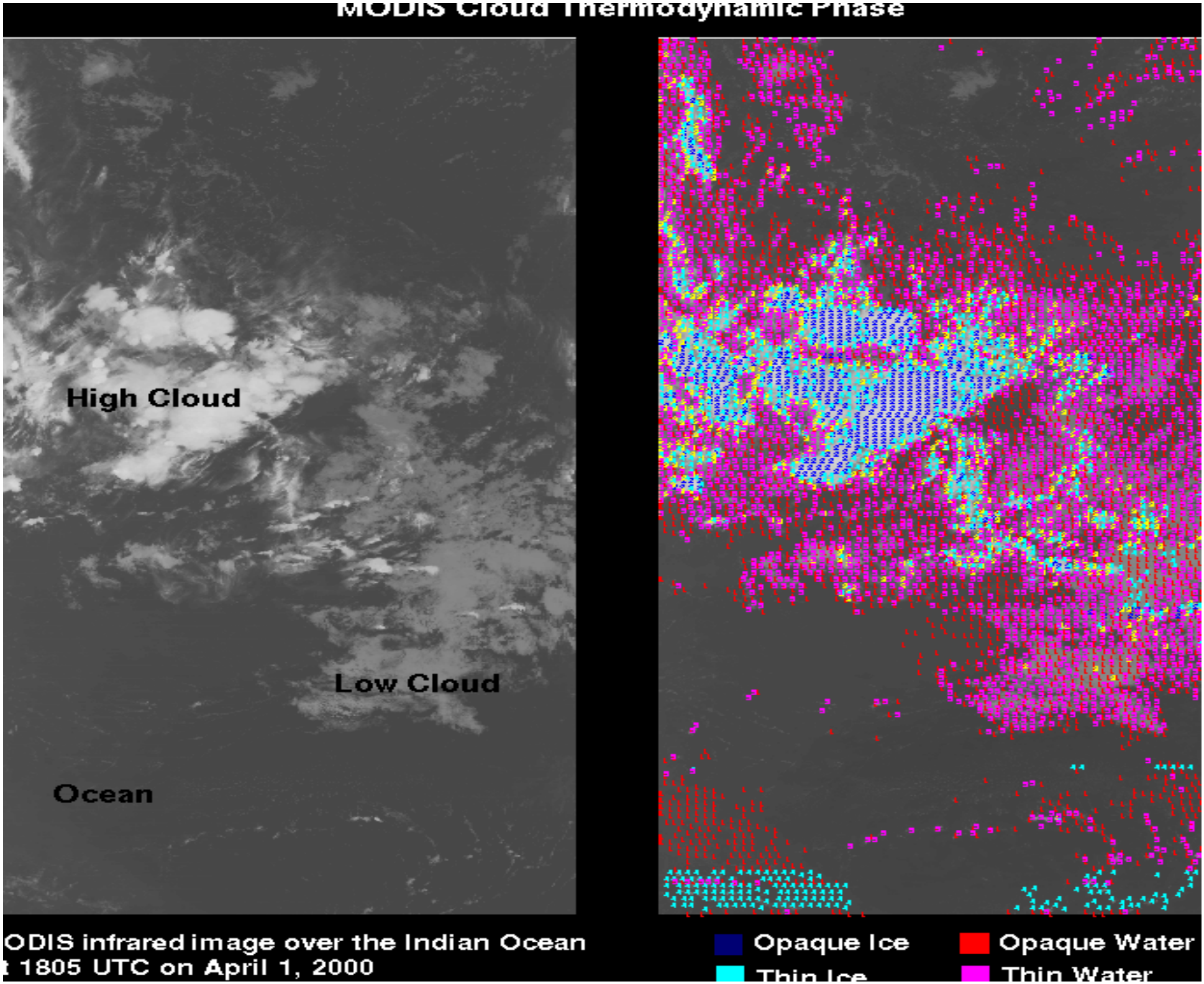
omparison of CLS (nadir view), HIRS (3 hrs later), RAOB, & MODIS Cloud Properti





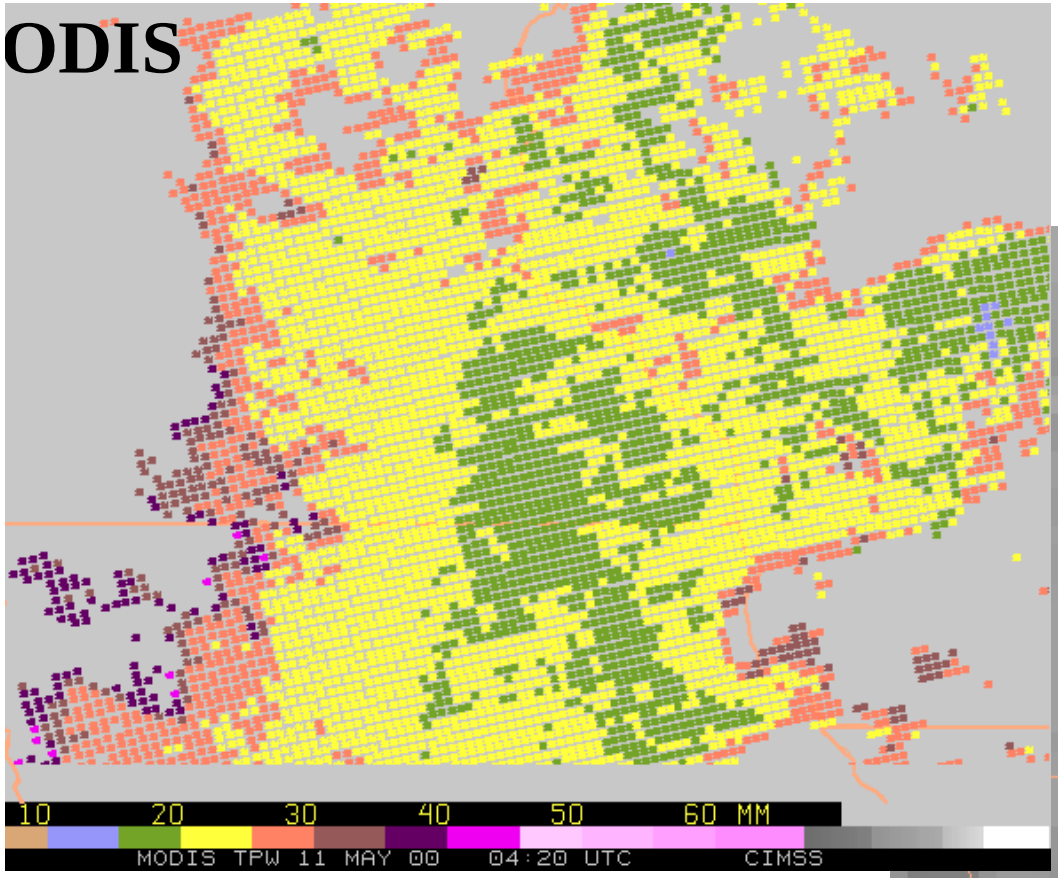


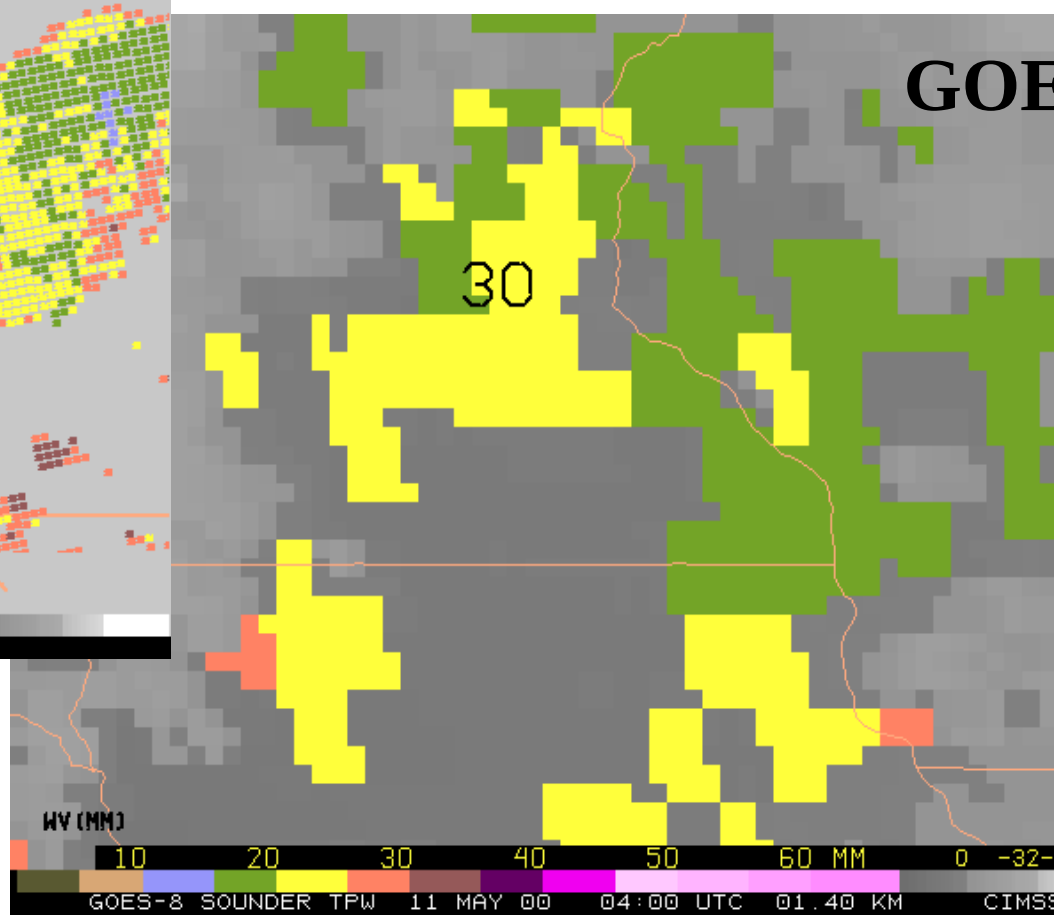



MODIS Cloud Thermodynamic Phase
High Cloud
Low Cloud
Ocean
ODIS infrared image over the Indian Ocean
1805 UTC on April 1, 2000
Opaque Ice
Opaque Water
Thin Ice
Thin Water

Atmospheric TPW

clear sky water vapor (mm)



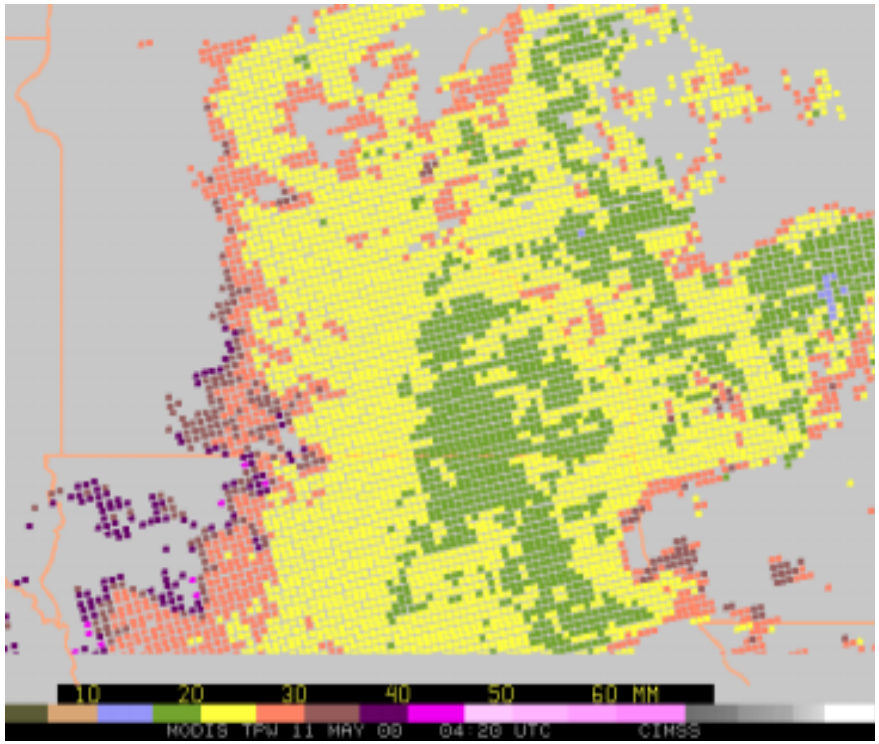


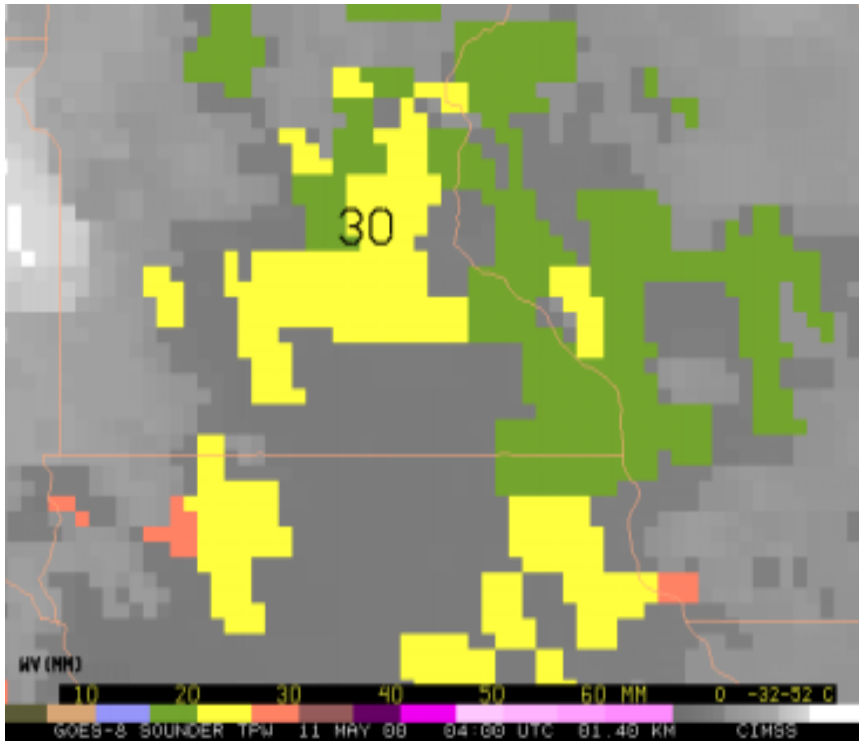
Upper Midwest 11 May 2000

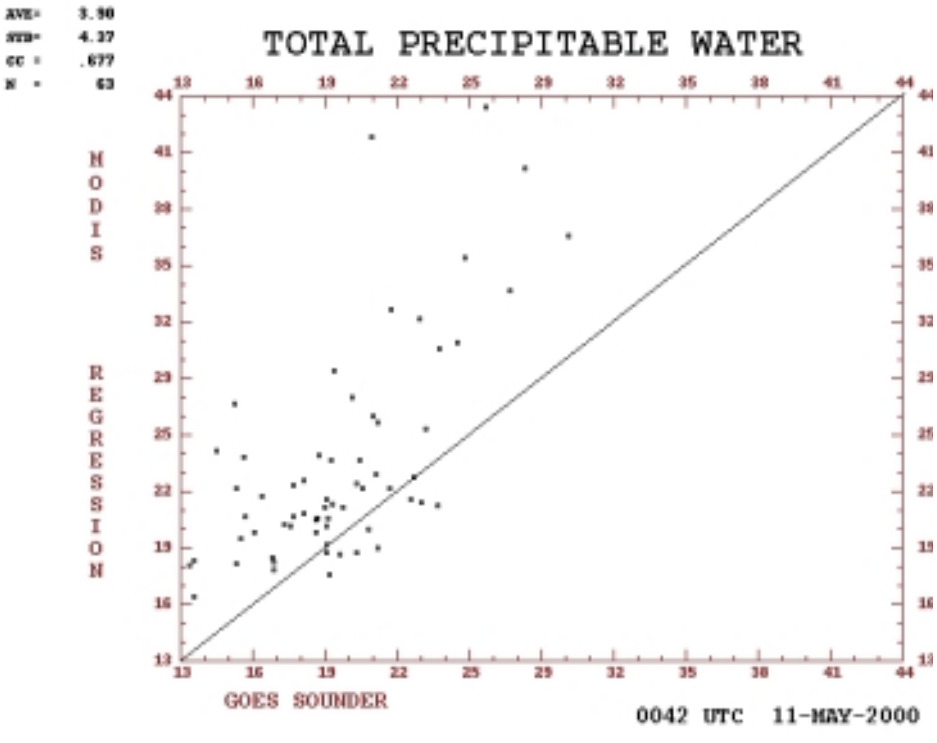
eft figure is MODIS TPW from 420 UTC (algorithm is regression based and uses no sfc ob
ight is GOES Sounder TPW from 400 UTC (simultaneous physical retrieval of T and q usi
fc obs and NWP model first guess). Similar values and gradients are evident (corr coeff 0.7
Both capture the most moist regions in eastern and western Iowa.

The large “30” is the precipitable water value from the 00 UTC Chanhassen , MN raob.

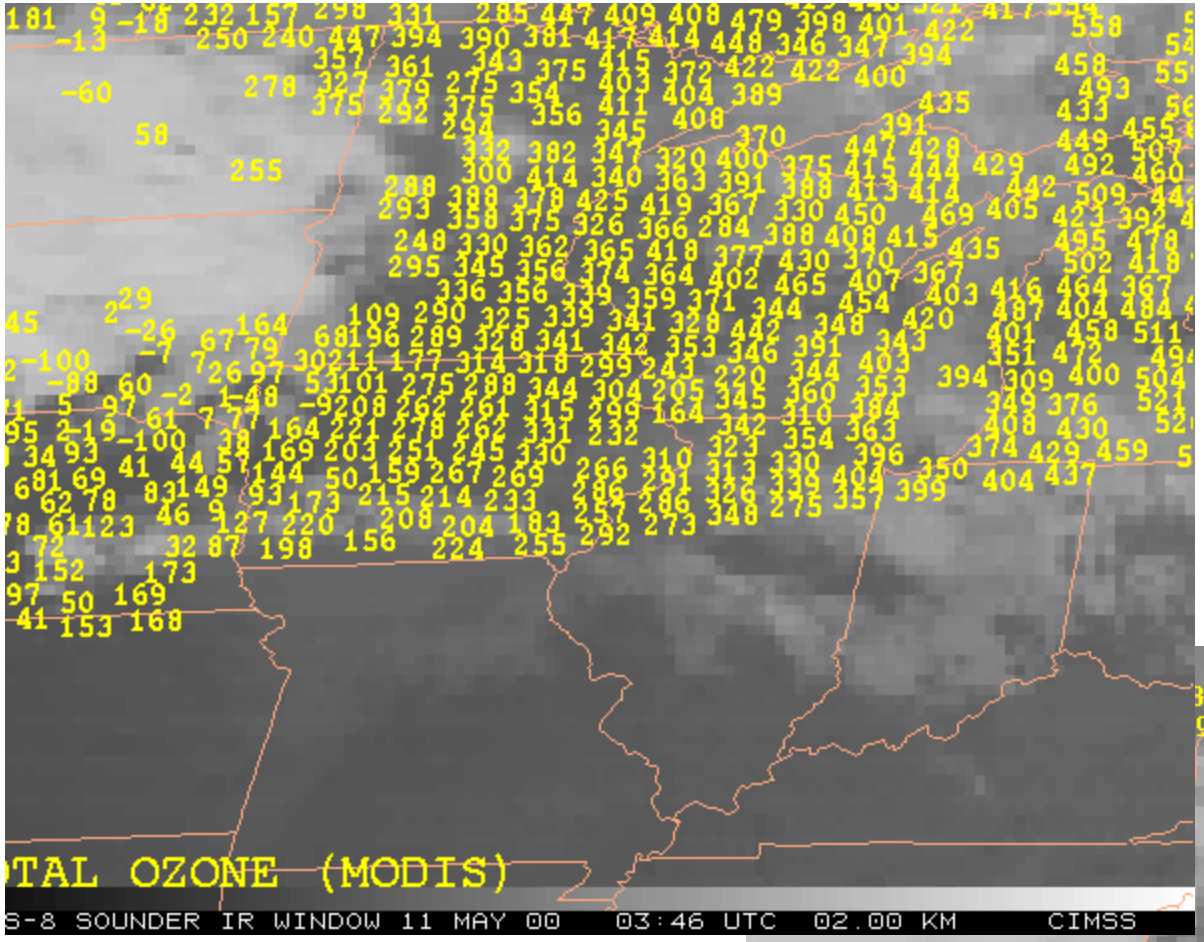
Atmospheric Properties (Total PW)

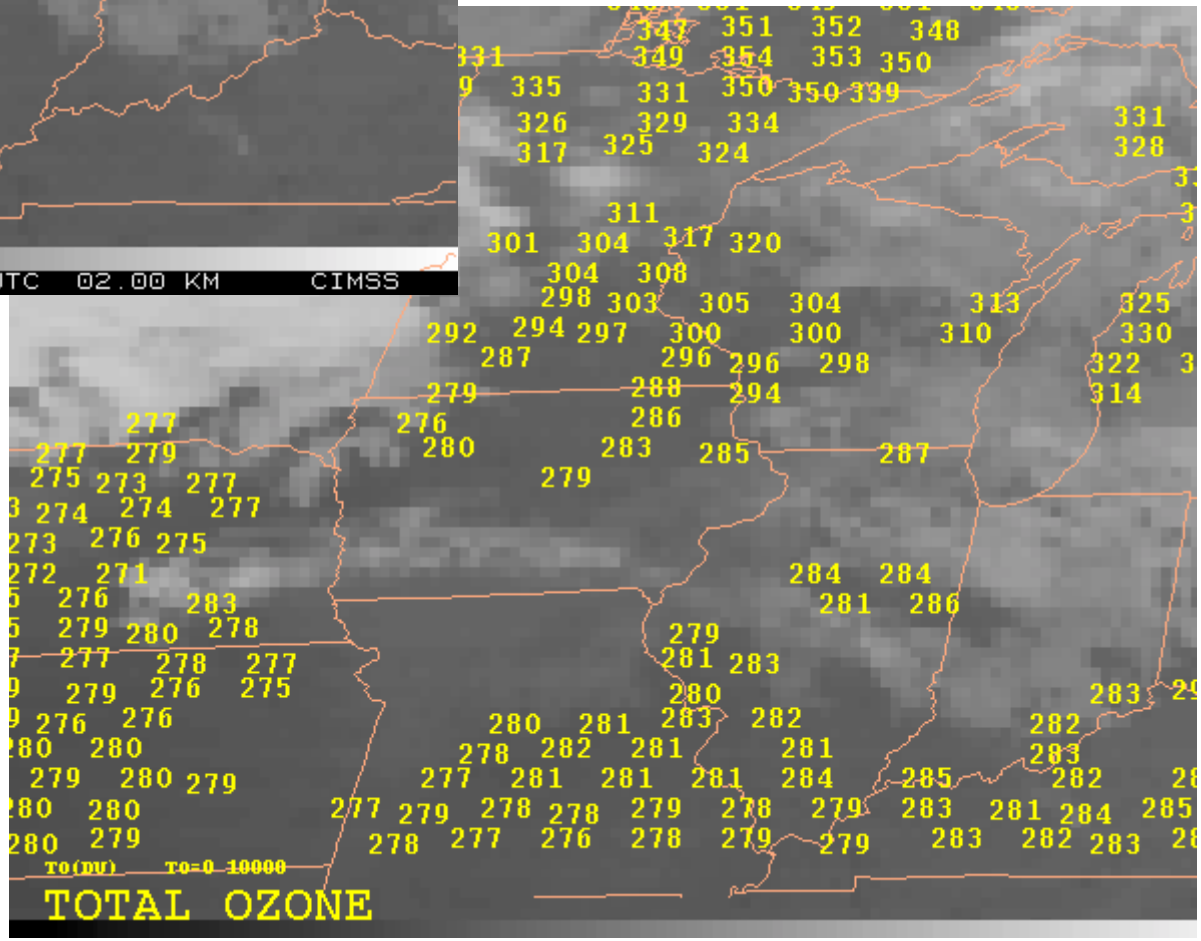






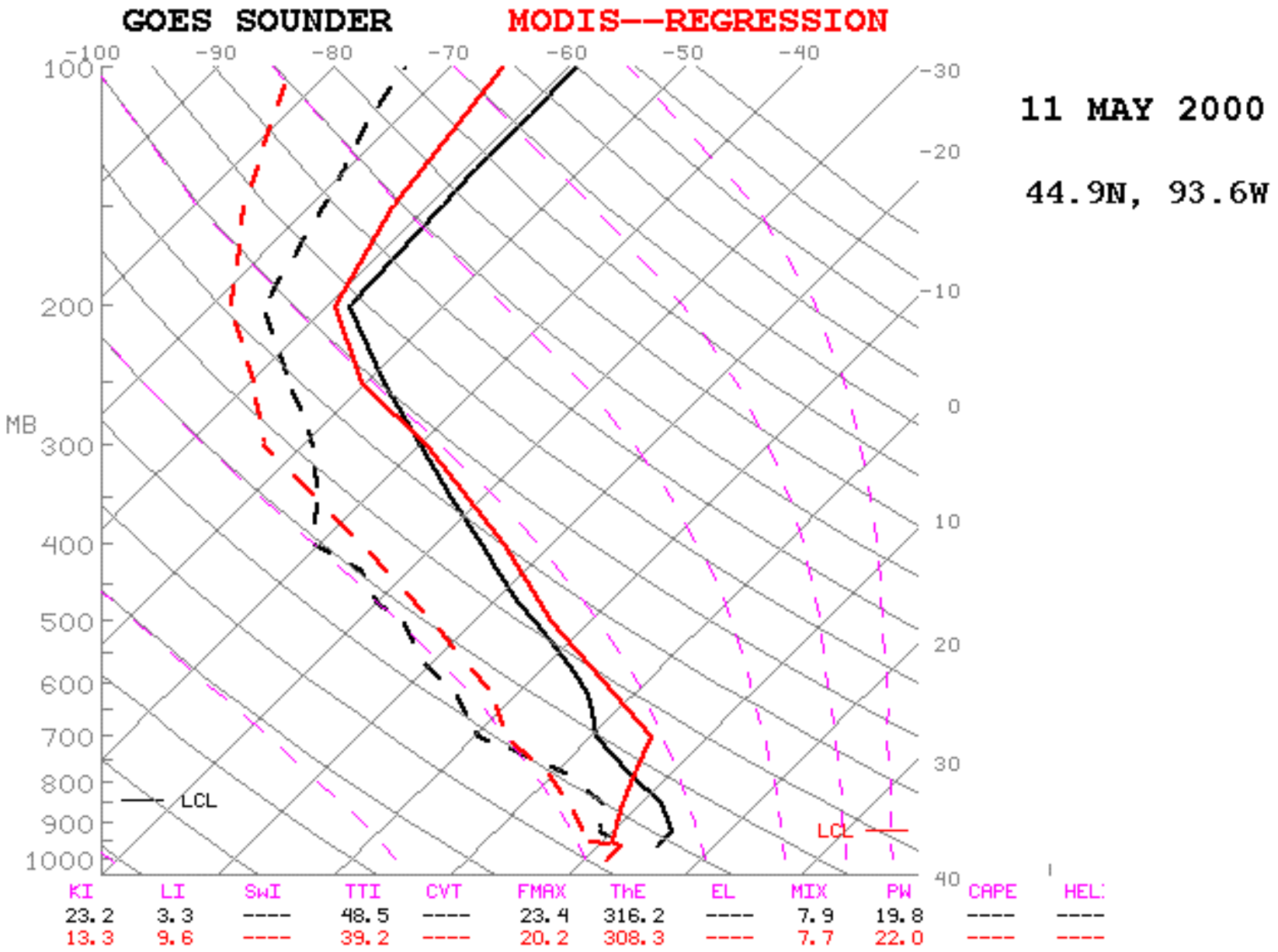
MODIS and GOES total column ozone





MODIS O3 exhibits erratic scatter

Atmospheric Profiles of Temperature and Moisture



MODIS retrieval is regression-based and uses no surface obs; GOES simultaneous physical retrieval and uses surface obs and NWP model output as a first guess. Qualitatively, the two are in good agreement with the exception of the near-surface levels.

Early MODIS Science Products: Cloud Mask, Cloud Properties and Atmospheric Profiles

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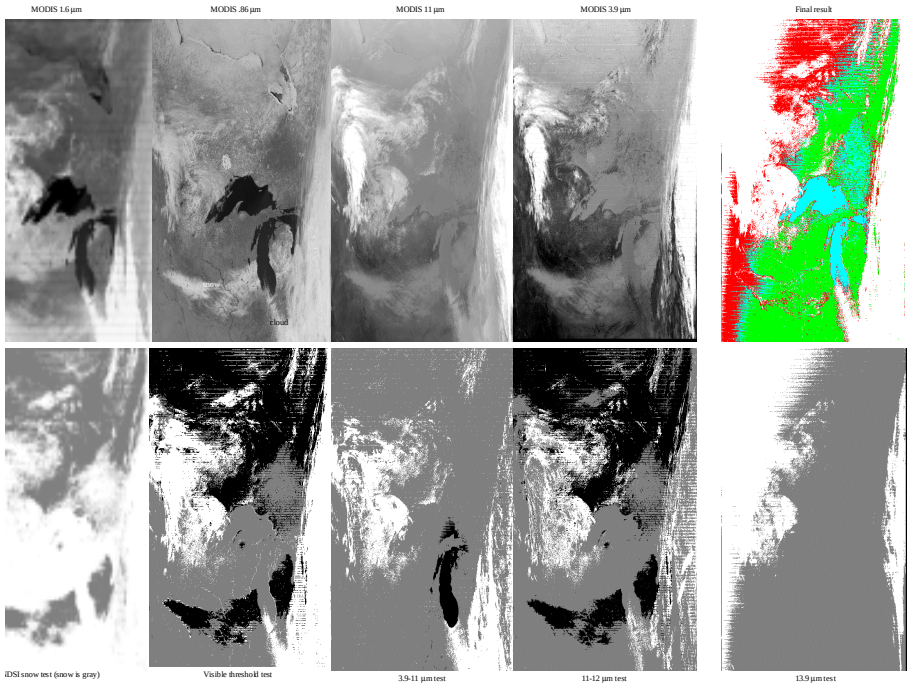
Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison, [1]NOAA/NESDIS/ORA

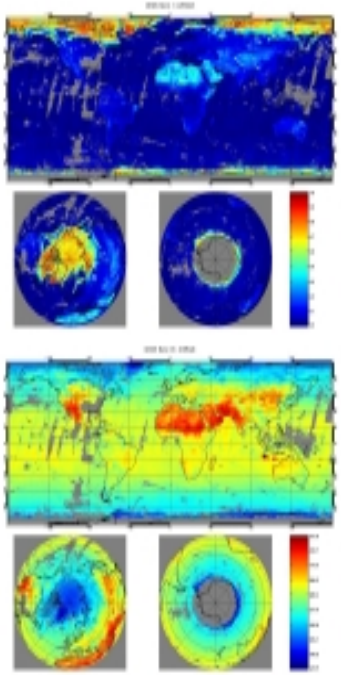
Cloud Mask

North American Scene from 17:10Z April 8, 2000



DIS cloud mask combines results of various spectral tests to produce a final confidence of clear sky. Four examples of spectral tests are shown above with the final product on the top right. High ce clear is colored green, confident clear is blue, uncertain is red and low confidence (cloudy) is white in the final product, while white indicates cloud in the individual test images. In this gramule, the snow test es which spectral tests will be performed and the thresholds used (left). Notice that the visible test is not used over snow-covered areas (black, left-center). The 3.9-11 µm test finds primarily low clouds (right-center) 11-12 µm test (right) finds primarily high clouds. The picture placed just below the final mask image shows results of the CO_2 threshold test (13.9 µm test). This test is causing problems in colder regions of the globe. many pixels to be labeled uncertain in this scene. The problem will be corrected in operations once calibration is stable.

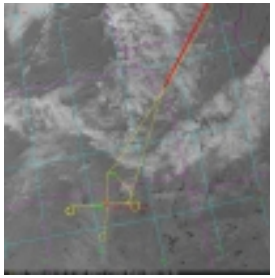
Composite Clear-sky Values Derived from the MODIS Cloud Mask May 4-7, 2000

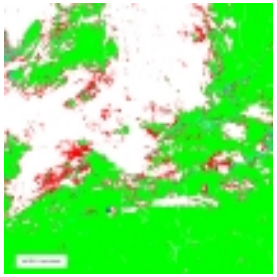


In this example of composite daytime, clear-sky data, a temporary fix has been implemented to correct the CO_2 test problem shown to the left. Note that some input Level-1b MODIS data was not produced for this time period.

Comparisons of MODIS Cloud Top Properties to Other Data

LIDAR, HIRS, RAOB from March 12, 2000 (WISC-T2000 Field Experiment)

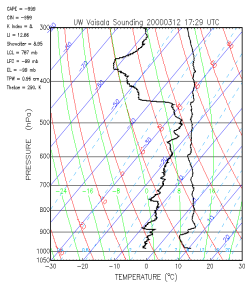


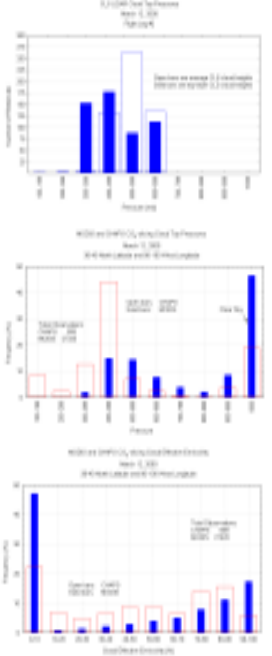


The MODIS group at UW-Madison is beginning the necessary effort to compare MODIS products to other data sets. One opportunity to do this was afforded by the WISC-T2000 (Wisconsin Snow, Ice, Cloud - Terra 2000) field experiment carried out in February and March of 2000. On March 12, a high-altitude research aircraft (ER-2) flew under the Terra spacecraft as it traversed central North America from north to south. Part of the ER-2 flight track (yellow line) is shown above, superimposed on the MODIS 0.86 µm image from 17:10Z. This scene is the same one as shown in the cloud top properties examples in the bottom left of the poster. The image above and to the right shows the cloud mask result which is important input to the MODIS cloud top properties algorithm. Note that the mask properly discriminates snow from cloud in almost all cases. Aircraft nadir-viewing LIDAR cloud top pressures from the CLS on board the ER-2 are compared to MODIS retrievals (right). LIDAR cloud top pressure values are shown in the histogram to the right. The red line in the above image shows the approximate coverage area of the CLS data. Directly beneath the LIDAR results are histograms of MODIS cloud top pressure retrievals and on the same figure, NOAA-14 HIRS (CHAPS) values from the same region. The CHAPS (Collocated HIRS and AVHRR Product S) data were collected about 3 hours later in the day.

There is generally good agreement between the LIDAR and MODIS results but note that the LIDAR covers a much smaller area than MODIS. The LIDAR is capable of sensing very thin cirrus clouds shown by the solid bar at 300-399 mb which is largely missing from the MODIS results. Good agreement is also seen between MODIS and CHAPS, where the smaller FOV of the MODIS leads to more clear-sky values. The histogram at bottom right shows a comparison between CHAPS and MODIS cloud effective emissivities. Again , good agreement is seen between the two, with MODIS finding more clear-sky scenes due to higher spatial resolution.

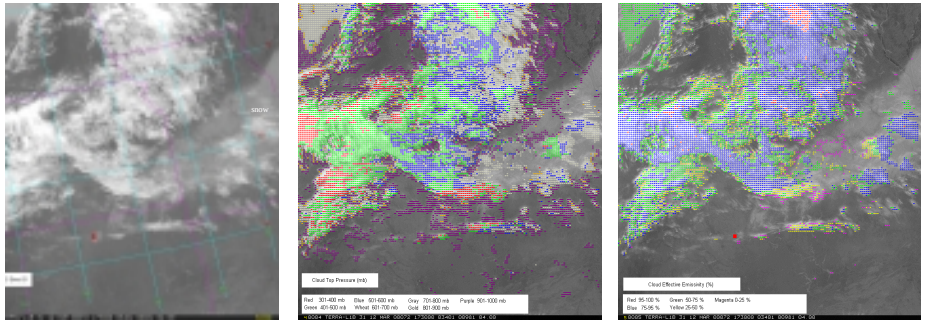
Shown directly below is a sounding taken at the CART Site beginning at 17:29Z. Note the rapid increase in dew point depression at approximately 450 mb. This agrees with the peak frequency of cloud top pressures in both the MODIS and CHAPS histogram.



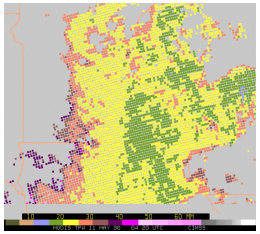


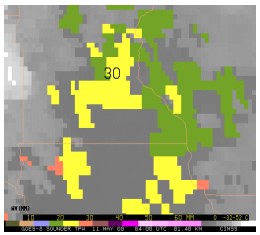
Cloud Top Properties

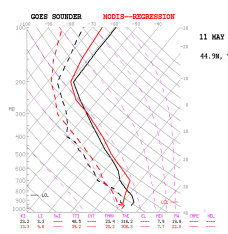
North American Scene from March 12, 2000



loud top properties include cloud top pressure and cloud effective emissivity. Shown here is a scene centered on northeast Kansas. The image on the left shows the 11 µm brightness temperature data (dark is warmer). The Southern Great Plains CART (Cloud ation Testbed) Site is marked with a red box. Notice the area of snow which runs diagonally through central Missouri and into southeast Kansas and which exhibits lower surface temperatures than surrounding regions. The cloud top properties algorithm uses the sk result (shown in top right corner of poster) as input. In this case, the cloud mask correctly identifies most of the cloudy pixels over the snow-covered areas but incorrectly classifies a few pixels in the southern part of the scene as cloudy. This leads to cloud property retrievals. The center image shows cloud top pressures in millibars and the right-hand figure shows cloud effective emissivity in percent.







Atmospheric Profiles

Upper Midwest May 11, 2000

Shown on the far left of this section are two images representing clear-sky, satellite-derived precipitable water in mm. The top figure is data from MODIS processing (04:20Z), while the lower one is from GOES Sounder (04:00Z). The region is centered on southeast Minnesota. Note the similar values and gradients of moisture. There are many more MODIS data points due to the higher spatial resolution of the MODIS instrument. The large "30" on the GOES image is the precipitable water value from the 0Z Chanhassen, MN RAOB. The MODIS algorithm is regression-based and uses no surface observations while the GOES is a simultaneous physical retrieval and uses surface observations and NWP model output as a first guess. General agreement in two data sets such as these gives greater confidence in the quality of both. On the immediate left are temperature and moisture soundings from both GOES and MODIS. Qualitatively, the two are in good agreement with the exception of the near-surface levels.

MODIS atmospheric investigations at UW

1 km WV
IR cal comparison with MAS and GOES
1.38 um thin cirrus detection
multi-spectral cloud mask
cloud heights with CO2 slicing
cloud phase with tri-spectral window
TPW with sounding channels

36 channel AVHRR or 1 km HIRS

UW MODIS QA web site and links to data examples

http://cimss.ssec.wisc.edu/modis1/modis1.html