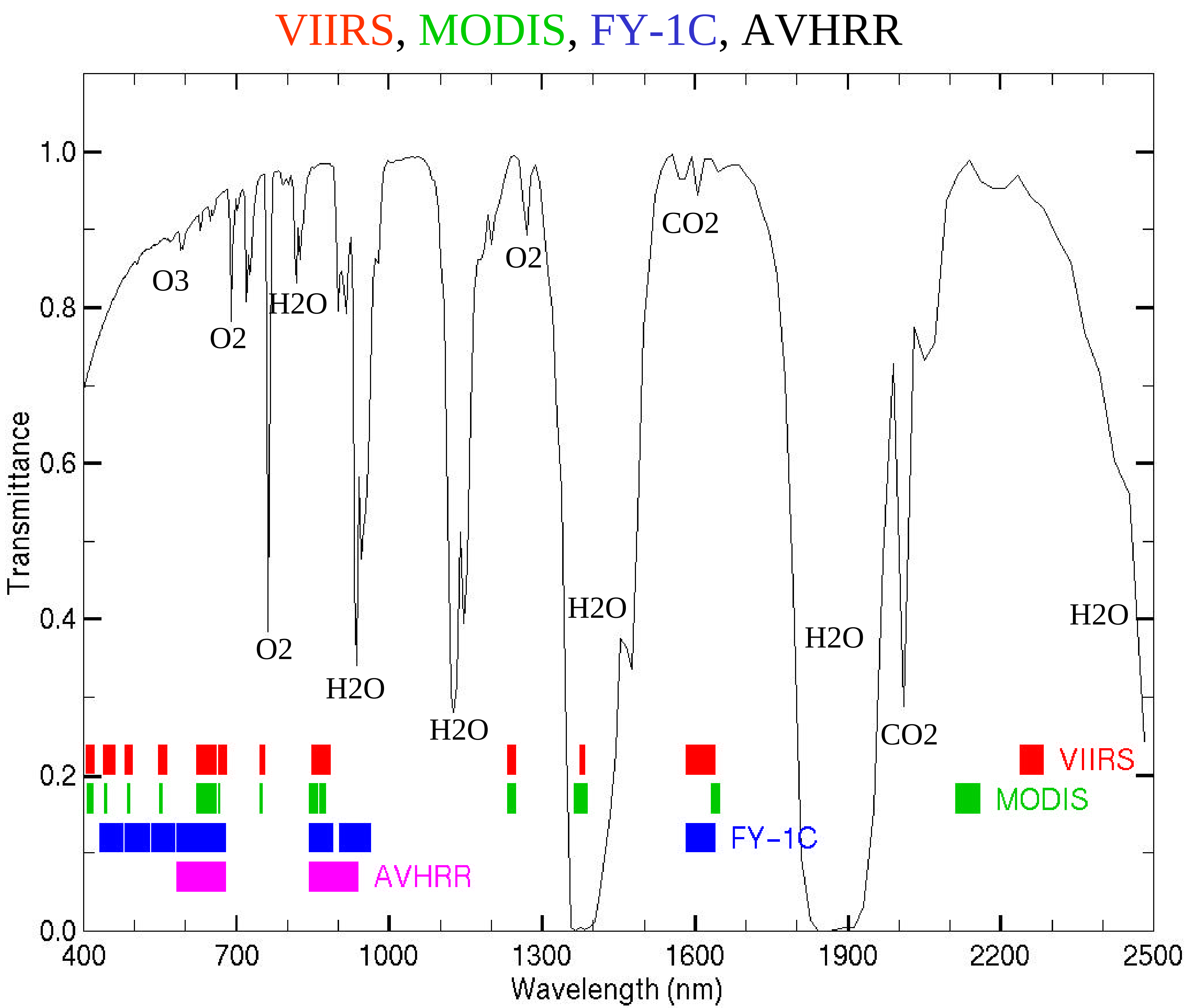
Atmospheric Temperature, Moisture, Ozone, and Motion – Infrared (MOD-07)

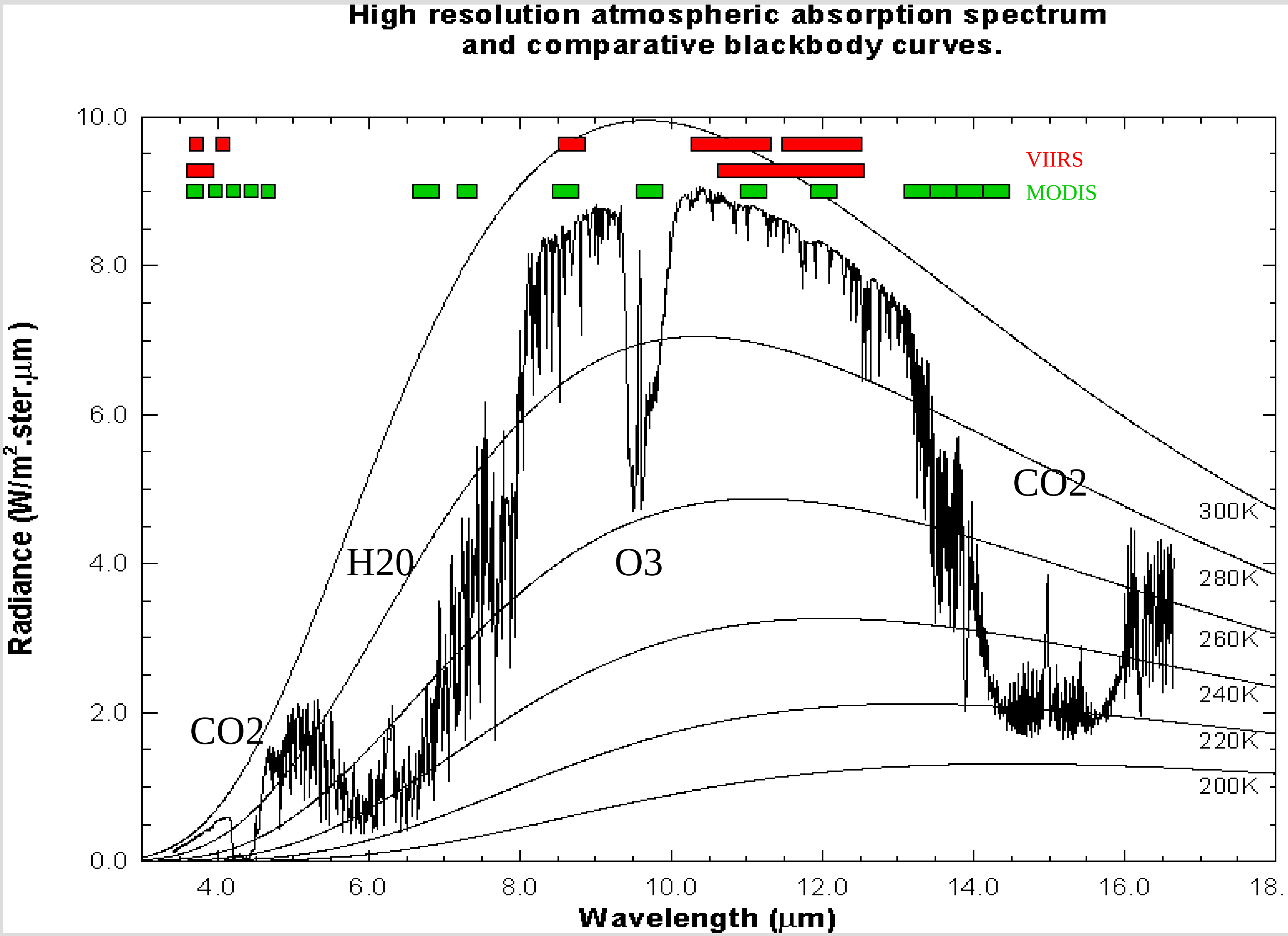
Jun Li, Liam Gumley, Suzanne Wetzel-Seemann, Chris Moeller, Steve Ackerman, Richard Frey, Dave Santek, Jeff Key, Chris Velden, and Paul Menzel

18 Dec 2001



VIIRS, MODIS, FY-1C, AVHRR
Transmittance
Wavelength (nm)
1.0
0.8
0.6
0.4
0.2
0.0
400
700
1000
1300
1600
1900
2200
2500
O3
O2
H2O
O2
H2O
H2O
O2
H2O
CO2
H2O
CO2
H2O
VIIRS
MODIS
FY-1C
AVHRR

Earth emitted spectra overlaid on Planck function envelopes



Atmospheric Profile Retrieval from MODIS Radiances

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \int_o^{p_s} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\; dp \,.$$

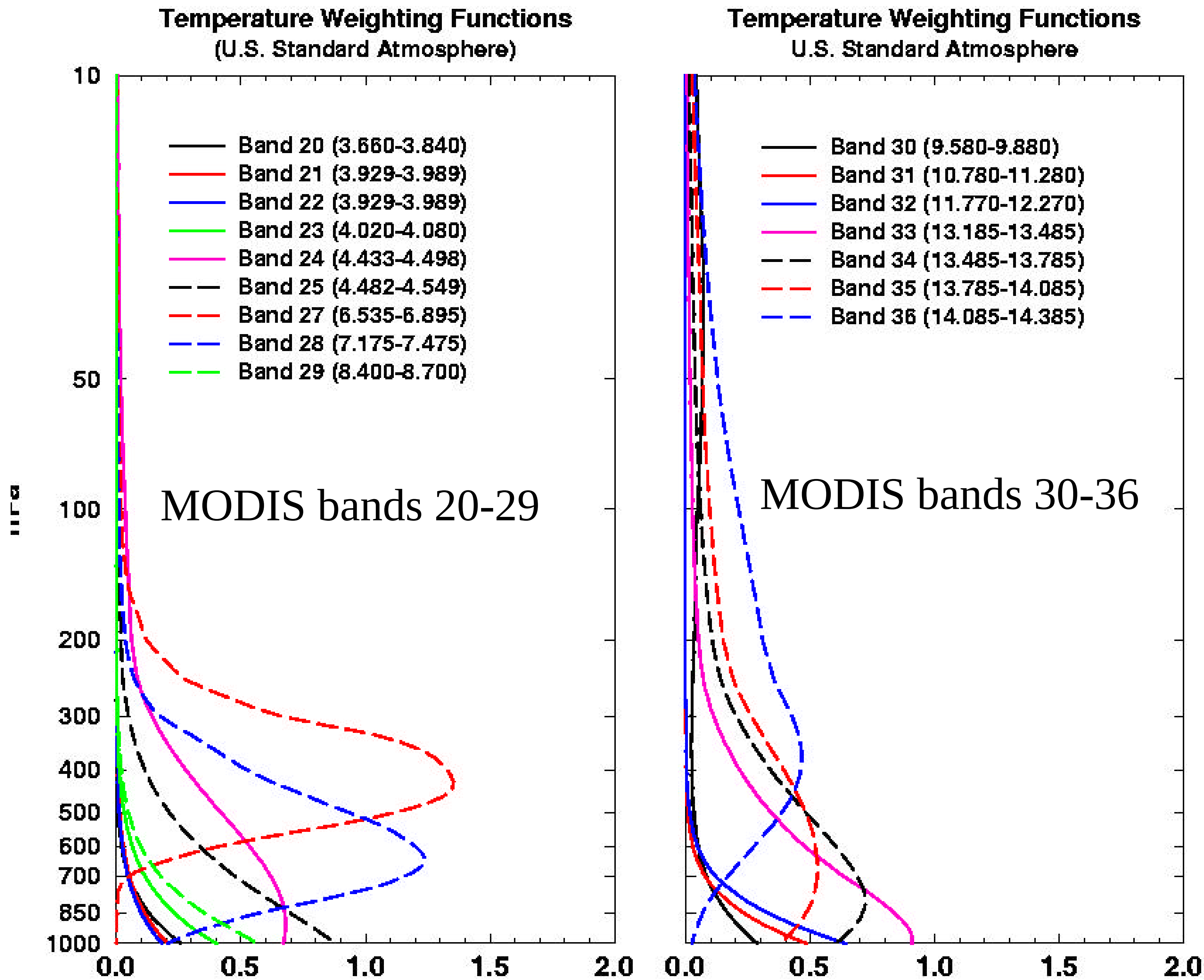
I1, I2, I3, ... , In are measured with MODIS

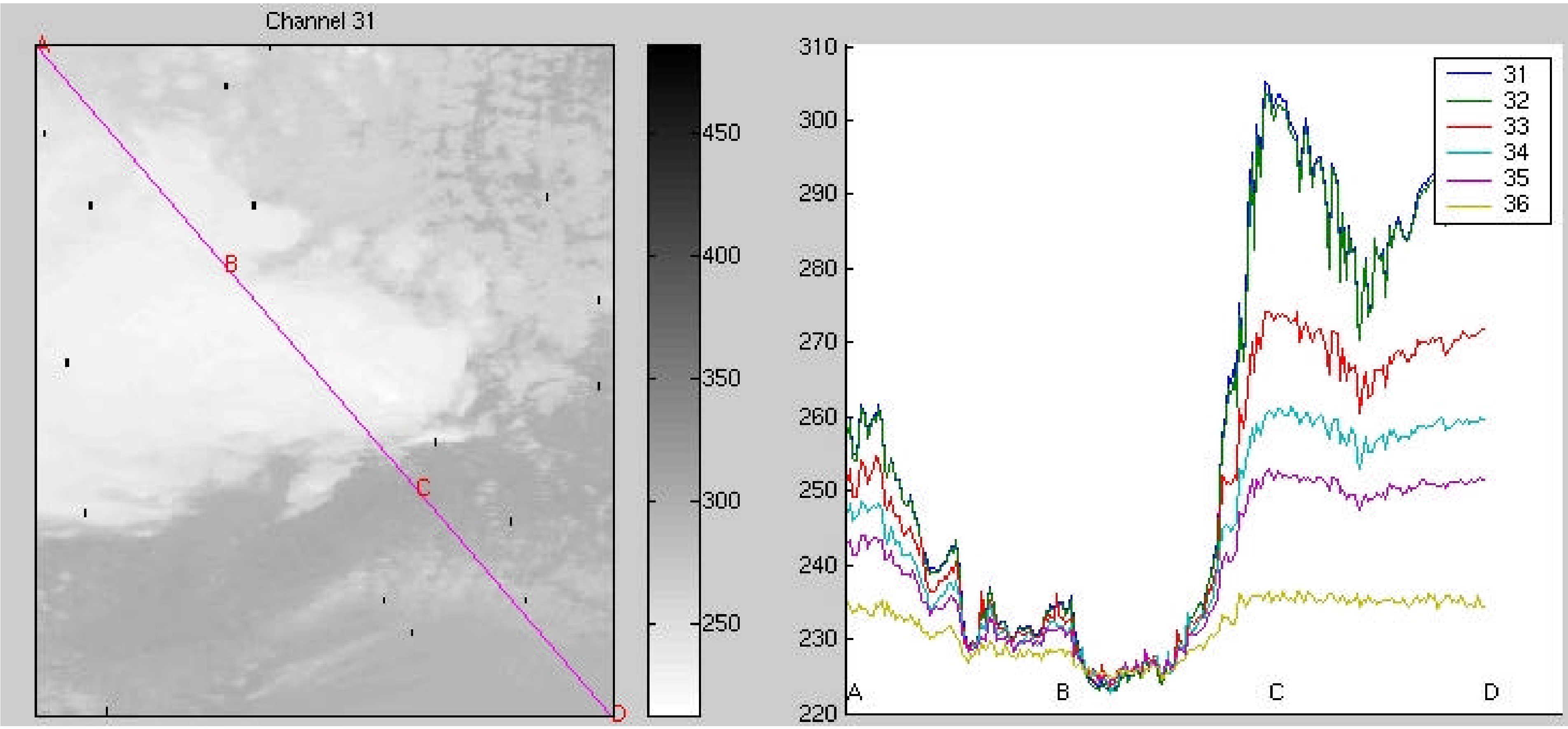
P(sfc) and T(sfc) come from ground based conventional observations

$\tau_\lambda(p)$ are calculated with physics models

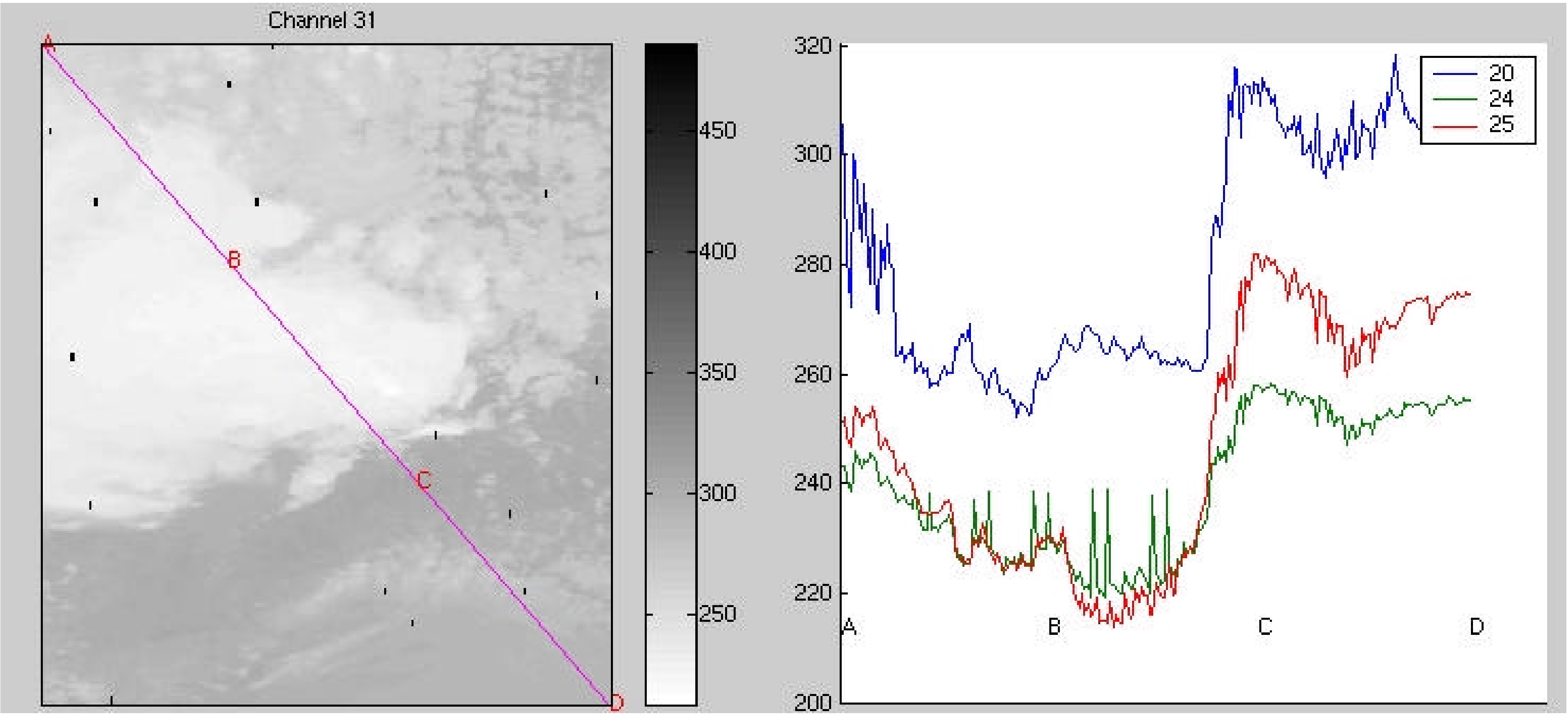
Regression relationship is inferred from (1) global set of in situ radiosonde reports, (2) calculation of expected radiances, and (3) statistical regression of observed raob profiles and calculated MODIS radiances

Need RT model, estimate of $\varepsilon_\lambda^{sfc}$, and MODIS radiances

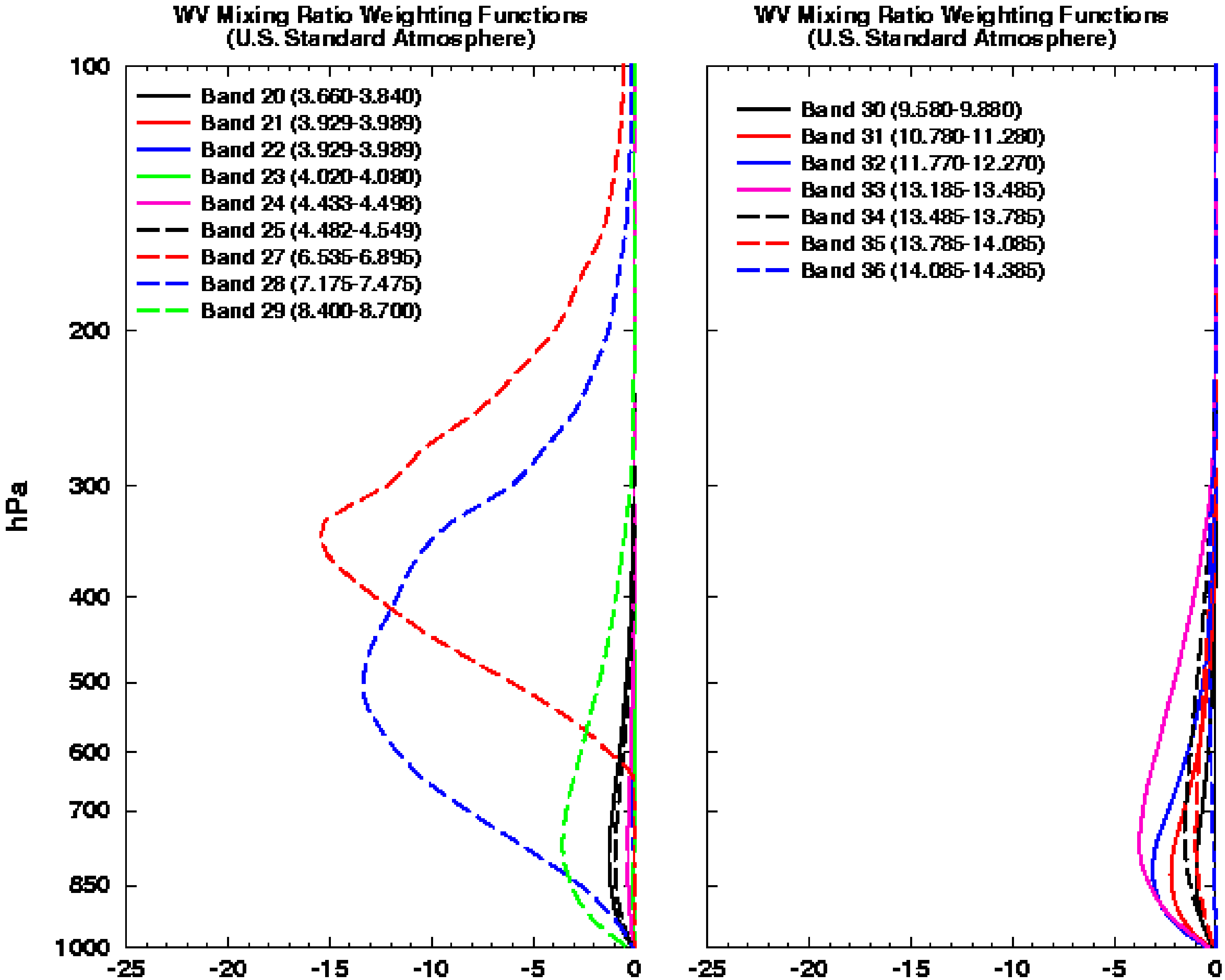

Temperature Weighting Functions
(U.S. Standard Atmosphere)
Band 20 (3.660-3.840)
Band 21 (3.929-3.989)
Band 22 (3.929-3.989)
Band 23 (4.020-4.080)
Band 24 (4.433-4.498)
Band 25 (4.482-4.549)
Band 27 (6.535-6.895)
Band 28 (7.175-7.475)
Band 29 (8.400-8.700)
MODIS bands 20-29
10
50
100
200
300
400
500
600
700
850
1000
0.0
0.5
1.0
1.5
2.0
Temperature Weighting Functions
U.S. Standard Atmosphere
Band 30 (9.580-9.880)
Band 31 (10.780-11.280)
Band 32 (11.770-12.270)
Band 33 (13.185-13.485)
Band 34 (13.485-13.785)
Band 35 (13.785-14.085)
Band 36 (14.085-14.385)
MODIS bands 30-36

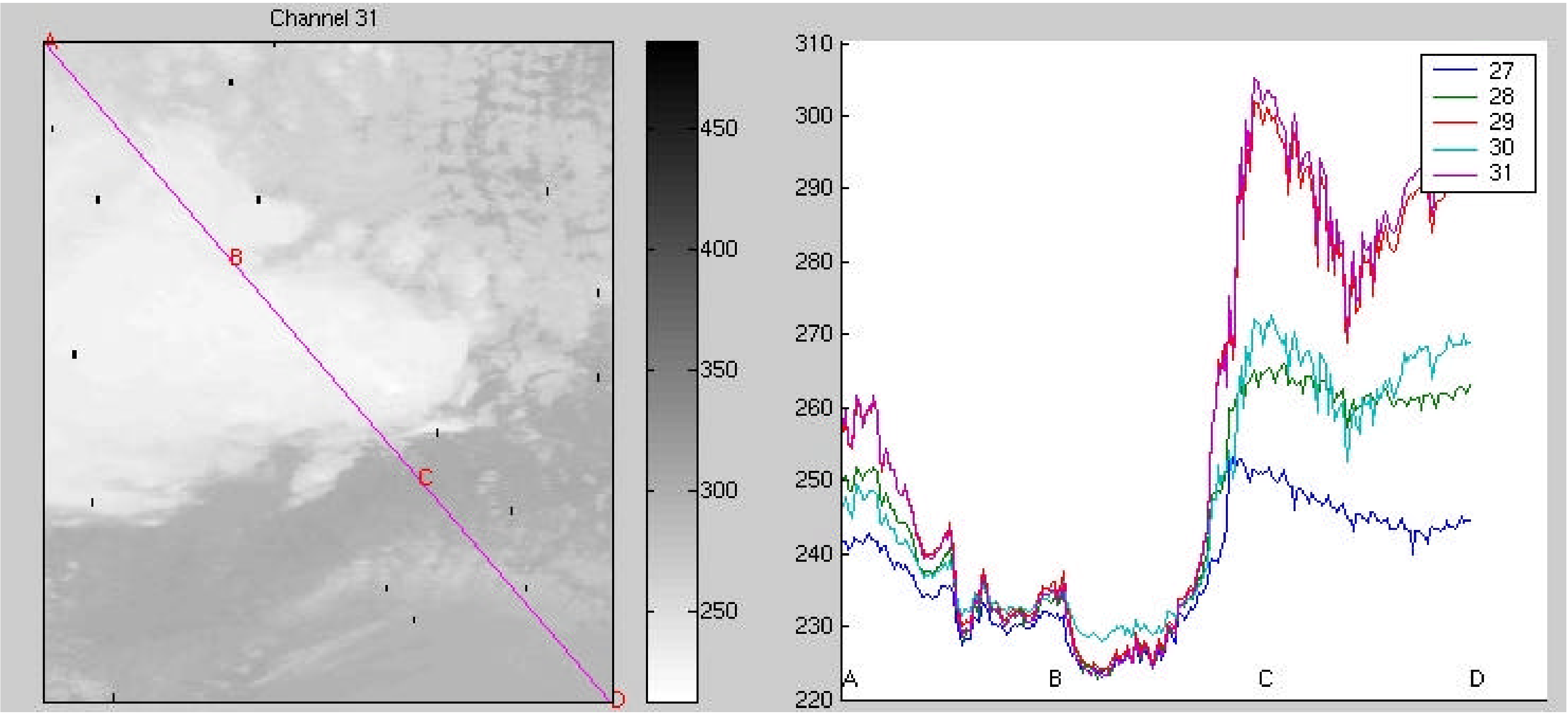


Channel 31
A
B
C
D
450
400
350
300
250
310
300
290
280
270
260
250
240
230
220
31
32
33
34
35
36



Channel 31
A
B
C
D
450
400
350
300
250
320
300
280
260
240
220
200
20
24
25
A
B
C
D

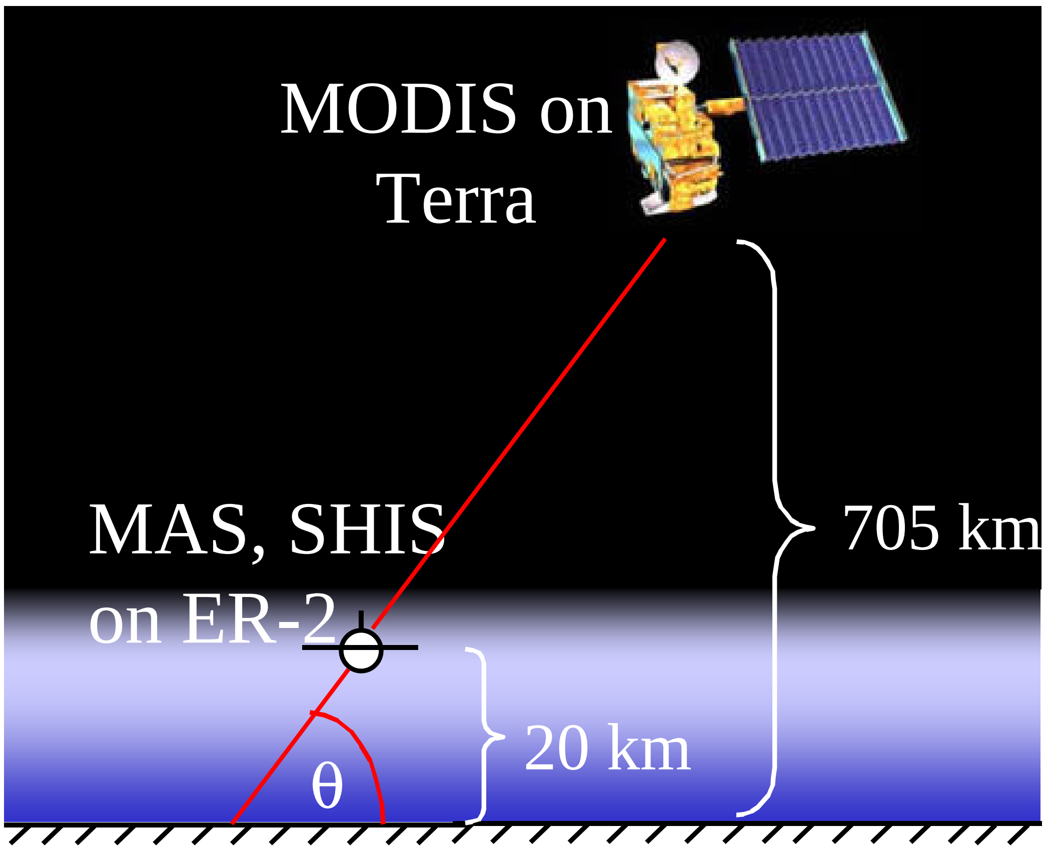

WV Mixing Ratio Weighting Functions
(U.S. Standard Atmosphere)
Band 20 (3.660-3.840)
Band 21 (3.929-3.989)
Band 22 (3.929-3.989)
Band 23 (4.020-4.080)
Band 24 (4.433-4.498)
Band 25 (4.482-4.549)
Band 27 (6.535-6.895)
Band 28 (7.175-7.475)
Band 29 (8.400-8.700)
hPa
100
200
300
400
500
600
700
850
1000
-25
-20
-15
-10
-5
0
WV Mixing Ratio Weighting Functions
(U.S. Standard Atmosphere)
Band 30 (9.580-9.880)
Band 31 (10.780-11.280)
Band 32 (11.770-12.270)
Band 33 (13.185-13.485)
Band 34 (13.485-13.785)
Band 35 (13.785-14.085)
Band 36 (14.085-14.385)
-25
-20
-15
-10
-5
0

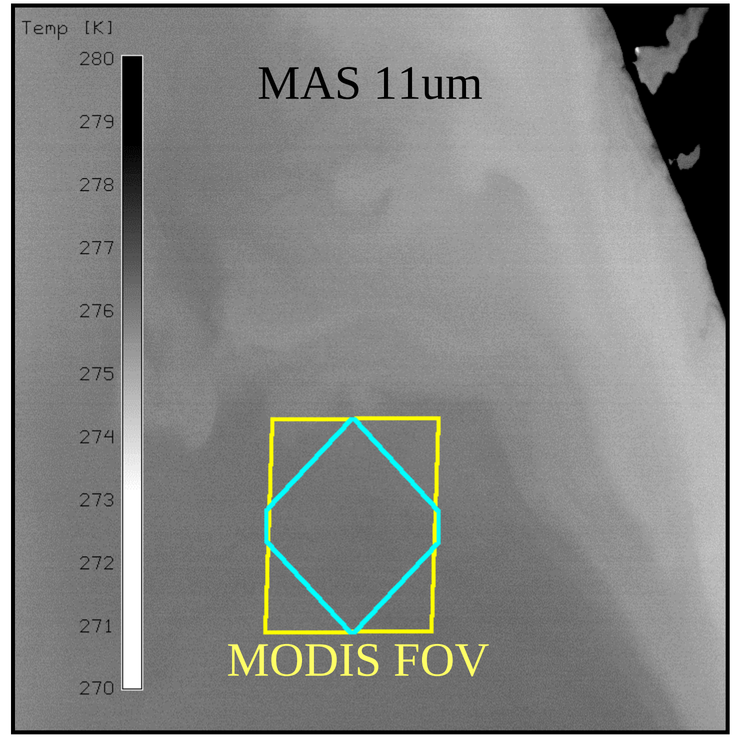


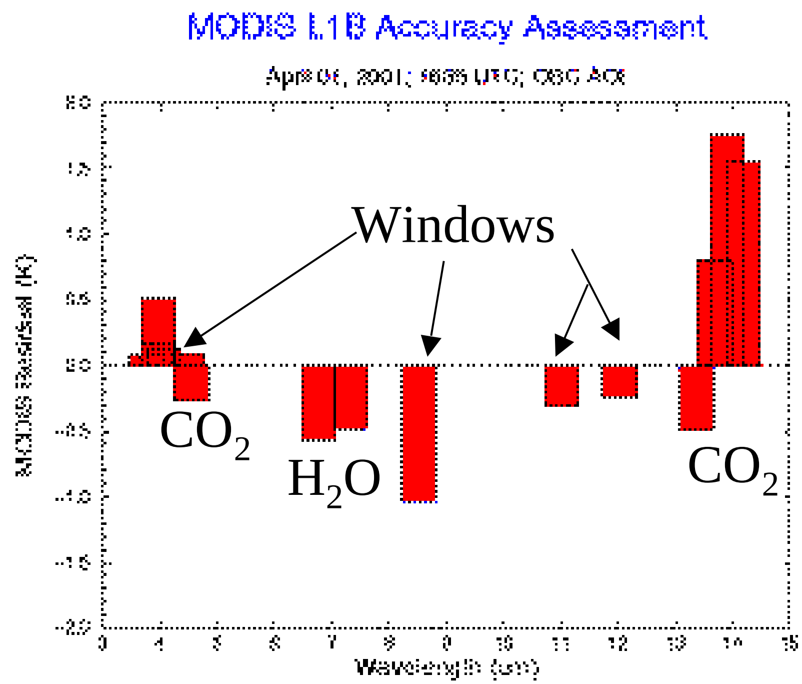
Channel 31
A
B
C
D
450
400
350
300
250
310
300
290
280
270
260
250
240
230
220
27
28
29
30
31
A
B
C
D

MODIS Emissive Band Cal/Val from ER-2 Platform

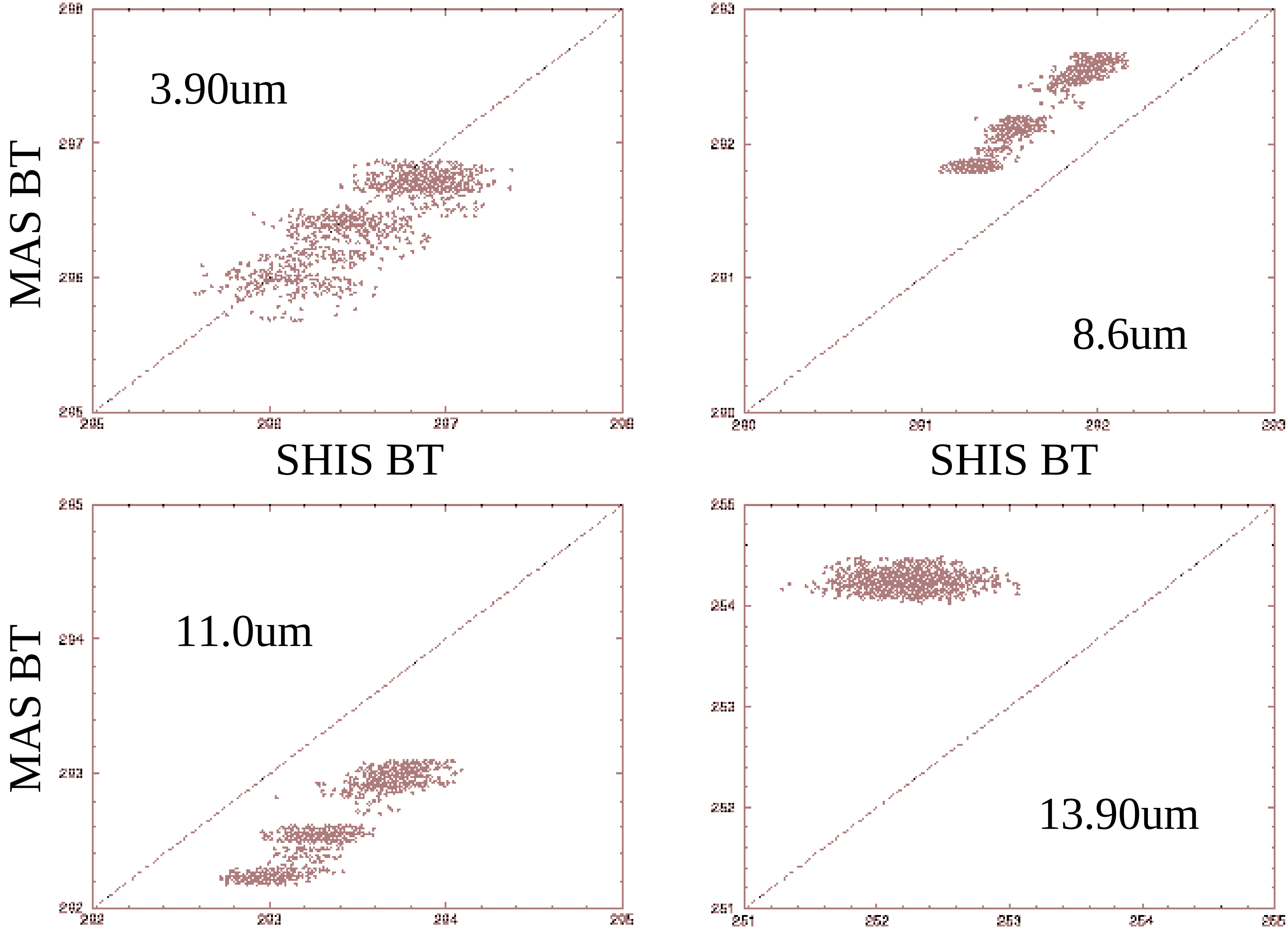
- Transfer S-HIS cal to MAS
- Co-locate MODIS FOV on MAS
- Remove spectral, geometric dependence
- WISC-T2000, SAFARI-2000, TX-2001



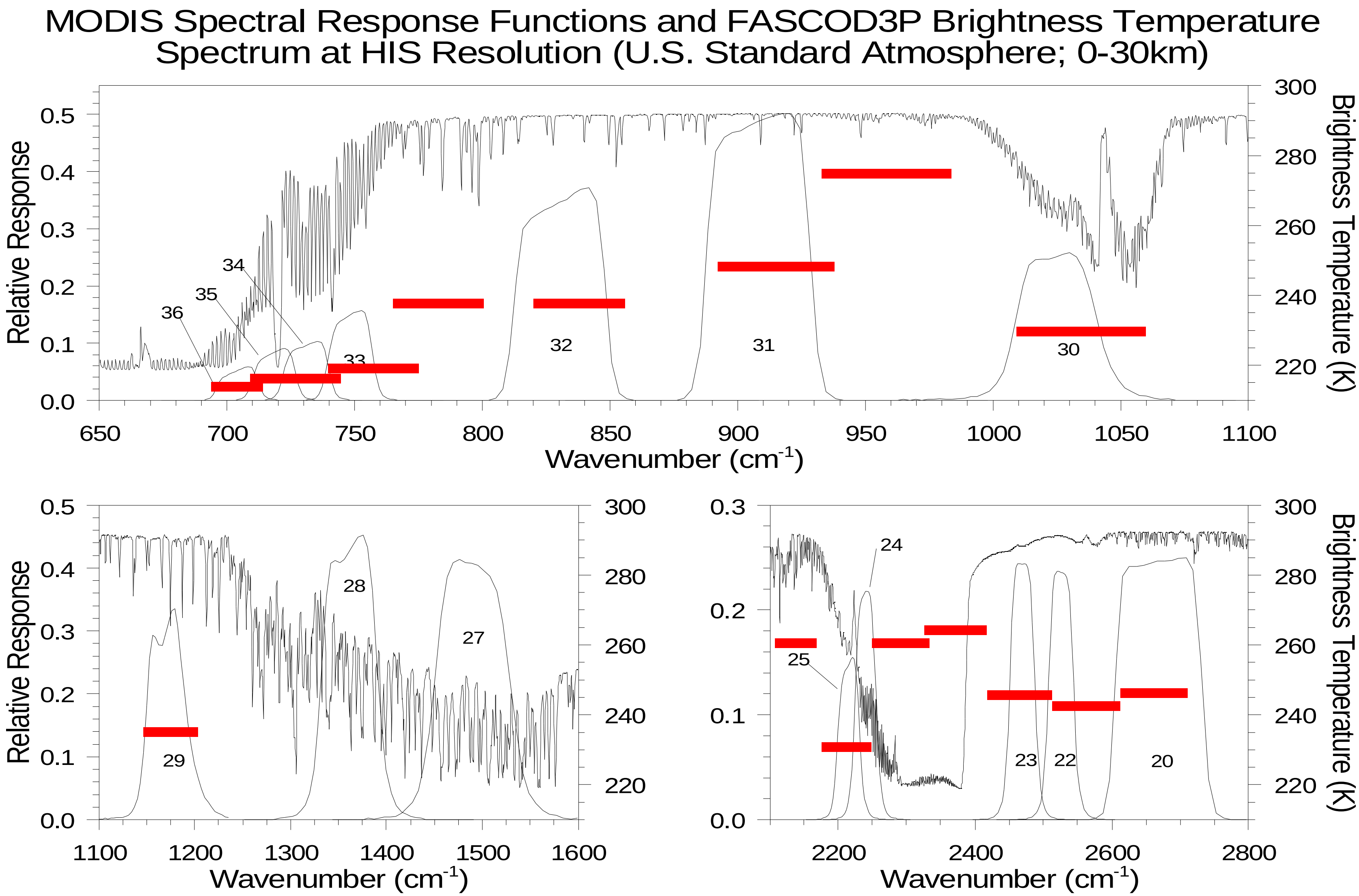


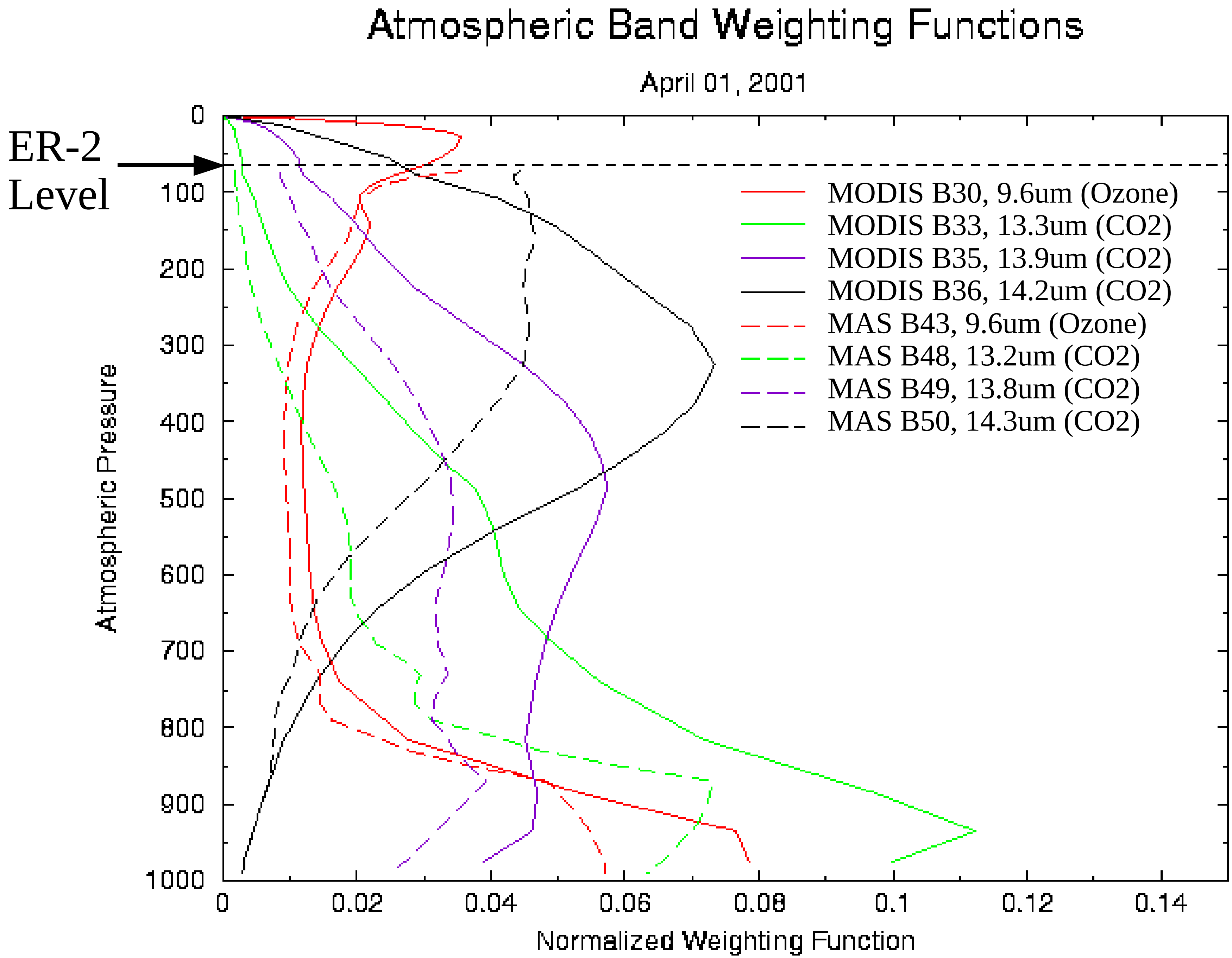


SHIS calibration transfer to MAS on March 22, 2001



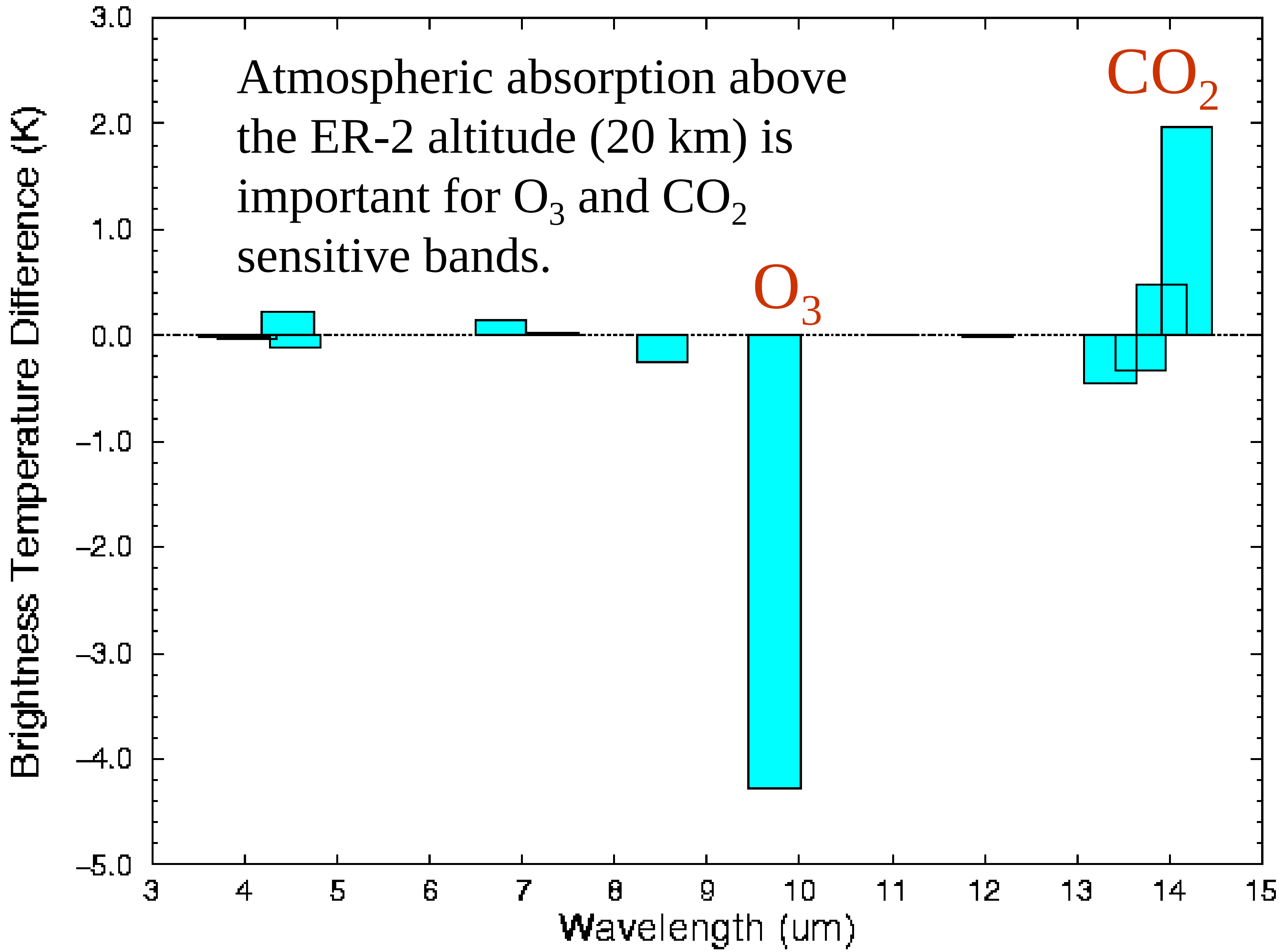
MODIS IR Spectral Bands, MAS FWHM

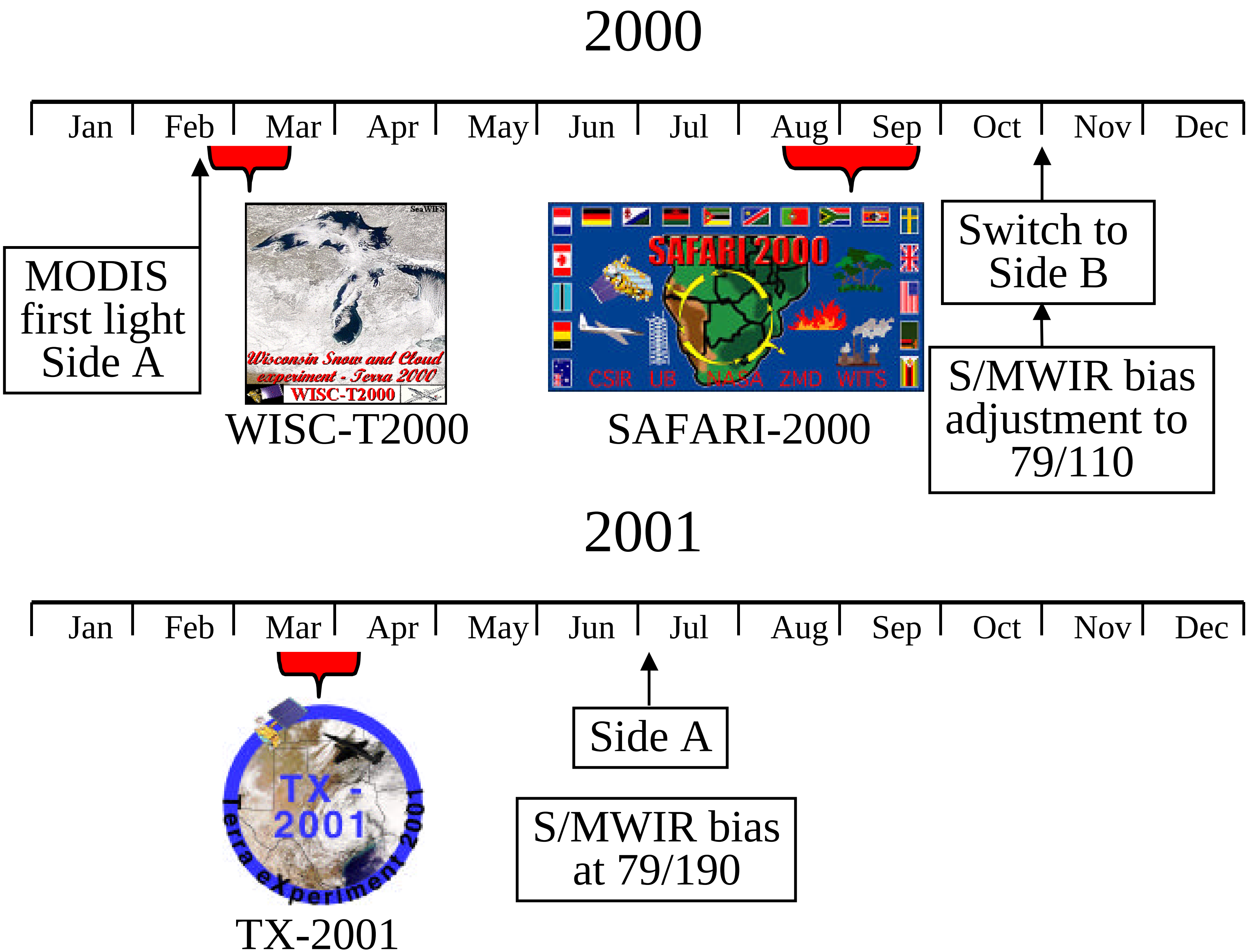




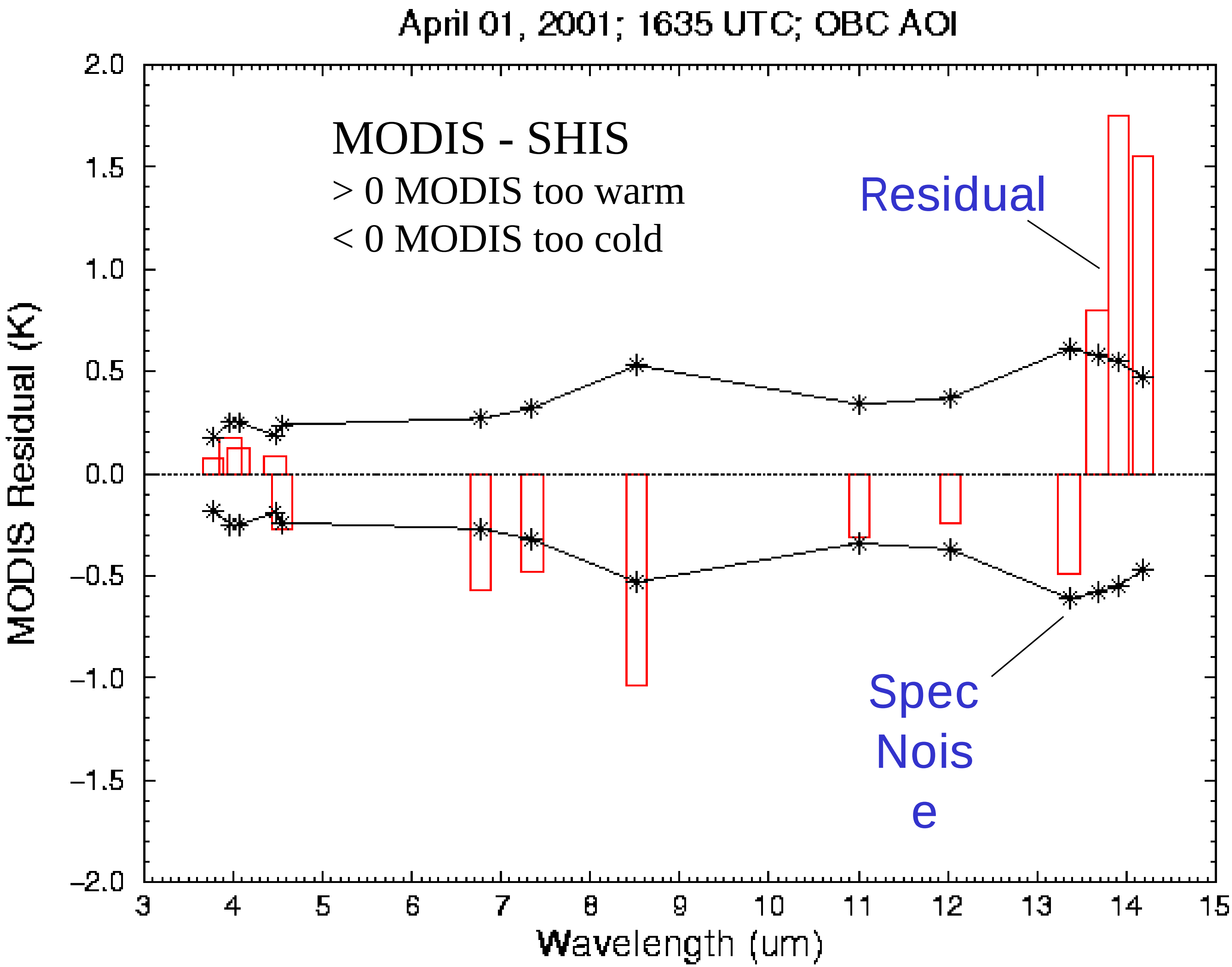
Atmospheric Band Weighting Functions
April 01, 2001
ER-2
Level
Atmospheric Pressure
Normalized Weighting Function
0
100
200
300
400
500
600
700
800
900
1000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
MODIS B30, 9.6um (Ozone)
MODIS B33, 13.3um (CO2)
MODIS B35, 13.9um (CO2)
MODIS B36, 14.2um (CO2)
MAS B43, 9.6um (Ozone)
MAS B48, 13.2um (CO2)
MAS B49, 13.8um (CO2)
MAS B50, 14.3um (CO2)

Influence of Altitude Difference between MODIS and MAS




2000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MODIS first light Side A
Wisconsin Snow and Cloud experiment - Terra 2000
WISC-T2000
WISC-T2000
SAFARI 2000
CSIR UB NASA ZMD WITS
SAFARI-2000
Switch to Side B
S/MWIR bias adjustment to 79/110
2001
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
TX - 2001
Terra eXperiment 2001
TX-2001
Side A
S/MWIR bias at 79/190

CalibrationMODIS L1B Accuracy Assessment



MODIS NEdR Estimate

Band 20	3.7 um	.007 mW/m2/ster/cm-1
Band 21	3.9	.02
Band 22	3.9	.04
Band 23	4.0	.025
Band 24	4.45	.03
Band 25	4.5	.045
Band 27	6.7	.08
Band 28	7.3	.07
Band 29	8.6	.25
Band 30	9.7	.2
Band 31	11.0	.3
Band 32	12.0	.3
Band 33	13.3	.4
Band 34	13.6	.6
Band 35	13.9	.4
Band 36	14.2	.5

Based on Earth Scene Data Day 01153, 20:10 UTC Clear scenes of the Pacific Ocean

Note: Some SG present in MWIR Used 150 x 28 box (420 data points per detector)

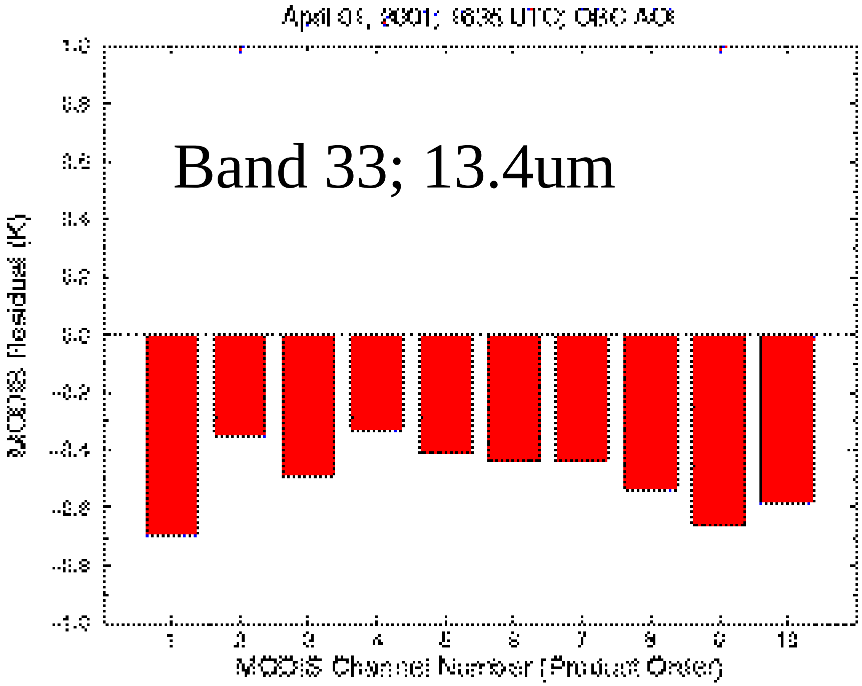
Band 34

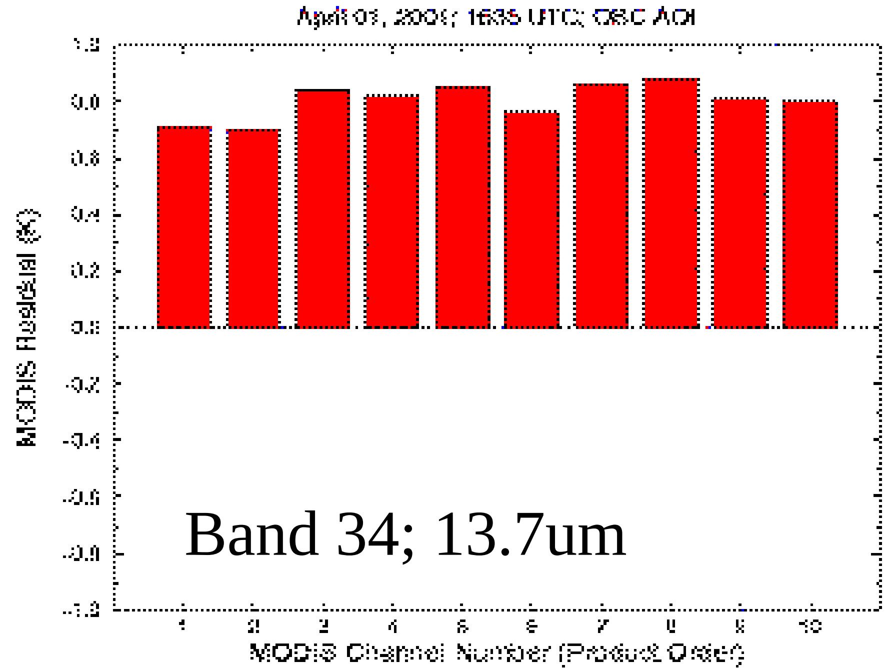
Detector Number (Product Order)	RMS (mW/m^2 sr cm^{-1})
1	.46725
2	.40609
3	.51104
4	.43430
5	.73425
6	1.0260
7	1.2547
8	1.1700
9	.56228
10	.35423

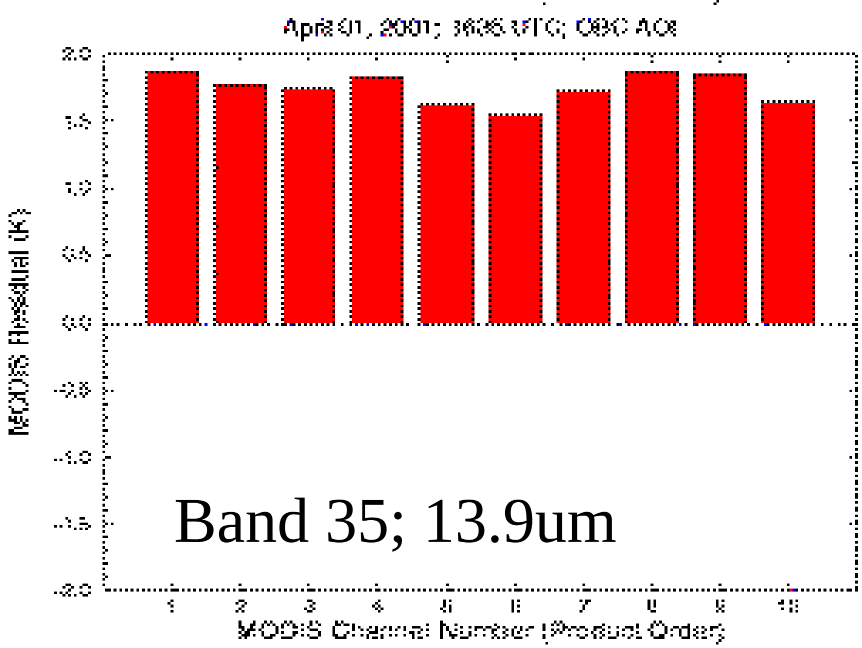
Noisy Detectors (5–8)

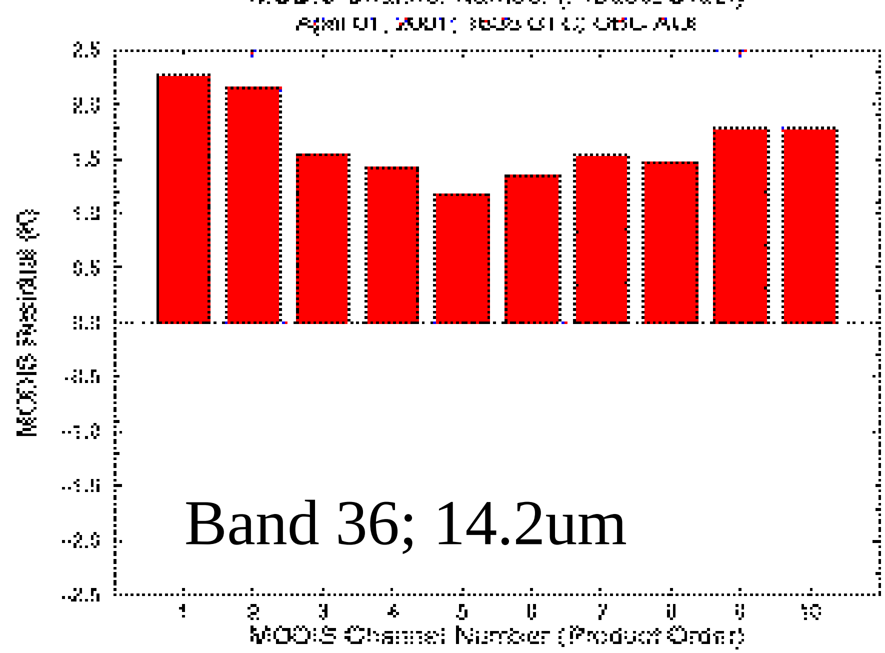
Detector to detector calibration

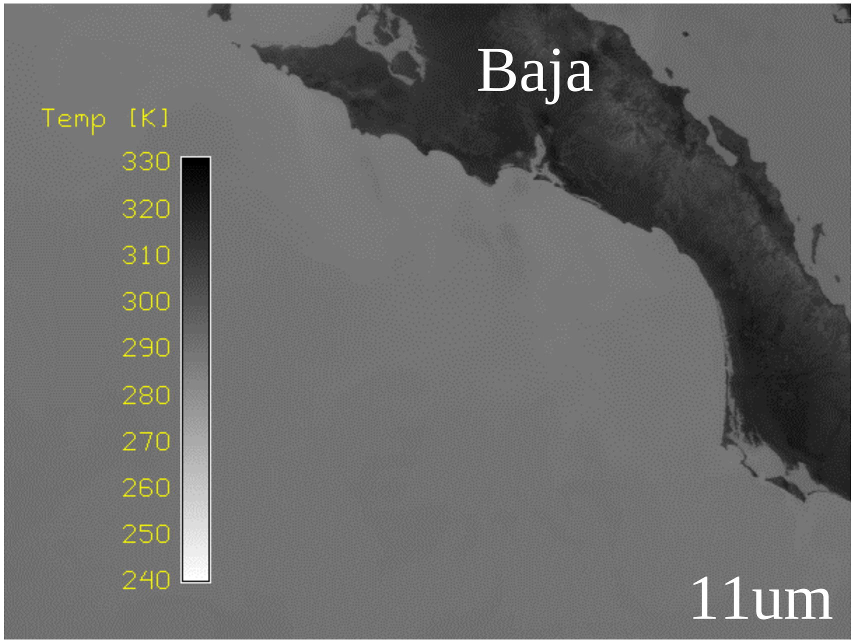
MODIS L1B Accuracy Assessment

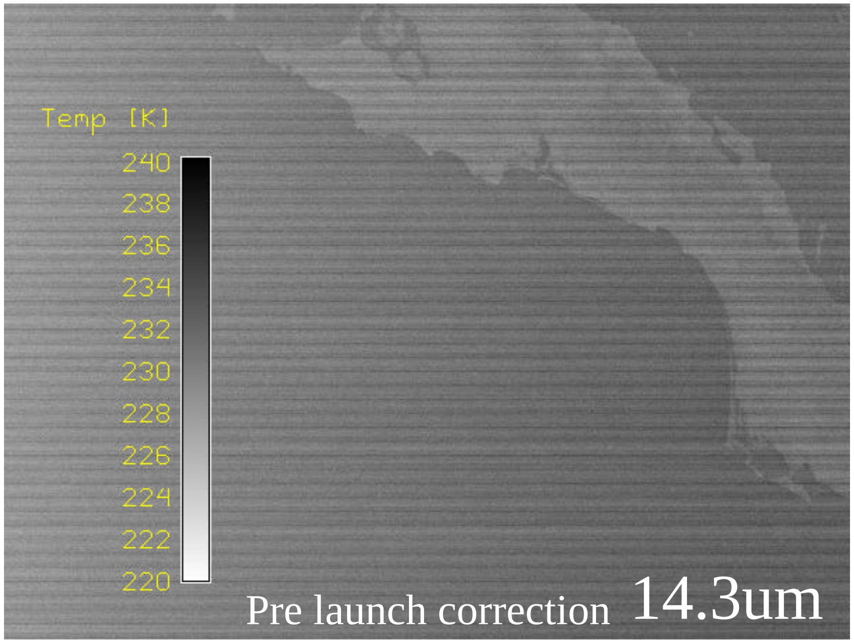


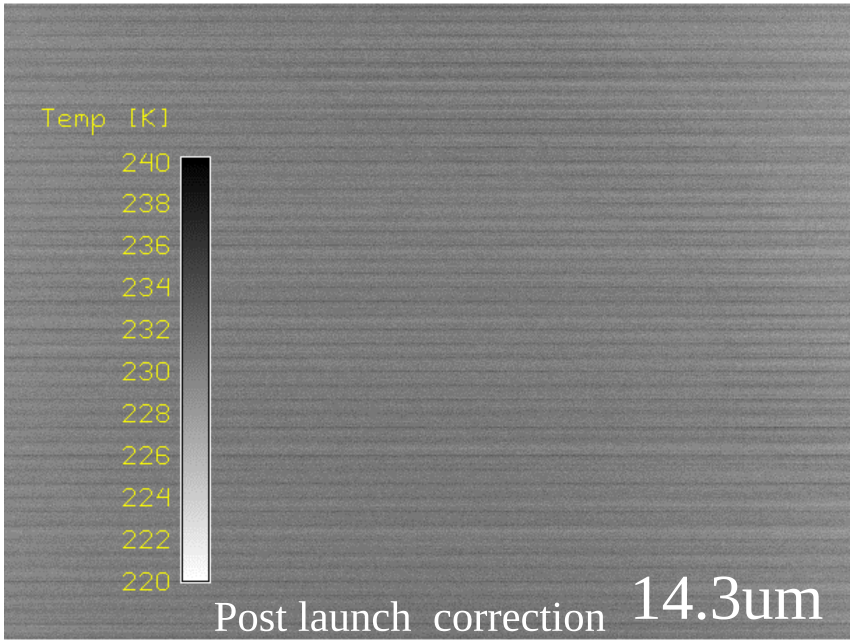






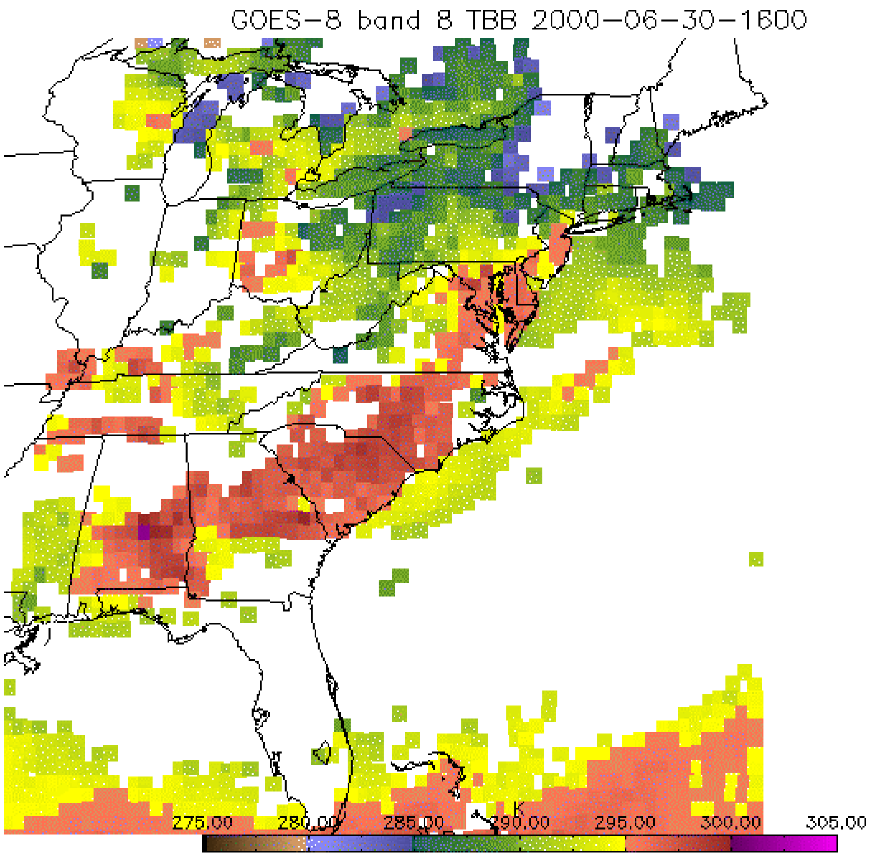






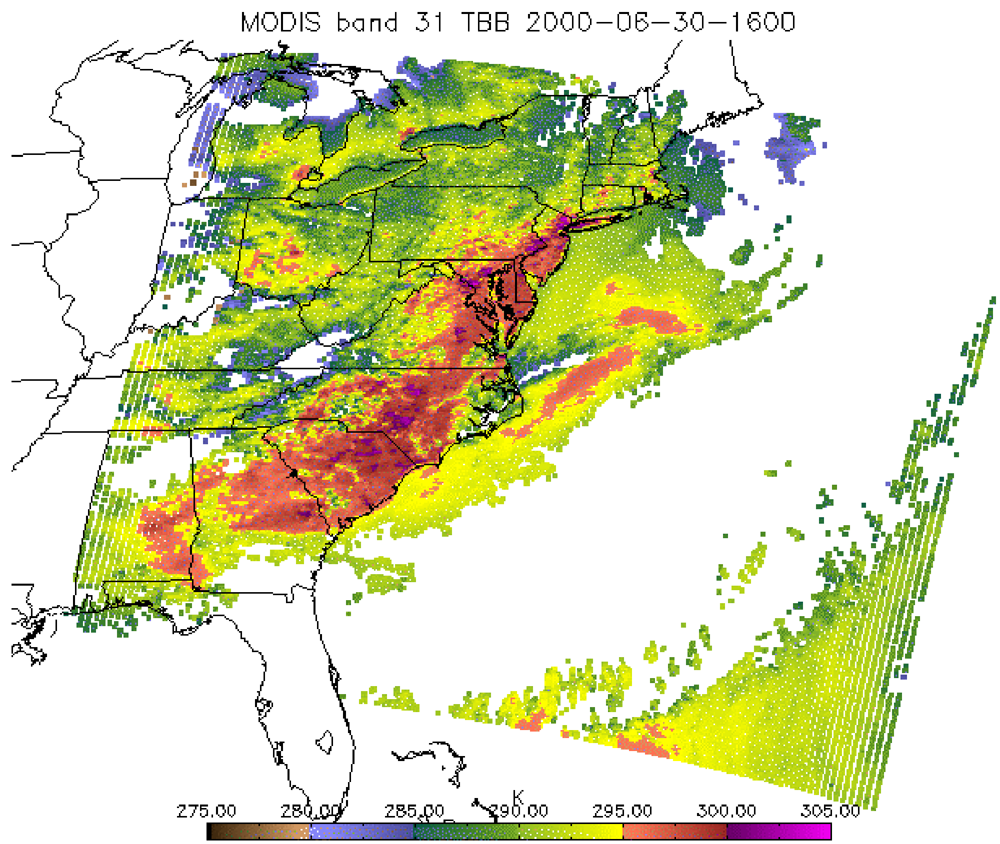
A known optical leak at 11um caused the image of the Baja peninsula to be present in MODIS 14.3um data. Through testing, the pre-launch correction coefficients were revised, removing the contamination.

Correcting Crosstalk



GOES 3 by 3 FOVs (30 km)

11 micron



MODIS 5 by 5 FOVs (5 km)

Atmospheric Profile Retrieval from MODIS Radiances

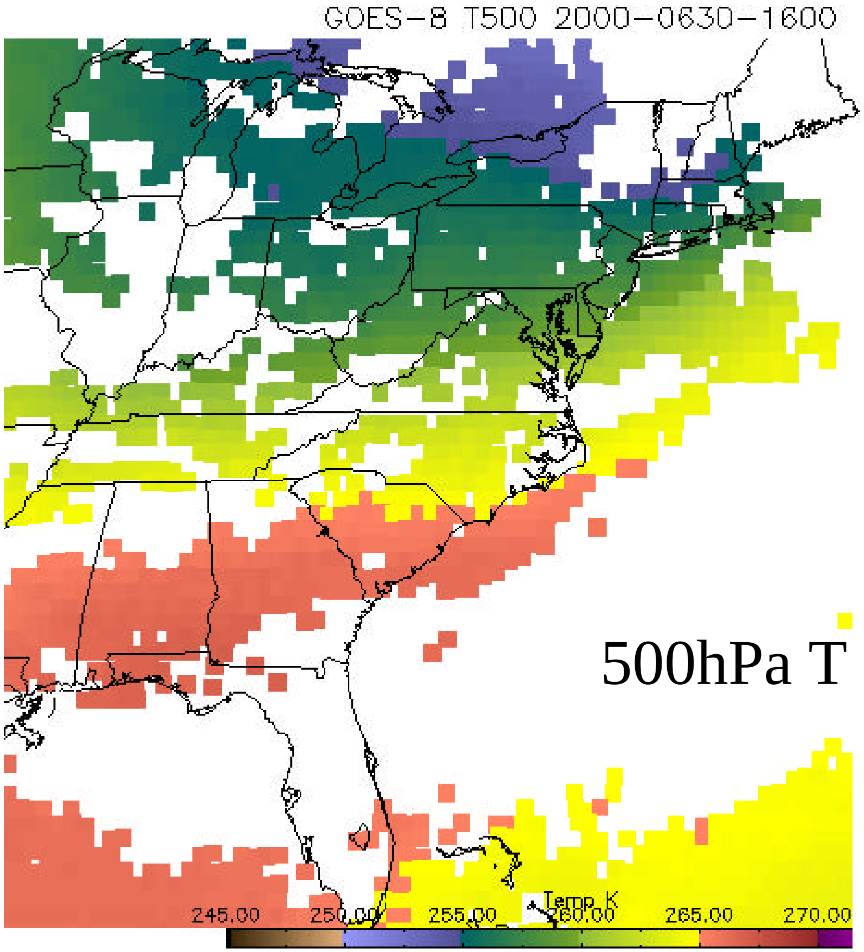
$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s)) \tau_\lambda(p_s) - \int_o^{p_s} B_\lambda(T(p)) [d\tau_\lambda(p) / dp] dp .$$

I1, I2, I3, ... , In are measured with MODIS
P(sfc) and T(sfc) come from ground based conventional observations
$\tau_\lambda(p)$ are calculated with physics models

Regression relationship is inferred from (1) global set of in situ radiosonde reports, (2) calculation of expected radiances, and (3) statistical regression of observed raob profiles and calculated MODIS radiances

Need RT model, estimate of $\varepsilon_\lambda^{sfc}$, and MODIS radiances

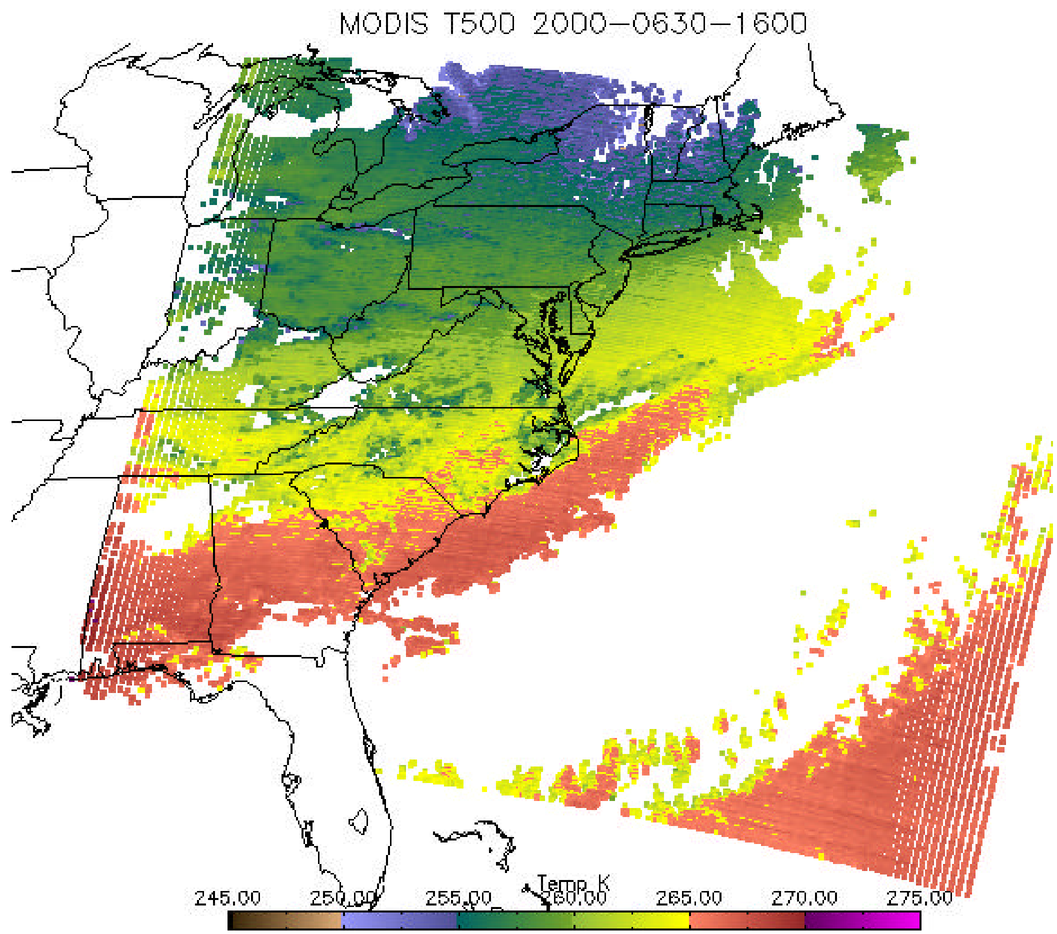
The **MODIS AP algorithms** are based on a **regression procedure**, and makes use of the **NOAA-88 data set containing more than 7500 global profiles** of temperature and moisture to determine the regression coefficients. The **radiative transfer calculation** of the MODIS spectral band radiances is performed for each training profile using the **Pressure layer Fast Algorithm for Atmospheric Transmittances (PFAAST) transmittance model**. This model has 101 pressure layer vertical coordinates from 0.1 to 1050 hPa and takes into account the satellite zenith angle, absorption by well-mixed gases (including nitrogen, oxygen, and carbon dioxide), water vapor, and ozone. The **MODIS instrument noise is added** into the calculated spectral band radiances, and these radiative transfer calculations provide a temperature-moisture-ozone profile and MODIS radiance pair for use in the statistical regression analysis.



30km resolution GOES

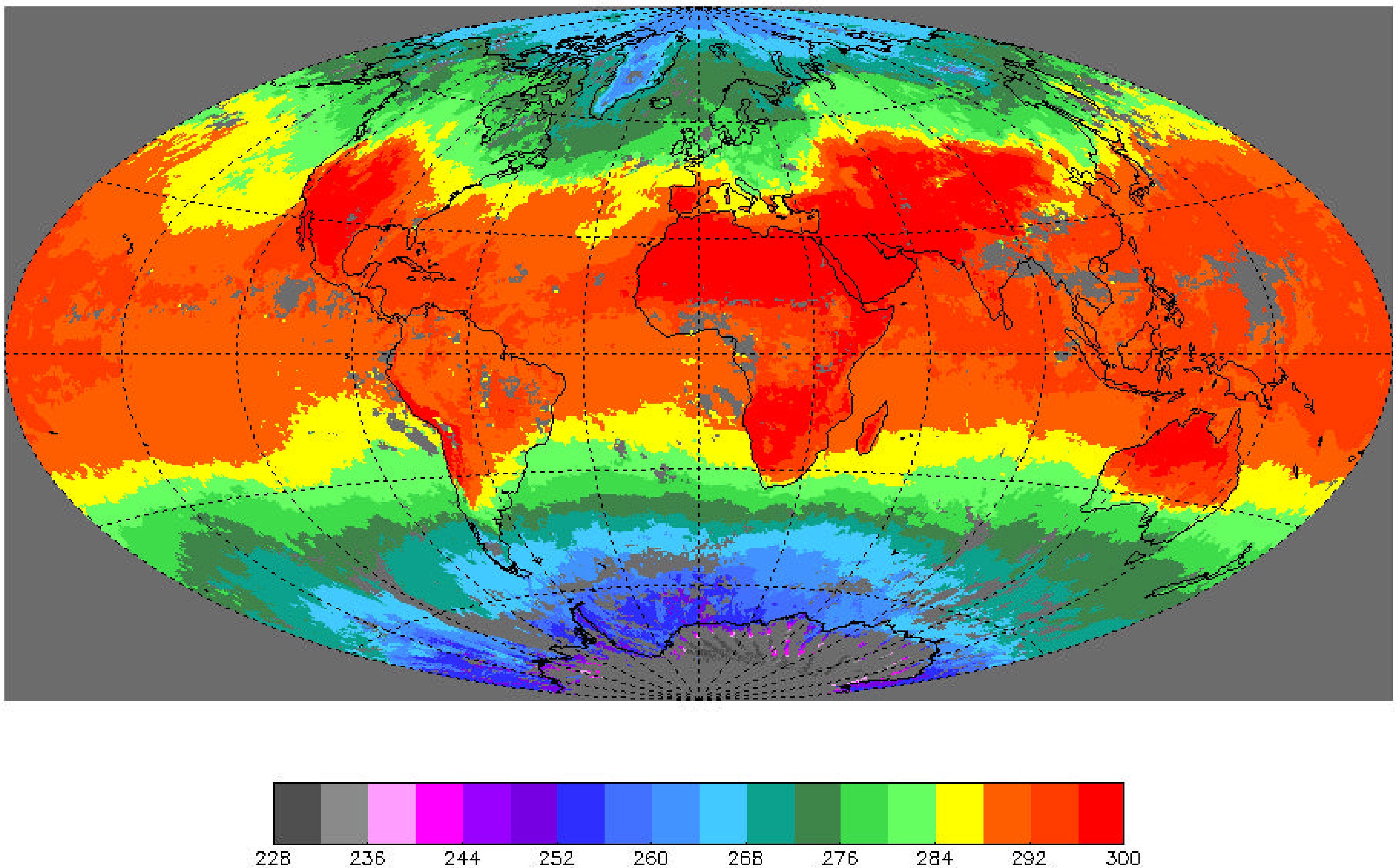
500hPa T

5km resolution MODIS

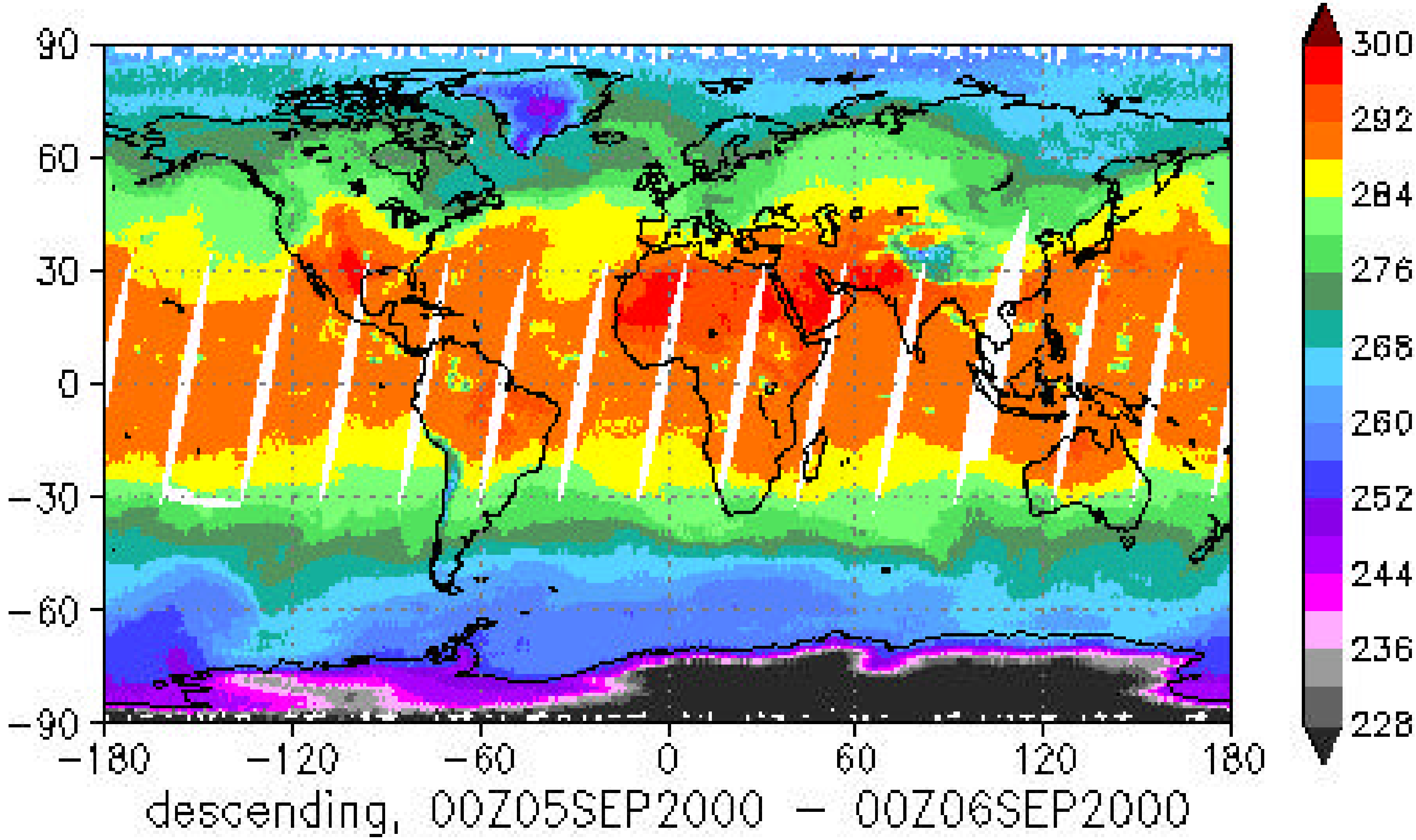


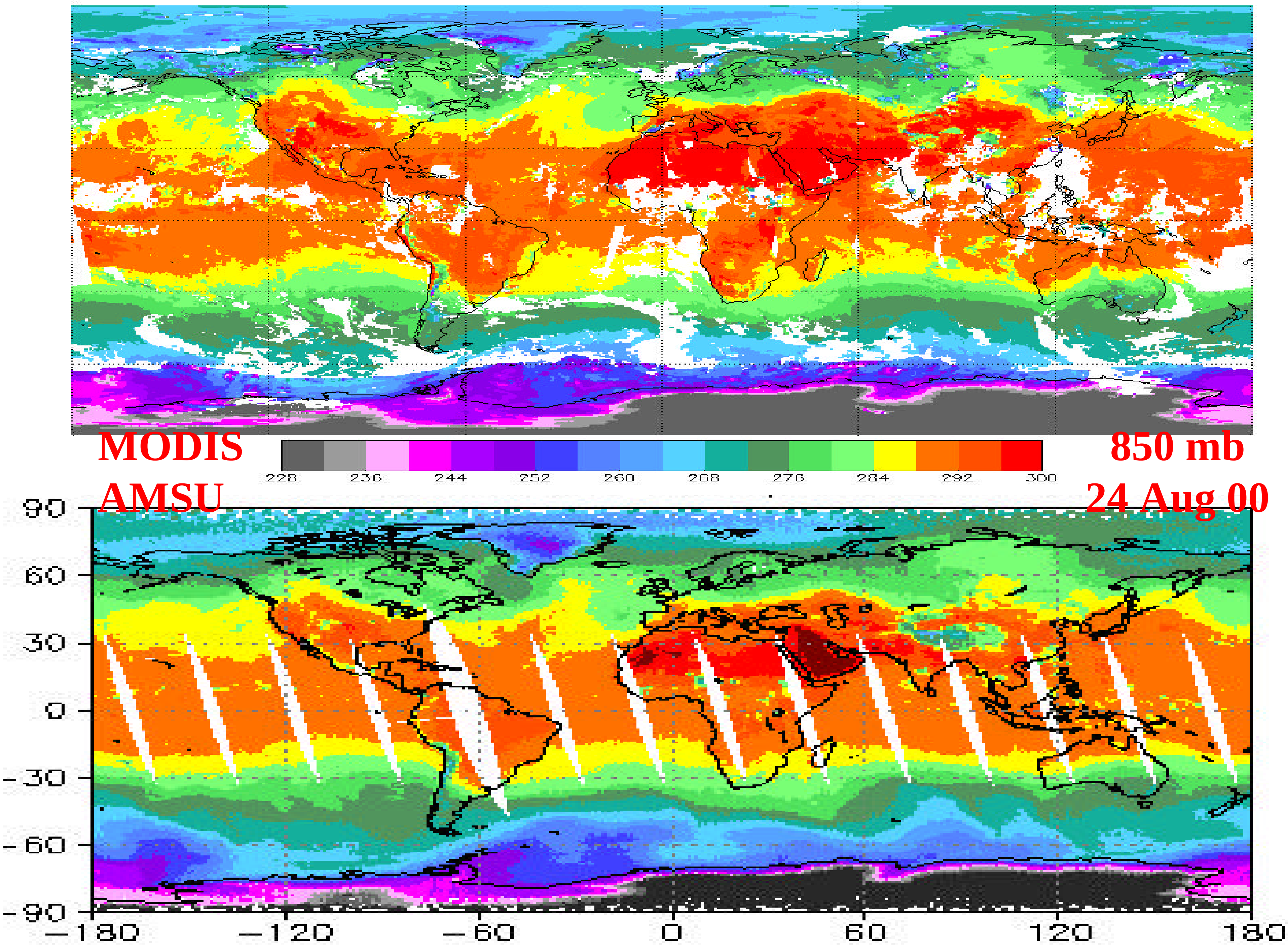
MODIS 2000/09/05-08

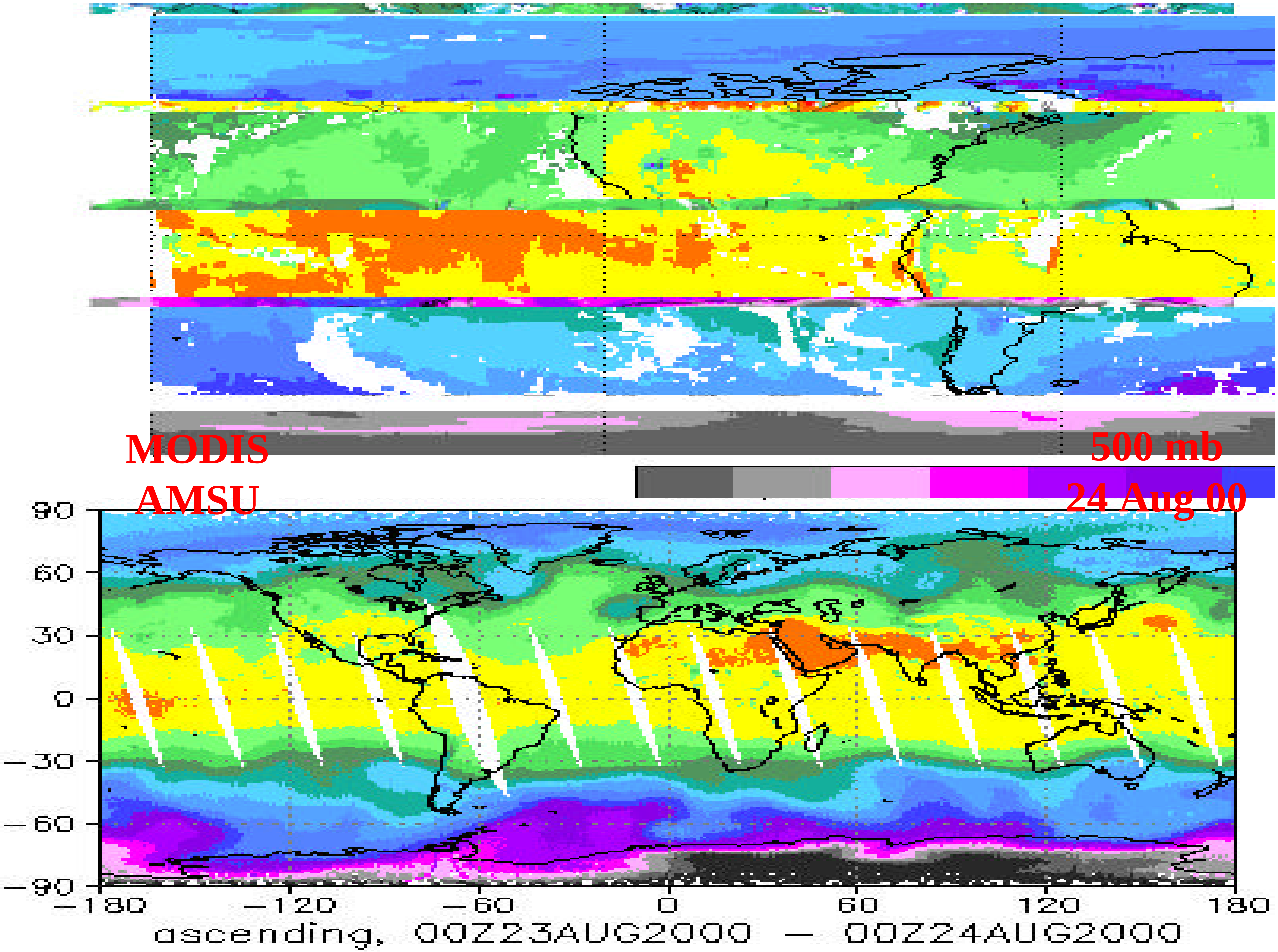
Daytime 850 hPa Temperature (K) for 4 days



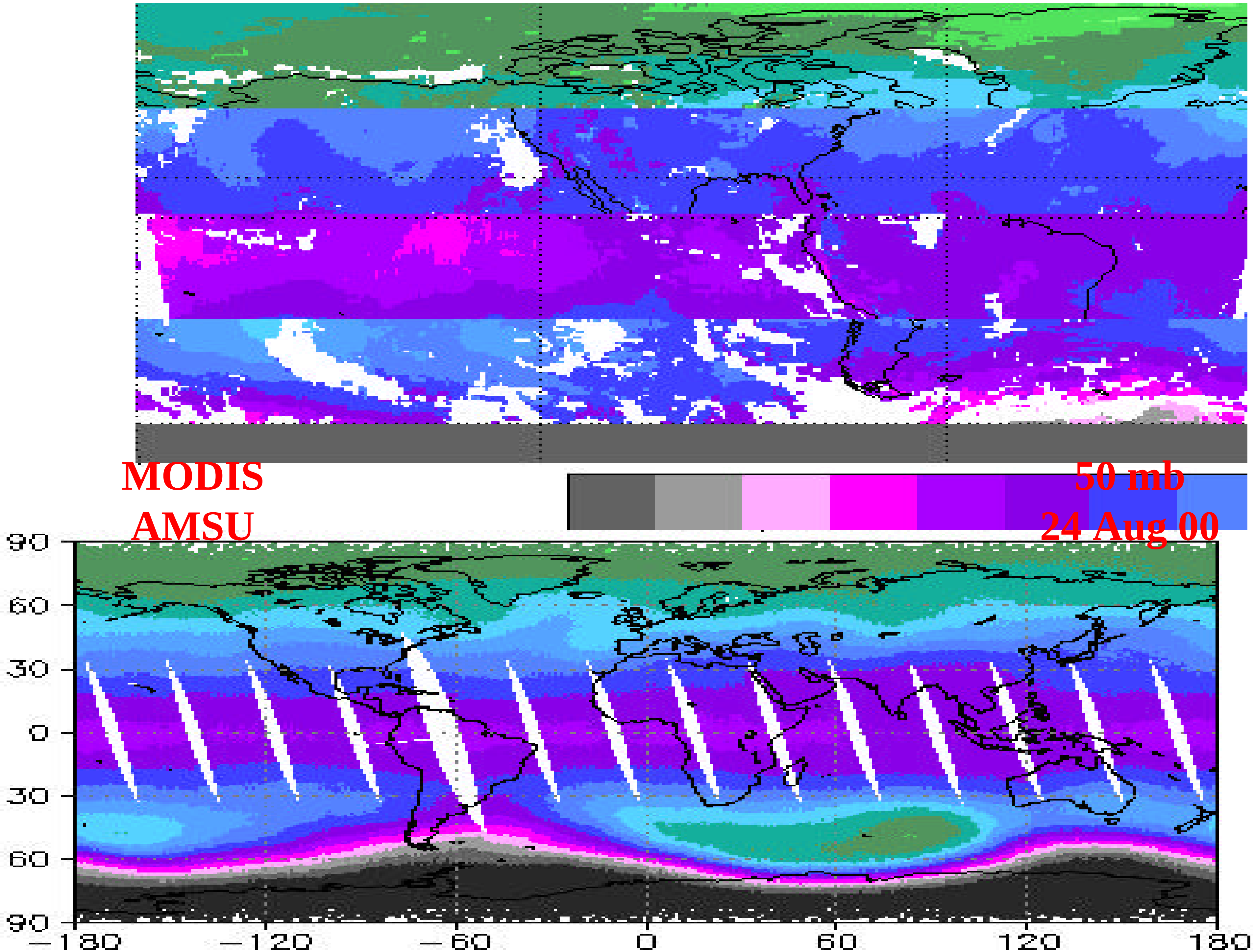
NOAA-15 AMSU-A 2000/09/05
Daytime 850 hPa Temperature (K) for one day



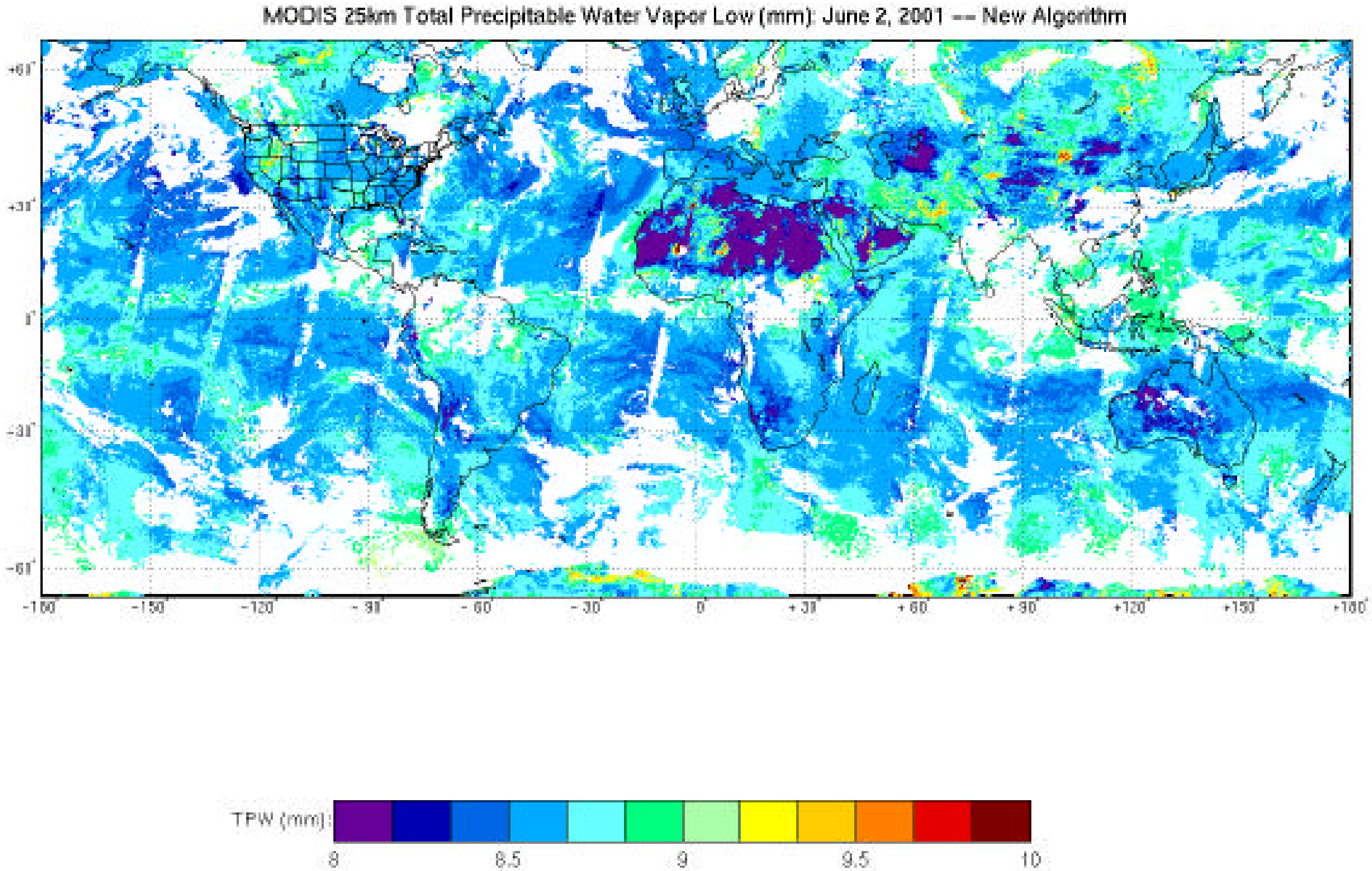

MODIS
AMSU
850 mb
24 Aug 00
228
236
244
252
260
268
276
284
292
300
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180



MODIS
AMSU
500 mb
24 Aug 00
90
60
30
0
−30
−60
−90
−180
−120
−60
0
60
120
180
ascending, 00Z23AUG2000 − 00Z24AUG2000


MODIS
AMSU
50 mb
24 Aug 00
90
60
30
0
30
60
90
−180
−120
−60
0
60
120
180

4μm Surface Reflection must be considered



Mitigating Problems in MODIS AP Algorithm

* Changed predictors band 24 and 25 (4.4 and 4.5 um) brightness temperatures to their BT difference to remove surface effects:

  Old algorithm had 12 predictors:

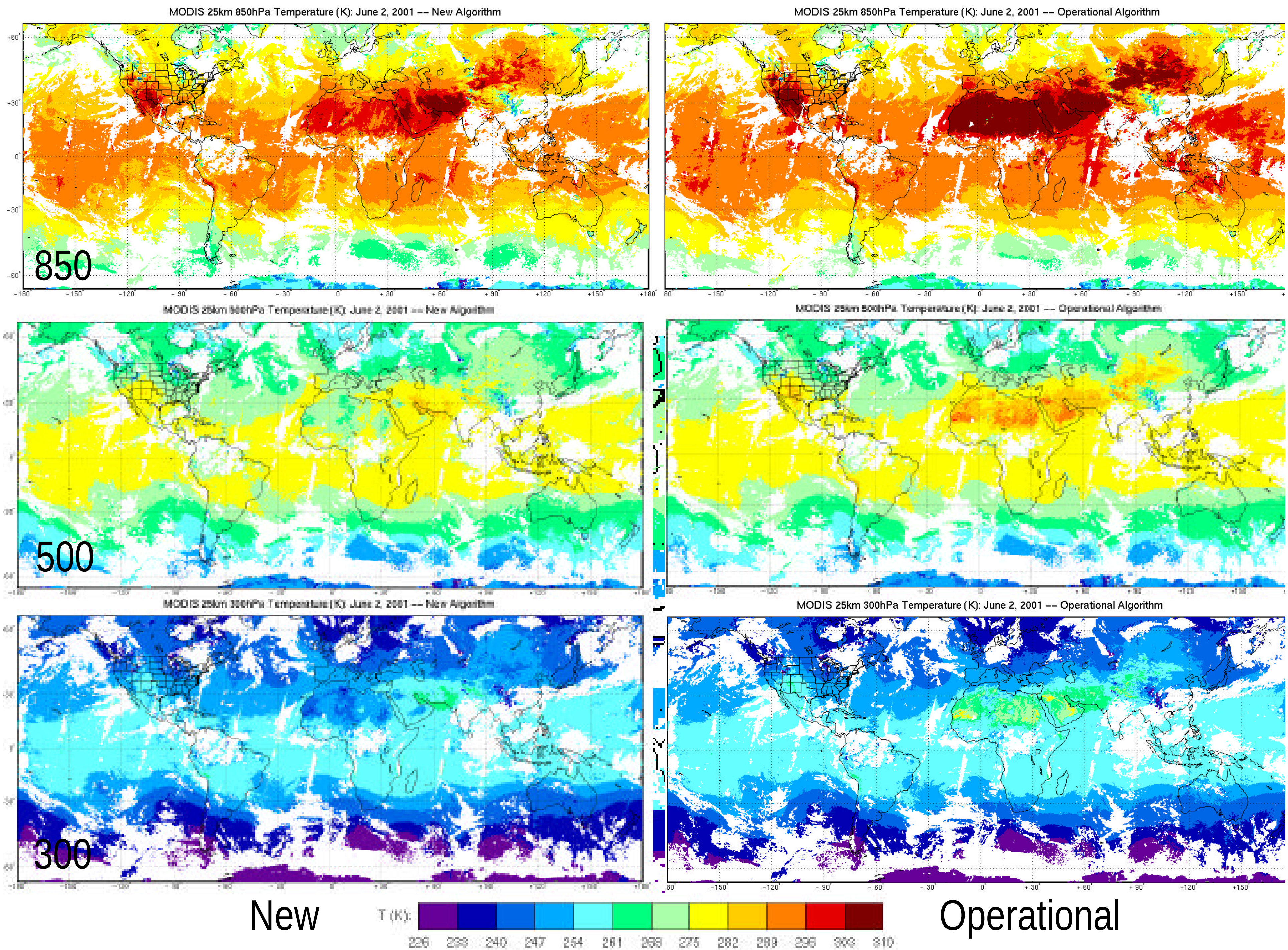
    individual bands 24, 25, and 27 through 36.

  New algorithm has 11 predictors:

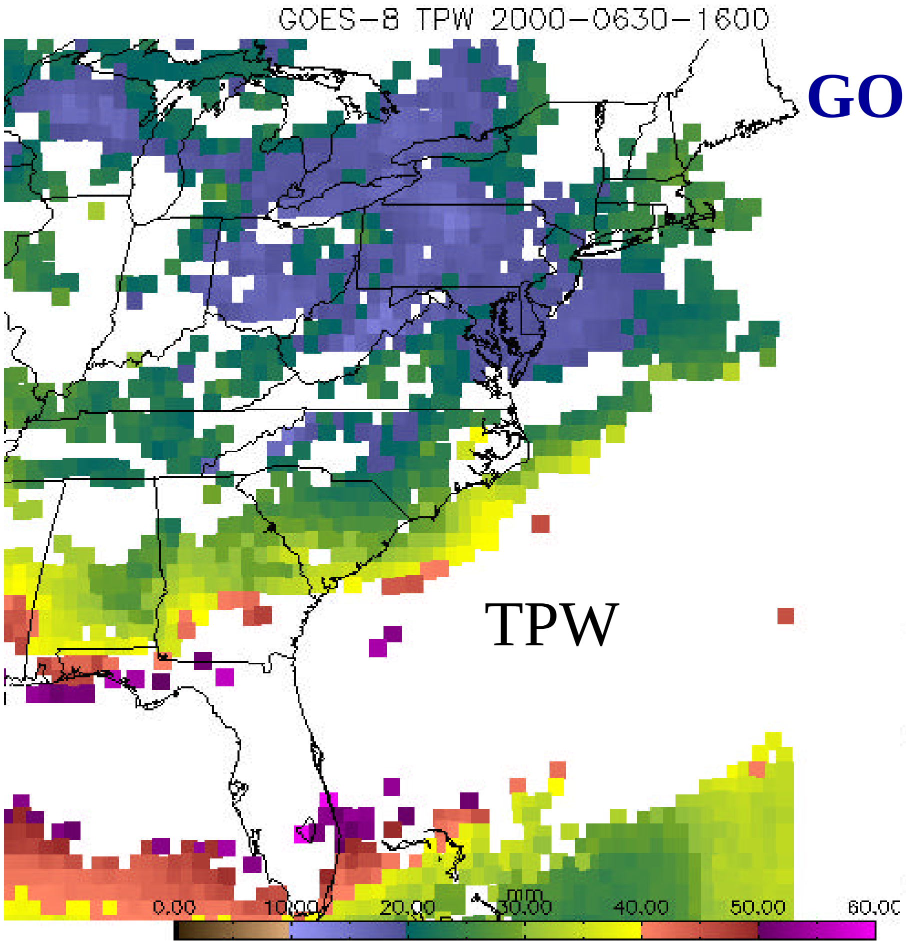
    band 25 - 24 BT difference and
    individual bands 27 through 36.

* Implemented *preliminary* radiance bias corrections. Currently based only on CART site data, global biases are in progress.

* Applied post-launch NEdT in place of pre-launch.

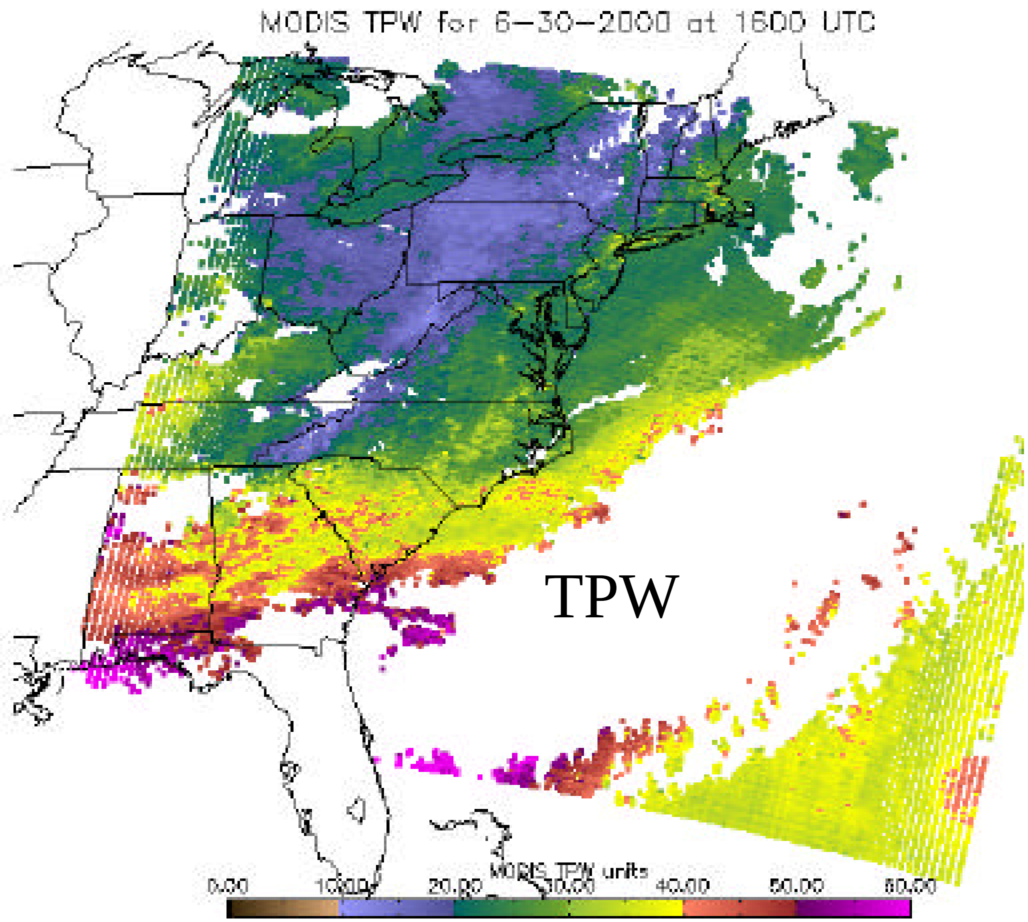

MODIS 25km 850hPa Temperature (K): June 2, 2001 -- New Algorithm
MODIS 25km 850hPa Temperature (K): June 2, 2001 -- Operational Algorithm
850
MODIS 25km 500hPa Temperature (K): June 2, 2001 -- New Algorithm
MODIS 25km 500hPa Temperature (K): June 2, 2001 -- Operational Algorithm
500
MODIS 25km 300hPa Temperature (K): June 2, 2001 -- New Algorithm
MODIS 25km 300hPa Temperature (K): June 2, 2001 -- Operational Algorithm
300
New
T (K):
226 233 240 247 254 261 268 275 282 289 296 303 310
Operational

GOES vs. MODIS 2000/06/30 1600 UTC
Total Precipitable Water (mm)

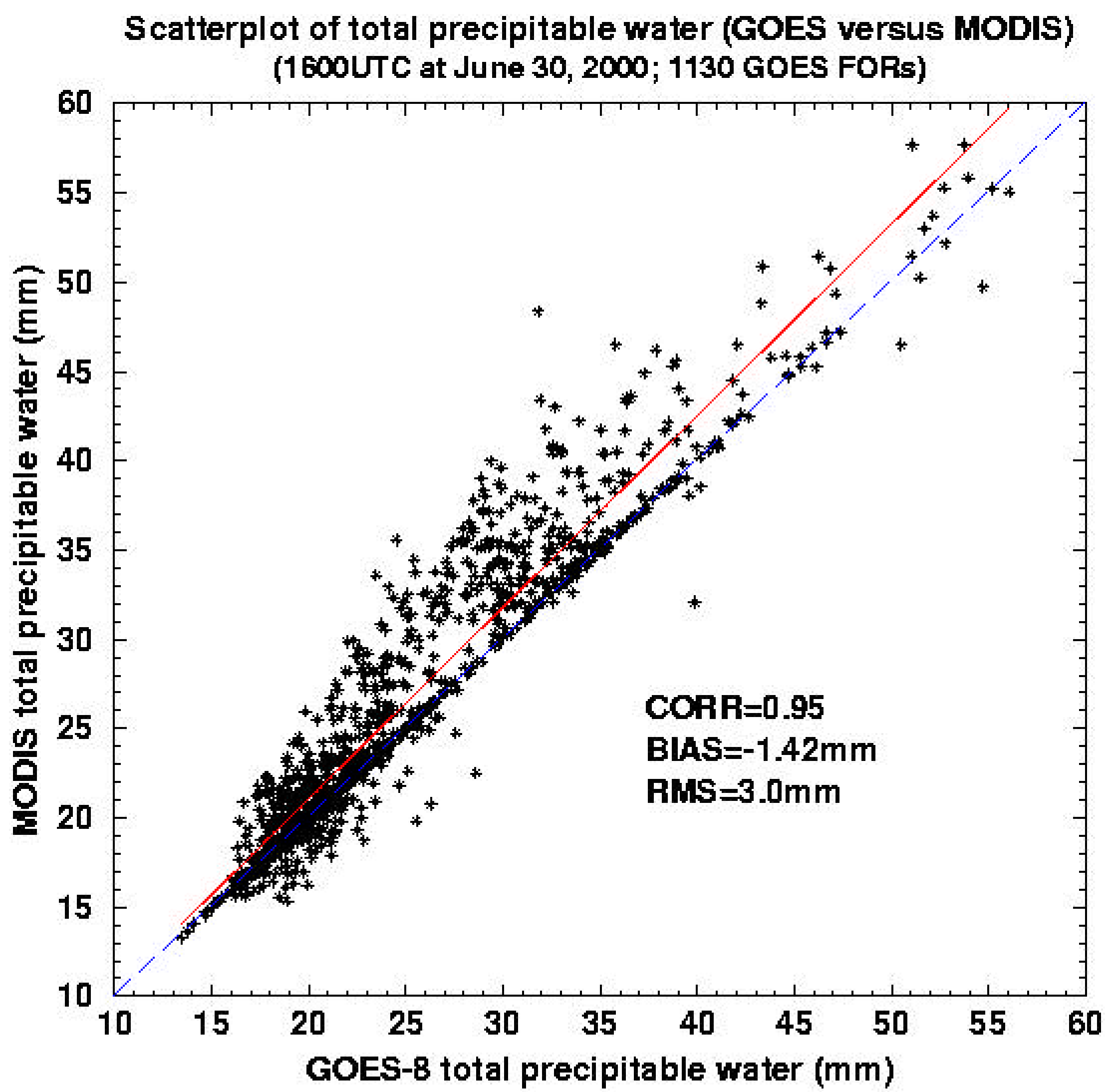


GOES 30 km resolution

MODIS 5 km resolution



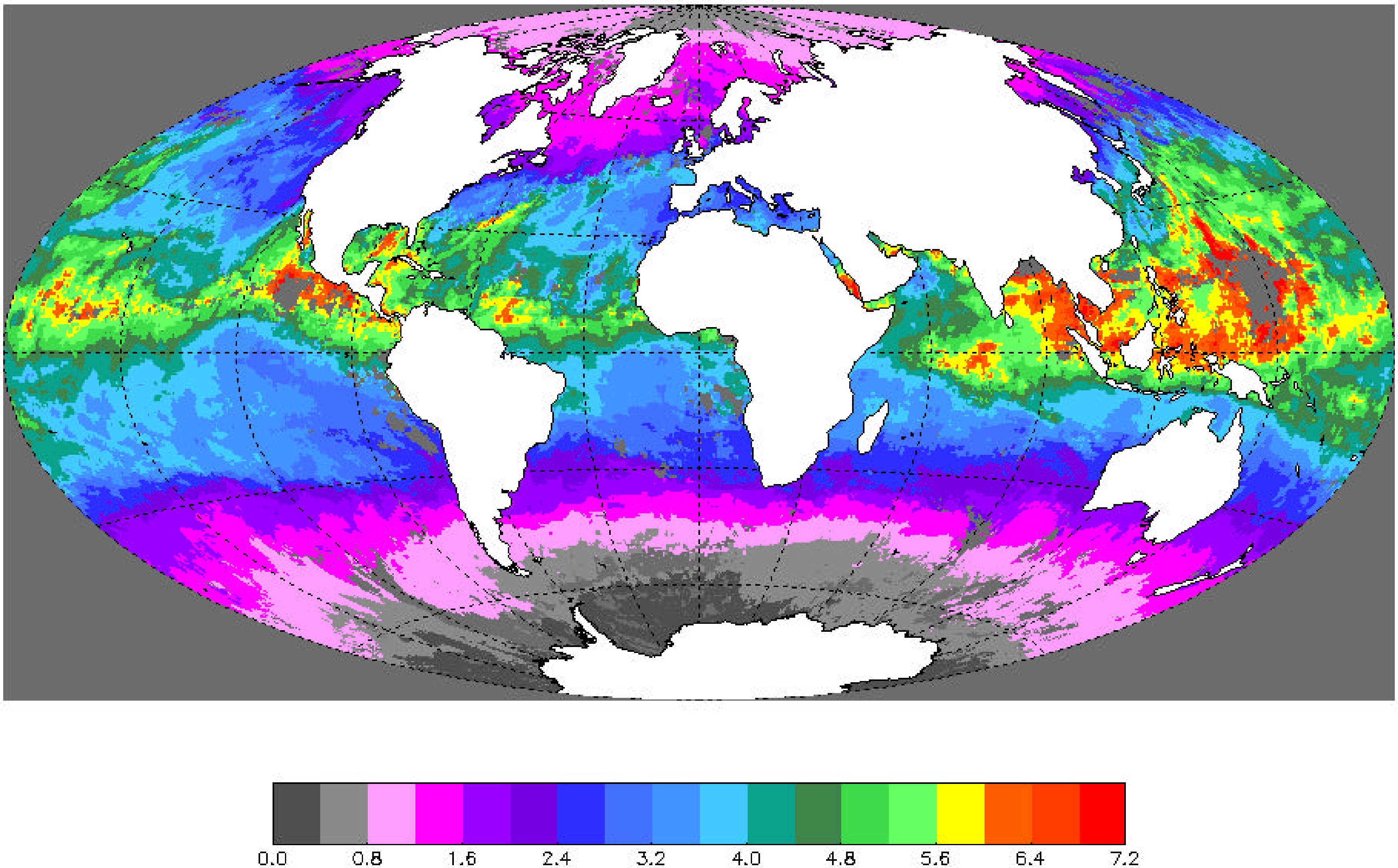
MODIS total precipitable water vapor shows a wet bias wrt GOES; bias 1.5 mm and rms of 3 mm; bias will be removed after more validation



MODIS 2000/09/05-08

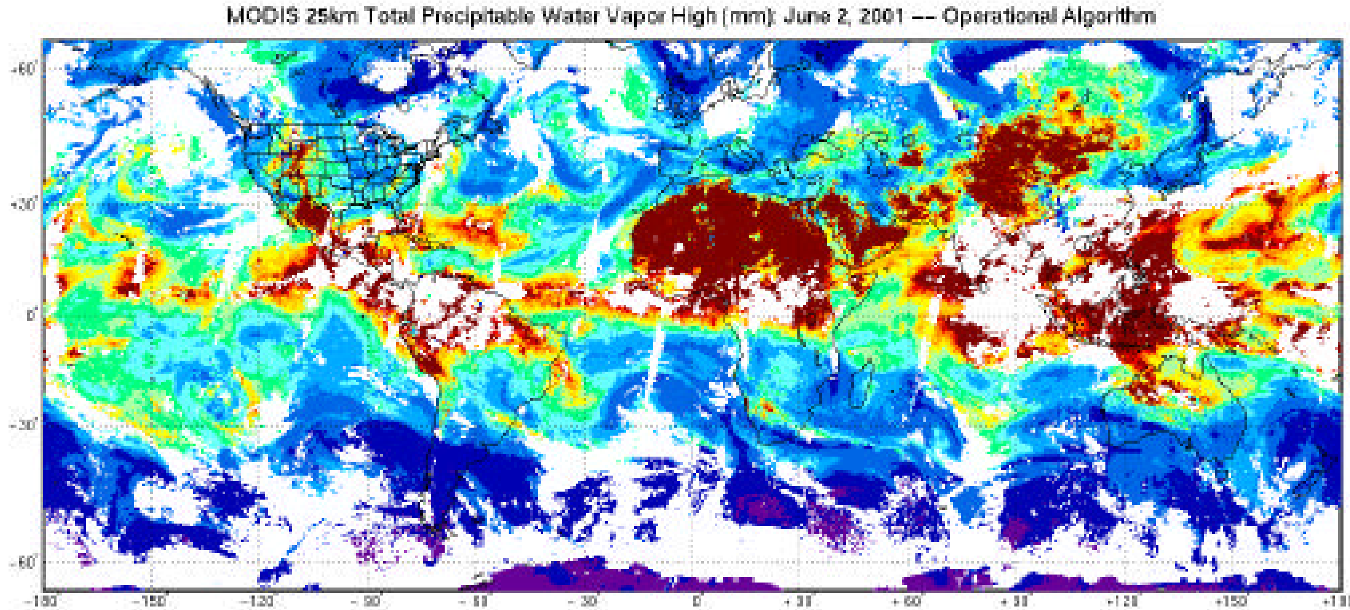
Daytime Total Precipitable Water (cm)

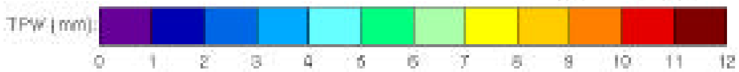
values over land not shown to facilitate comparison with AMSU



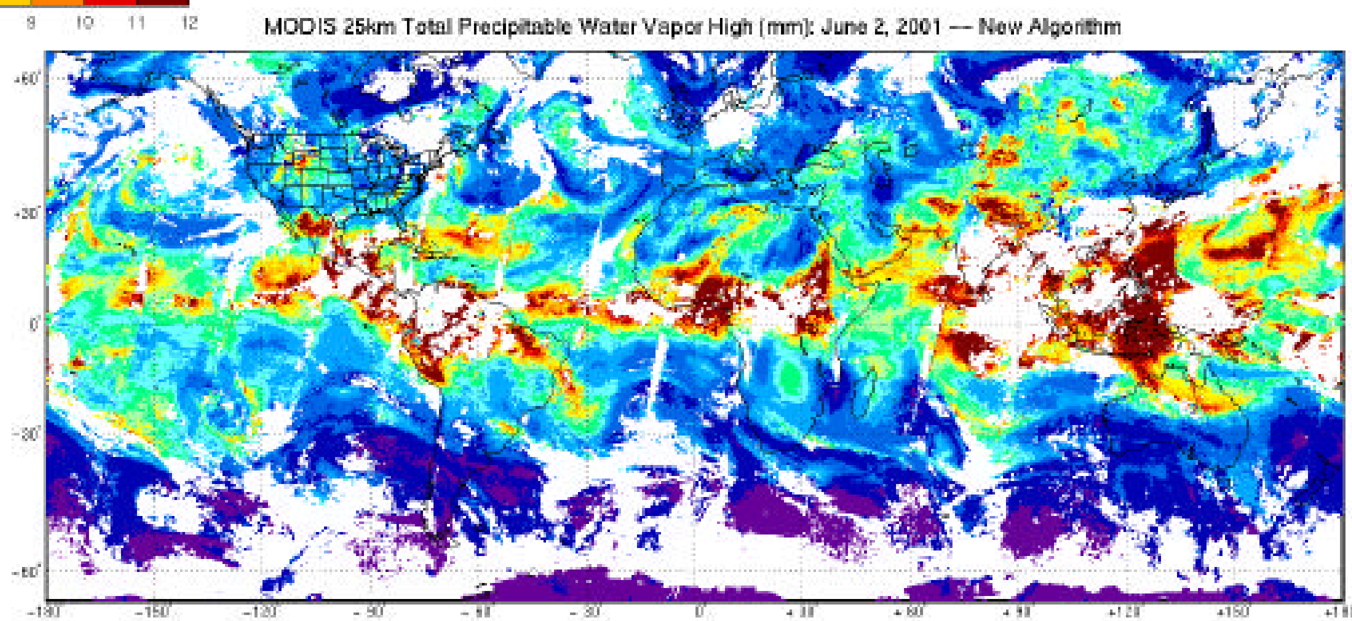
Other MOD07 Products: Water Vapor High (mm)

Operational

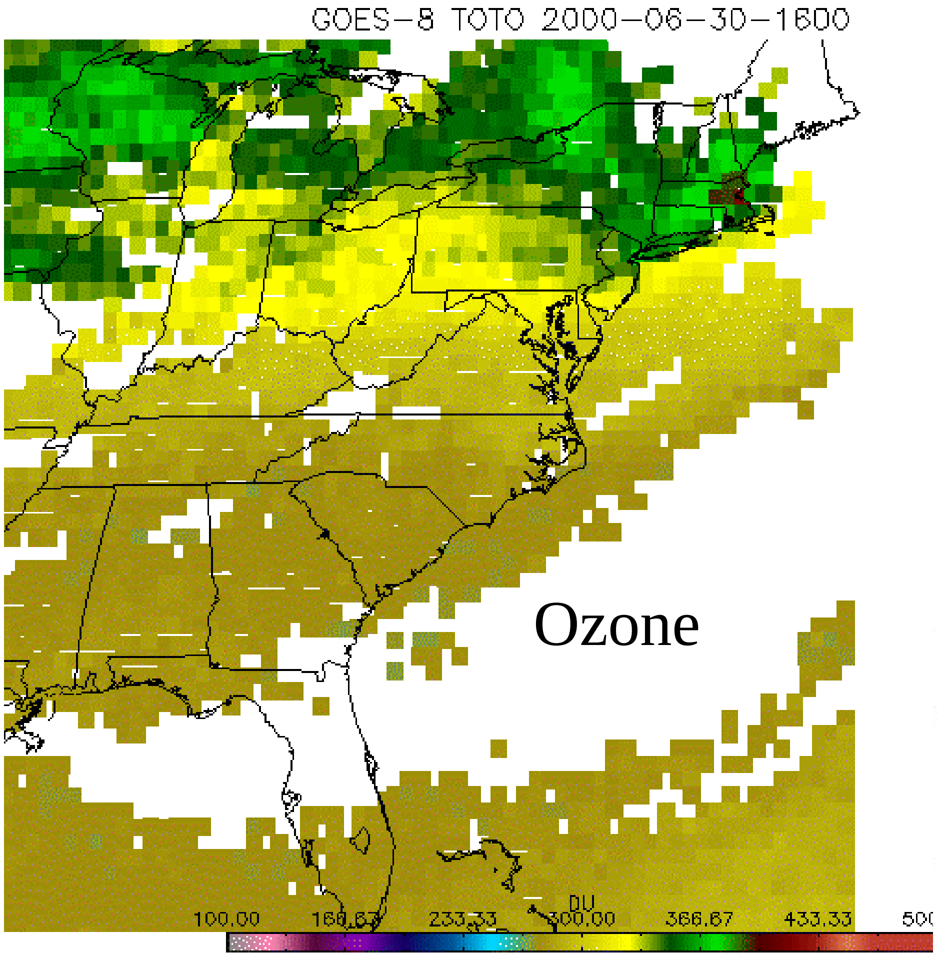




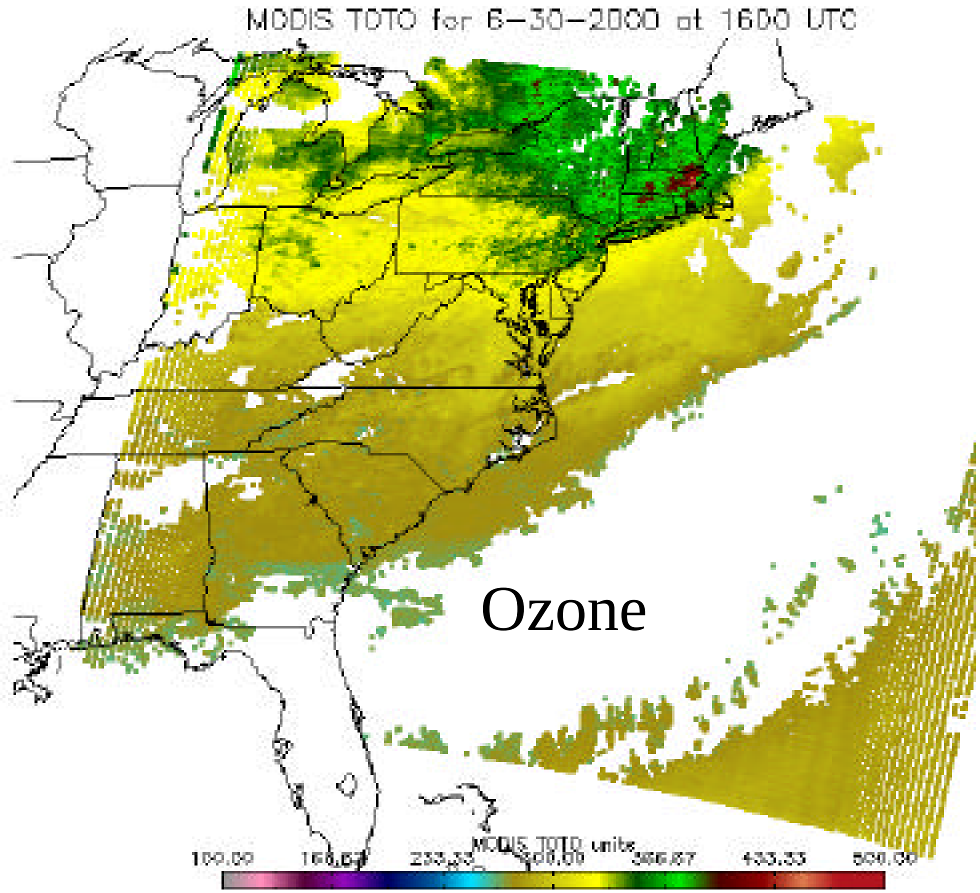
New



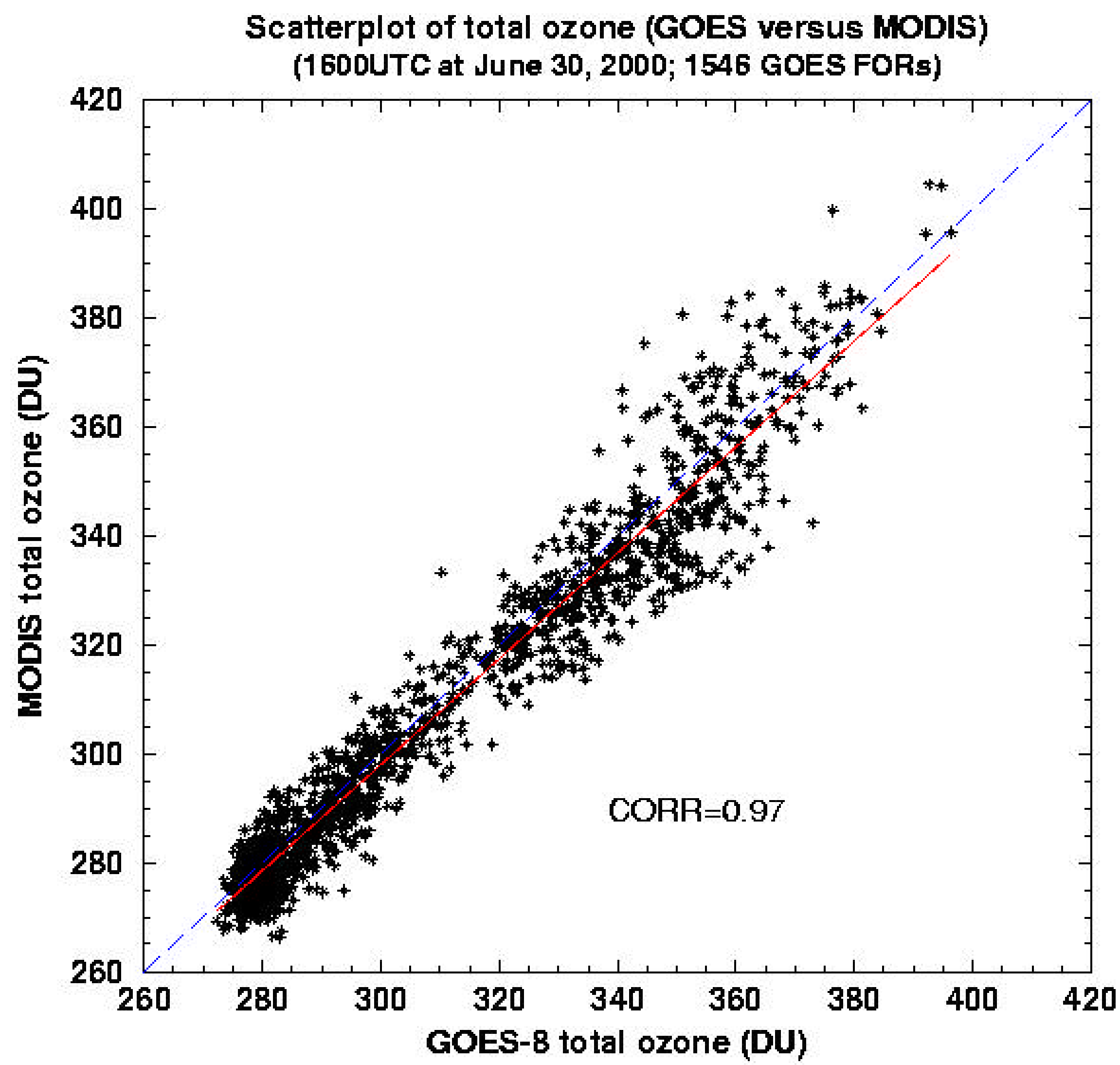
MODIS 5 km resolution



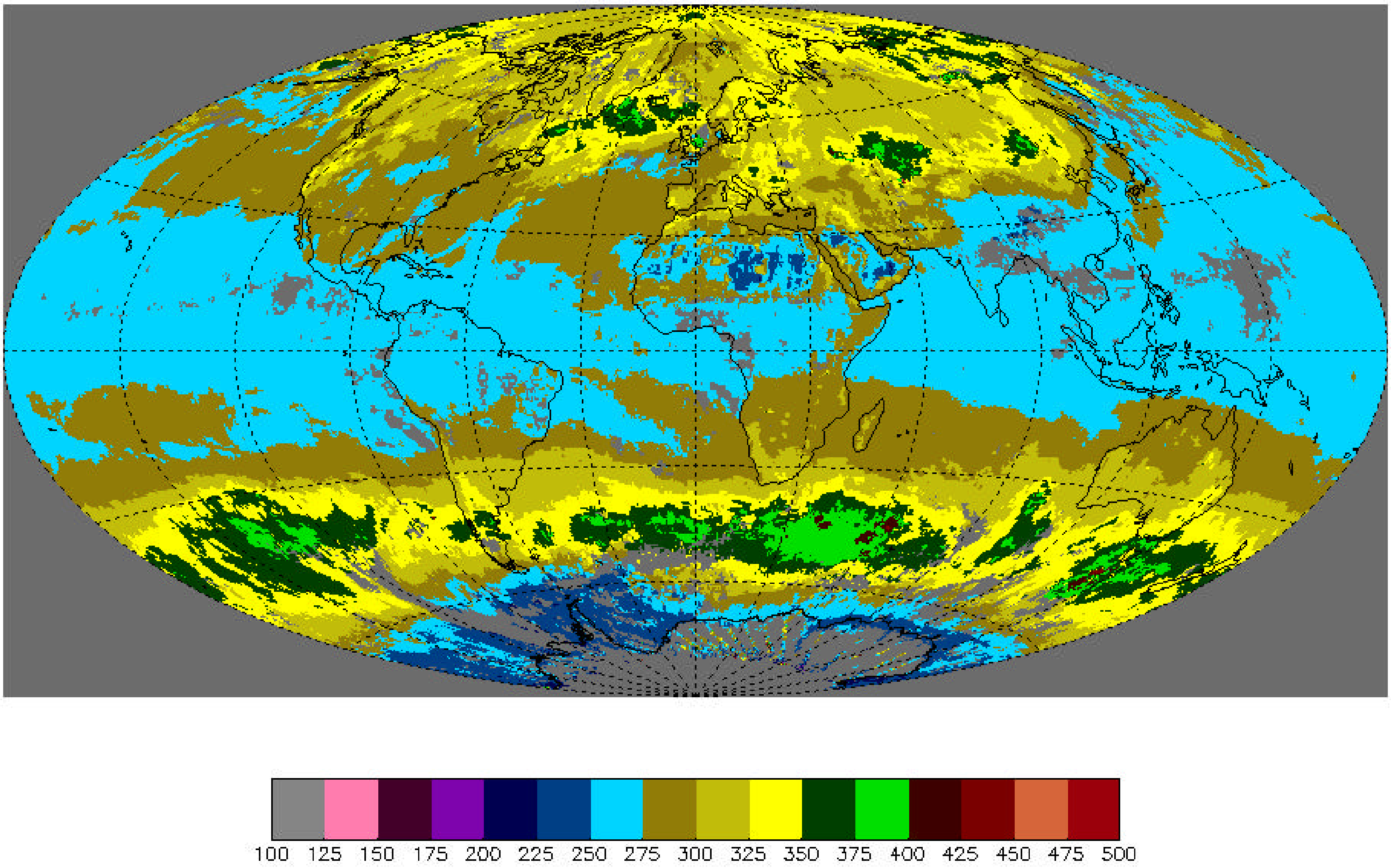
GOES 30 km resolution



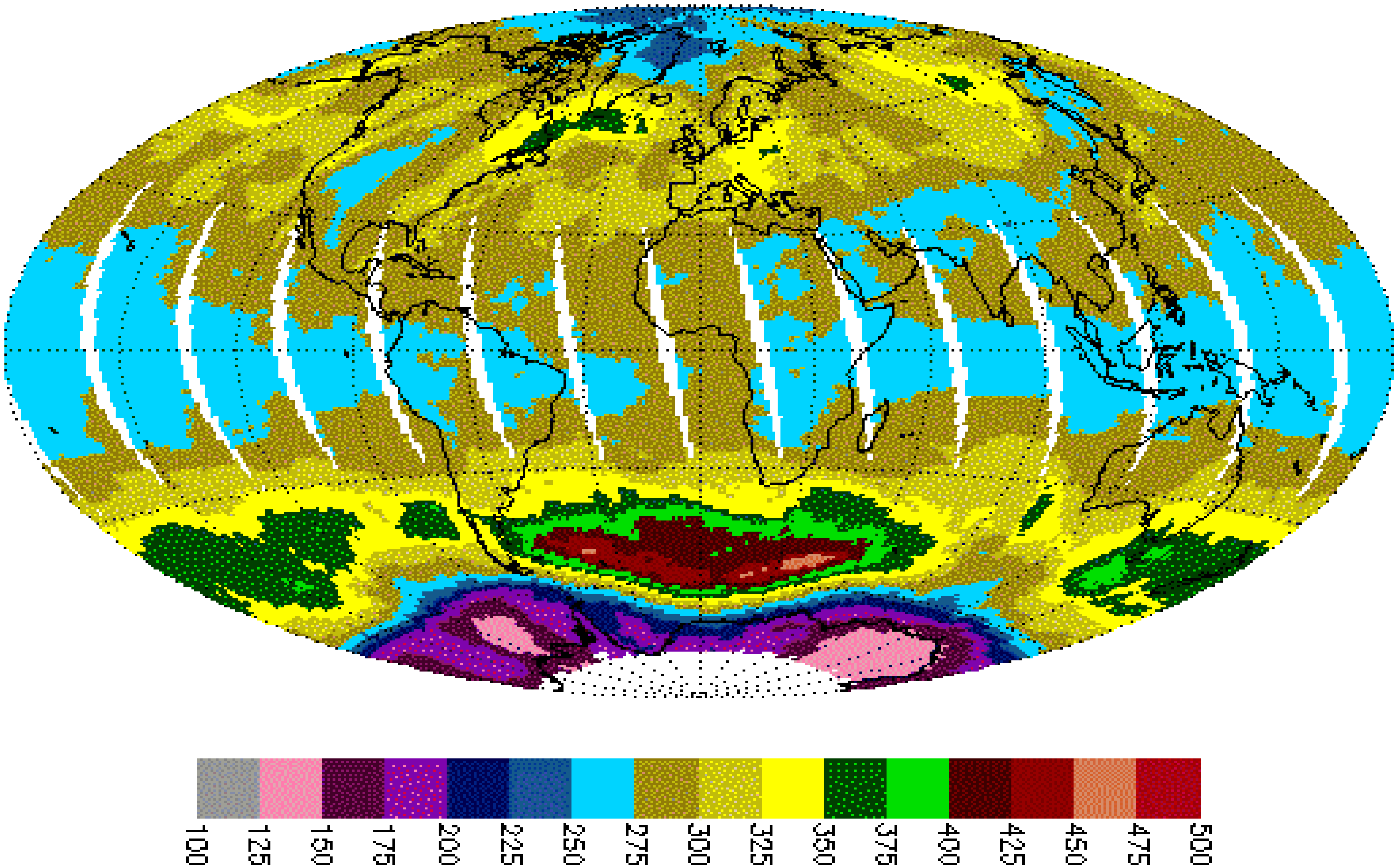
MODIS ozone is very close to the GOES ozone (over North America); rms of about 10 Dobsons; polar extreme ozone values will be improved

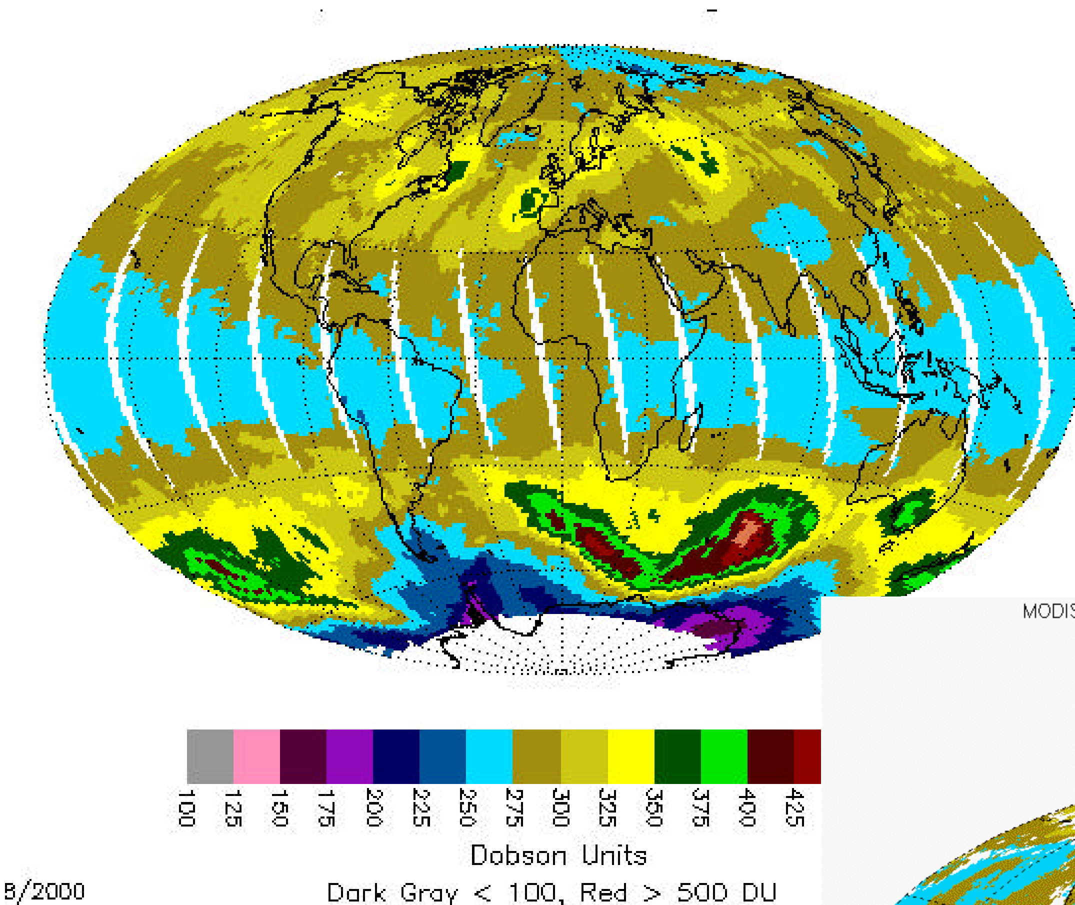


MODIS 2000/09/05-08
Daytime Total Ozone (Dobsons)



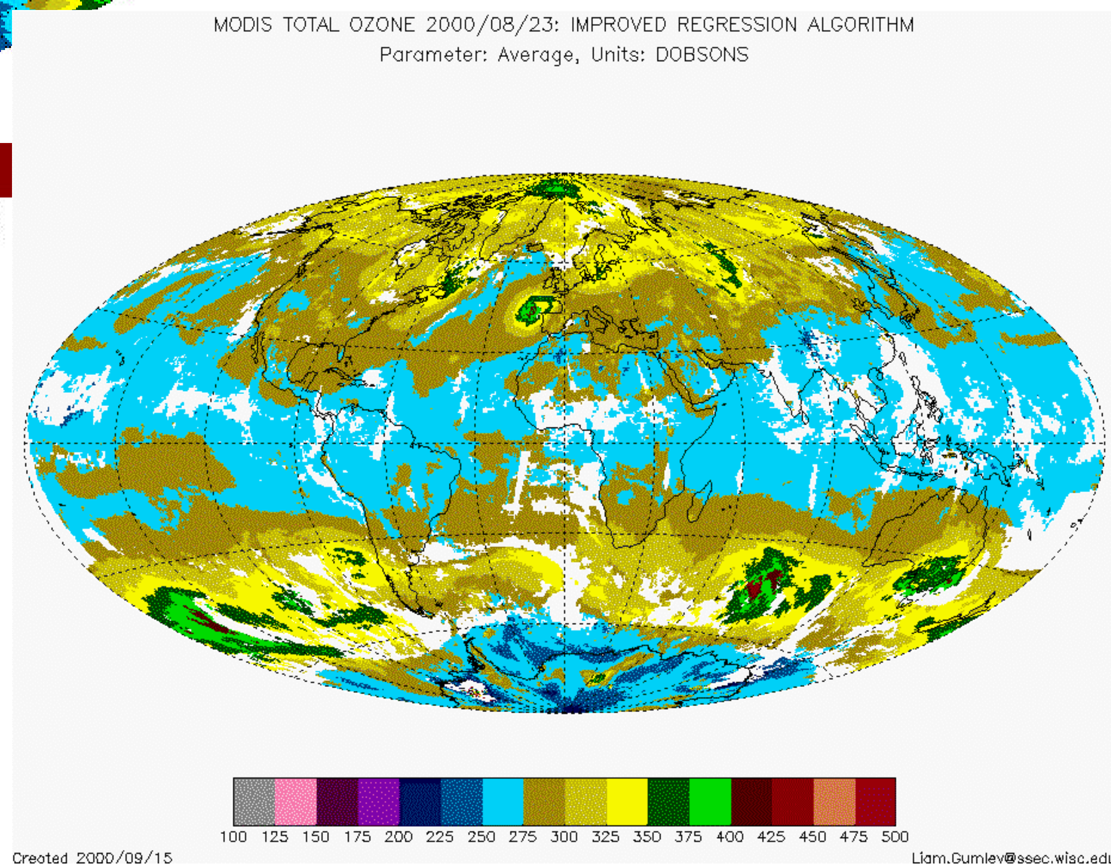
Earth Probe TOMS 2000/09/05
Total Ozone (Dobsons)





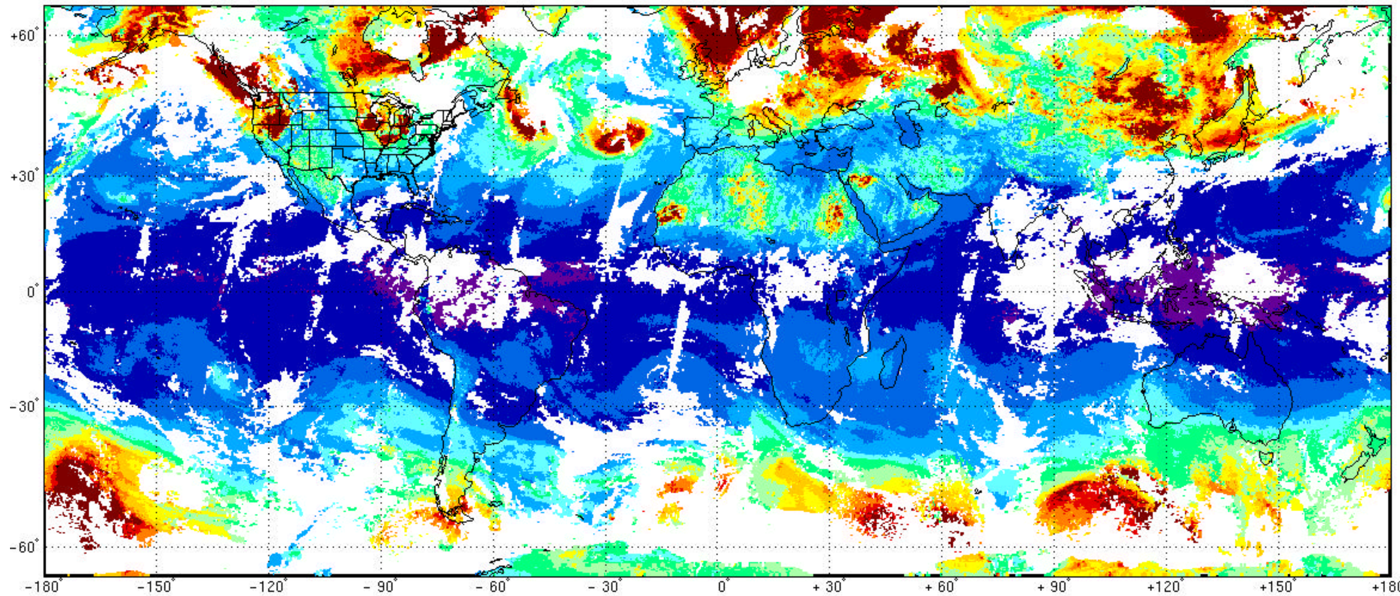
TOMS Ozone

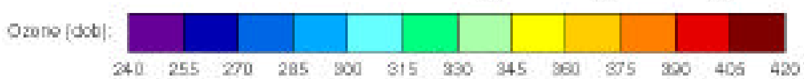
MODIS Ozone



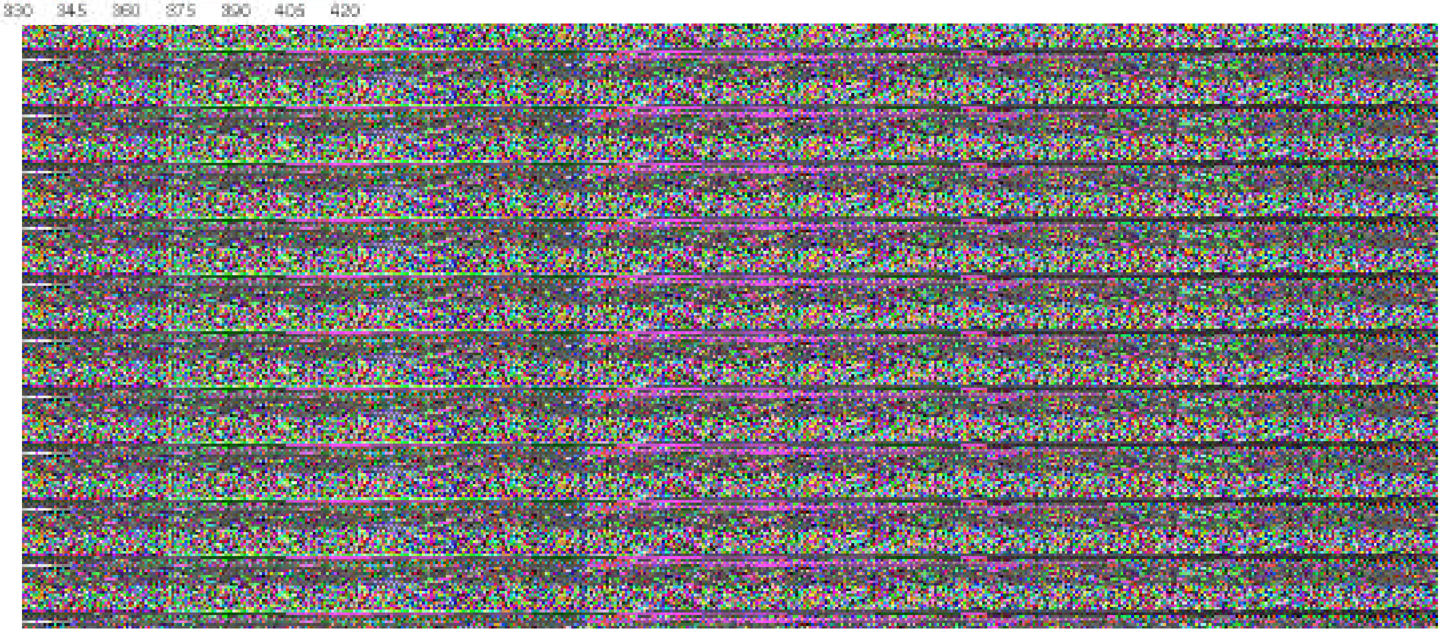
Algorithm Change effect on Total Column Ozone (dob)

Operational

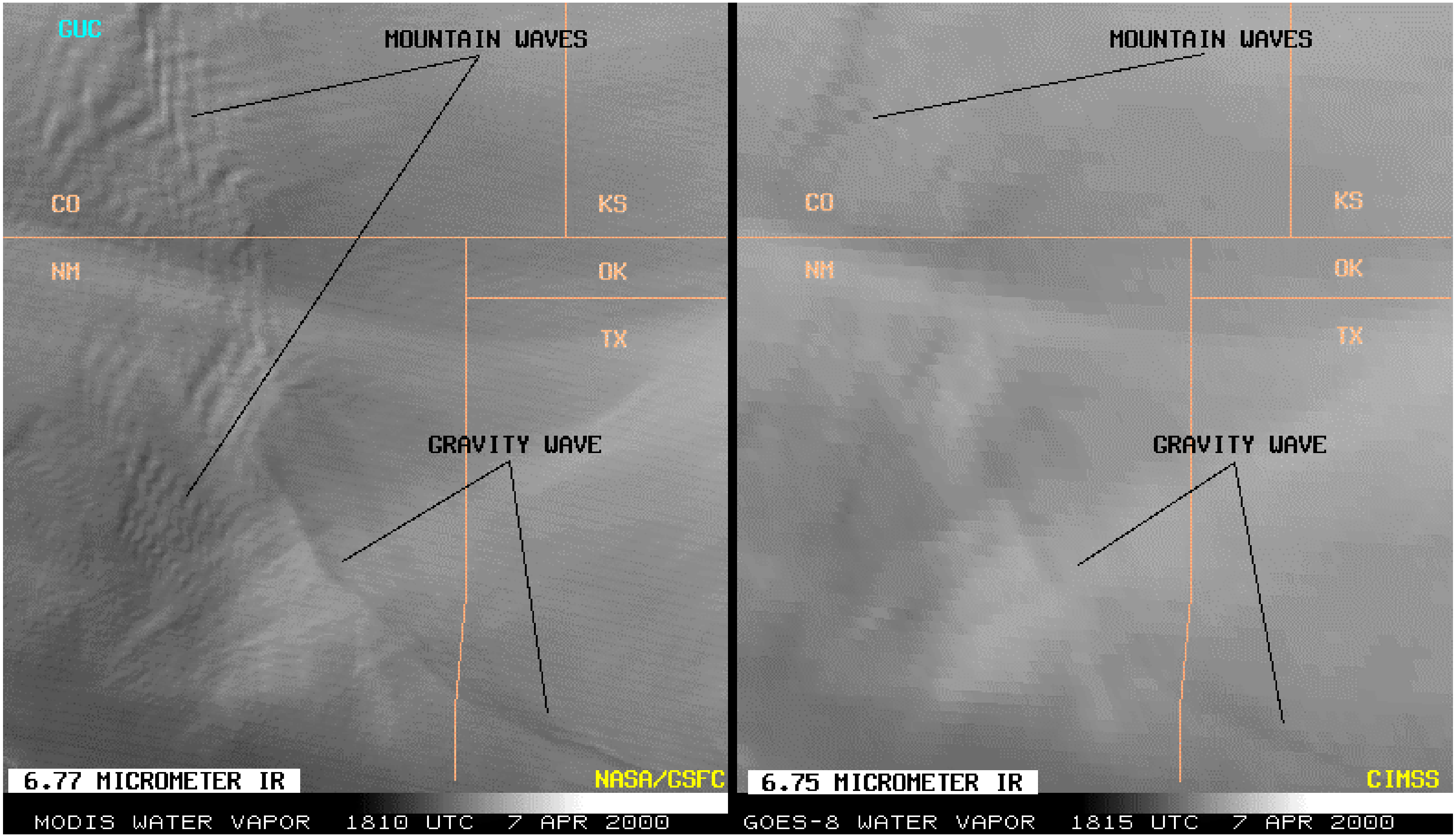




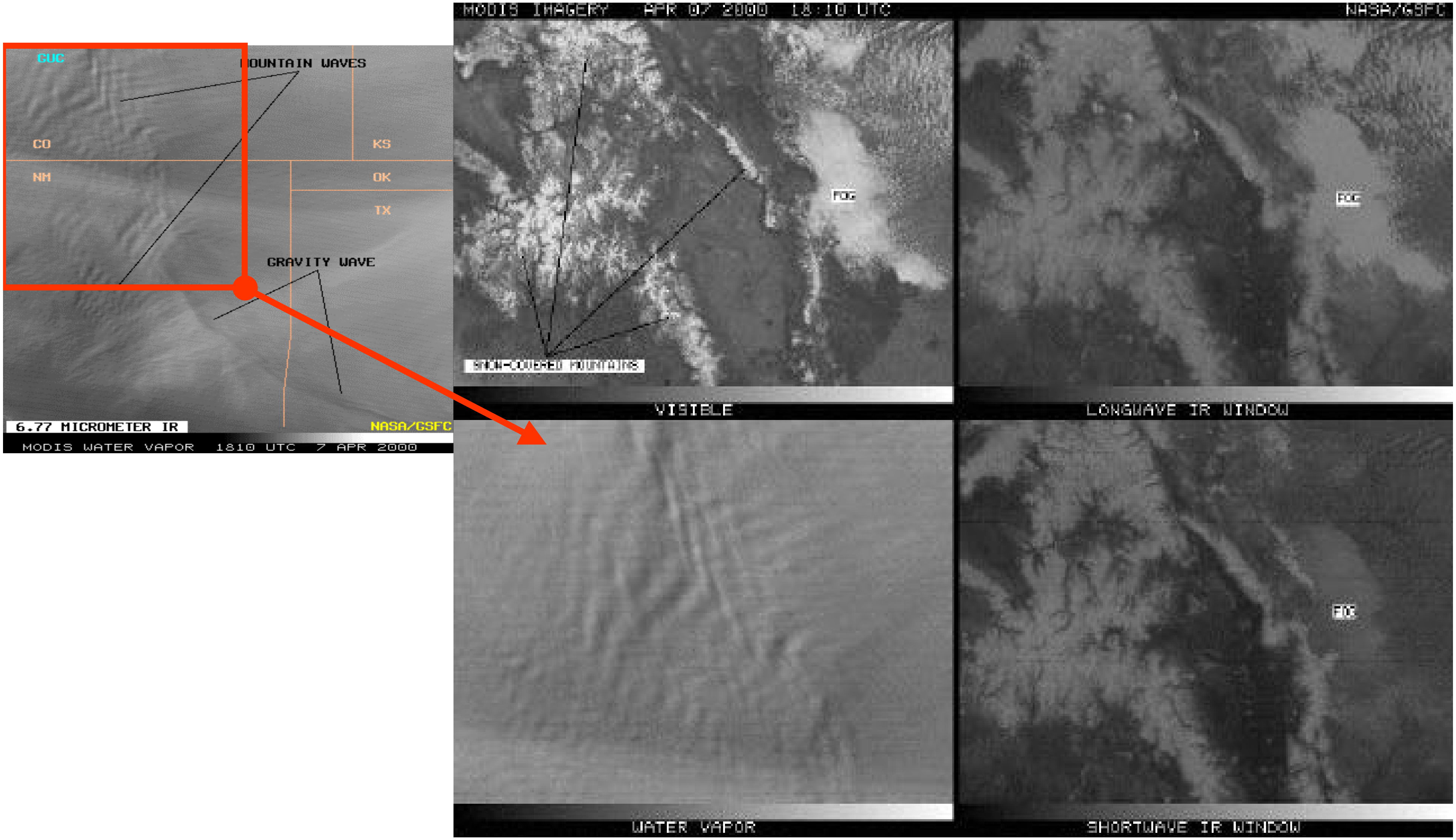
"New"

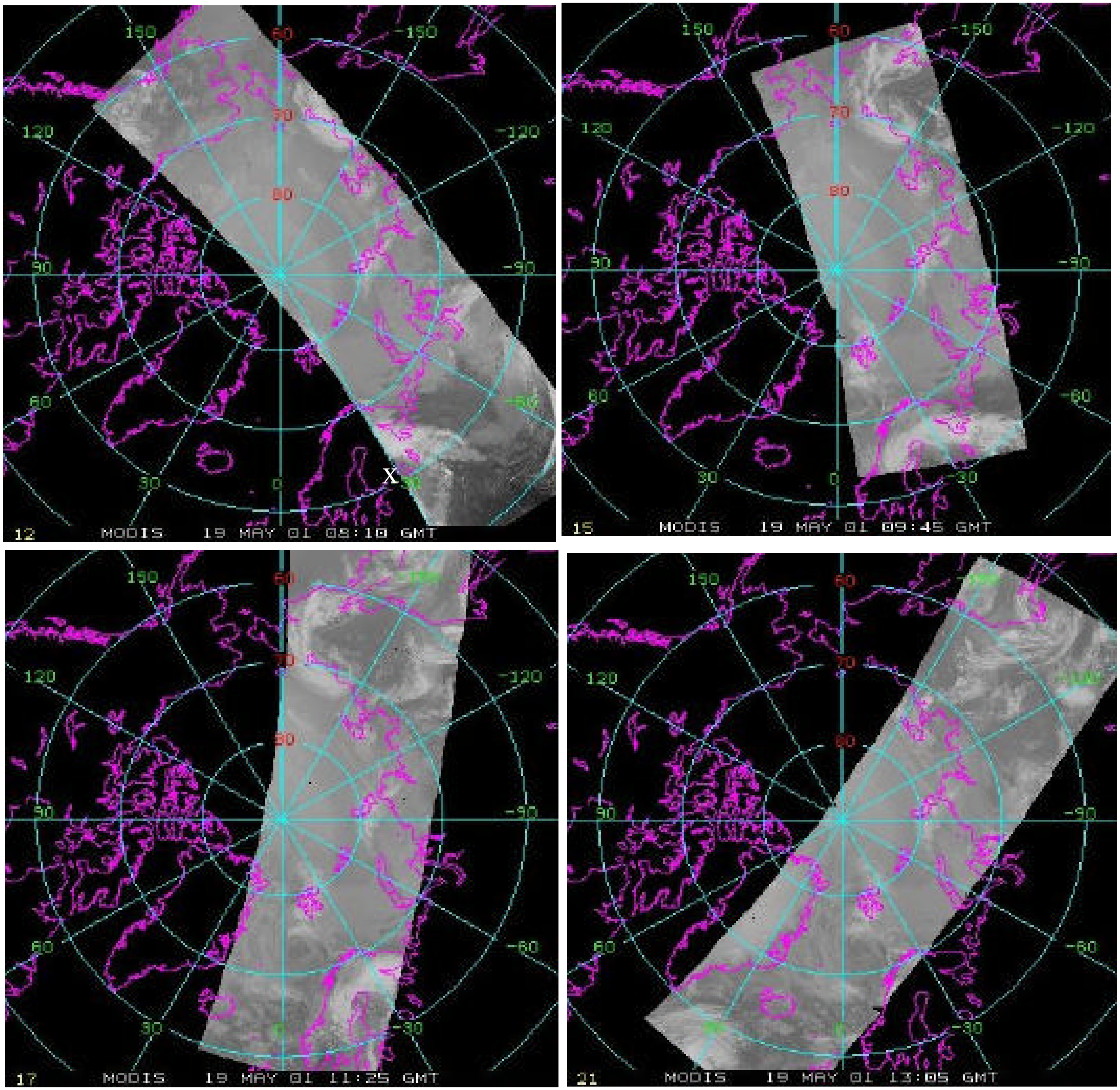


A Preview of ABI
High Resolution Water Vapor Imagery
1 km MODIS & 4x8 km GOES

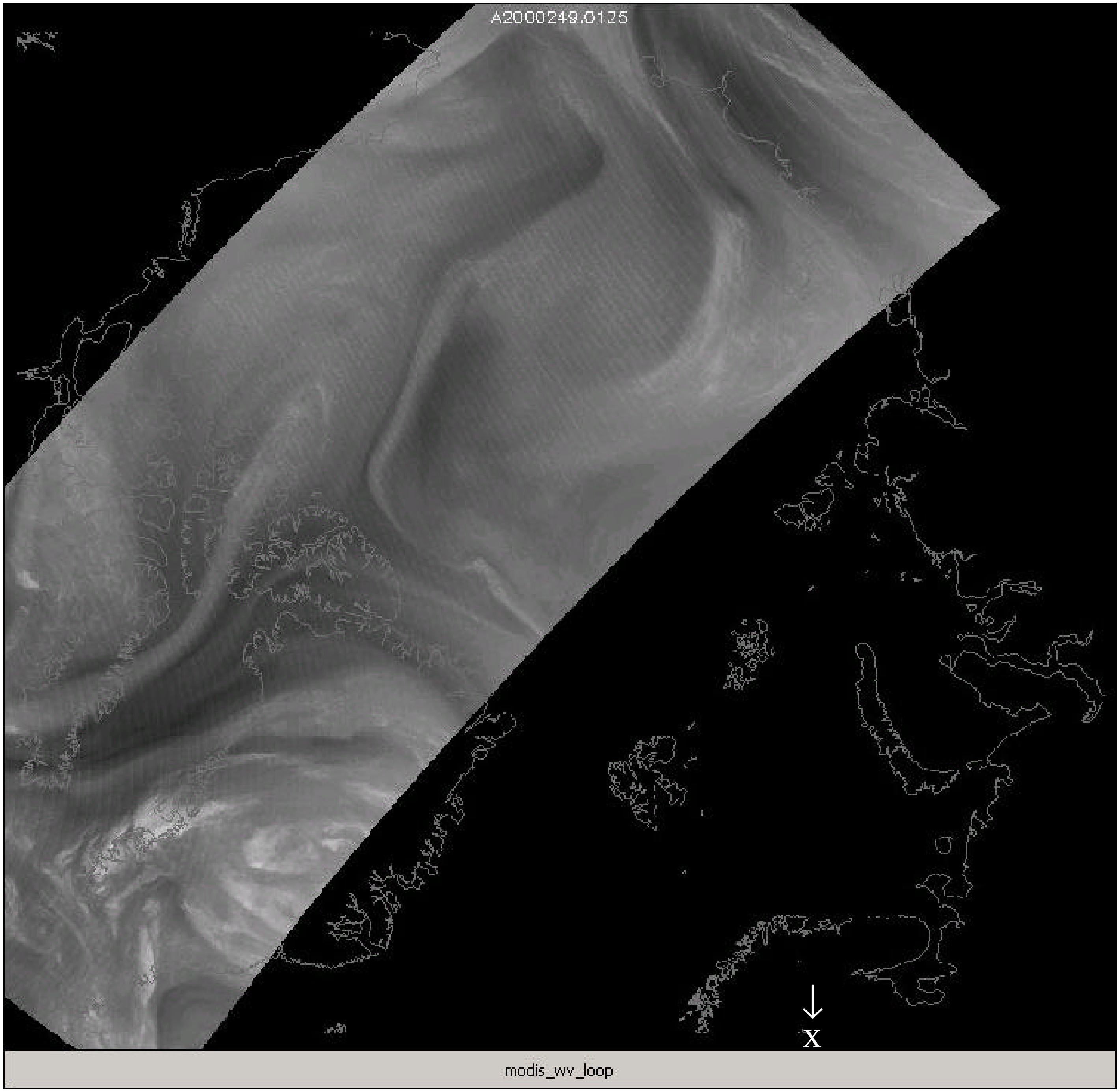


Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery



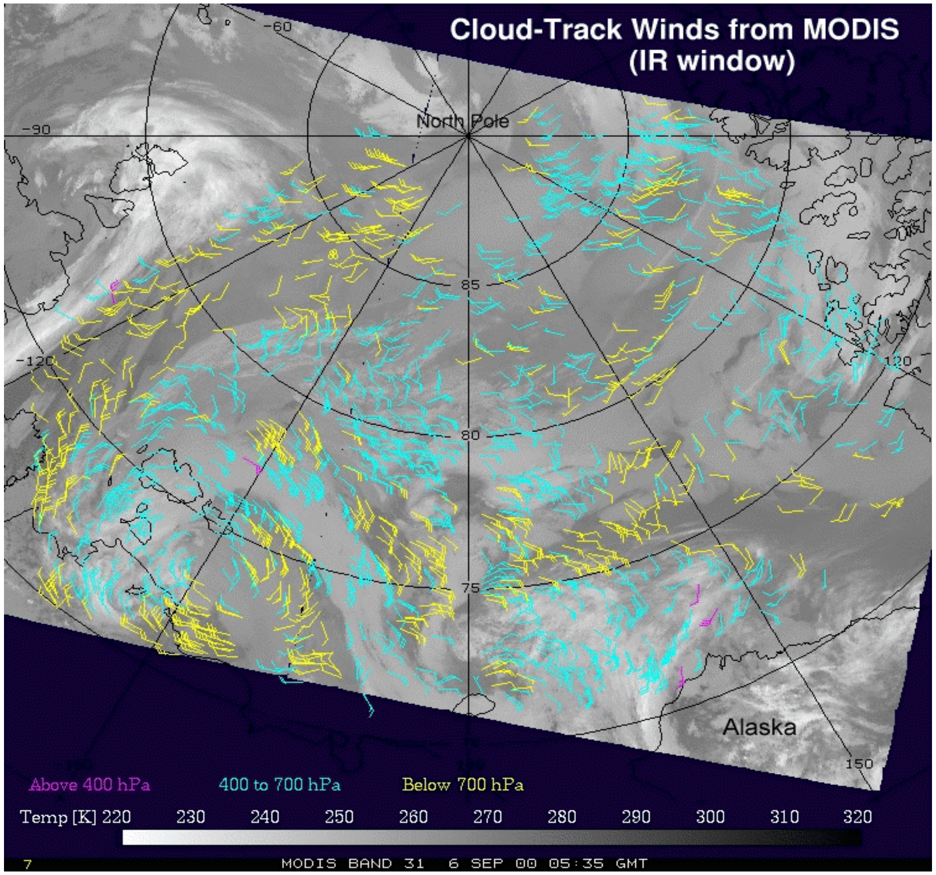


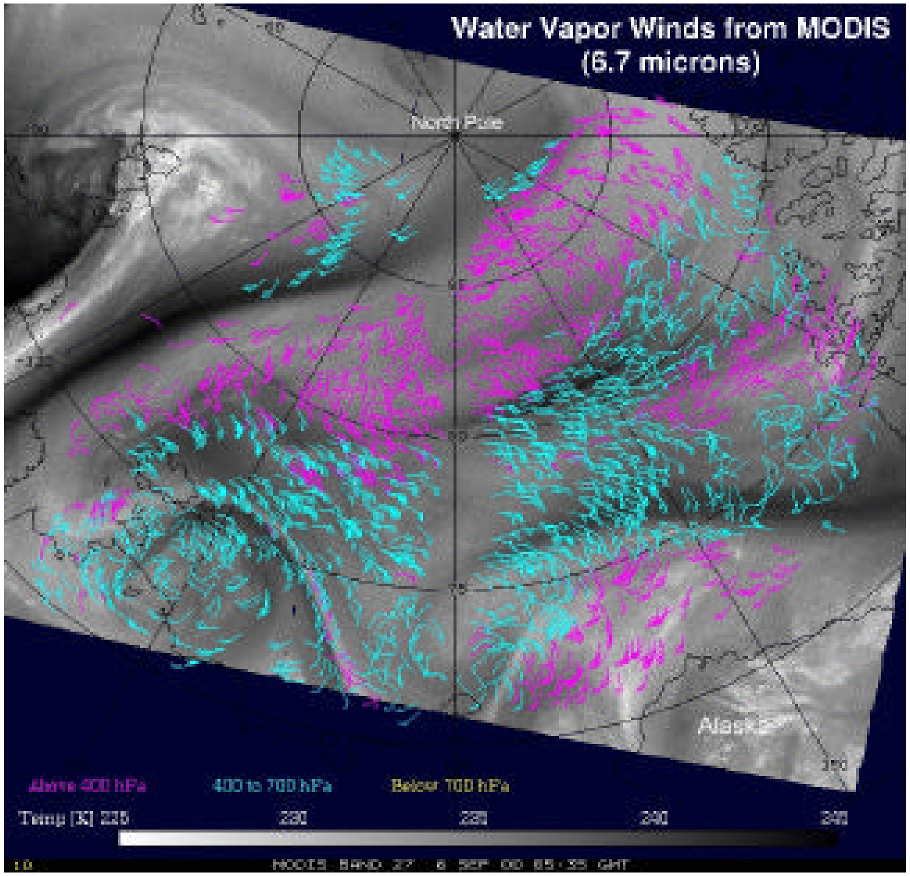
Every 100 min MODIS covers polar regions


A2000249.0125
X
modis_wv_loop

Winds from MODIS: An Arctic Example

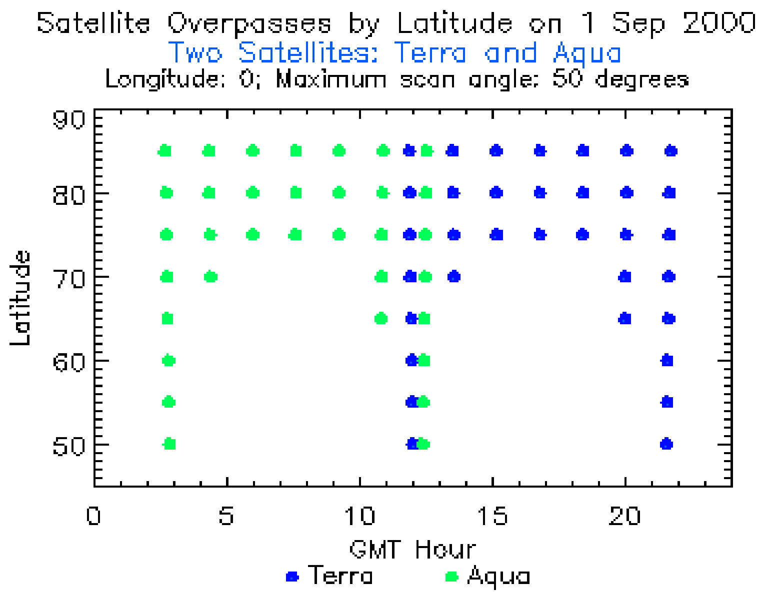
Cloud-track winds (left) and water vapor winds (right) from MODIS for a case in the western Arctic. The wind vectors were derived from a sequence of three images, each separated by 100 minutes. They are plotted on the first 11 μm (left) and 6.7 μm (right) images in the sequence.

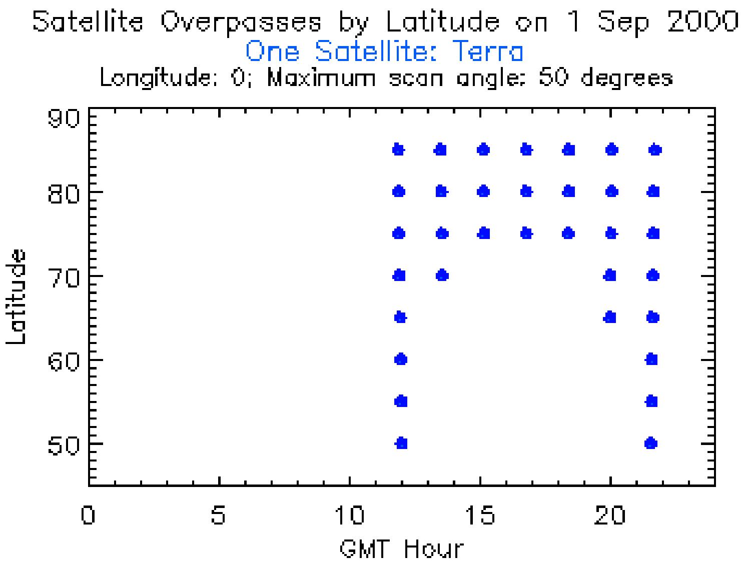


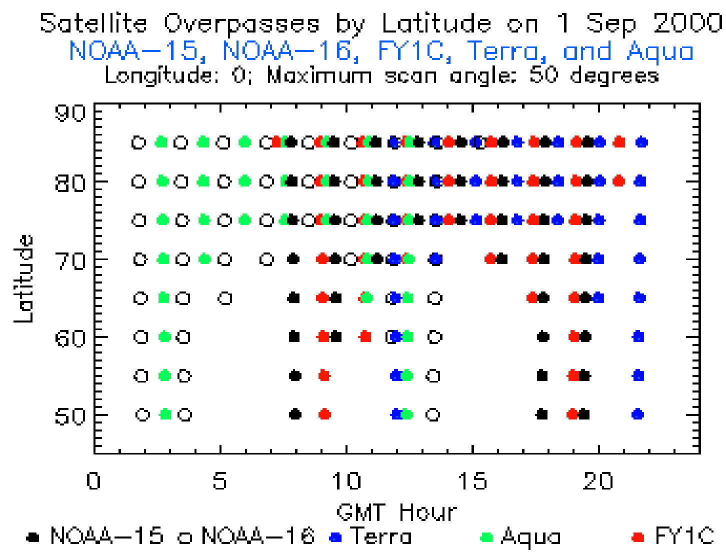


Orbital Issues

How often can wind vectors be obtained from a polar-orbiting satellites? The figure below shows the time of successive overpasses at a given latitude-longitude point on a single day with only the Terra satellite. The figure at the upper right shows the frequency of "looks" by two satellites: Terra and (the future) Aqua. The figure at the lower right shows the temporal sampling with five satellites.







Early Estimates of UW MODIS Atmospheric Products Quality

MODIS IR radiances agree to within 1.5 C with GOES and ER-2 MAS/SHIS

MODIS layer tropospheric temperatures compare well with AMSU;
- rms better than 1 C, both within 2 C of radiosonde observations;
- validated with know characteristics
- CART site validation ongoing.

MODIS layer dewpoint temperatures depict gradients very well;
- are within 3-4 C of radiosonde observations.

MODIS ozone is very close to the GOES ozone (over North America);
- rms of about 10 Dobsons;
- polar extreme ozone values will be improved with more training data.
- validated with known characteristics.

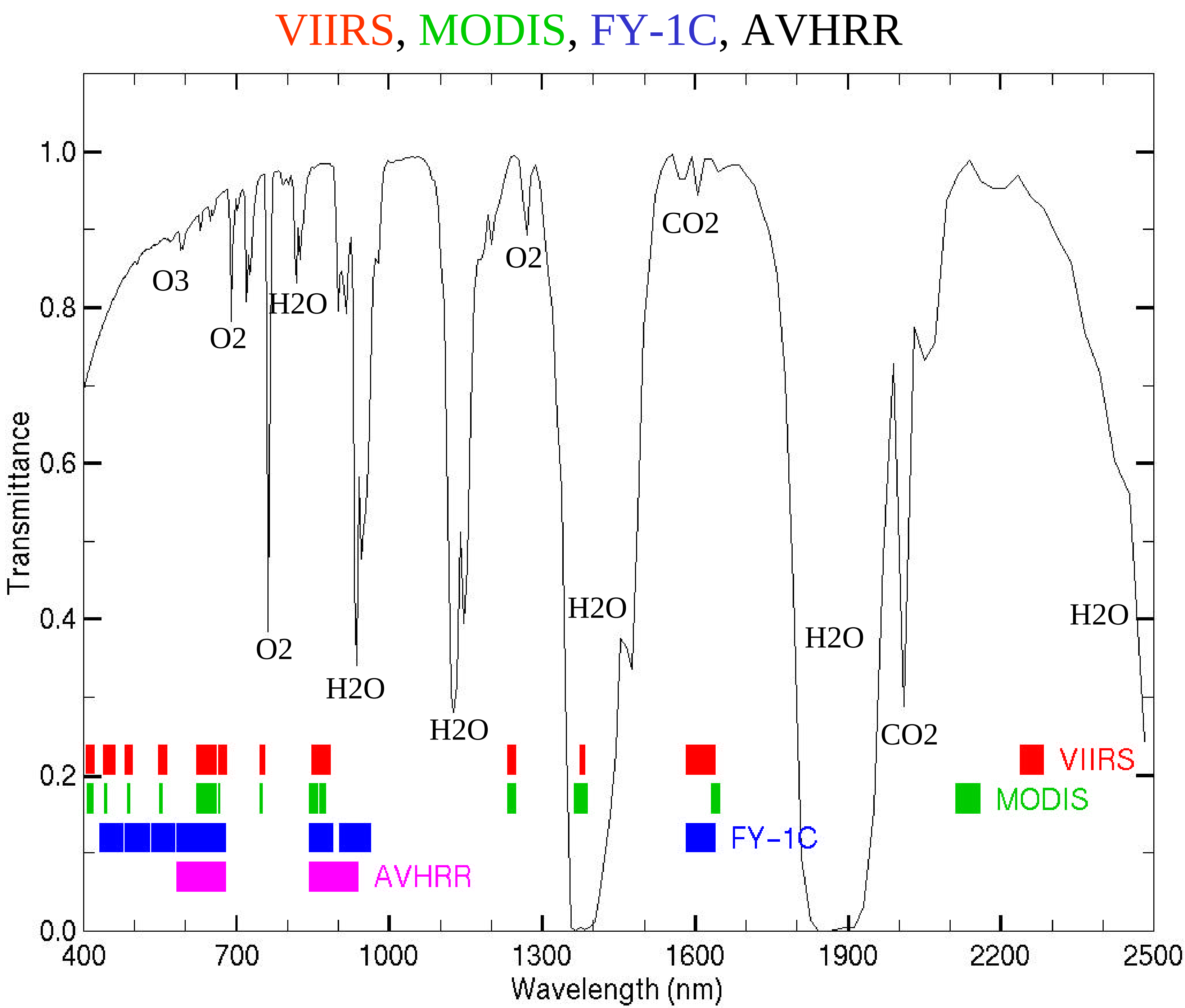
MODIS polar winds represent coherent atmospheric motion;
- model assimilation underway;
- geo-like quality observed;
- within 7 – 10 m/s of the few raobs available for validation.

Total Precipitable Water Vapor – Infrared (MOD-05)

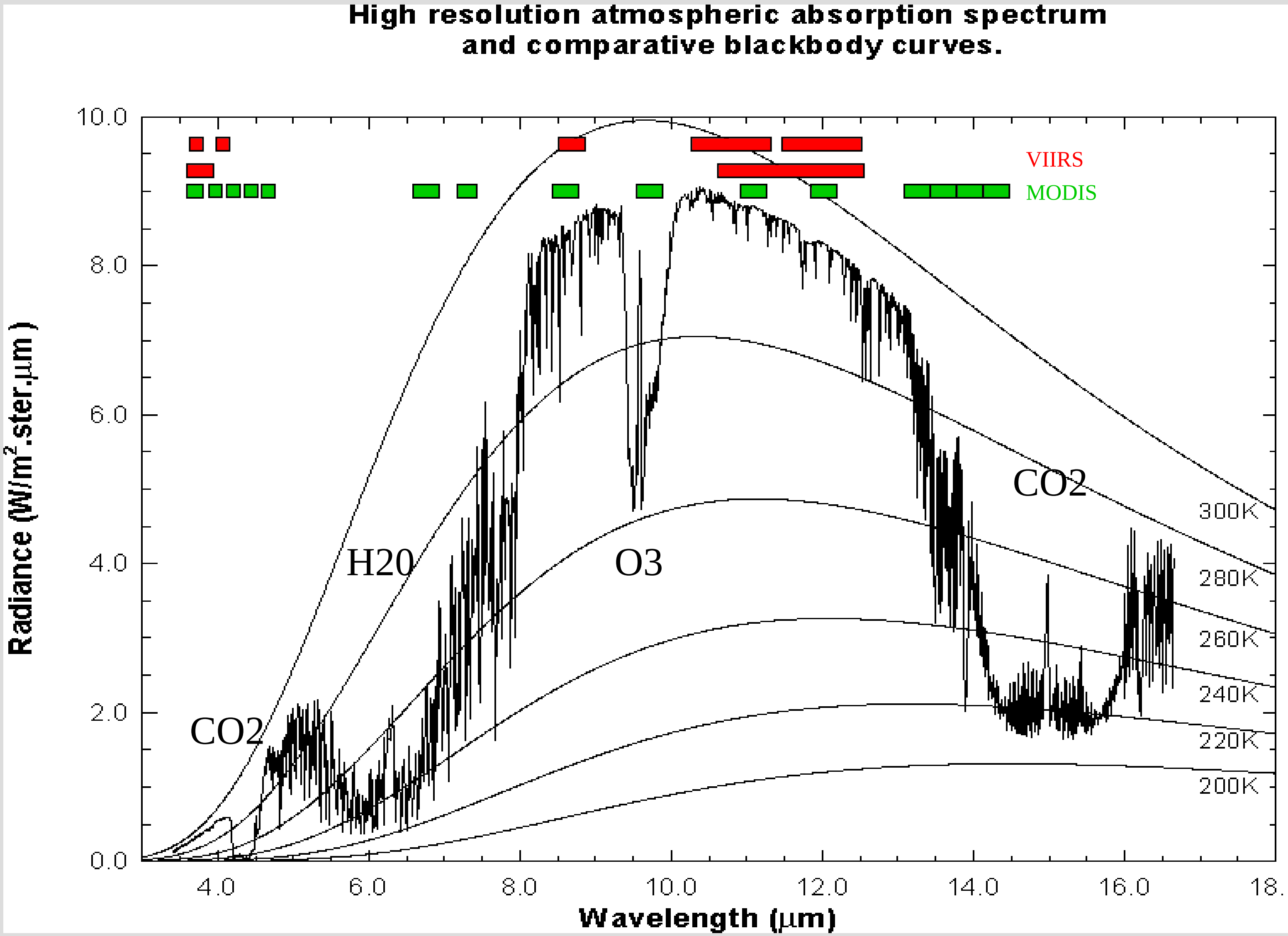
Suzanne Wetzel-Seemann, Jun Li, Liam Gumley, and Paul Menzel

18 Dec 2001

CIMSS


VIIRS, MODIS, FY-1C, AVHRR
Transmittance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
400
700
1000
1300
1600
1900
2200
2500
O3
O2
H2O
O2
H2O
H2O
O2
H2O
CO2
H2O
CO2
H2O
VIIRS
MODIS
FY-1C
AVHRR

Earth emitted spectra overlaid on Planck function envelopes



Total Water Vapor Retrieval from MODIS IR Radiances

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \int_o^{p_s} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\, dp \, .$$

I1, I2, I3, ... , In are measured with MODIS
P(sfc) and T(sfc) come from ground based conventional observations
$\tau_\lambda(p)$ are calculated with physics models

Regression relationship is inferred from (1) global set of in situ radiosonde reports, (2) calculation of expected radiances, and (3) statistical non-linear regression of observed Raob TPW and calculated MODIS radiances (brightness temperatures)

Need RT model, estimate of $\varepsilon_\lambda^{sfc}$, and MODIS radiances

The **MODIS TPW algorithm** is based on a **regression procedure**, and makes use of the **NOAA-88 data set containing more than 7500 global profiles** of temperature and moisture to determine the regression coefficients. The **radiative transfer calculation** of the MODIS spectral band radiances is performed for each training profile using the **Pressure layer Fast Algorithm for Atmospheric Transmittances (PFAAST) transmittance model**. This model has 101 pressure layer vertical coordinates from 0.1 to 1050 hPa and takes into account the satellite zenith angle, absorption by well-mixed gases (including nitrogen, oxygen, and carbon dioxide), water vapor, and ozone. The **MODIS instrument noise is added** into the calculated spectral band radiances, and these radiative transfer calculations provide a temperature-moisture-ozone profile and MODIS radiance pair for use in the statistical regression analysis.

Total Water Vapour can be evaluated in multiple infrared window channels where absorption is weak, so that

$$\tau_w = \exp[-k_w u] \sim 1 - k_w u \text{ where w denotes window channel}$$

and

$$d\tau_w = -k_w du$$

What little absorption exists is due to water vapour, therefore, u is a measure of precipitable water vapour. RTE in window region

$$I_w = B_{sw}(1-k_w u_s) + k_w \int_o^{u_s} B_w du$$

u_s represents total atmospheric column absorption path length due to water vapour, and s denotes surface. Defining an atmospheric mean Planck radiance, then

$$I_w = B_{sw}(1-k_w u_s) + k_w u_s \bar{B}_w \text{ with } \bar{B}_w = \int_o^{u_s} B_w du \Big/ \int_o^{u_s} du$$

Since B_{sw} is close to both I_w and B_w, first order Taylor expansion about the surface temperature T_s allows us to linearize the RTE with respect to temperature, so

$$T_{bw} = T_s(1-k_w u_s) + k_w u_s \bar{T}_w$$, where T_w is mean atmospheric temperature corresponding to B_w.

For two window channels (11 and 12um) the following ratio can be determined.

$$\frac{T_s - T_{bw1}}{T_s - T_{bw2}} = \frac{k_{w1} u_s (T_s - \bar{T}_{w1})}{k_{w1} u_s (T_s - \bar{T}_{w2})} = \frac{k_{w1}}{k_{w2}}$$

where the mean atmospheric temperature measured in the one window region is assumed to be comparable to that measured in the other, $T_{w1} \sim T_{w2}$,

Thus it follows that

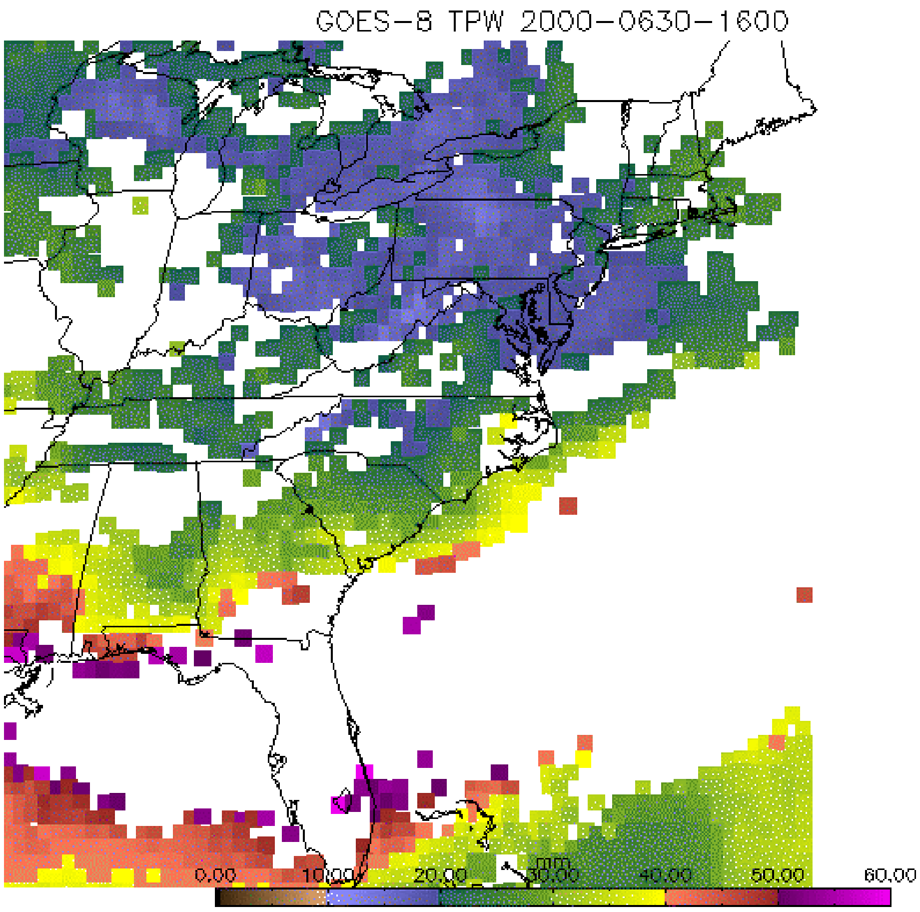
$$T_s = T_{bw1} + \frac{k_{w1}}{k_{w2} - k_{w1}} [T_{bw1} - T_{bw2}]$$

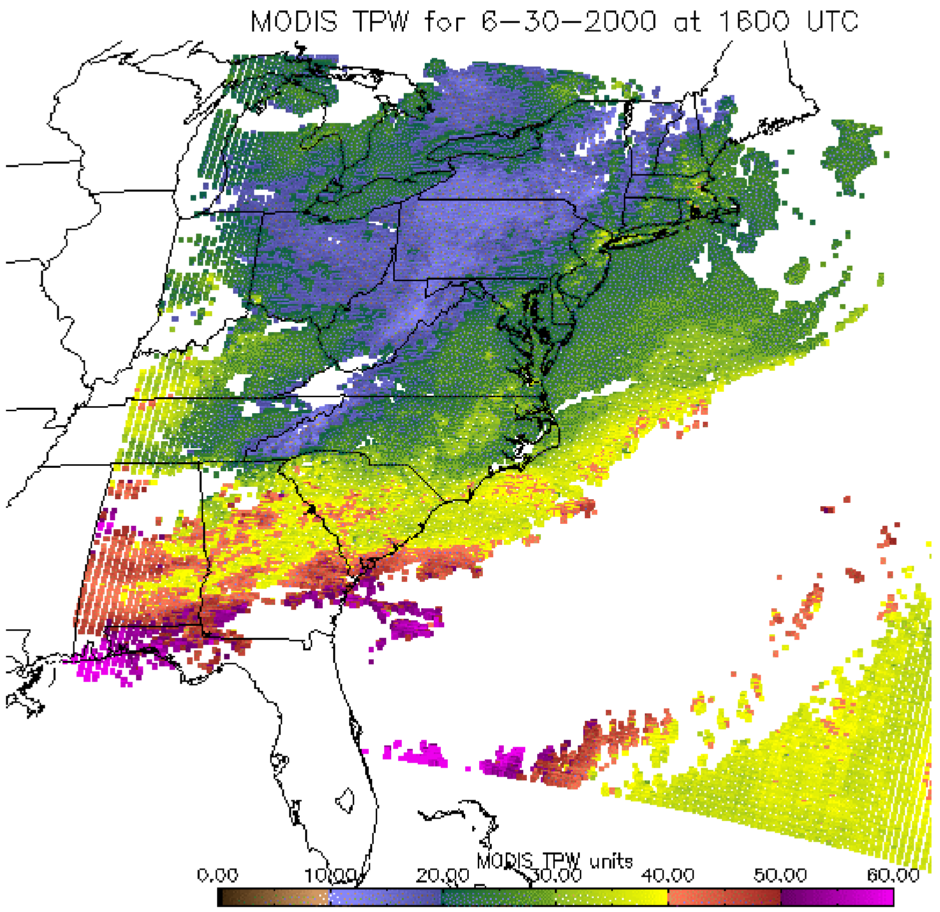
and

$$u_s = \frac{T_{bw} - T_s}{k_w (\bar{T}_w - T_s)} .$$

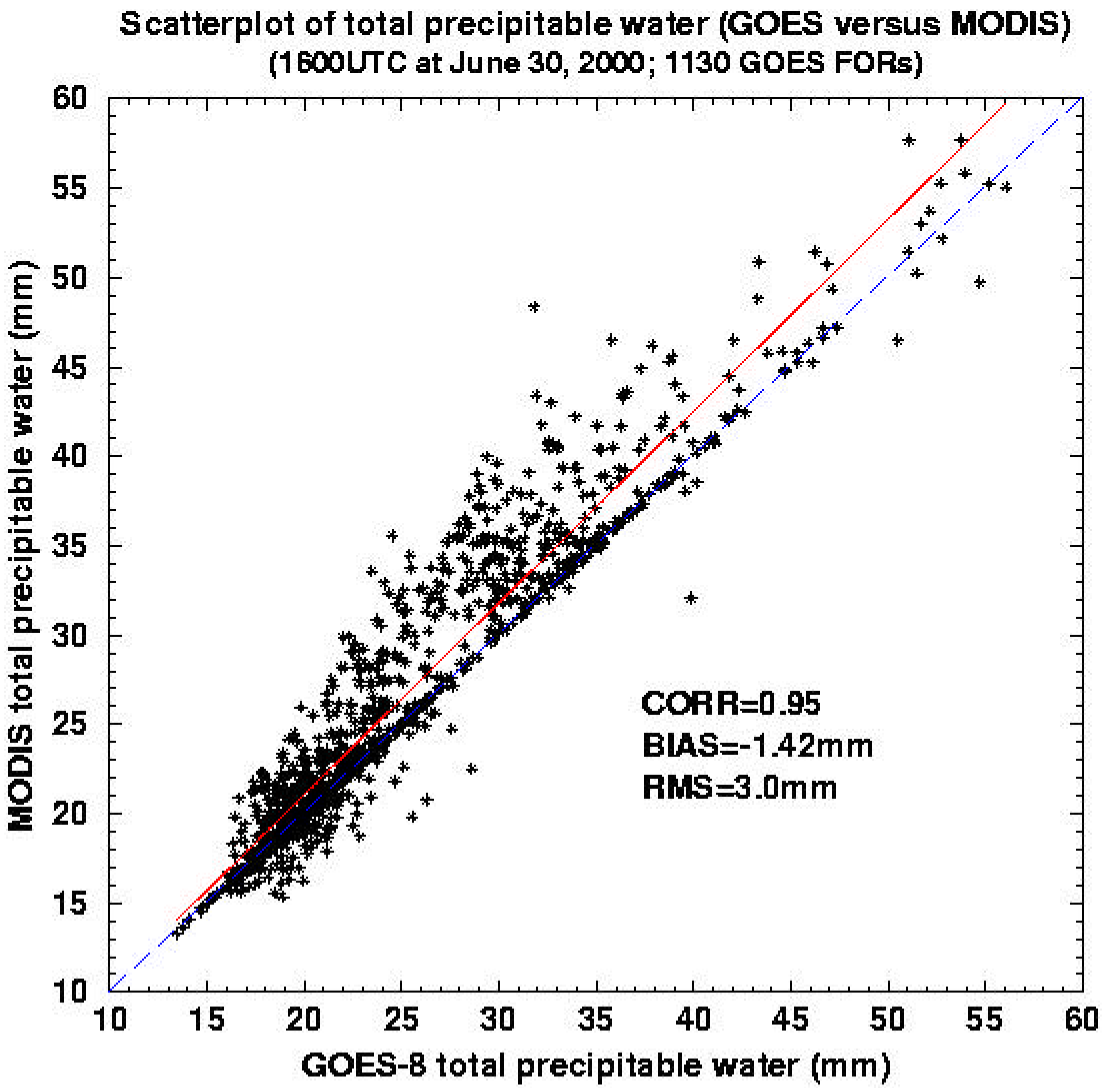
Obviously, the accuracy of the determination of the total water vapour concentration depends upon the contrast between the surface temperature, T_s, and the effective temperature of the atmosphere $\bar{T}_w$

GOES vs. MODIS 2000/06/30 1600 UTC
Total Precipitable Water (mm)

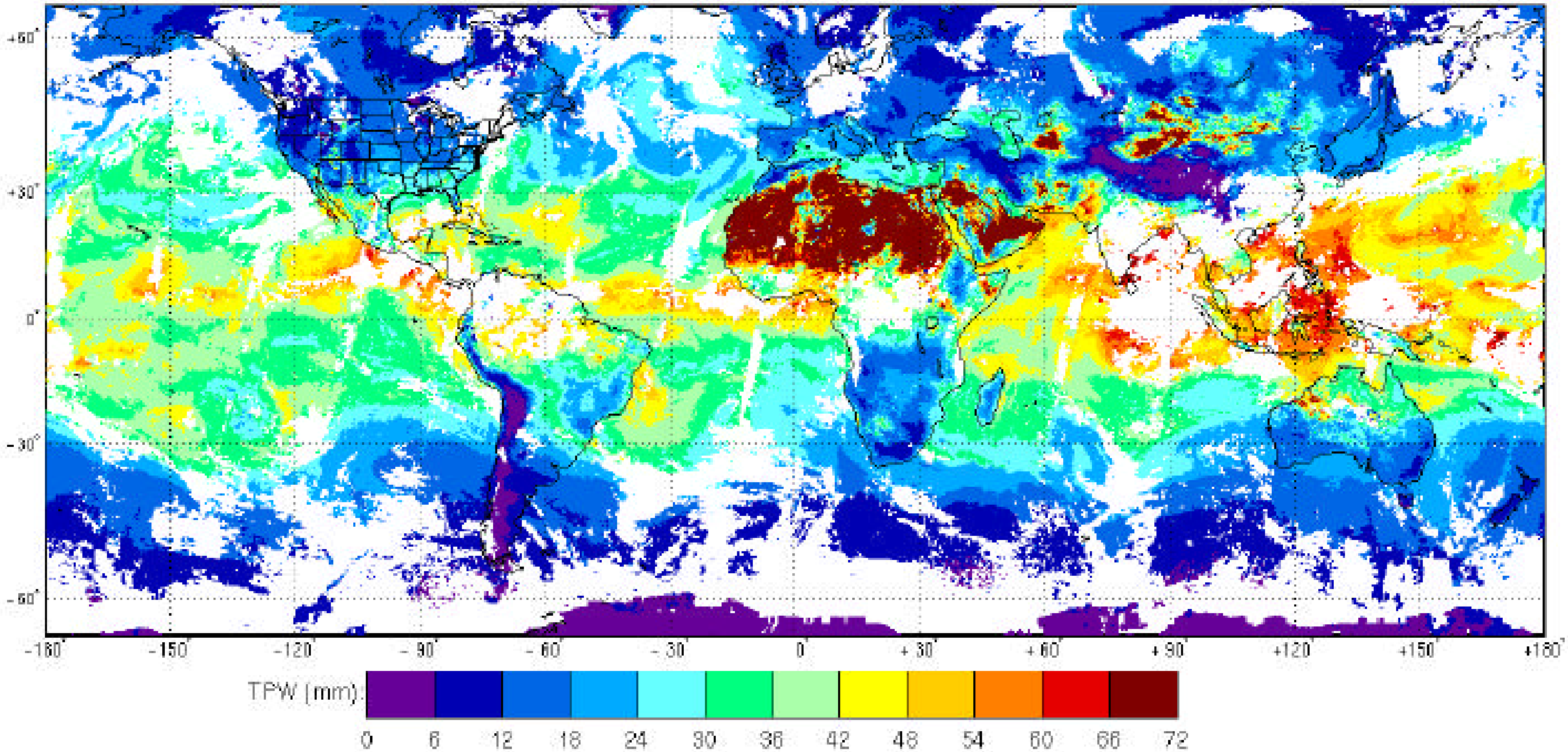




MODIS total precipitable water vapor shows a wet bias wrt GOES; bias 1.5 mm and rms of 3 mm; bias will be removed after more validation



MODIS TPW June 2, 2001: Operational Algorithm



SWIR daytime reflection causing wet atm over African desert

Mitigating Problems in MODIS TPW Algorithm

* Changed predictors band 24 and 25 (4.4 and 4.5 um) brightness temperatures to their BT difference to remove surface effects:

Old algorithm had 12 predictors:

individual bands 24, 25, and 27 through 36.

New algorithm has 11 predictors:

band 25 - 24 BT difference and

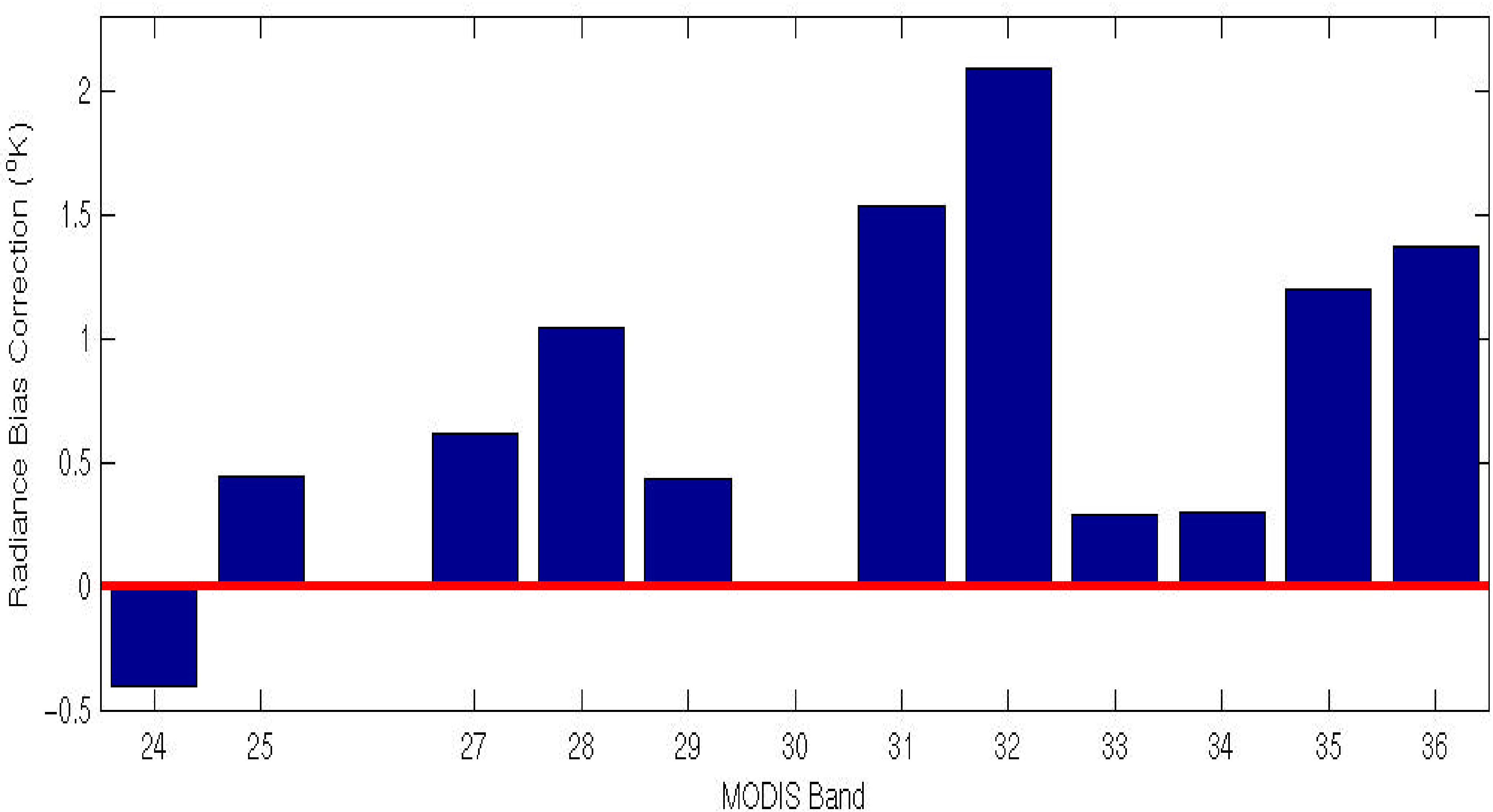
individual bands 27 through 36.

* Separated training into five regression BT zones to include a broader range of moisture regimes

* Implemented *preliminary* radiance bias corrections. Currently based only on CART site data, global biases are in progress.

* Applied post-launch NEdT in place of pre-launch.

MODIS Radiance (BT) Bias wrt CART Site



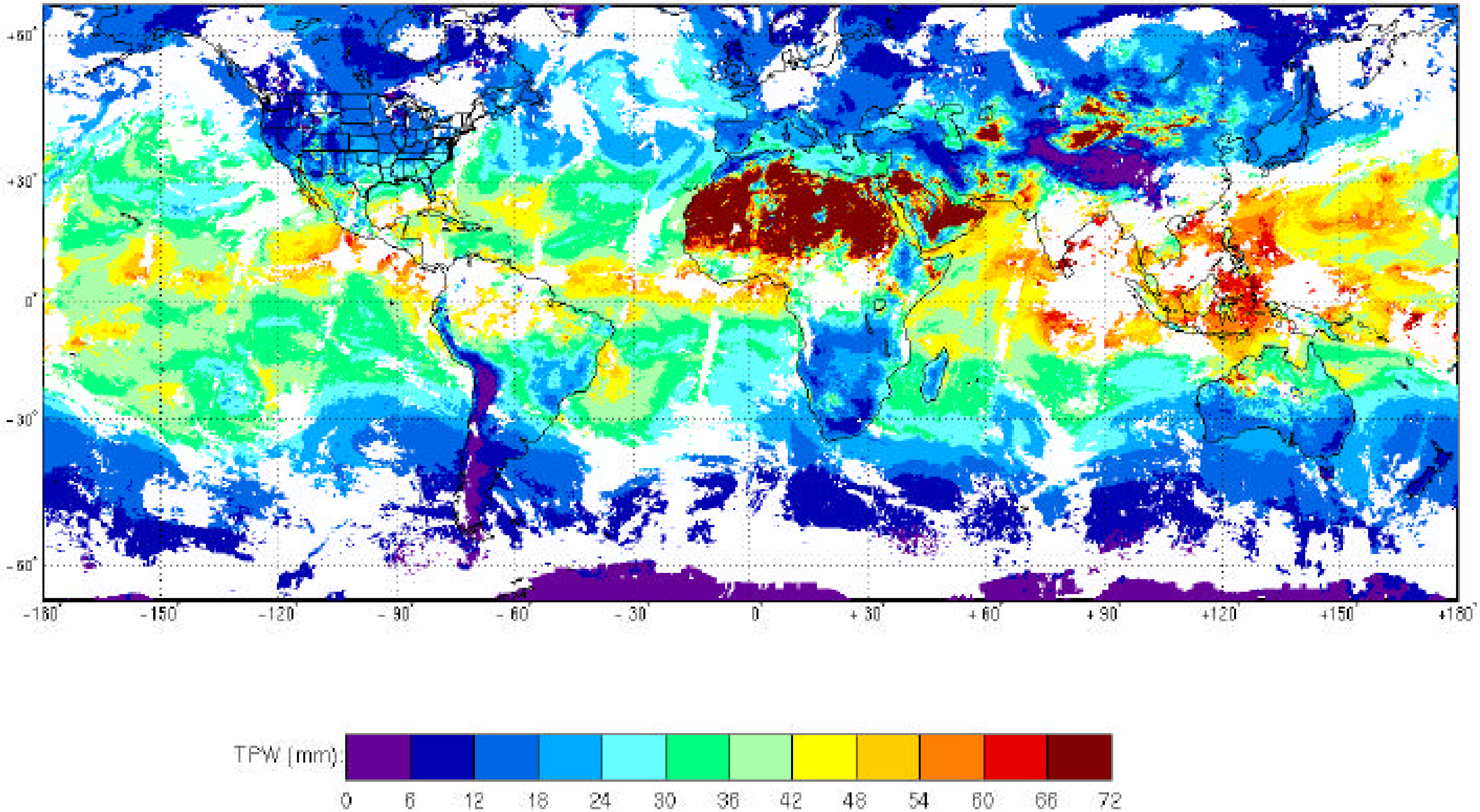
MODIS NEdR Estimate

Band 20	3.7 um	.007 mW/m2/ster/cm-1
Band 21	3.9	.02
Band 22	3.9	.04
Band 23	4.0	.025
Band 24	4.45	.03
Band 25	4.5	.045
Band 27	6.7	.08
Band 28	7.3	.07
Band 29	8.6	.25
Band 30	9.7	.2
Band 31	11.0	.3
Band 32	12.0	.3
Band 33	13.3	.4
Band 34	13.6	.6
Band 35	13.9	.4
Band 36	14.2	.5

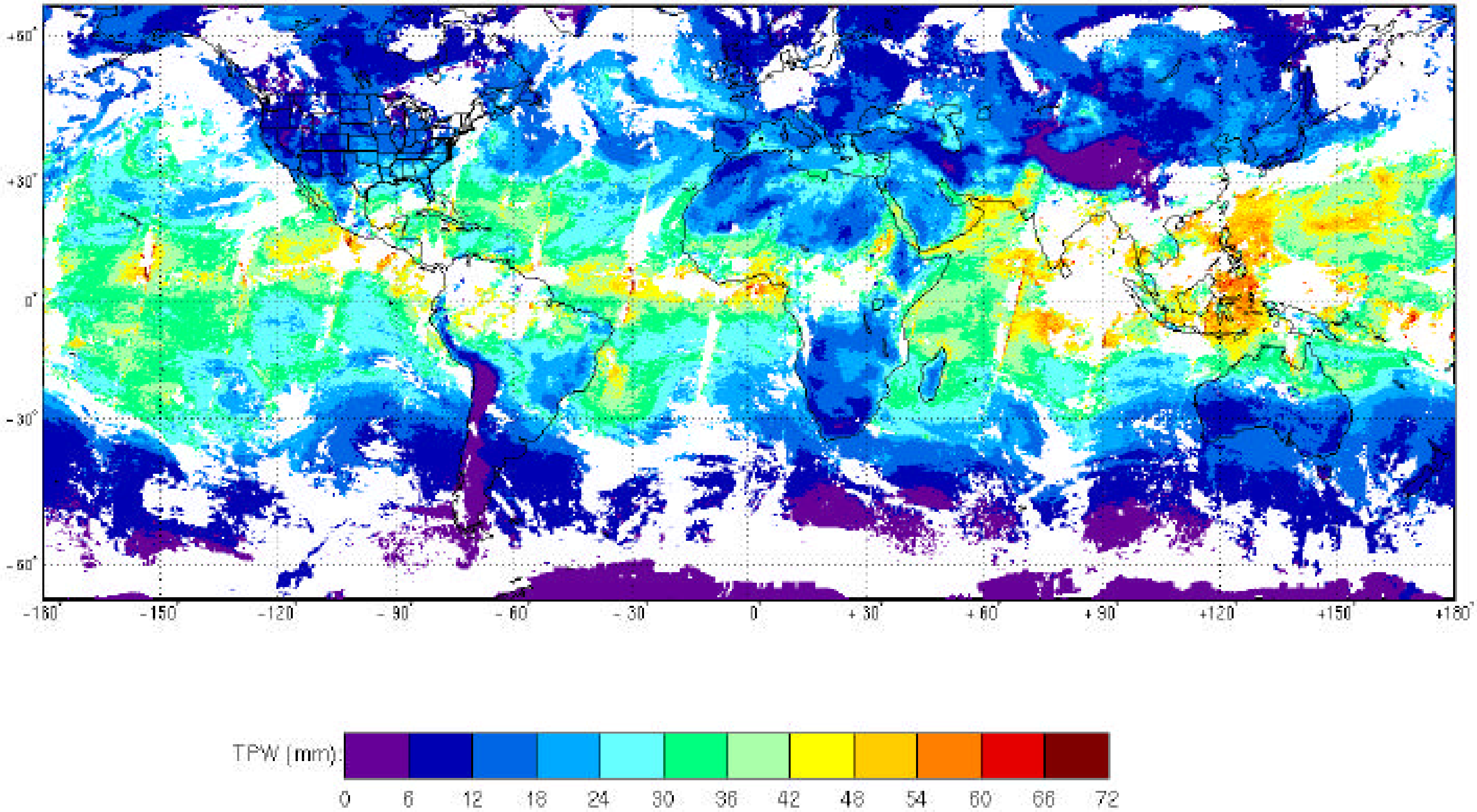
Based on Earth Scene Data Day 01153, 20:10 UTC Clear scenes of the Pacific Ocean

Note: Some SG present in MWIR Used 150 x 28 box (420 data points per detector)

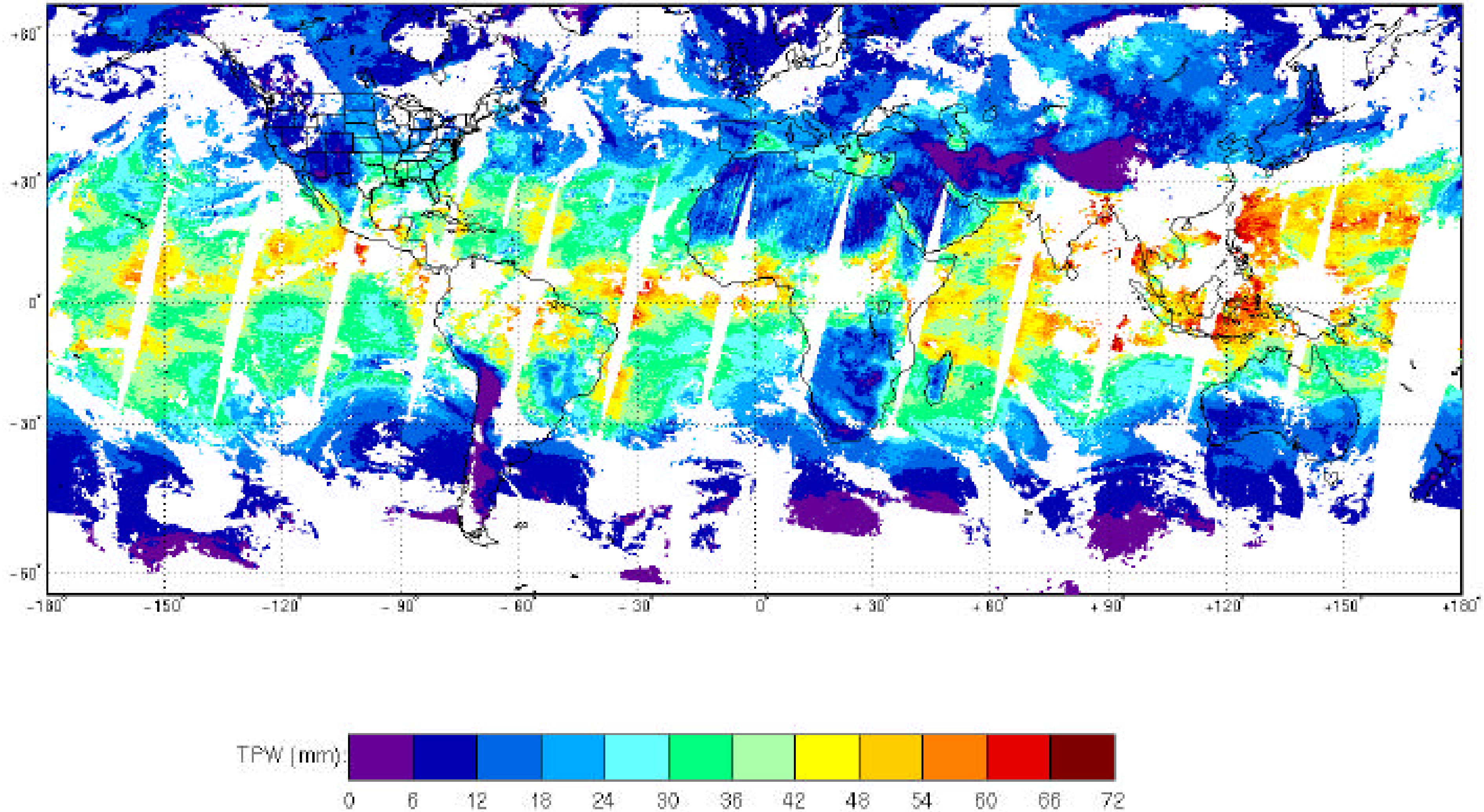
MODIS TPW June 2, 2001:
Operational Algorithm (IR ch 24 –> 36)



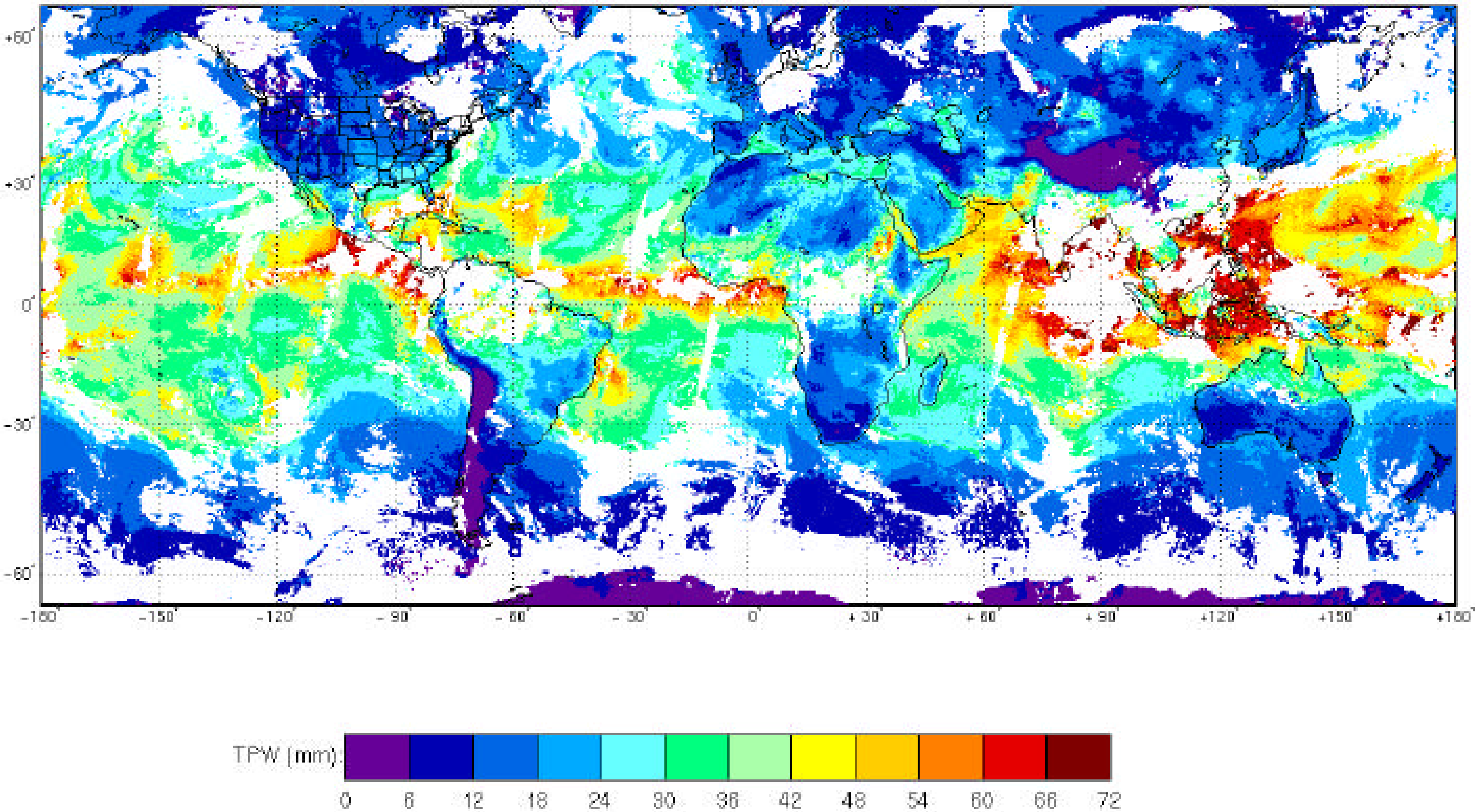
MODIS TPW June 2, 2001:
New Algorithm 1 (Ch 24 -25)



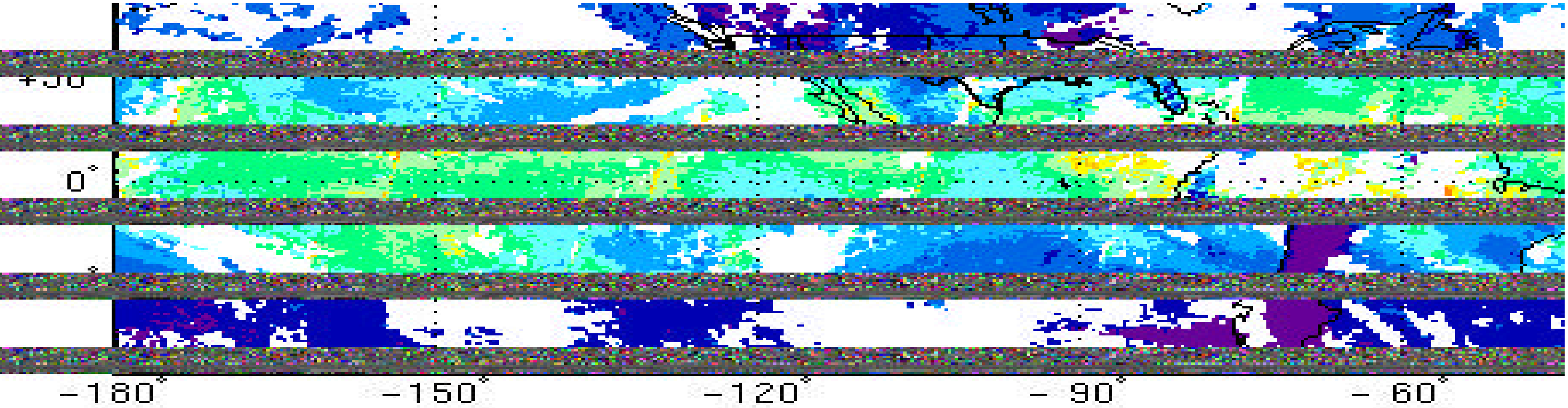
MODIS TPW June 2, 2001:
New Algorithm 2 (5 zones)



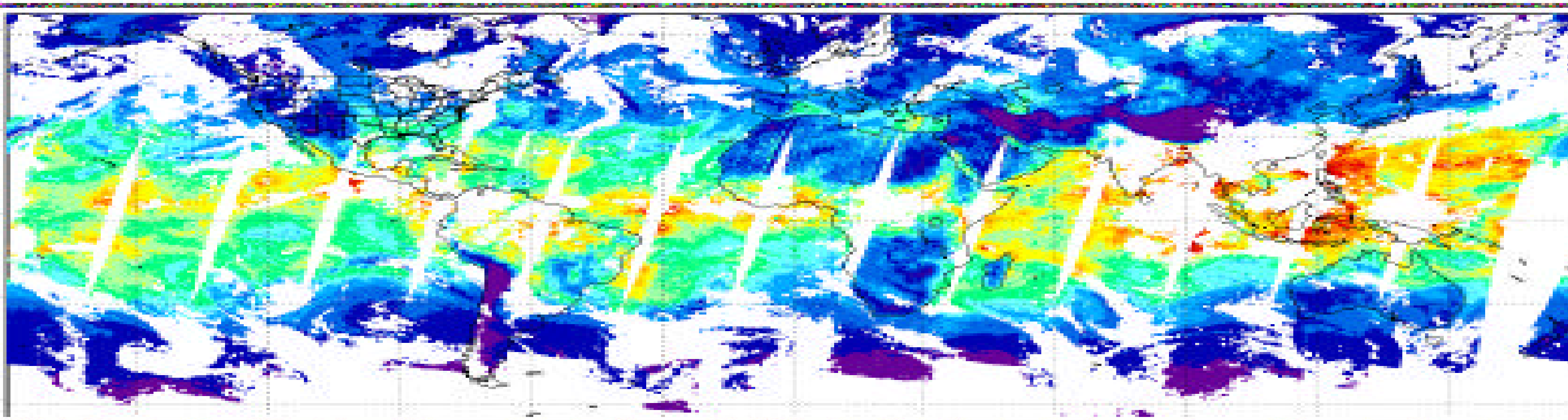
MODIS TPW June 2, 2001:
New Algorithm 3 (5 overlapping zones)



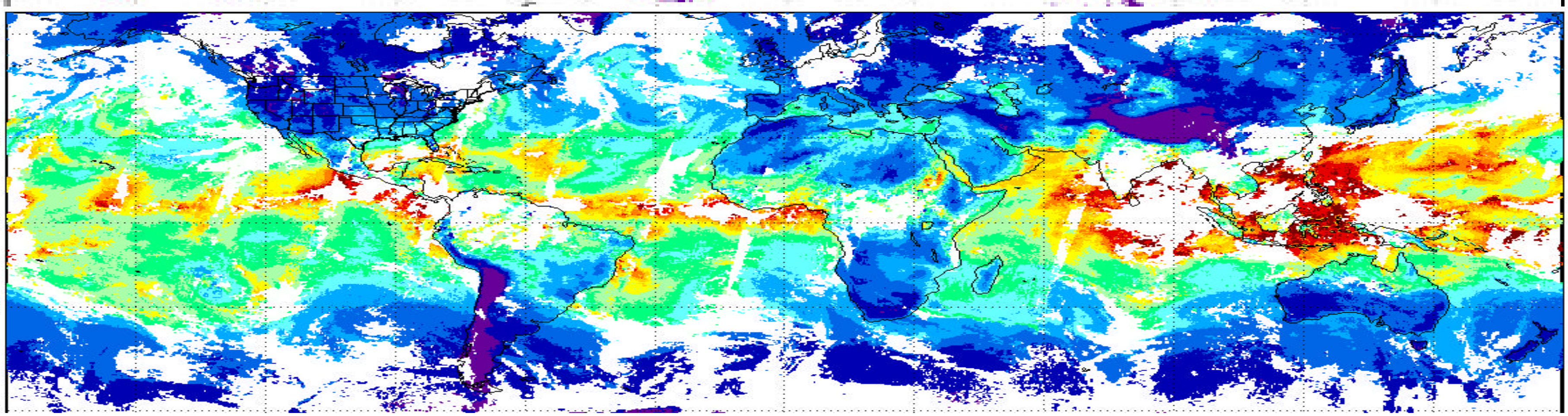
1

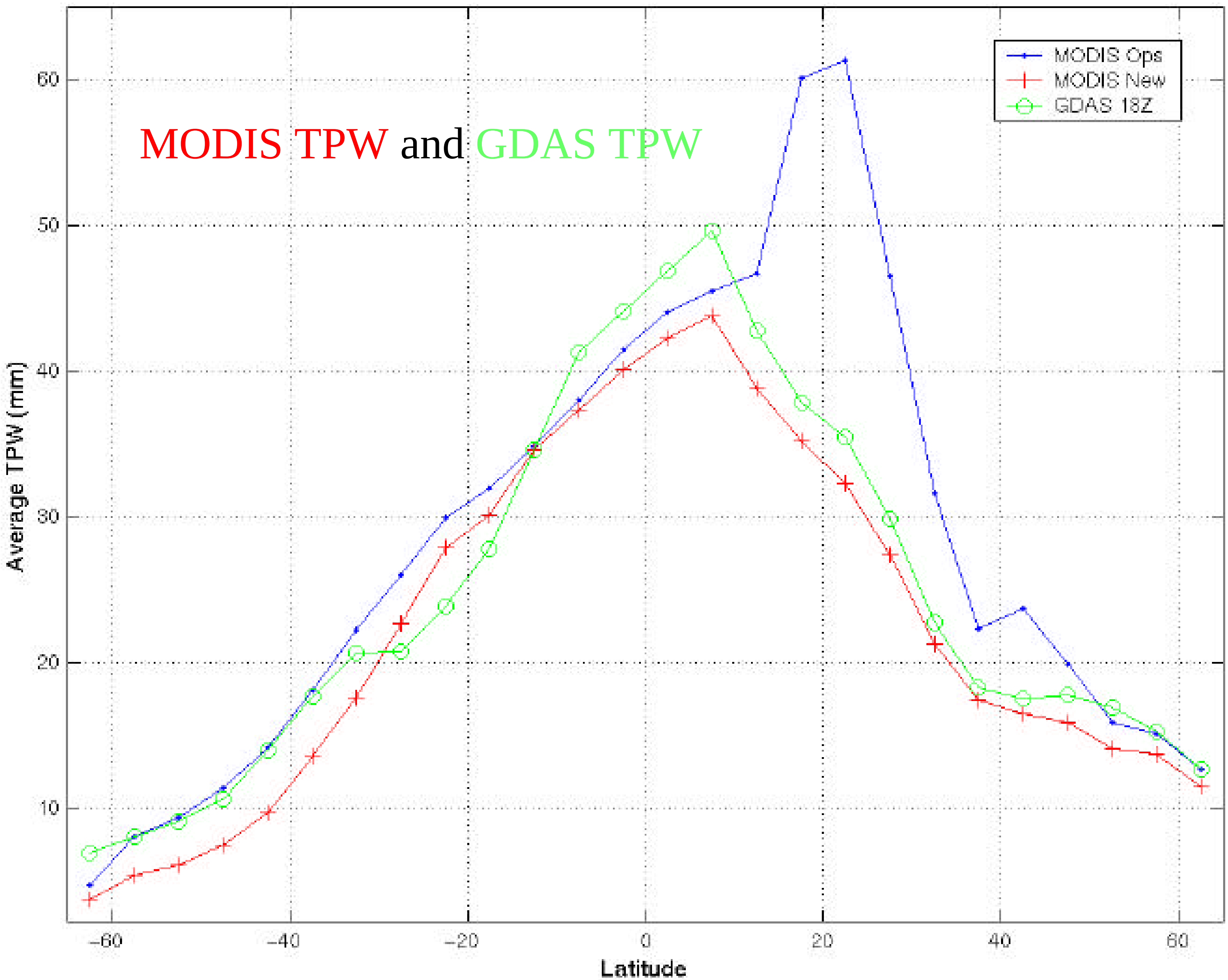


2



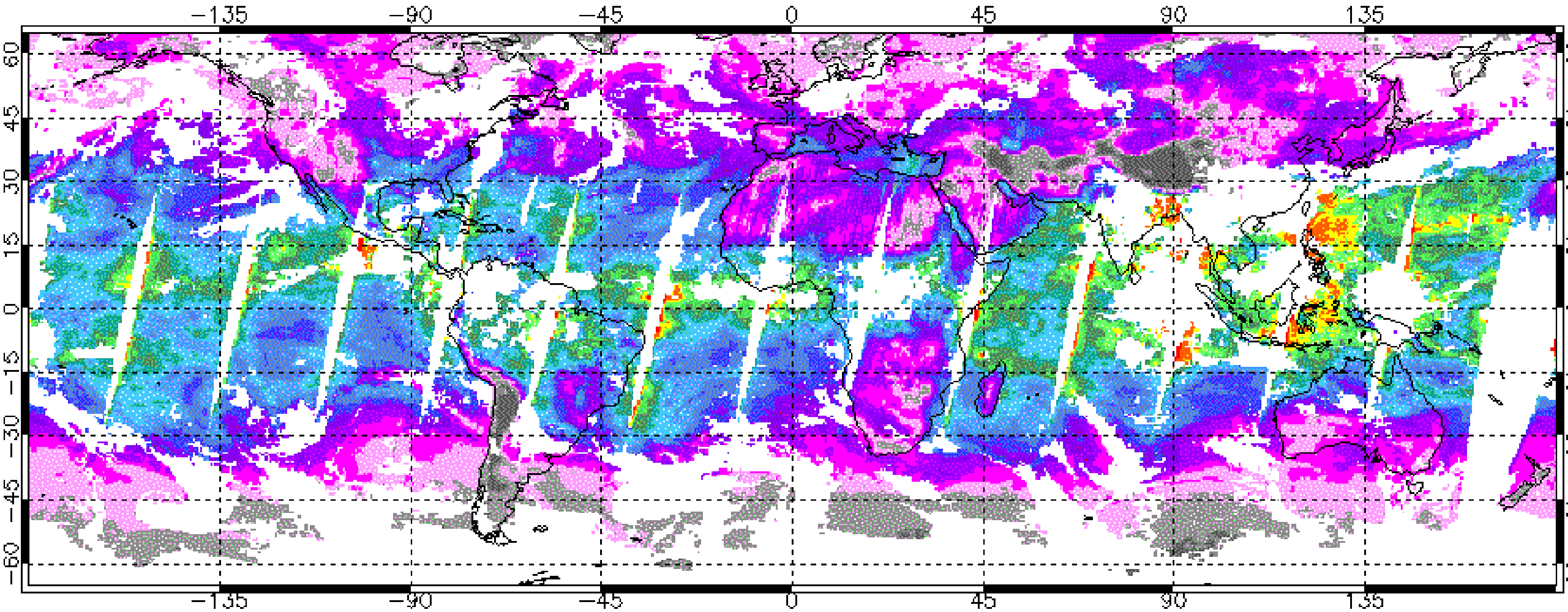
3



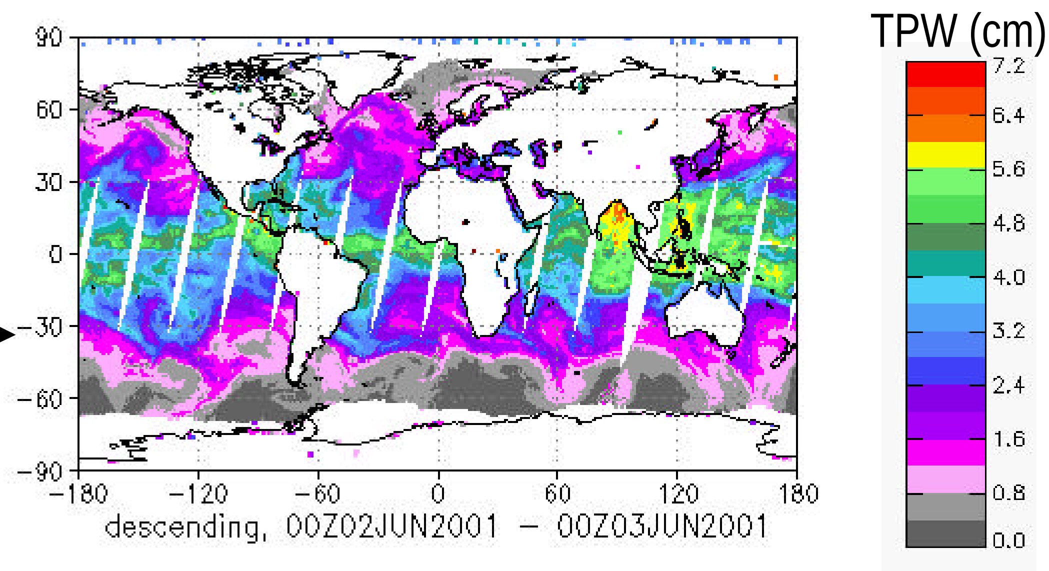


MODIS TPW and GDAS TPW
MODIS Ops
MODIS New
GDAS 18Z
Average TPW (mm)
Latitude
60
50
40
30
20
10
-60
-40
-20
0
20
40
60

New MODIS TPW Algorithm: Comparison with NOAA-15 Advanced Microwave Sounding Unit (AMSU) for June 2, 2001



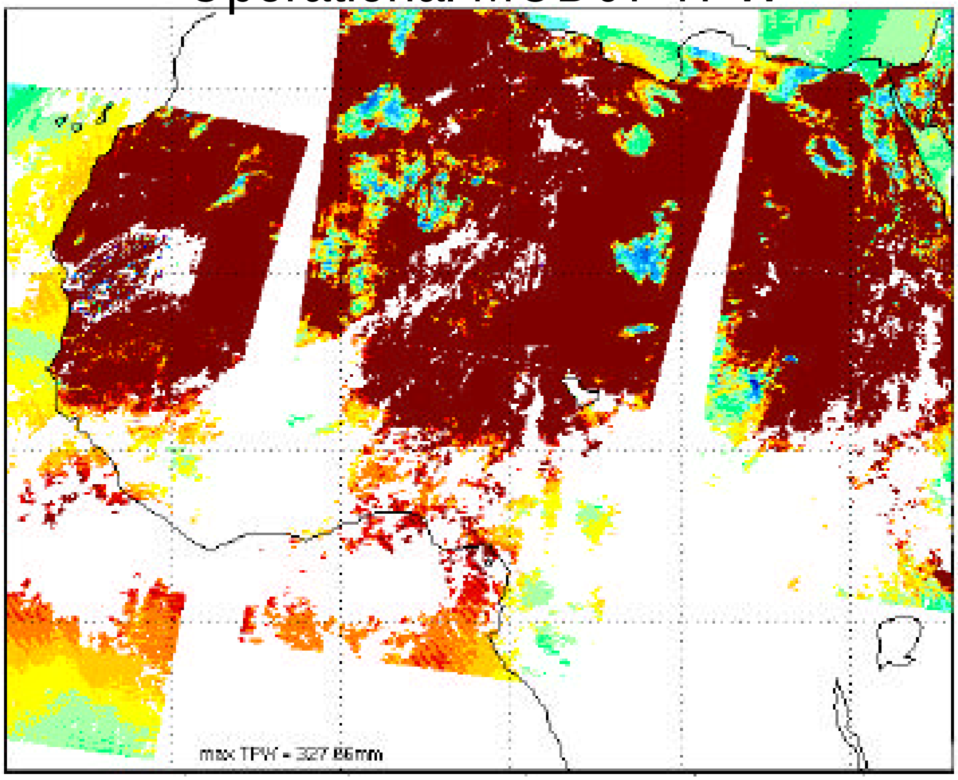
MODIS new TPW (cm)
June 2, 2001



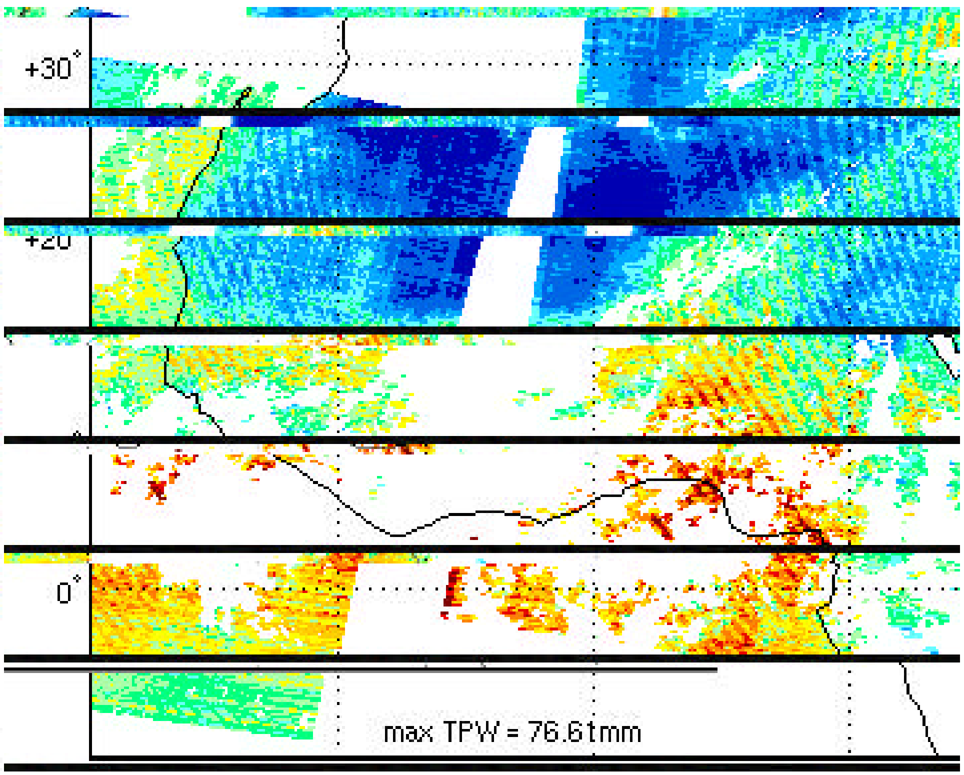
AMSU TPW (cm)
June 2, 2001

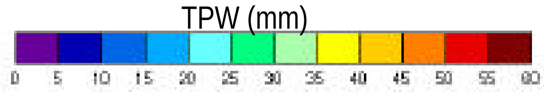
Improvement in Desert TPW: North Africa
June 2, 2001: 0830, 0835, 1010, 1015, 1150, 1155 UTC

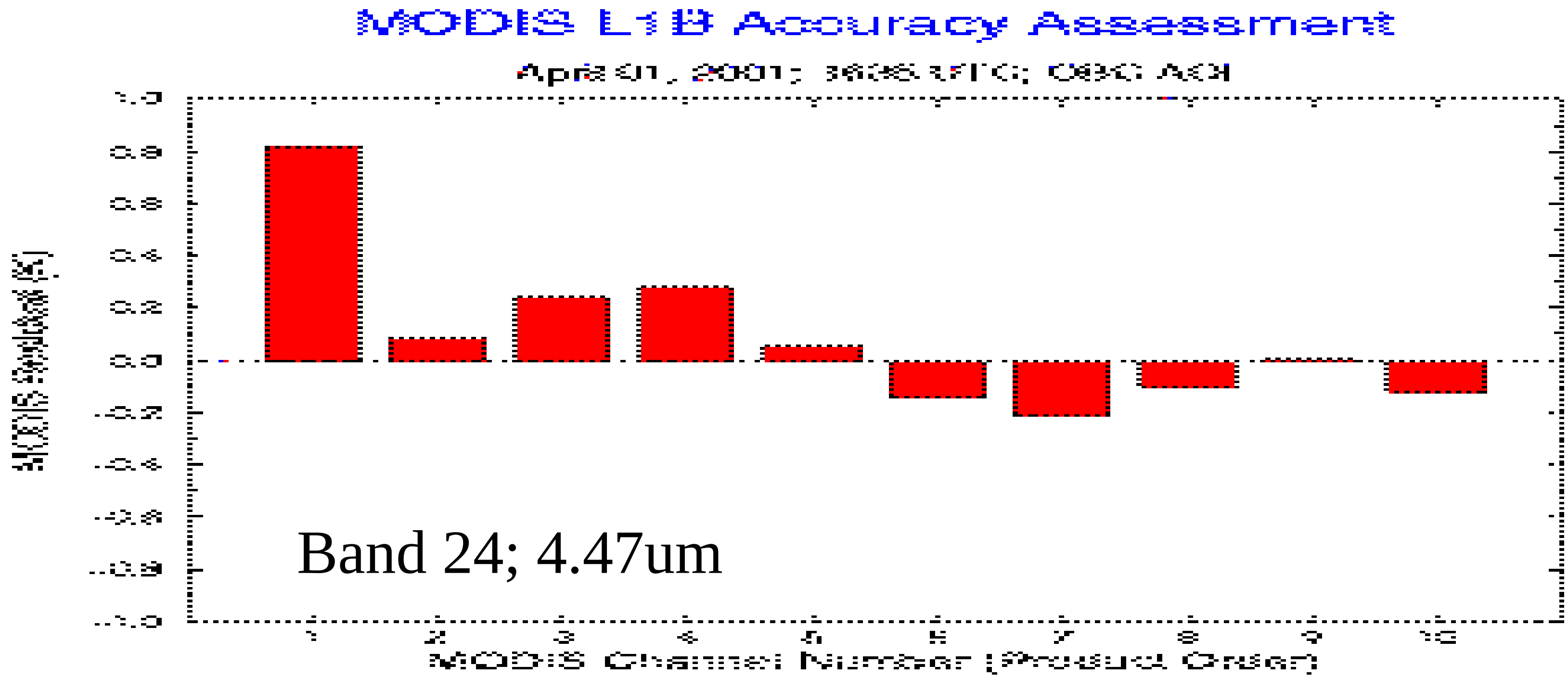
Operational MOD07 TPW

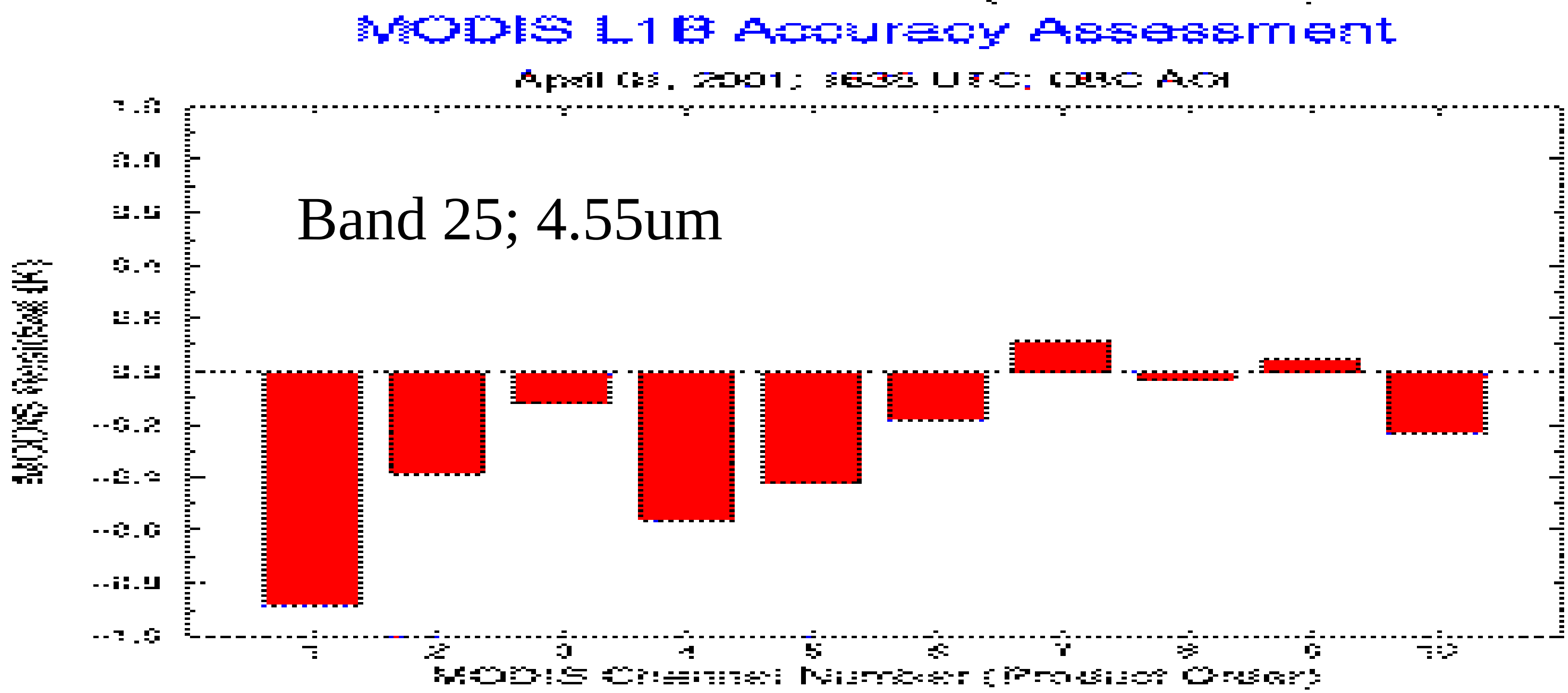


New MOD07 TPW

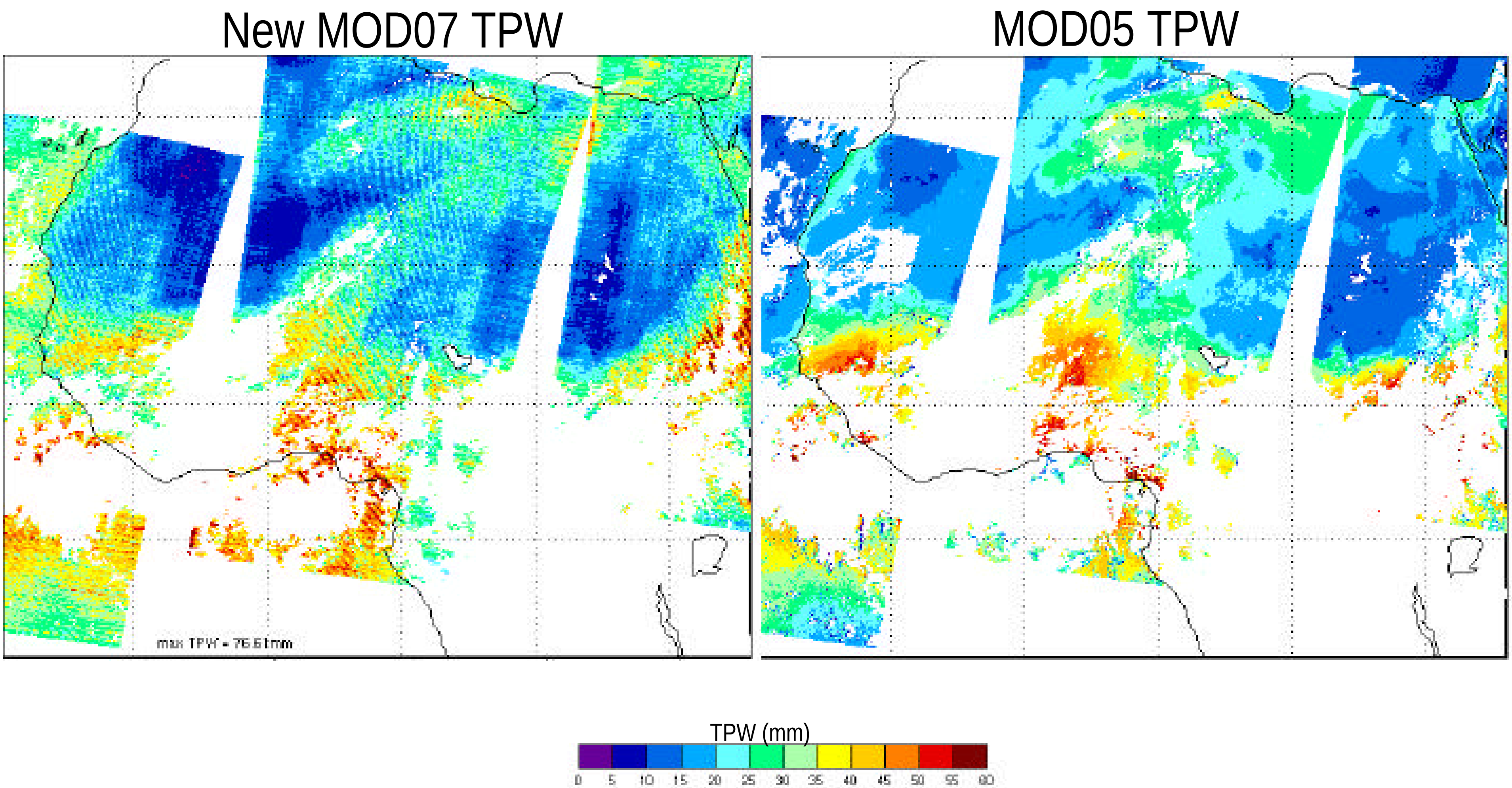


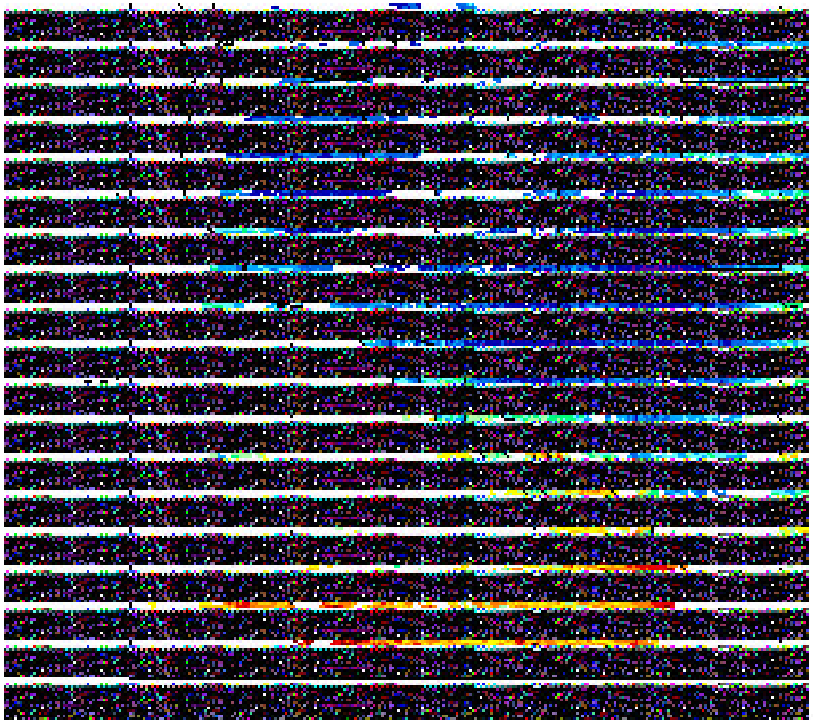



MODIS L1B Accuracy Assessment
Band 24; 4.47um
MODIS Channel Number (Product Order)

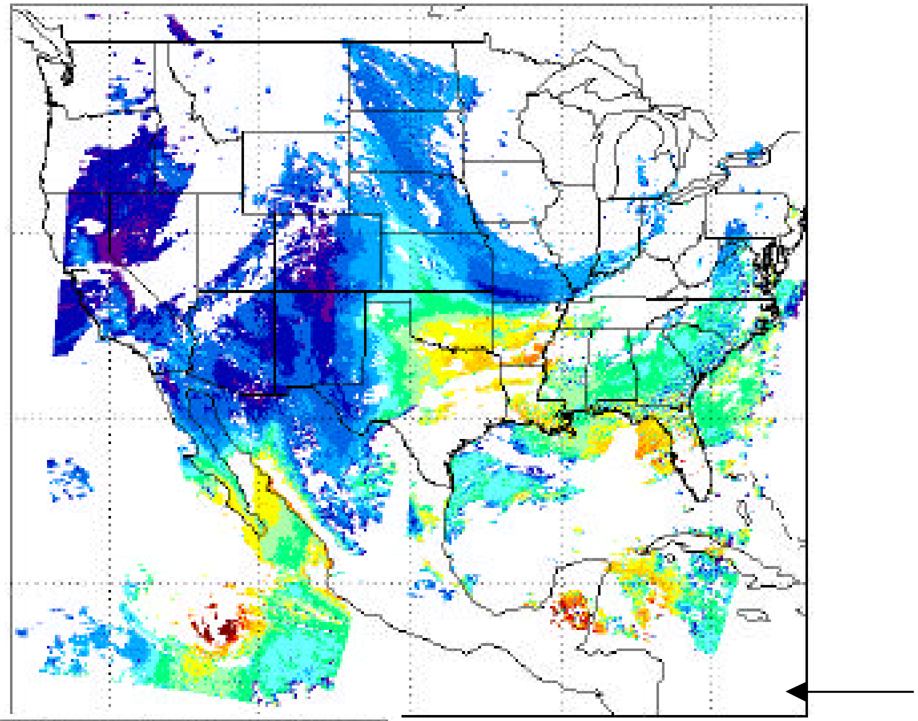

MODIS L1B Accuracy Assessment
Band 25; 4.55um
MODIS Channel Number (Product Order)

Comparison with MOD05: North Africa
June 2, 2001: 0830, 0835, 1010, 1015, 1150, 1155 UTC

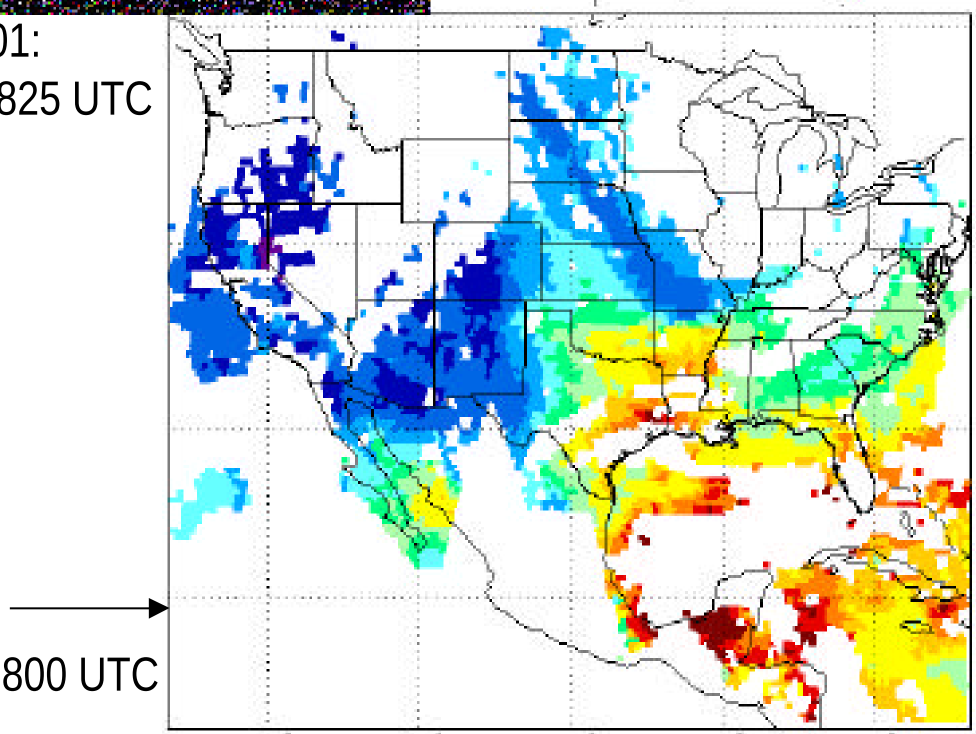




MOD 07 June 2, 2001:
1640, 1645, 1820, 1825 UTC

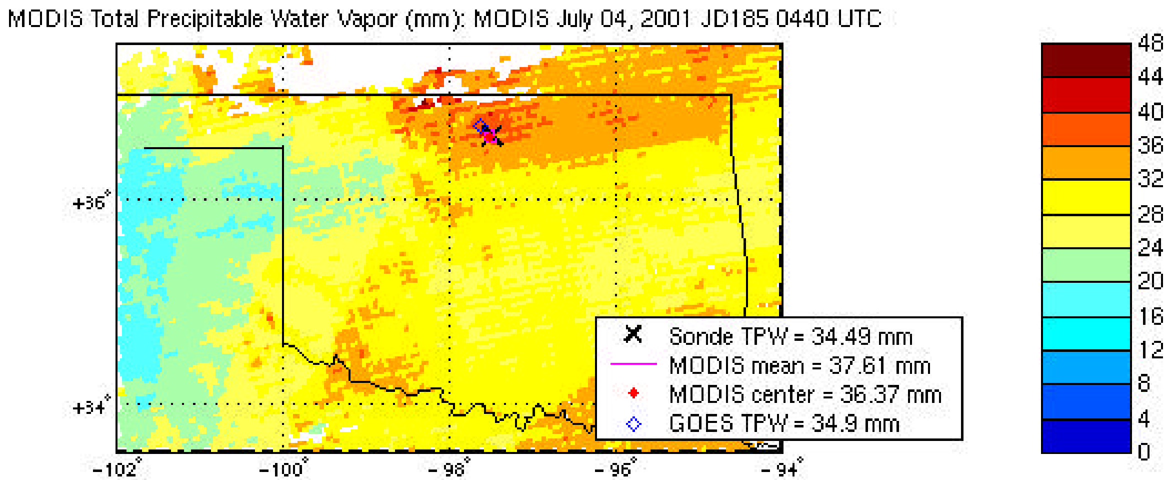


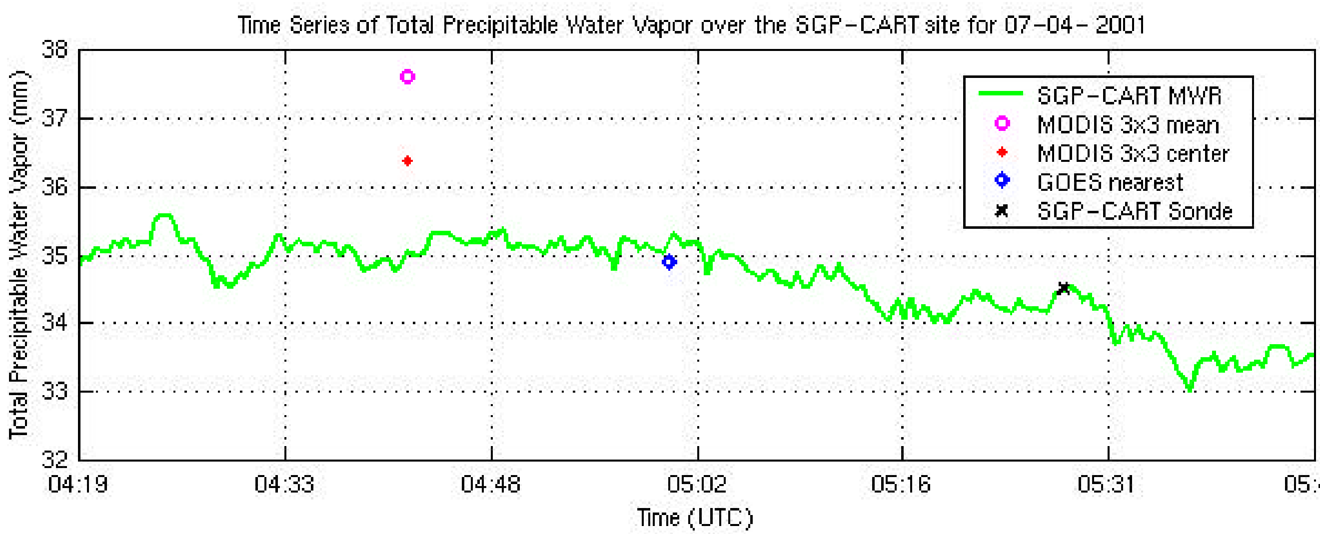
MOD 05 June 2, 2001:
1640, 1645, 1820, 1825 UTC



GOES 8 & 10
June 2, 2001:1800 UTC

CART Site TPW Comparison: Sample of One Case

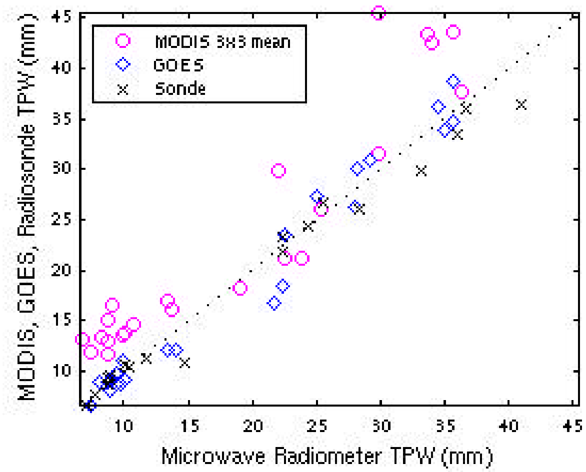


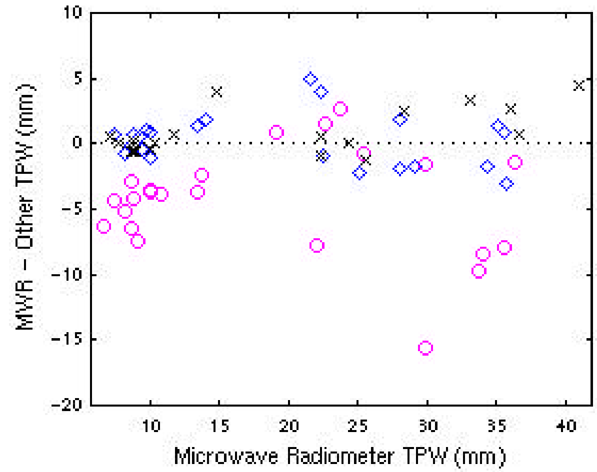


CART Site TPW Comparison: 27 Cases
March 15 - December 2, 2001

Operational Algorithm

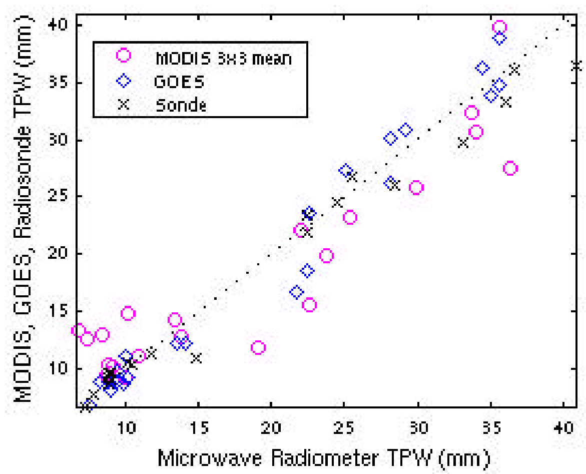
MWR – MODIS = - 4.4mm
for TPW < 15mm:
MWR - MODIS = - 4.5mm
for TPW > 15mm:
MWR – MODIS = - 4.4mm

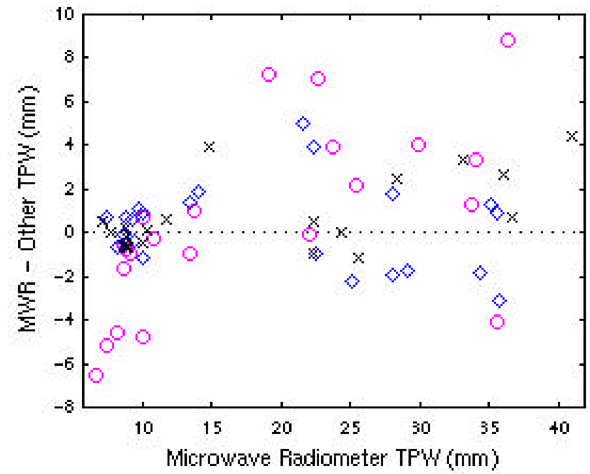




New Algorithm

MWR - MODIS = 0.576 mm
for TPW < 15mm:
MWR - MODIS = - 2mm
for TPW > 15mm:
MWR - MODIS = + 3.4mm





MODIS: Product Image Artifacts

Product striping introduced because:

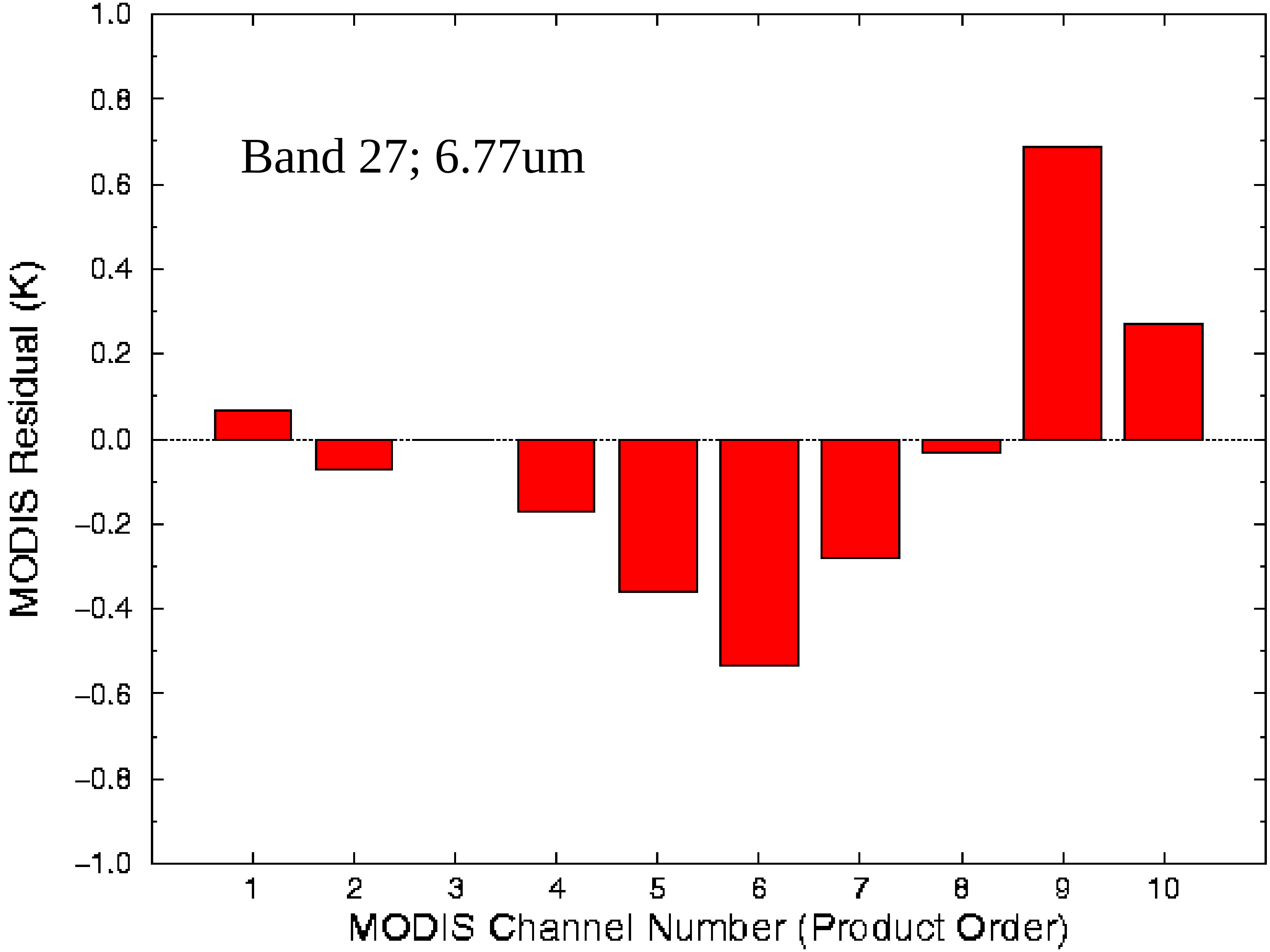
- two mirror sides not identical and not characterized perfectly,
- each detector calibrated independently,
- some detectors "out of family" compared to majority for a given band,
- out of band response influencing measured radiance.

Destriping approaches being tested:

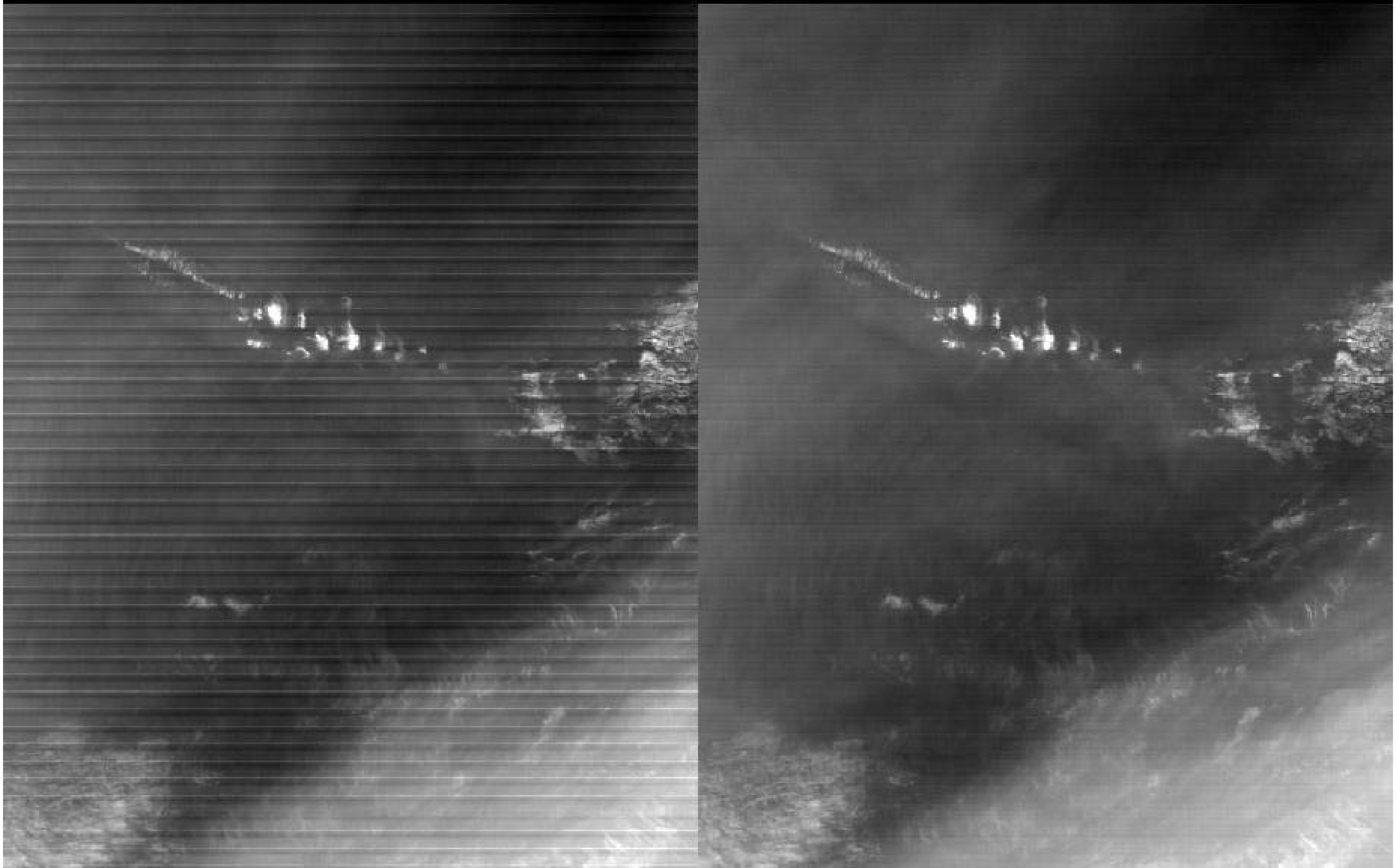
- generate granule overall mean and standard deviation
  for each detector each mirror side;
- in regions of low standard deviation, select reference detector
  and compute radiance ratios of different detectors;
- scale other detectors using computed radiance ratio.

MODIS L1B Accuracy Assessment

March 26, 2001; 1713 UTC; Nadir (AOI = 38 deg)



MODIS Band 27 (6.7 µm), 2001-06-04 16:45 UTC



Original L1B (V003) | *Destriped*

Early Estimates of UW MODIS IR TPW Product Quality

MODIS IR total precipitable water vapor

*** captures TPW gradients very well over oceans**
*** has been improved over daytime non vegetated land**
*** is very sensitive to multi-spectral striping**
*** shows a wet bias wrt microwave for TPW < 15mm,**
a dry bias for TPW > 15mm
*** bias will be removed after more validation.**

MODIS and GOES TPW agree well with rms difference of 3 mm

MODIS TPW
*** best IR TPW is five zone split window regression**
on de-striped data
*** vis-NIR TPW also available over daytime land**

STATUS – Validated with known characteristics

Cloud Top Properties – Infrared (MOD-06)

Richard Frey, Bryan Baum, Kathy Strabala,
Shaima Nasiri, Hong Zhang, Jun Li,
and Paul Menzel

18 Dec 2001

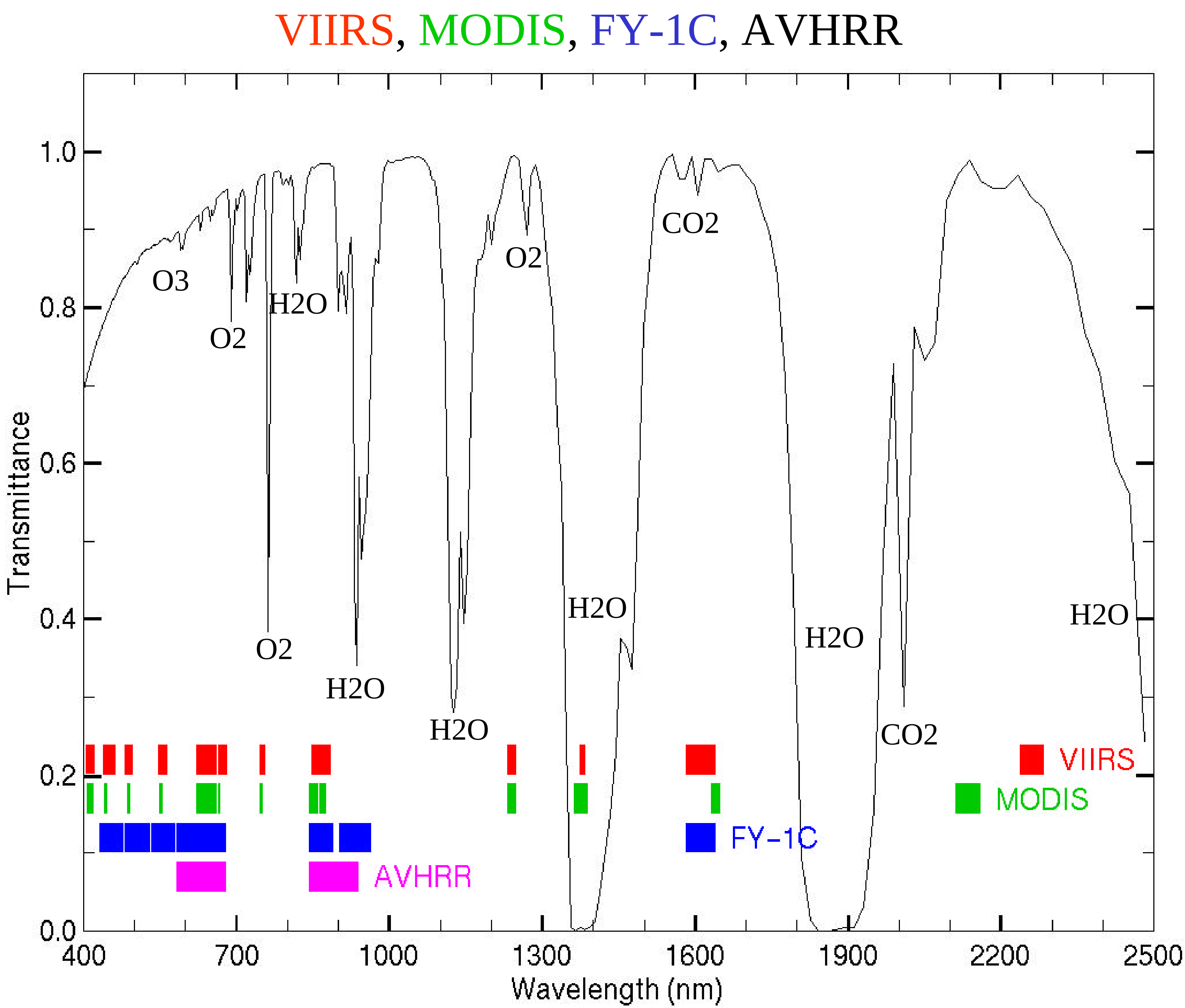
Cloud Top Properties

Objective: Retrieve cloud top properties for every 5 x 5 box of 1000 m FOVs where at least 5 FOVs are cloudy.

Method: Longwave infrared CO2 slicing; tri-spectral for cloud phase.

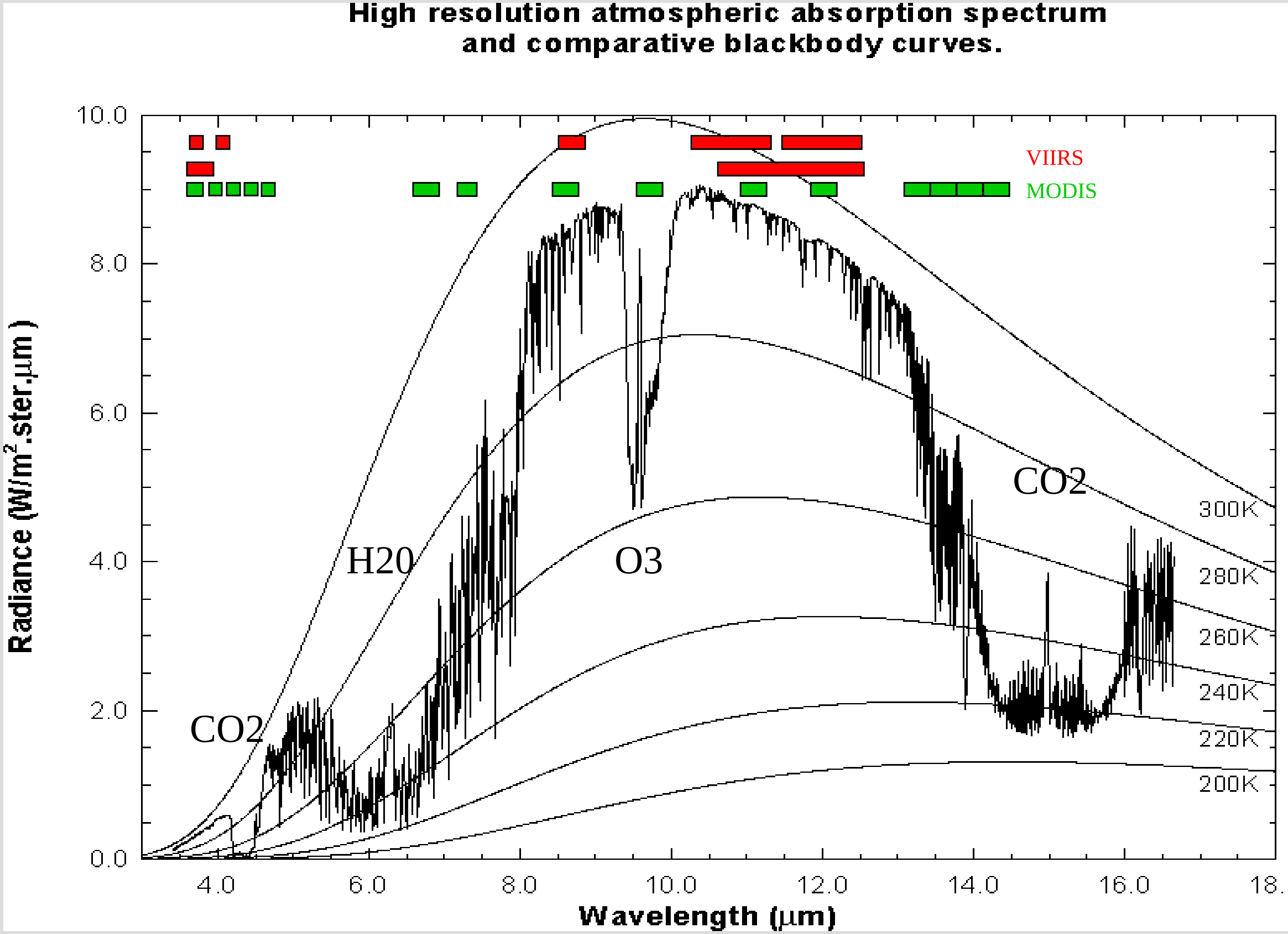
Products: Cloud top pressure and temperature; Cloud fraction and effective emissivity; Cloud phase (water, ice, mixed).

Frey, R. A. et al, 1999: A comparison of cloud top heights computed from airborne lidar and MAS radiance data. *J. Geophys. Res.*, 104, 24547-24555.

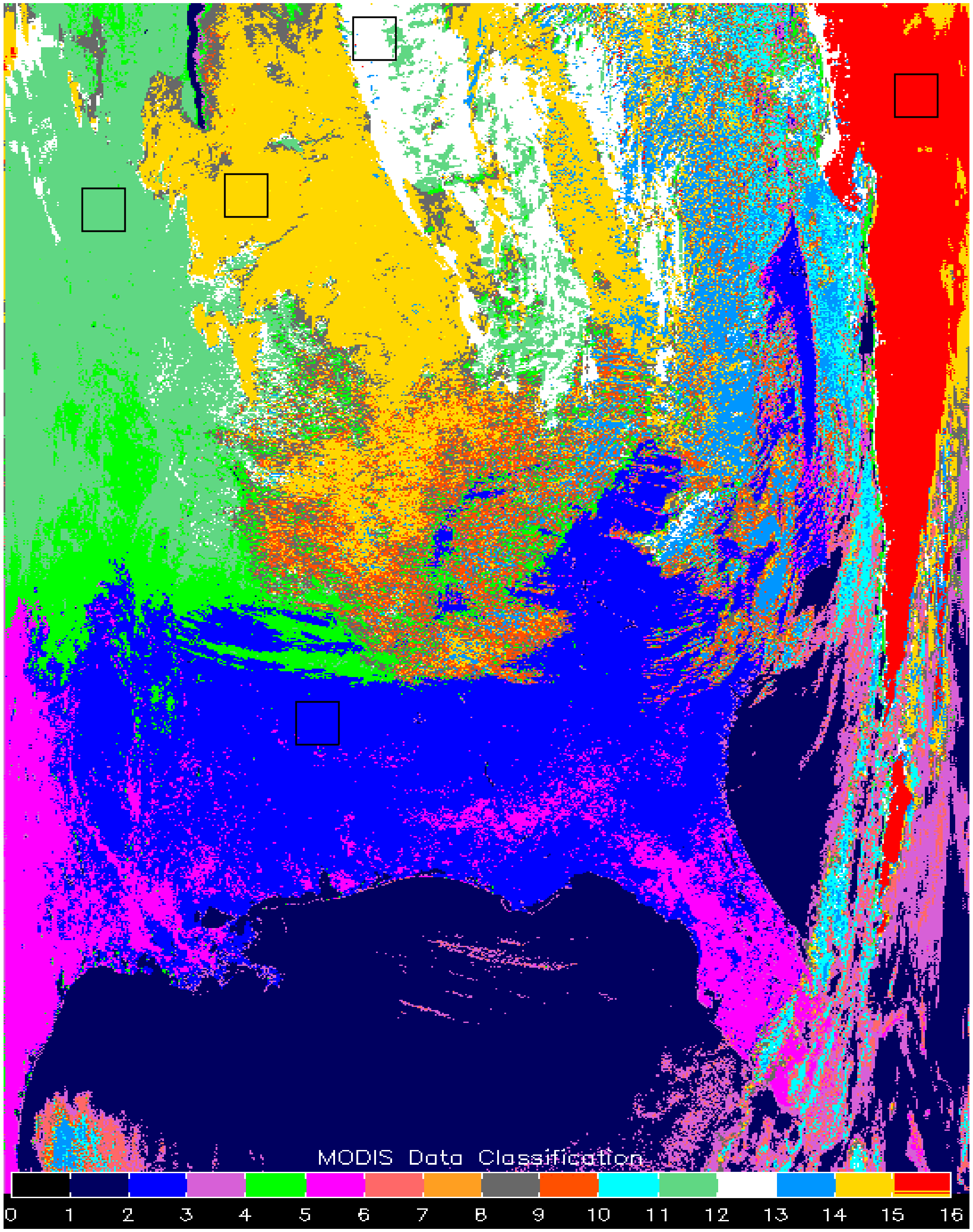


VIIRS, MODIS, FY-1C, AVHRR
Transmittance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
400
700
1000
1300
1600
1900
2200
2500
O3
O2
H2O
O2
H2O
H2O
O2
H2O
CO2
H2O
CO2
H2O
VIIRS
MODIS
FY-1C
AVHRR

Earth emitted spectra overlaid on Planck function envelopes

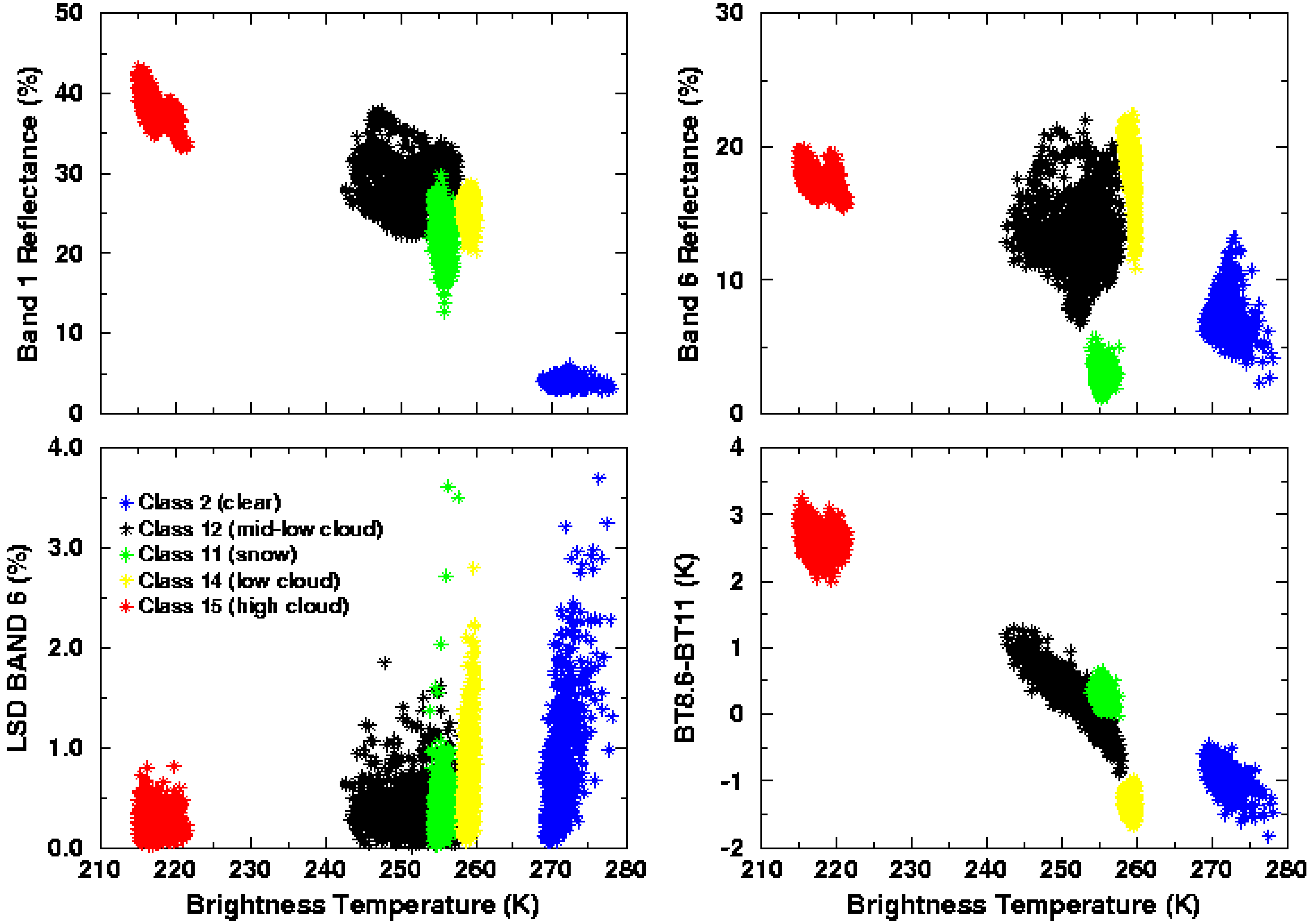


MODIS identifies cloud classes



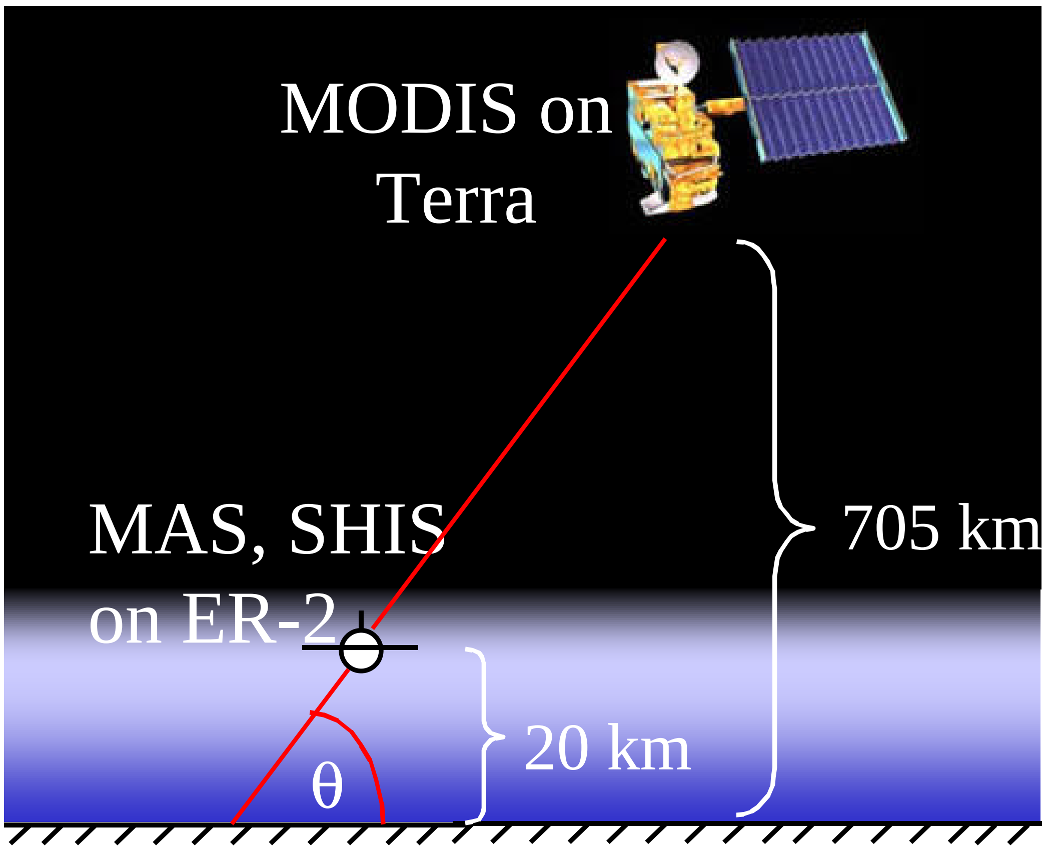
Clear
Snow
Low Cloud
Mid-low Cloud
High Cloud

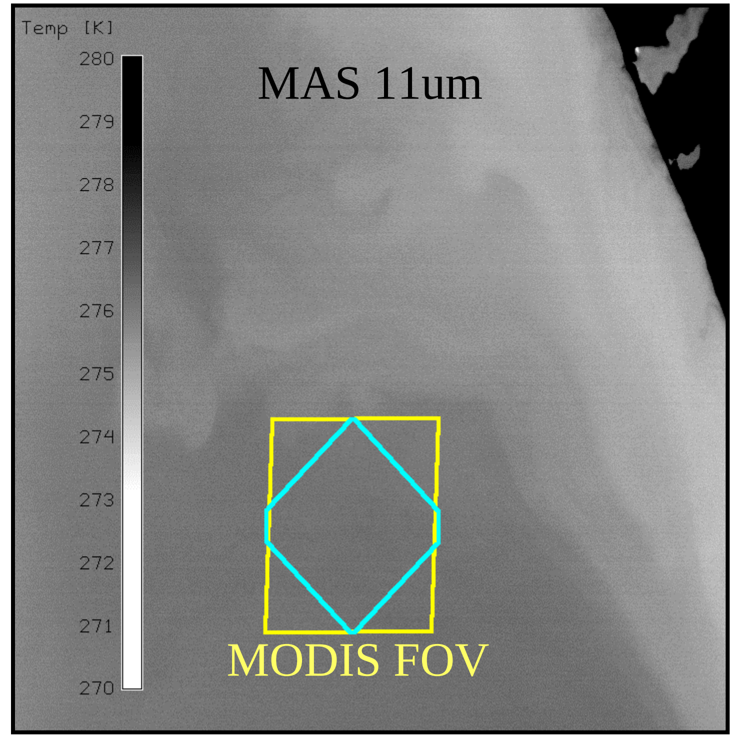
Clouds separate into classes when multispectral radiance information is viewed

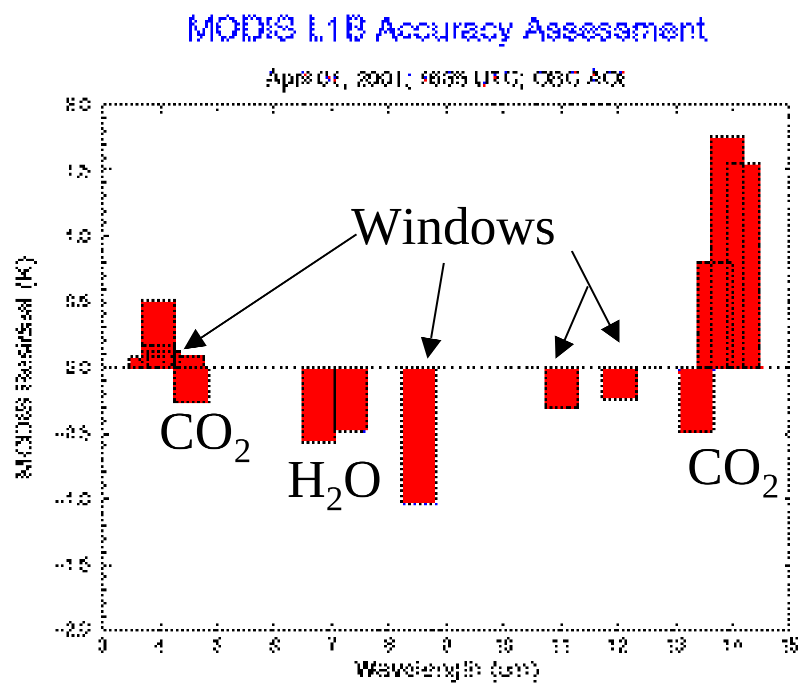


MODIS Emissive Band Cal/Val from ER-2 Platform

- Transfer S-HIS cal to MAS
- Co-locate MODIS FOV on MAS
- Remove spectral, geometric dependence
- WISC-T2000, SAFARI-2000, TX-2001







RTE in Cloudy Conditions

$$I_{\_} = \_\, I^{cd}_{\_} + (1 - \_)\, I^{c}_{\_}$$ where cd = cloud, c = clear, _ = cloud fraction

$$I^{c}_{\_} = B_{\_}(T_s)\,\tau_{\_}(p_s) + \int_{p_s}^{o} B_{\_}(T(p))\, d\tau_{\_} .$$

$$I^{cd}_{\_} = (1-\_{\_})\,B_{\_}(T_s)\,\tau_{\_}(p_s) + (1-\_{\_})\int_{p_s}^{p_c} B_{\_}(T(p))\,d\tau_{\_}$$

$$+ \_{\_}\,B_{\_}(T(p_c))\,\tau_{\_}(p_c) + \int_{p_c}^{o} B_{\_}(T(p))\,d\tau_{\_}$$

$\_{\_}$ is emittance of cloud. First two terms are from below cloud, third term is cloud contribution, and fourth term is from above cloud. After rearranging

$$I_{\_} - I^{c}_{\_} = \_\_{\_} \int_{p_s}^{p_c} \tau(p)\, \frac{dB_{\_}}{dp}\, dp .$$

Techniques for dealing with clouds fall into three categories: (a) searching for cloudless fields of view, (b) specifying cloud top pressure and sounding down to cloud level as in the cloudless case, and (c) employing adjacent fields of view to determine clear sky signal from partly cloudy observations.

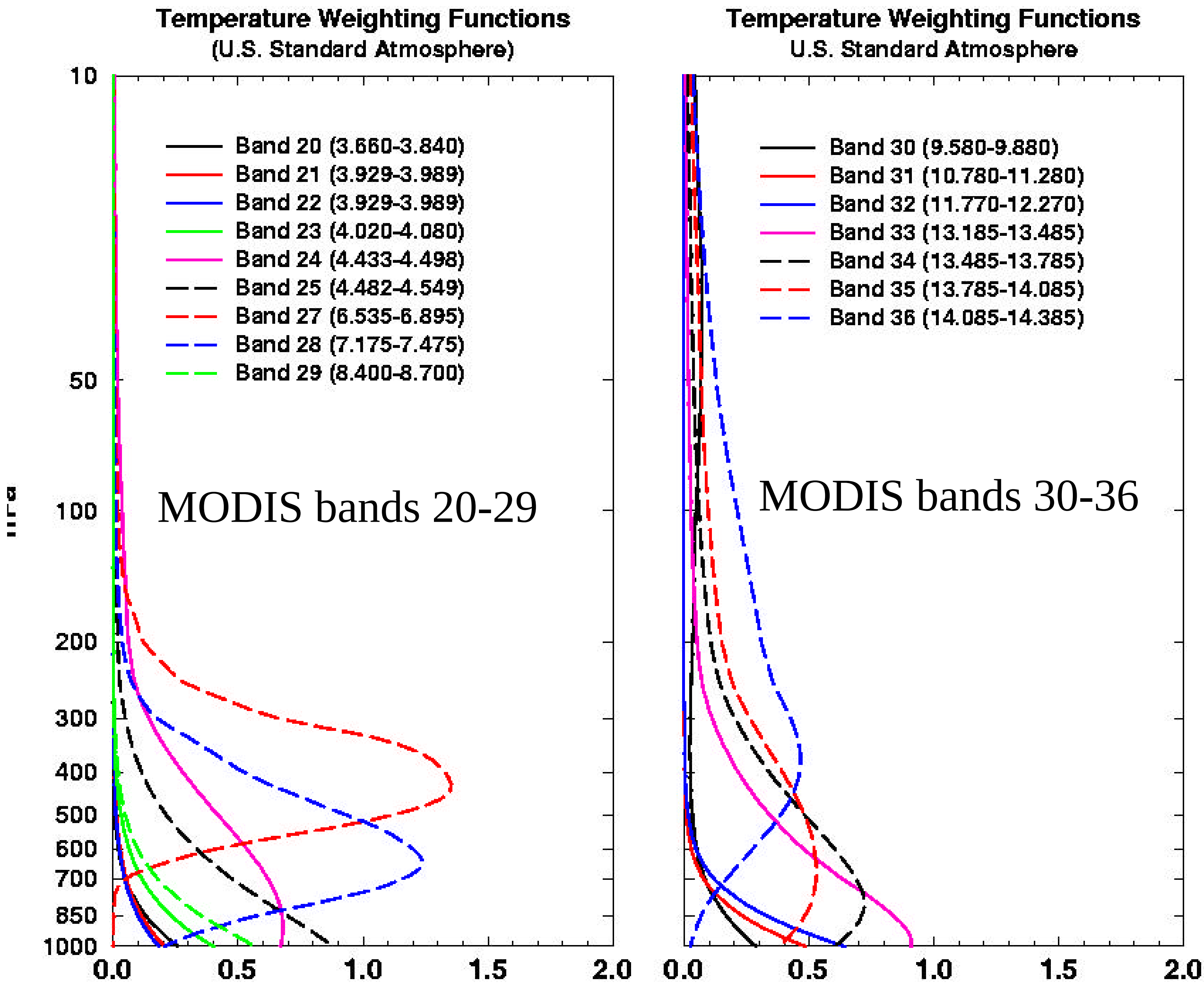
Cloud Properties

RTE for cloudy conditions indicates dependence of cloud forcing (observed minus clear sky radiance) on cloud amount ($\eta\varepsilon_\lambda$) and cloud top pressure (p_c)

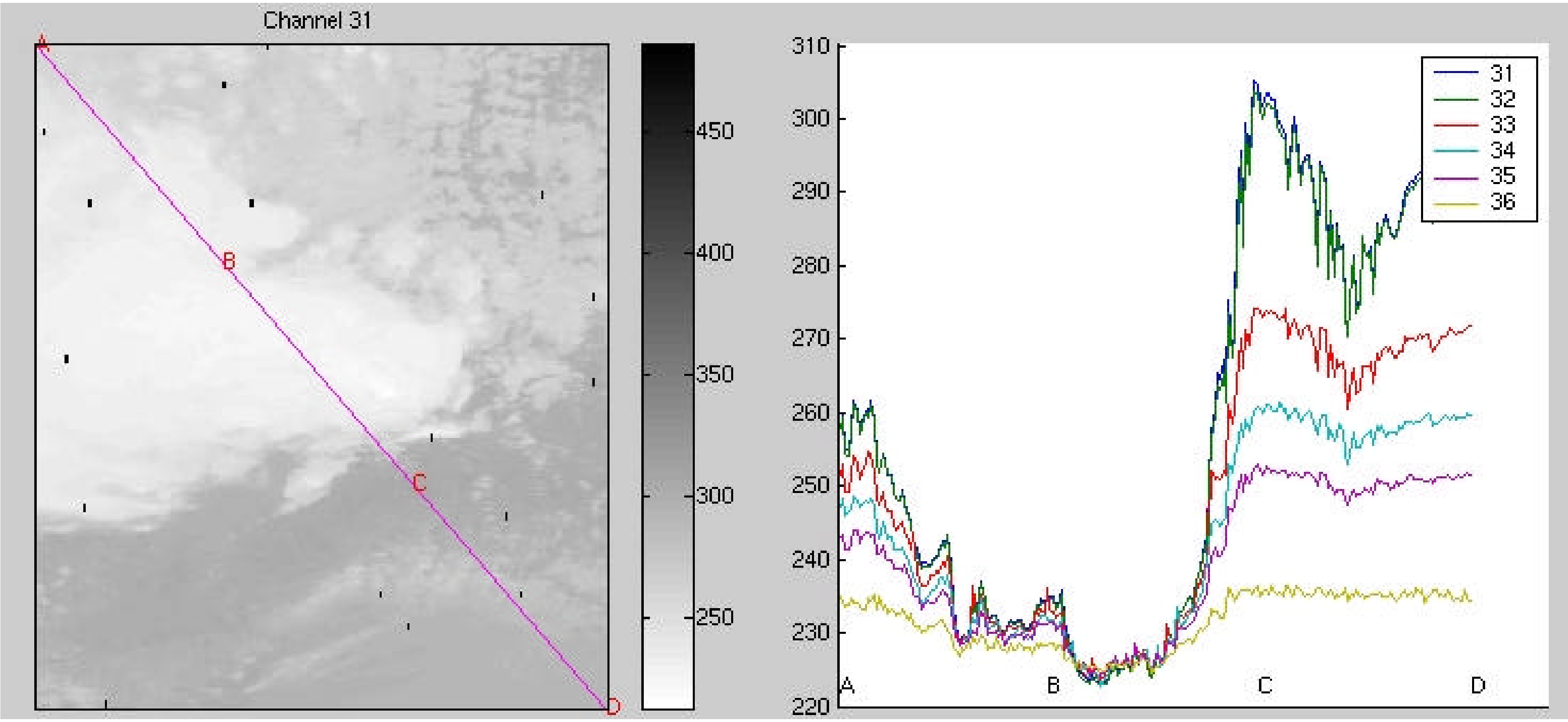
$$(I_\lambda - I_\lambda^{clr}) = \eta\varepsilon_\lambda \int_{p_s}^{p_c} \tau_\lambda \, dB_\lambda .$$

Higher colder cloud or greater cloud amount produces greater cloud forcing; dense low cloud can be confused for high thin cloud. Two unknowns require two equations.

p_c can be inferred from radiance measurements in two spectral bands where cloud emissivity is the same. $\eta\varepsilon_\lambda$ is derived from the infrared window, once p_c is known. This is the essence of the CO2 slicing technique.

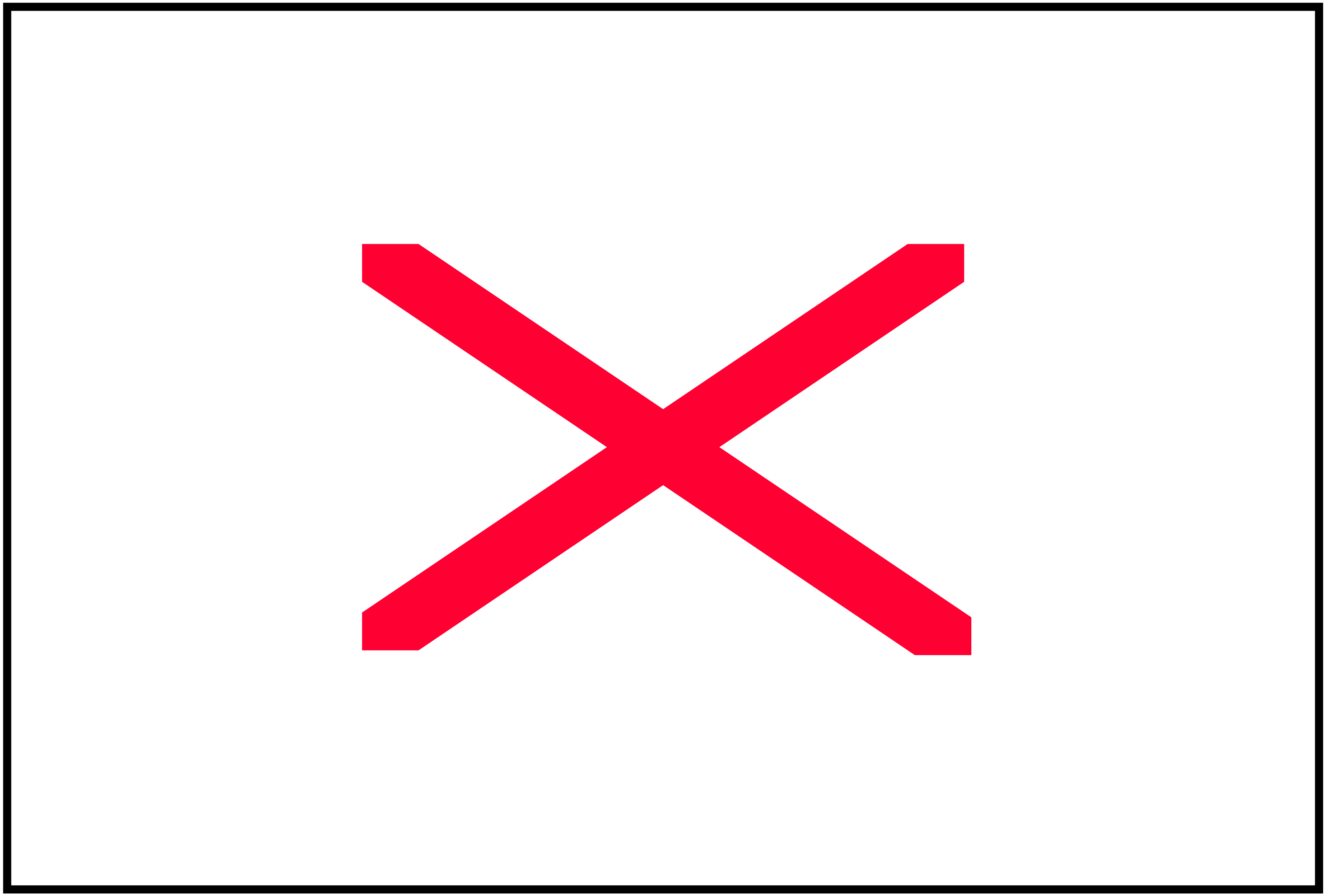


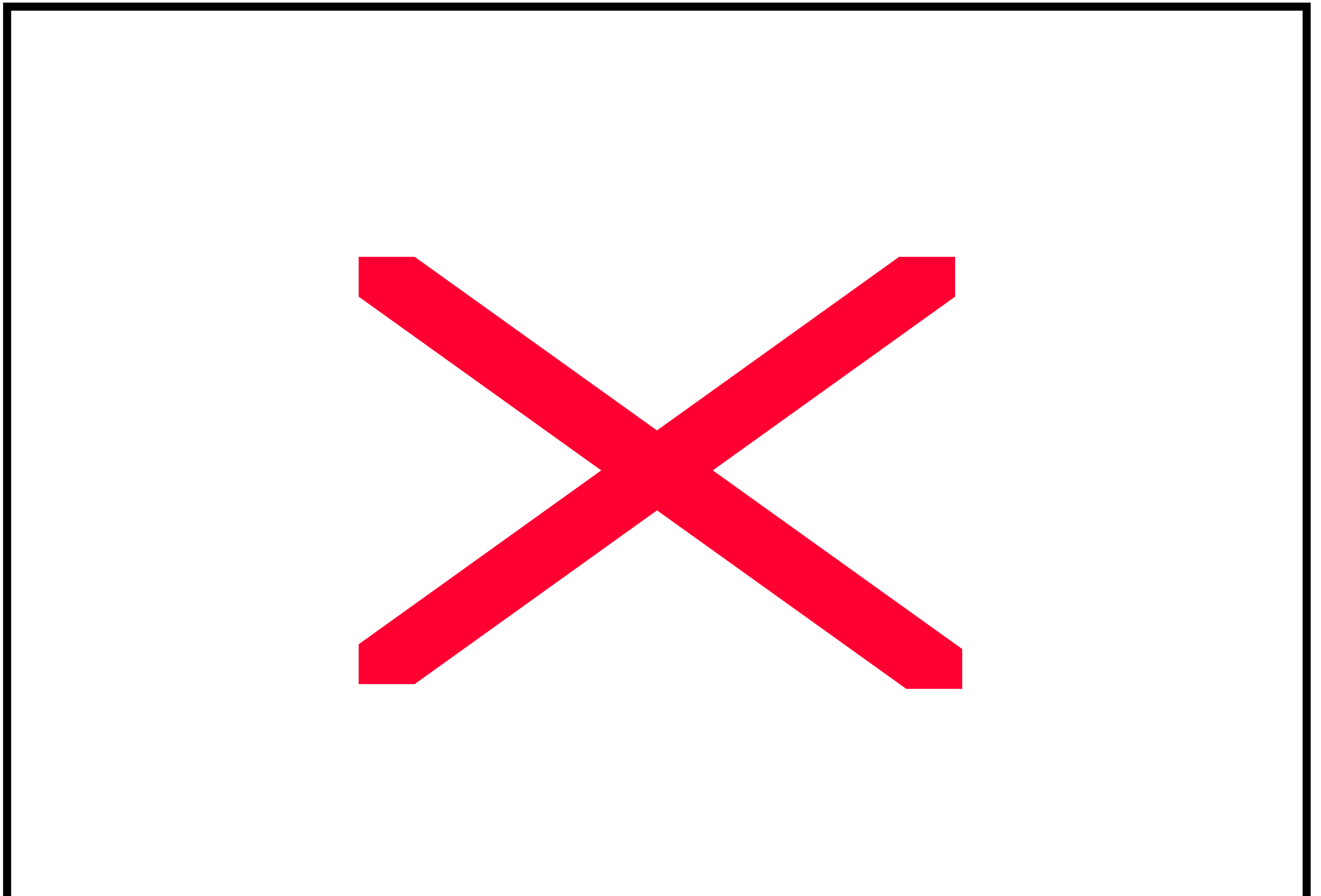
Temperature Weighting Functions
(U.S. Standard Atmosphere)
Band 20 (3.660-3.840)
Band 21 (3.929-3.989)
Band 22 (3.929-3.989)
Band 23 (4.020-4.080)
Band 24 (4.433-4.498)
Band 25 (4.482-4.549)
Band 27 (6.535-6.895)
Band 28 (7.175-7.475)
Band 29 (8.400-8.700)
MODIS bands 20-29
10
50
100
200
300
400
500
600
700
850
1000
0.0
0.5
1.0
1.5
2.0
Temperature Weighting Functions
U.S. Standard Atmosphere
Band 30 (9.580-9.880)
Band 31 (10.780-11.280)
Band 32 (11.770-12.270)
Band 33 (13.185-13.485)
Band 34 (13.485-13.785)
Band 35 (13.785-14.085)
Band 36 (14.085-14.385)
MODIS bands 30-36



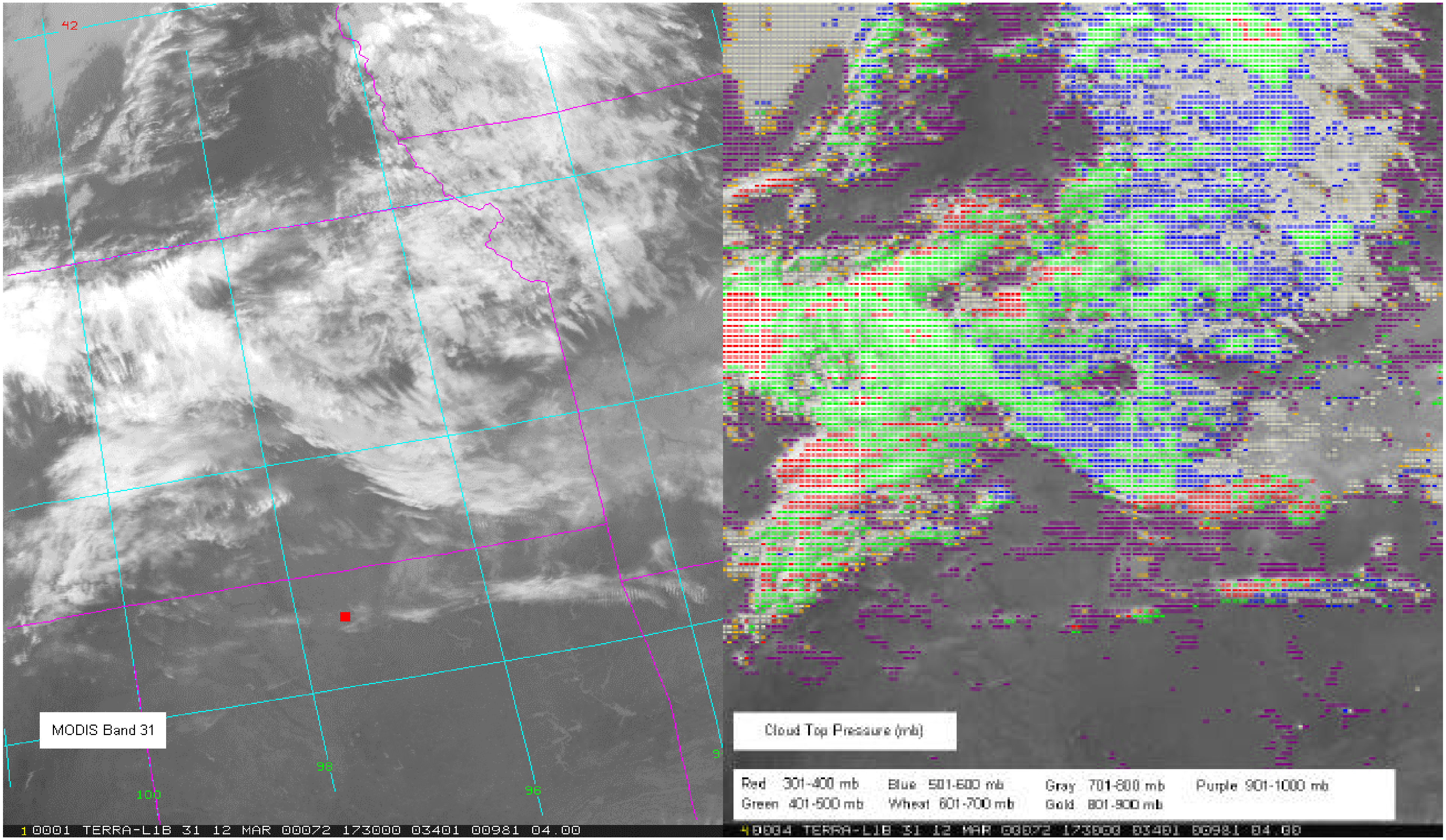
Channel 31
A
B
C
D
450
400
350
300
250
310
300
290
280
270
260
250
240
230
220
31
32
33
34
35
36

MAS CO2 heights validated with 4700 Lidar measurements

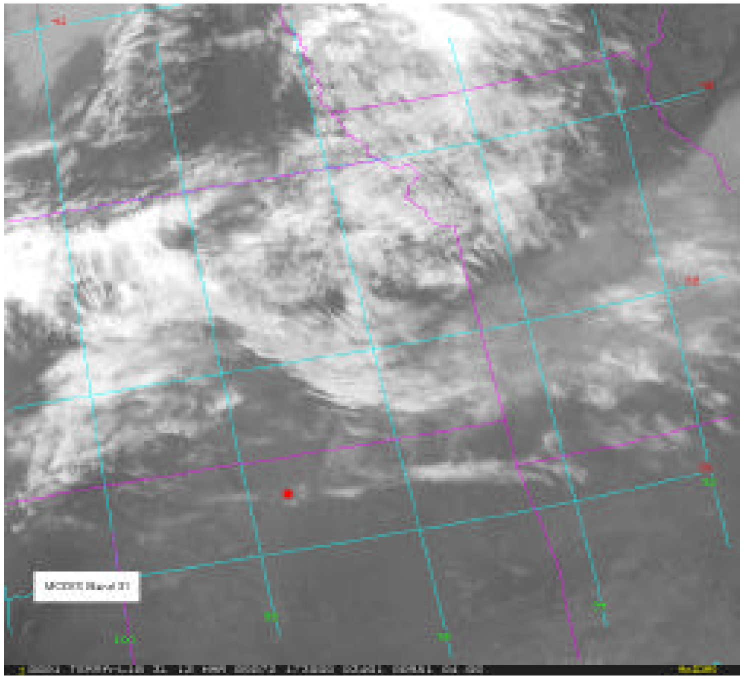




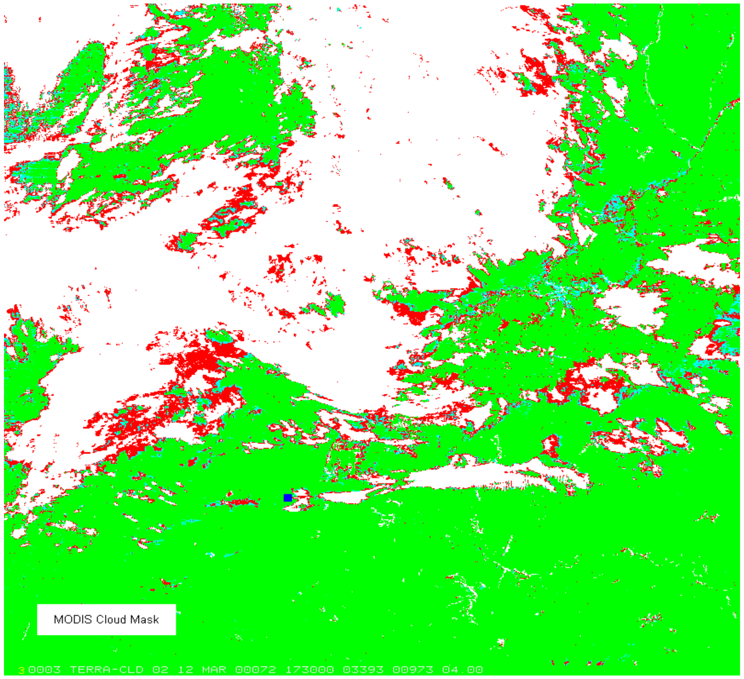
MODIS 2000/03/12 1730 UTC Cloud Top Pressure



VIS

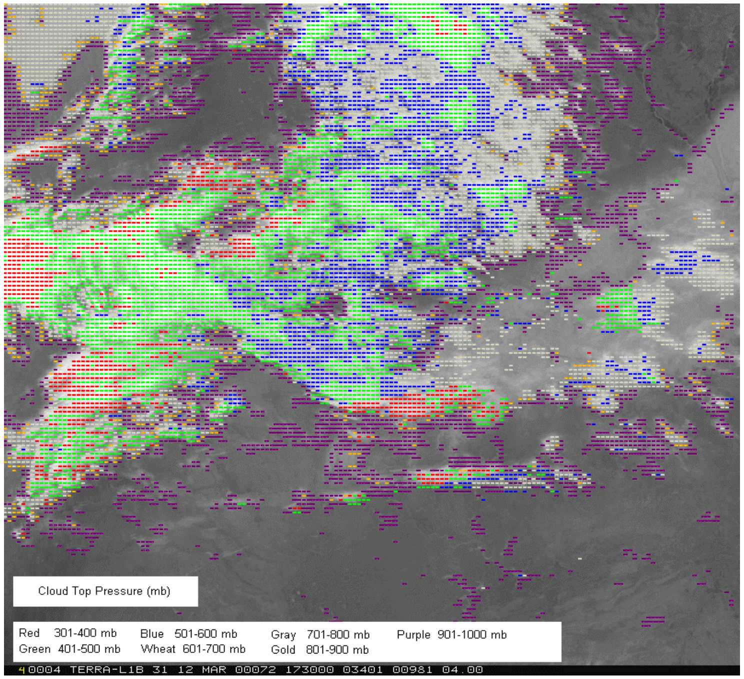


CM

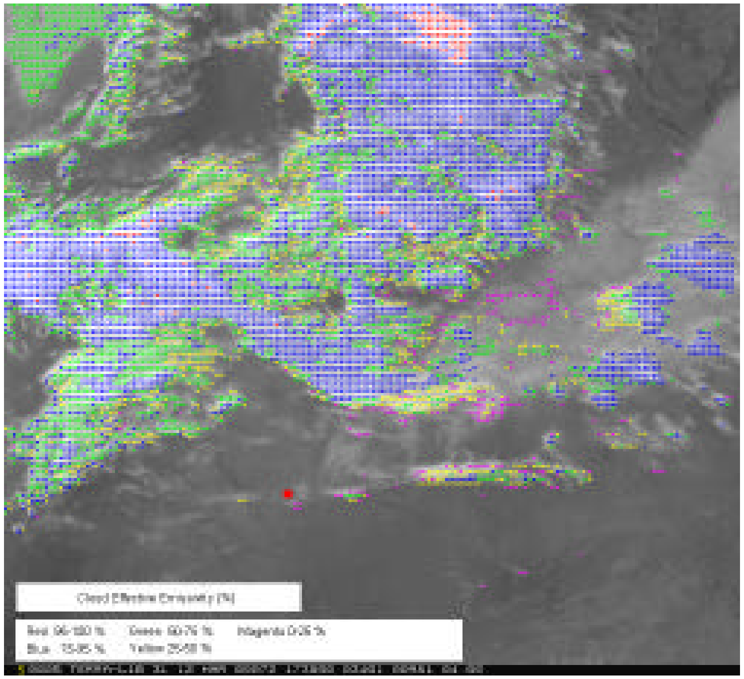


MODIS
Cloud
Mask

CTP



Nε

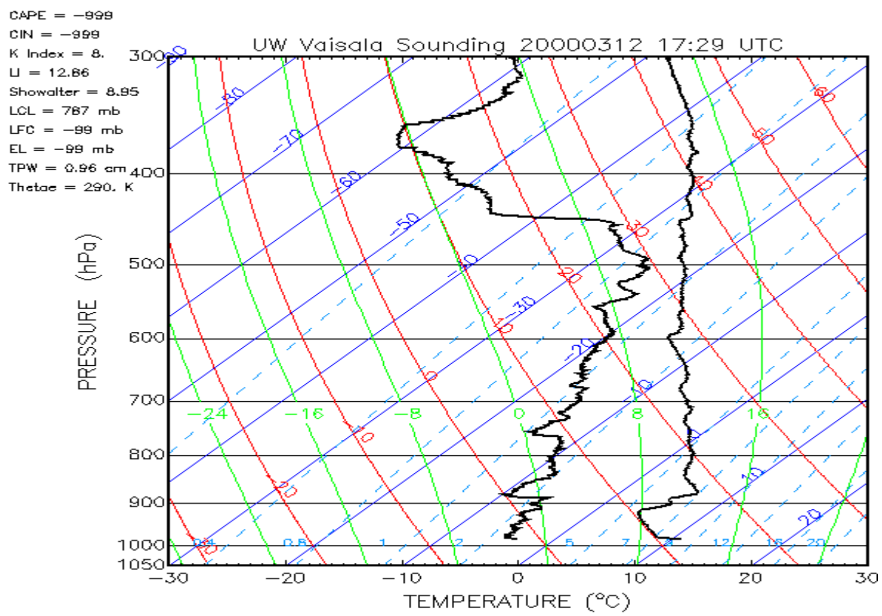


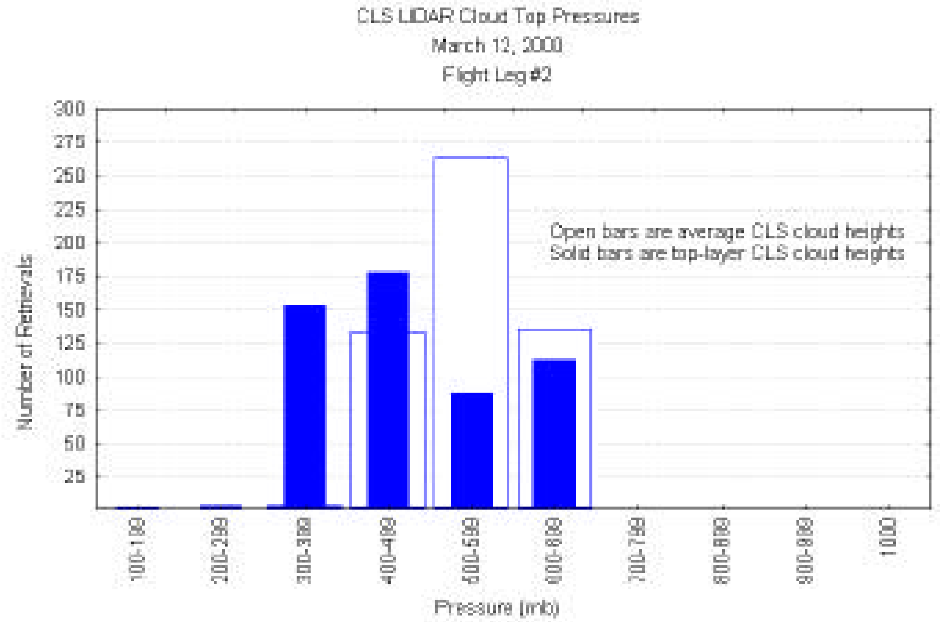
MODIS
Cloud
Properties

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

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

Comparison of CLS (nadir view), HIRS (3 hrs later), RAOB, & MODIS Cloud Properties

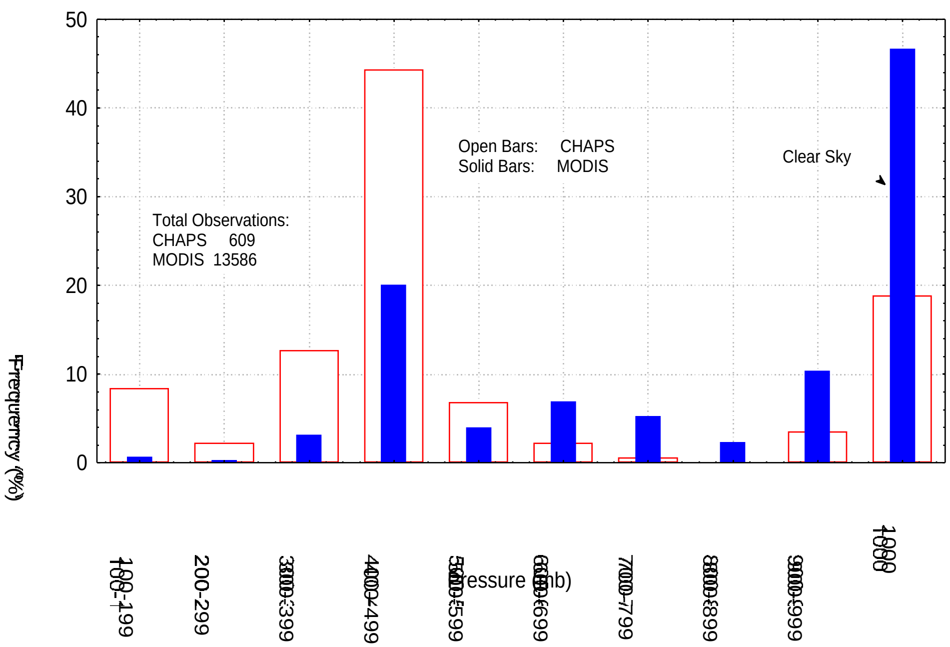




MODIS and CHAPS CO_2-slicing Cloud Top Pressures

17:30 UTC 12 March, 2000

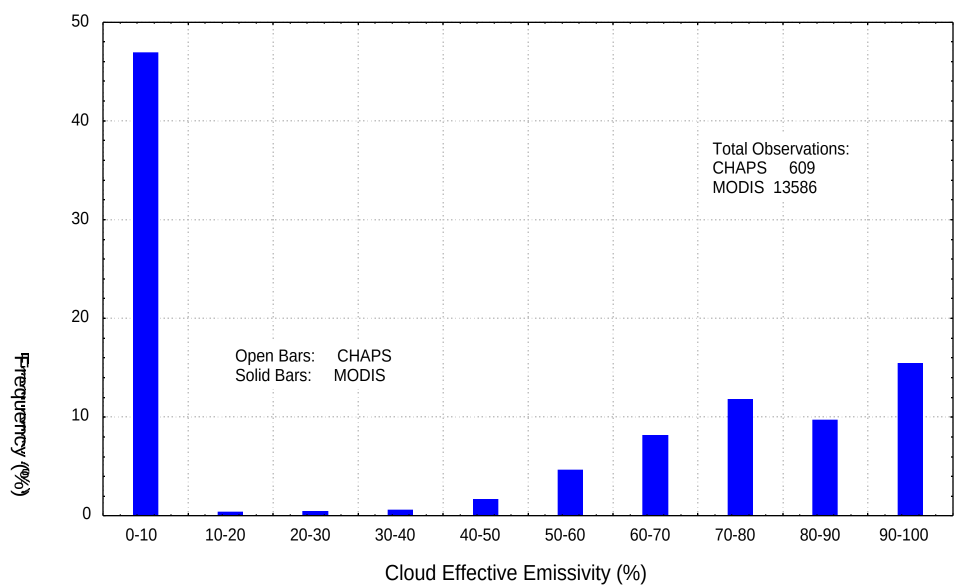
36-40 North Latitude and 90-100 West Longitude



MODIS and CHAPS CO_2-slicing Cloud Effective Emissivity

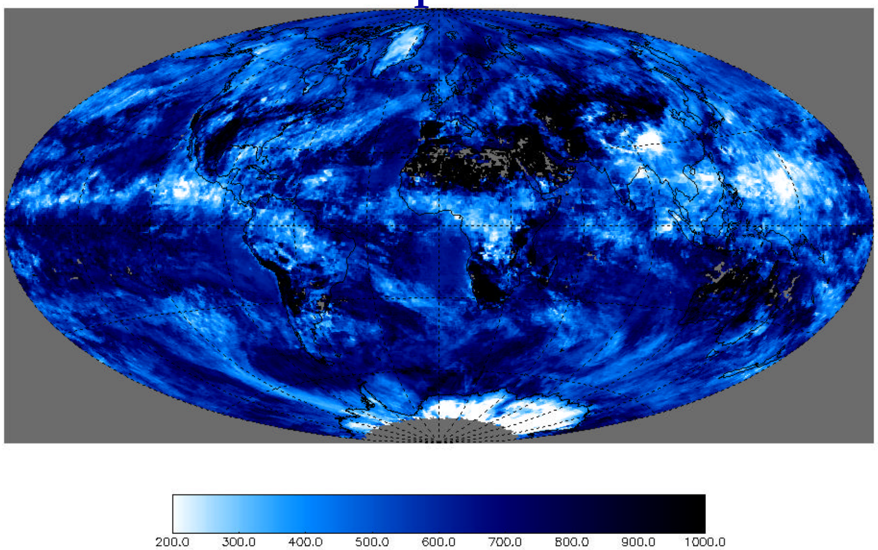
17:30 UTC 12 March, 2000

36-40 North Latitude and 90-100 West Longitude

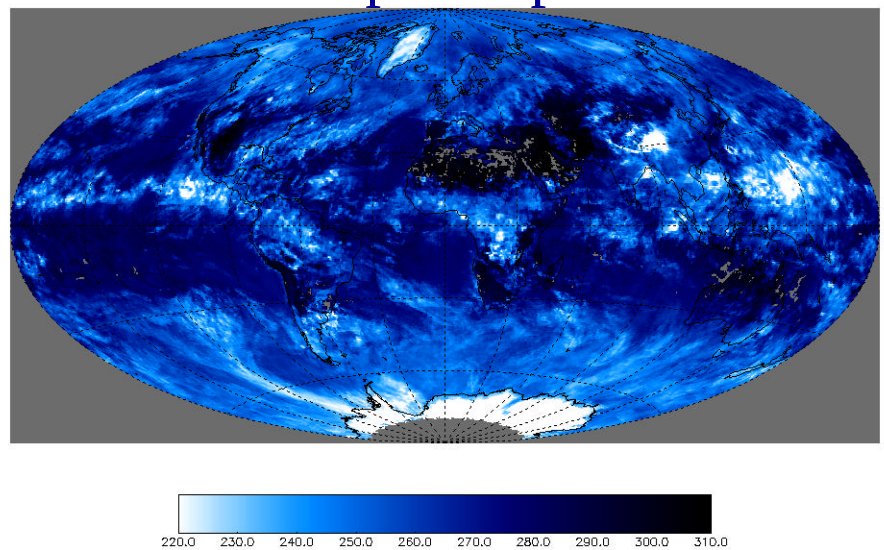


MODIS 2000/09/05-08

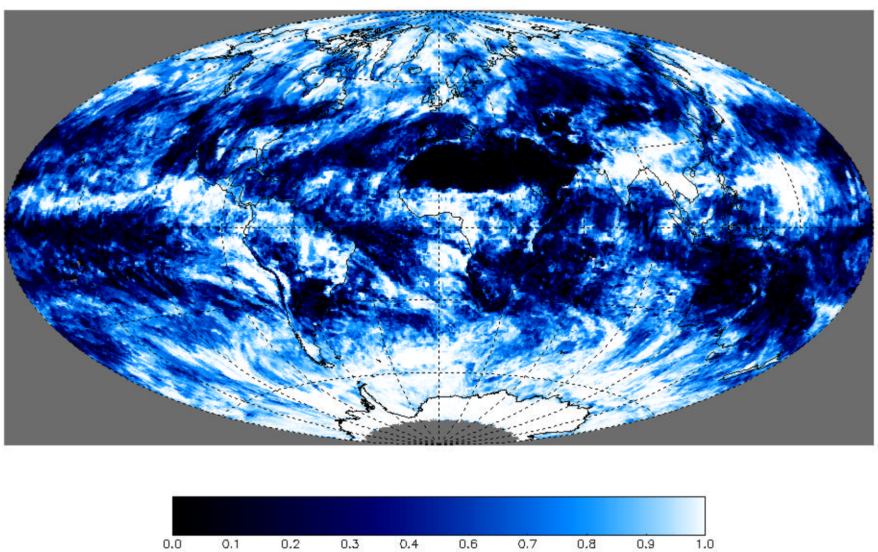
Cloudtop Pressure



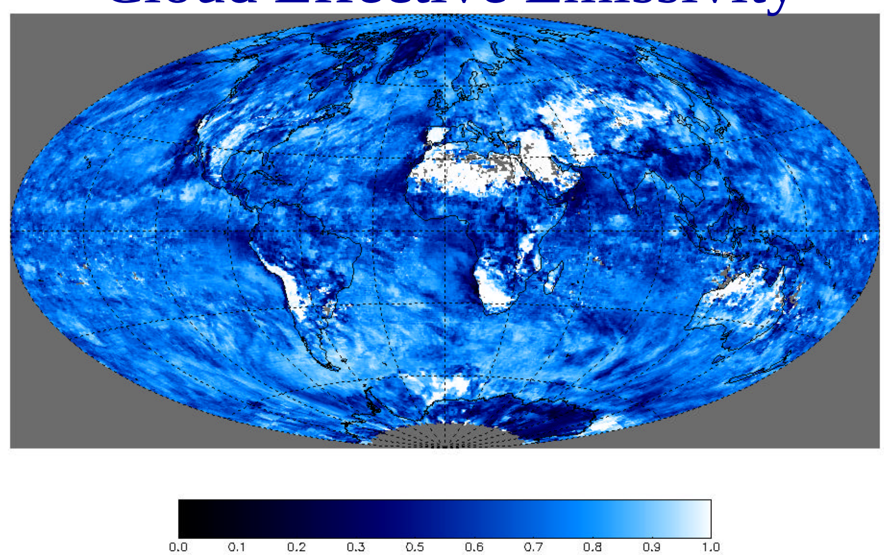
Cloudtop Temperature



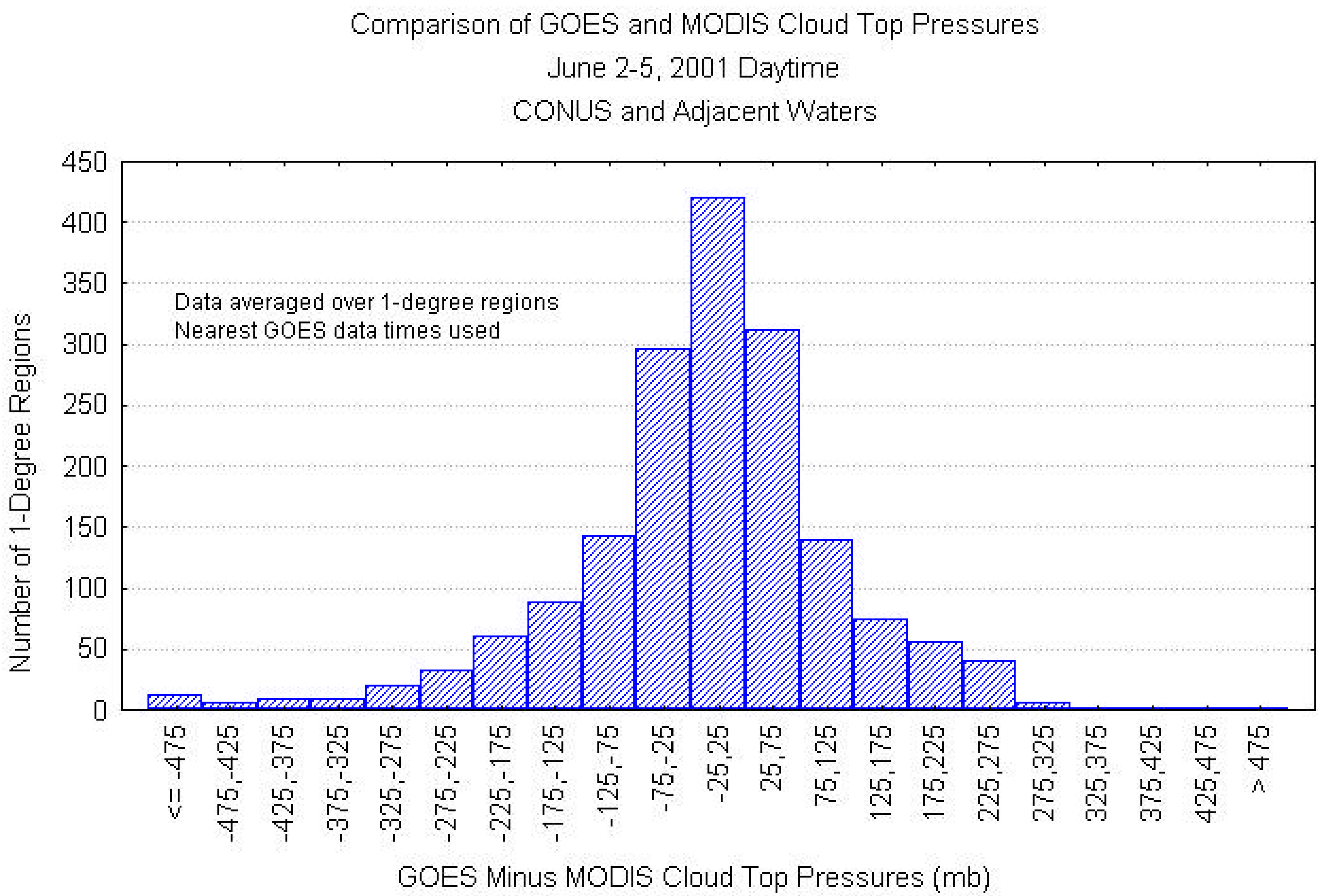
Cloud Fraction



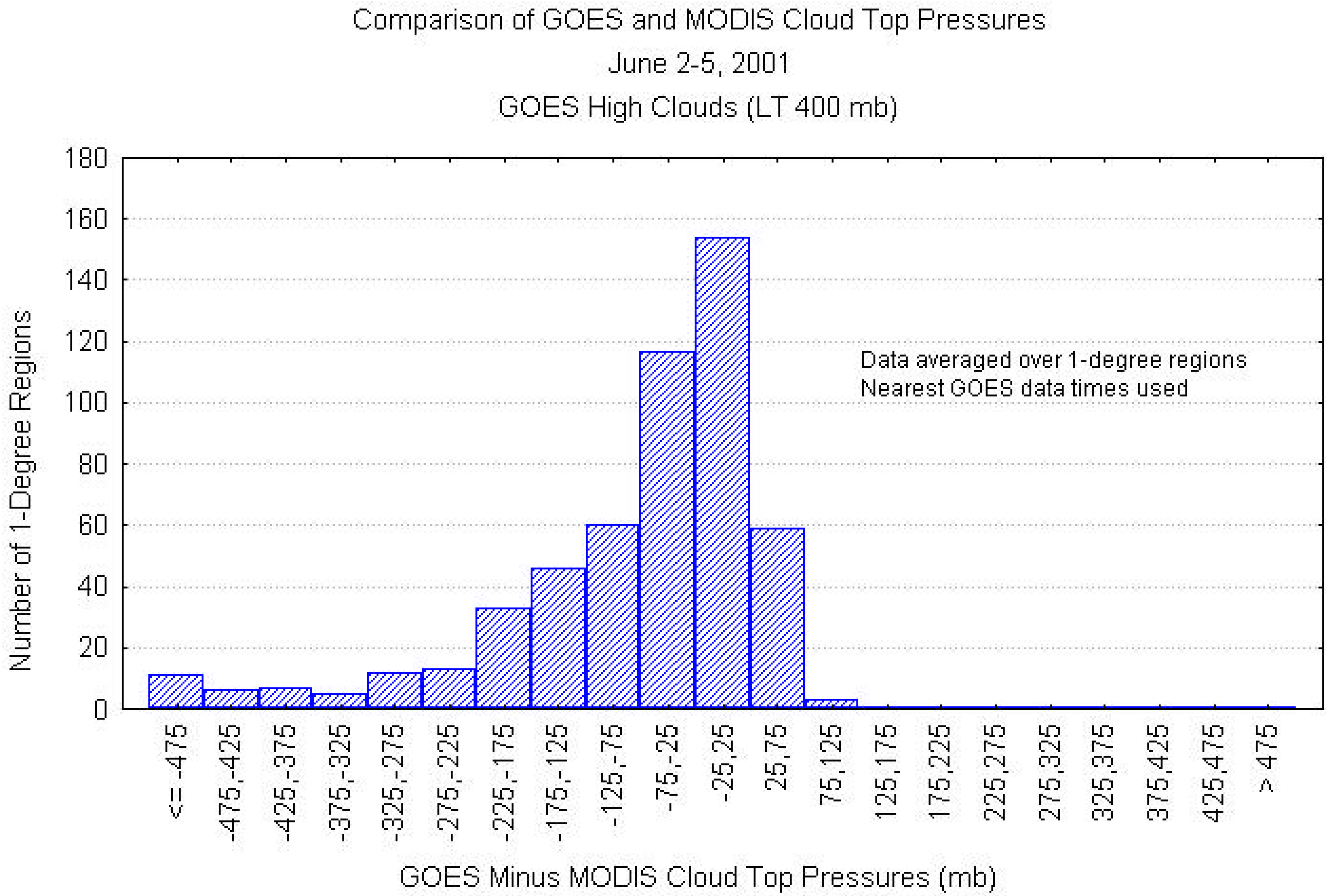
Cloud Effective Emissivity



MODIS CO2 heights compared with GOES CO2 heights

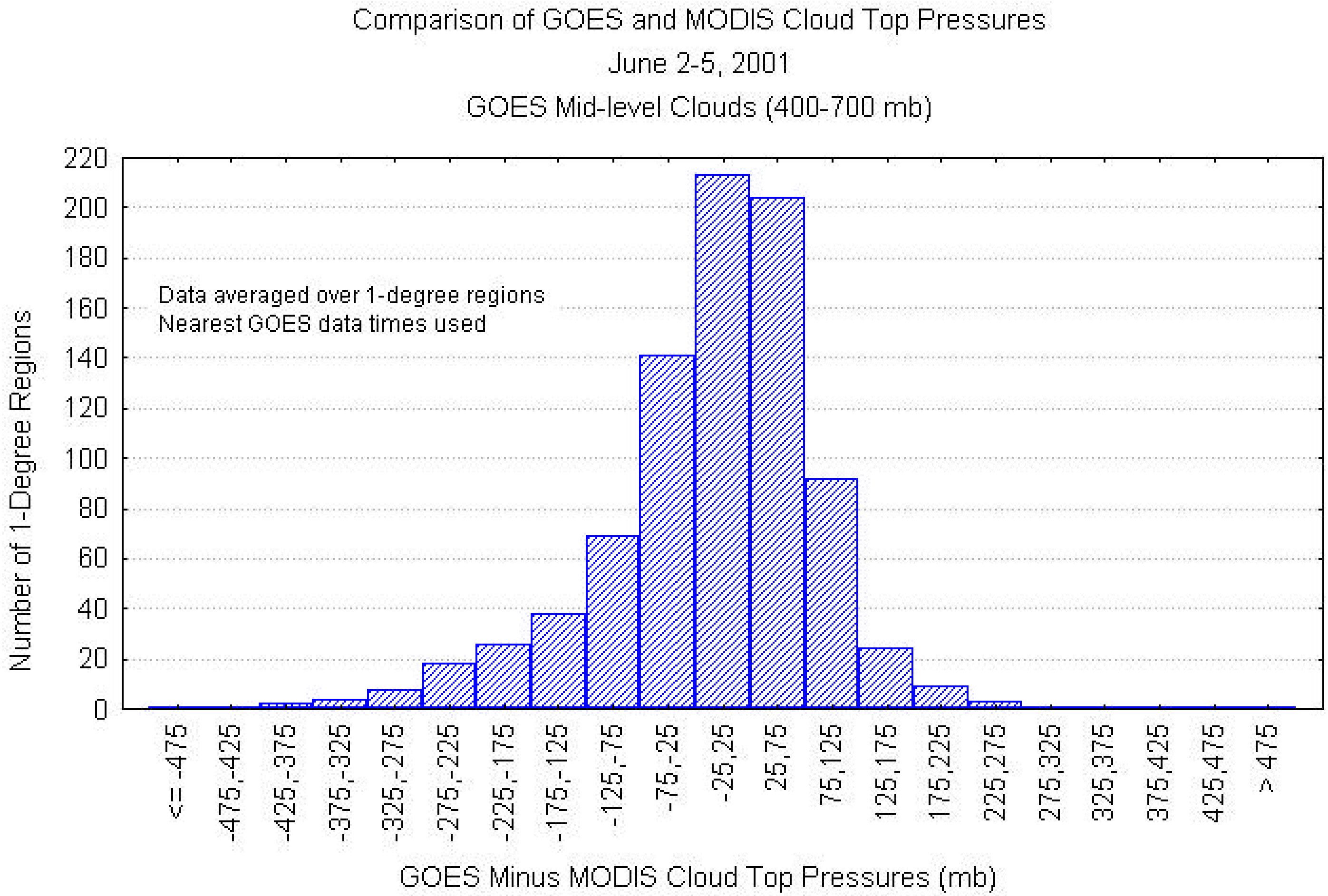


MODIS CO2 heights compared with GOES CO2 heights
High clouds < 400 mb

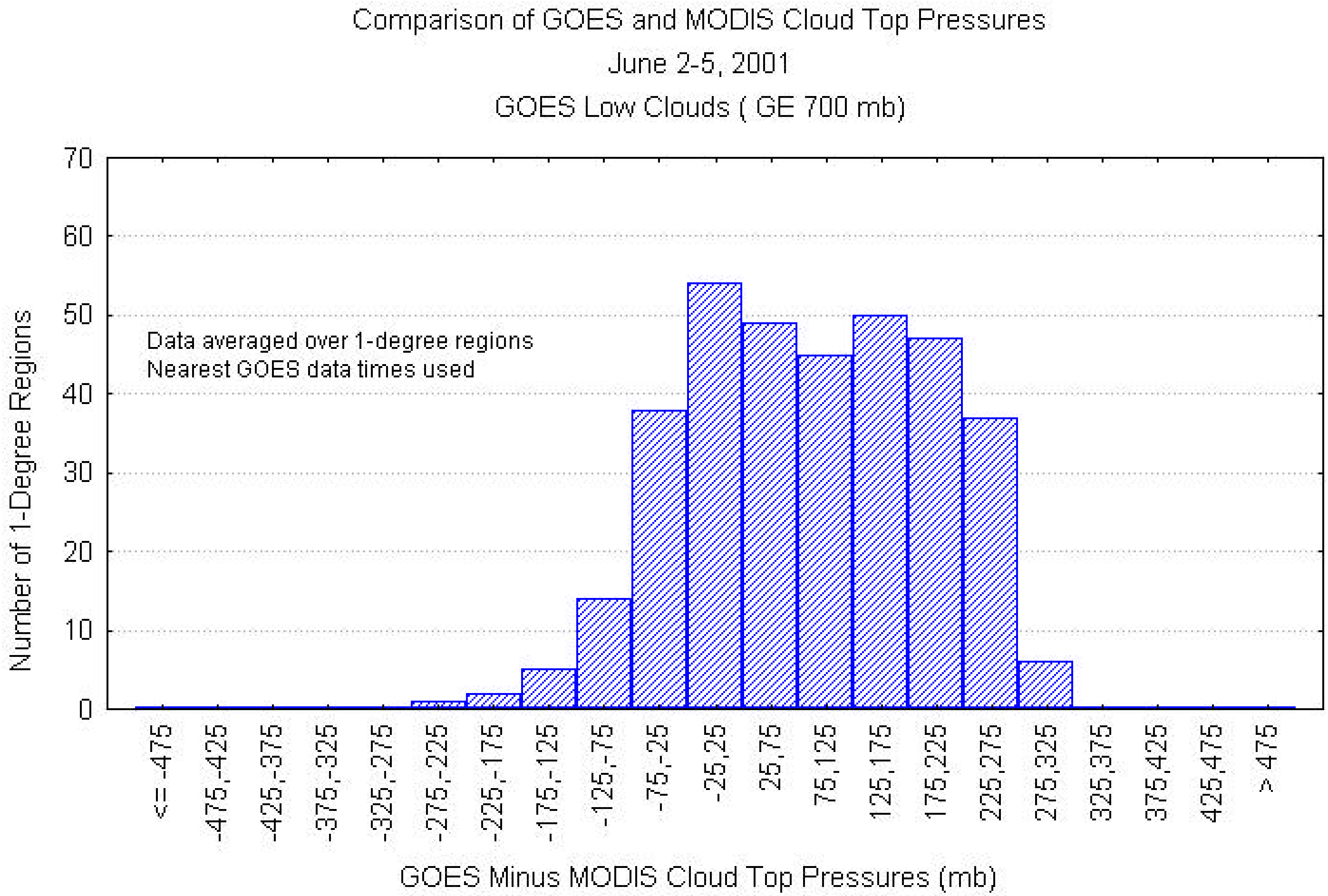


MODIS sees high clouds lower in atmosphere

MODIS CO2 heights compared with GOES CO2 heights mid level clouds between 400 and 700 mb

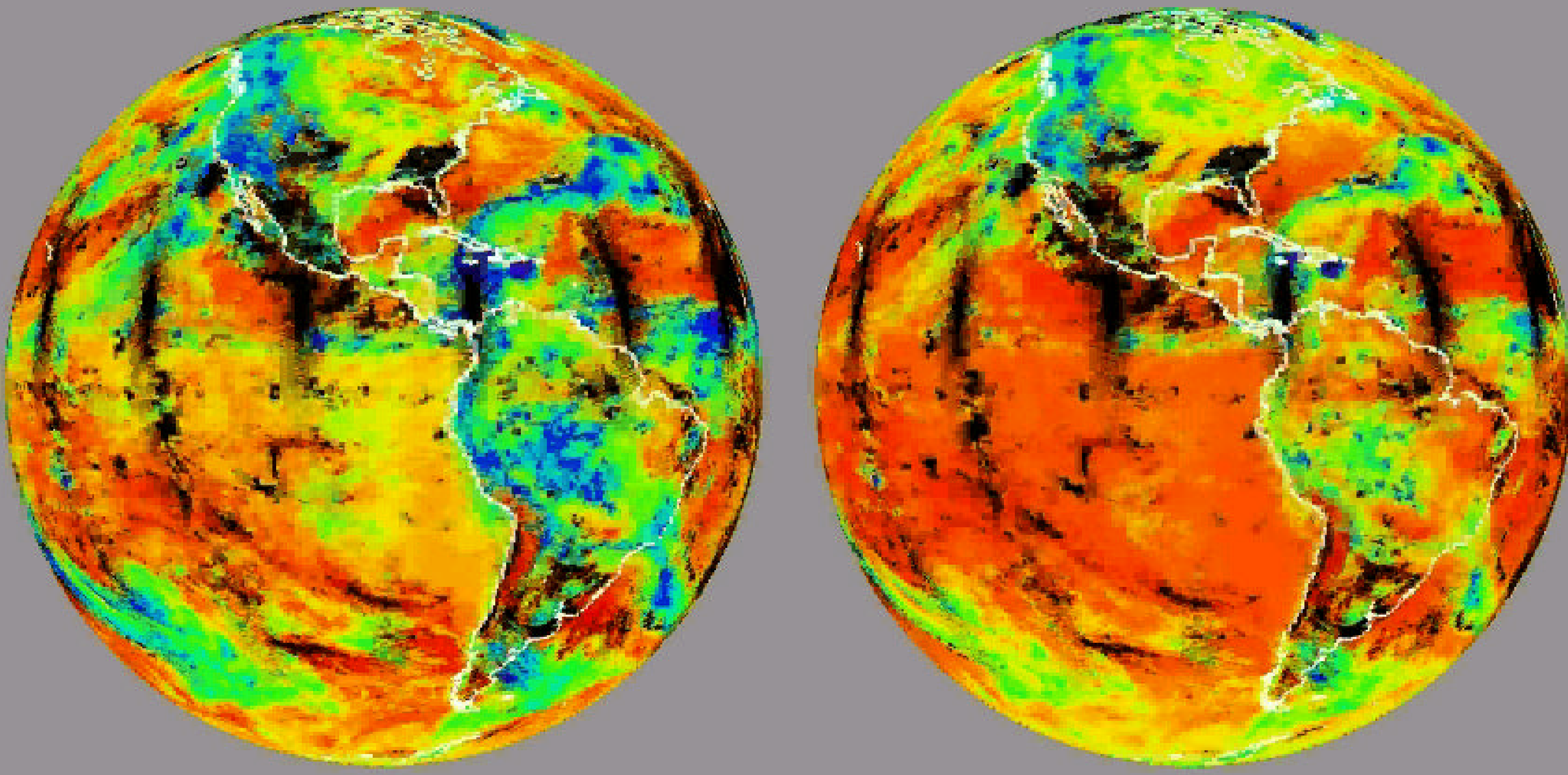


MODIS CO2 heights compared with GOES CO2 heights
Low clouds > 700 mb



MODIS sees low clouds higher in atmosphere

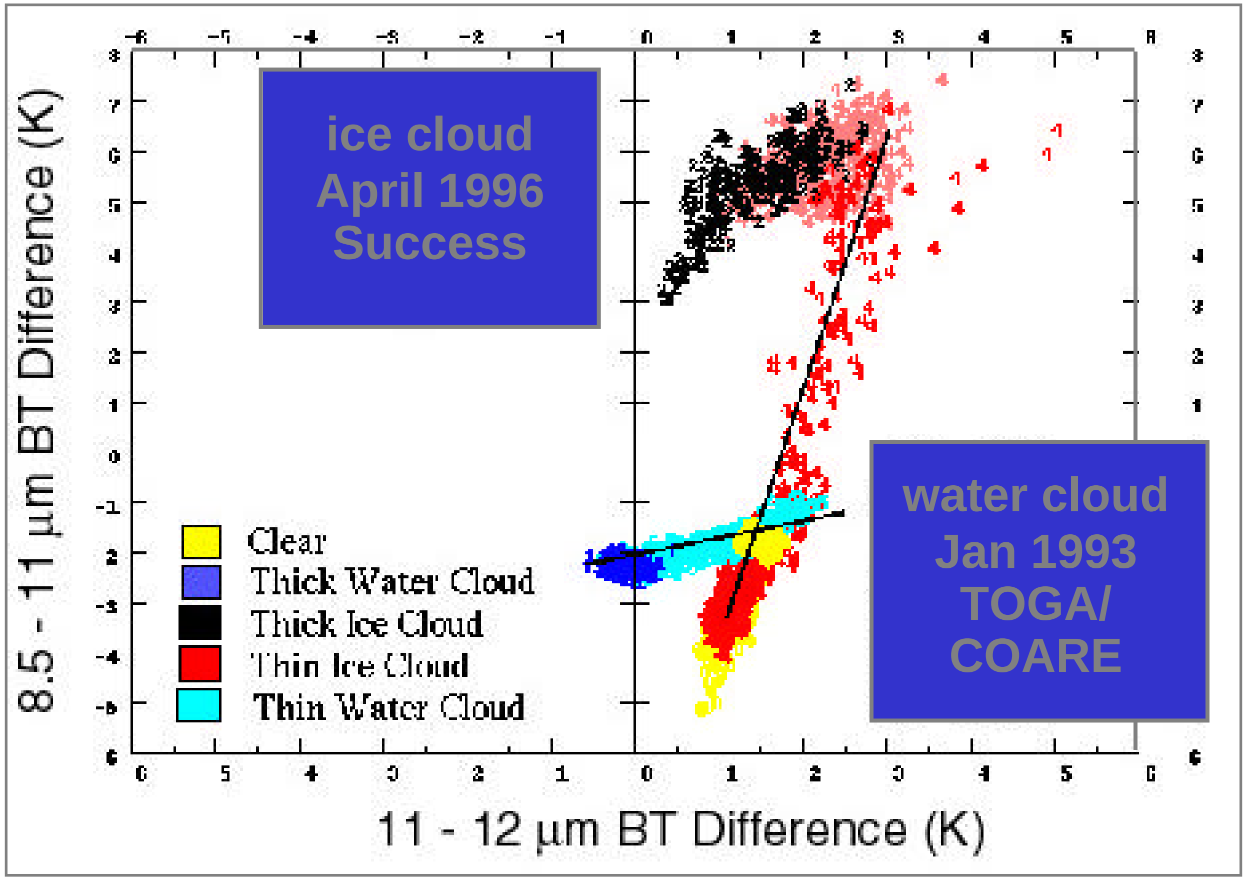
Cloud Top Pressure *Cloud Top Temperature*



Cloud Top Properties – December 1, 2000

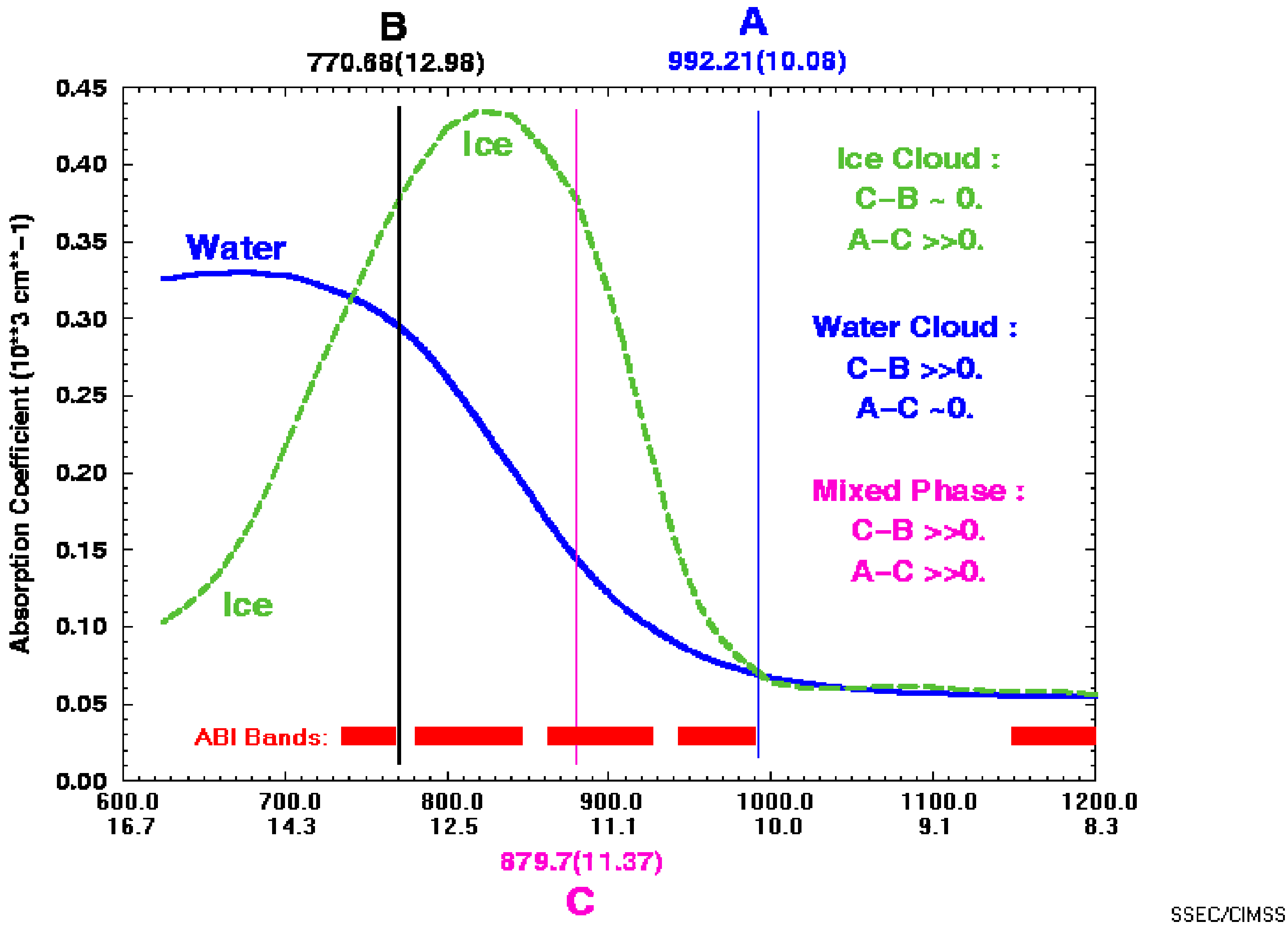
Tri-spectral IR thermodynamic phase algorithm

- 8.6-11 vs 11-12
- when slope > 1 then ice
- when slope < 1 then water



Strabala, Menzel, and Ackerman, 1994, *JAM*, **2**, 212-229.
Baum et al, 2000, *JGR*, **105**, 11781-11792.

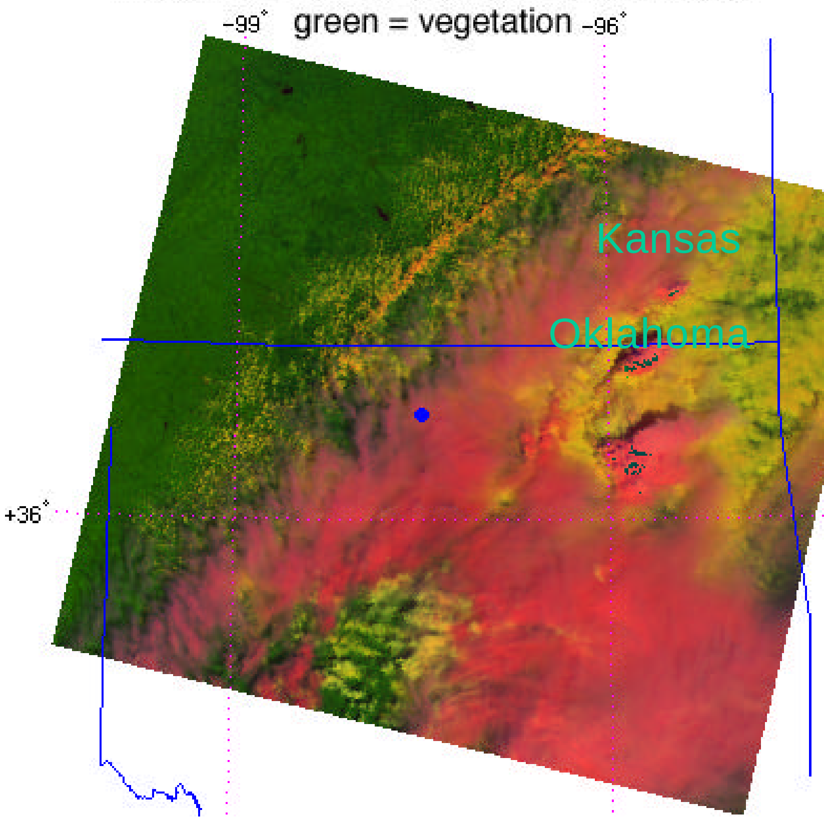
Multispectral data reveals improved information about ice / water clouds



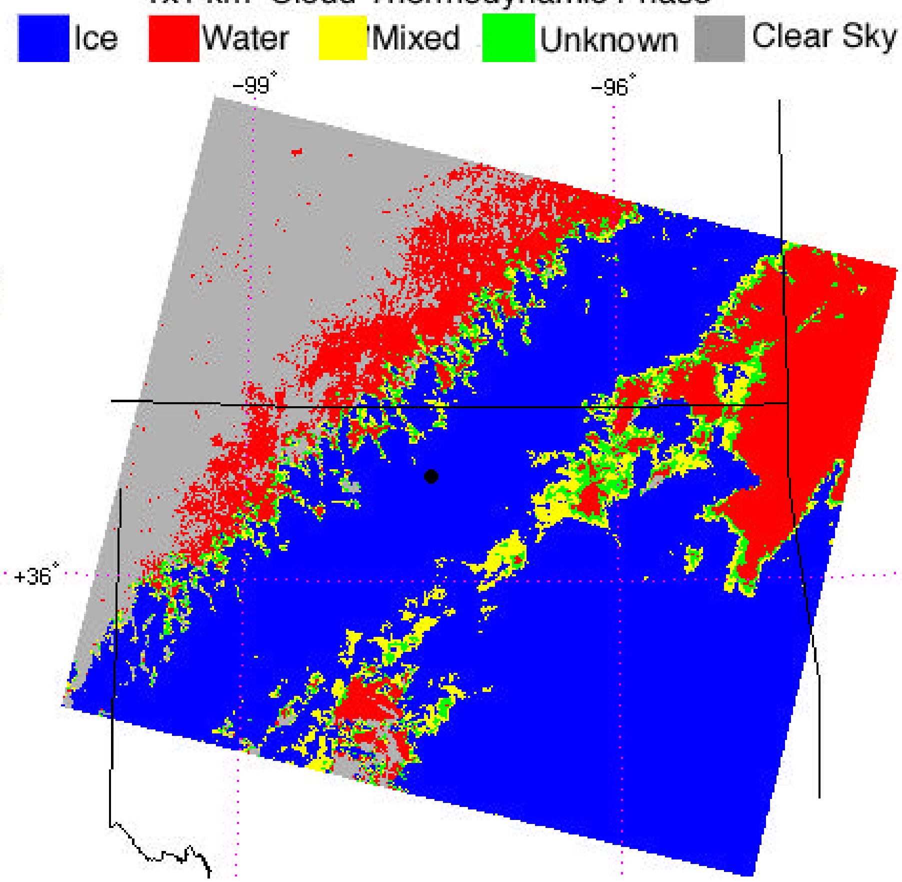
Cloud Thermodynamic Phase

21 April, 2001 at 1745Z
ARM Southern Great Plains Site

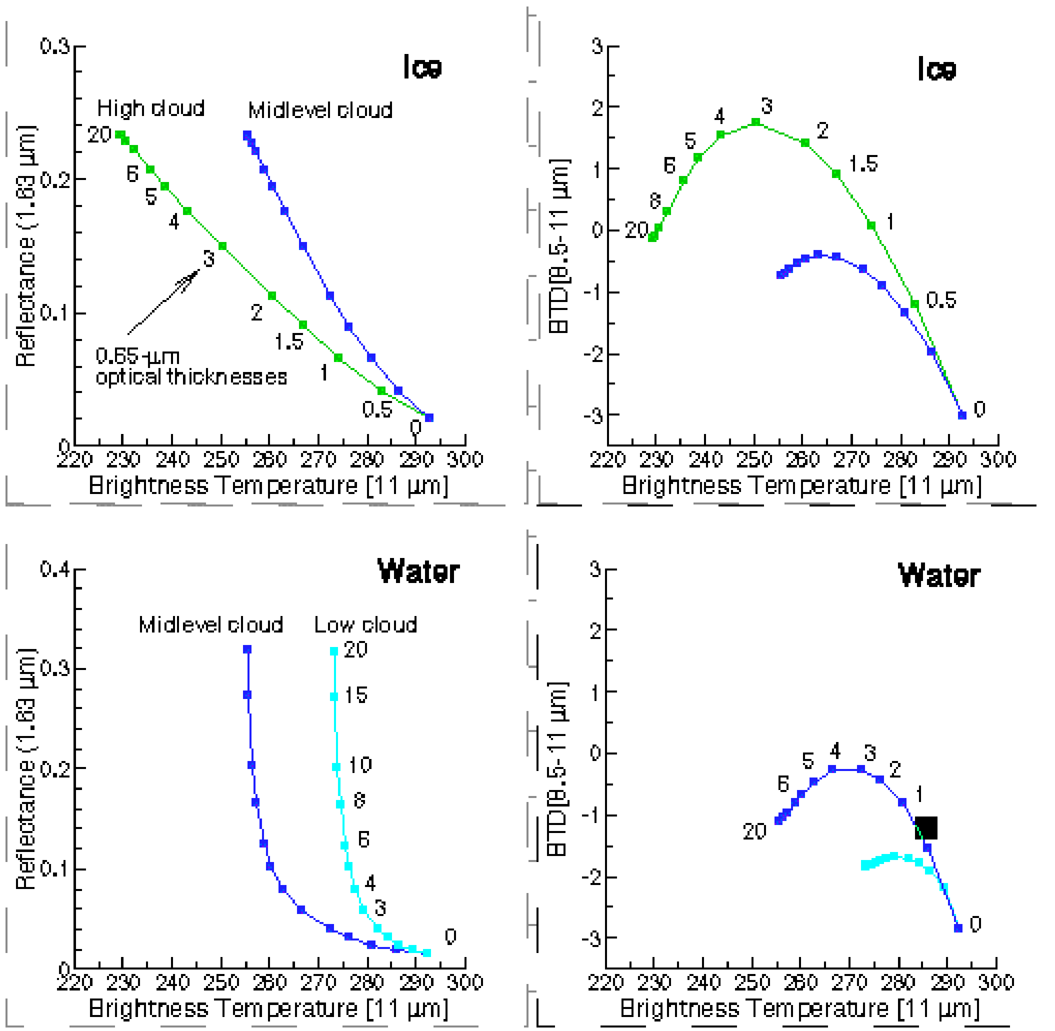
1x1 km MODIS False Color Cloud Phase Image
RGB = 0.65 µm R, 1.64 µm R, 11 µm BT (flipped)
magenta = ice cloud, yellow = water cloud,
green = vegetation



1x1 km Cloud Thermodynamic Phase



Simulations of Ice and Water Phase Clouds



Radiative transfer simulations for a cirrus model derived from in-situ data collected during the FIRE-I field campaign (upper two panels) and a water cloud having an effective radius of 10 μm. Viewing angles are $\theta_0 = 45^o$, $\theta = 20^o$, and $\phi = 40^o$ and midlatitude summer temperature and relative humidity profiles are assumed.

Ice clouds:

• BTD[8.5-11] > 0 over a large range of optical thicknesses
•1.6-μm reflectances for ice clouds tend to be lower than for water clouds

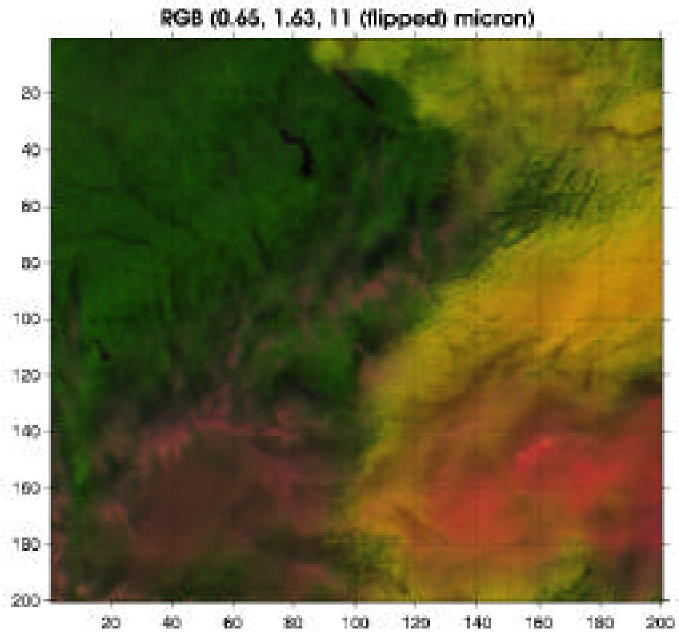
Midlevel clouds:

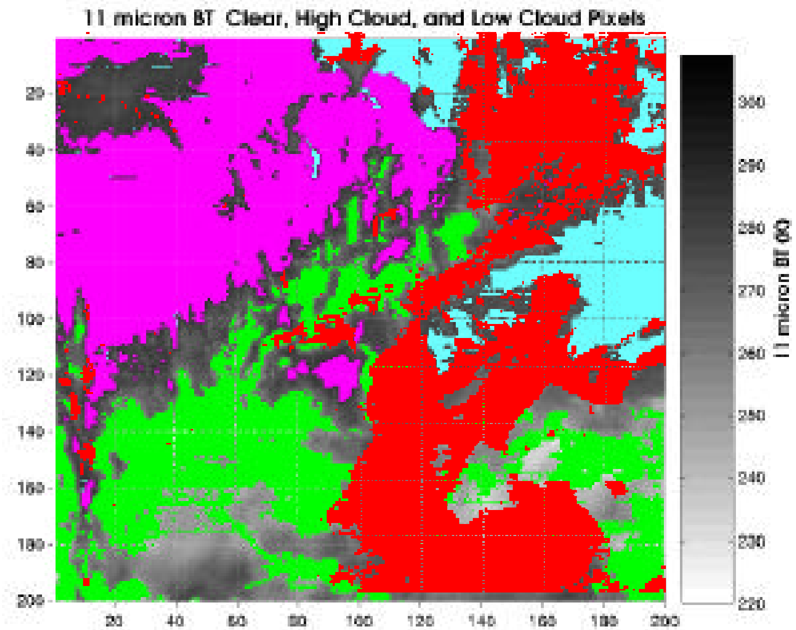
•BTD[8.5-11] < 0 for both water and ice clouds

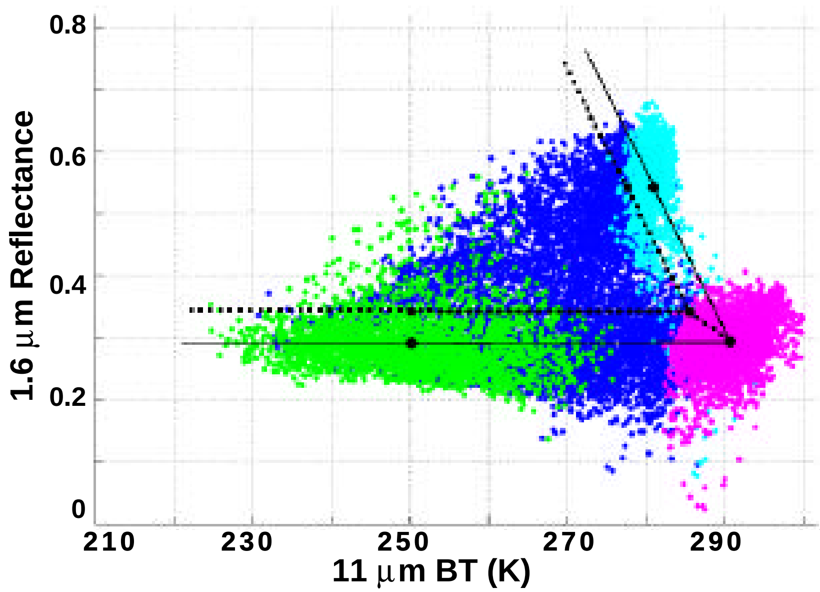
Low-level, warm clouds:

•BTD[8.5-11] always negative
•1.6-μm reflectances for water clouds tend to be higher than for ice clouds

200 by 200 pixels of MODIS Data from 15 Oct. 2000 at 1725Z







Low Cloud (from MODIS Phase)

High Cloud (from MODIS Phase)

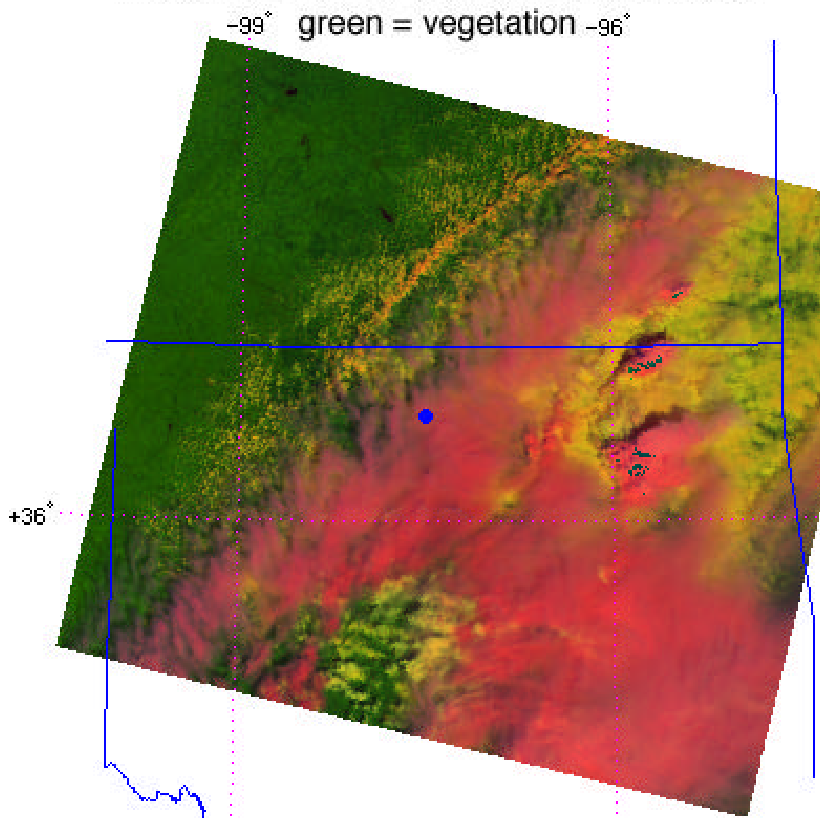
Clear (from MODIS Cloud Mask)

Other (to be determined)

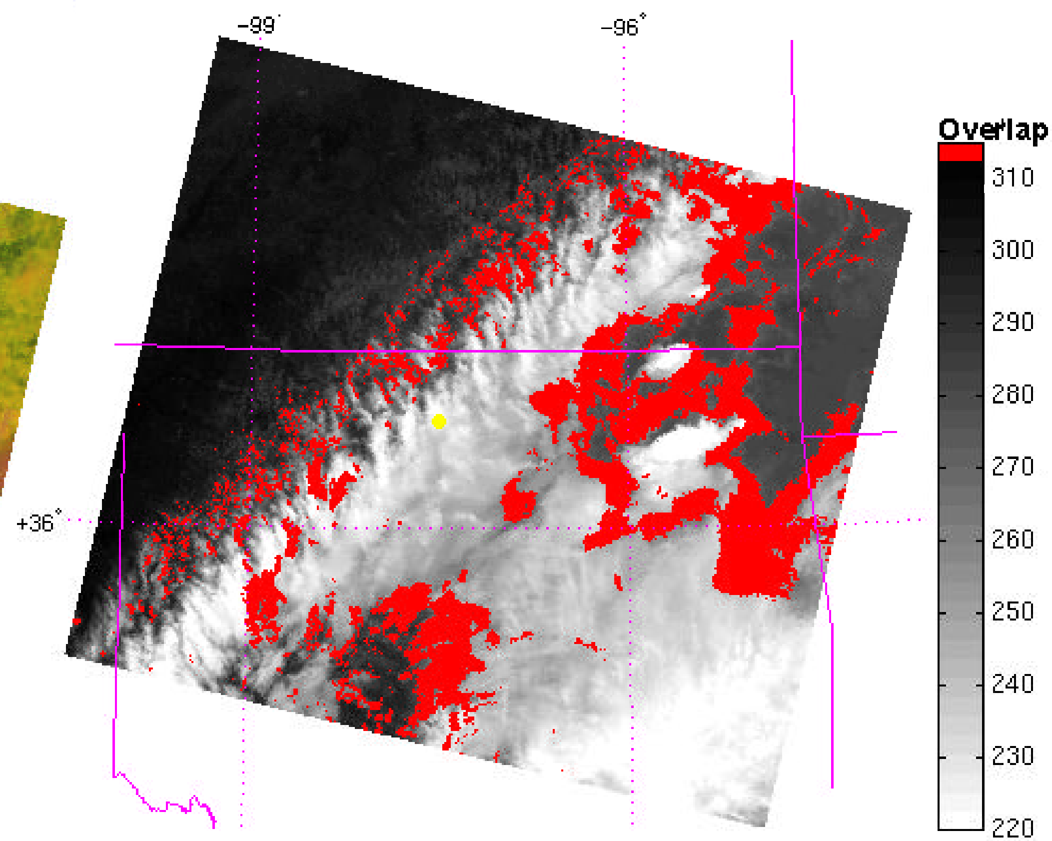
Cloud Overlap Detection

21 April, 2001 at 1745Z
ARM Southern Great Plains Site

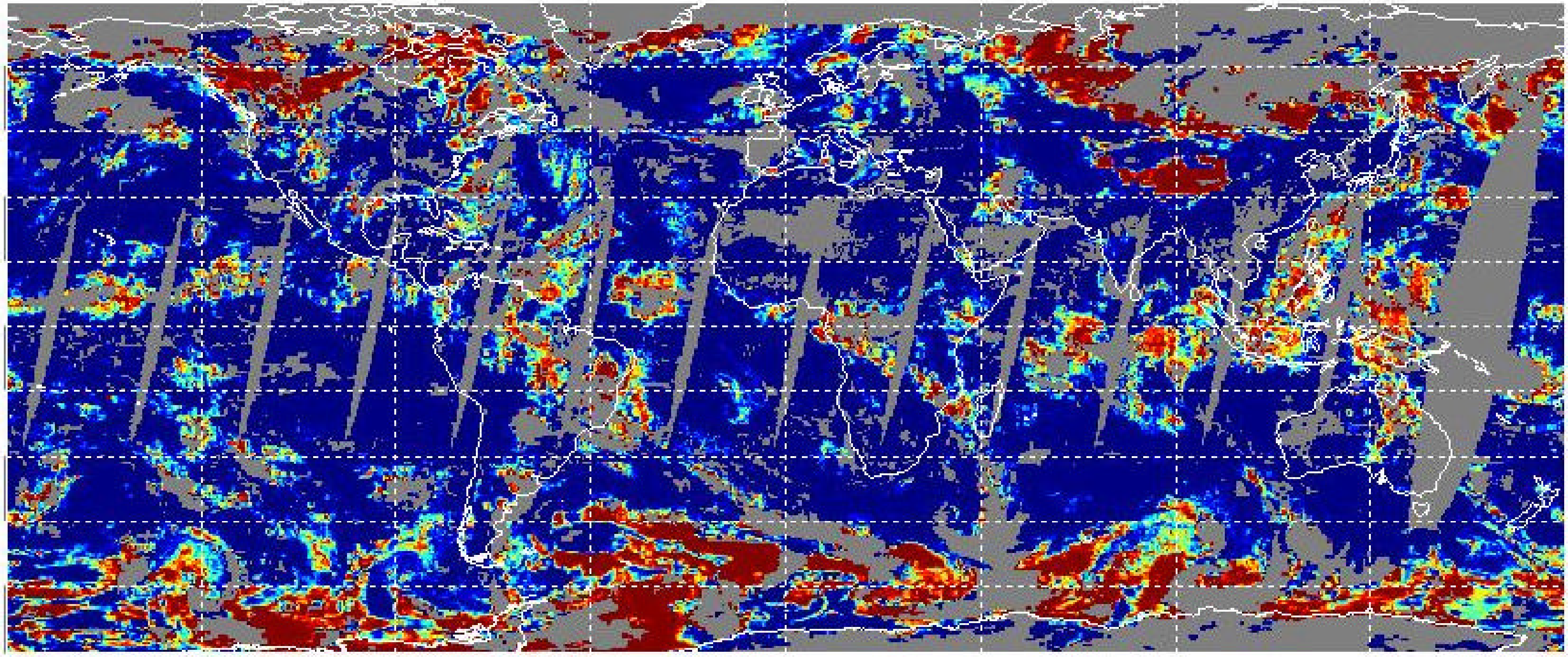
1x1 km MODIS False Color Cloud Phase Image
RGB = 0.65 µm R, 1.64 µm R, 11 µm BT (flipped)
magenta = ice cloud, yellow = water cloud,
green = vegetation

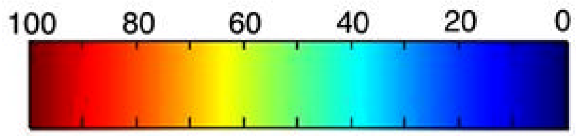


Potentially Overlapped Pixels in Red



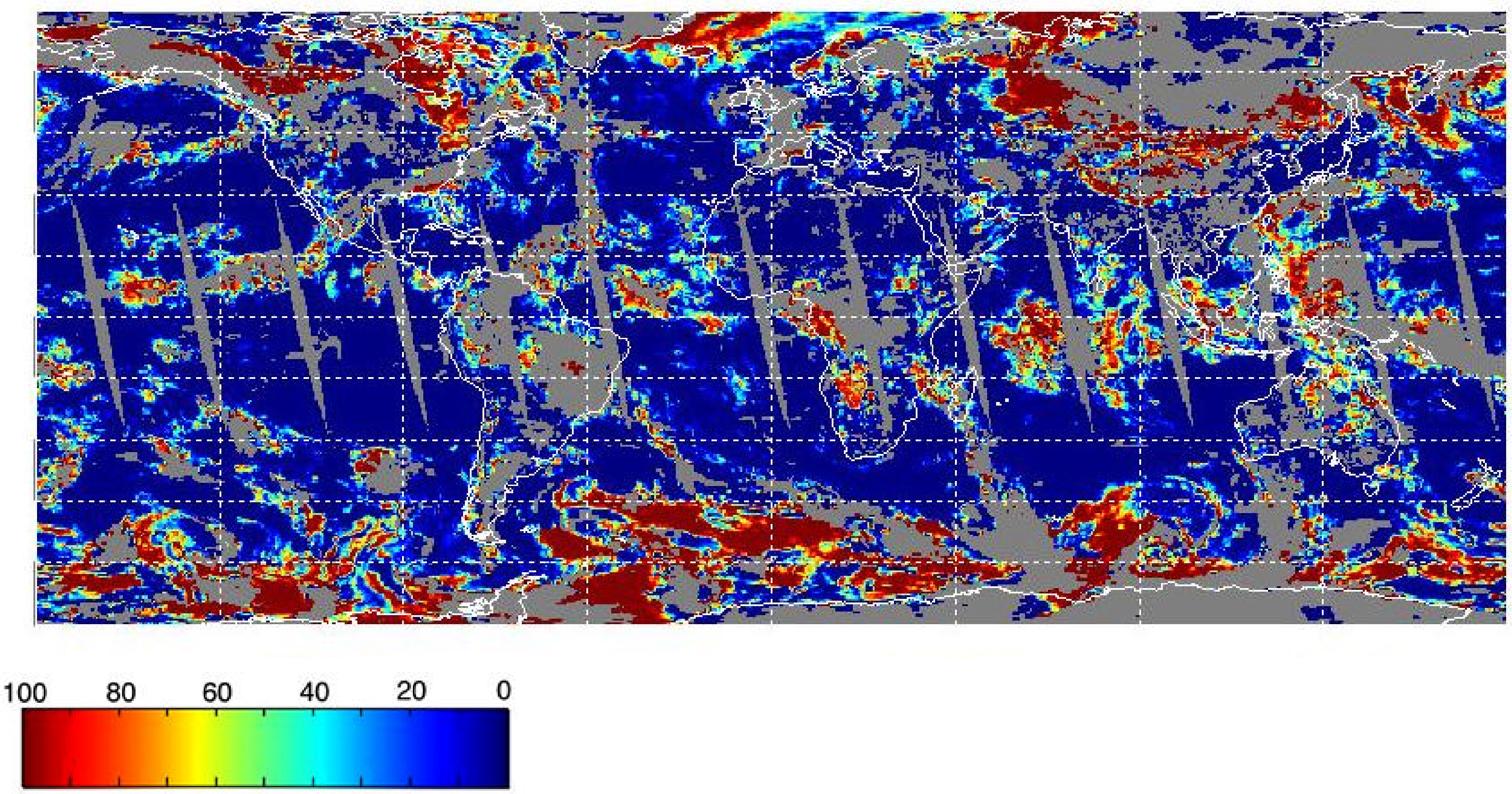
MODIS Frequency of Co-occurrence
Water Phase with 253 K < T_{cld} < 268 K
05 Nov. 2000 - Daytime Only





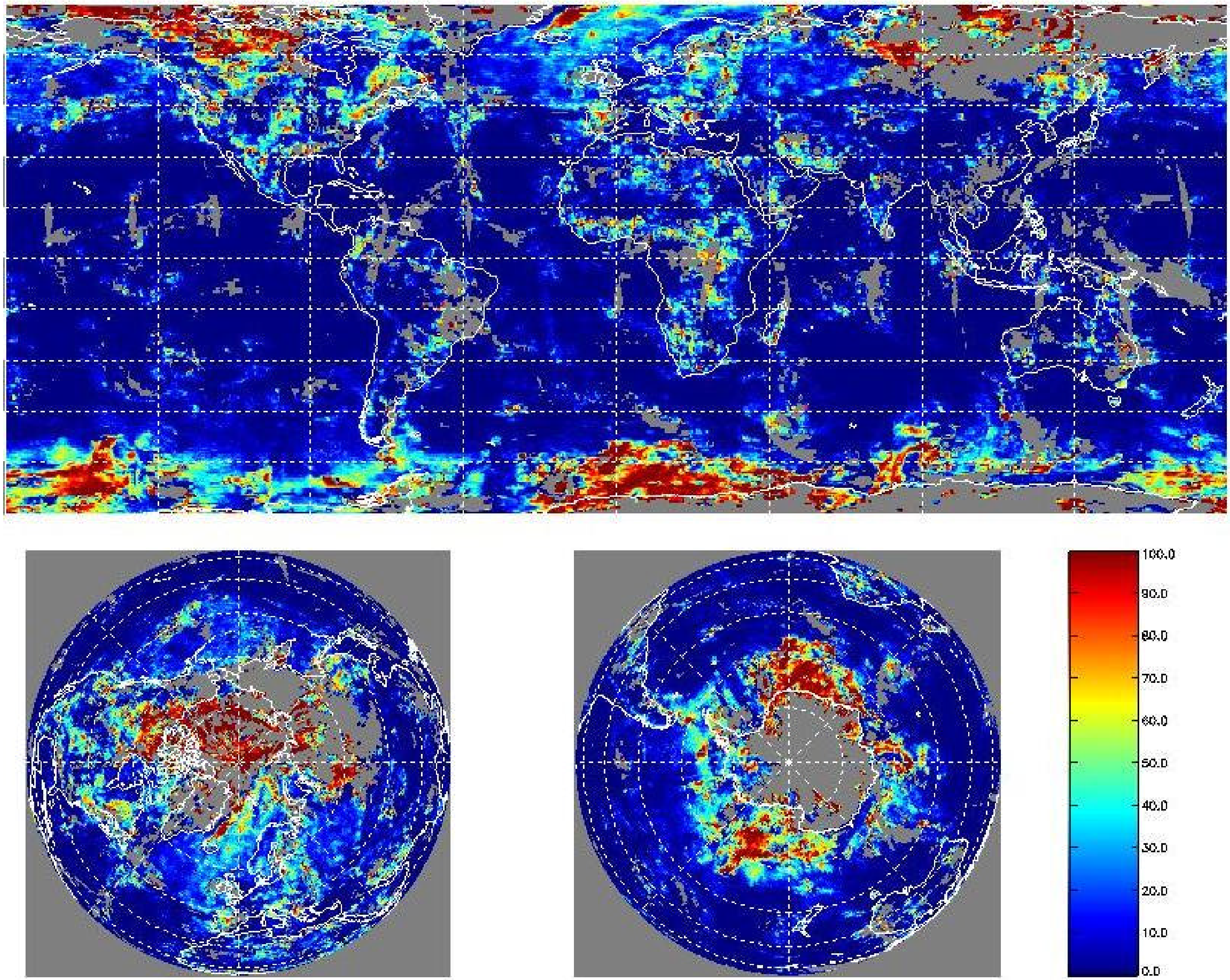
frequency of occurrence in percent (%)

MODIS Frequency of Co-occurrence
Water Phase with $253 < T_{cld} < 268$ K
05 Nov. 2000 - Nighttime Only



frequency of occurrence in percent (%)

Water phase clouds with $238K < T_c < 253K$



Early Estimates of UW MODIS Cloud Products Quality

Cloud mask has demonstrated advantages of new multispectral approach;
  sun glint, desert, and polar problems diminished.

MODIS cloud top pressures compare well with GOES;
  aircraft validation is better than 50 mb;
  best product from de-striped data;
  validated with known characteristics.

MODIS cloud phase determinations are revealing interesting patterns;
  first global day/night ice/water cloud determinations;
  validations pending (e.g. CLEX).

Validation committee incognito

Early Estimates of MODIS Cloud and Atmospheric Products Quality

IR radiances agree to within 1.5 C with GOES and ER-2 MAS/SHIS
Cloud mask has demonstrated advantages of new multispectral approach;
- **sun glint, desert, and polar problems diminished.**

Layer tropospheric temperatures compare well with AMSU
- **rms better than 1 C, both within 2 C of radiosonde observations;**

Layer dewpoint temperatures depict gradients very well
- **are within 2-3 C rms of radiosonde observations.**

IR total precipitable water vapor within 3 mm rms
- **captures TPW gradients very well over oceans**
- **has been improved over daytime non vegetated land**

Ozone is very close to the GOES ozone (over North America)
- **rms of about 10 Dobsons**
- **polar extreme ozone values will be improved with more training data.**

Polar winds represent coherent atmospheric motion;
- **geo-like quality observed**
- **within 7 – 10 m/s of the few raobs available for validation**

Cloud top pressures compare well with GOES
- **aircraft validation is better than 50 mb**

Cloud phase determinations are revealing interesting patterns
- **first global day/night ice/water cloud determinations**

Provisional Products

- Product quality may not be optimal
- Incremental product improvements are still occurring
- General research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
- Users are urged to contact science team representatives prior to use of the data in publications
- May be replaced in archive when the validated product becomes available

Validated Products

- Formally validated product, although validation is still ongoing
- Uncertainties are well defined
- Ready for use in scientific publications, and by other agencies
- There may be later improved versions
- Earlier validated versions will be deleted from the archive after a 6 month overlap period, but code for earlier versions will be maintained indefinitely