MODIS CTP (MOD06) Webinar #7

Cloud top pressure, effective emissivity, and phase

Studying Clouds

The CTP Problem

The CO2 Slicing Solution

Resolving some early Issues

C6 Results

20 August 2014

Richard Frey, Bryan Baum, Andy Heidinger,
Steve Ackerman, Brent Maddux, Paul Menzel

Studying Clouds

The difficulty in studying clouds

- Aerosols <0.1 micron, cloud systems >1000 km.
- Cloud particles grow in seconds: climate is centuries.
- Cloud growth can be explosive (e.g. thunderstorms) and carry a lot of energy.
- Cloud properties can vary by a factor of 1000 in hours.
- Few percent change in cloud cover can drive climate sensitivity
- Current climate models have resolutions of more than 100 km
- Cloud updrafts are a 100 m to a few km.

Clouds are important for understanding the global energy balance

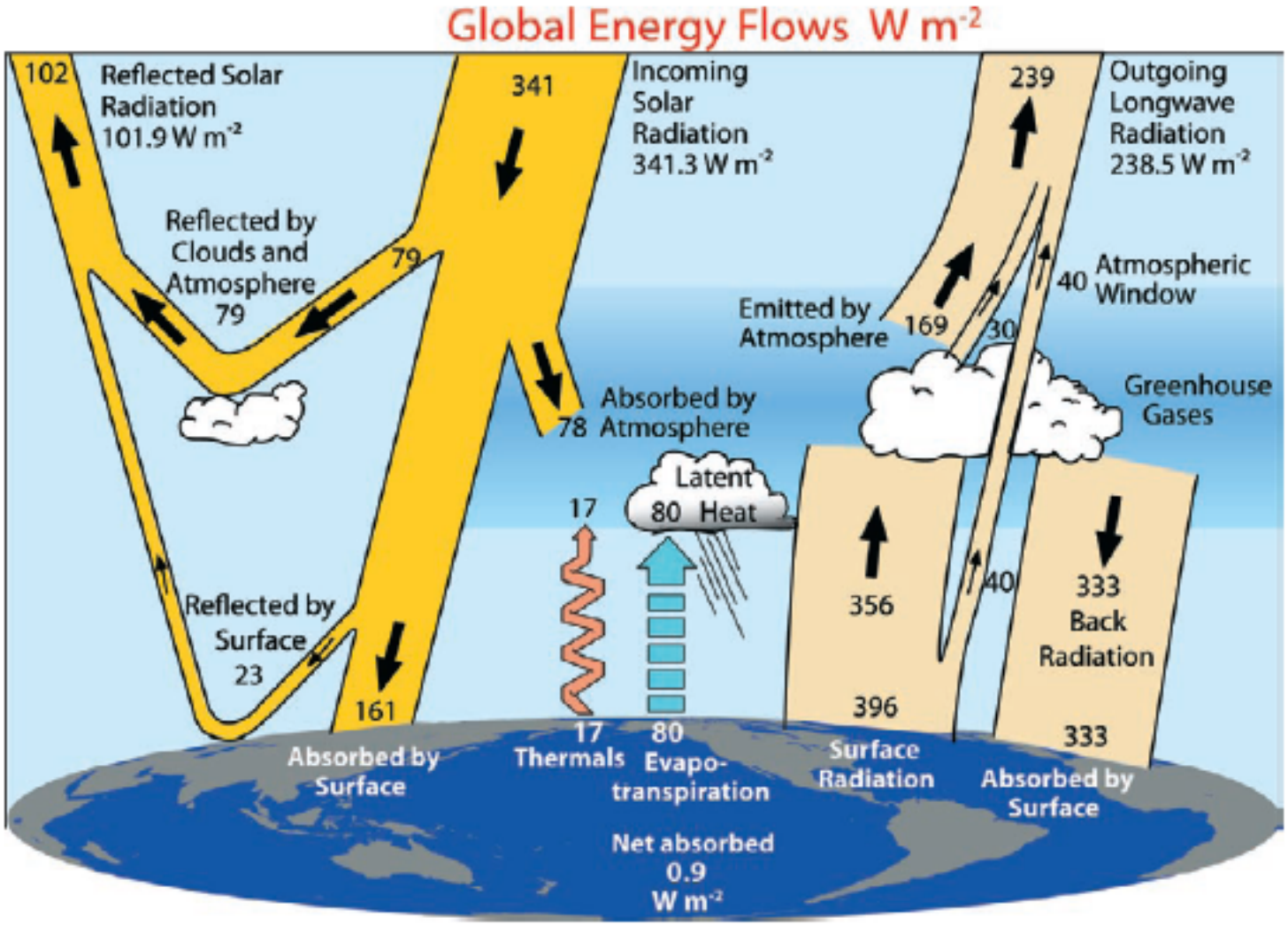


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Trenberth et al, BAMS 2009

Studying Clouds

clouds are a strong modulator of shortwave and longwave; their effect on global radiative processes is large

(1% change in global cloud cover equivalent to about 4% change in CO_2 concentration)

accurate determination of global cloud cover has been elusive

(semi transparent clouds often underestimated by 10%)

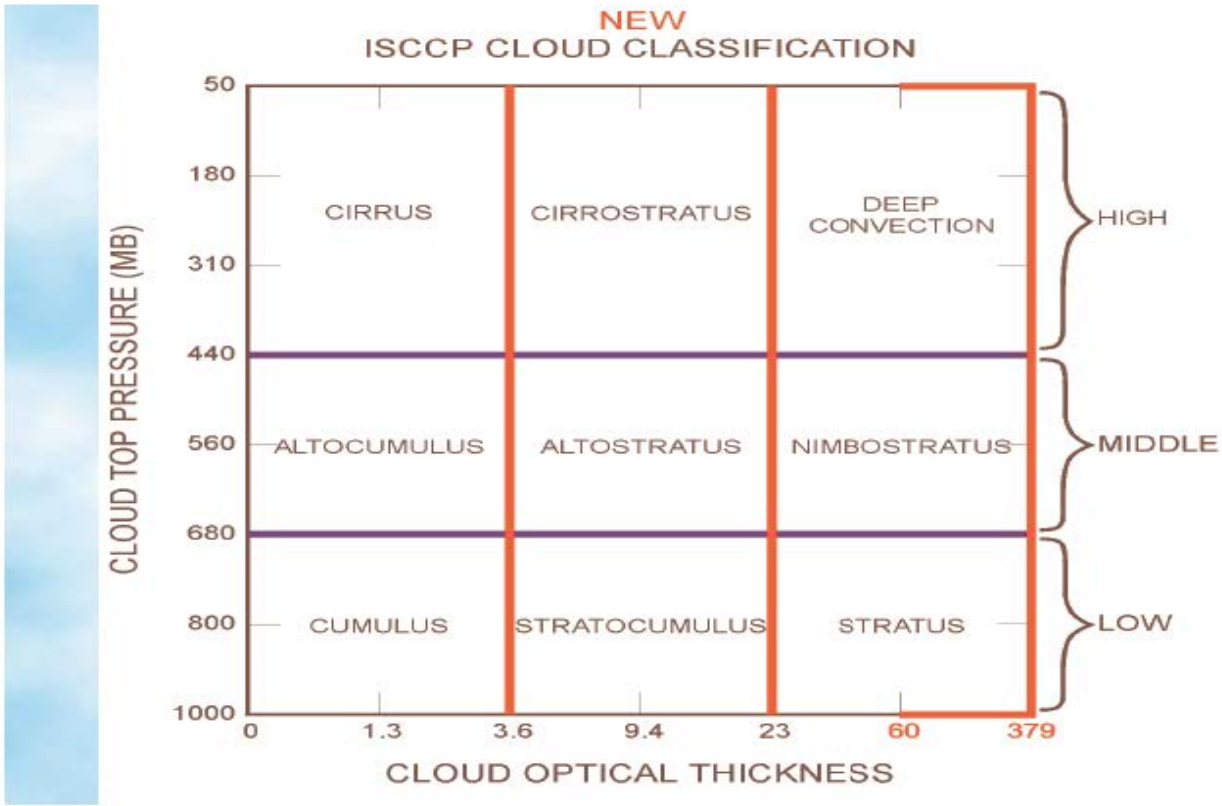
global climate change models need accurate estimation of cloud cover, height, emissivity, thermodynamic state, particle size

(high/low clouds give positive/negative feedback to greenhouse effect, and higher albedo from anthropogenic aerosols may be negative feedback)

there is a need for consistent long term observation records to enable better characterization of weather and climate variability

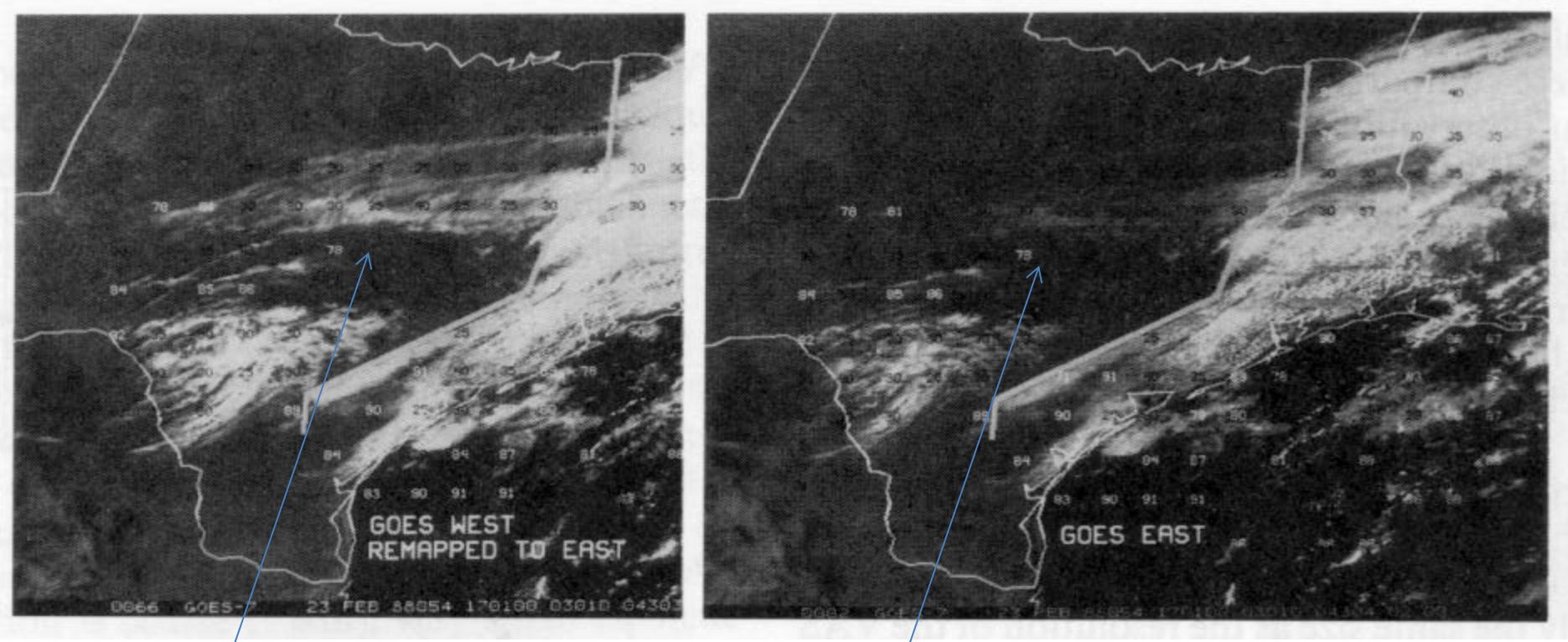
(ISSCP is a good start)

A global cloud climatology using imagers on geo & leo op weather satellites (GOES-E & –W, Meteosats, GMS, and am and pm AVHRRs).
5 countries collect and feed data to NASA/GISS.
VIS & IRW radiances are used.
Data are calibrated wrt NOAA-9.
Global cloud analysis is produced every 3 hours for tracking diurnal periods to decadal changes.
Data record of 1983 to 2006 is being expanded.



The CTP Problem

Cirrus detection has been elusive in the visible bands

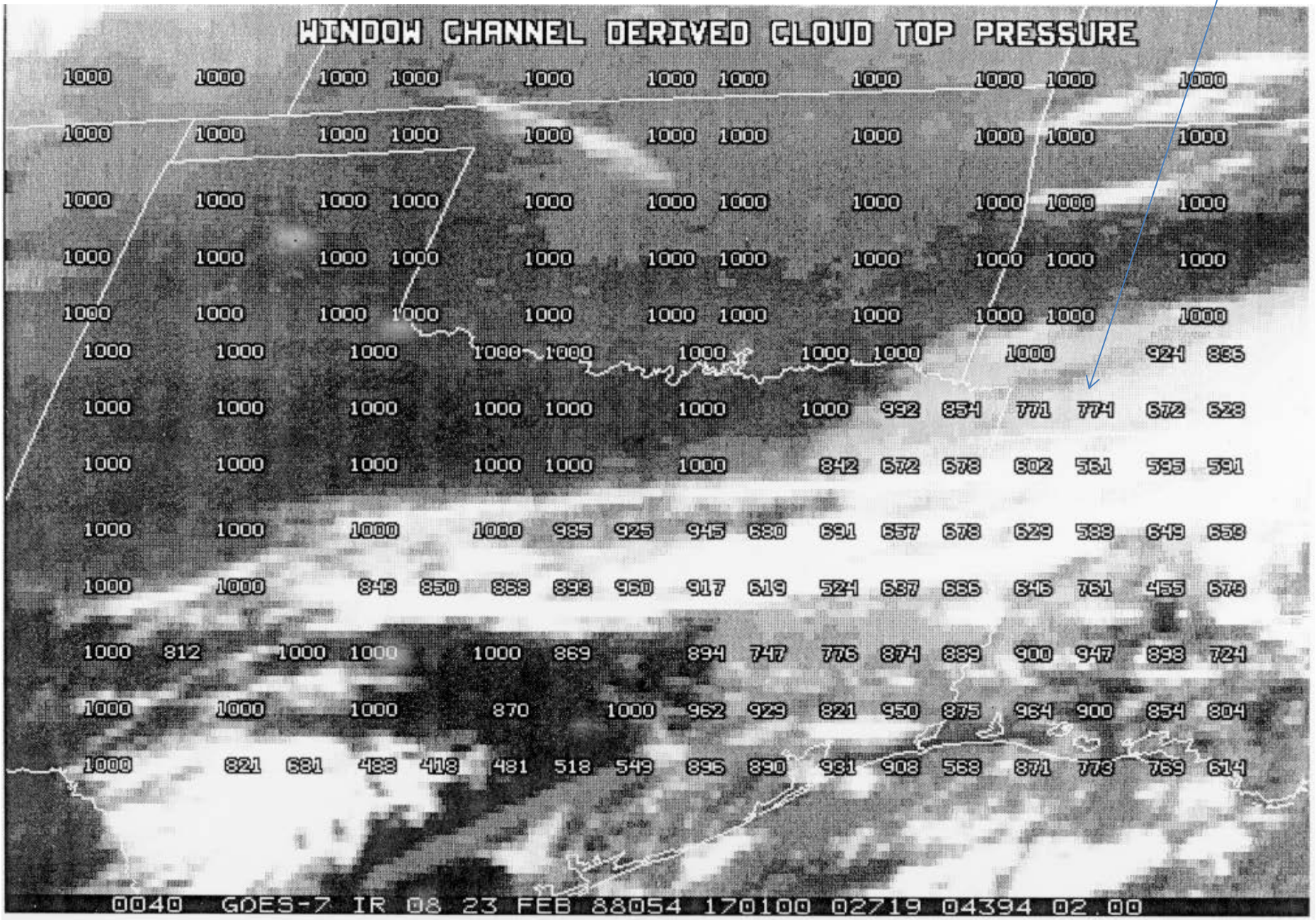


yes

no

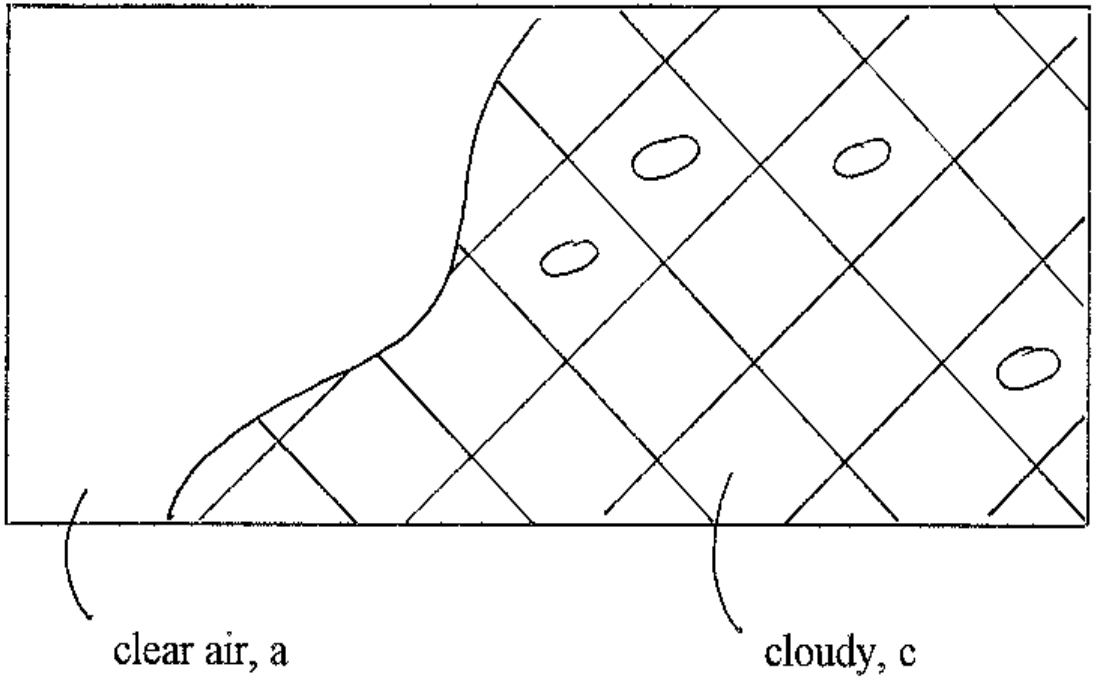
Depending on view angle cirrus is seen in visible image

IR window sees cirrus but places cloud height too low



Need correction for cloud semi-transparency

Radiance from a partly cloudy FOV



$$R=[1-N\varepsilon]R_{\text{clear air}} + N\varepsilon\, R_{\text{opq cld}}\,(P_c)$$

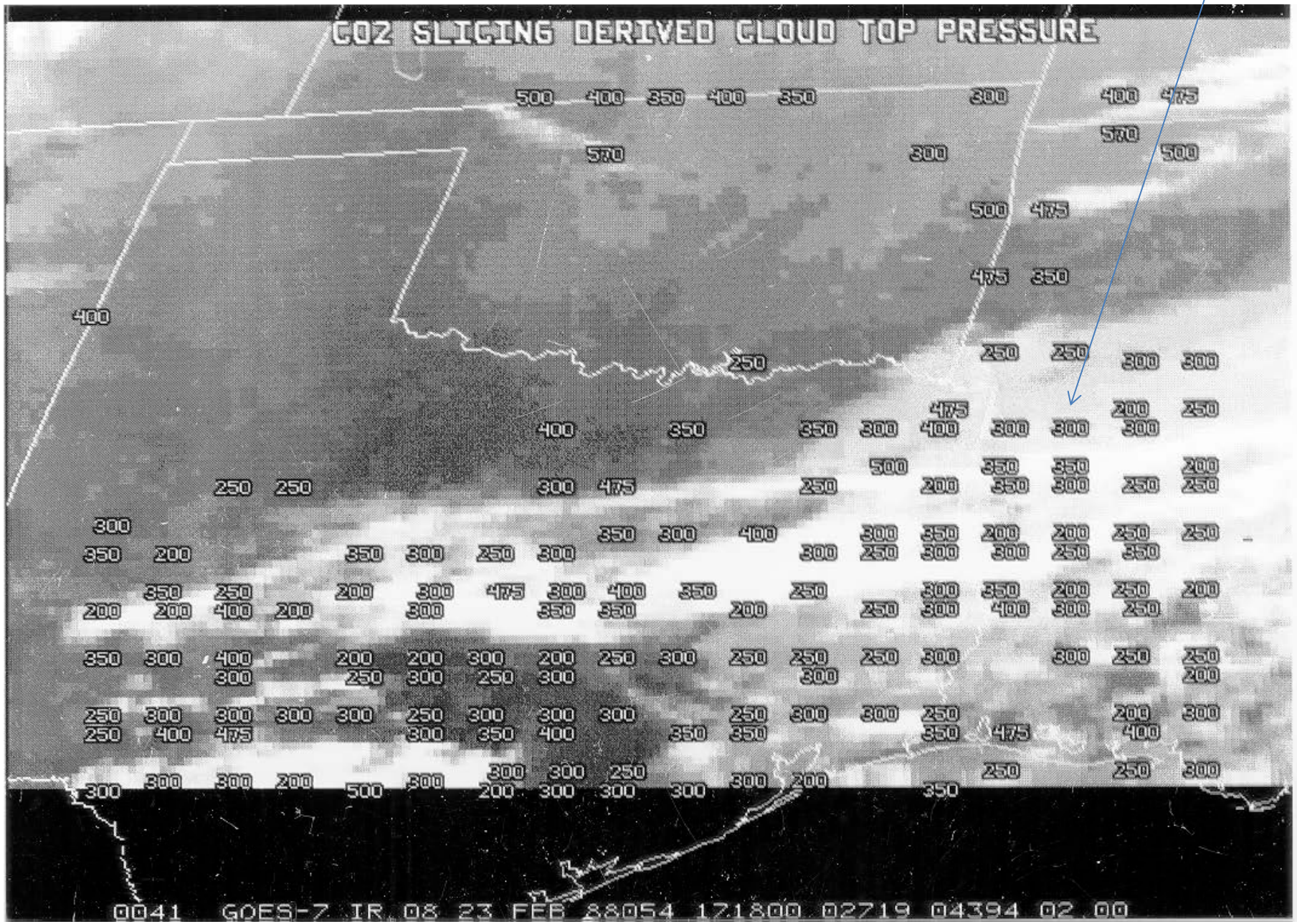
Two unknowns, $N\varepsilon$ and P_c, require two measurements

The CO2 Slicing Solution

Cloud Top Properties Algorithm Overview

Cloud-top properties (temperature, pressure, and effective emissivity) are derived using the IR window and longwave CO_2 absorption bands (both day and night). Pressure is derived from ratios of differences in radiances between cloudy and clear-sky regions at two spectrally close channels. Adjustments are made for radiance biases so that clear (calculated) and cloudy (observed) radiances are both referenced to the NCEP/EMC Global Forecast System forward calculated radiances. Effective cloud amount (cloud fraction times cloud emissivity at 11 μm) is derived using the inferred cloud top pressure and the radiative transfer equation for the 11 μm band. For low clouds (> 700 hPa), the CO_2 channel SNR decreases, so the IR window 11 μm brightness temperature is assumed to be the opaque cloud-top temperature and a cloud-top pressure is assigned using the NCEP/EMC GFS temperature profile. Cloud phase is primarily determined from the beta ratio of the 8.5 and 11 μm clear minus cloudy radiances with some IR adjustments for high versus low and thin versus thick clouds.

CO2 slicing corrects for semi-transparency of cirrus



RTE in Cloudy Conditions

$$I_\lambda = \eta\, I_\lambda^{cd} + (1 - \eta)\, I_\lambda^{clr}$$ where cd = cloud, clr = clear, η = cloud fraction

$$I_\lambda^{clr} = B_\lambda(T_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} B_\lambda(T(p))\, d\tau_\lambda \,.$$

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

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

ε_λ 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

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

Cloud Properties from CO2 Slicing

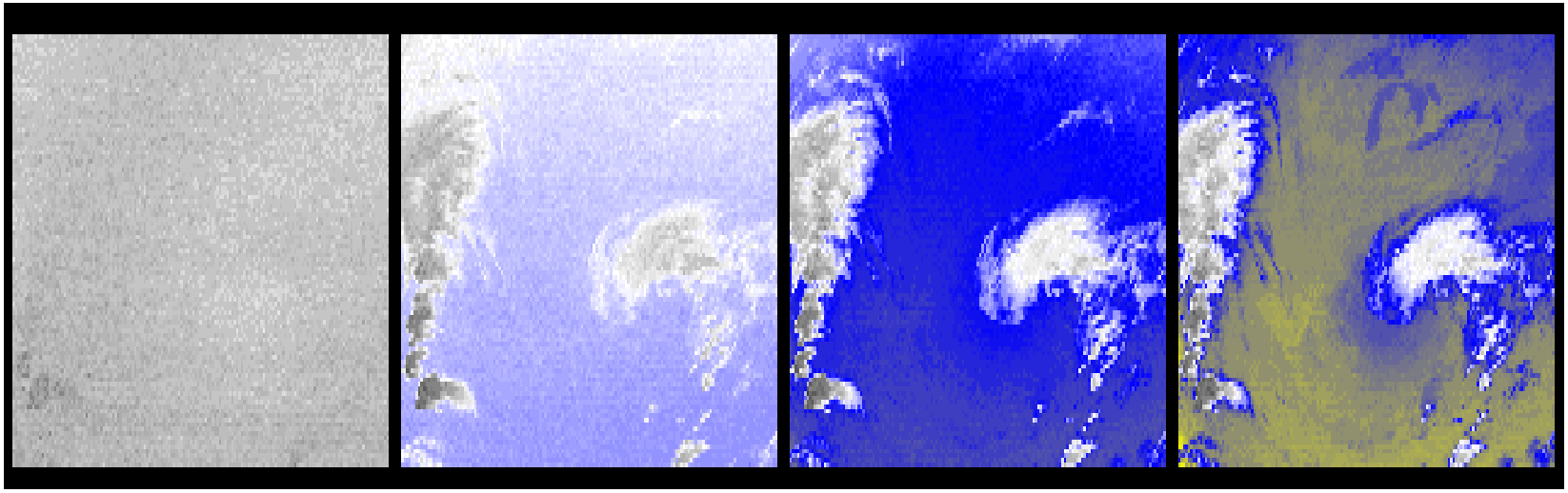
RTE for cloudy conditions indicates dependence of cloud forcing (observed minus clear sky radiance) on cloud amount ($\eta\varepsilon_\lambda$) and cloud top pressure (p_c)

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

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.

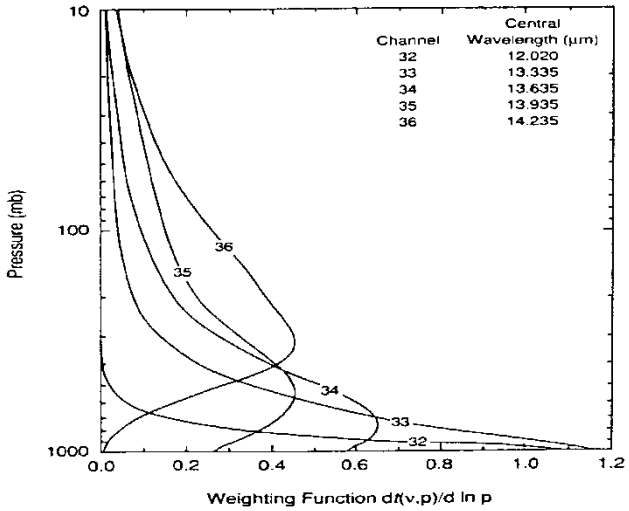
CO2 channels see to different levels in the atmosphere

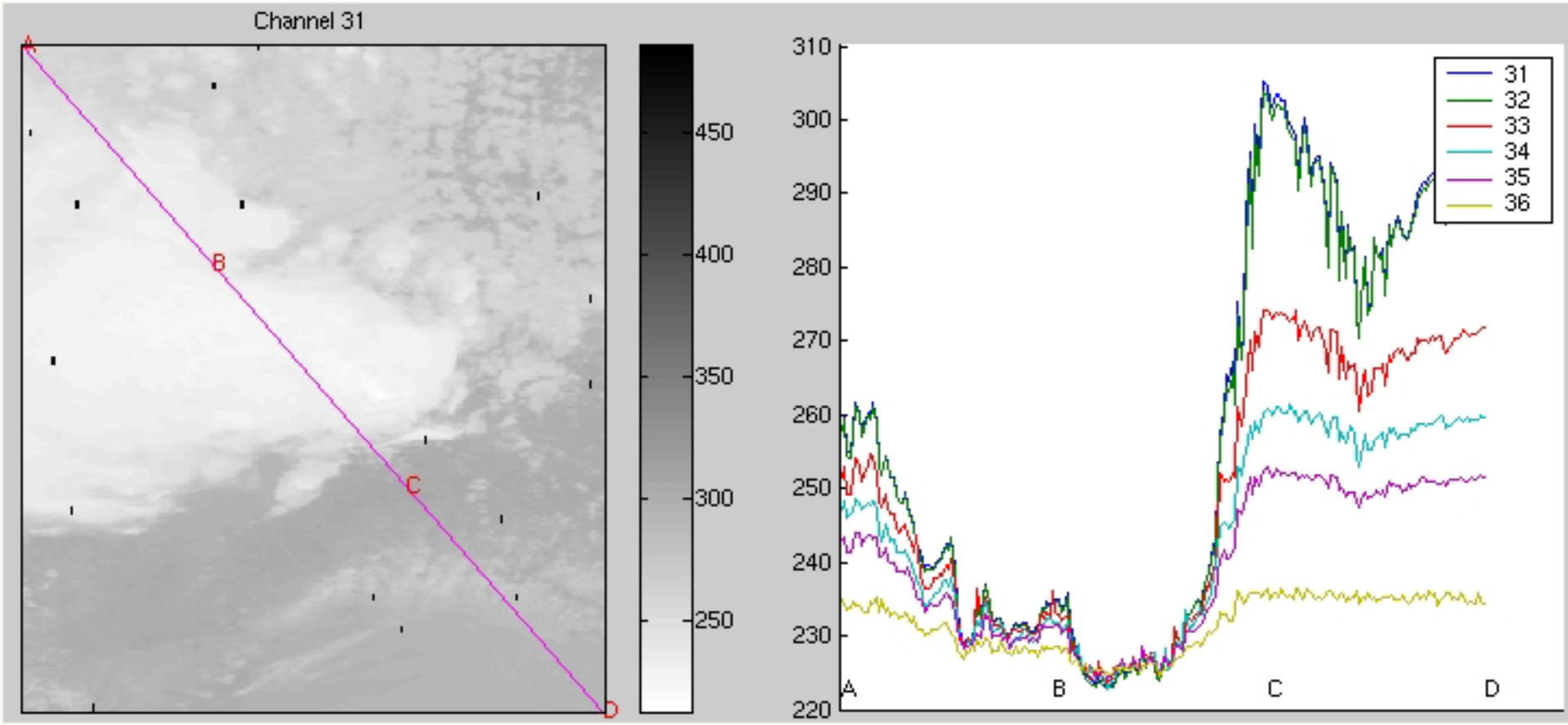


14.2 um 13.9 um 13.6 um 13.3 um

BTs in and out of clouds for MODIS CO_2 bands

demonstrate weighting functions and cloud top algorithm





CTPs using CO2 Slicing

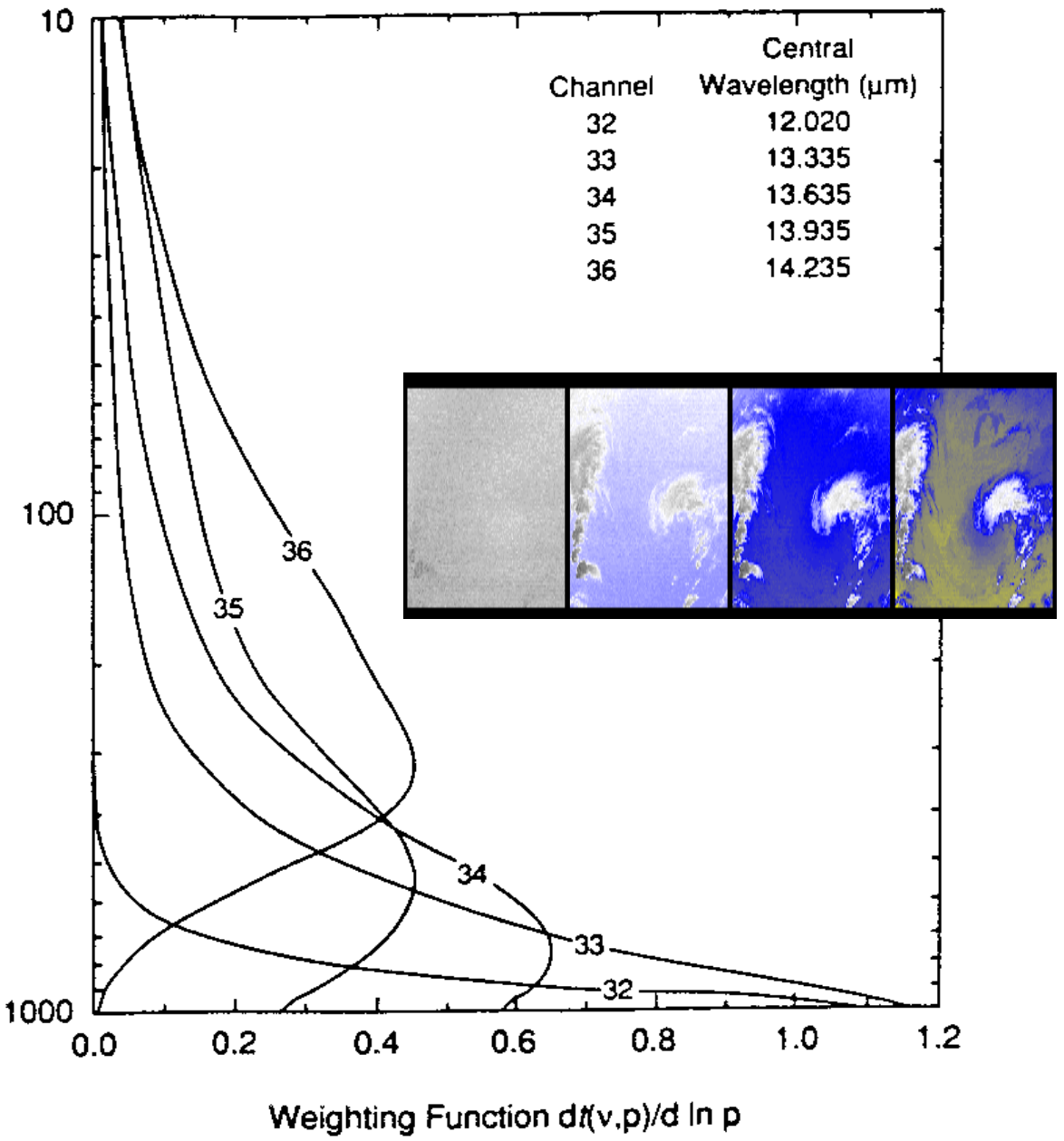
Different ratios reveal cloud properties at different levels

hi - 14.2/13.9
mid - 13.9/13.6
low - 13.6/13.3

Meas **Calc**

$$\frac{(I_{\lambda 1}-I_{\lambda 1}^{clr})}{(I_{\lambda 2}-I_{\lambda 2}^{clr})} = \frac{\eta\varepsilon_{\lambda 1}\int_{p_s}^{p_c}\tau_{\lambda 1}\,dB_{\lambda 1}}{\eta\varepsilon_{\lambda 2}\int_{p_s}^{p_c}\tau_{\lambda 2}\,dB_{\lambda 2}}$$

if $(I_\lambda^{clr} - I_\lambda) < \Delta$
then IRW is used



CTPs using CO2 Slicing

Different ratios reveal cloud properties at different levels

hi - 14.2/13.9
mid - 13.9/13.6
low - 13.6/13.3

Meas **Calc**

$$\frac{(I_{\lambda 1}-I_{\lambda 1}^{clr})}{(I_{\lambda 2}-I_{\lambda 2}^{clr})} = \frac{\eta\varepsilon_{\lambda 1}\int_{p_s}^{p_c}\tau_{\lambda 1}\,dB_{\lambda 1}}{\eta\varepsilon_{\lambda 2}\int_{p_s}^{p_c}\tau_{\lambda 2}\,dB_{\lambda 2}}$$

if $(I_\lambda^{clr} - I_\lambda) < \Delta$
then IRW is used

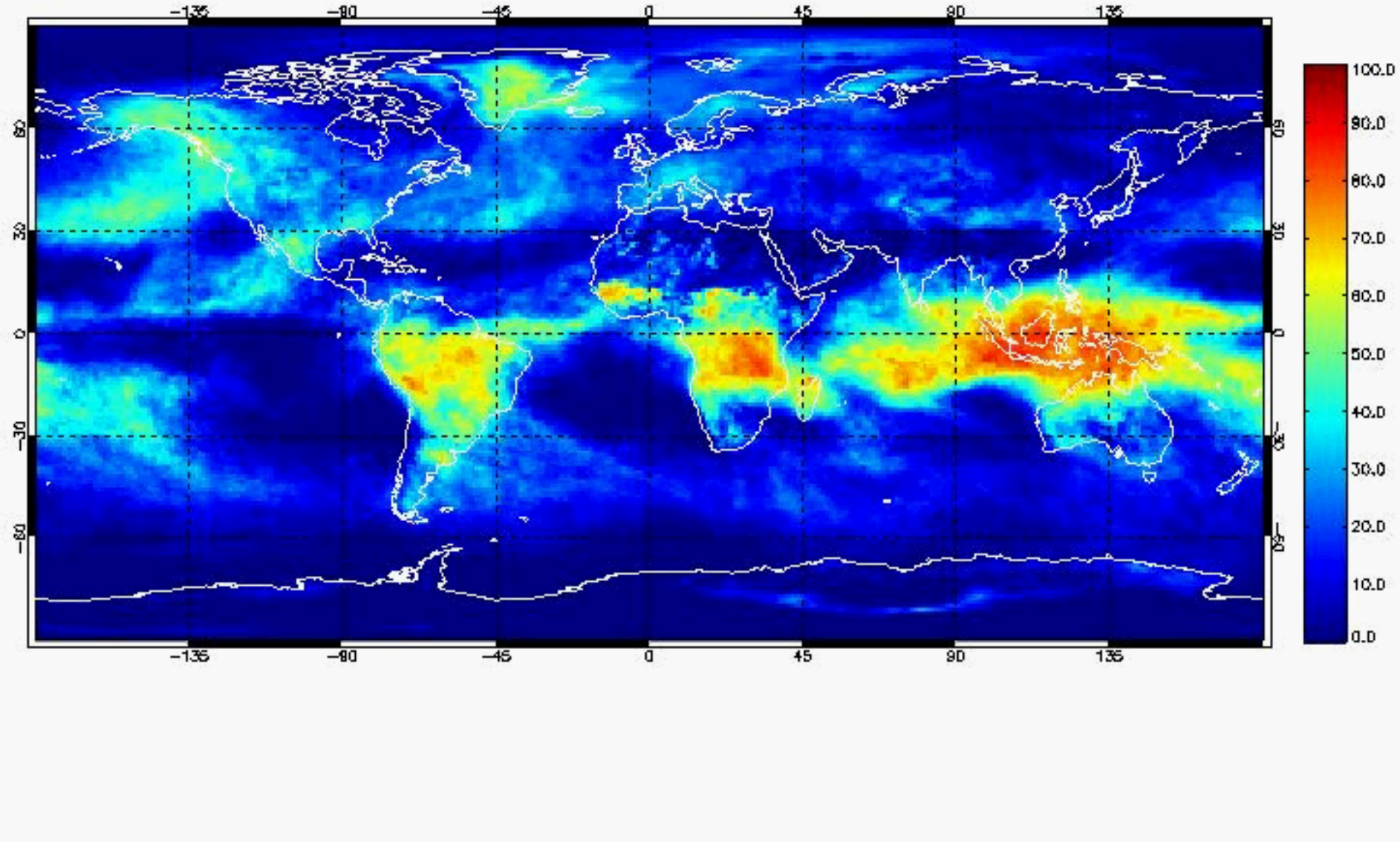
For spectrally close bands cloud emissivities are the same, $\varepsilon_{\lambda 1} = \varepsilon_{\lambda 2}$

Clear sky radiances I_λ are calculated from GDAS (Global Data Assimilation System)

Corrections up to several tenths of a radiance unit (W/m2/ster/μm) for observed minus calculated radiance differences are applied for eight day composites of clear sky observations (in 1 degree latitude bins accumulated separately for ocean-day&night, land-day, and land-night)

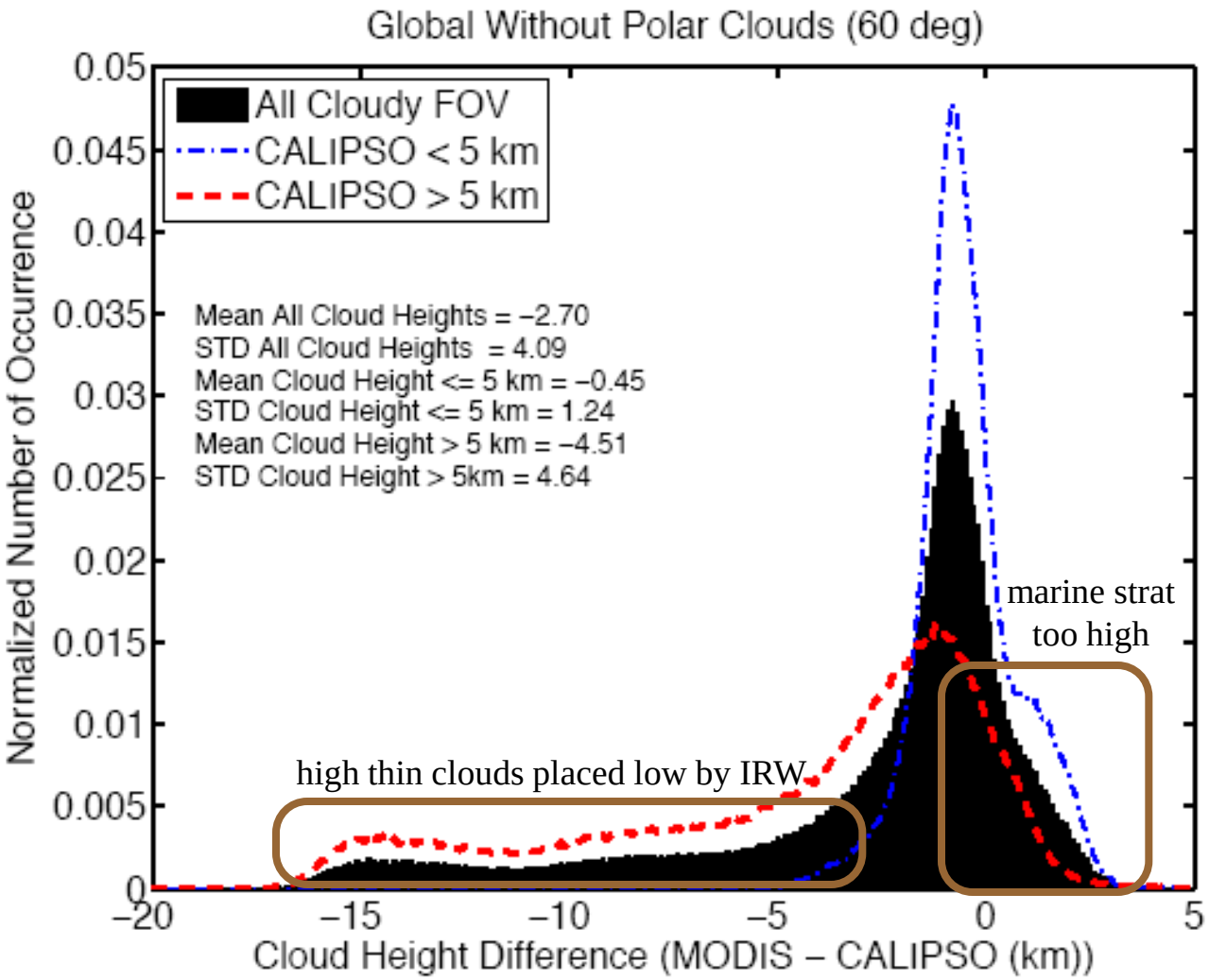
k

January 2001: MODIS High Clouds (0–400 mb)



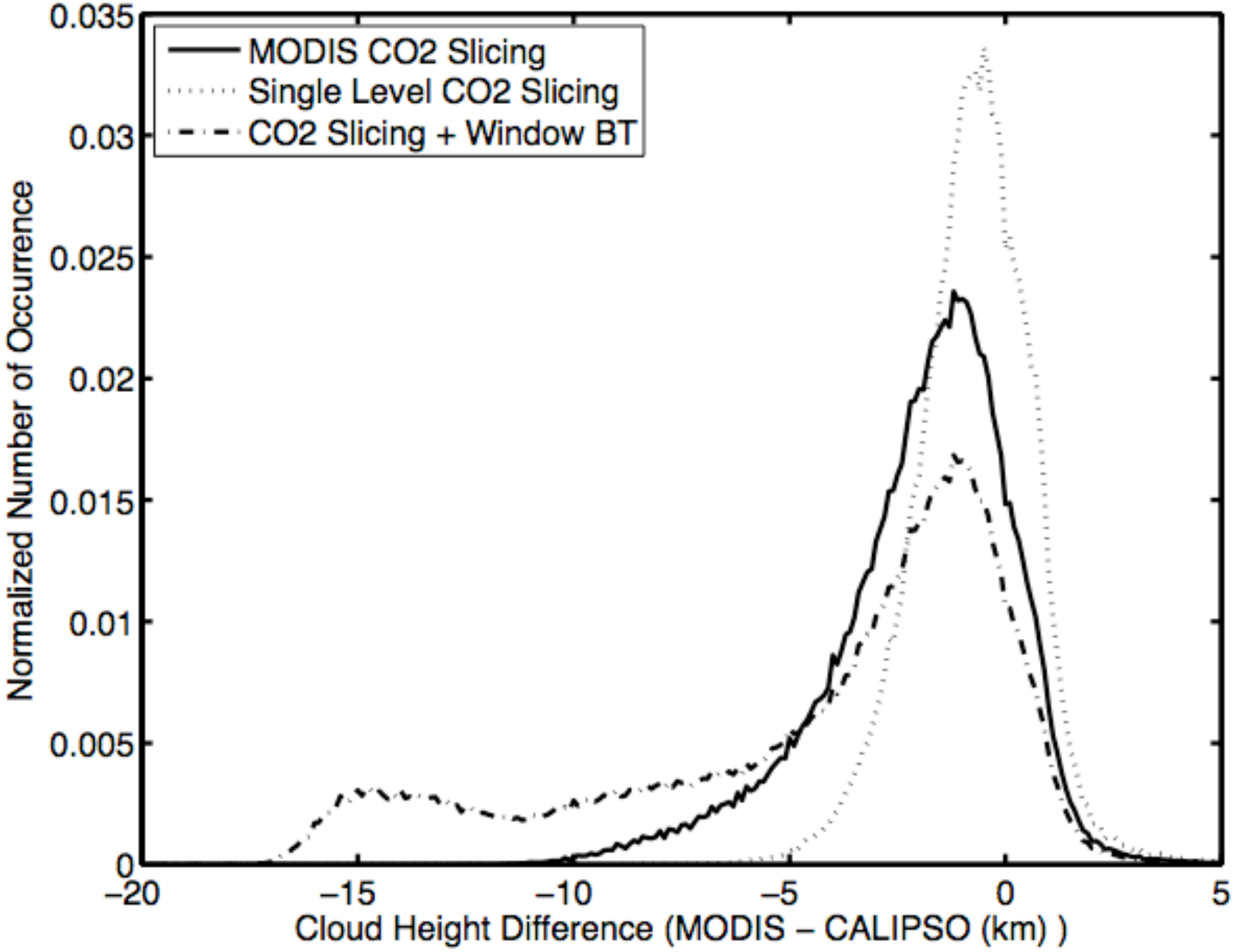
Resolving some early issues

MODIS C5 and CALIOP Cloud Properties Comparison

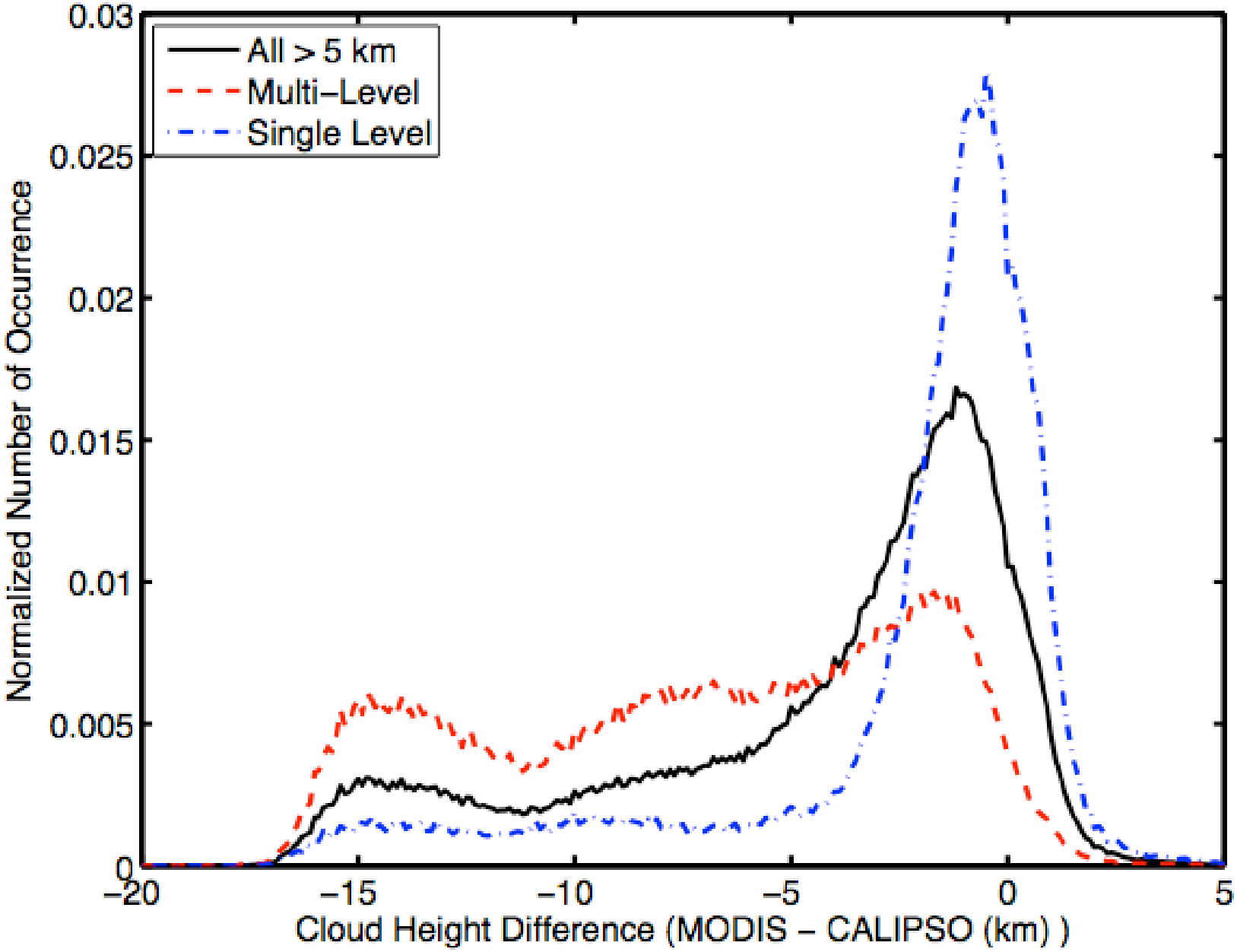


August 2006

Collect 5 Single Level CO2 Slicing CTHs



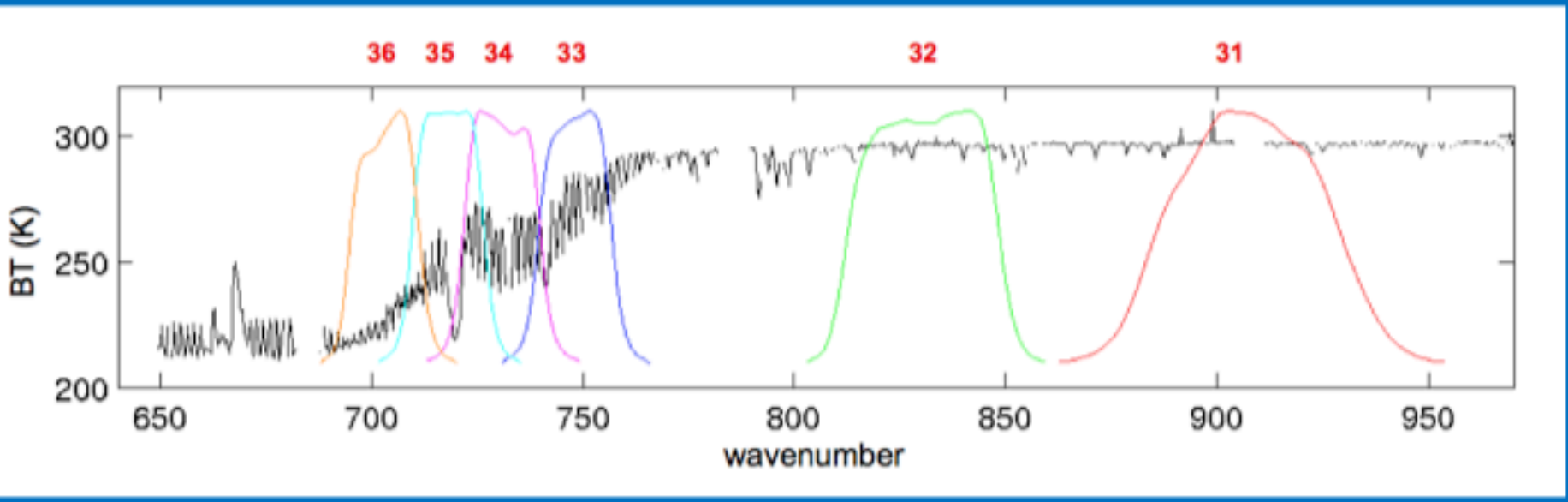
Collect 5 Impact of Multilevel Clouds



Summary of Changes for Collect 6 (MOD06CT & MYD06CT)

- **Lower "noise" thresholds** (clear minus cloudy radiances required to indicate cloud presence in CO_2 bands) enabling more CO_2 slicing solutions for high thin clouds.
- **Implement CO_2 spectral band shifts** suggested by Tobin et al. (JGR 2006) for Terra and Aqua MODIS.
- **Adjust ozone profile between 10 and 100 hPa** to GDAS values instead of using climatology (so that CO_2 radiances influenced by O_3 profiles are calculated correctly).
- **Incorporate sinusoidal CO2 increase**.
- **Prohibit CO_2 slicing solutions for water clouds**; use only IRW solution. **Avoid IRW solutions for ice clouds**; use CO_2 slicing whenever possible.
- **Restrict CO_2 solution to the appropriate part of troposphere** (determined by CO_2 band weighting functions so 36/35 < 450 hPa, 35/34 < 550 hPa, and 34/33 < 650 hPa).
- **Implement marine stratus improvement** where a constant lapse rate is assumed in low level inversions according to latitude region.
- **Add Upper Troposphere / Lower Stratosphere Flag**
- **Use Beta-ratios to determine cloud phase**.

Evaluation of MODIS Spectral Response Functions Using AIRS



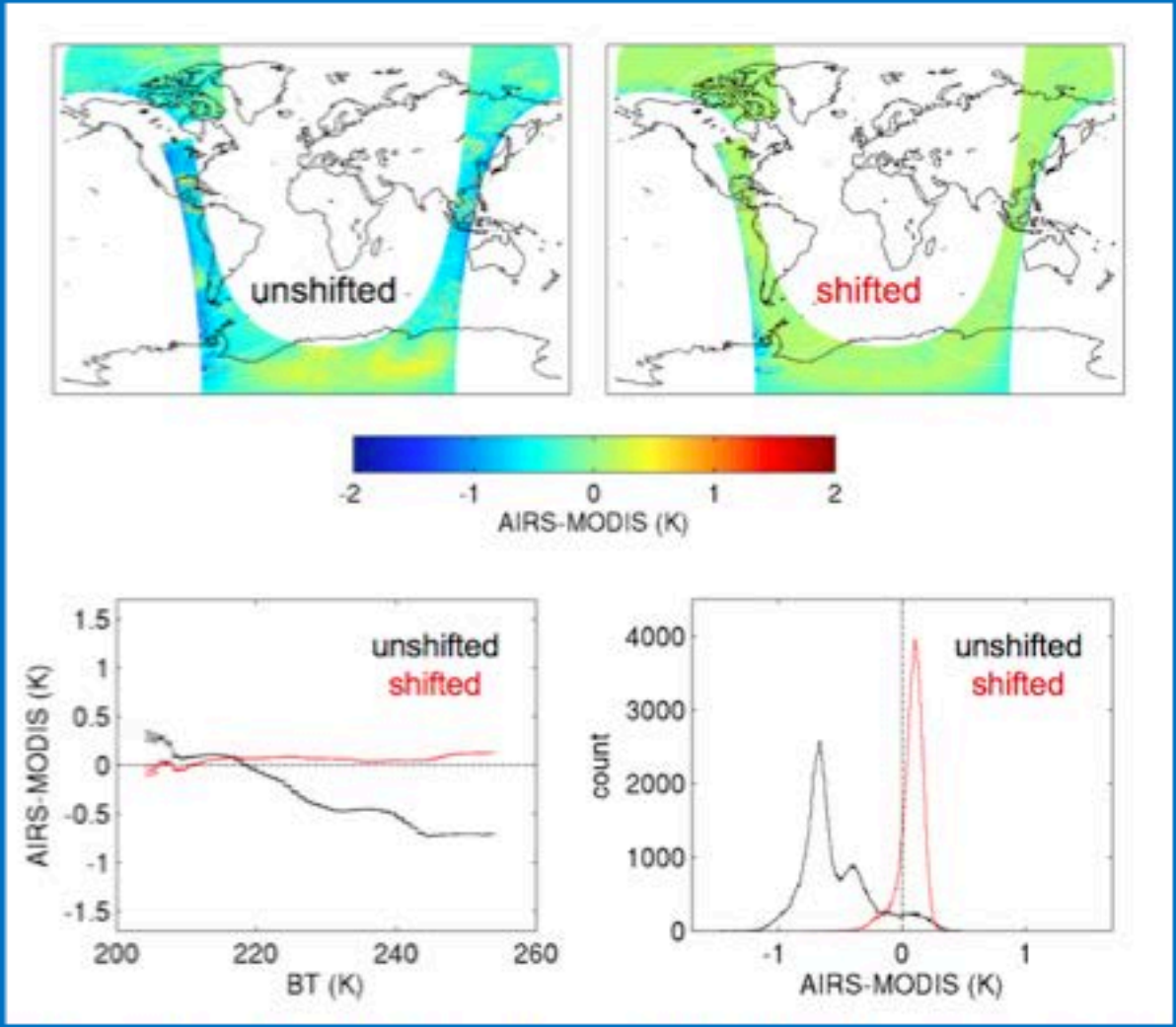
A sample AIRS brightness temperature spectrum (black line) collected on 18 February 2004 at ~0630 UTC off the east coast of Florida with the detector averaged Aqua MODIS spectral response functions (SRFs) overlaid. The MODIS spectral band numbers are noted along the top of the panel, with central wavelengths as follows: 31 (11 μm), 32 (12 μm), 33 (13.3 μm), 34 (13.6 μm), 35 (13.9 μm), and 36 (14.2 μm).

Tobin, D. C., H. E. Revercomb, C. C. Moeller, and T. S. Pagano, 2006: Use of Atmospheric Infrared Sounder high-spectral resolution spectra to assess the calibration of Moderate resolution Imaging Spectroradiometer on EOS Aqua. J. Geophys. Res., 111, D09S05, doi:10.1029/2005JD006095.

SSEC

AIRS minus MODIS Comparison: 13.9 microns

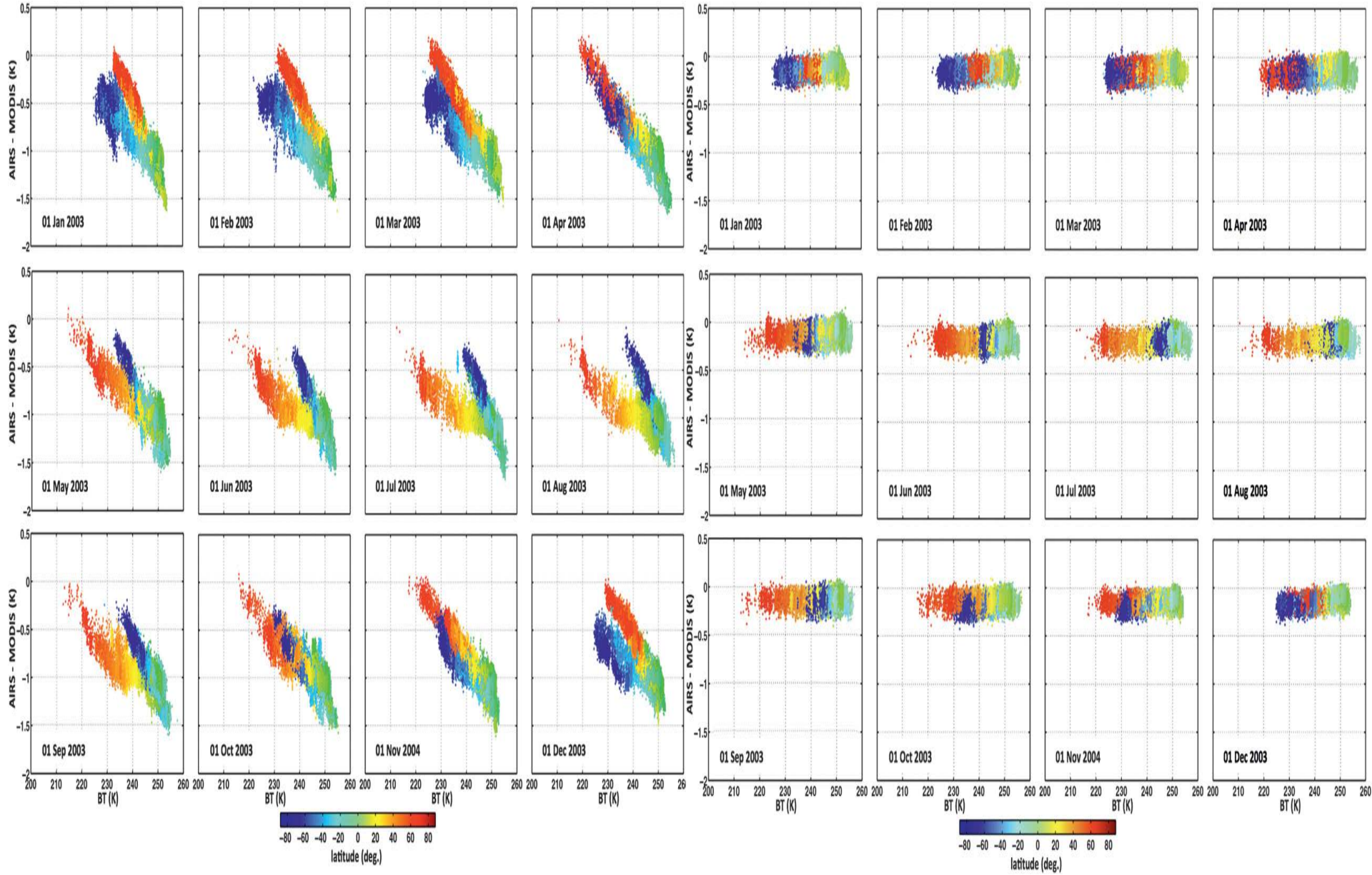
Exploring MODIS SRF Shifts



MODIS Band 35 (13.9 μm) brightness temperature differences using the nominal detector averaged MODIS SRF and using the SRF shifted by +0.8 cm^{-1} (15.5 nm) for one orbit on 6 September 2002. The panels are images of the brightness temperature differences without (left) and with (right) the shift.

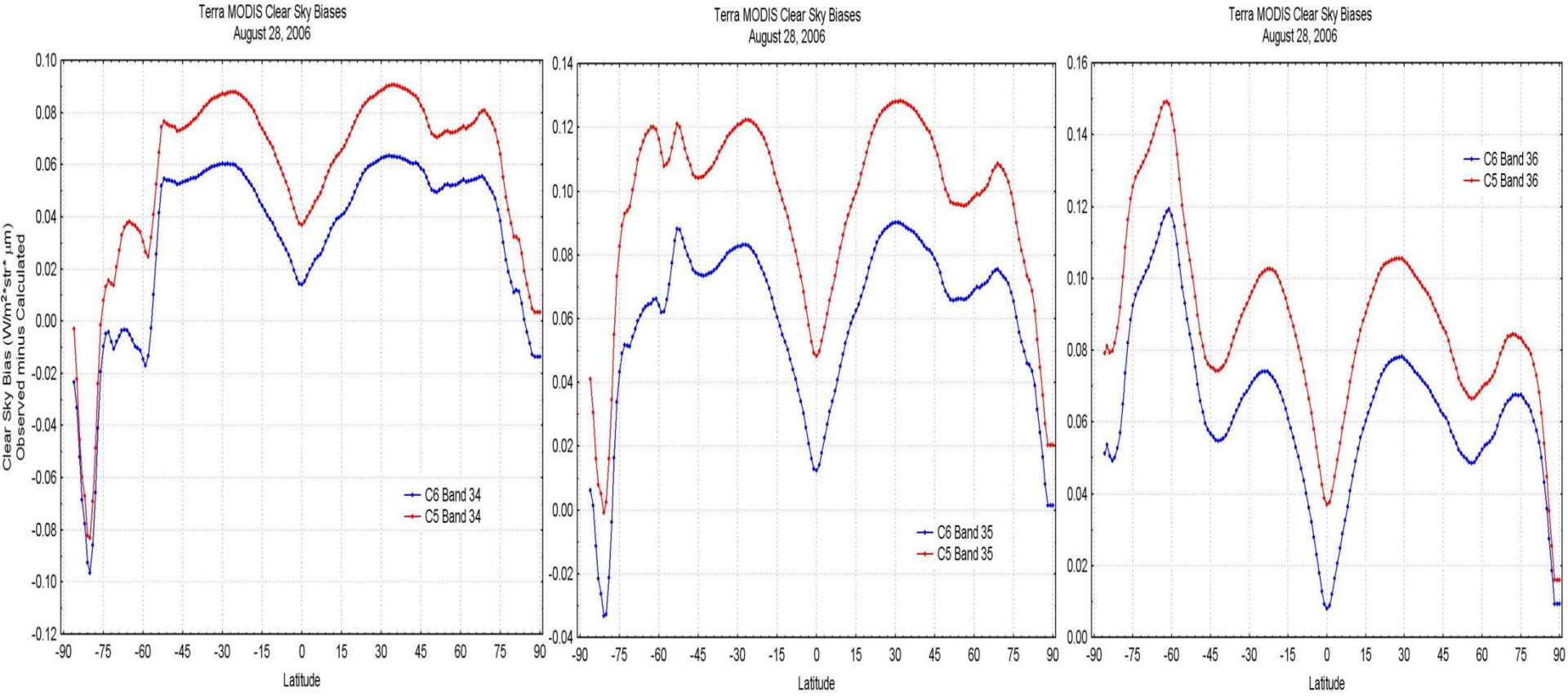
SSEC

Band 35



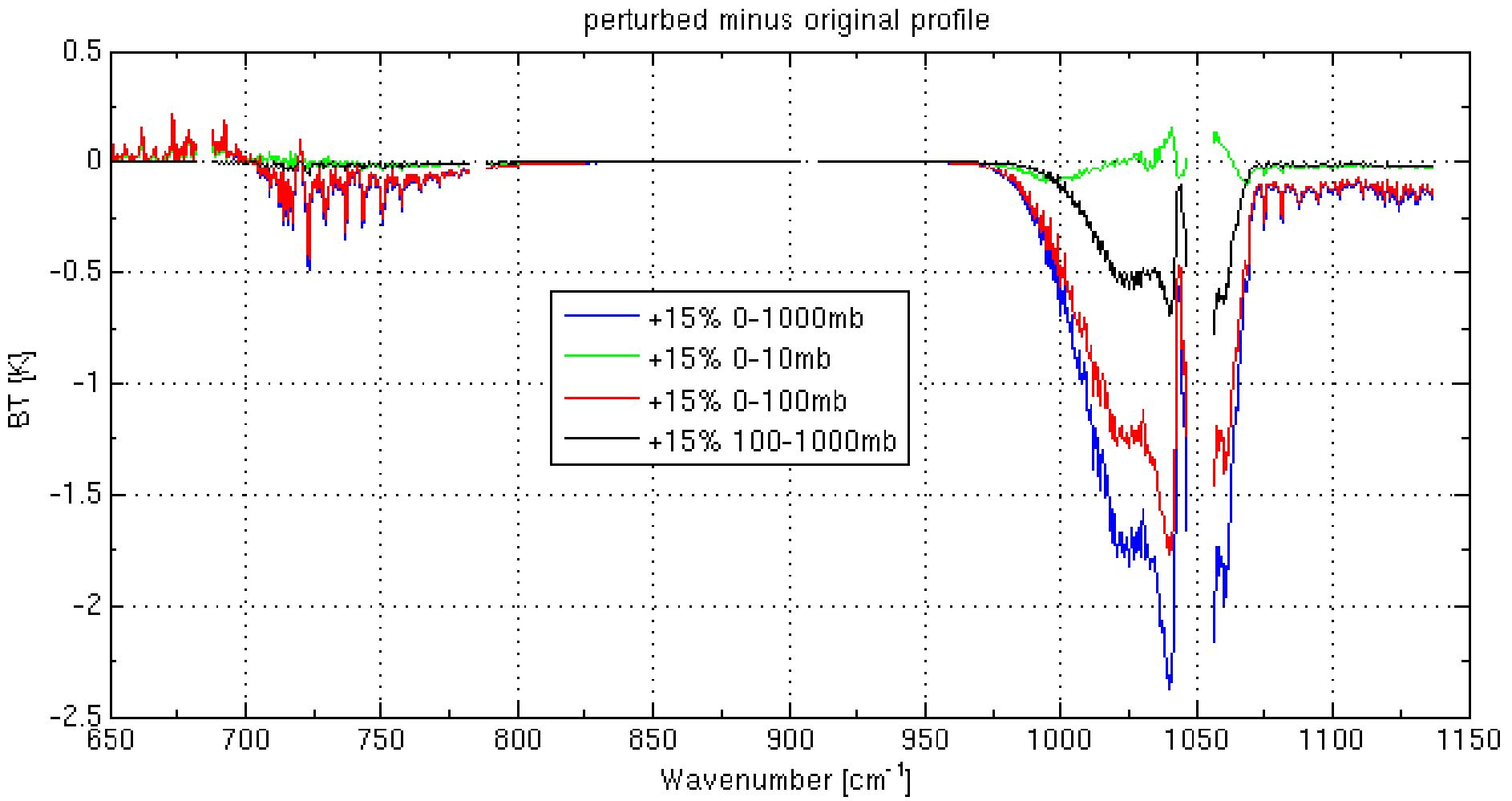
(AIRS–MODIS band35) BTDs as a function of 11-μm BTs, calculated with AIRS convolved using unshifted (left) and shifted (right) Aqua MODIS SRFs. BTDs are color coded with red (blue) points coming from high NH (SH) latitudes (Baum et al JAMC 2012)

Spectral Shifts Reduce Calculated vs Observed Radiance Biases

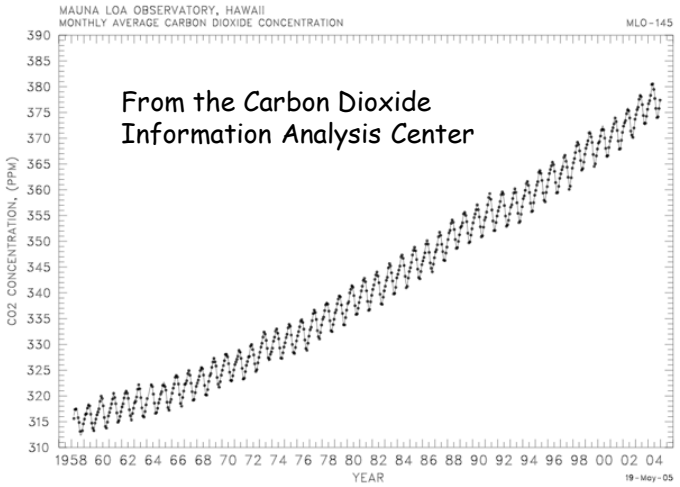


8-day 1-degree latitude zone means of observed minus calculated clear-sky radiances for Terra MODIS bands 33-36 (in 5-zone moving averages) are created from 8-day 25-km biases for daytime land, nighttime land, and ocean data. Day and night land data are combined south of 60˚S due to poor clear-sky sampling and the difficulty of discriminating between clear and cloudy conditions in this region. Figures show C5 versus C6 band 34-36 biases from 26 August 2006 over ocean. Land values (not shown) are used for ocean ice cases in polar regions.

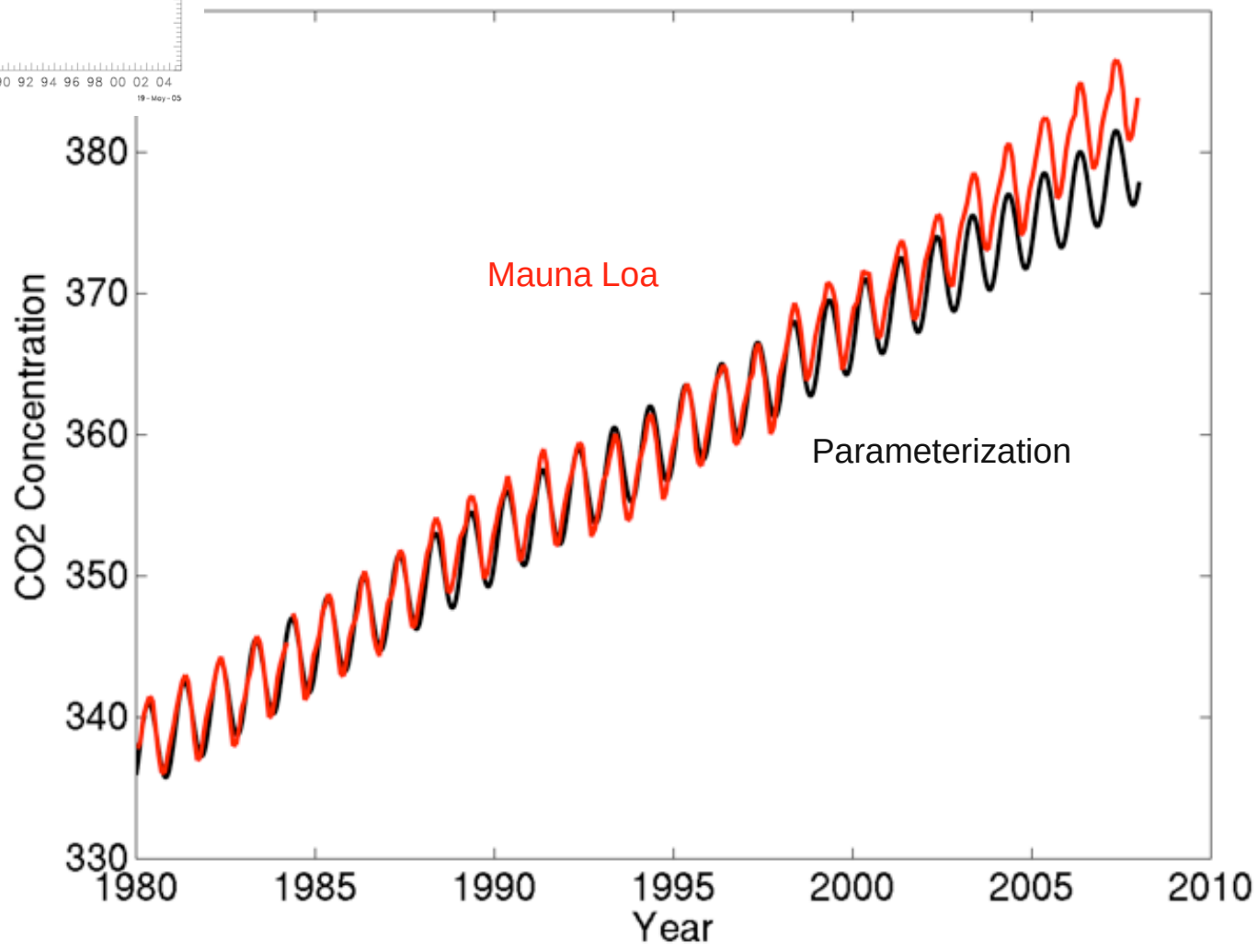
O3 affects CO2 bands



Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO_2 radiances influenced by O_3 profiles are calculated correctly).

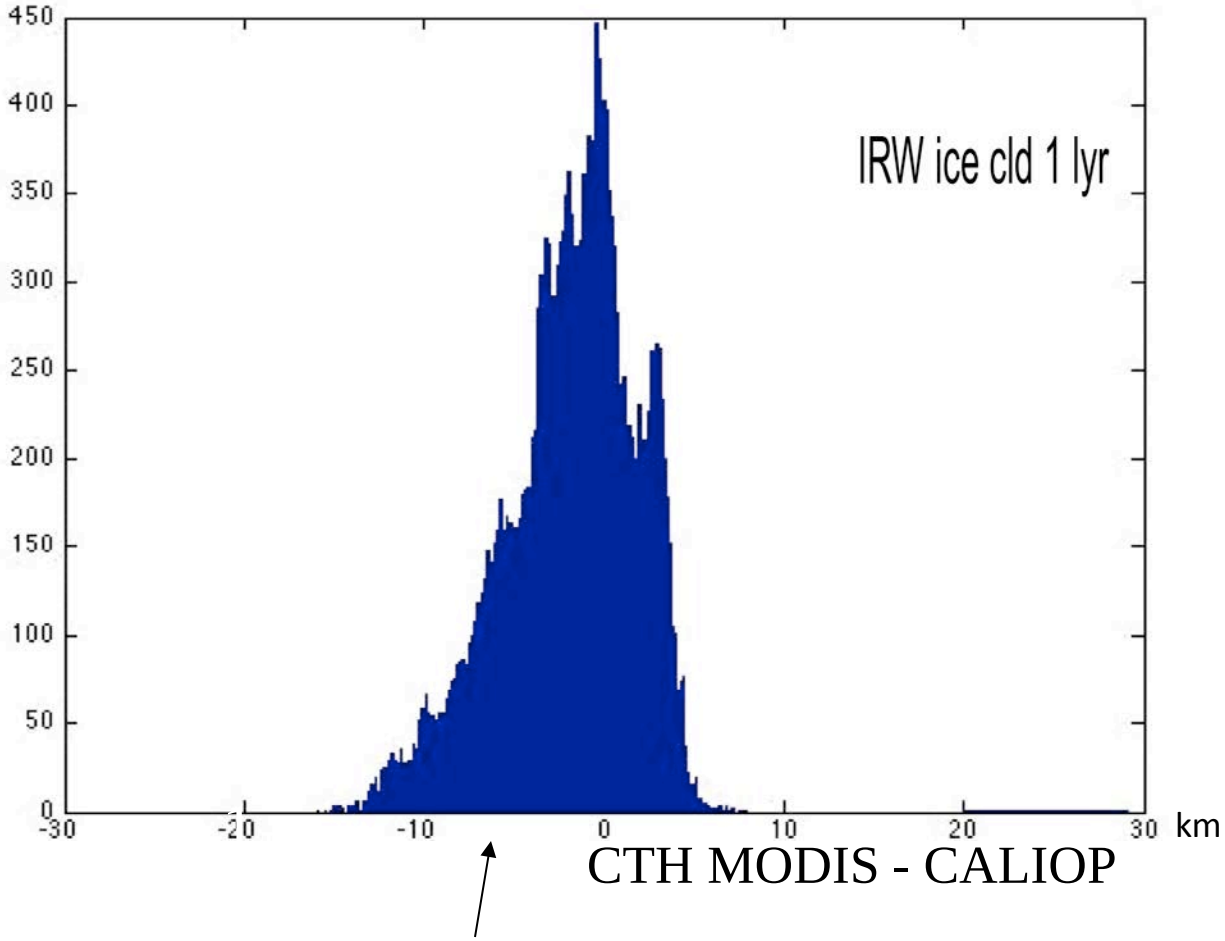


MODIS-C6: Tracking CO_2 changes over time



Avoid IRW solutions for ice clouds

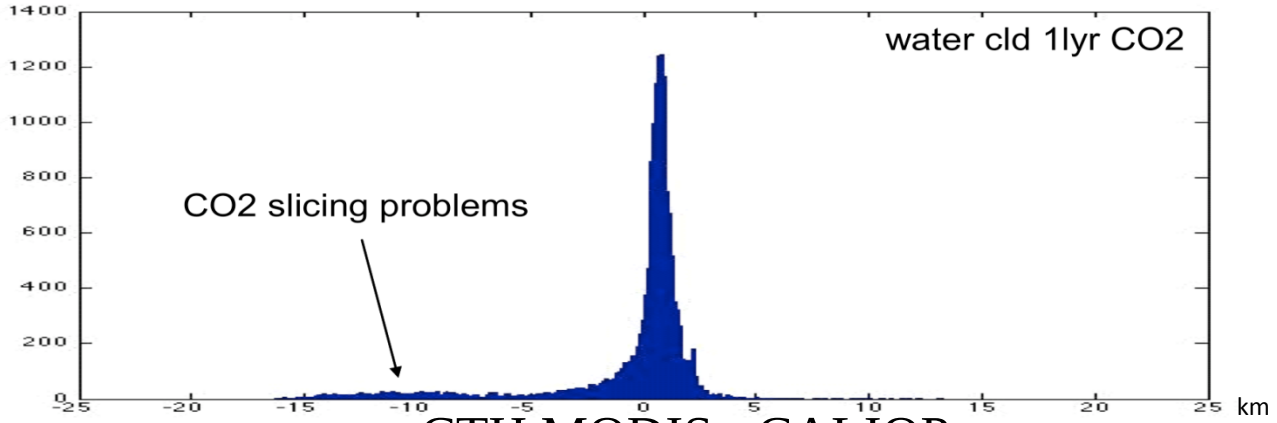
Number for Aug 2006



IRW CTHs are too low for ice clouds

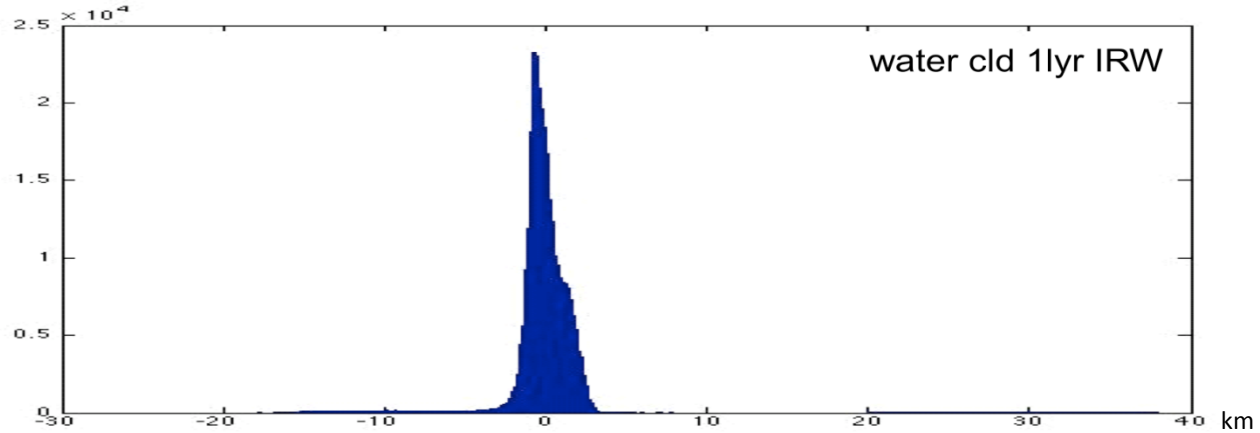
Avoid CO2 slicing solutions for water clouds

Number for Aug 2006



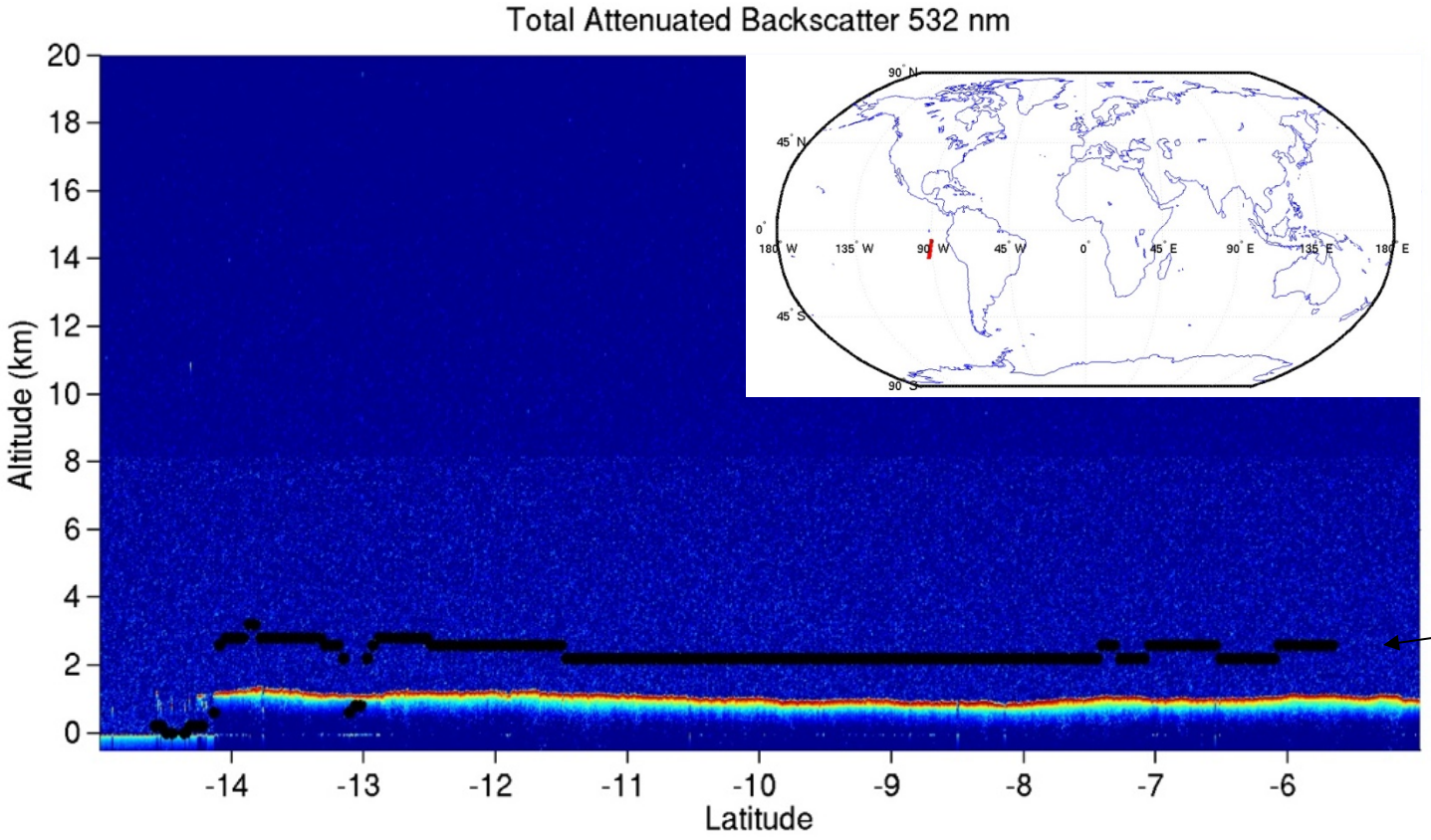
CTH MODIS - CALIOP

Number for Aug 2006



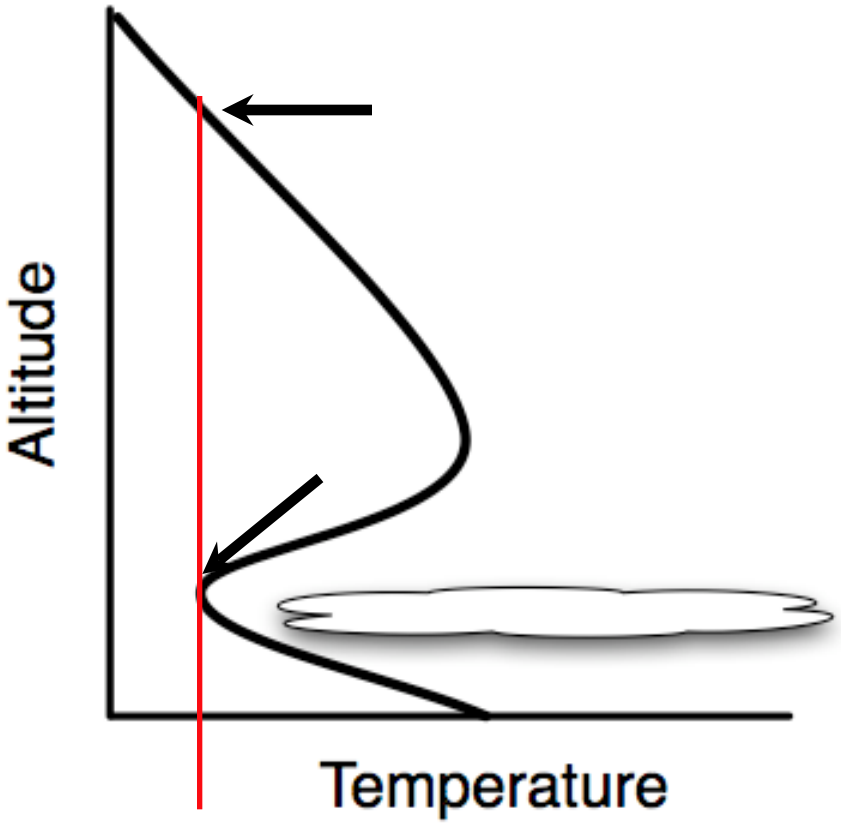
CTH MODIS - CALIOP

Marine Stratus CTH Over-Estimated

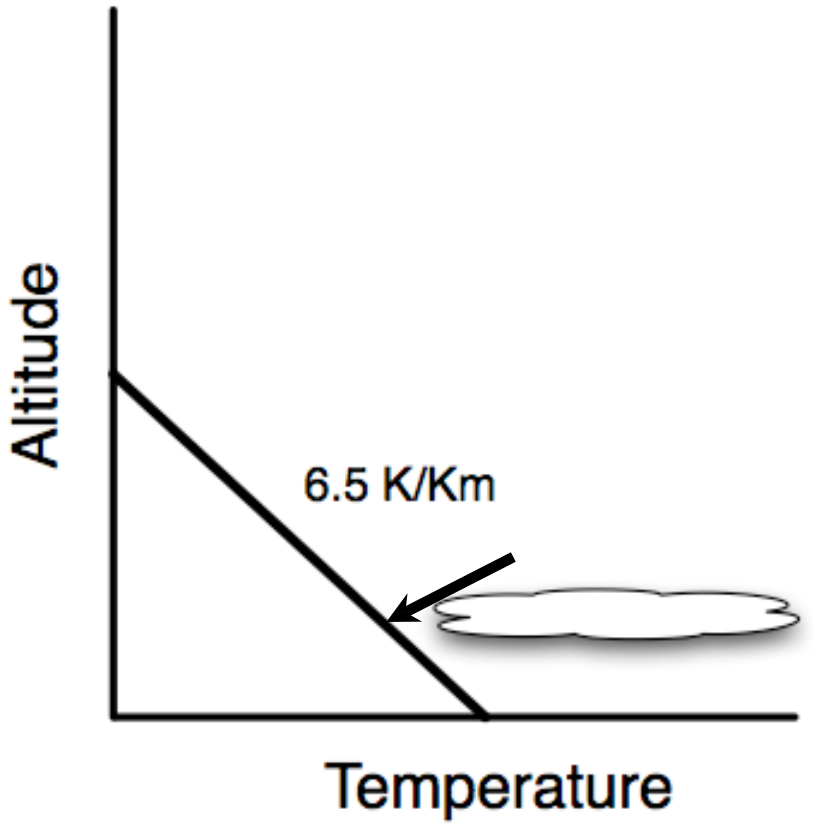


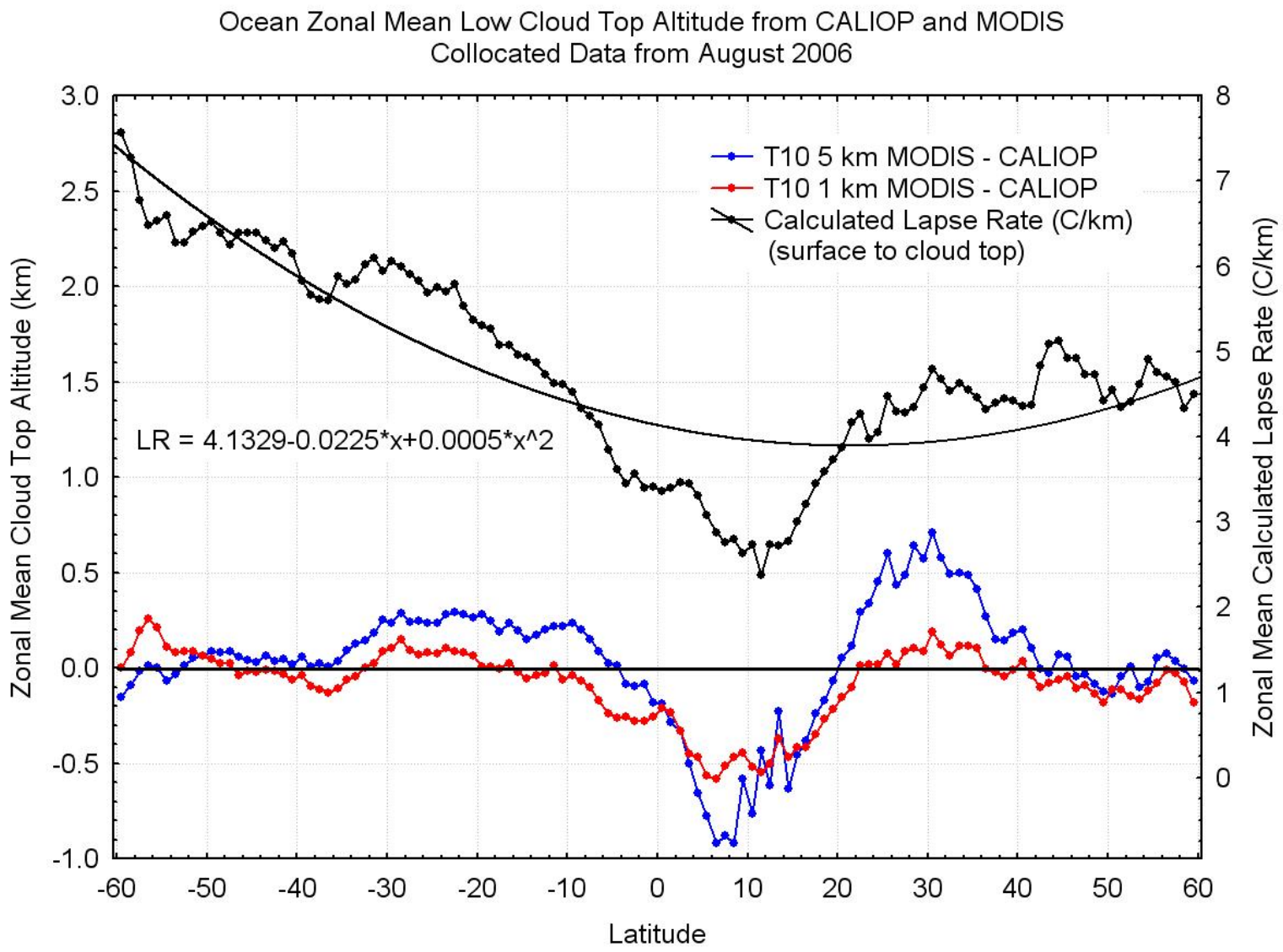
Marine Stratus Correction for Low Level Inversion

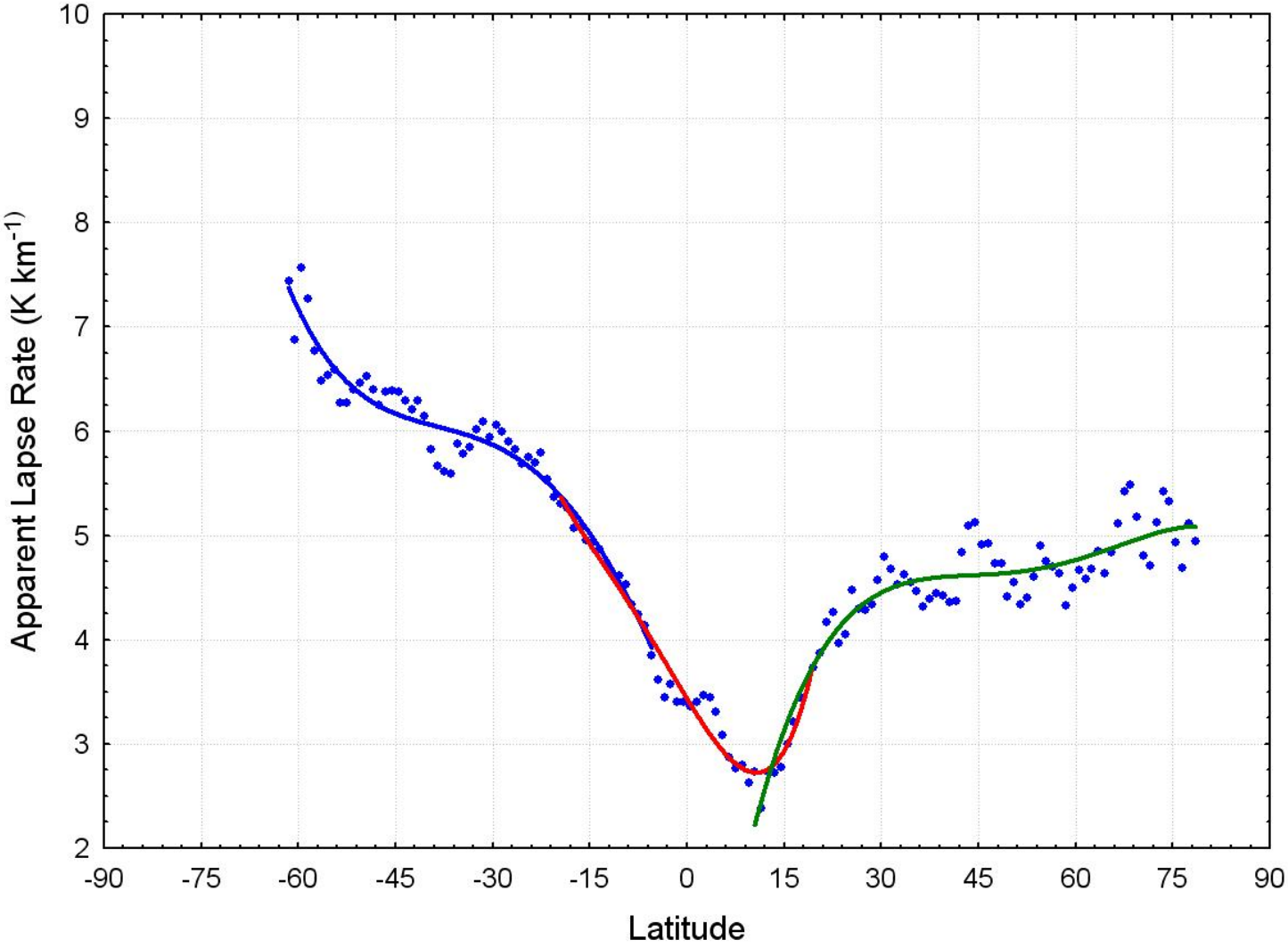
Current



Modified (Minnis 1992)




Ocean Zonal Mean Low Cloud Top Altitude from CALIOP and MODIS
Collocated Data from August 2006
T10 5 km MODIS - CALIOP
T10 1 km MODIS - CALIOP
Calculated Lapse Rate (C/km)
(surface to cloud top)
LR = 4.1329-0.0225*x+0.0005*x^2
Zonal Mean Cloud Top Altitude (km)
Zonal Mean Calculated Lapse Rate (C/km)
Latitude
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
8
7
6
5
4
3
2
1
0
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

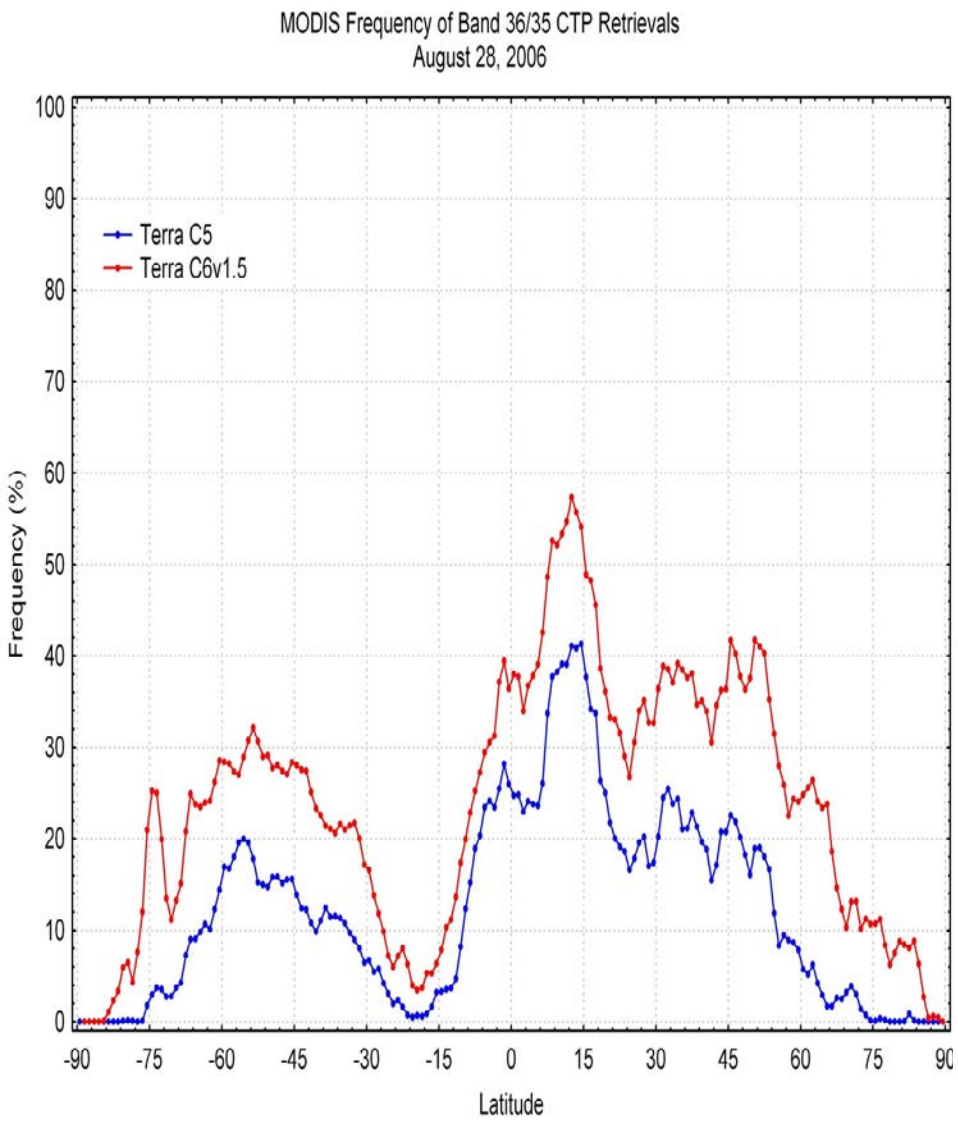


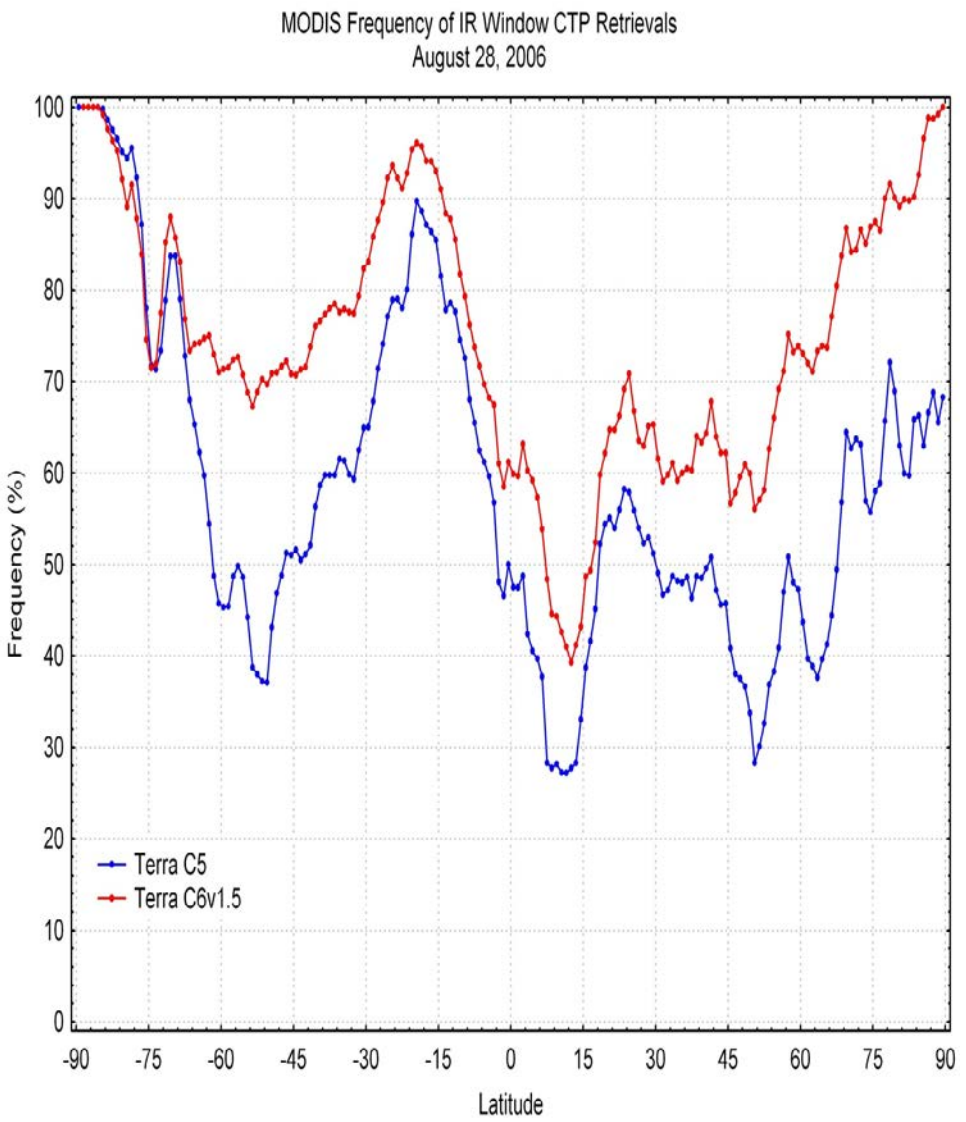
The apparent lapse rates are based on 11-micron differences between clear-sky and measured cloud radiances. Regression coefficients are based on latitude, using curve fitting for three different segments as shown above. Coefficients are provided for each month.

SSEC

C6 Produces More High CO_2 Slicing and Low IRW Solutions

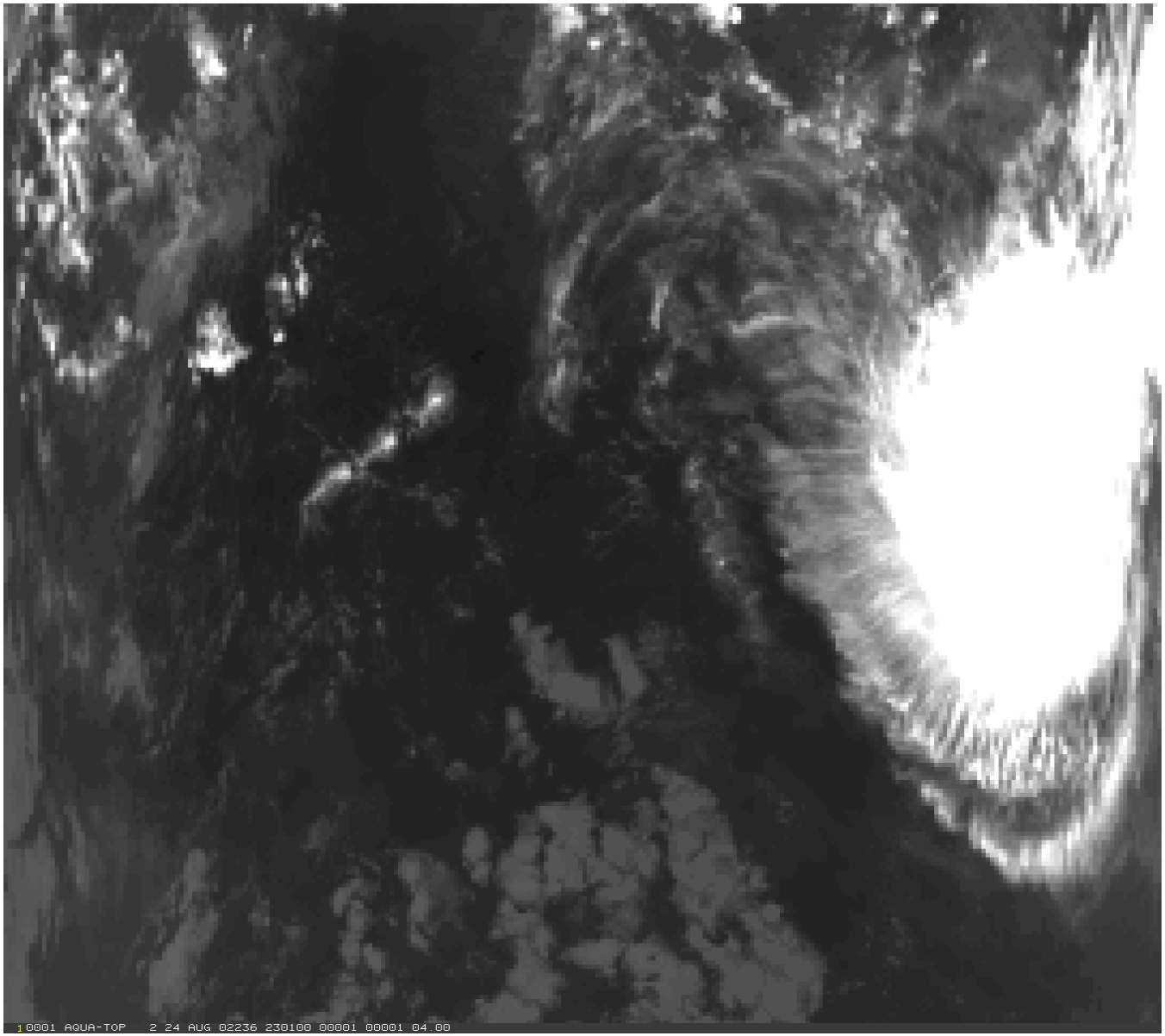
caused by spectral shift and cloud phase discriminator



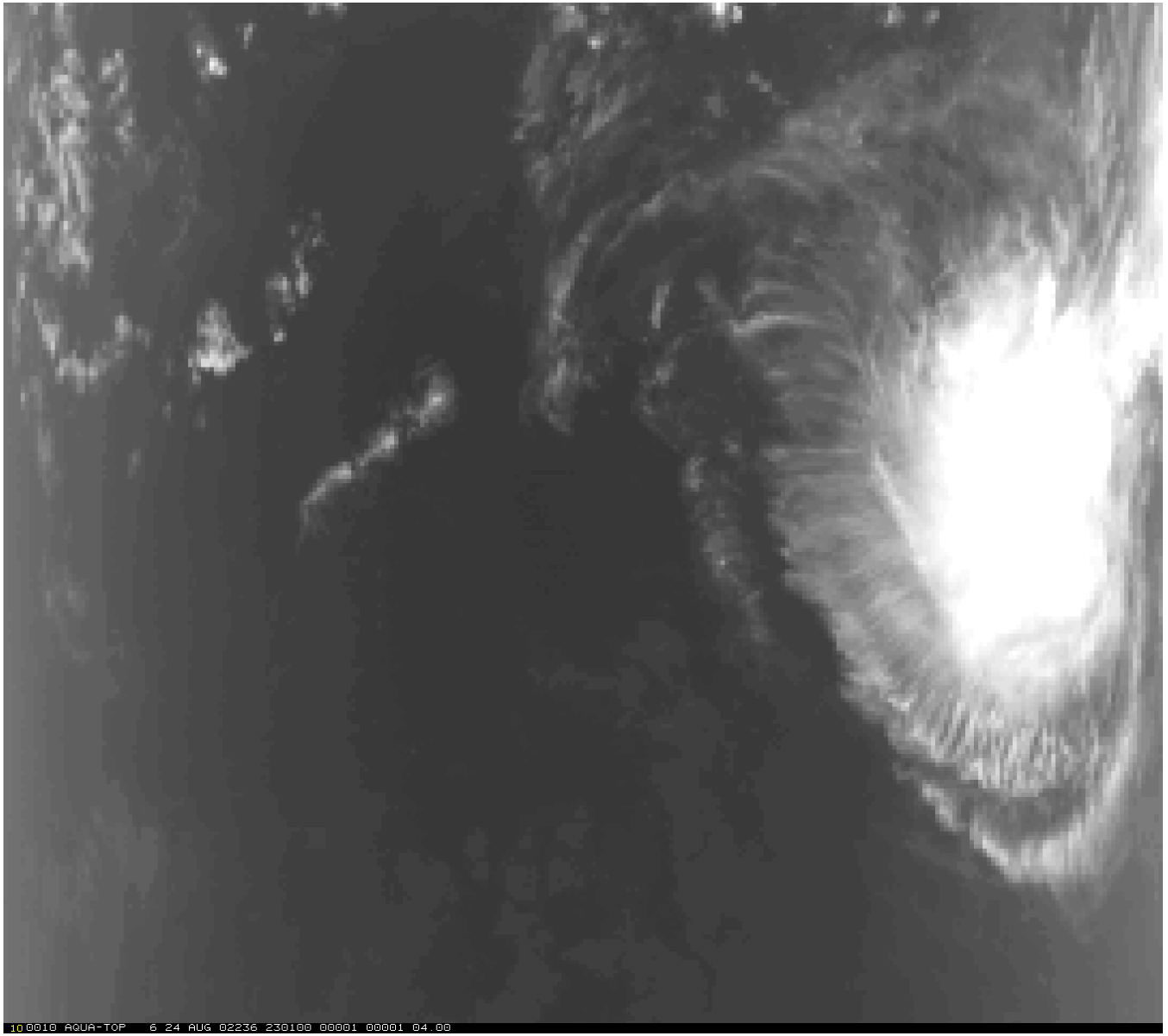


Collect 5 versus 6 latitudinal distribution of high cloud CO_2 slicing solutions (from 36/35) and low water cloud IRW solutions for Terra MODIS on 28 August 2006 (in % of all cloudy observations)

Example of High Clouds in the Equatorial Pacific

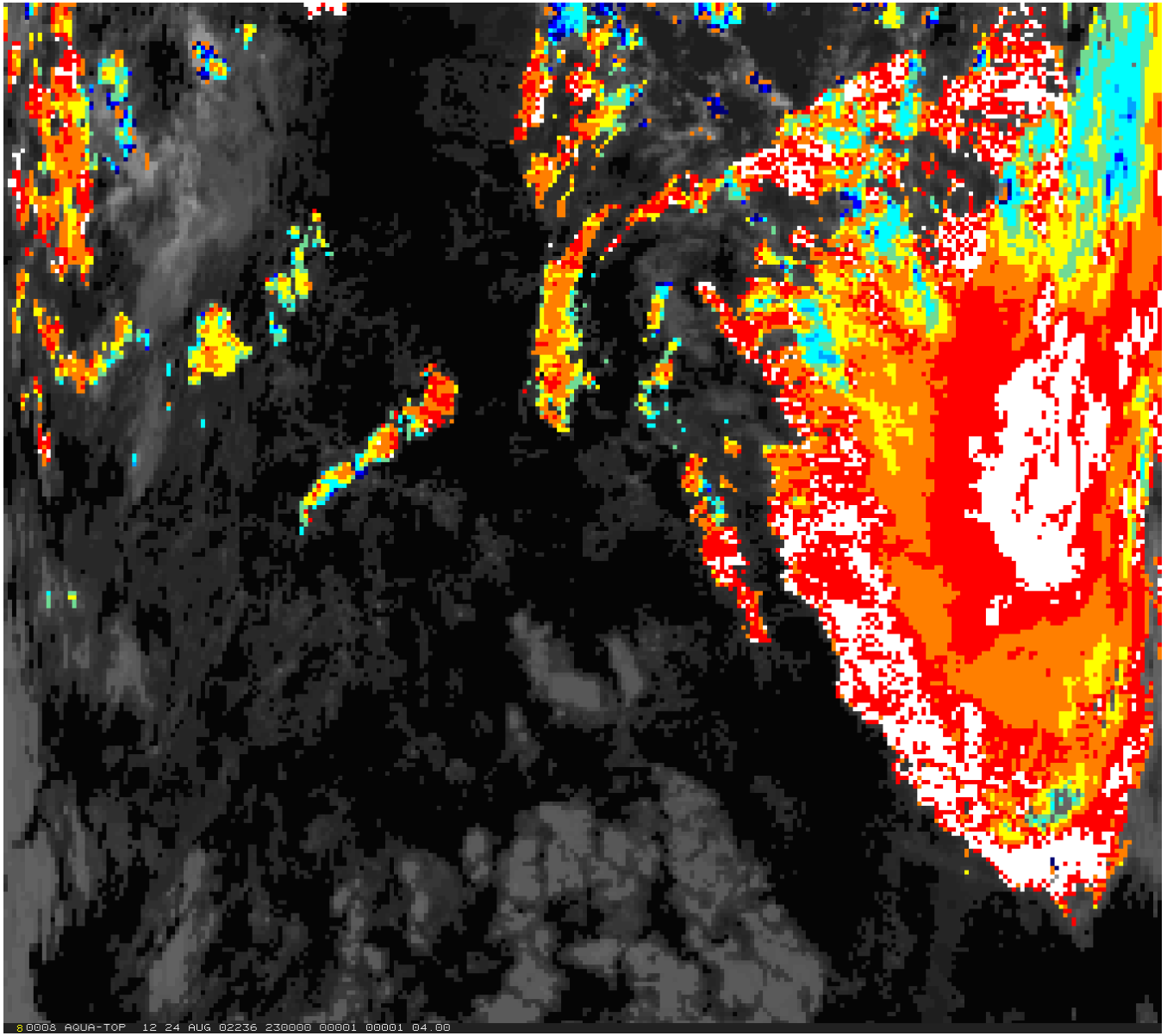


IRW



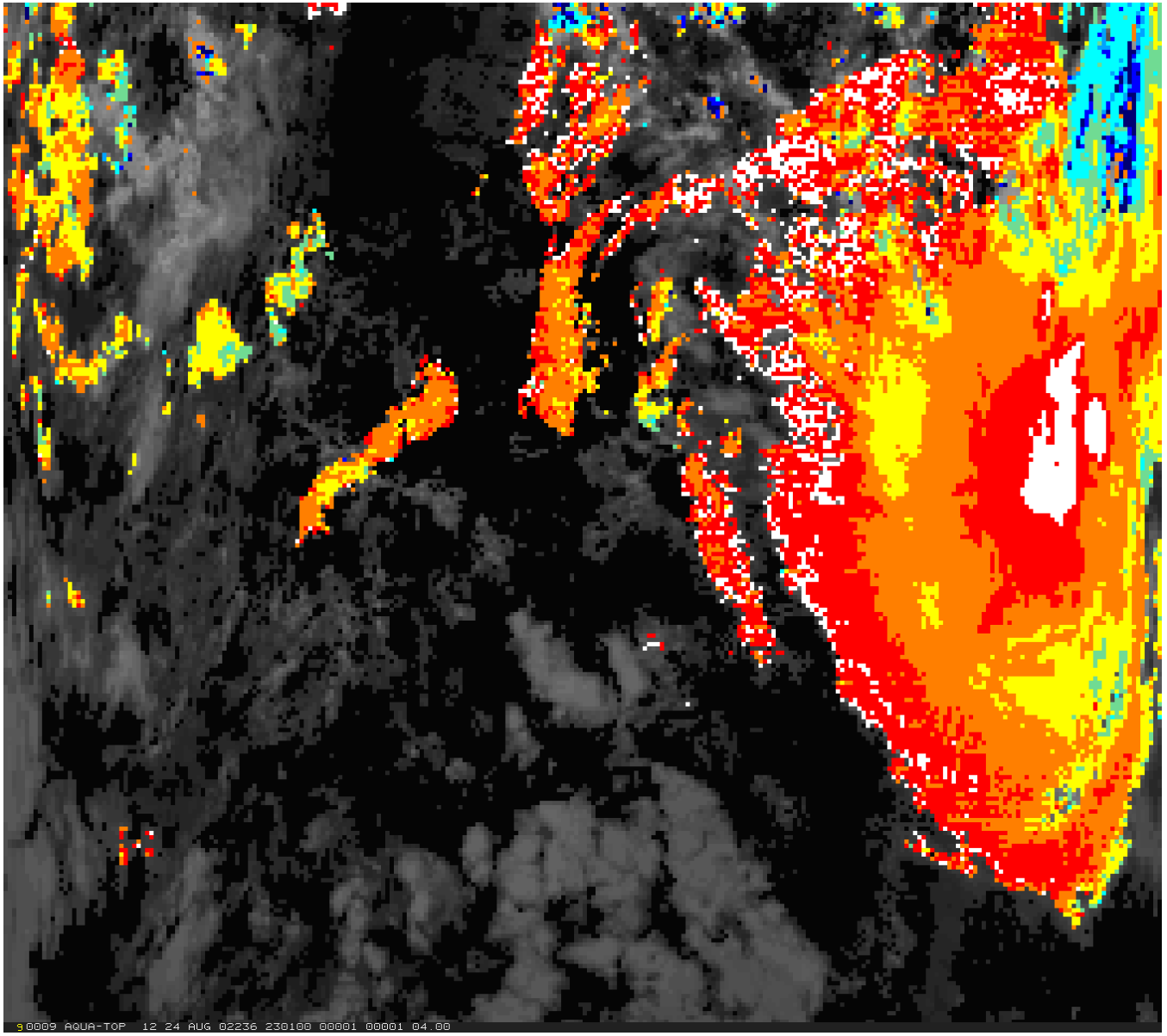
CO2 at 13.9 µm

C5 CTP



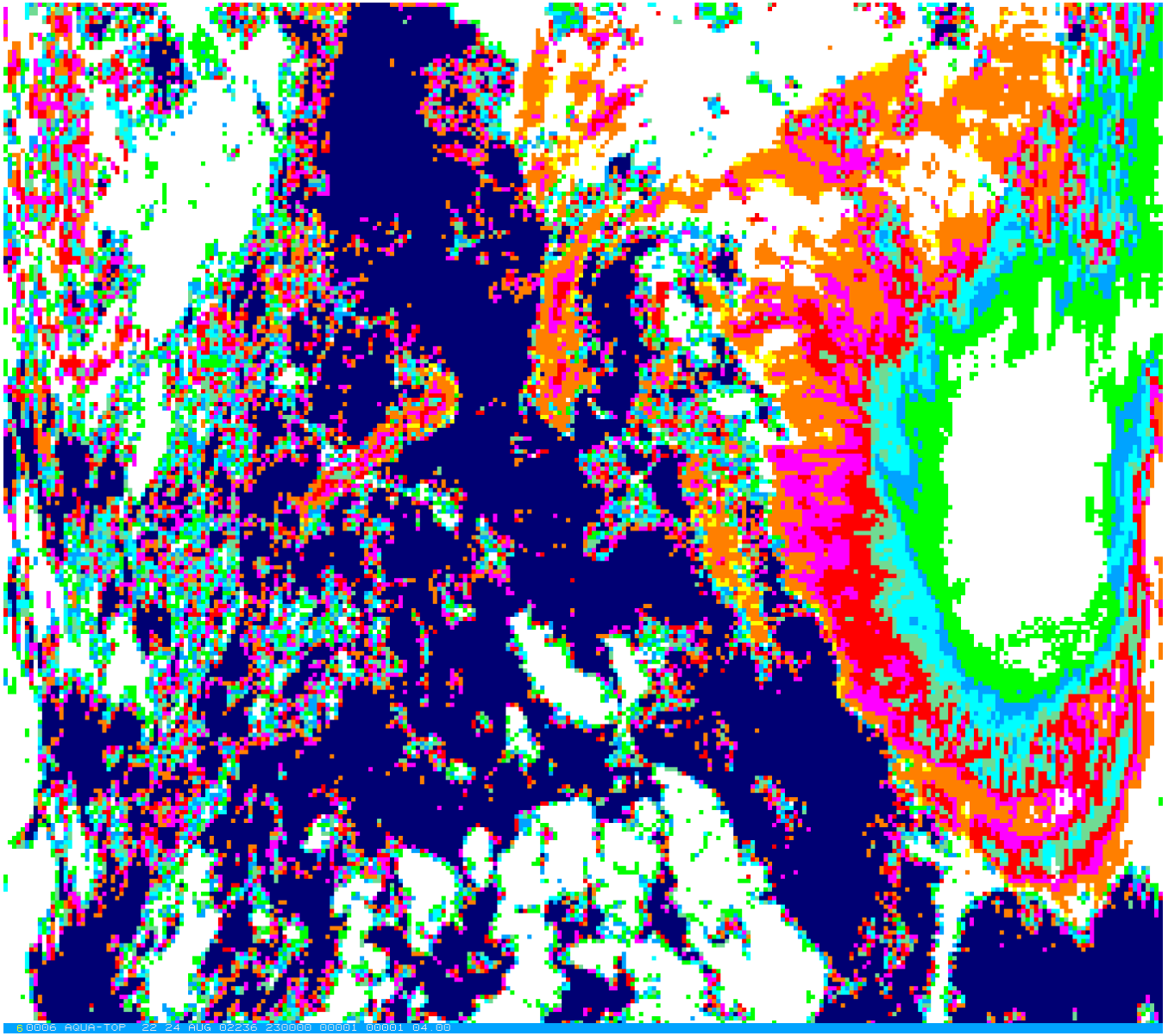
(hPa) - White 95-125; Red 125-160; Orange 160-190; Yellow 190-225; Aqua 225-260; Cyan 260-300; Sky 300-330; Blue 330-360; Navy 360-390; Light Orange 390-440

C6 CTP



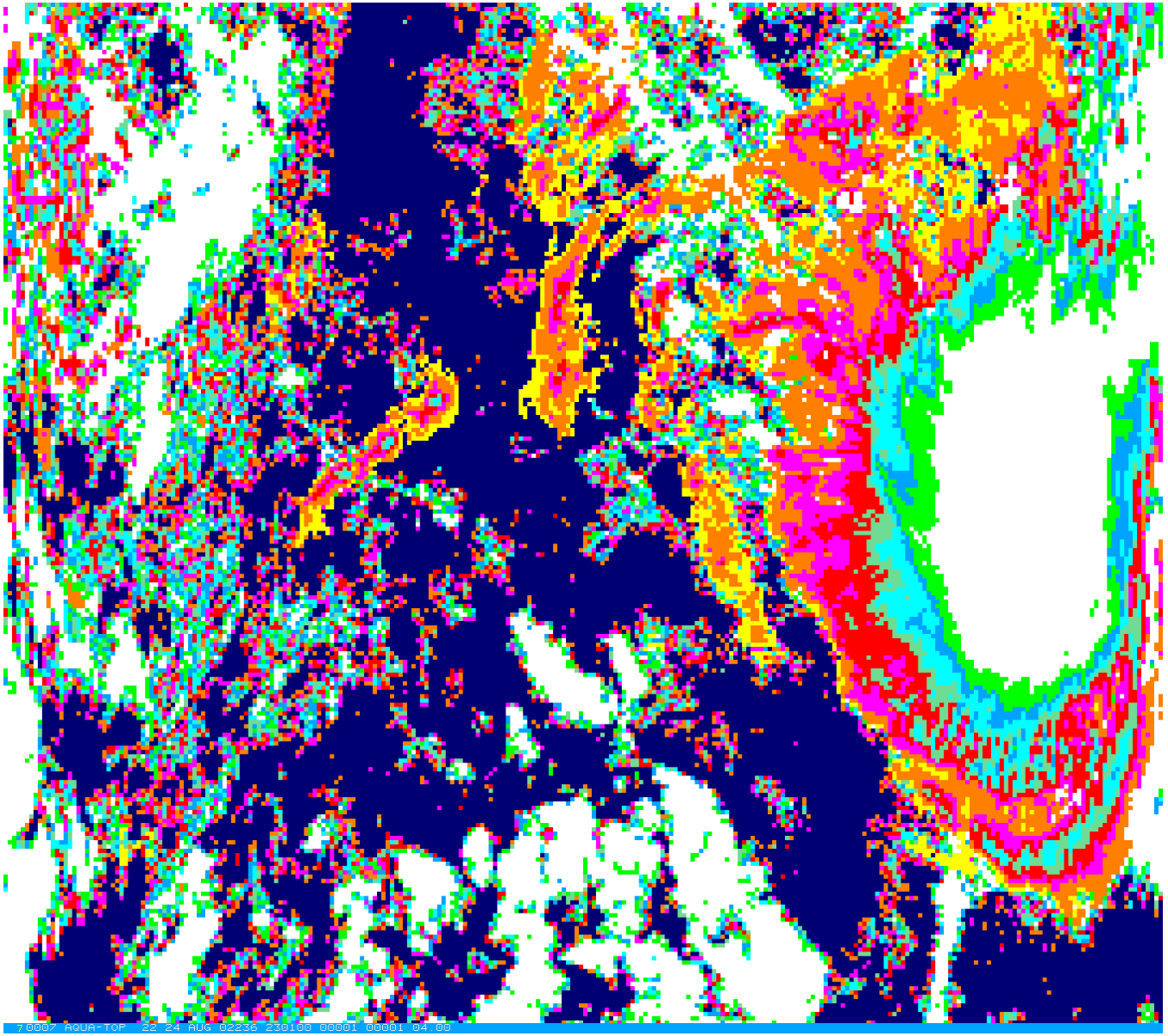
(hPa) - White 95-125; Red 125-160; Orange 160-190; Yellow 190-225; Aqua 225-260; Cyan 260-300; Sky 300-330; Blue 330-360; Navy 360-390; Light Orange 390-440

C5 ECA



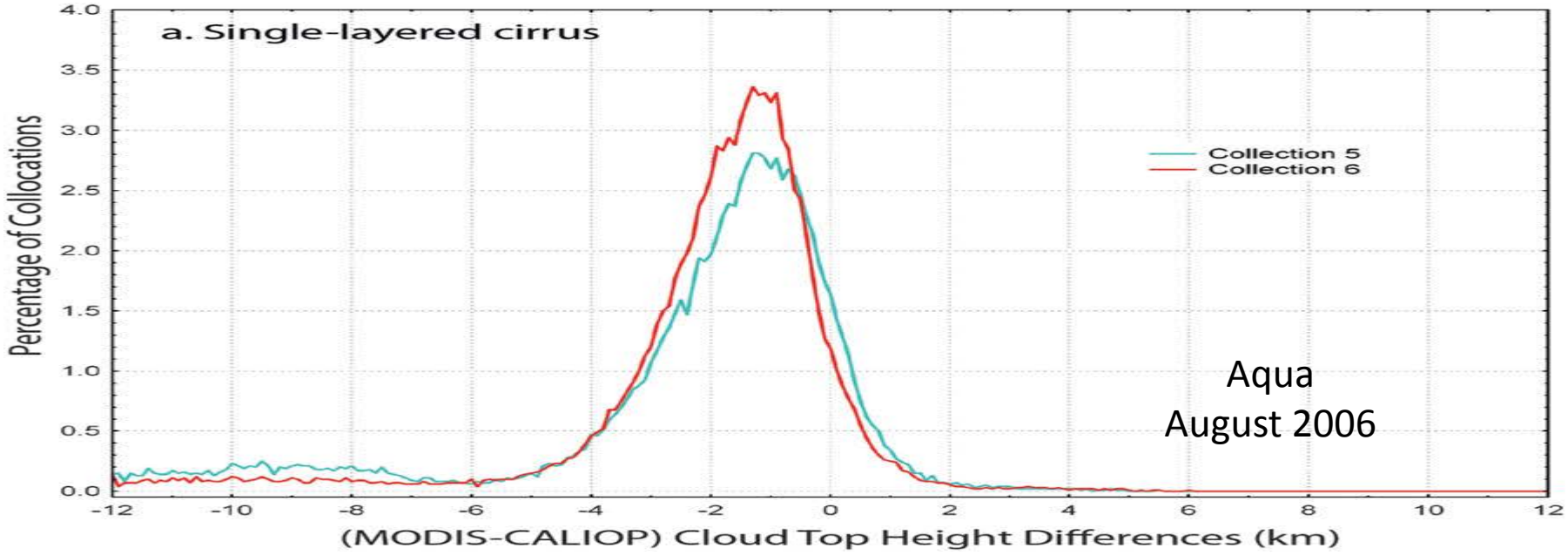
White 0.9-1.0; Green 0.8-0.9; Sky 0.7-0.8; Cyan 0.6-0.7; Aqua 0.5-0.6; Red 0.3-0.5; Magenta 0.2-0.3; Orange 0.1-0.2, Yellow 0.0-0.1; Navy Clear

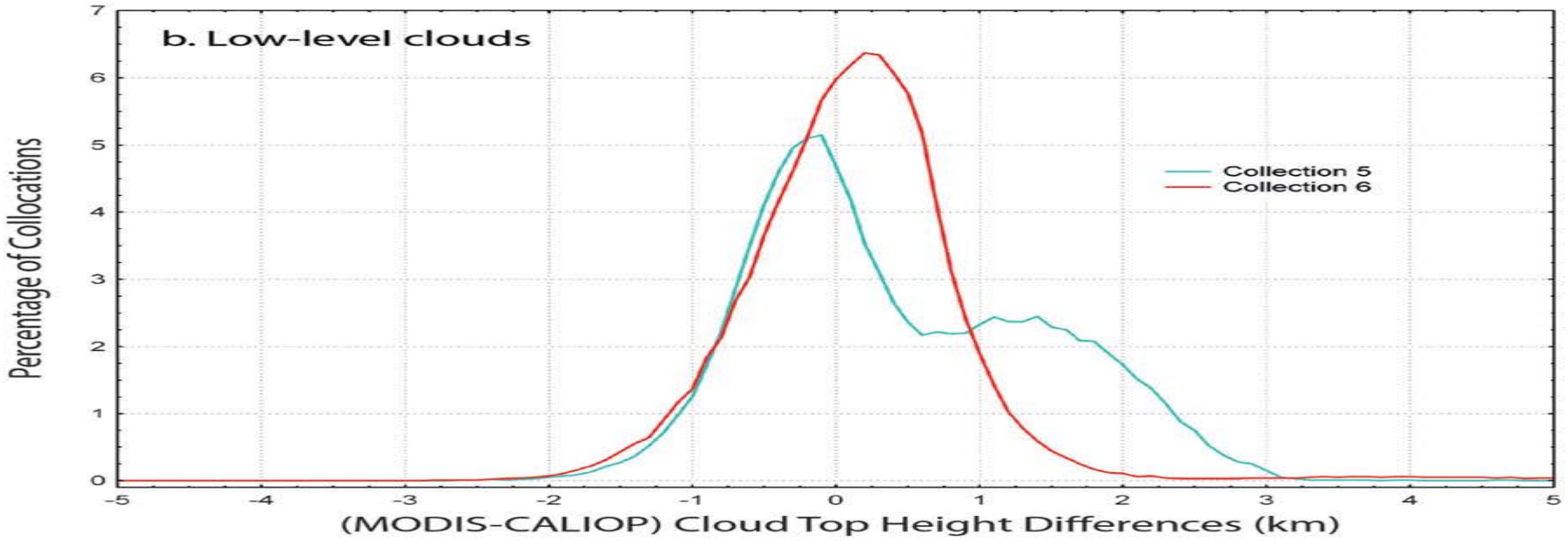
C6 ECA

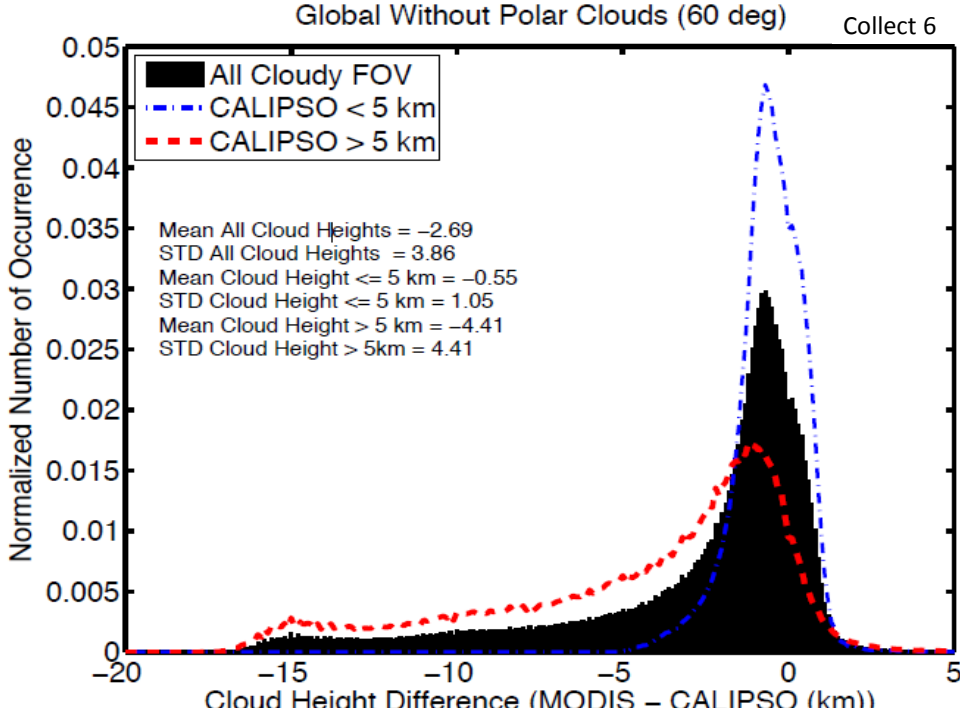


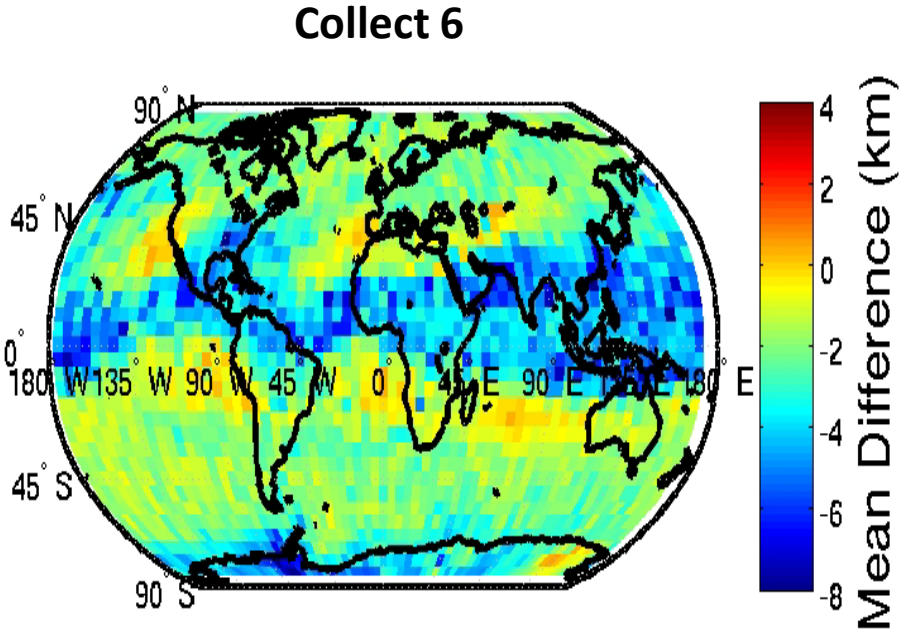
White 0.9-1.0; Green 0.8-0.9; Sky 0.7-0.8; Cyan 0.6-0.7; Aqua 0.5-0.6; Red 0.3-0.5; Magenta 0.2-0.3; Orange 0.1-0.2, Yellow 0.0-0.1; Navy Clear

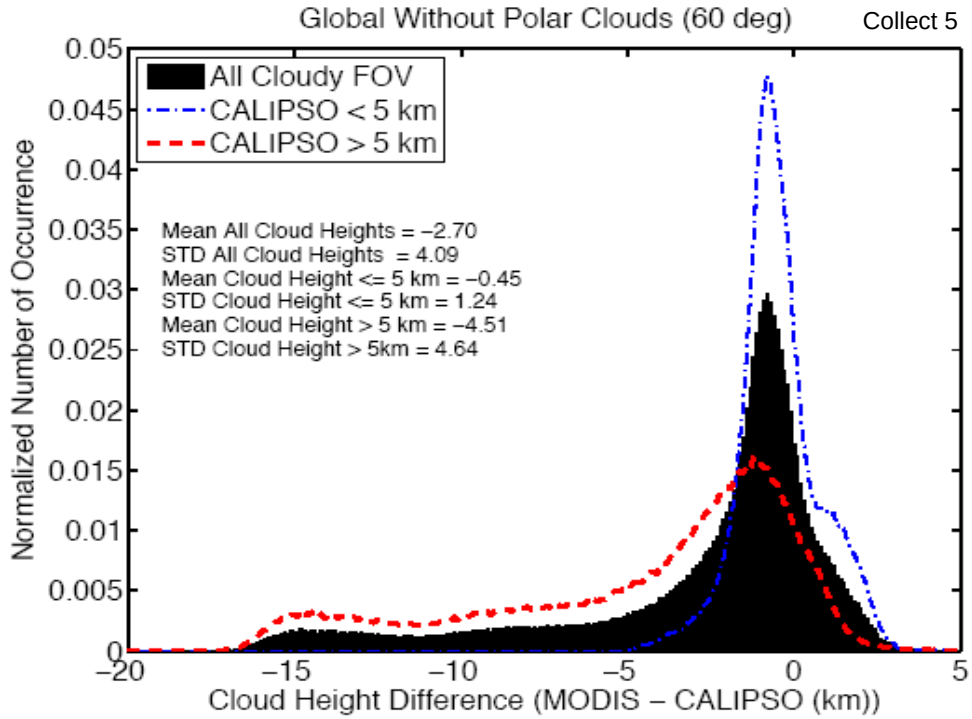
Comparisons with CALIOP Confirm C6 Improvements

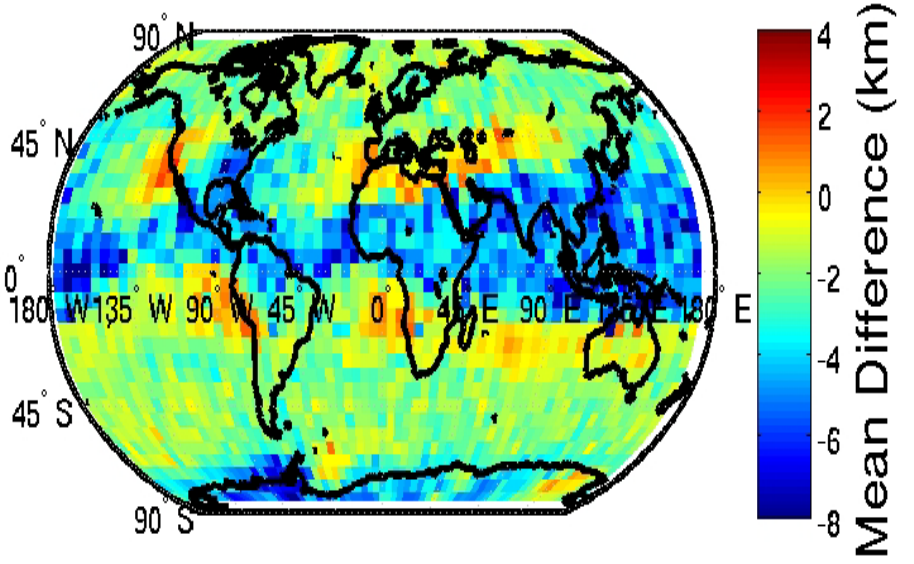





Global Without Polar Clouds (60 deg)
Collect 6
All Cloudy FOV
CALIPSO < 5 km
CALIPSO > 5 km
Mean All Cloud Heights = −2.69
STD All Cloud Heights = 3.86
Mean Cloud Height <= 5 km = −0.55
STD Cloud Height <= 5 km = 1.05
Mean Cloud Height > 5 km = −4.41
STD Cloud Height > 5km = 4.41
Normalized Number of Occurrence
Cloud Height Difference (MODIS – CALIPSO (km))

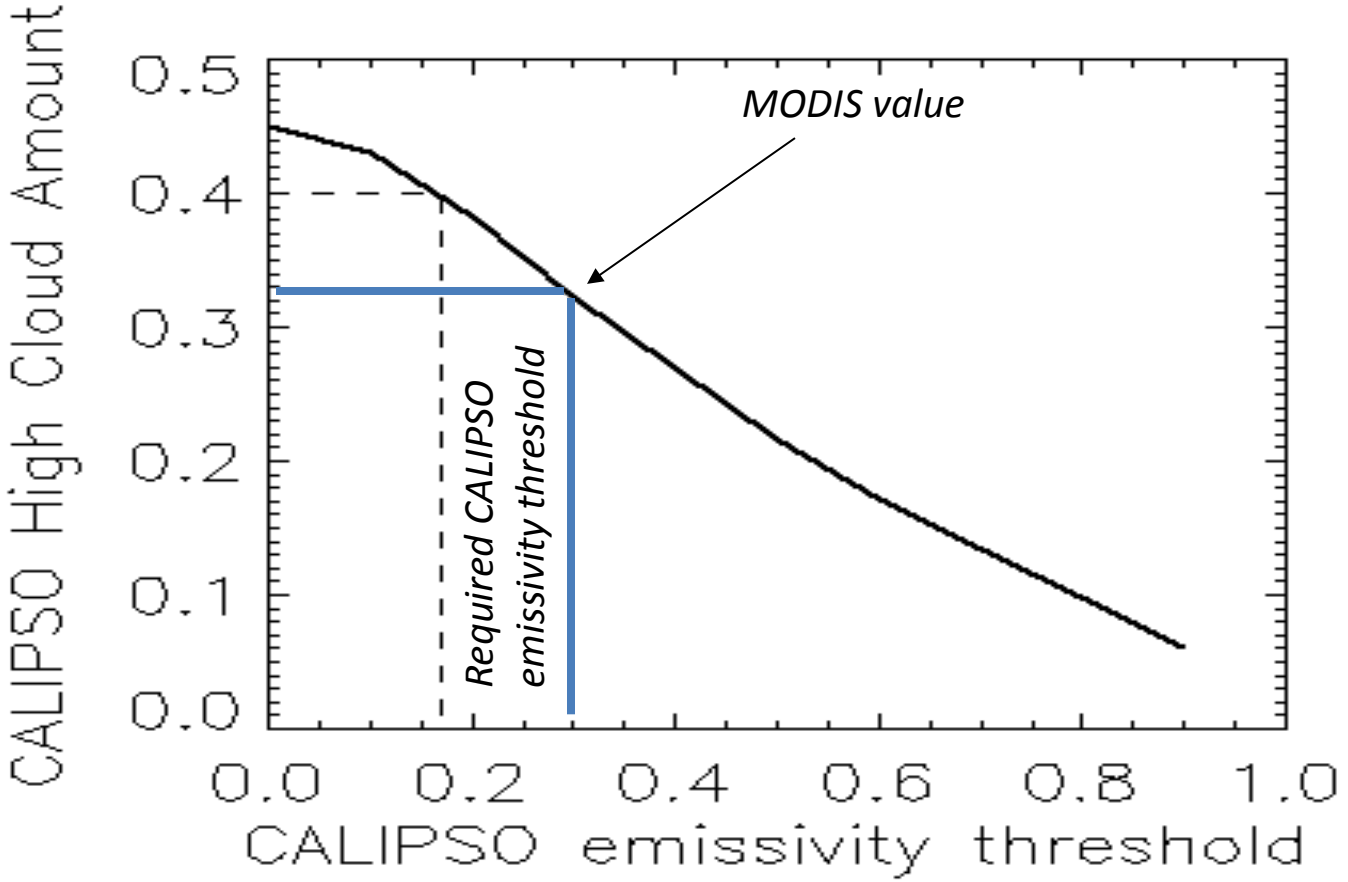

Collect 6
90° N
45° N
0°
45° S
90° S
180° W135° W 90° W 45° W 0° 45° E 90° E 135° E 180° E
Mean Difference (km)


Global Without Polar Clouds (60 deg)
Collect 5
All Cloudy FOV
CALIPSO < 5 km
CALIPSO > 5 km
Mean All Cloud Heights = −2.70
STD All Cloud Heights = 4.09
Mean Cloud Height <= 5 km = −0.45
STD Cloud Height <= 5 km = 1.24
Mean Cloud Height > 5 km = −4.51
STD Cloud Height > 5km = 4.64
Normalized Number of Occurrence
Cloud Height Difference (MODIS – CALIPSO (km))


Collect 5
90° N
45° N
0°
45° S
90° S
180° W135° W 90° W 45° W 0° 45° E 90° E 135° E 180° E
Mean Difference (km)

CALIOP Estimates MODIS Thin Cloud Sensitivity

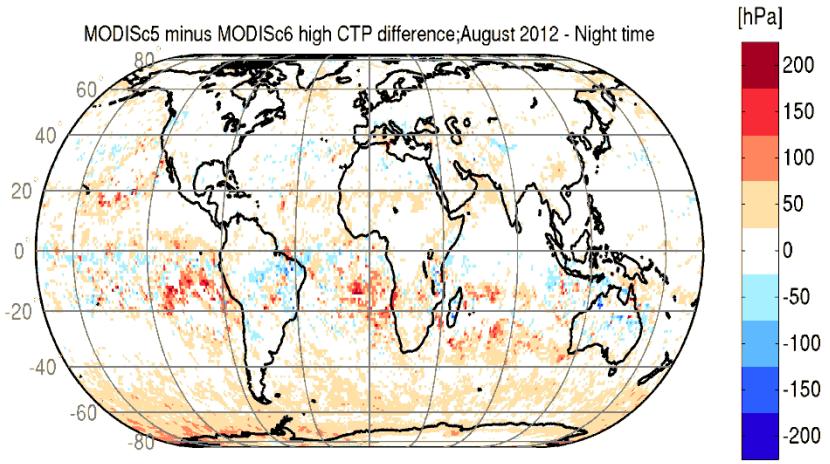
By matching the Aqua MODIS high cloud amount values to CALIPSO's curve of high cloud amount versus cloud emissivity, we can determine the sensitivity of MODIS to cloud emissivity.

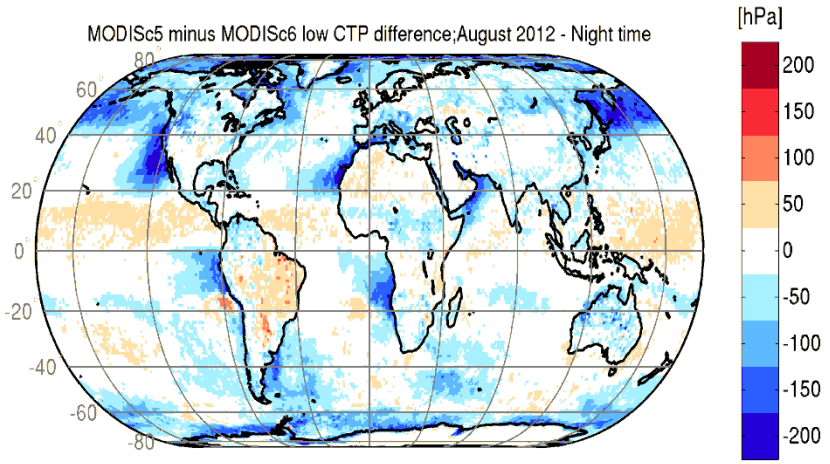


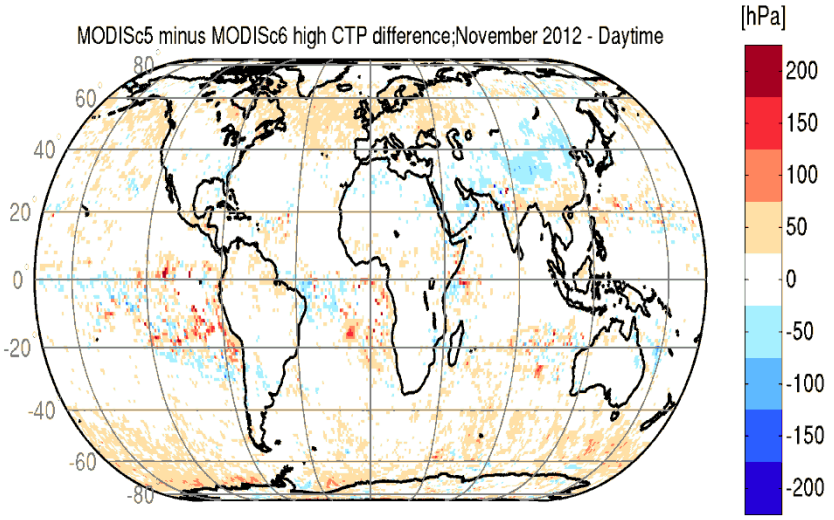
For the Tropics in August 2006, the MODIS high cloud amounts are about 0.32. This gives a cloud emissivity limit of about 0.3.

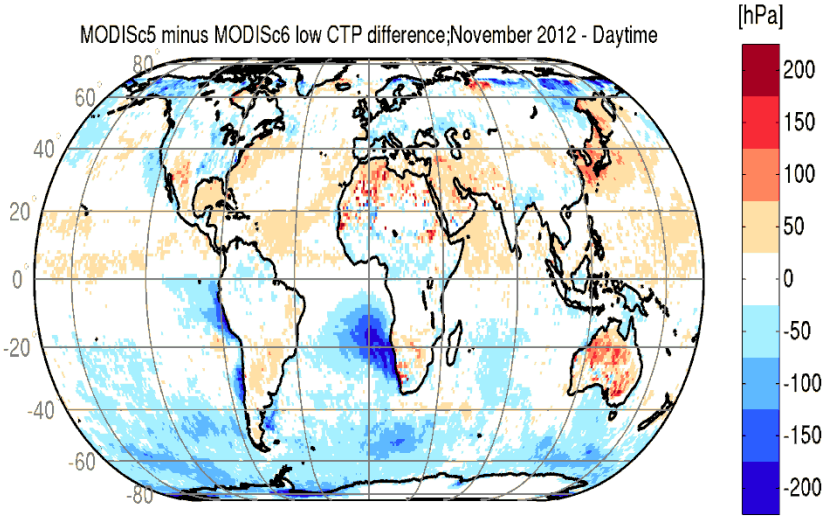
Global Distribution of C5 minus C6 CTP Differences

CTPs from Aqua C5 and C6 for August and November 2012 have been compared using the Space-Time-Grid software (Smith et al. JAMC 2013). More transmissive cirrus are being reported as high cloud both day and night. C6 high cloud CTPs in mid-latitude oceans have decreased by ~50 hPa. C6 low marine stratus CTPs have increased by ~150 hPa. C5 to C6 adjustments vary seasonally.



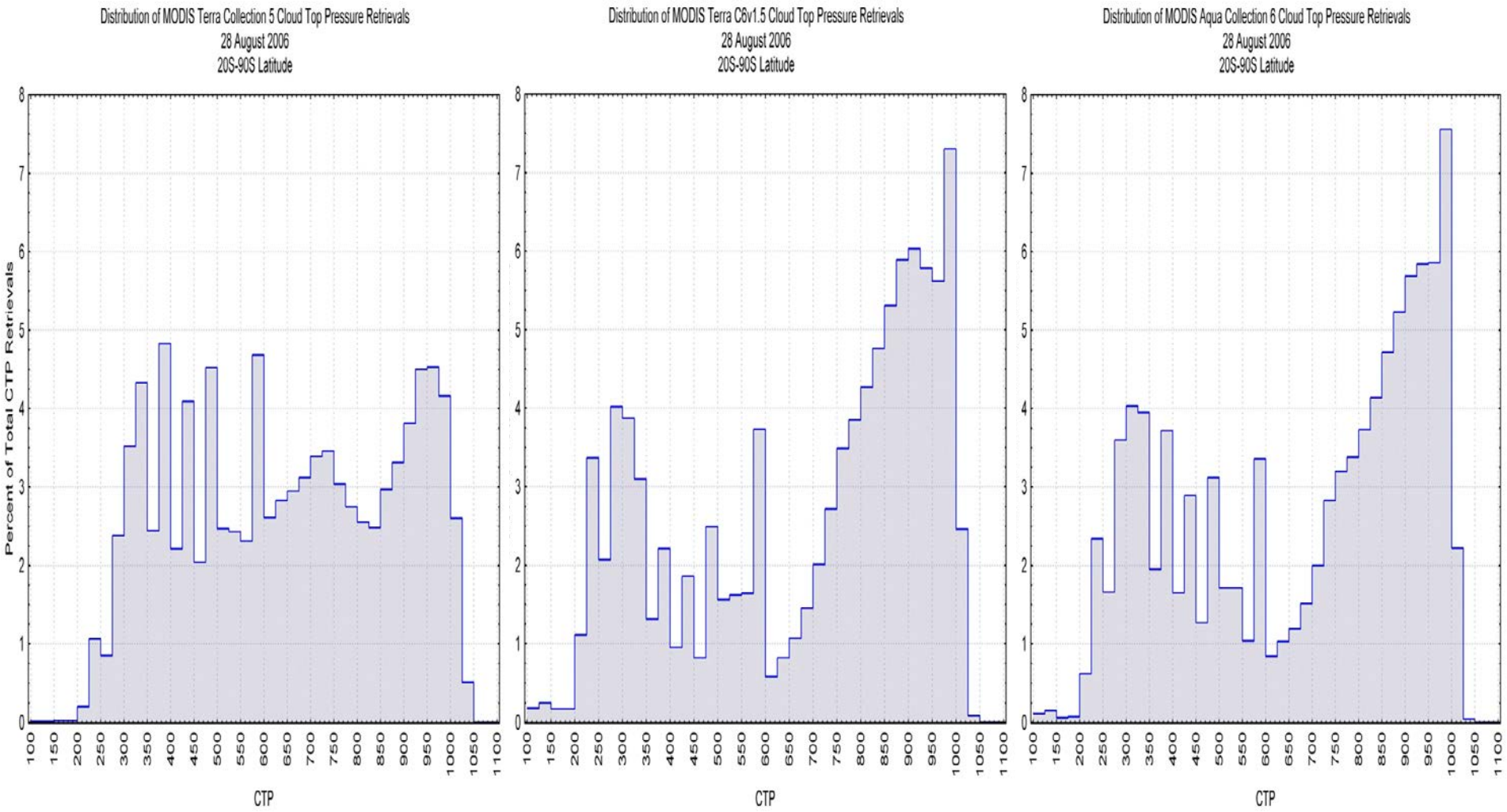






With C6, Vertical Distribution of Terra and Aqua Clouds Comes Into Agreement

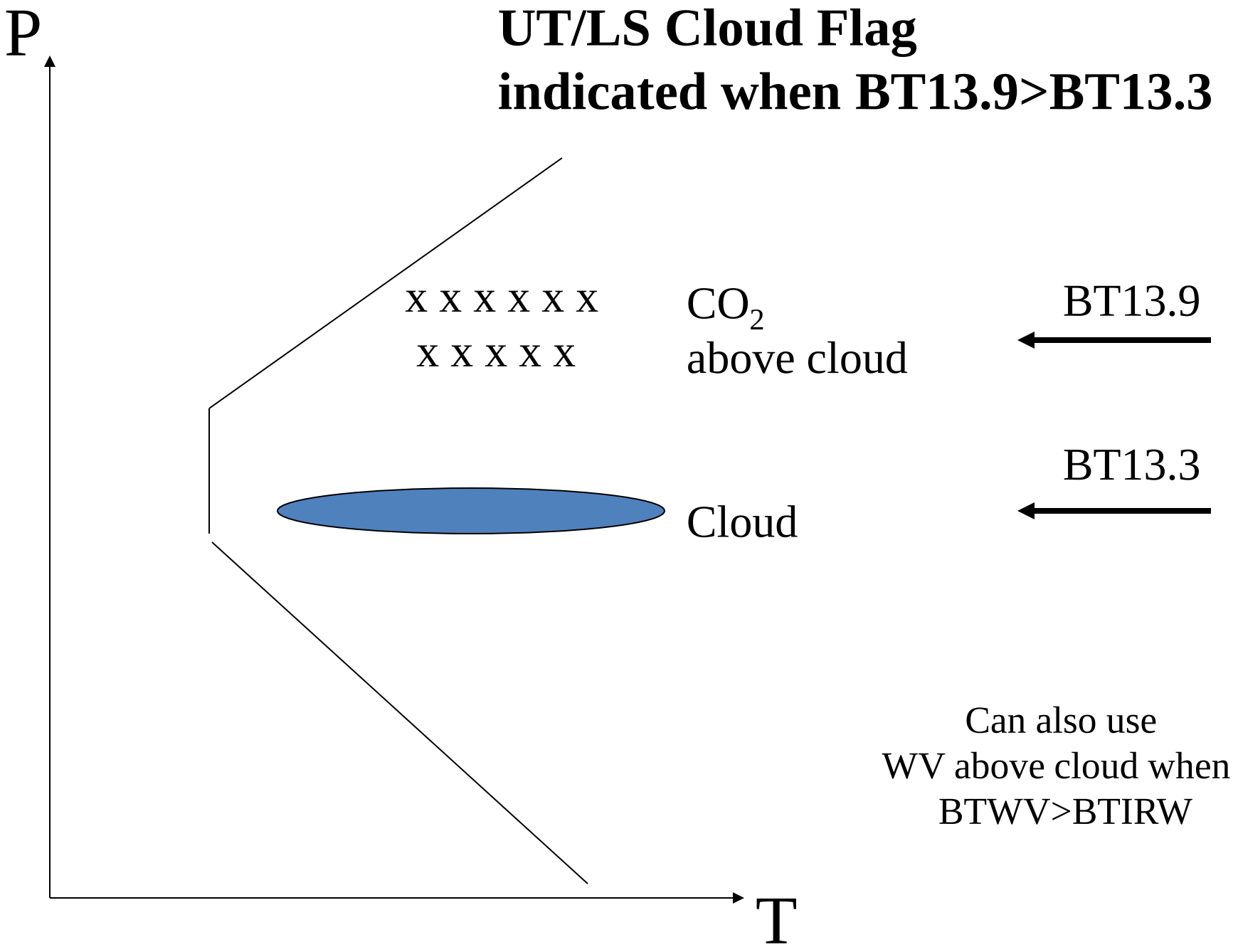
Vertical distribution of clouds in latitude bands (90S-20S, 20˚S-20˚N, and 20˚N–90˚N) for 28 August 2006 show closer agreement for Terra and Aqua with C6 algorithm changes.

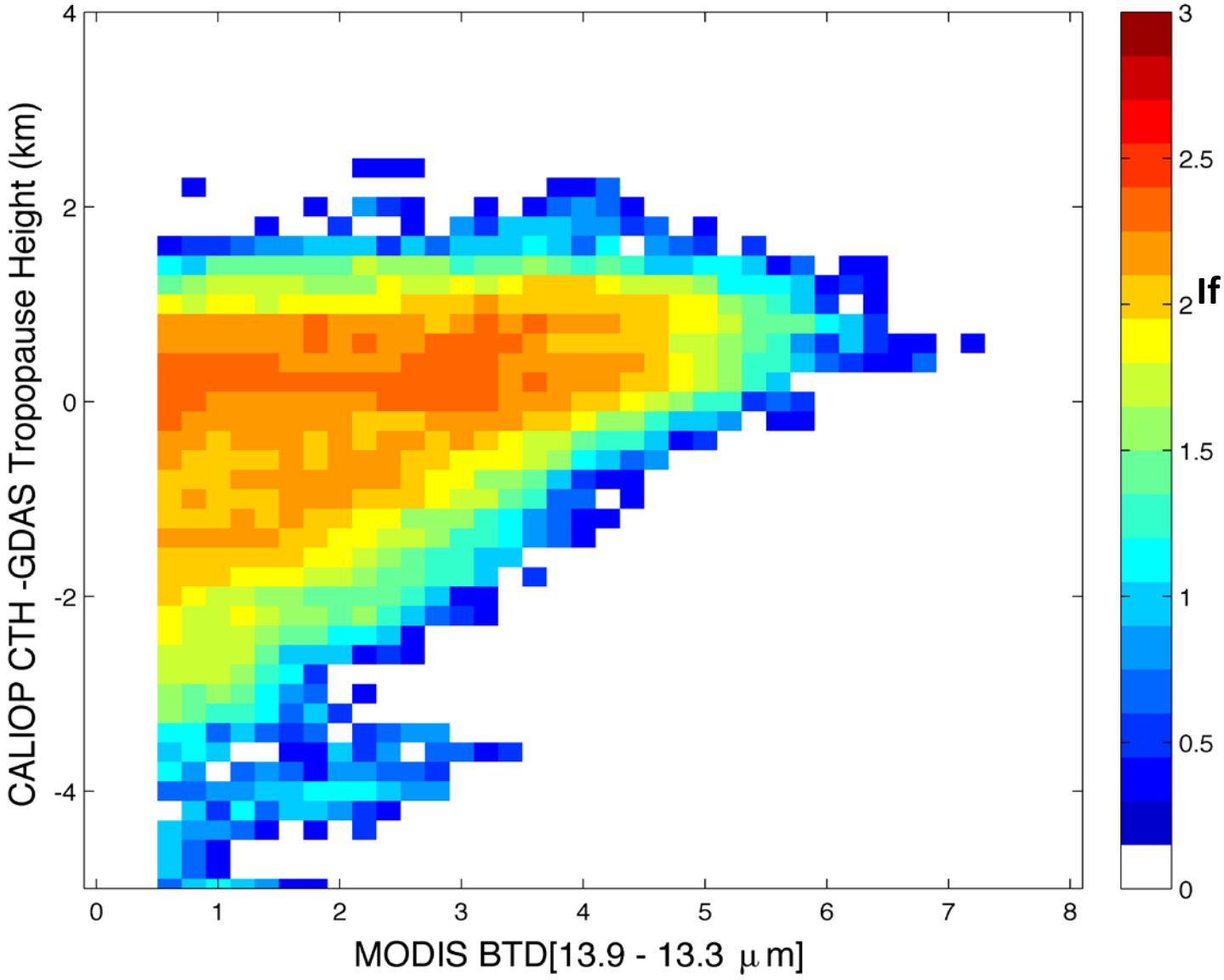


Terra C5 (left) & C6 (middle) along with Aqua C6 (right) results for 90˚S-20˚S

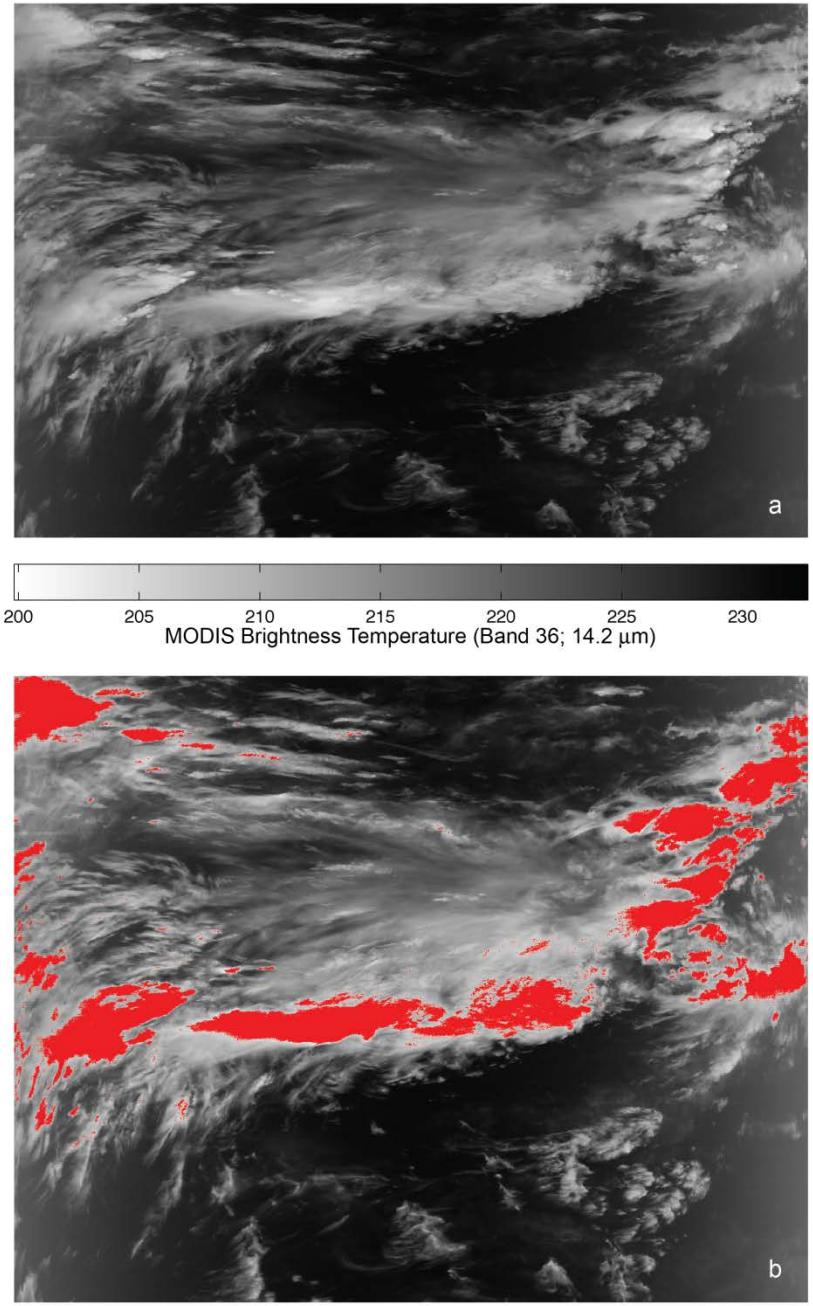
Summary of Changes for Collect 6 (MOD06CT & MYD06CT)

- **Lower "noise" thresholds** (clear minus cloudy radiances required to indicate cloud presence in CO_2 bands) enabling more CO_2 slicing solutions for high thin clouds.
- **Implement CO_2 spectral band shifts** suggested by Tobin et al. (JGR 2006) for Terra and Aqua MODIS.
- **Adjust ozone profile between 10 and 100 hPa** to GDAS values instead of using climatology (so that CO_2 radiances influenced by O_3 profiles are calculated correctly).
- **Incorporate sinusoidal CO2 increase**.
- **Prohibit CO_2 slicing solutions for water clouds**; use only IRW solution. **Avoid IRW solutions for ice clouds**; use CO_2 slicing whenever possible.
- **Restrict CO_2 solution to the appropriate part of troposphere** (determined by CO_2 band weighting functions so 36/35 < 450 hPa, 35/34 < 550 hPa, and 34/33 < 650 hPa).
- **Implement marine stratus improvement** where a constant lapse rate is assumed in low level inversions according to latitude region.
- **Add Upper Troposphere / Lower Stratosphere Flag**.
- **Use Beta-ratios to determine cloud phase**.


P
UT/LS Cloud Flag
indicated when BT13.9>BT13.3
x x x x x x
x x x x x
CO_2
above cloud
BT13.9
BT13.3
Cloud
T
Can also use
WV above cloud when
BTWV>BTIRW



If BT13.9-13.3) > 0.5 C then 87% of obs within 2 km of tropopause



UTLS Clouds (flagged in red)

IR Phase Modifications

Bryan A. Baum, Richard Frey, and Andrew Heidinger

Collection 5:

- Based on 8.5/11-μm BTs and their differences
- Provided at 5-km resolution

Collection 6:

Supplement BT/BTD tests with emissivity ratios (♌ ratio)

♌ ratios are based on 7.3, 8.5, 11, 12-μm bands

Use of ♌ ratio mitigates influence of the surface

Approach imposes new requirements:

- clear-sky radiances, which implies knowledge of…
- atmospheric profiles, surface emissivity, and a fast RT model

This approach can be implemented for only the 1-km products

The Beta ratio is based on cloud emissivity profiles

A cloud emissivity profile for a single band:

$$\mathcal{M}(p) = \frac{(I - I_{clr})}{[I_{ac}(p) + \text{❄}_{ac}(p) I_{bb}(p) - I_{clr})]}$$

where
I_{clr} = clear-sky radiance
$I_{ac}(p)$ = above cloud emission at pressure p
$I_{bb}(p)$ = TOA radiance for opaque cloud at pressure p
$\text{❄}_{ac}(p)$= above cloud transmission

$$\beta_{x,y}(p) = \frac{\ln[1 - \mathcal{M}_{c,y}(p)]}{\ln[1 - \mathcal{M}_{c,x}(p)]}$$

where x and y are two channels used to compute the ratio

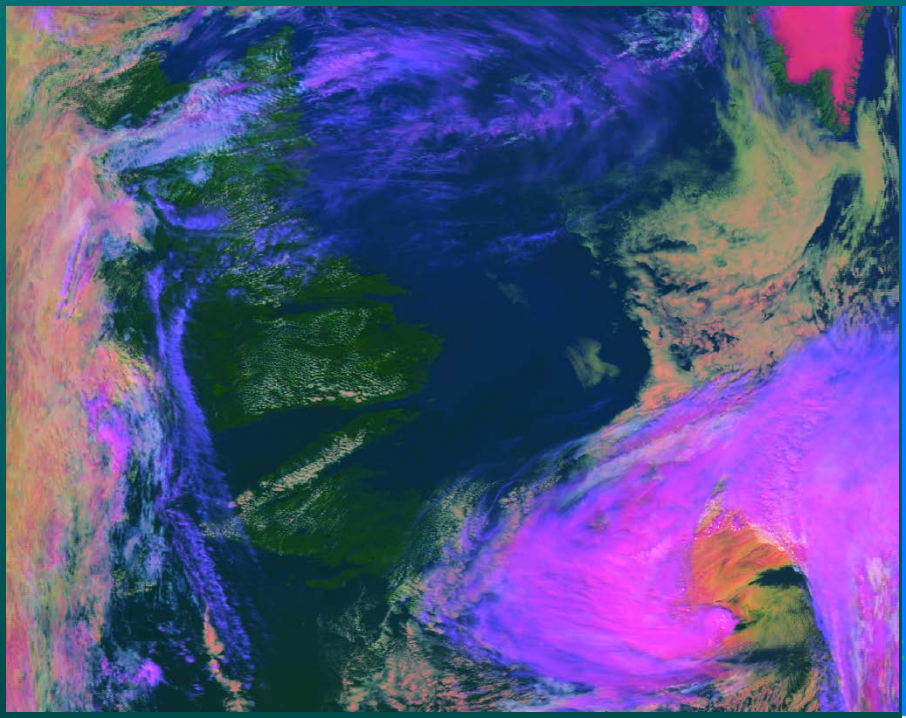
Beta ratios used for C6 IR phase tests

8.5/11: has the most sensitivity to cloud phase

11/12: sensitive to cloud opacity; implementation of this pair helps with optically thin clouds (improves phase discrimination for thin cirrus)

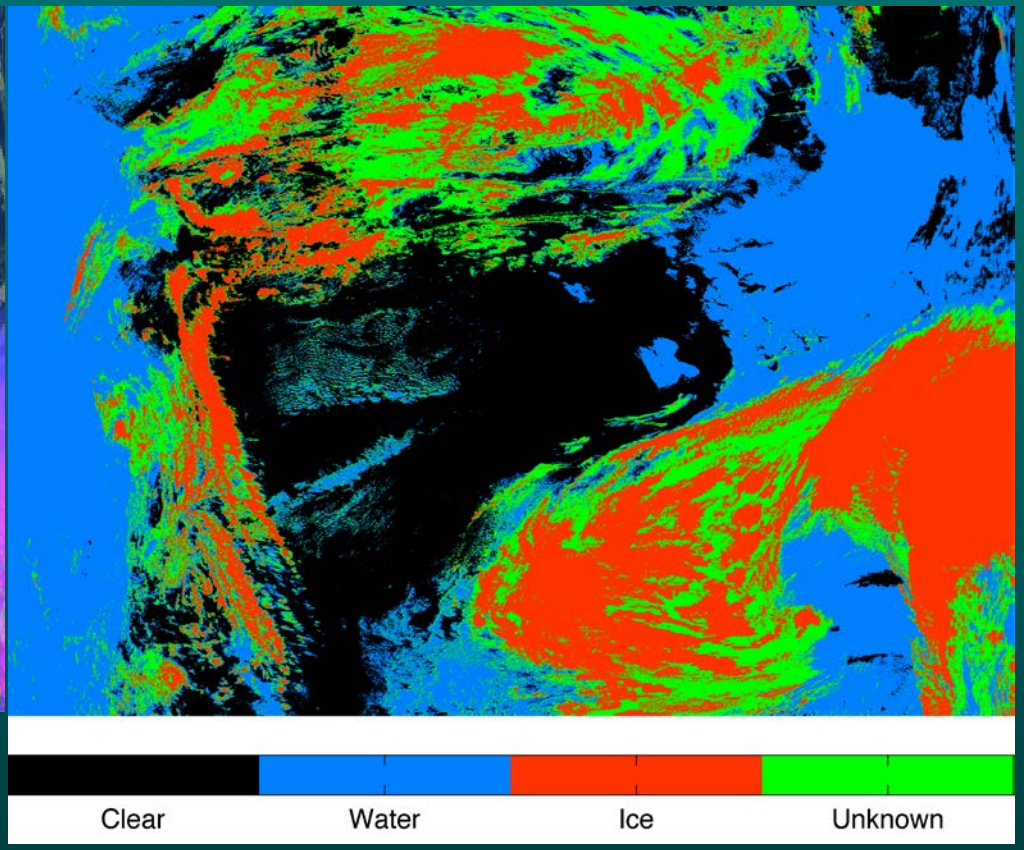
7.3/11: sensitive to high versus low clouds; helps with low clouds (one of the issues was a tendency for low-level water clouds to be ringed with ice clouds as the cloud thinned out near the edges)

MODIS IR Phase for a granule on 28 August, 2006 at 1630 UTC Over N. Atlantic Ocean between Newfoundland and Greenland



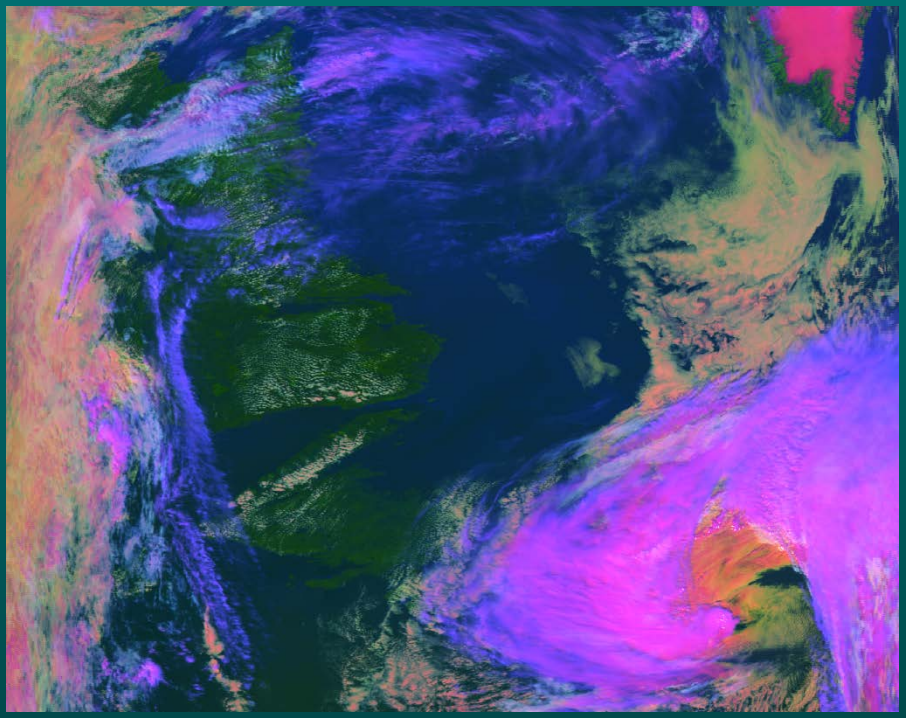
False color image
Red: 0.65 ❍m; Green: 2.1 ❍m; Blue: 11 ❍m

Thin cirrus: blue
Opaque ice clouds: pink
Water clouds: white/yellow
Snow/ice: magenta (Southern tip of Greenland)
Ocean: dark blue
Land: green

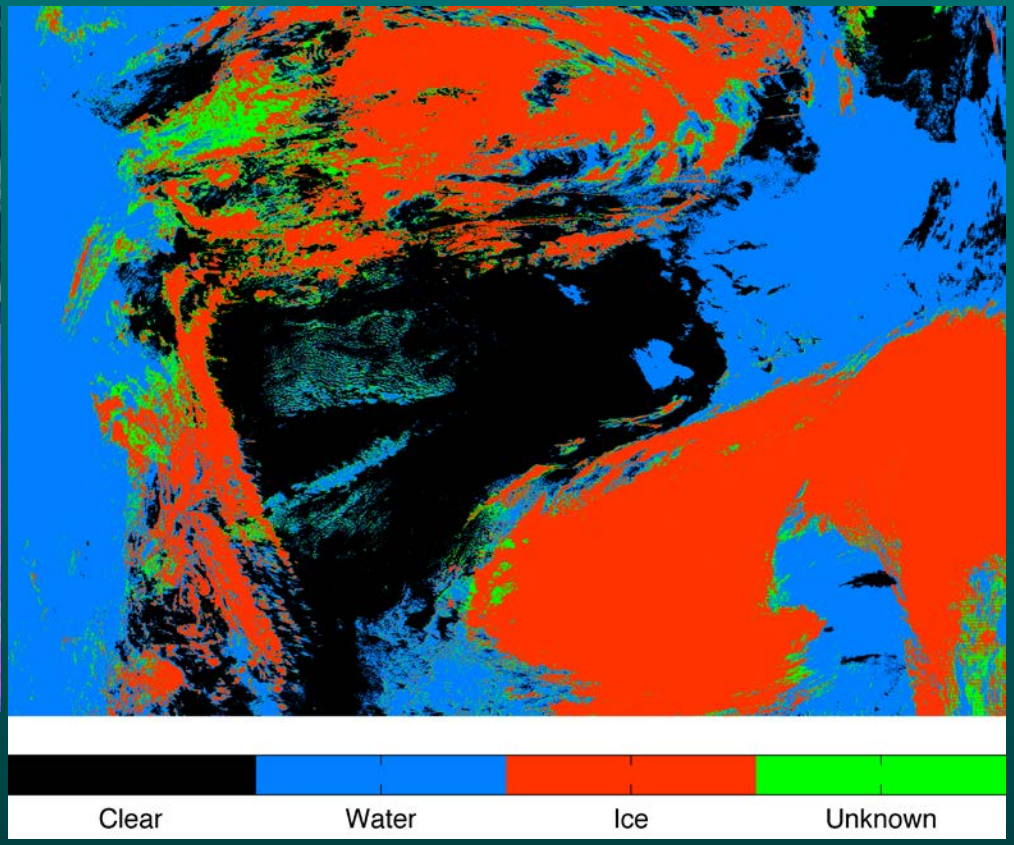


Collection 5 algorithm but with uncertain and mixed phase pixels combined into "uncertain" category

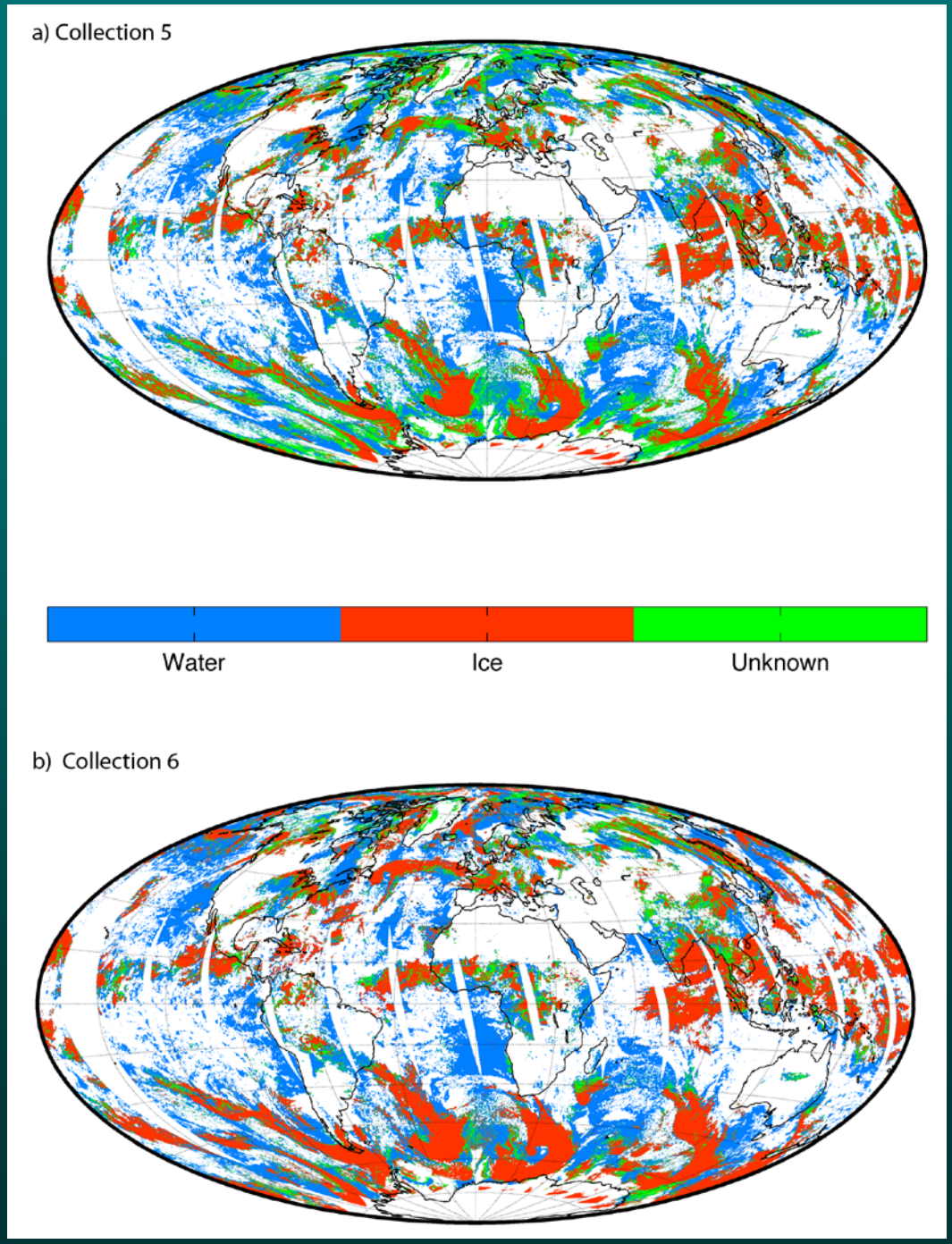
MODIS IR Phase for a granule on 28 August, 2006 at 1630 UTC Over N. Atlantic Ocean between Newfoundland and Greenland



False color image
Red: 0.65 μm; Green: 2.1 μm; Blue: 11 μm



Collection 6 algorithm:
Propose 3 categories, deleting mixed phase since there is no justification for this category



For C5, most of the uncertain phase pixels occurred in the storm tracks, i.e., at high latitudes

For C6, there are many less uncertain phase retrievals now that cirrus is more likely to be identified as ice phase clouds

Conclusions on CO2 Slicing CTH Algorithm Adjustments

- The largest cloud height errors (>15 km) result from not using CO2 slicing
- Spectral shifts reduce the bias in observed minus calculated radiances
- Reducing the cloud detection threshold increases thin cloud sensitivity and produces more CO2 slicing solutions so that CTPs are decreased for high clouds
- A high bias in marine stratus CTHs is mitigated by assuming a latitudinally dependent wet lapse rate
- Using β-ratio cloud phase algorithm produces fewer uncertain retrievals and cirrus is more likely to be identified as ice
- Vertical distributions of Terra and Aqua CTPs show better agreement
- Making multiple passes through large data sets was necessary
- Using CALIOP as a reference was invaluable

Example MODIS Collection 6 Results monthly statistics of cloud top pressure March 2012 to February 2013

High vs. Low

Day vs. Night

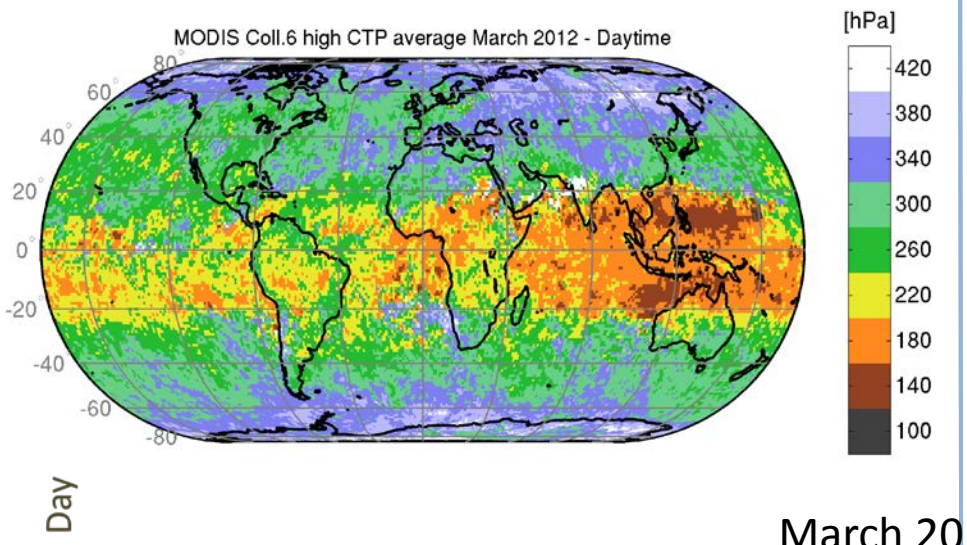
Filtering and aggregation based on STG method described in Smith et al. (2013) JAMC

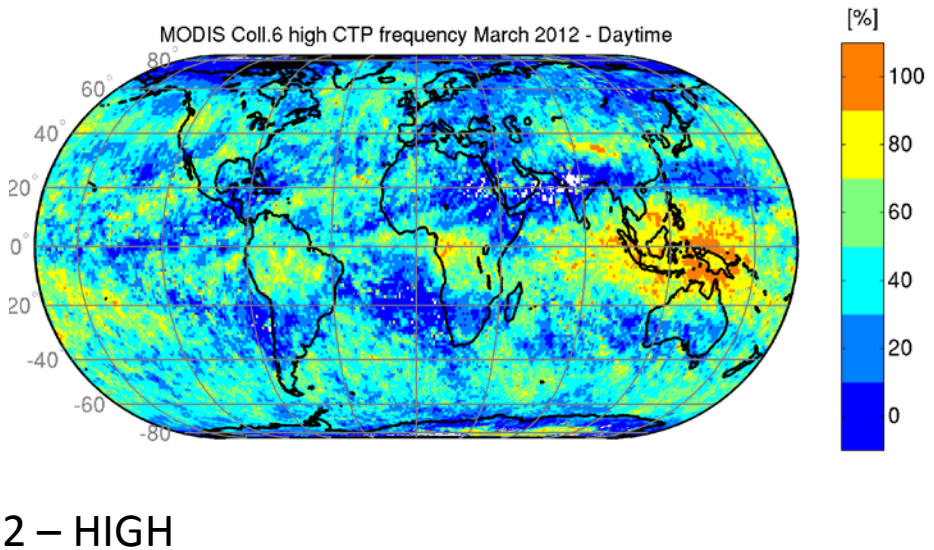
Richard Frey, Bryan Baum, Nadia Smith,

Nick Bearson, and Paul Menzel

CTP average [hPa]

CTP frequency [%]

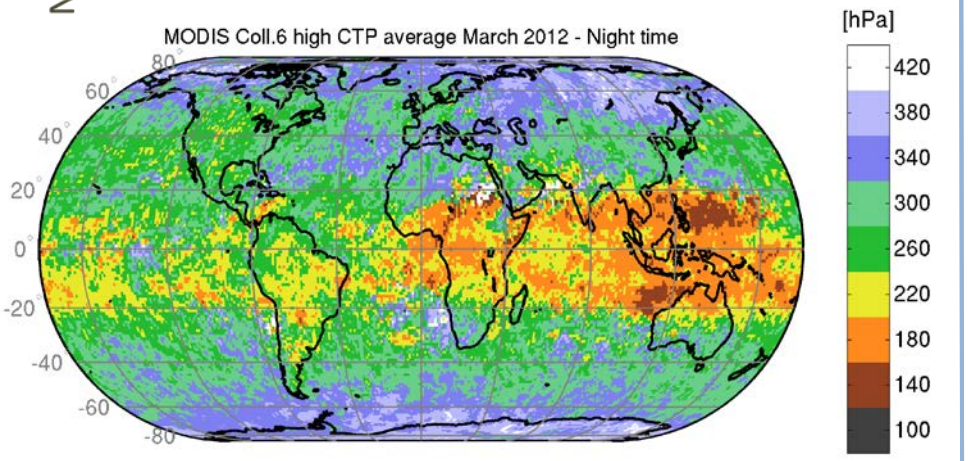


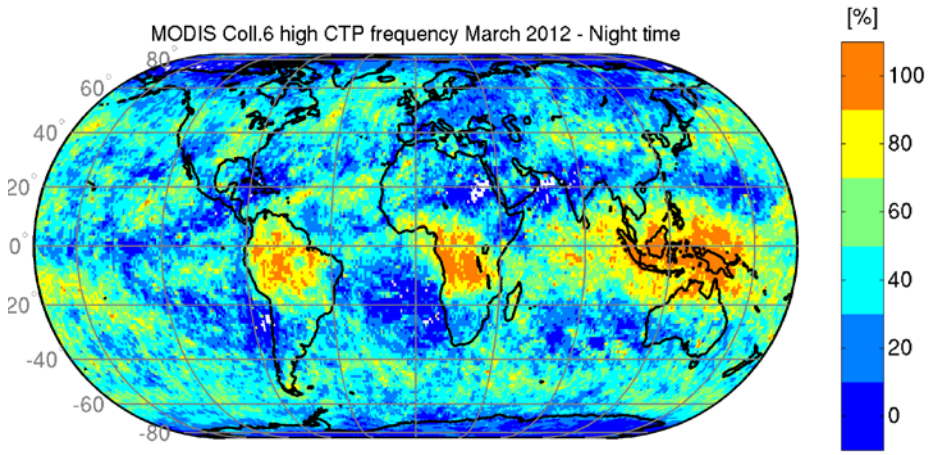


Day

March 2012 – HIGH

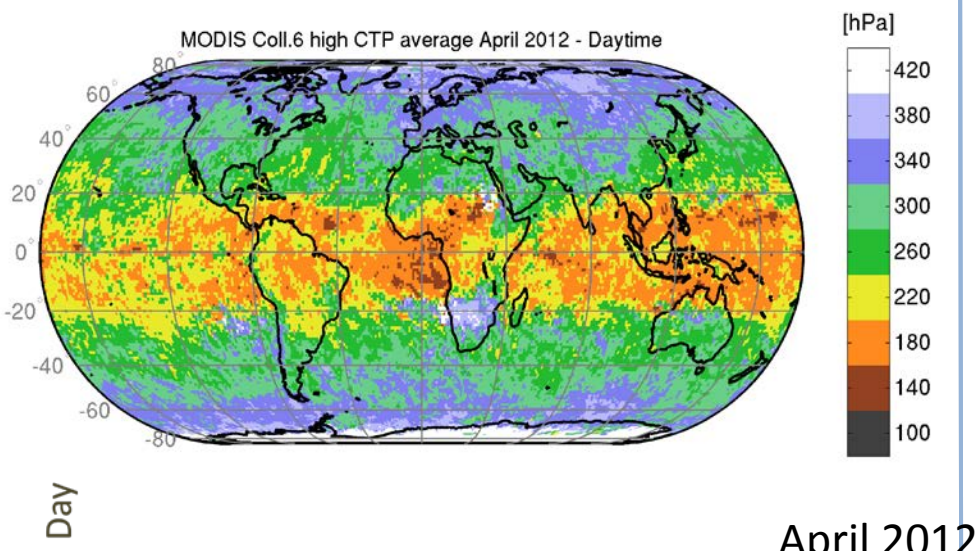
Night

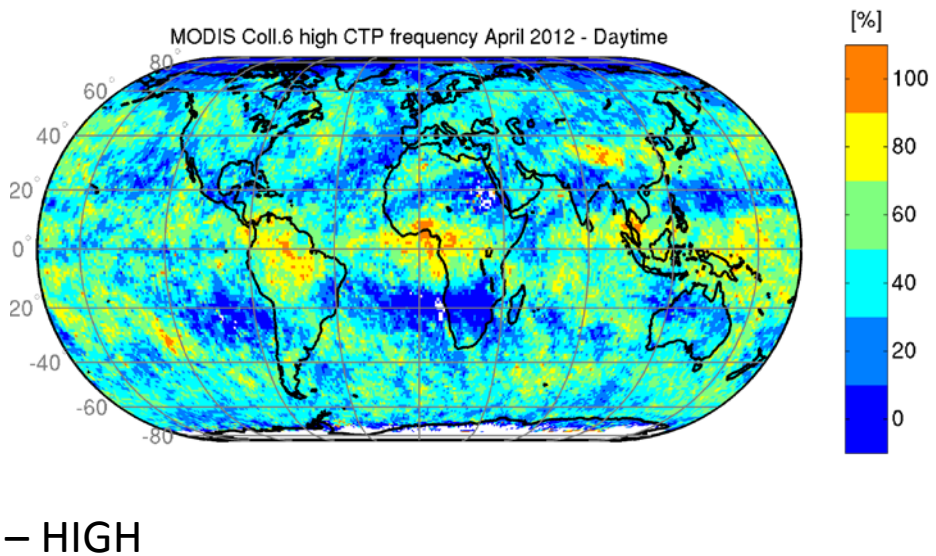




CTP average [hPa]

CTP frequency [%]

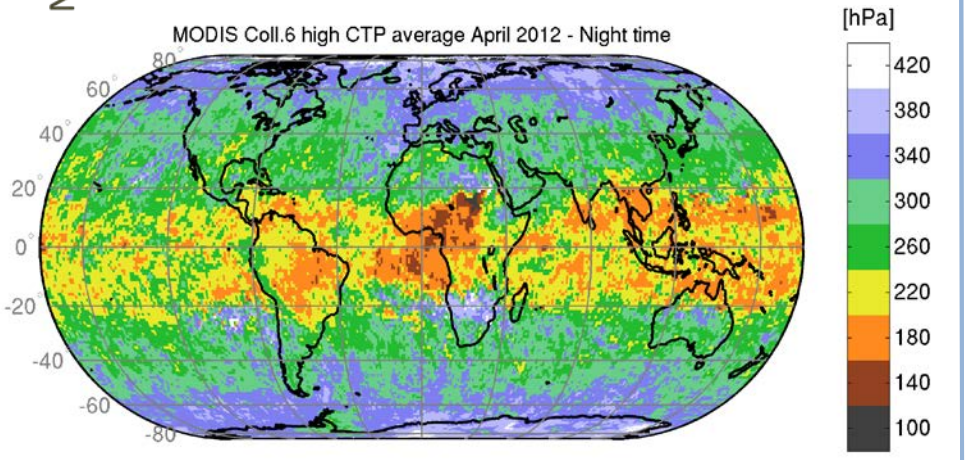


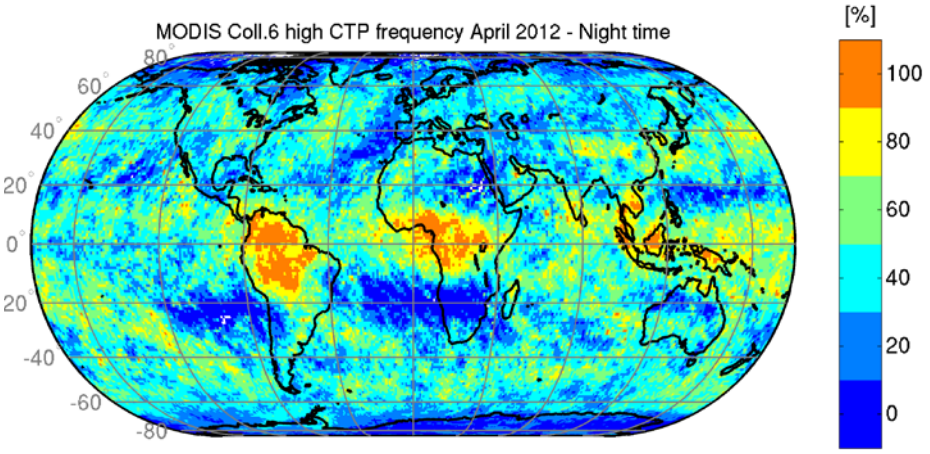


Day

April 2012 – HIGH

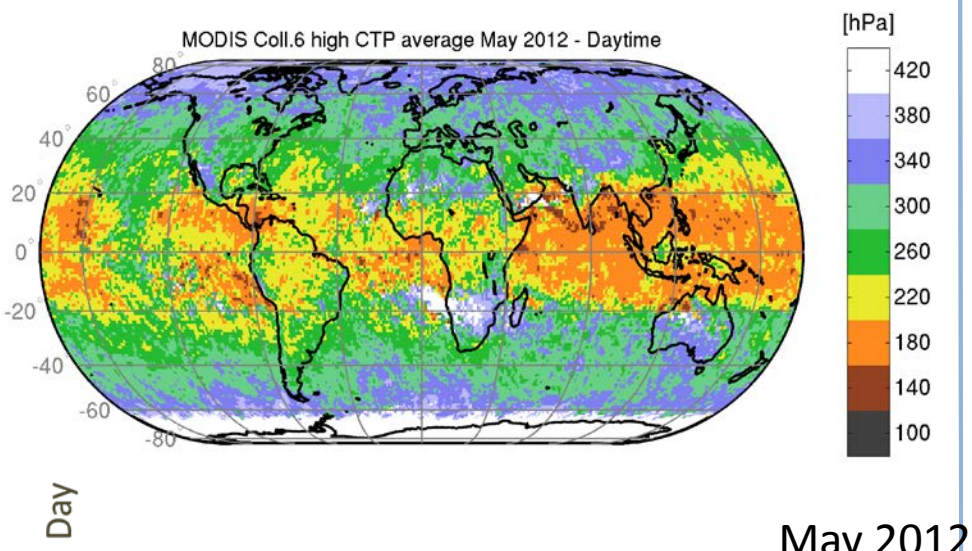
Night

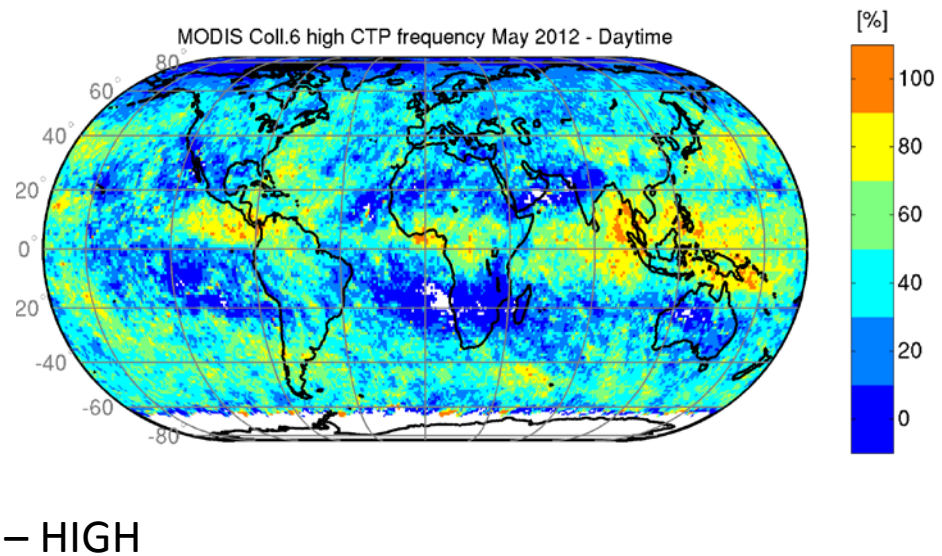




CTP average [hPa]

CTP frequency [%]

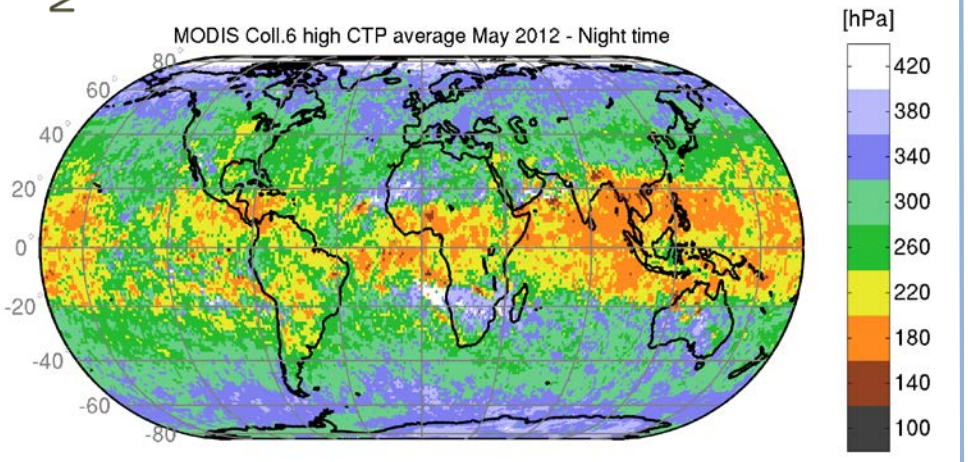


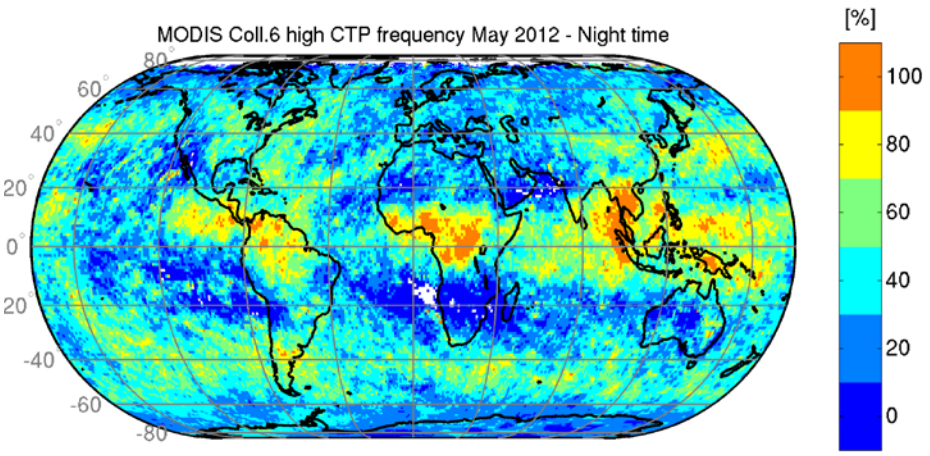


Day

May 2012 – HIGH

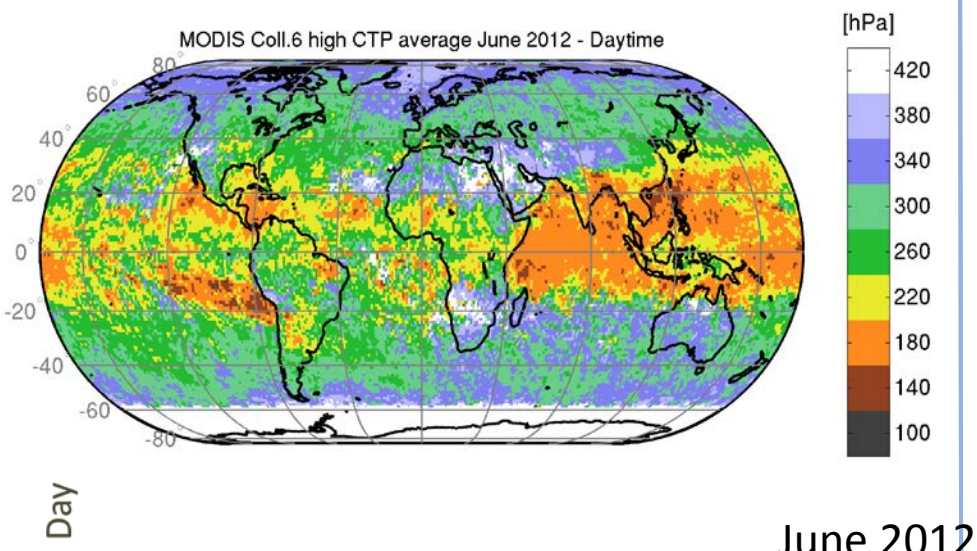
Night

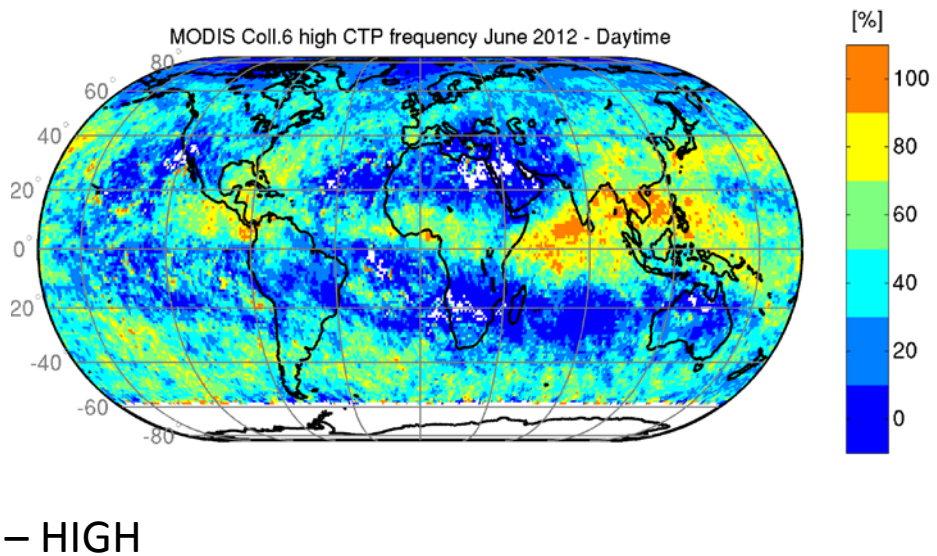




CTP average [hPa]

CTP frequency [%]

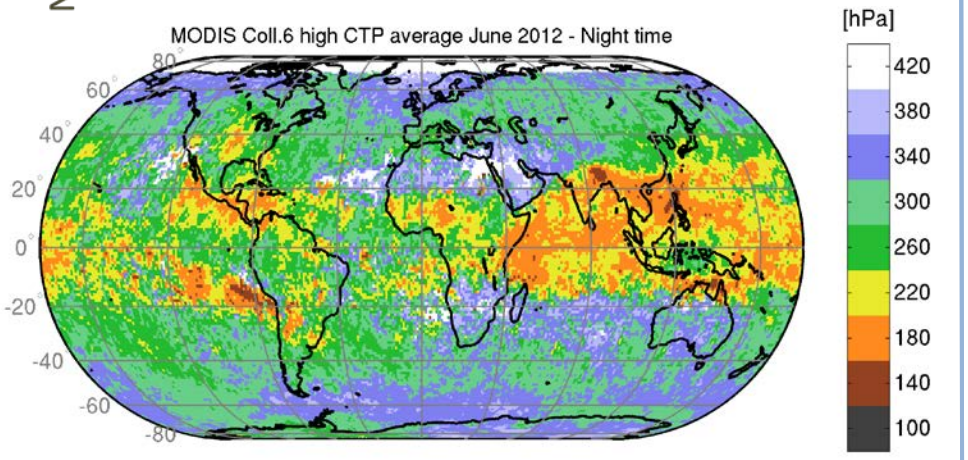


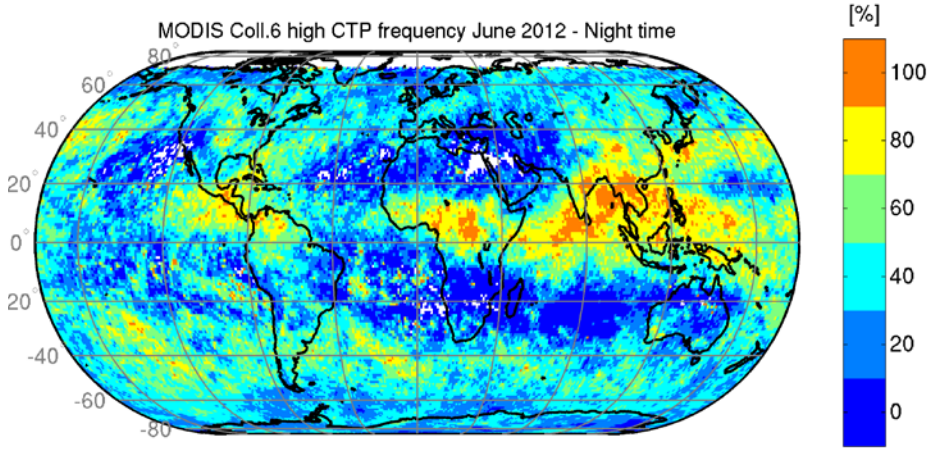


Day

June 2012 – HIGH

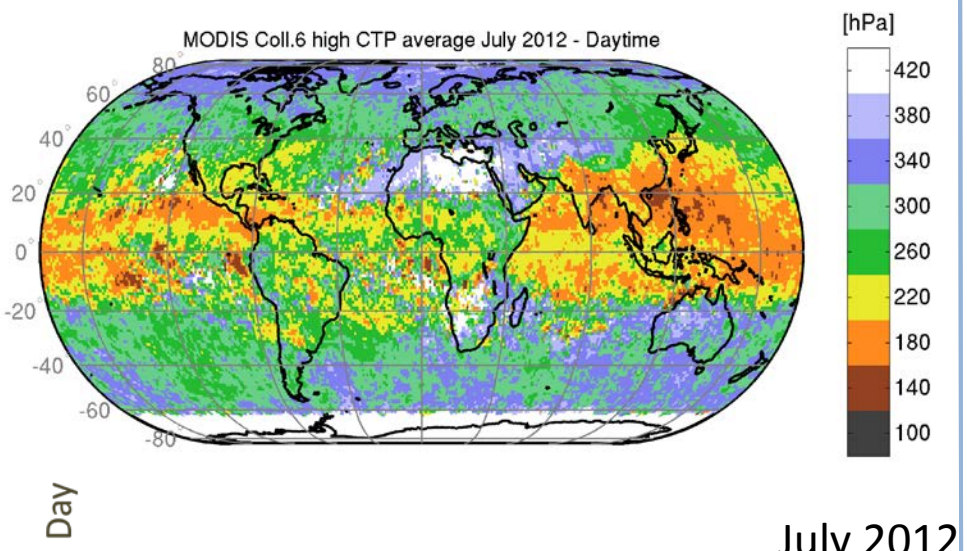
Night

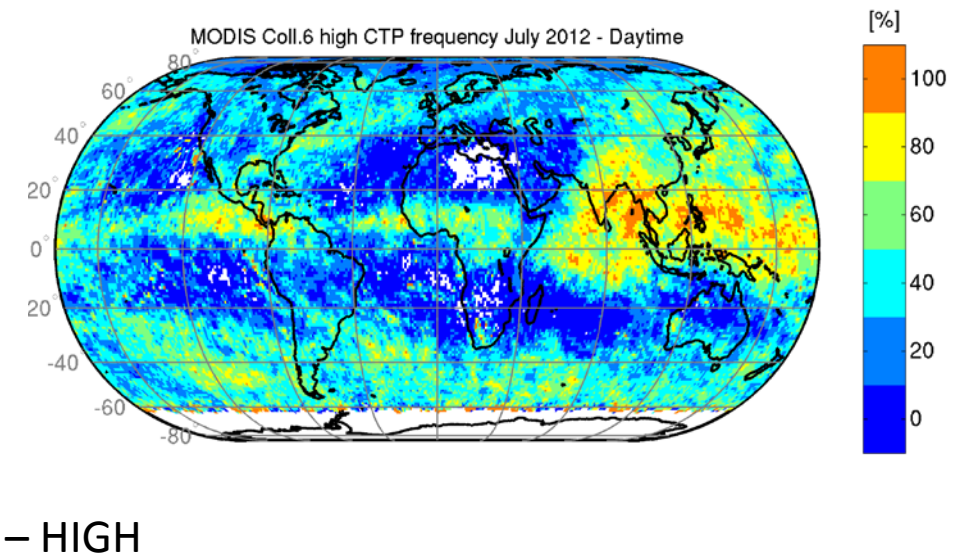




CTP average [hPa]

CTP frequency [%]

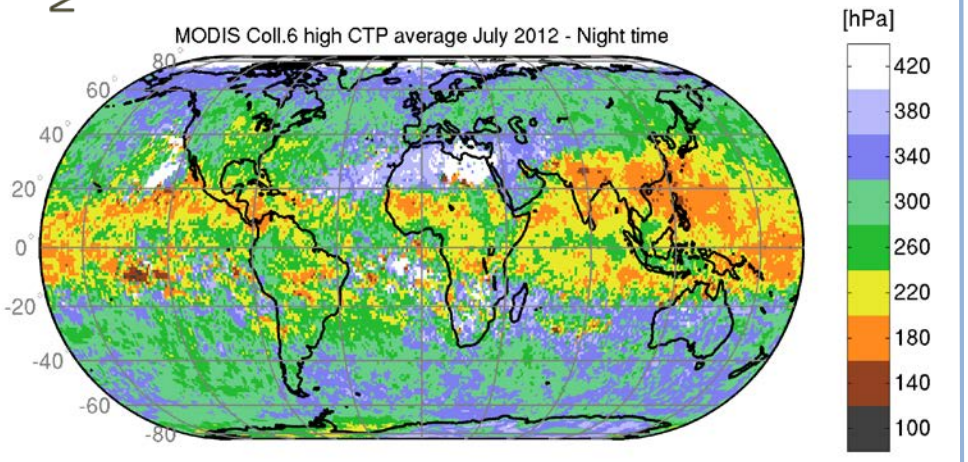


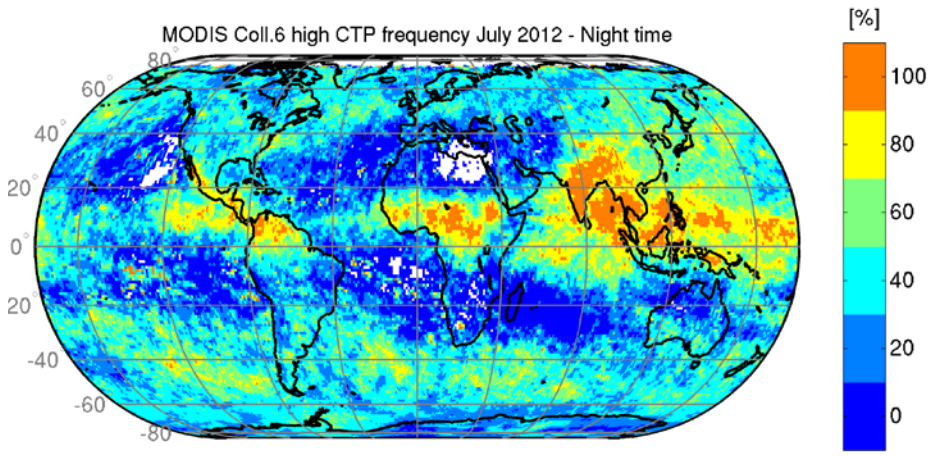


Day

July 2012 – HIGH

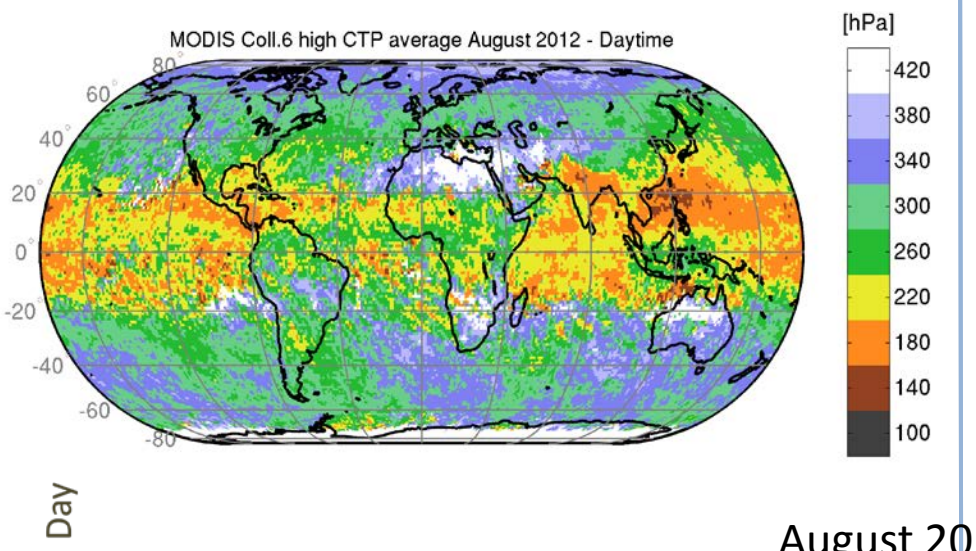
Night

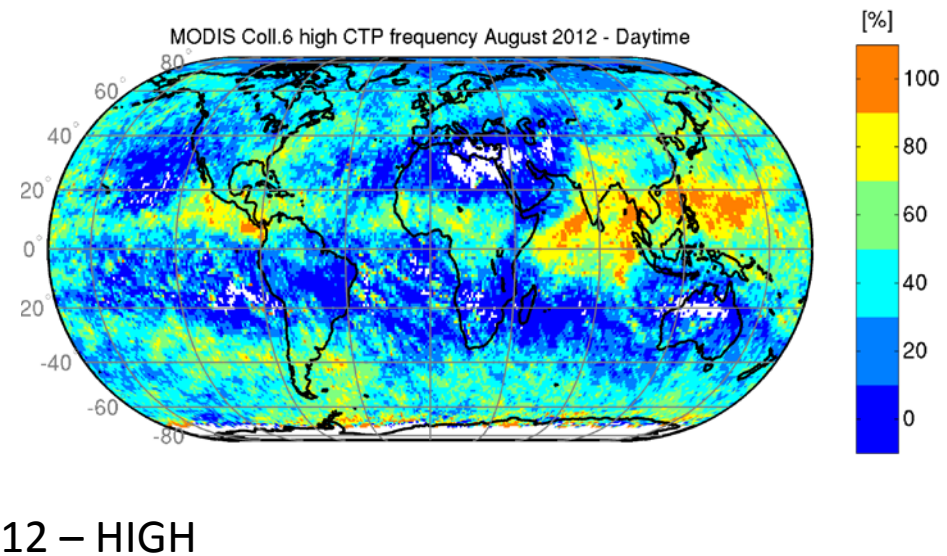




CTP average [hPa]

CTP frequency [%]

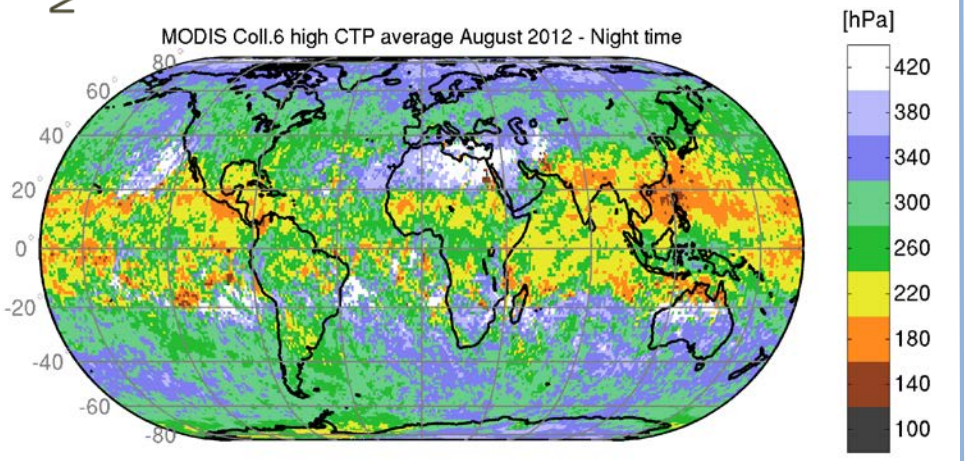


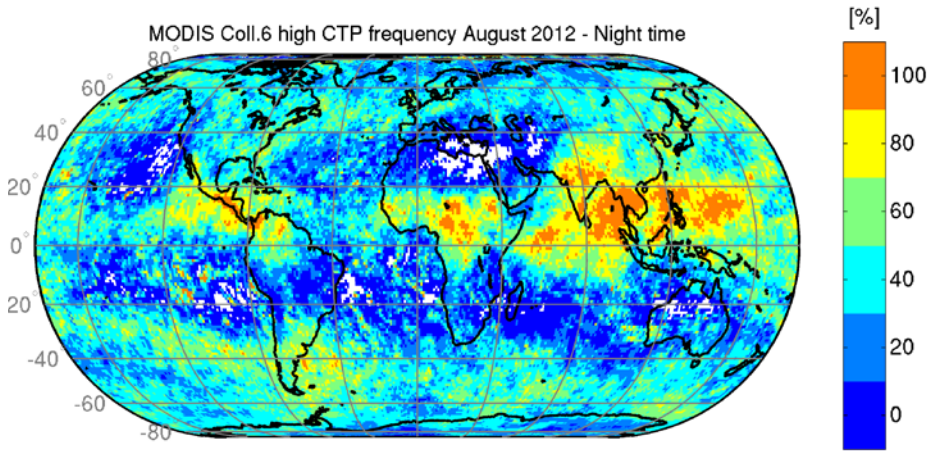


Day

August 2012 – HIGH

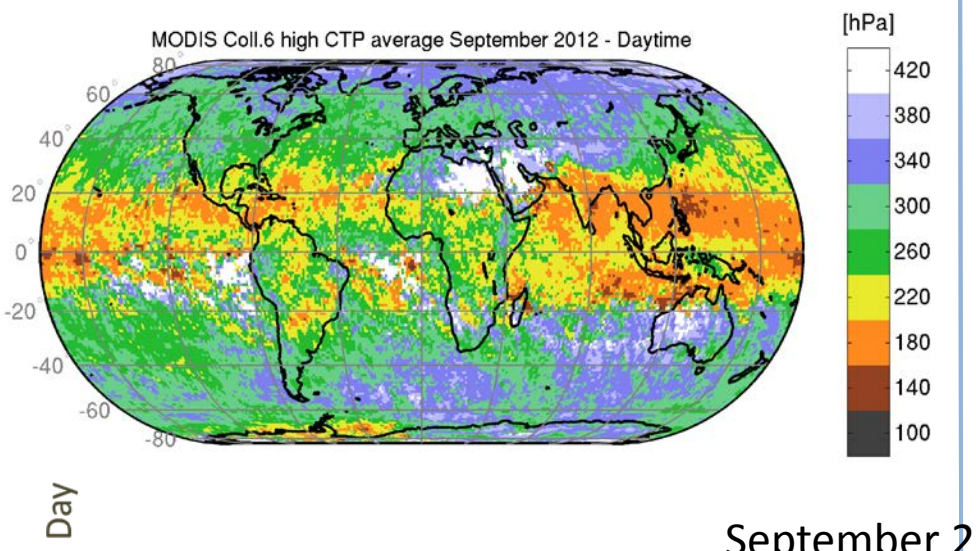
Night

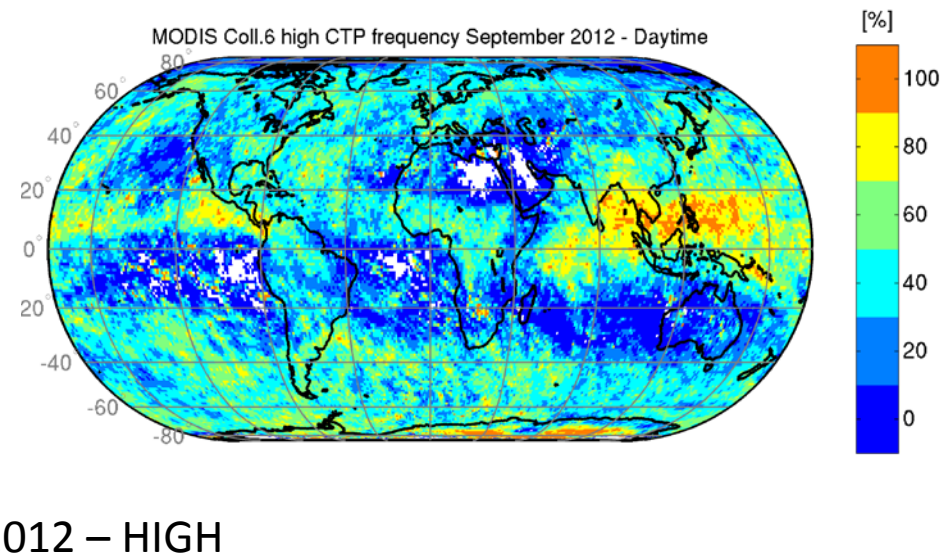




CTP average [hPa]

CTP frequency [%]

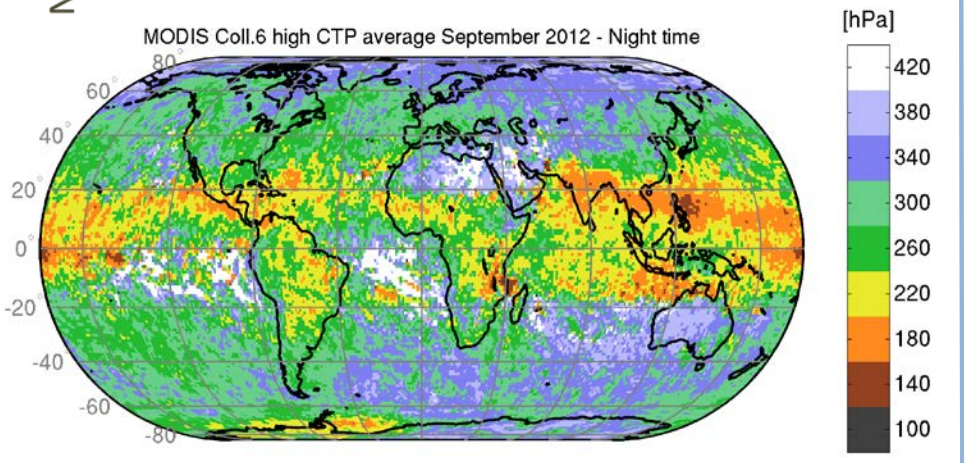


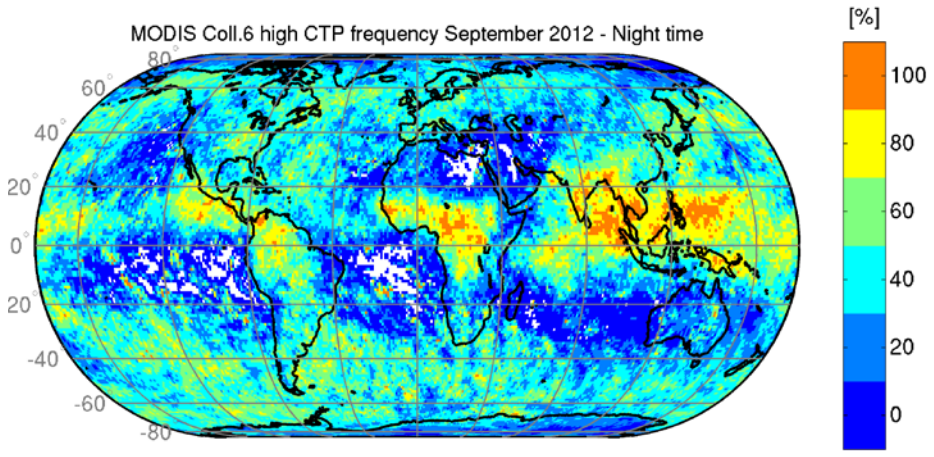


Day

September 2012 – HIGH

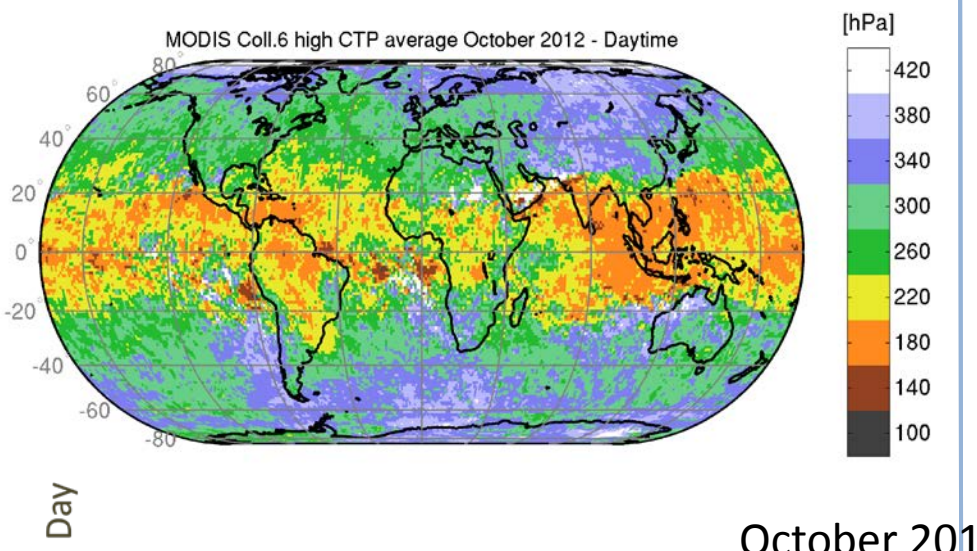
Night

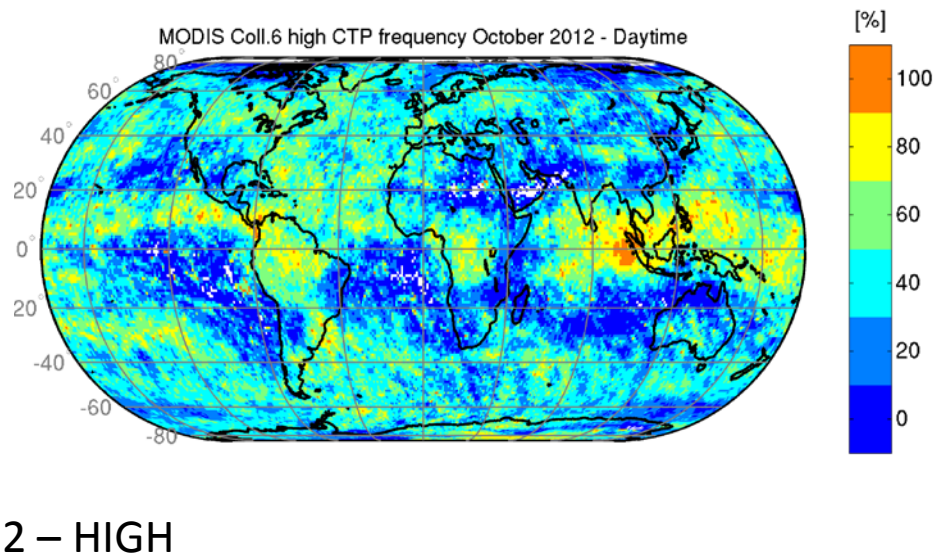




CTP average [hPa]

CTP frequency [%]

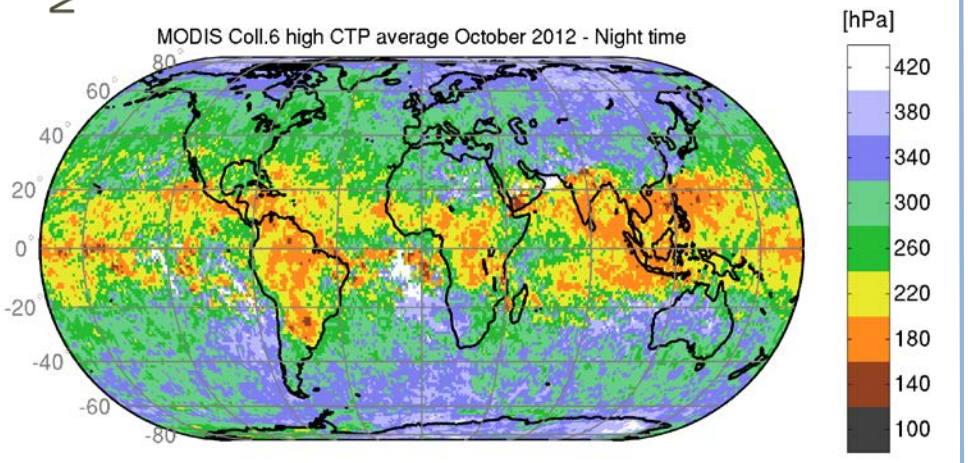


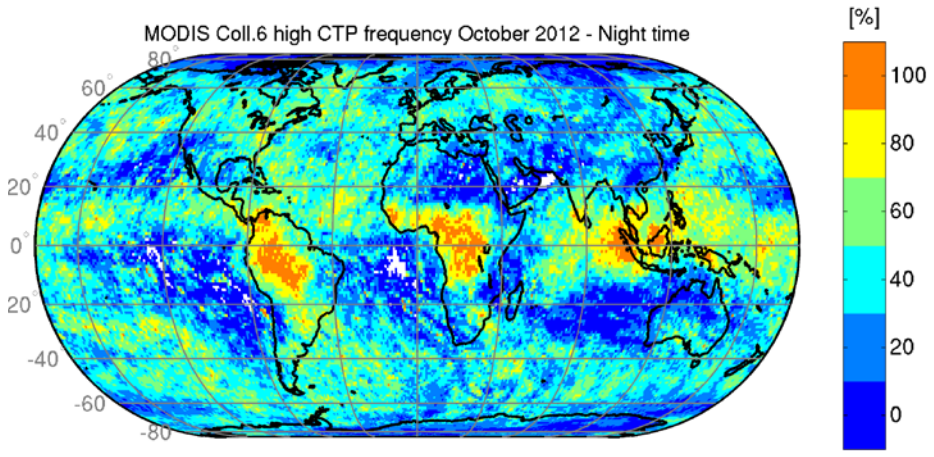


Day

October 2012 – HIGH

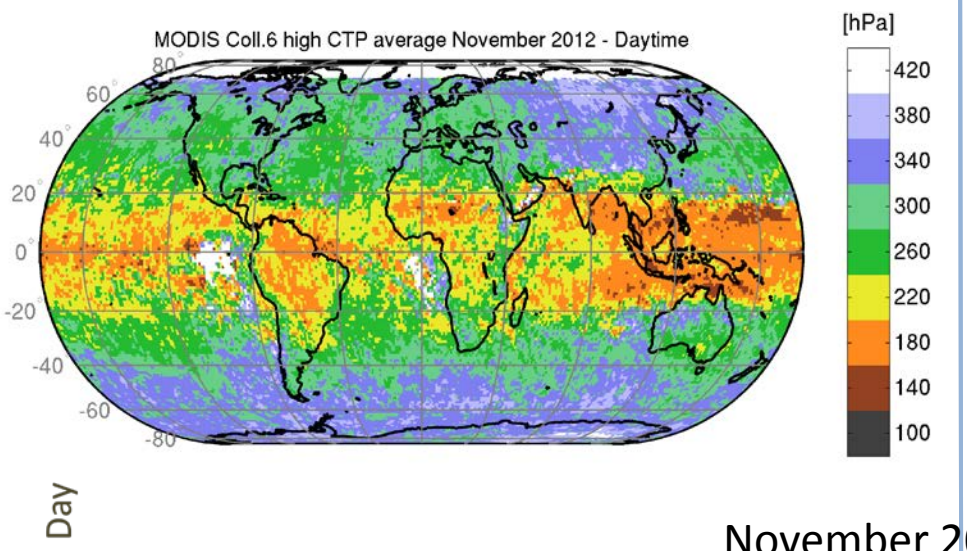
Night

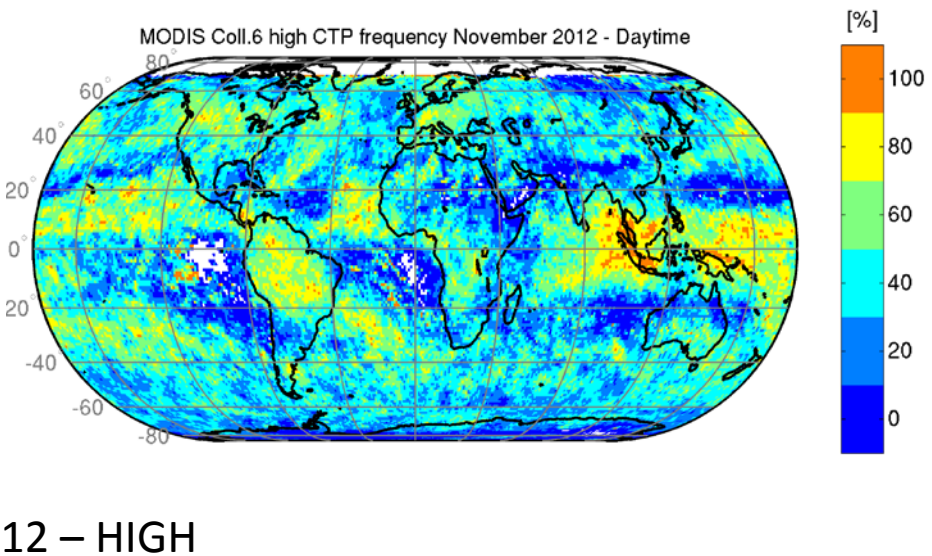




CTP average [hPa]

CTP frequency [%]

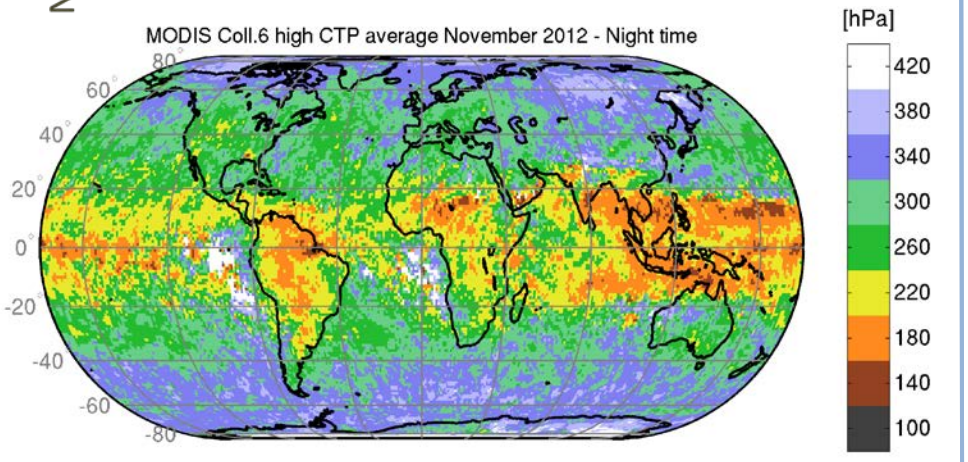


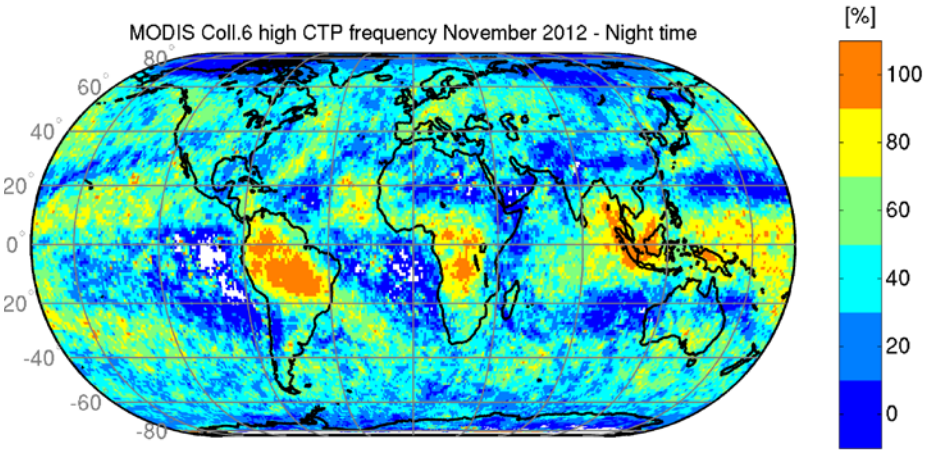


Day

November 2012 – HIGH

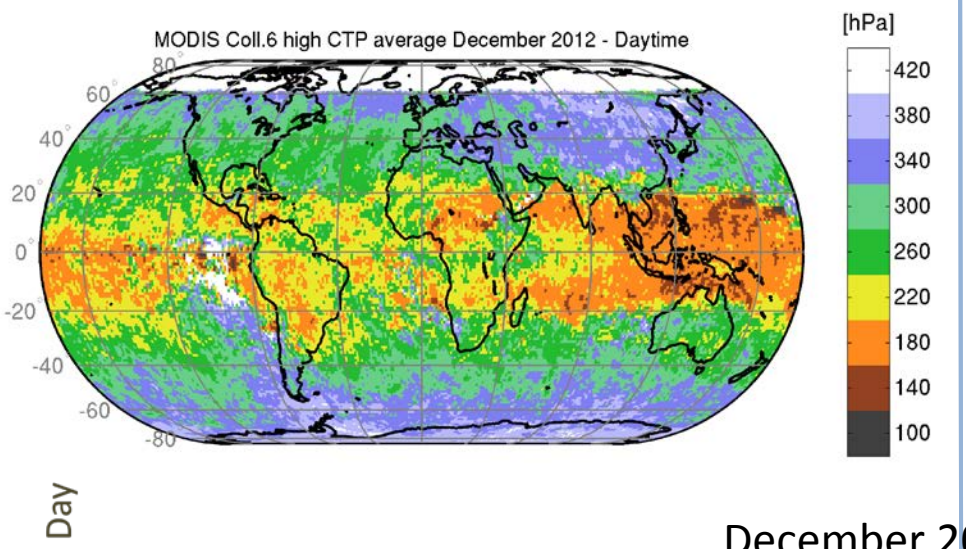
Night

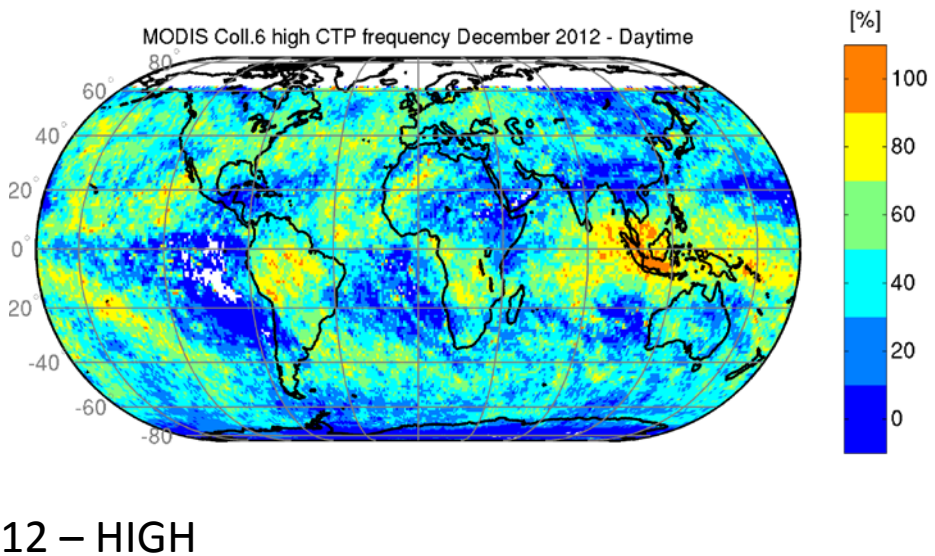




CTP average [hPa]

CTP frequency [%]

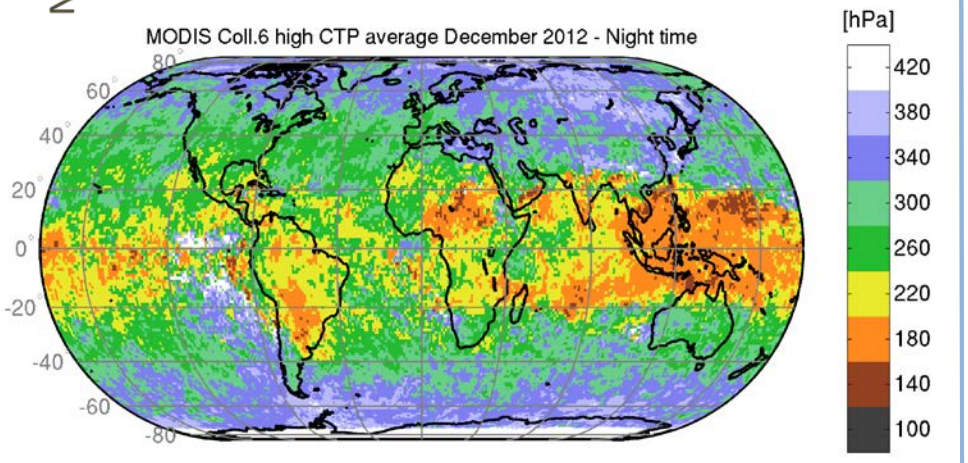


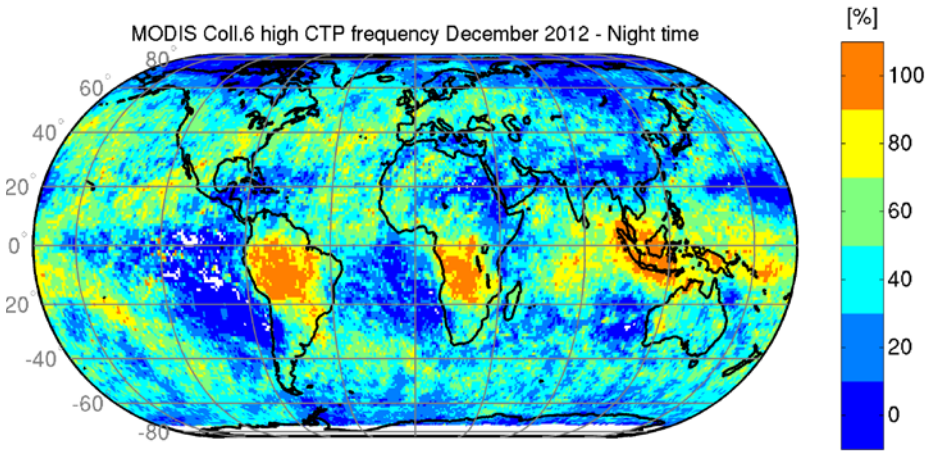


Day

December 2012 – HIGH

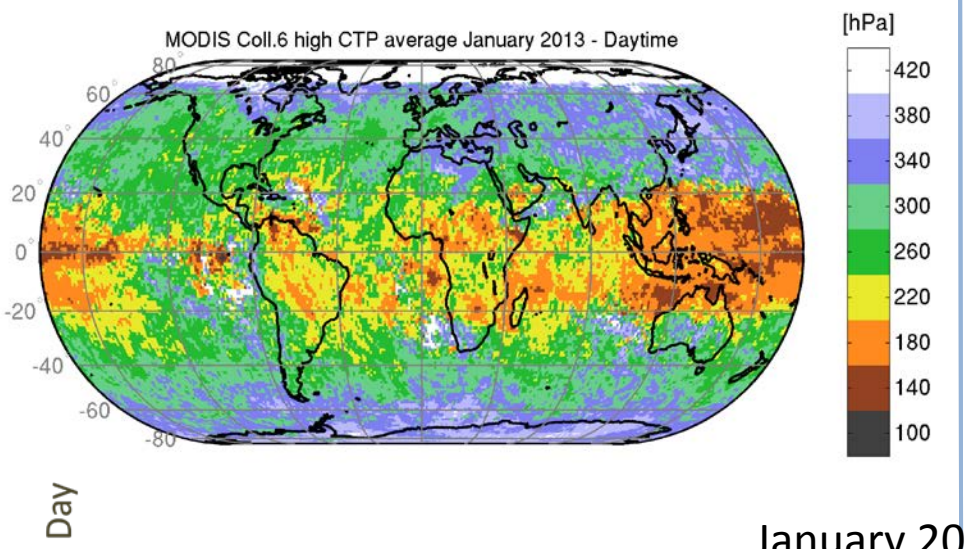
Night

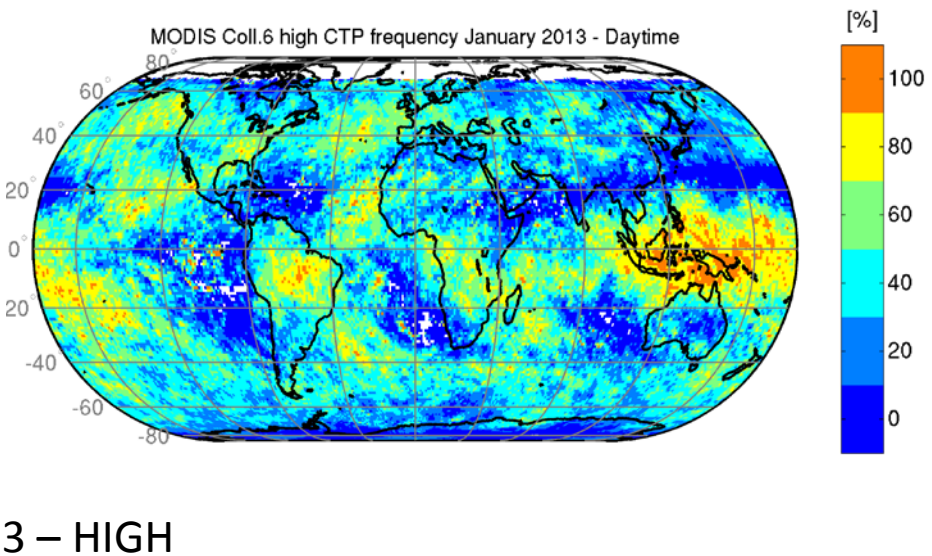




CTP average [hPa]

CTP frequency [%]

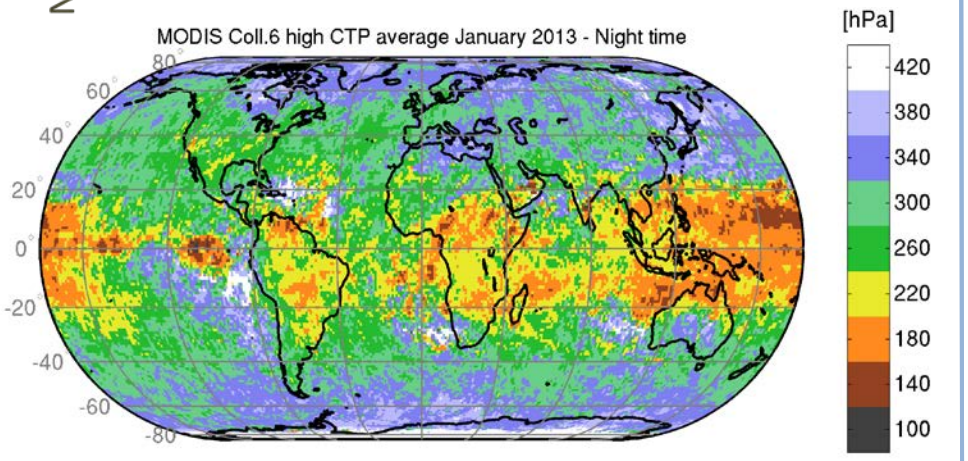


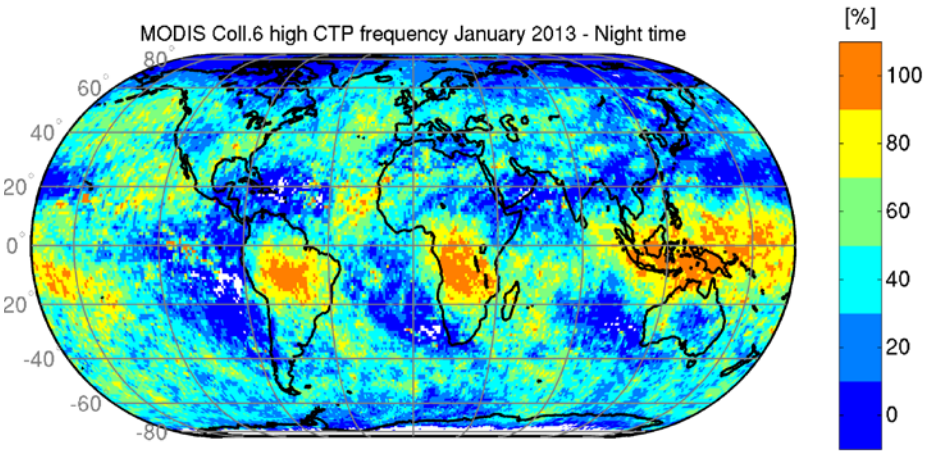


Day

January 2013 – HIGH

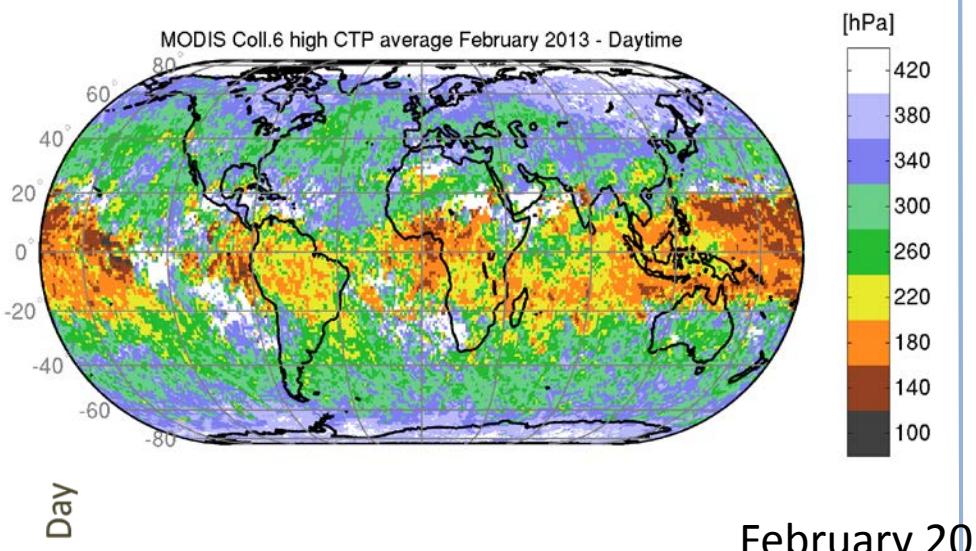
Night

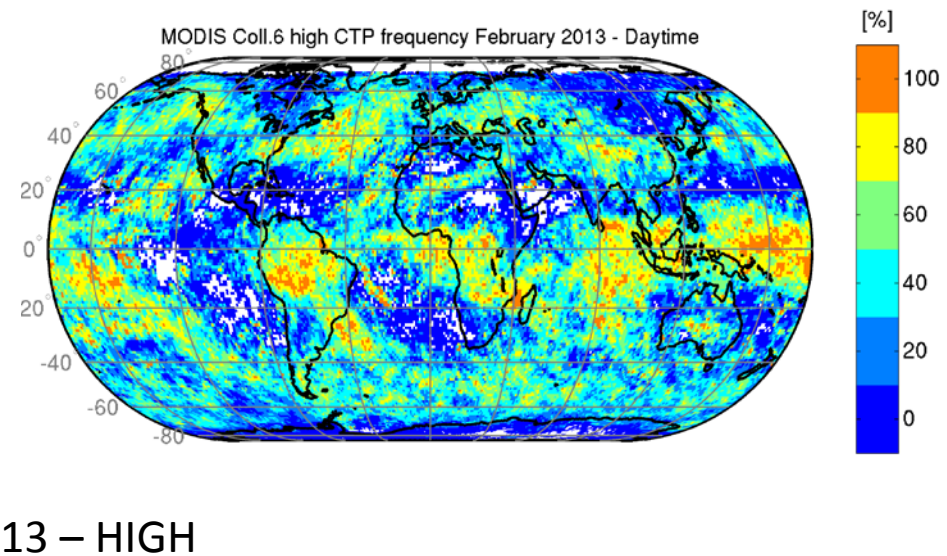




CTP average [hPa]

CTP frequency [%]

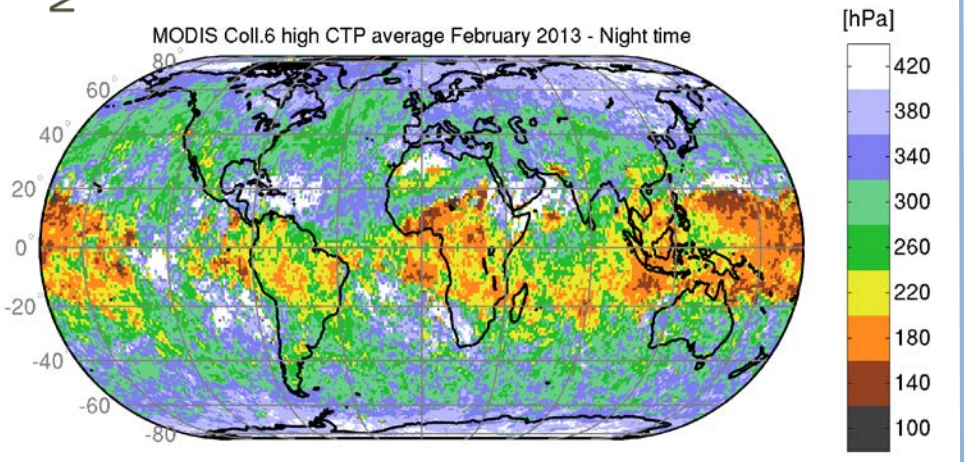


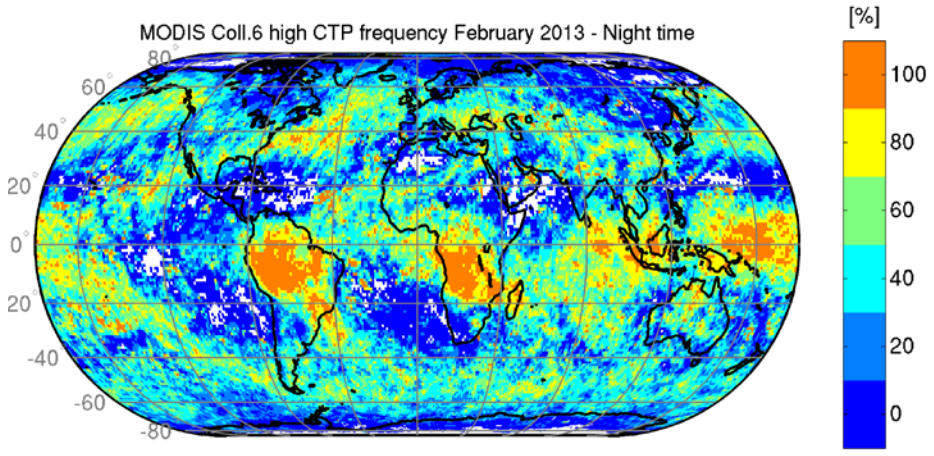


Day

February 2013 – HIGH

Night

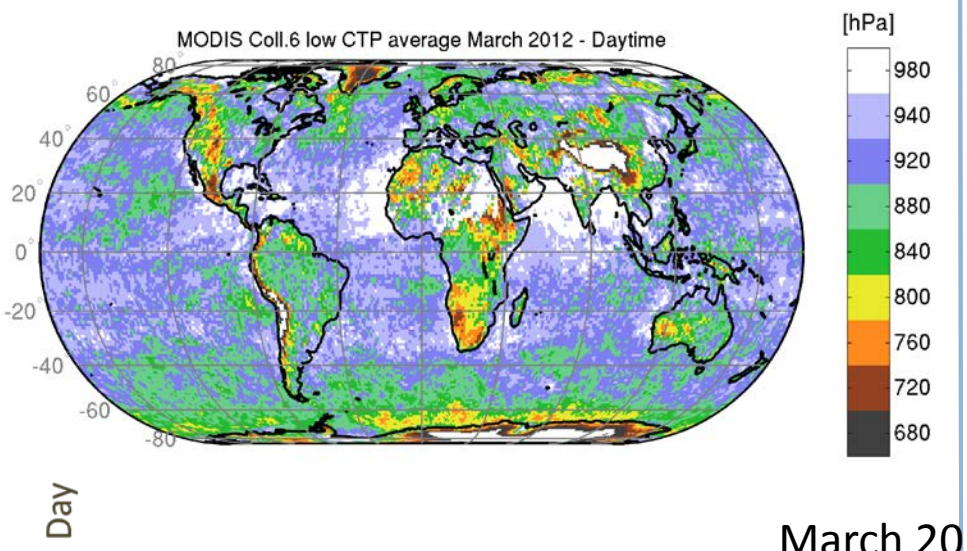


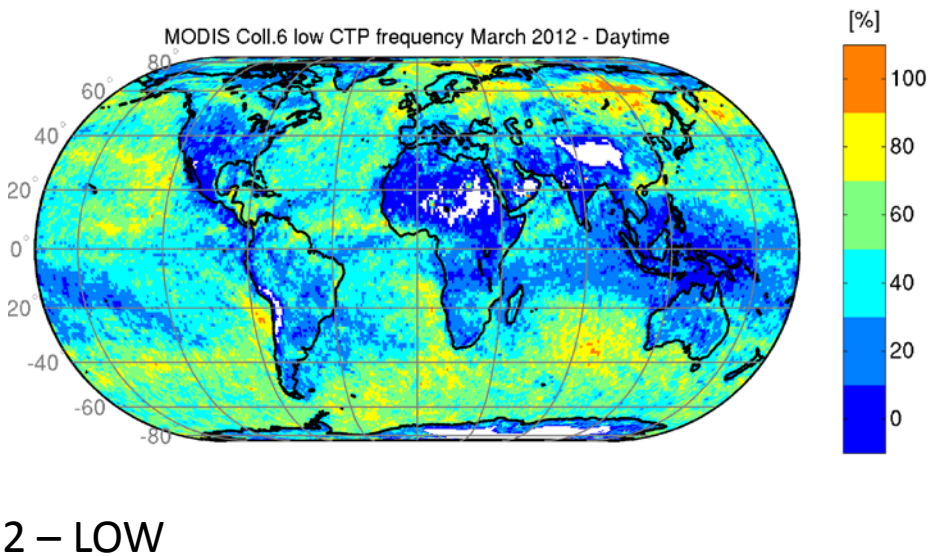


Low Clouds Study

CTP average [hPa]

CTP frequency [%]

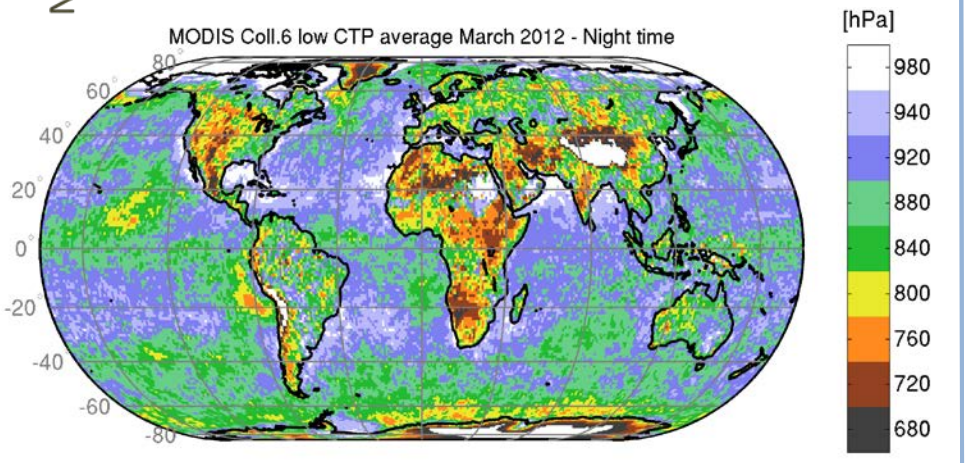


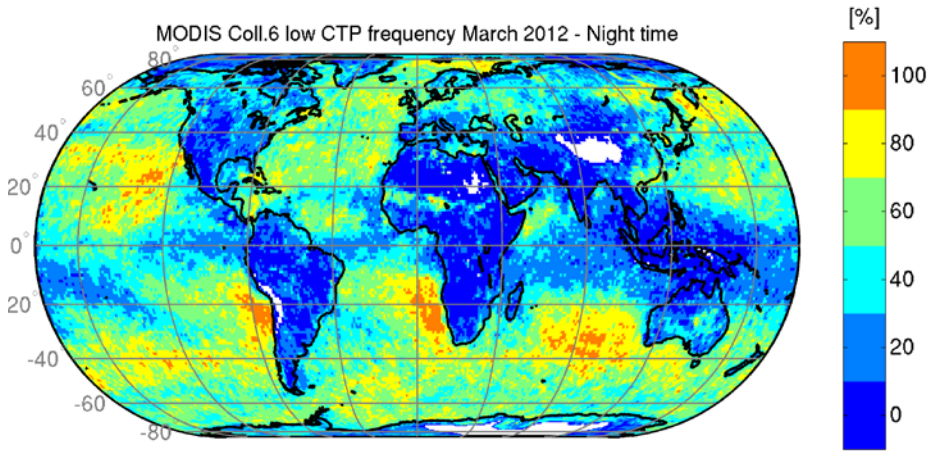


Day

March 2012 – LOW

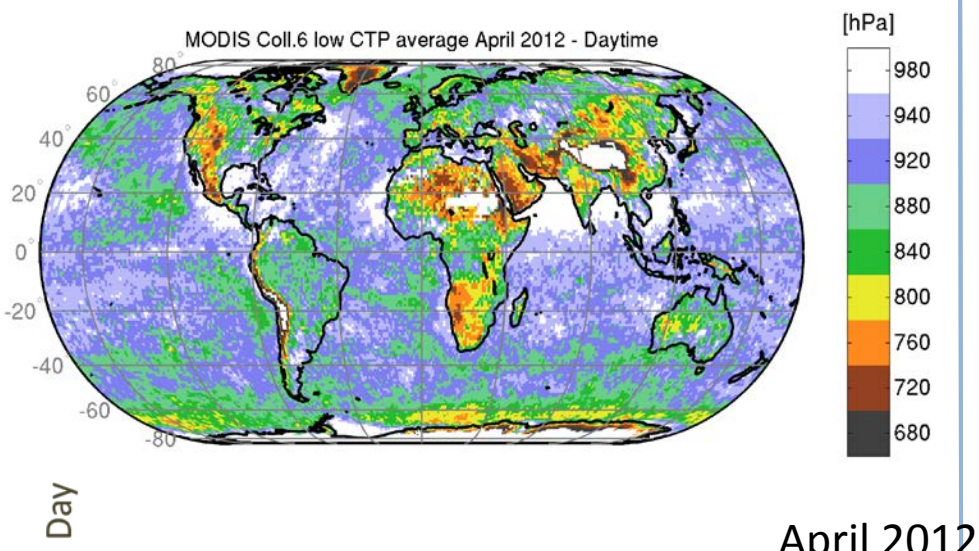
Night

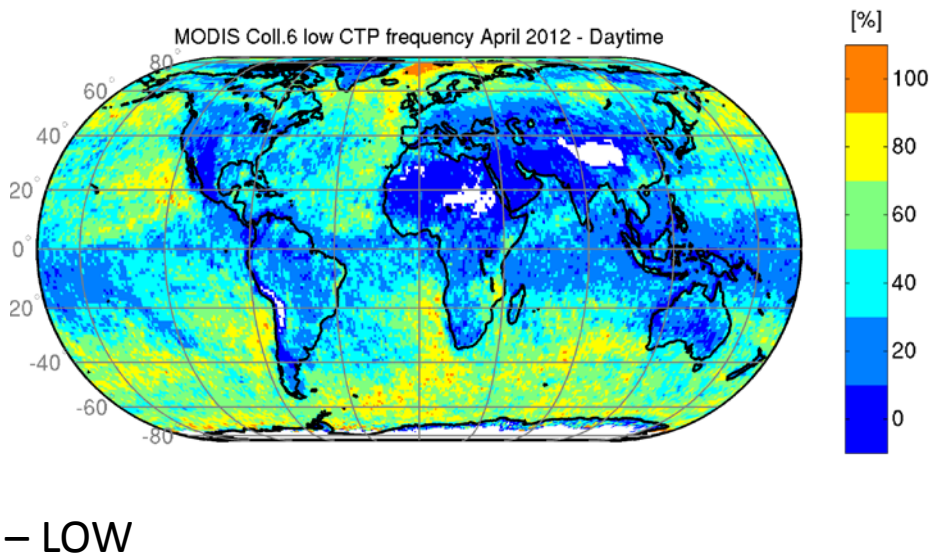




CTP average [hPa]

CTP frequency [%]

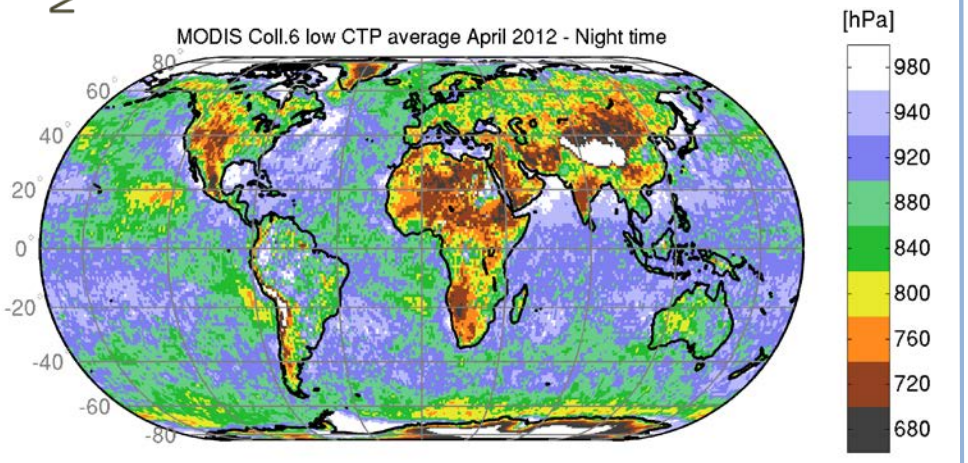


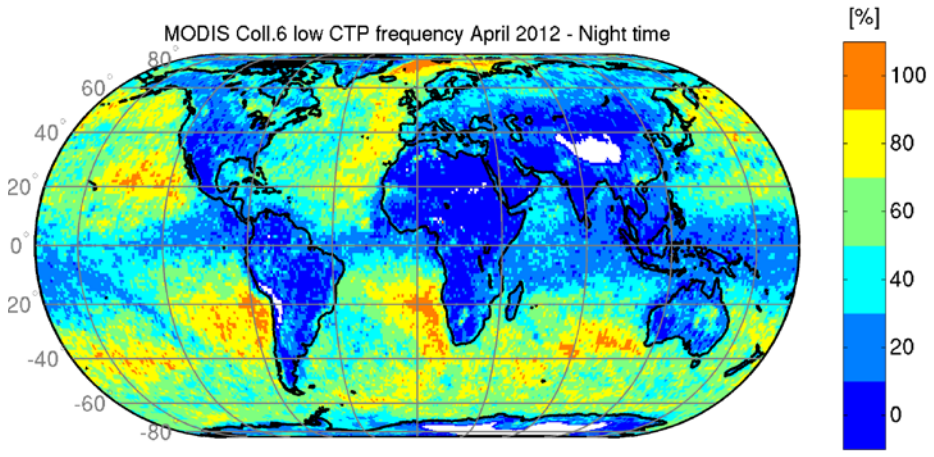


Day

April 2012 – LOW

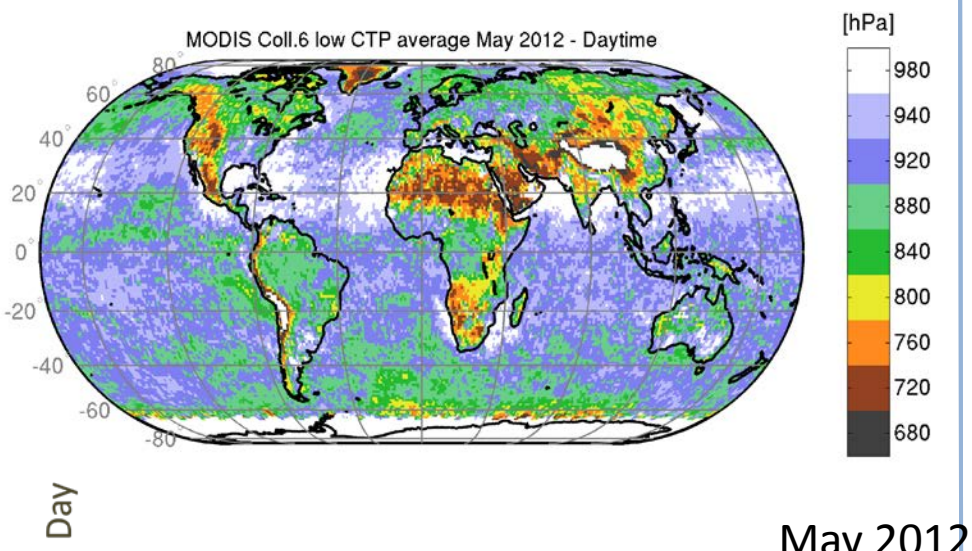
Night

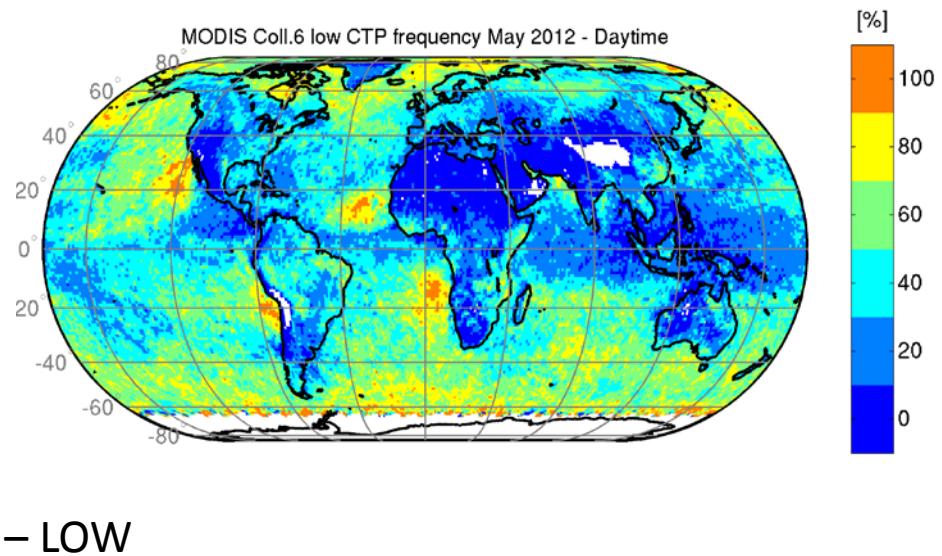




CTP average [hPa]

CTP frequency [%]

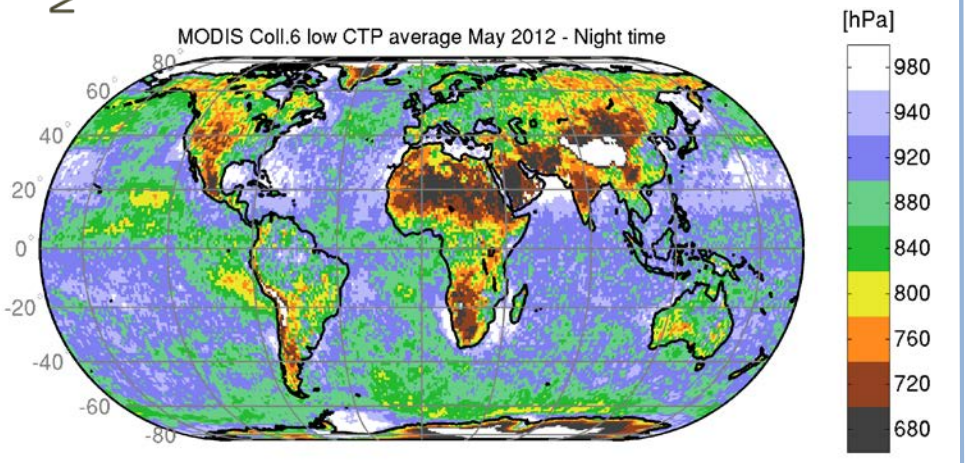


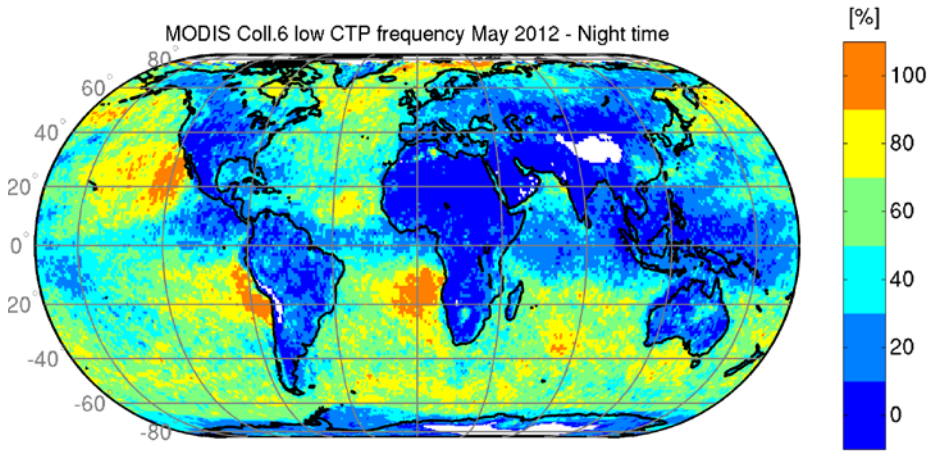


Day

May 2012 – LOW

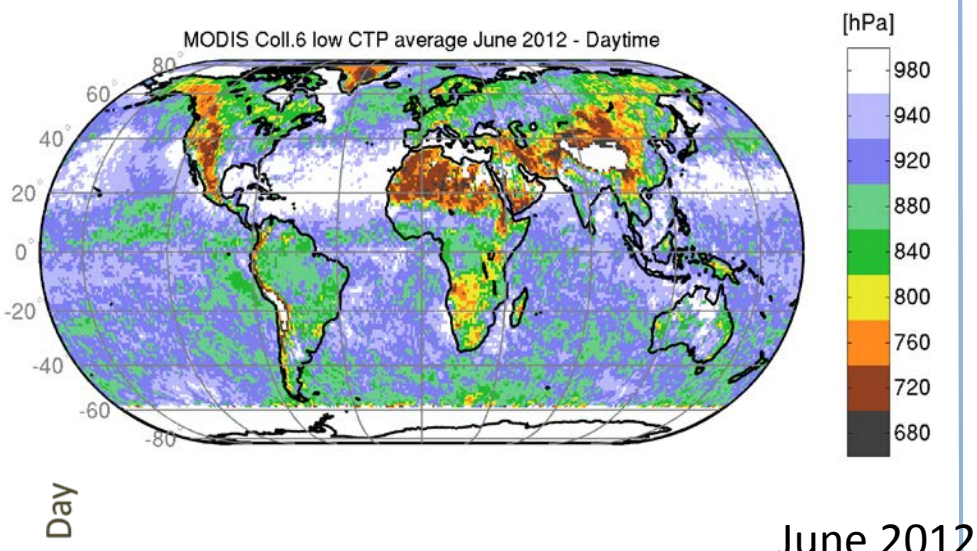
Night

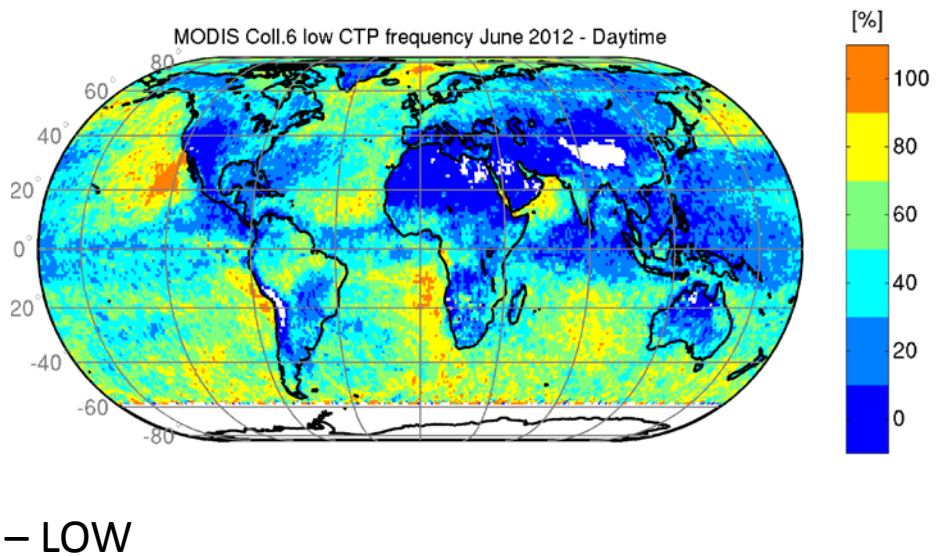




CTP average [hPa]

CTP frequency [%]

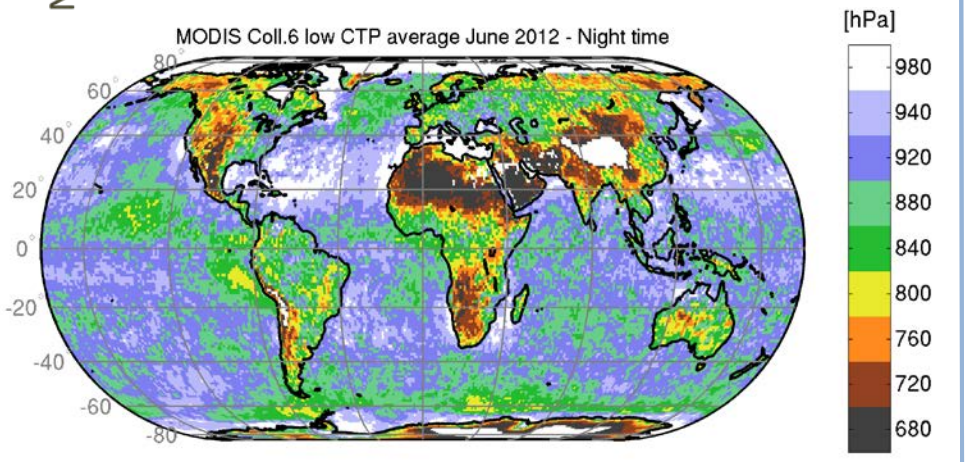


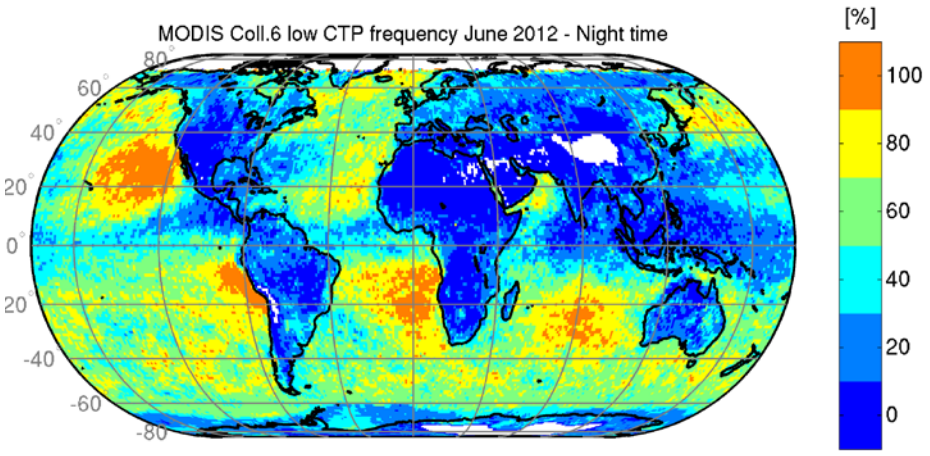


Day

June 2012 – LOW

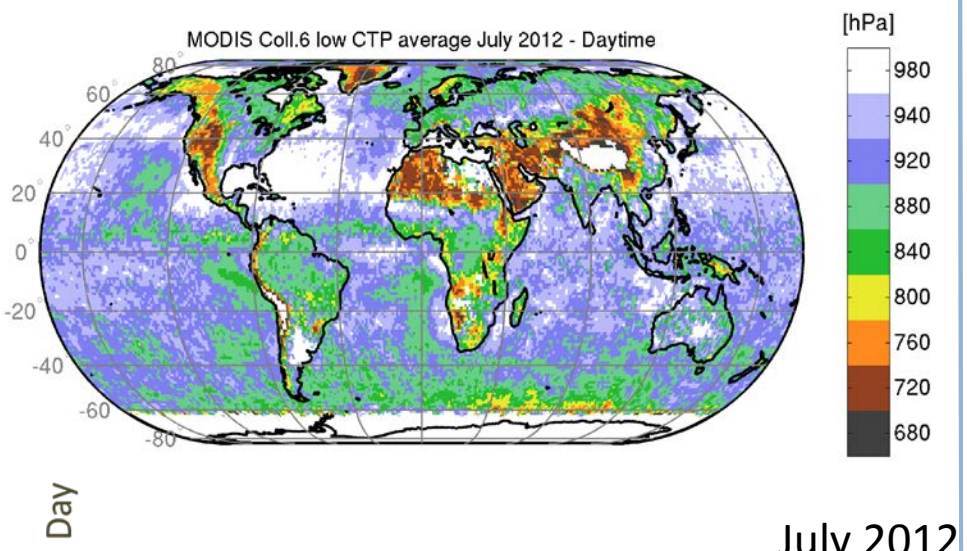
Night

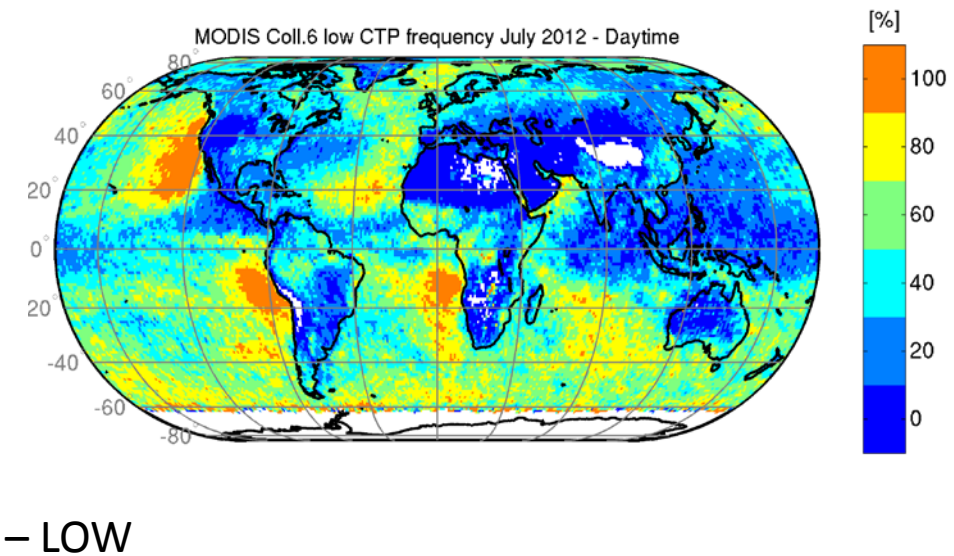




CTP average [hPa]

CTP frequency [%]

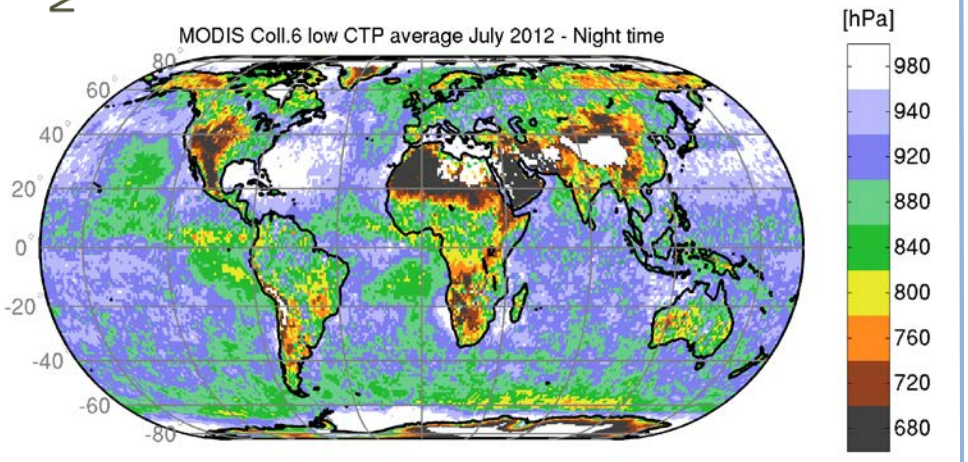


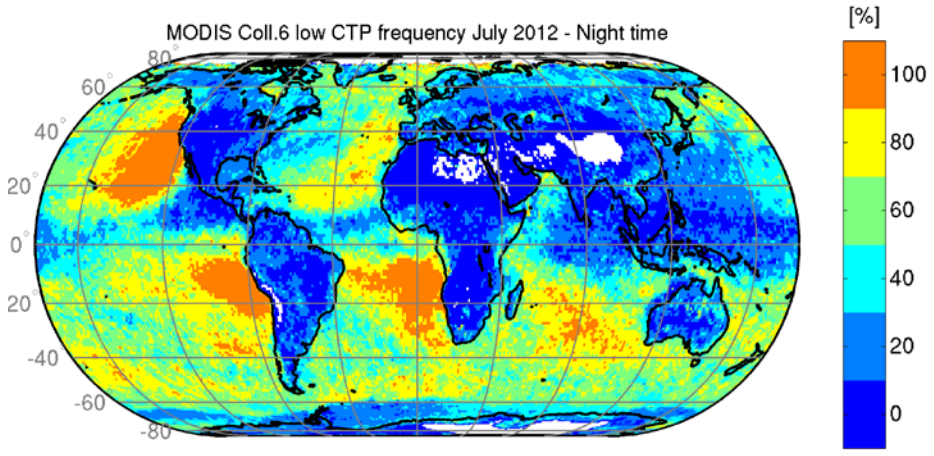


Day

July 2012 – LOW

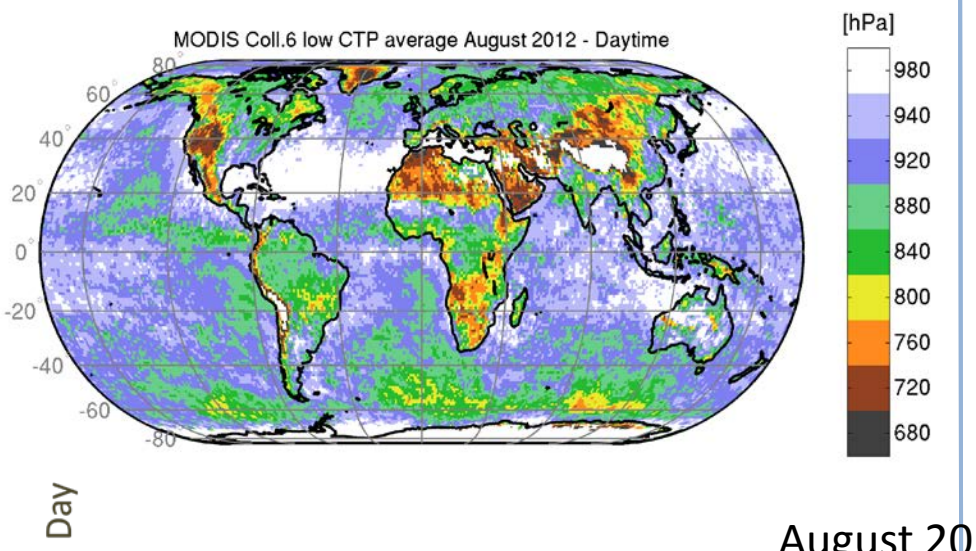
Night

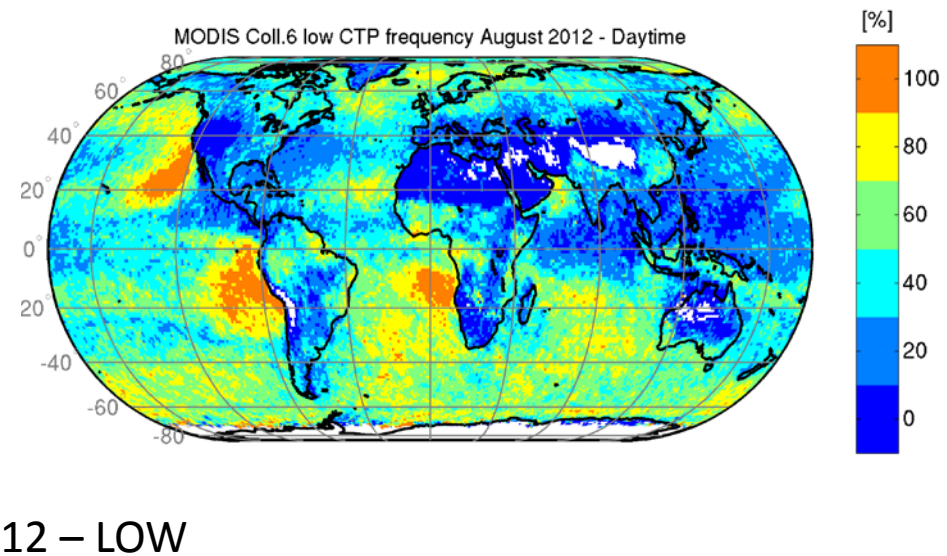




CTP average [hPa]

CTP frequency [%]

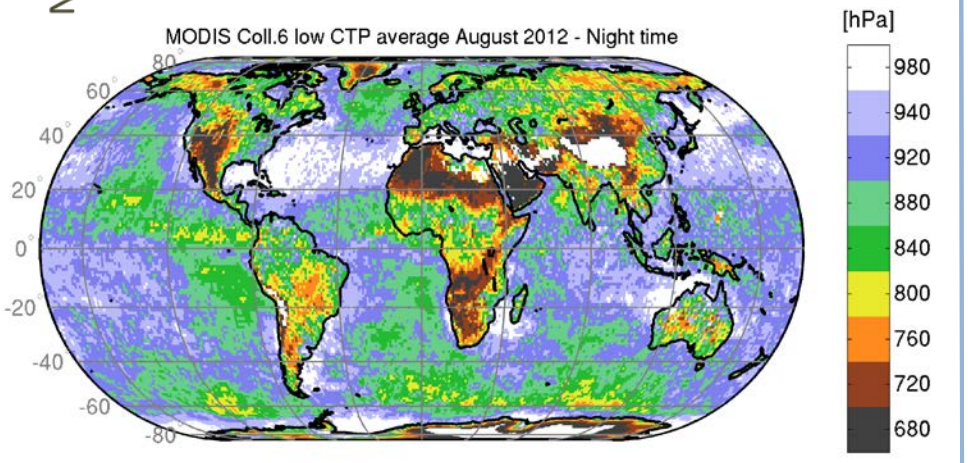


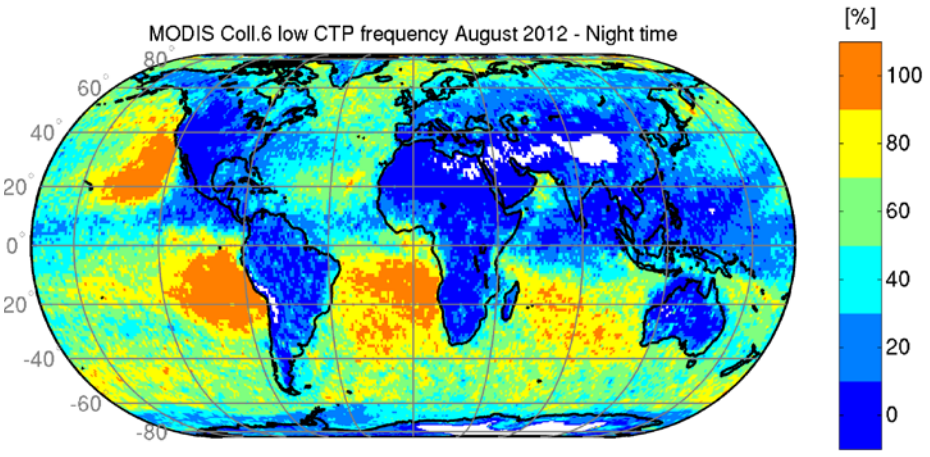


Day

August 2012 – LOW

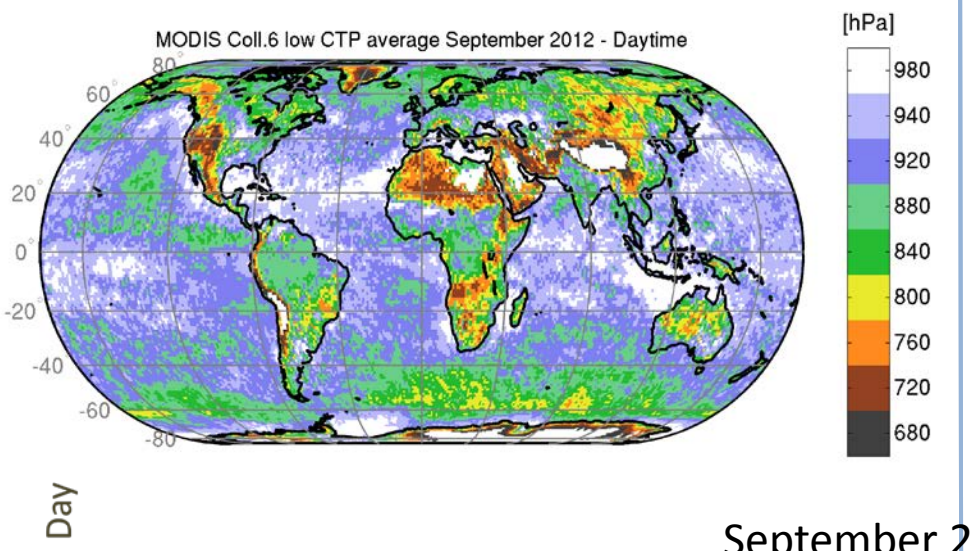
Night

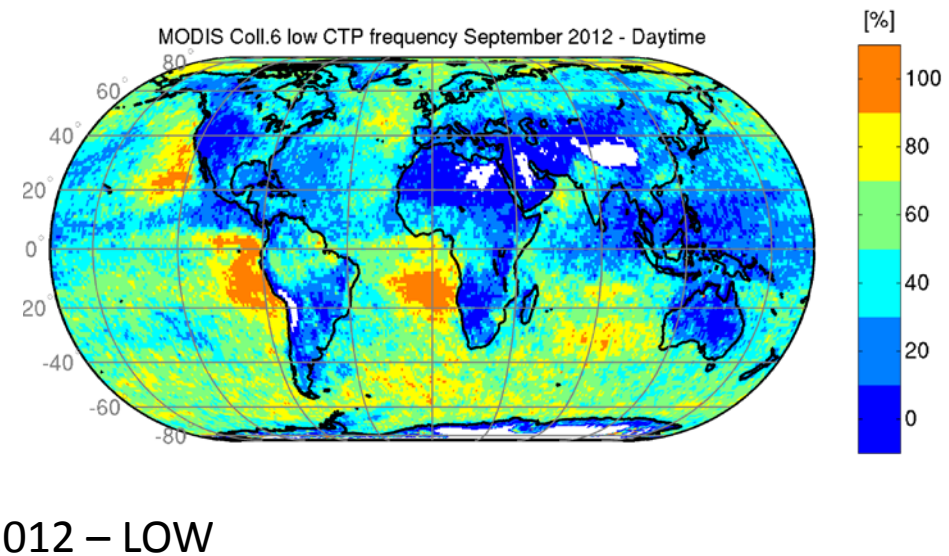




CTP average [hPa]

CTP frequency [%]

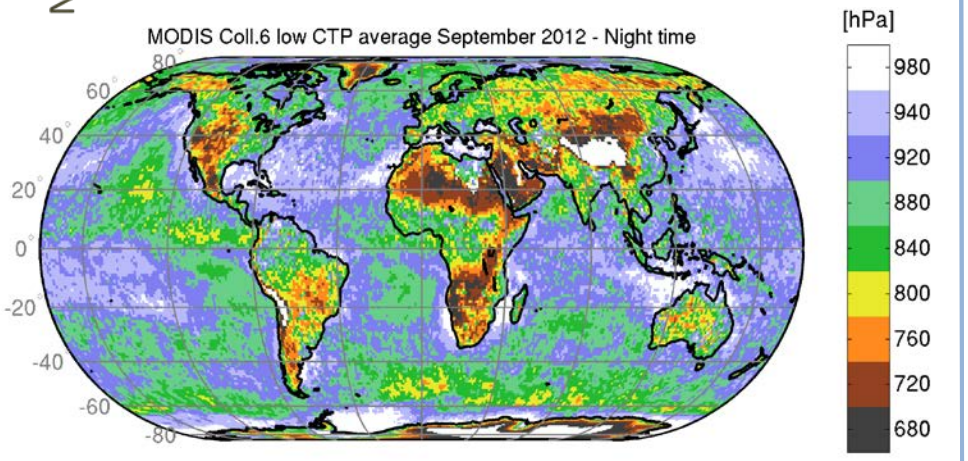


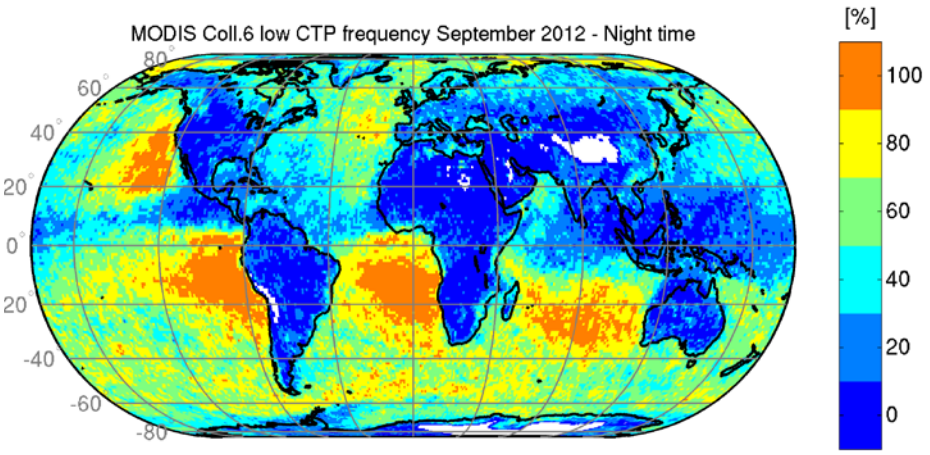


Day

September 2012 – LOW

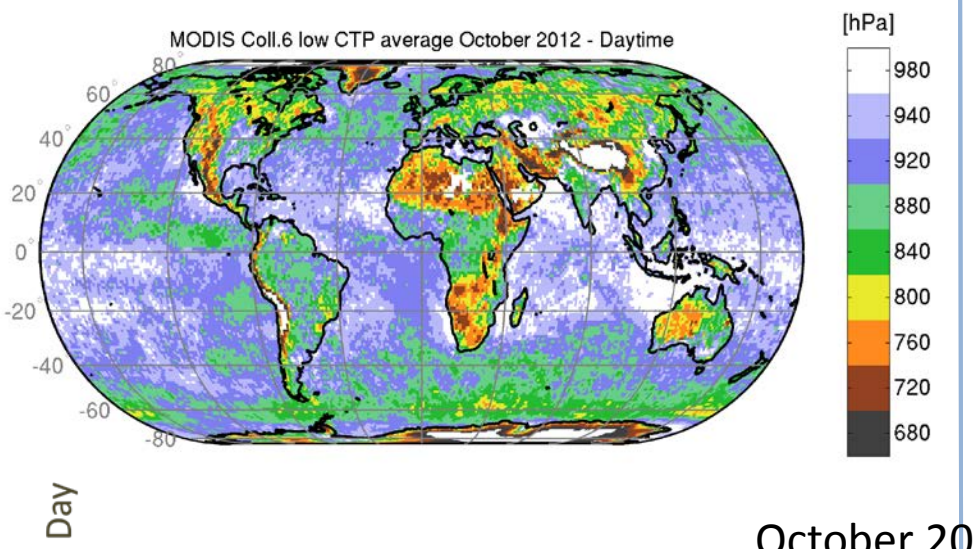
Night

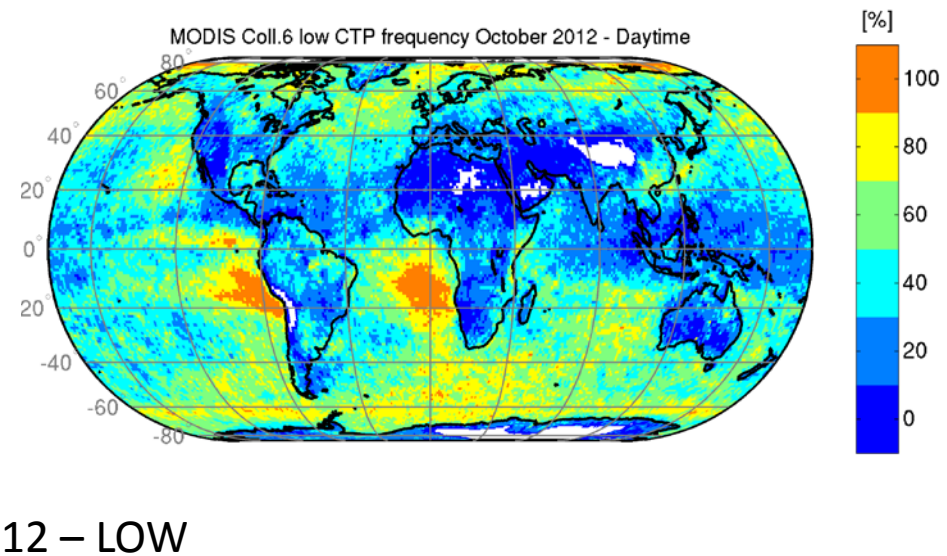




CTP average [hPa]

CTP frequency [%]

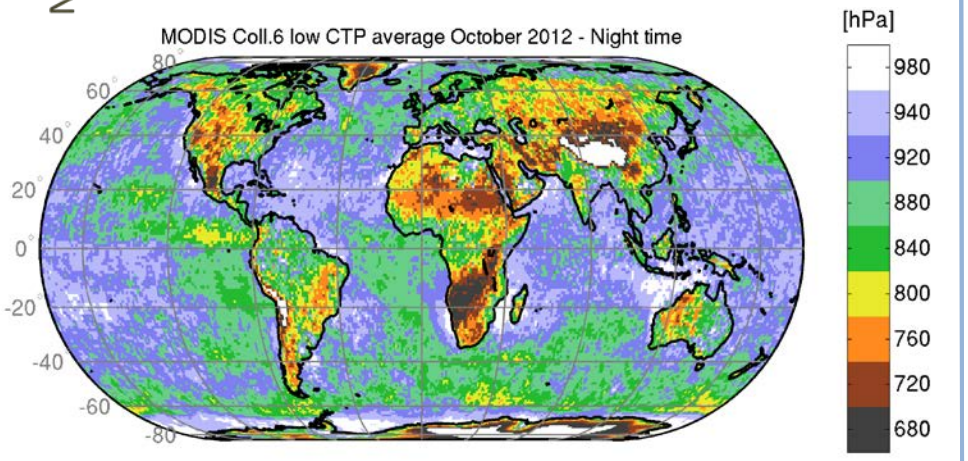


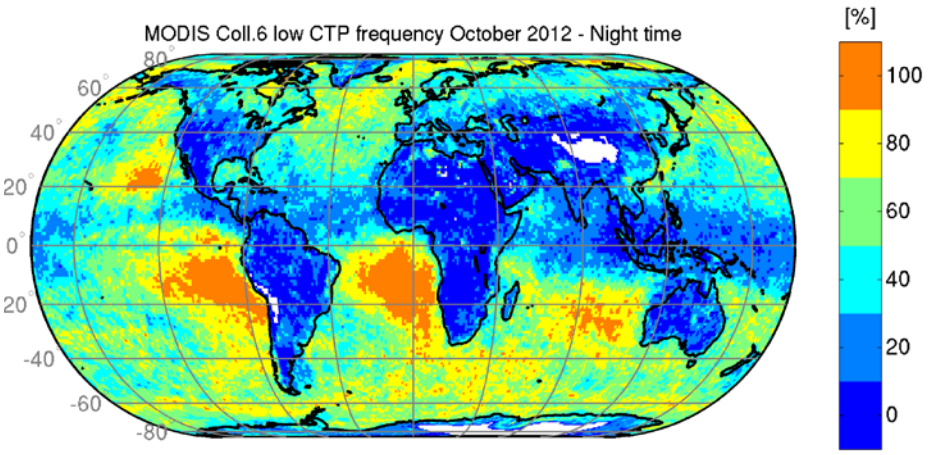


Day

October 2012 – LOW

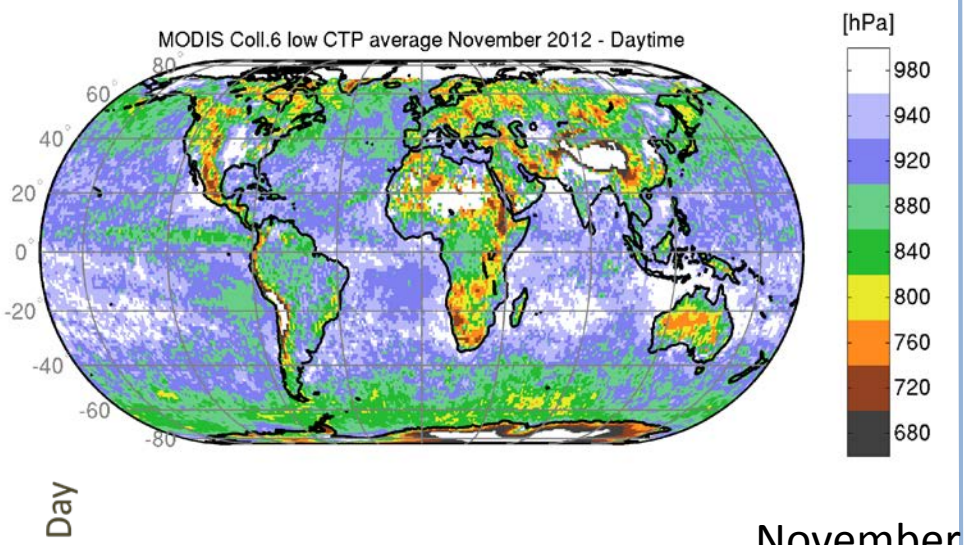
Night

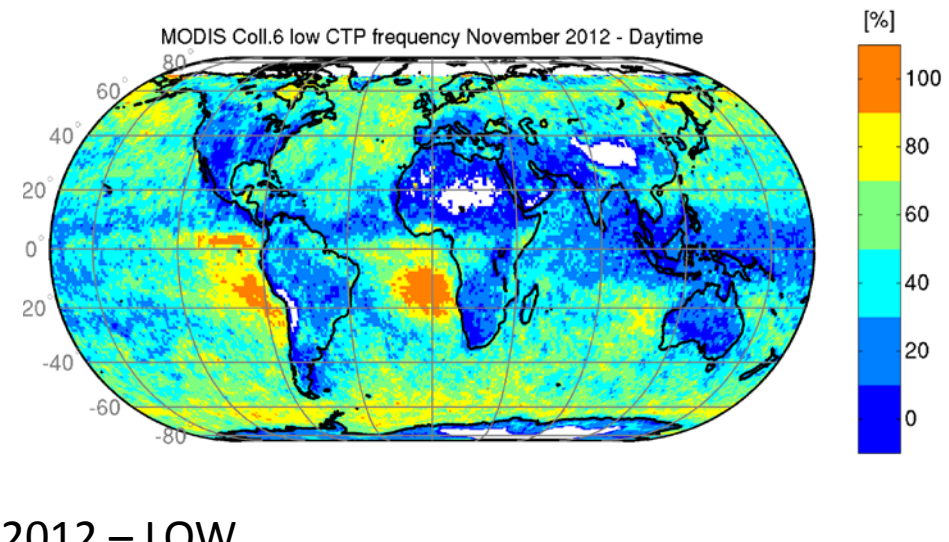




CTP average [hPa]

CTP frequency [%]

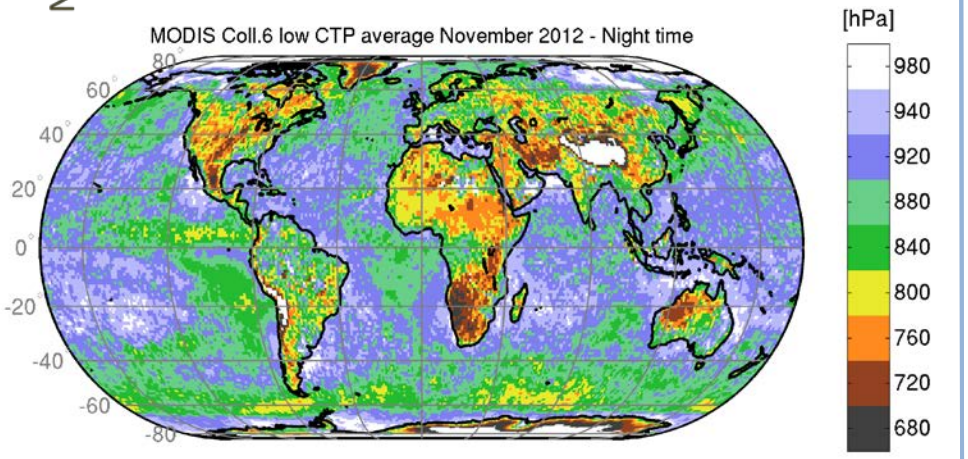


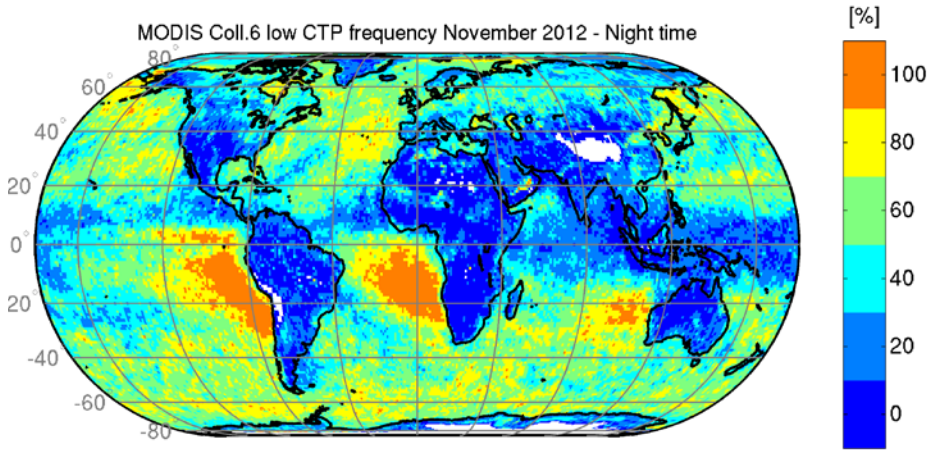


Day

November 2012 – LOW

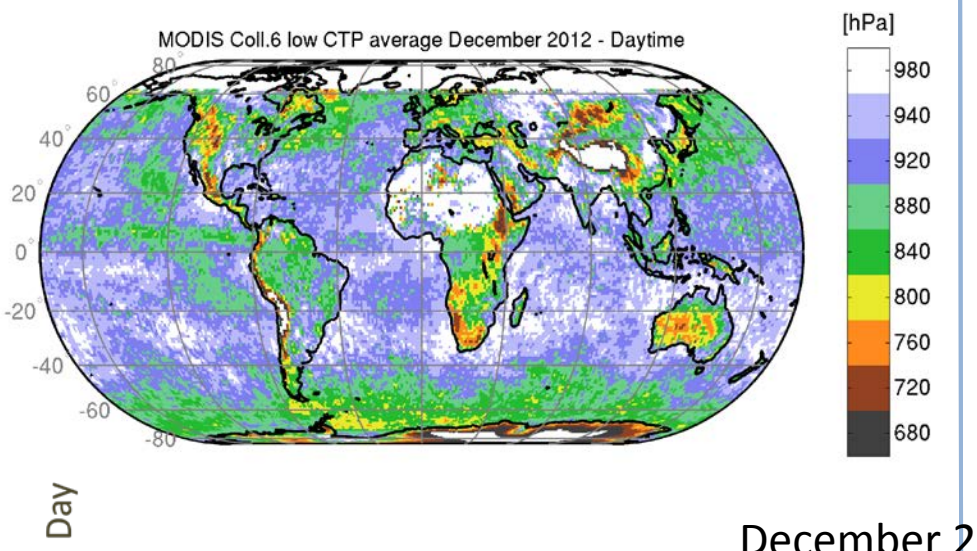
Night

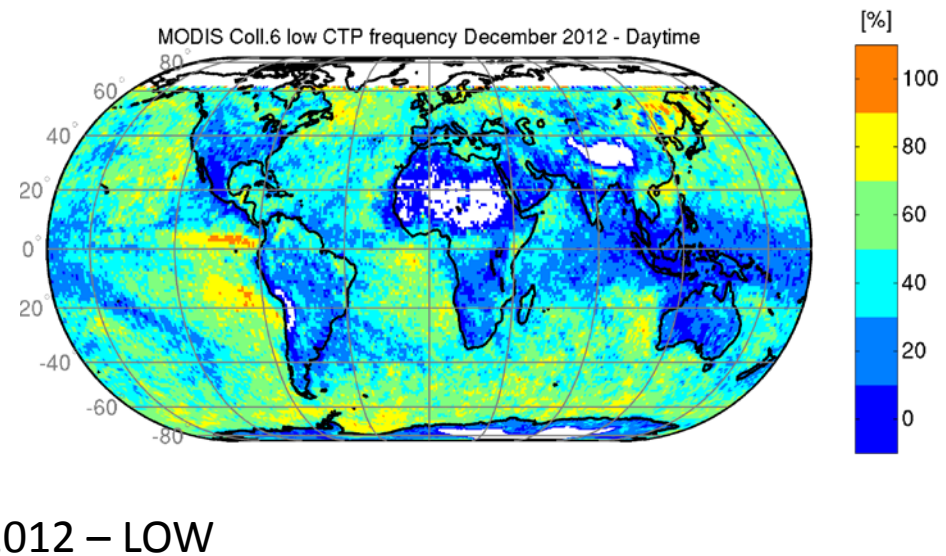




CTP average [hPa]

CTP frequency [%]

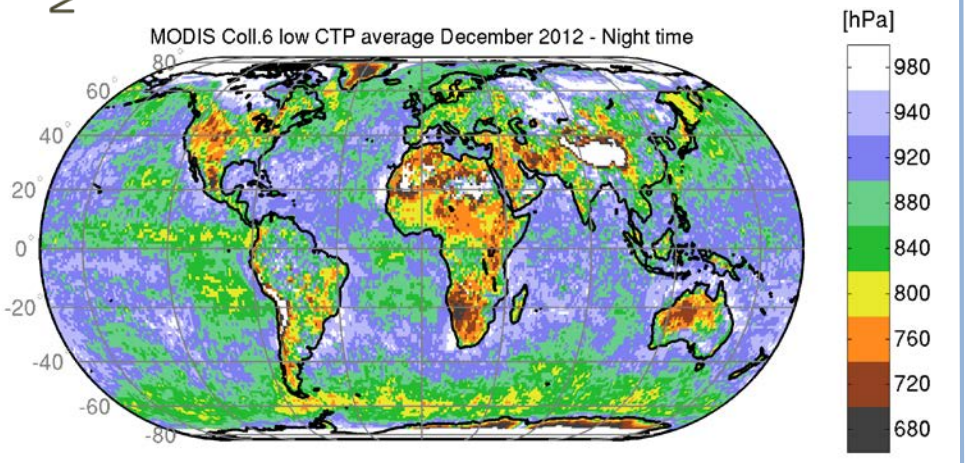


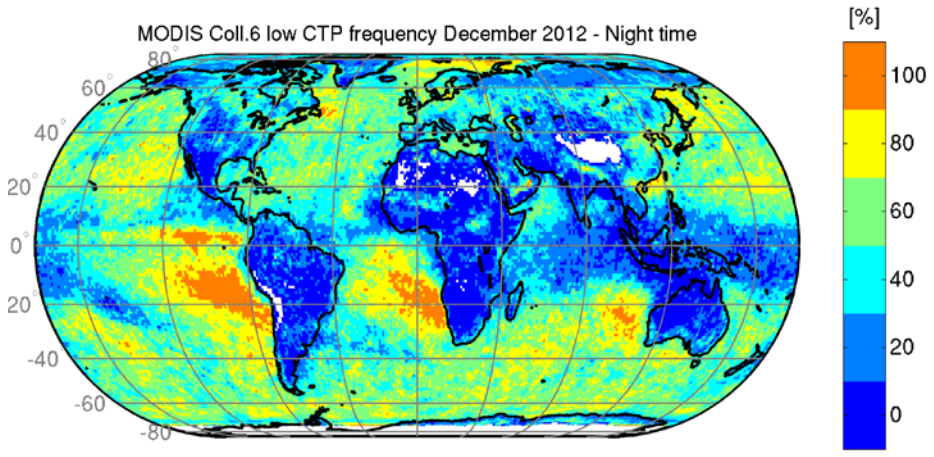


Day

December 2012 – LOW

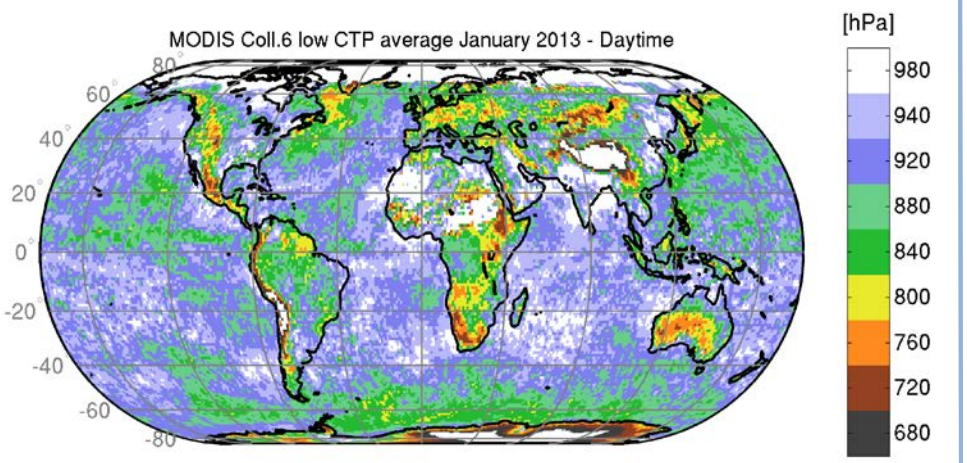
Night

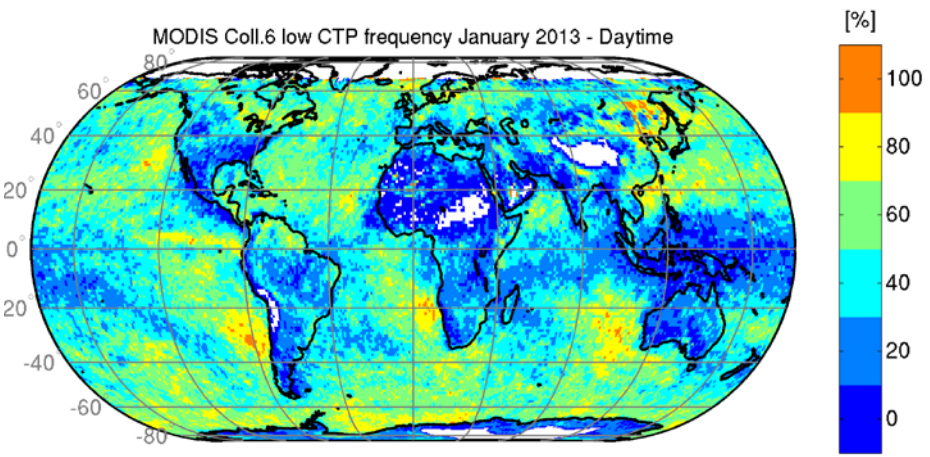




CTP average [hPa]

CTP frequency [%]

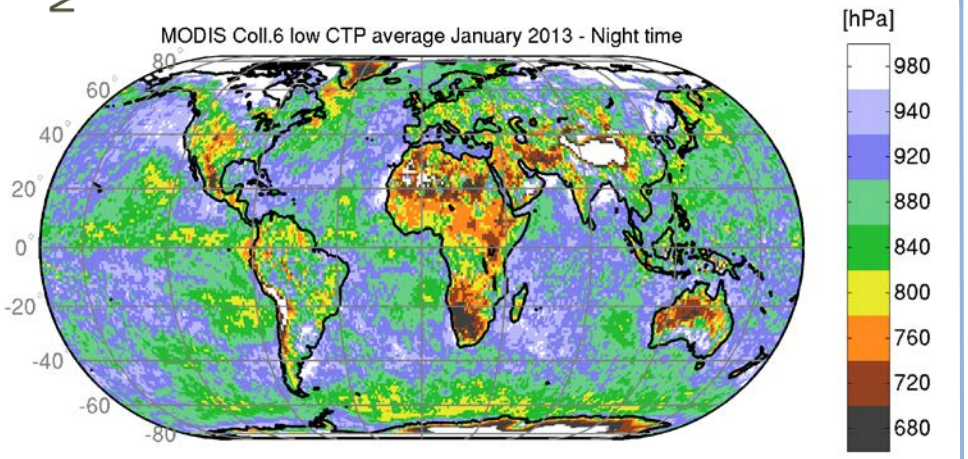


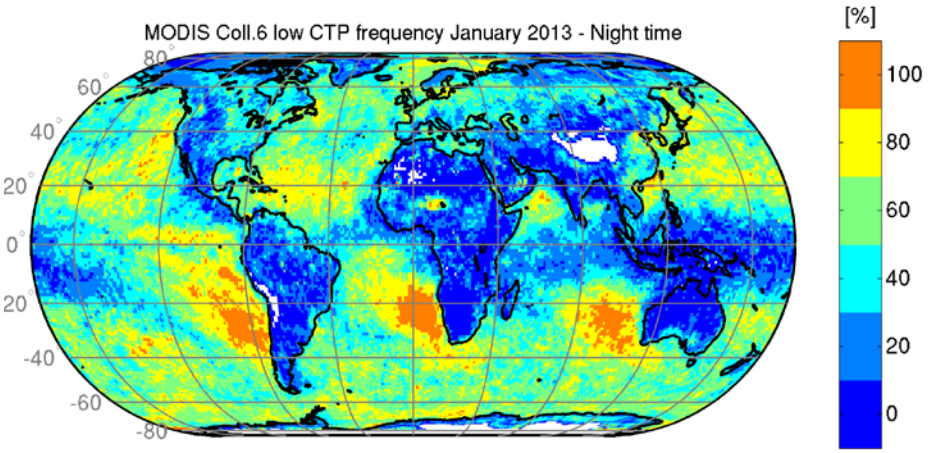


Day

January 2013 - LOW

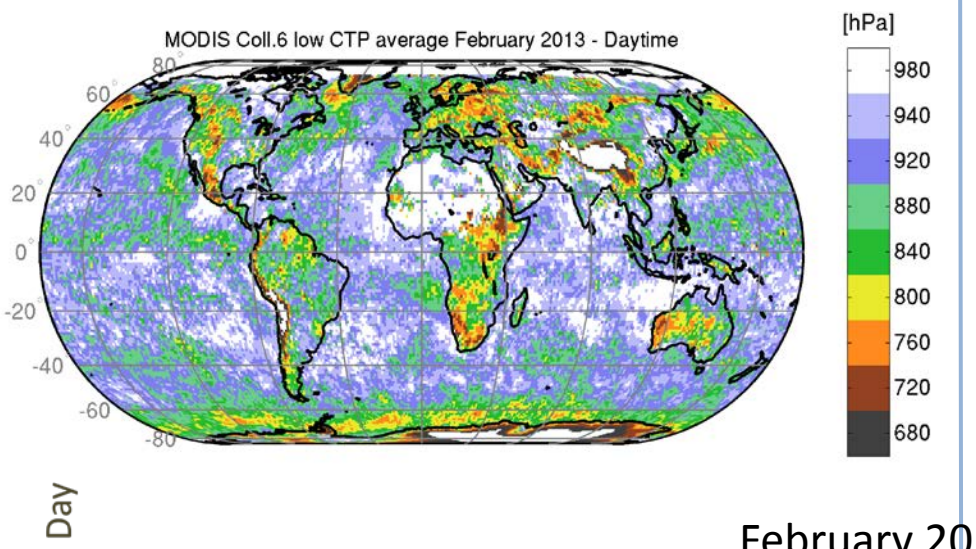
Night

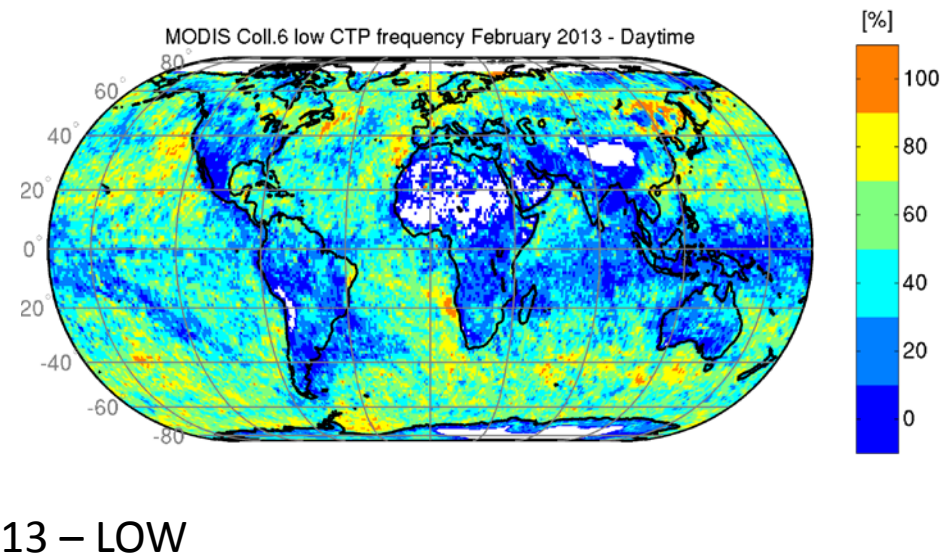




CTP average [hPa]

CTP frequency [%]

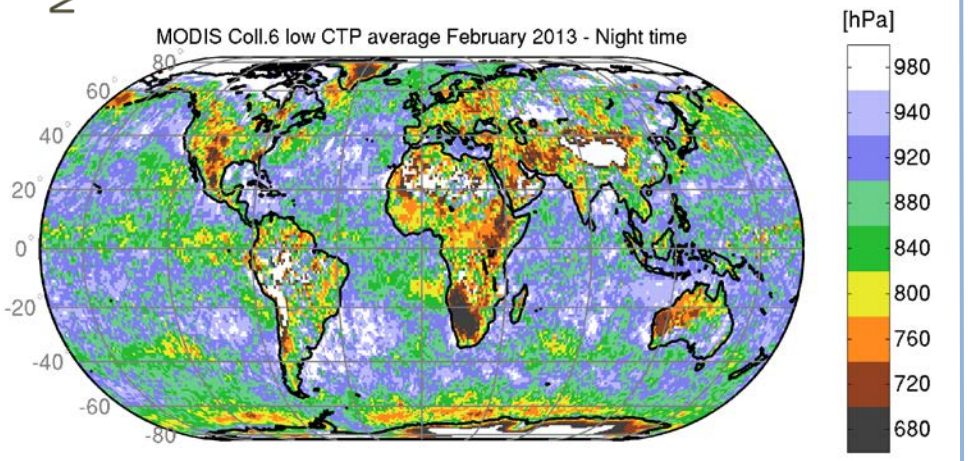


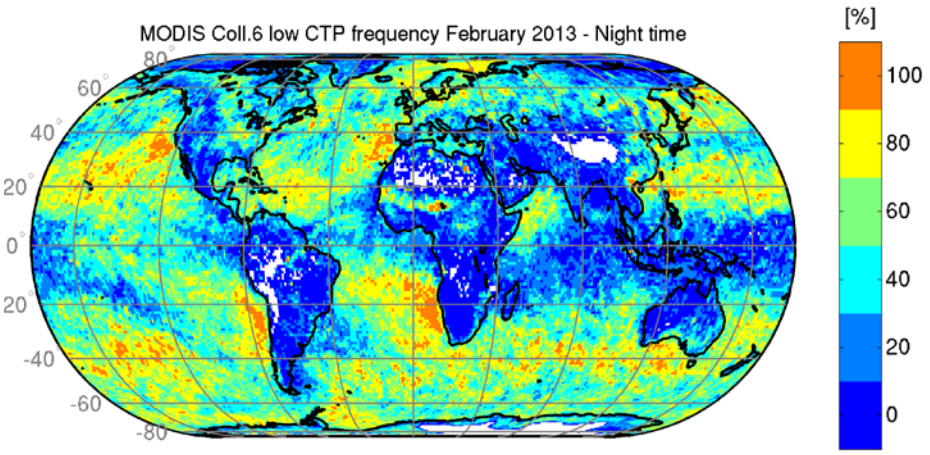


Day

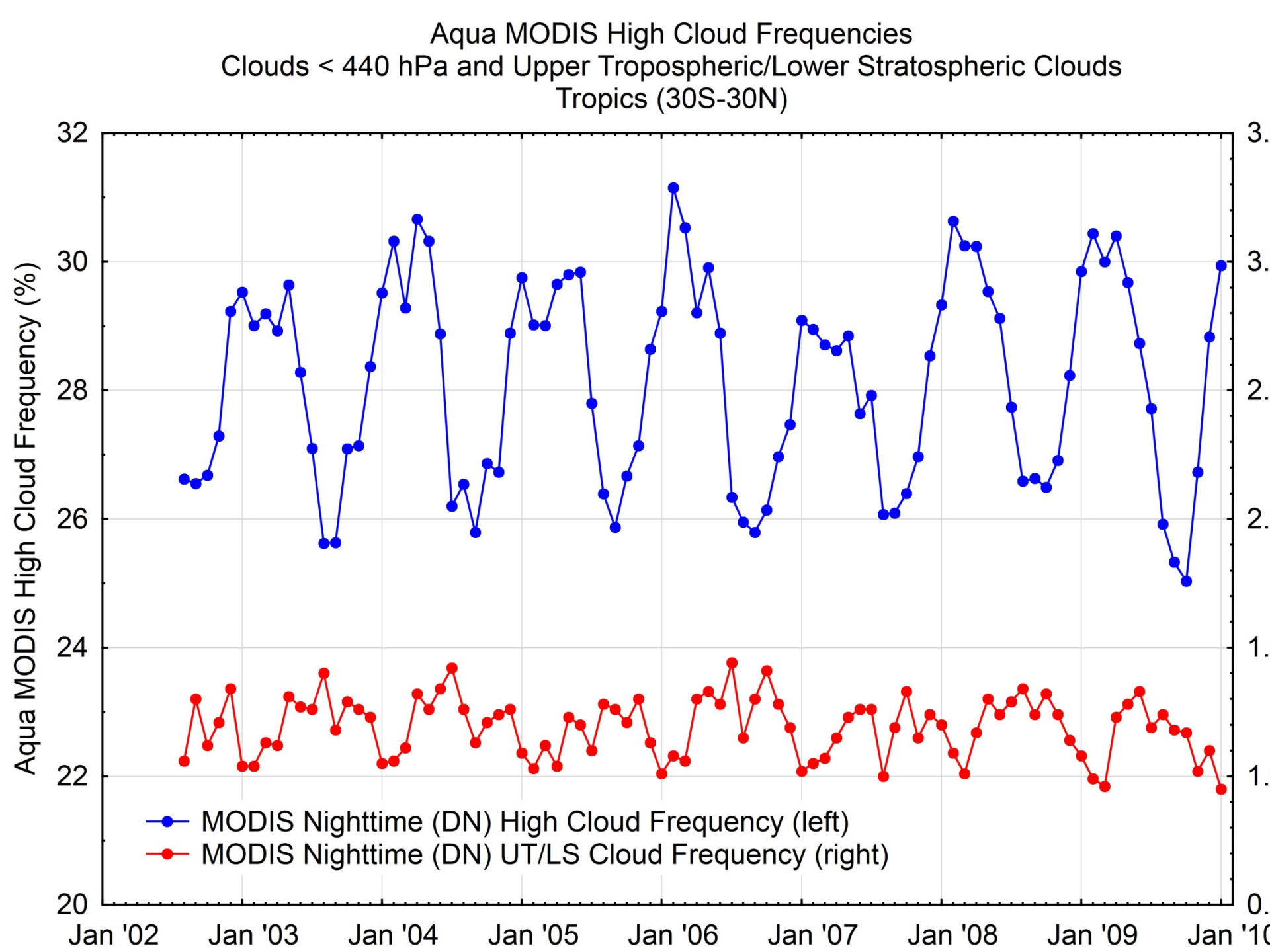
February 2013 – LOW

Night





Ten Year Trends


Aqua MODIS High Cloud Frequencies
Clouds < 440 hPa and Upper Tropospheric/Lower Stratospheric Clouds
Tropics (30S-30N)
Aqua MODIS High Cloud Frequency (%)
32
30
28
26
24
22
20
3.
3.
2.
2.
1.
1.
0.
Jan '02
Jan '03
Jan '04
Jan '05
Jan '06
Jan '07
Jan '08
Jan '09
Jan '10
MODIS Nighttime (DN) High Cloud Frequency (left)
MODIS Nighttime (DN) UT/LS Cloud Frequency (right)

Contents of Output File

The Output File Contains

Time, Lat, Lon, SZA
BTs of bands 29, 31-36
Cloud height method (CO_2 slicing or IR window)
CTP, CTT, N, CEE (solutions selected by algorithm)
CTP (using IRW)
CTPs (from ratios 33/31, 34/33, 35/33, 35/34, 36/35)
Sfc Type
Cloud phase infrared
UTLS Flag