MOD06 Cloud Top Properties

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CTPs using CO2 Slicing

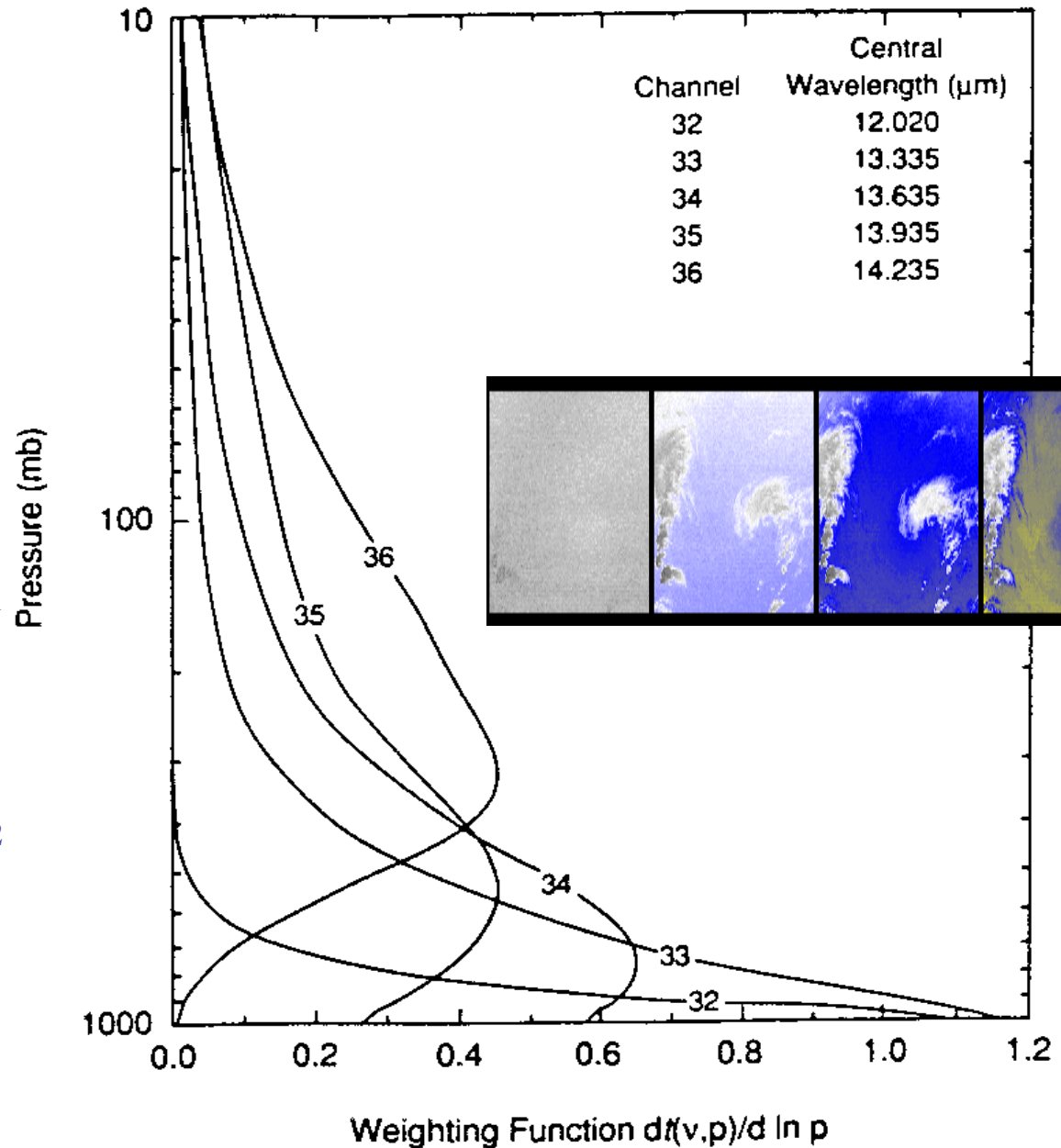**Different ratios reveal cloud properties at different levels**

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

Channel	Central Wavelength (μm)
32	12.020
33	13.335
34	13.635
35	13.935
36	14.235

Pressure (mb)

Weighting Function dt(v,p)/d ln p

MODIS Algorithm Improvements before Collect 6

Collect 3. night-time cloud phase introduced
Collect 4. destriping started, instrument IR calibration improved
Collect 5. cloud mask improved (deserts, poles, night), radiance bias
adjustment for measured versus calculated introduced

MODIS Algorithm Adjustments for Collect 6

A*: Implement Band 34, 35, 36 spectral shifts suggested by Tobin et al. (2005) for Aqua.*

B: Use "top-down" channel pairs 36/35, 35/34, 34/33 in that order to select CTP.

C: Lower "noise" thresholds (clear minus cloudy radiances required to indicate cloud presence in bands 33 to 36) to force more CO_2 slicing solutions for high thin clouds.

D: Restrict CO_2 channel pair solutions to appropriate portion of troposphere (determined by weighting functions – 36/35 < 450 hPa, 35/34 < 550 hPa, and 34/33 < 650 hPa).

E: Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO_2 radiances influenced by O3 profiles are calculated correctly).

F: Use $CO_2 = [mx + a*\sin(2\pi x/365)] + b$ where m = 1.5 ppmv / 365, b = 337.5 ppmv, a = 3 ppmv, and x = # days since 1 Jan 1980 to accommodate CO_2 increase.

G: Prohibit CO_2 slicing solutions for water clouds; use only IRW solution. Avoid IRW solutions for ice clouds; use CO_2 slicing whenever possible.

H: Add marine stratus improvement where a constant lapse rate is assumed in low level inversions – lapse rate is adjusted according to latitude region.

I. Add stratospheric cloud flag responding to BT13.9>BT13.3+0.5.
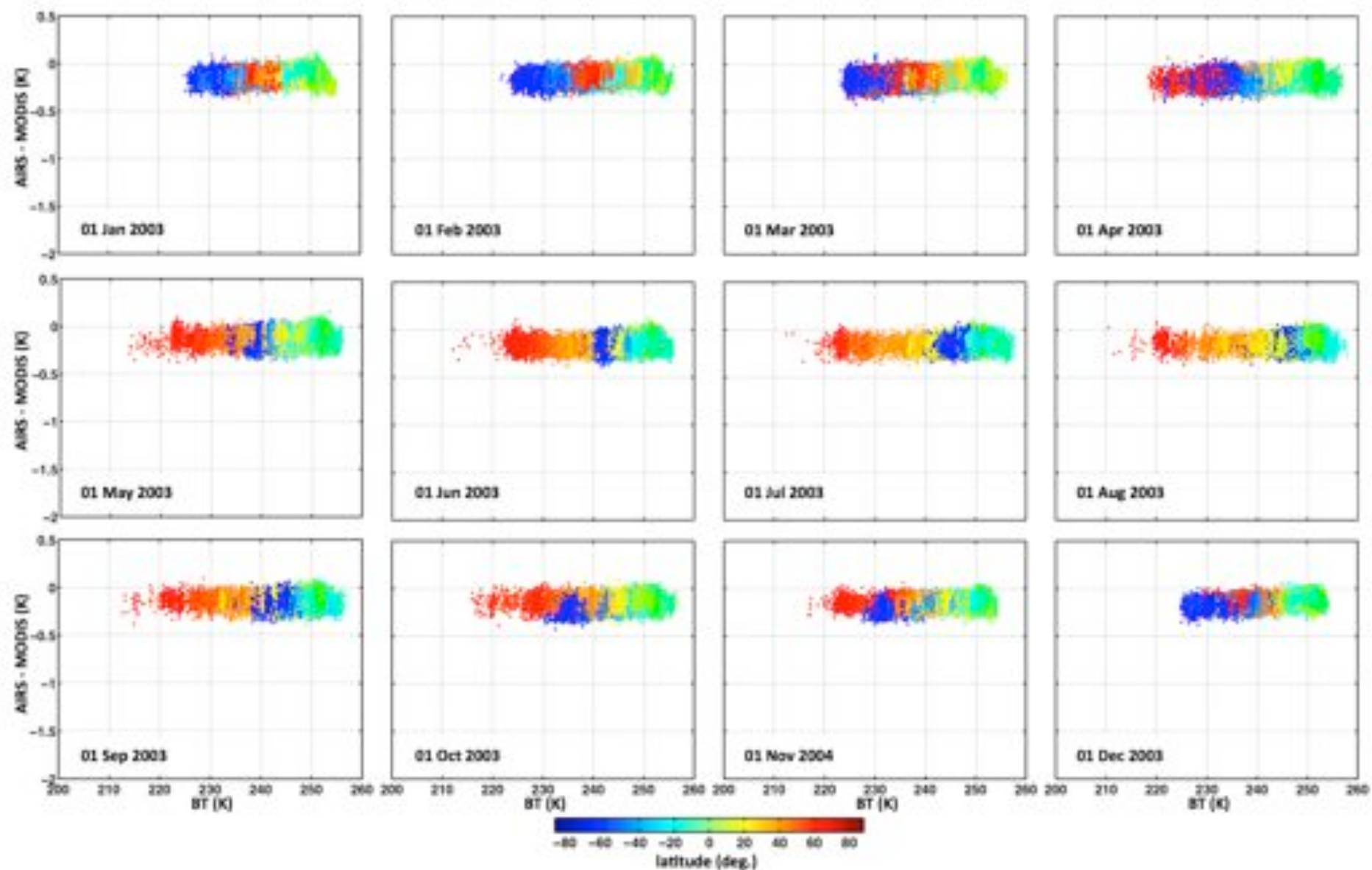
AIRS minus MODIS Comparison: 13.9 microns
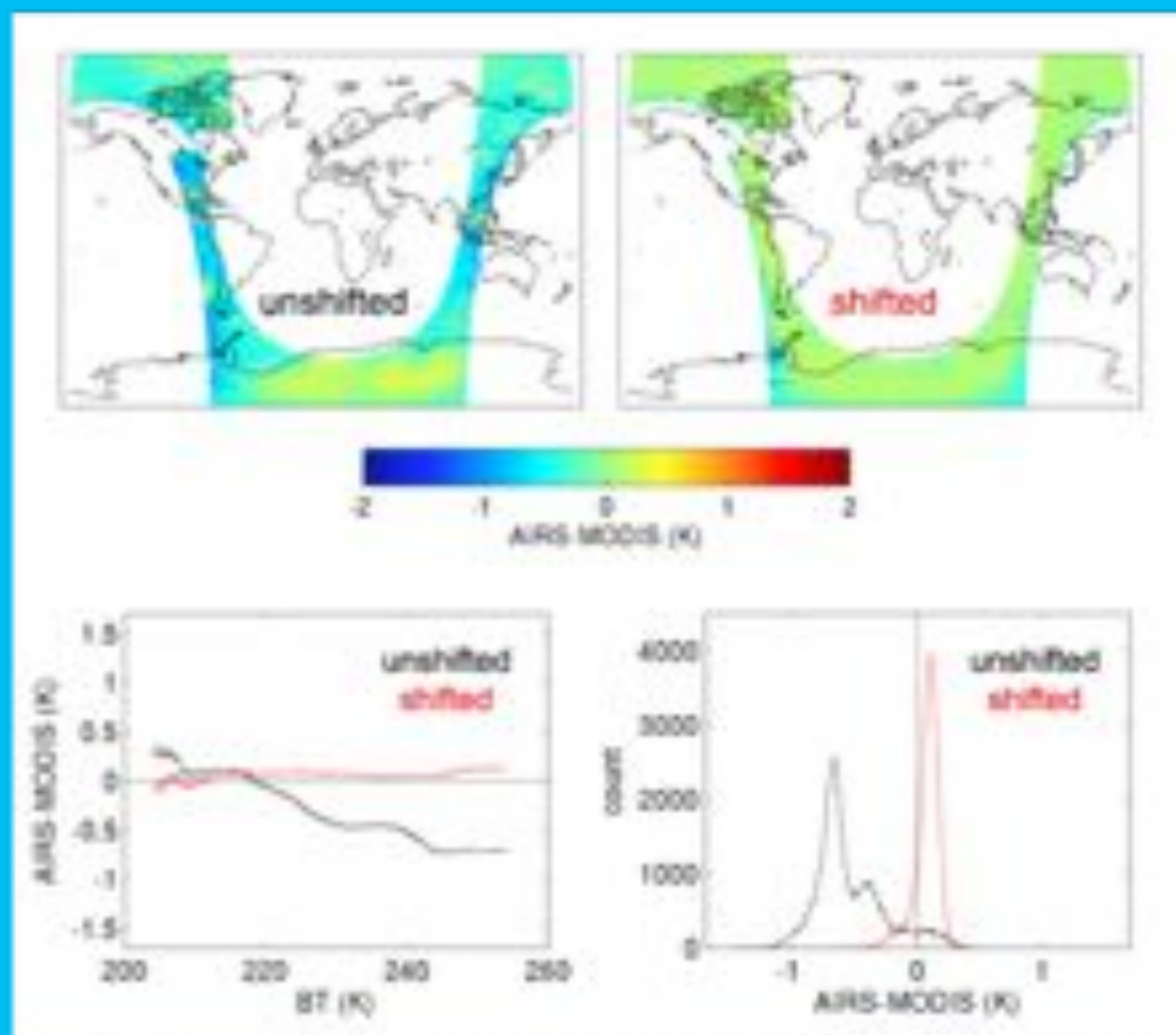
MODIS Band 35 (13.9 μm) brightness temperature differences using the nominal detector averaged MODIS SRF and using the SRF shifted by -0.8 cm⁻¹ (15.5 nm) for one orbit on 6 September 2002. The panels are images of the brightness temperature differences without (left) and with (right) the shift.

SSEC

AIRS-MODIS for MODIS Band 35 (13.8 microns)
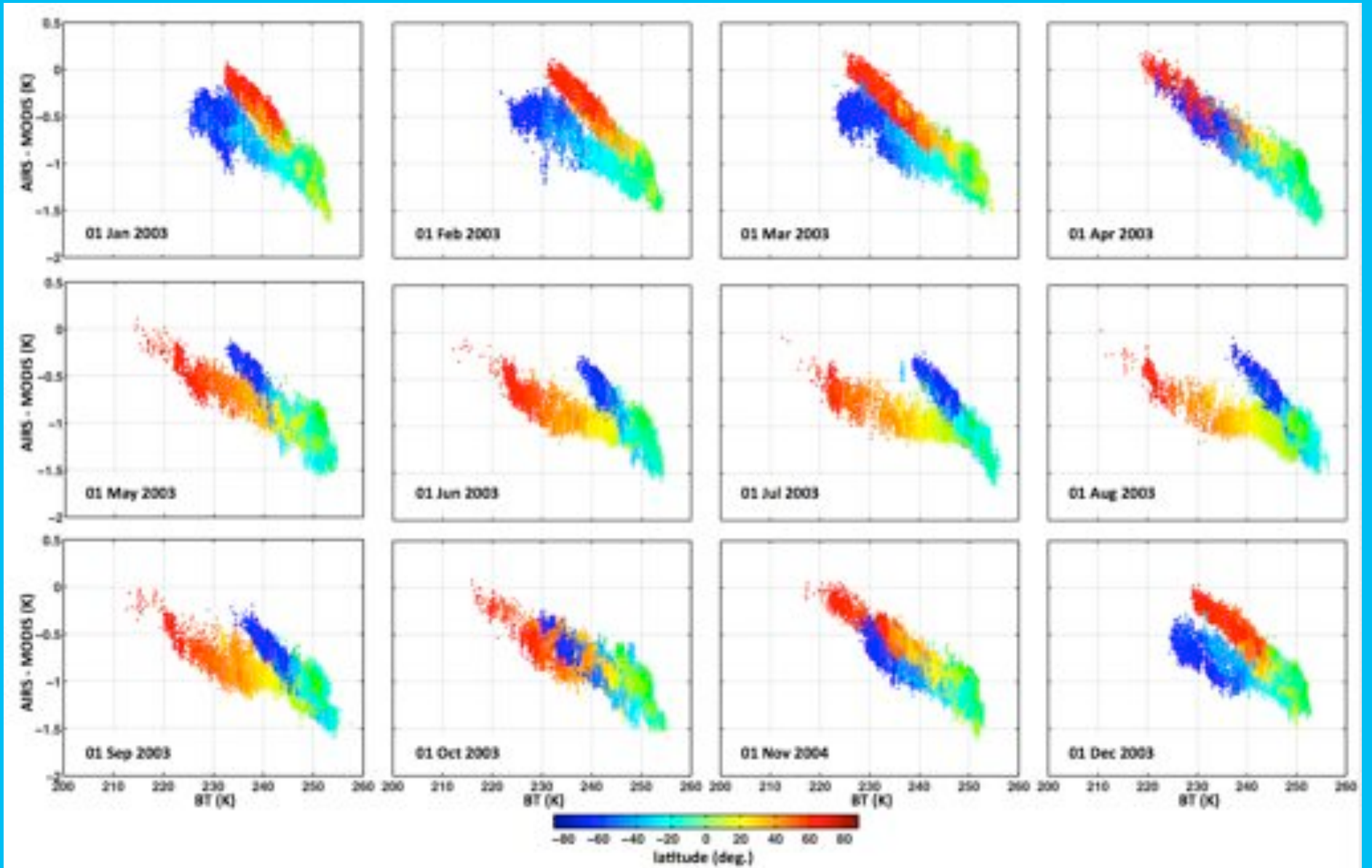
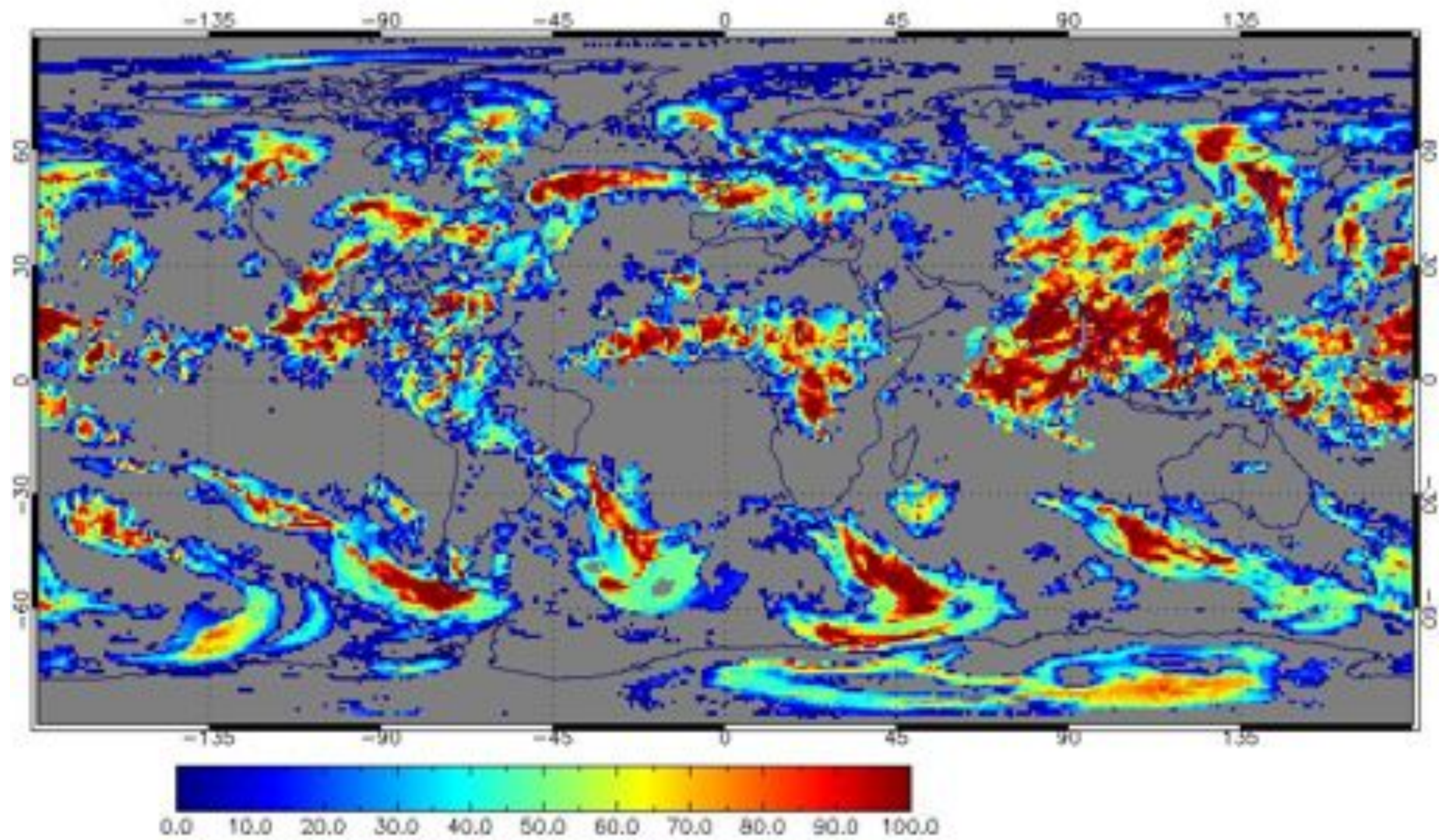# AIRS–MODIS for MODIS Band 35 shifted by 0.8 cm^{-1}

MODIS Algorithm Adjustments for Collect 6

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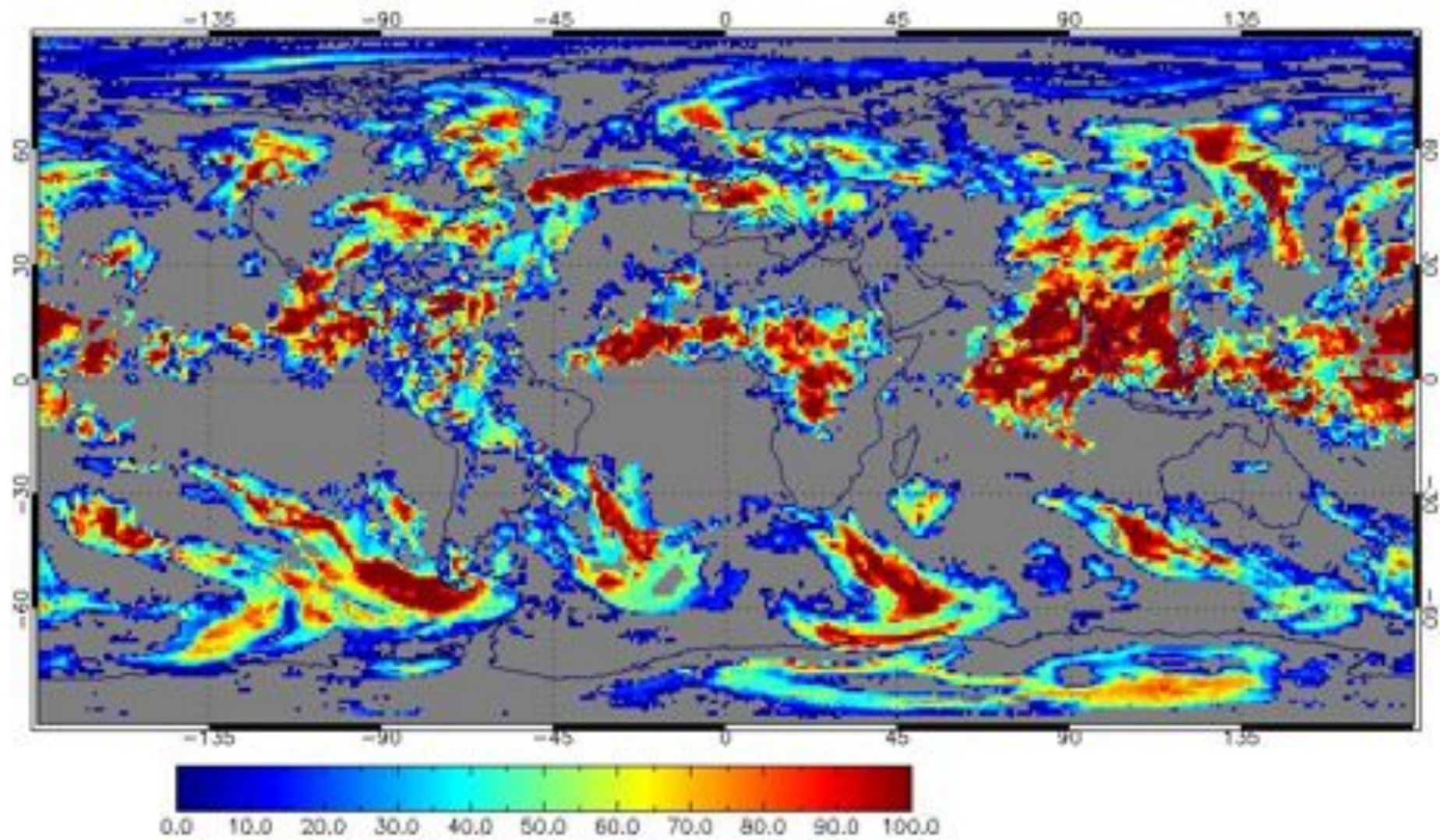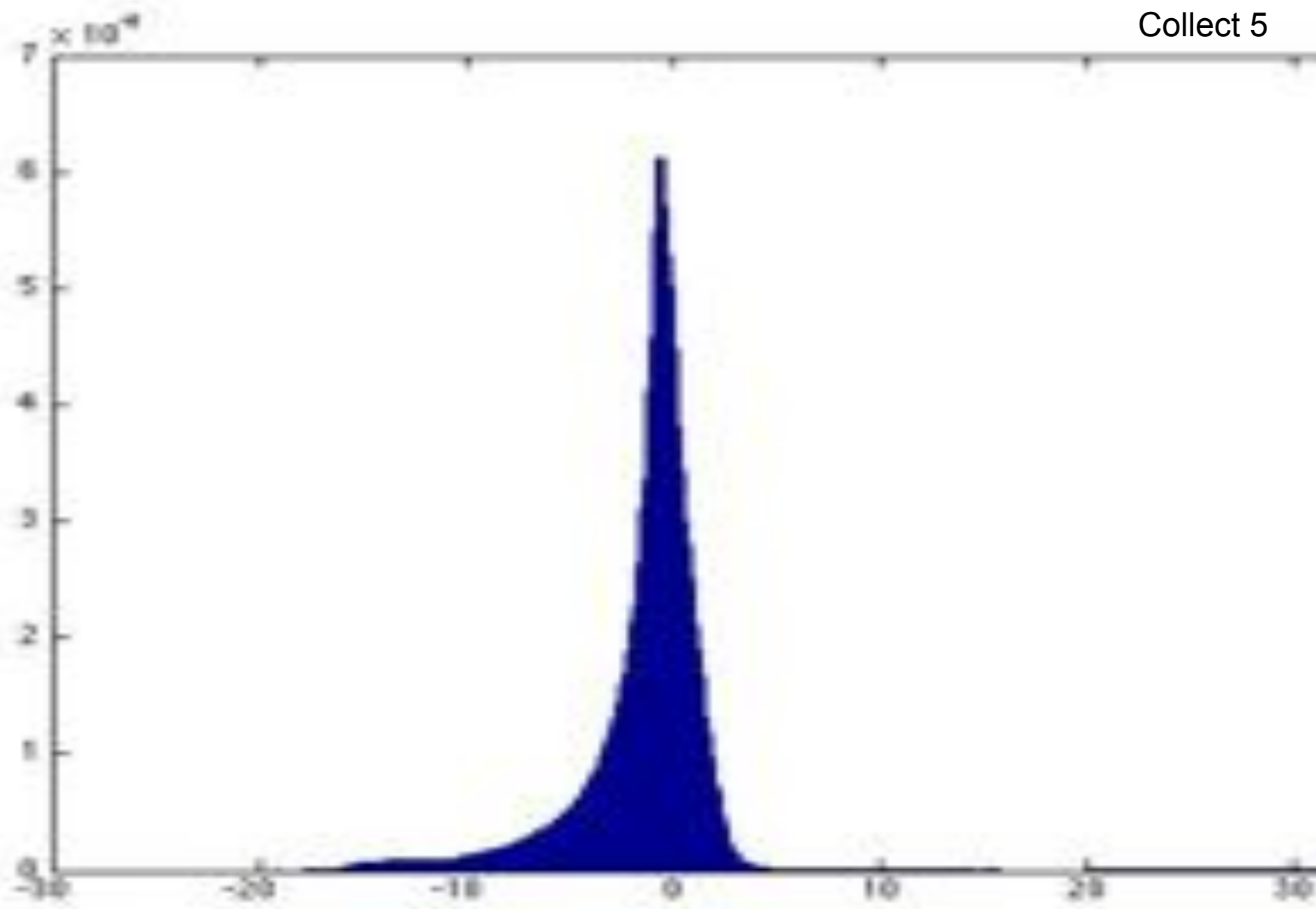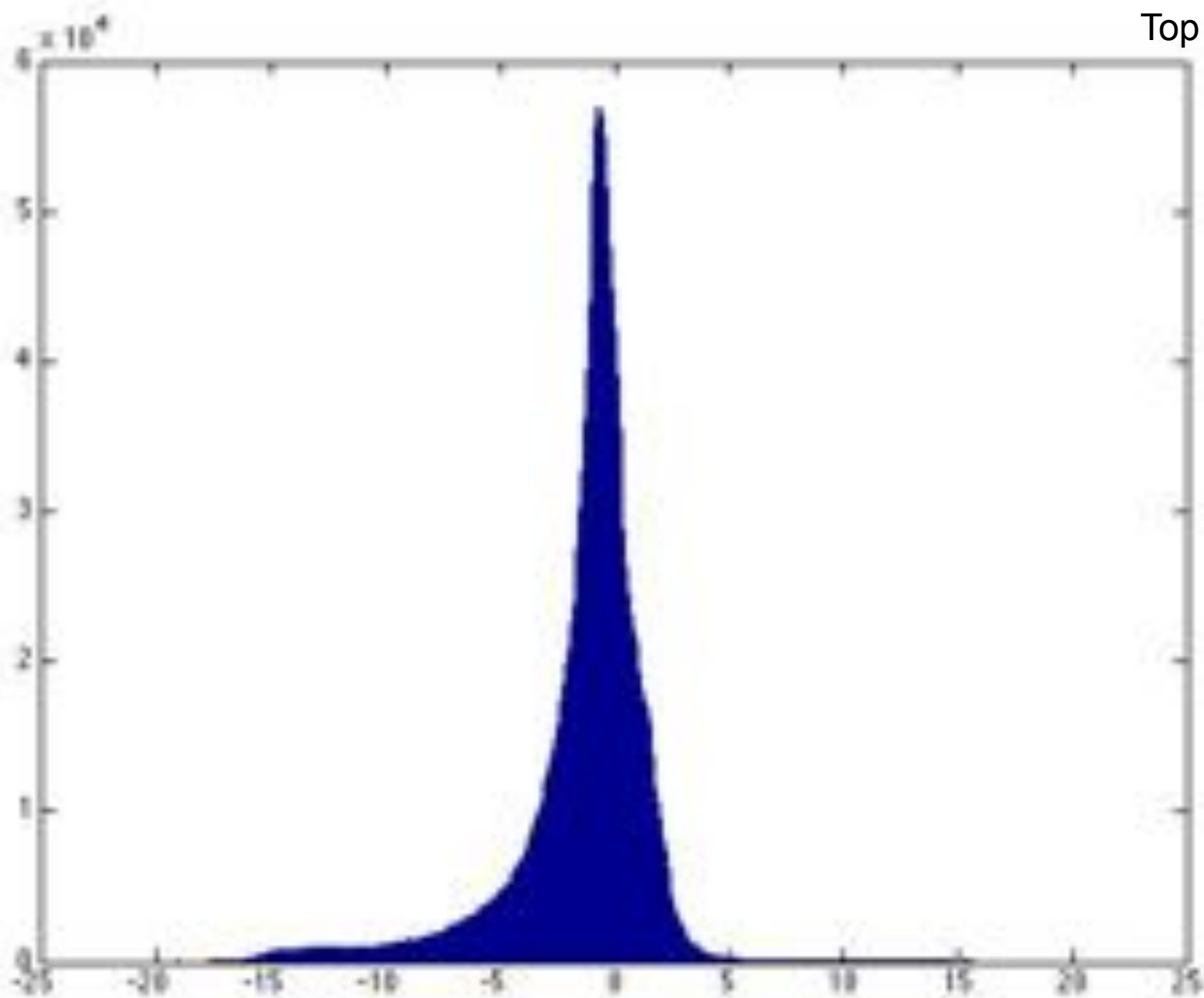
MODIS AQUA CTP (V5)

Frequency of High Clouds (8/28/2006)

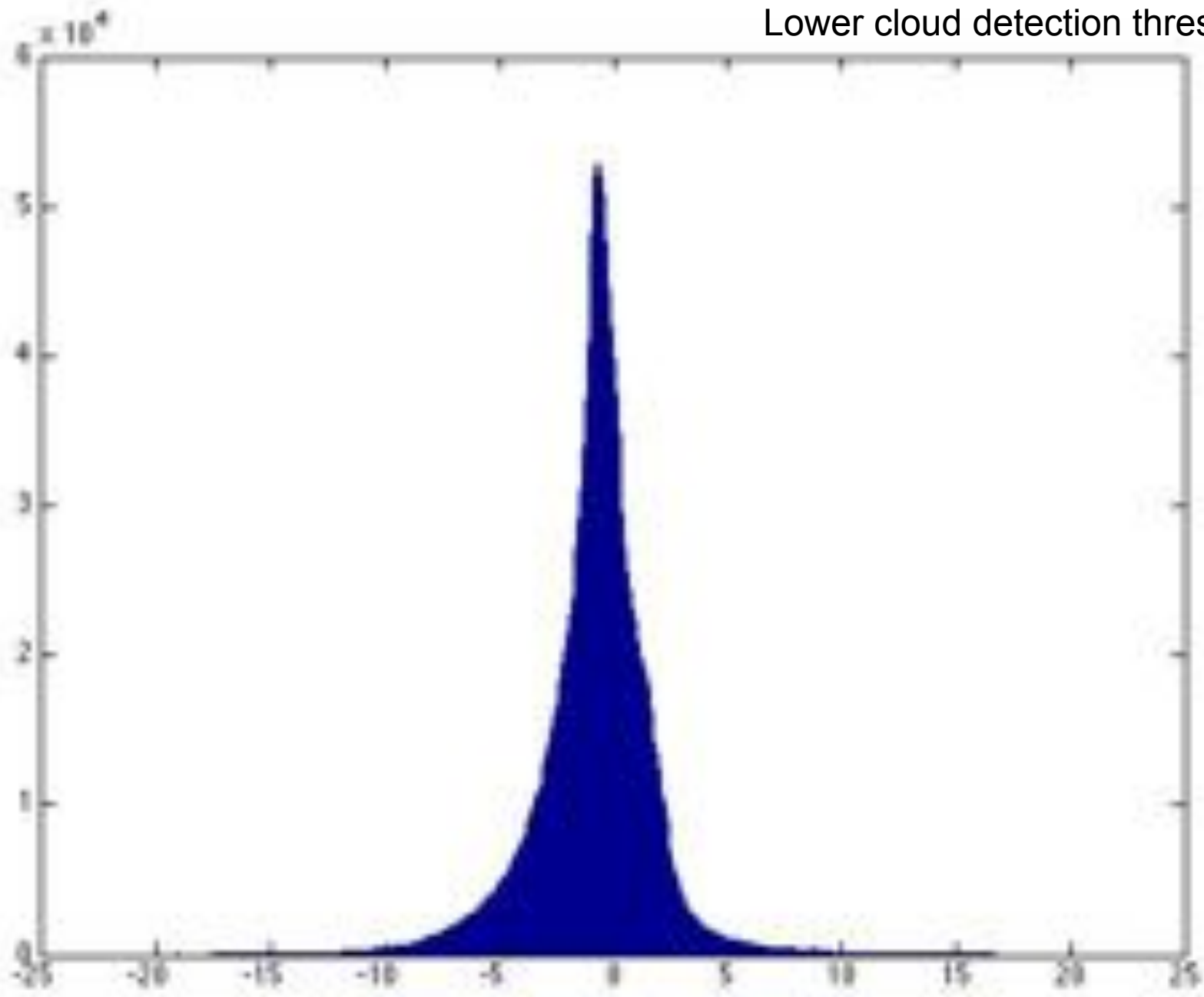MODIS AQUA CTP (V5 + topdownaccpoint_rmin)

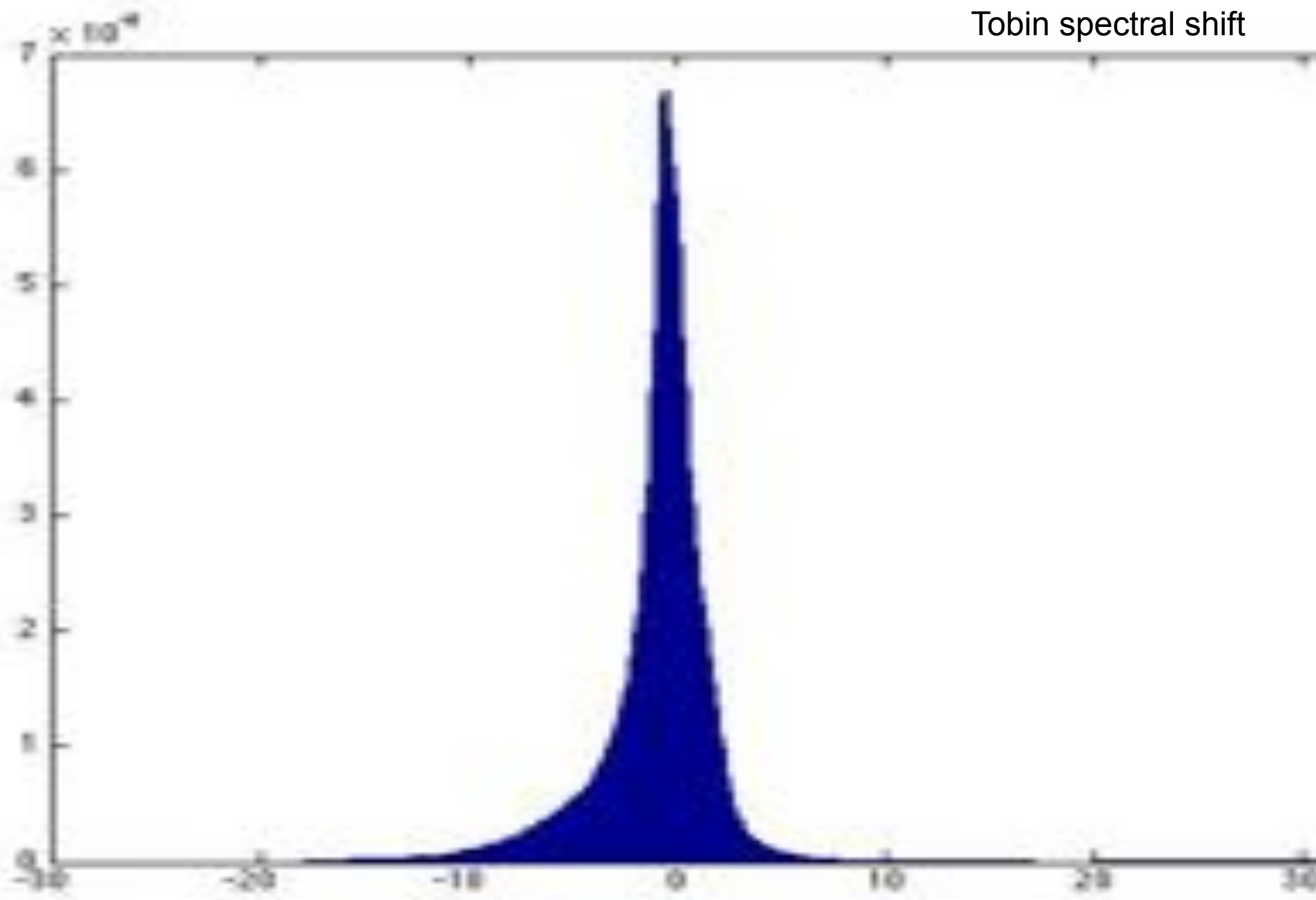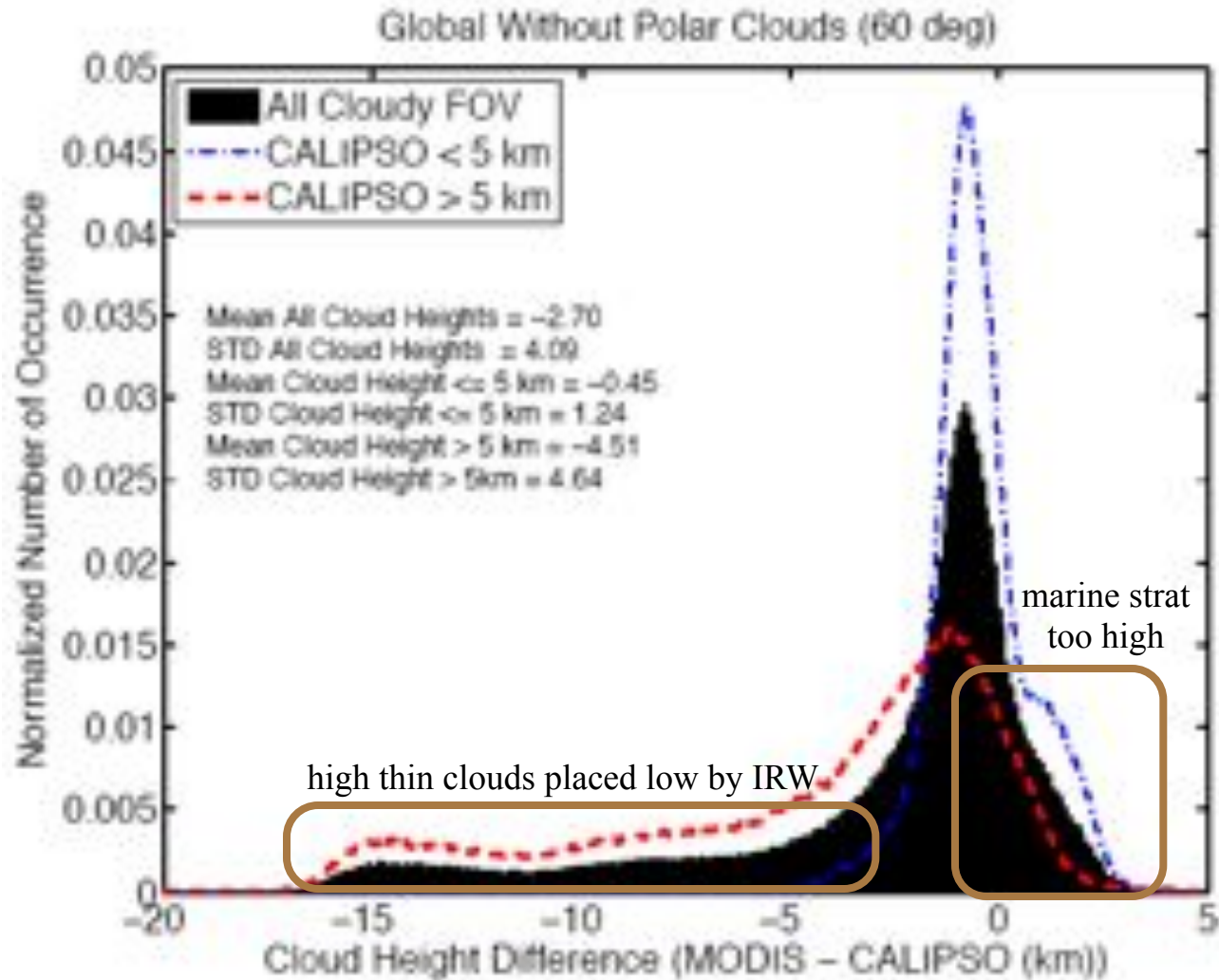Frequency of High Clouds (8/28/2006)

Collect 5

Top down

Lower cloud detection threshold
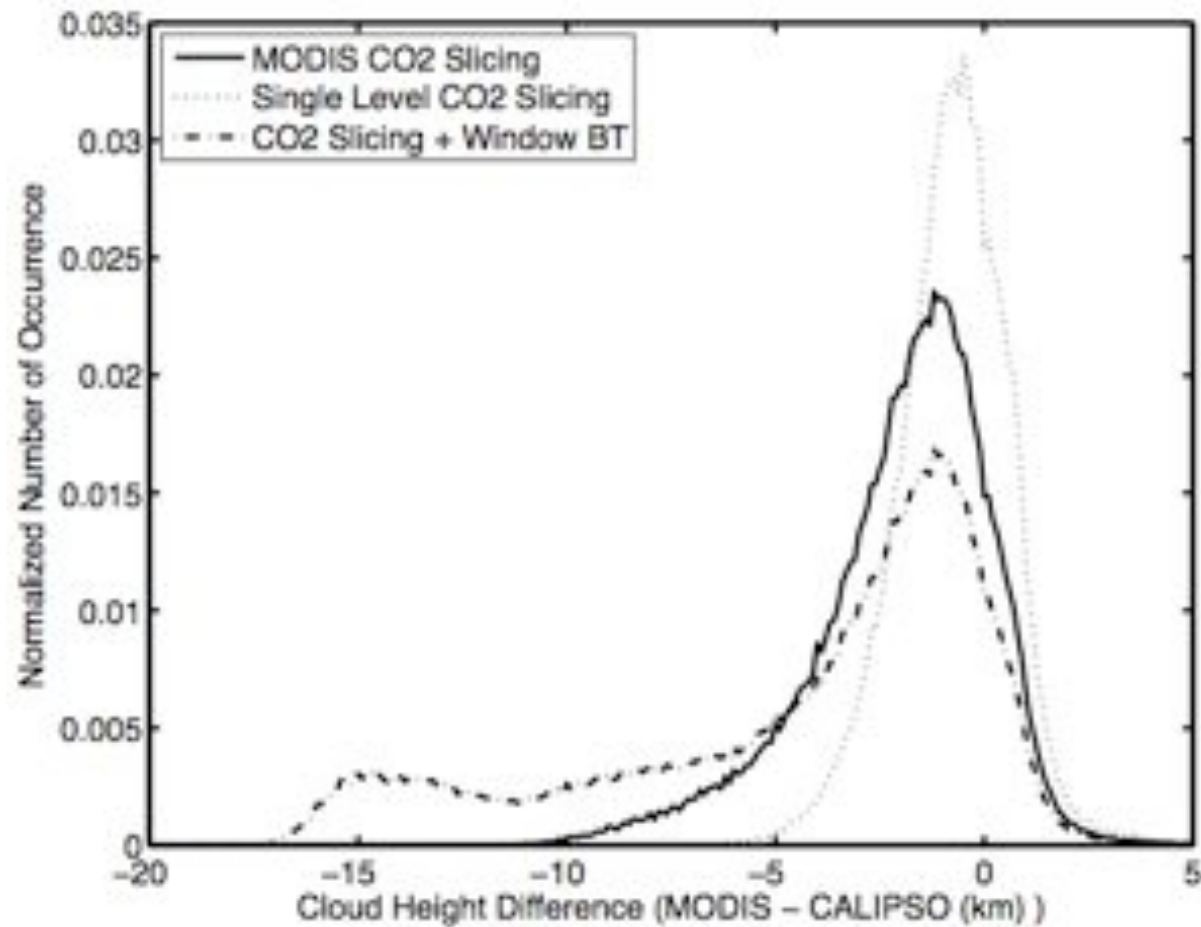
Tobin spectral shift

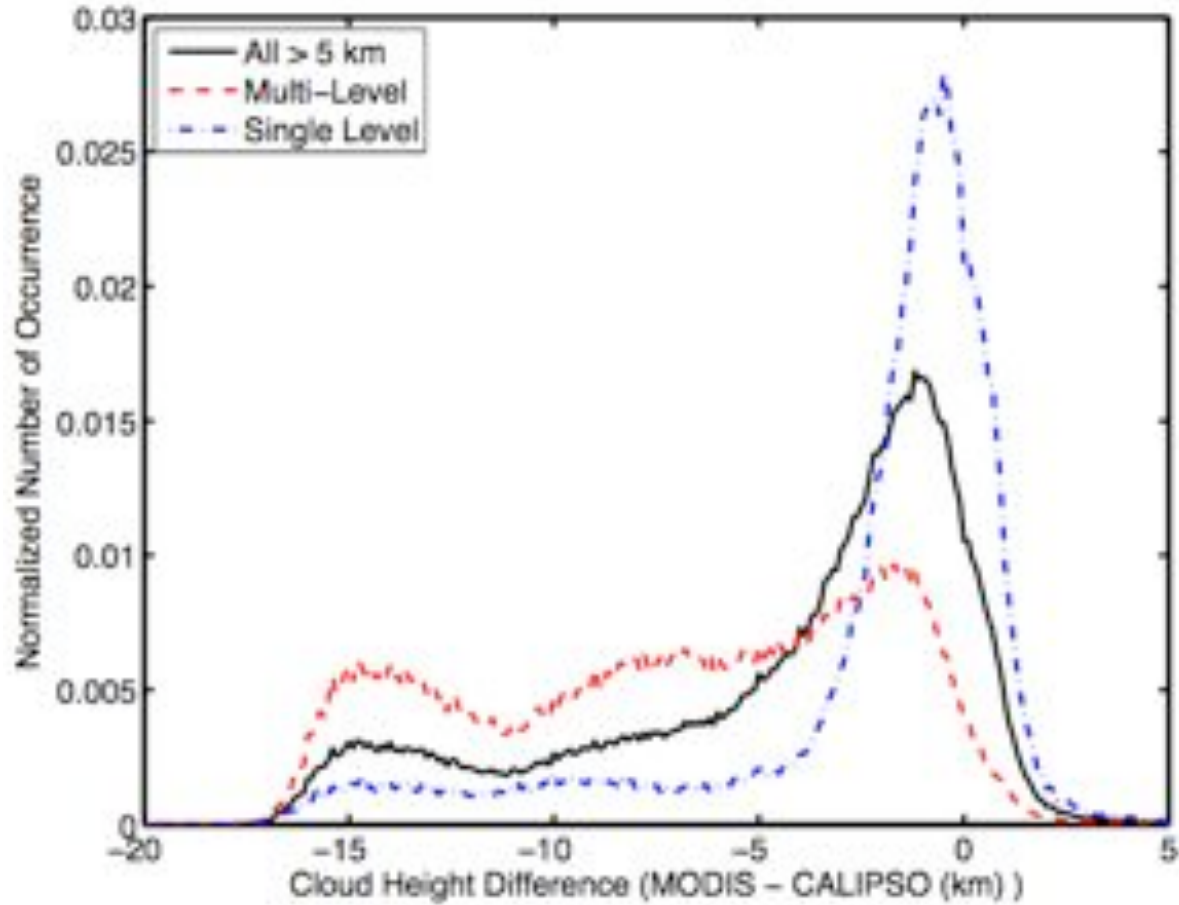# MODIS and CALIOP Cloud Properties Comparison

August 2006

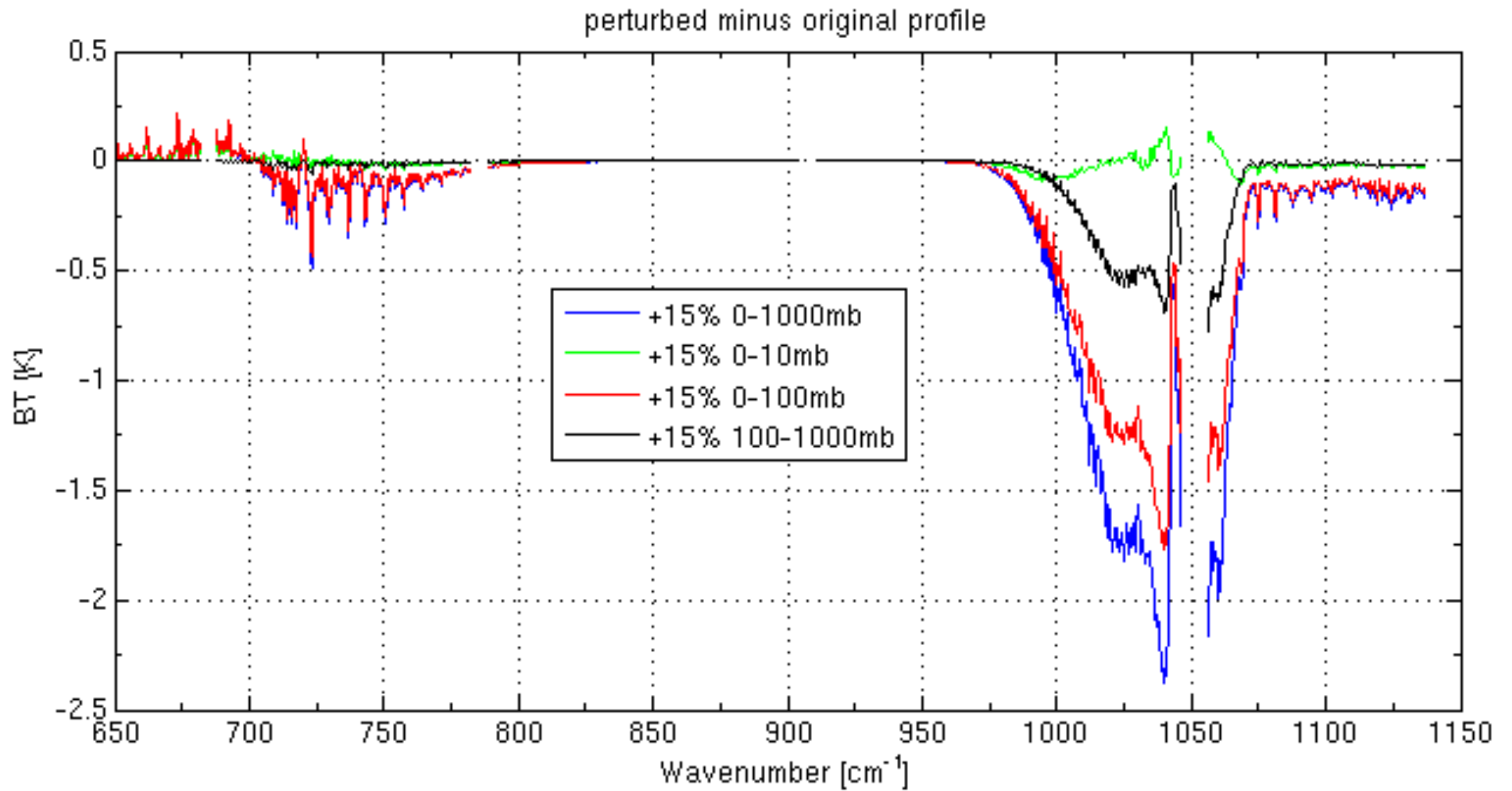# Collect 5 Single Level CO2 Slicing CTHs

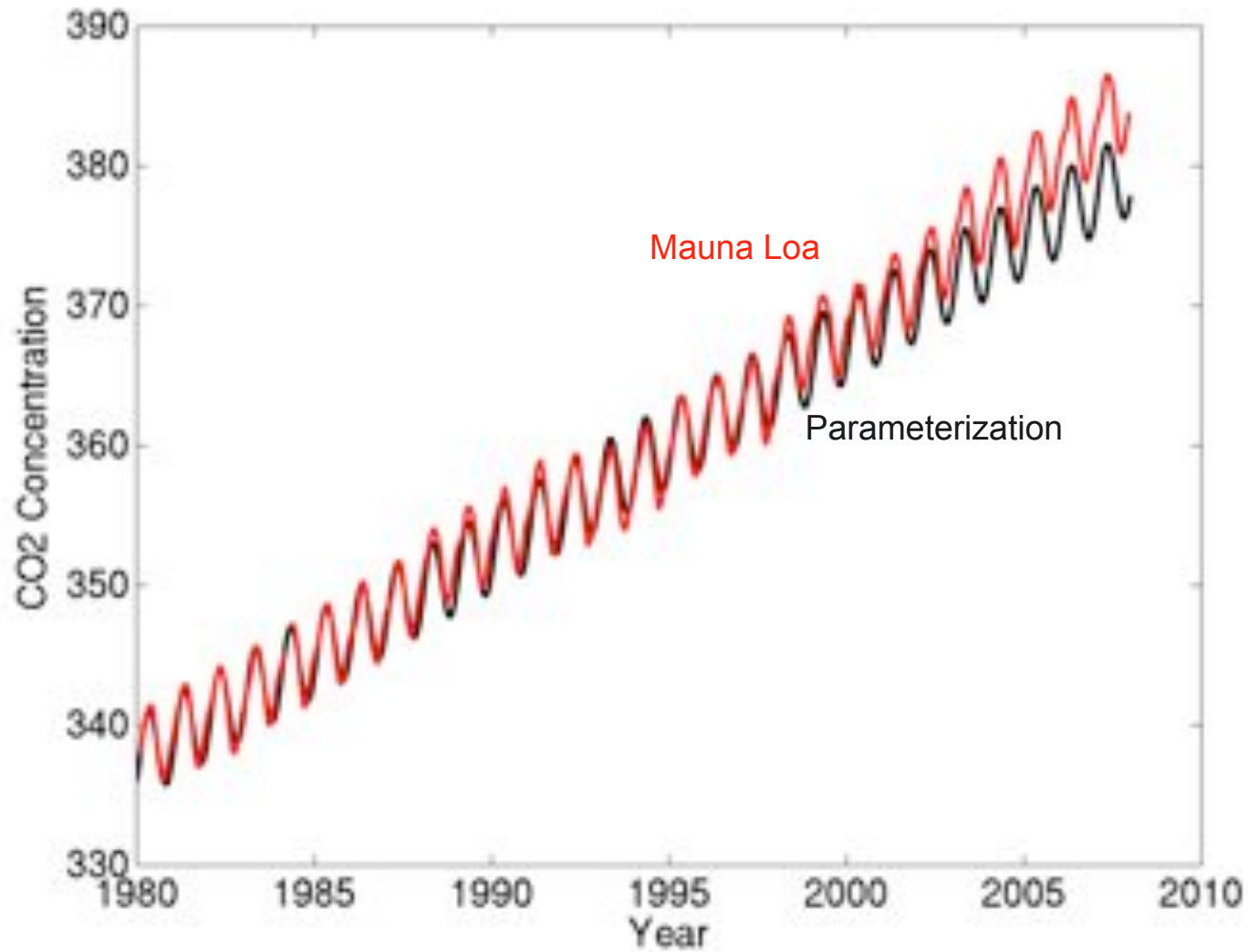# Collect 5 Impact of Multilevel Clouds

MODIS Algorithm Adjustments for Collect 6

A: Implement Band 34, 35, 36 spectral shifts suggested by Tobin et al. (2005) for Aqua.

B: Use "top-down" channel pairs 36/35, 35/34, 34/33 in that order to select CTP.

C: Lower "noise" thresholds (clear minus cloudy radiances required to indicate cloud presence in bands 33 to 36) to force more CO_2 slicing solutions for high thin clouds.

D: Restrict CO_2 channel pair solutions to appropriate portion of troposphere (determined by weighting functions – 36/35 < 450 hPa, 35/34 < 550 hPa, and 34/33 < 650 hPa).

E: *Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO_2 radiances influenced by O3 profiles are calculated correctly).*

F: *Use $CO_2 = [mx+a*sin(2\pi x/365)]+b$ where m = 1.5 ppmv / 365, b = 337.5 ppmv, a = 3 ppmv, and x = # days since 1 Jan 1980 to accommodate CO_2 increase.*

G: Prohibit CO_2 slicing solutions for water clouds; use only IRW solution. Avoid IRW solutions for ice clouds; use CO_2 slicing whenever possible.

H: Add marine stratus improvement where a constant lapse rate is assumed in low level inversions – lapse rate is adjusted according to latitude region.

I. Add stratospheric cloud flag responding to BT13.9>BT13.3+0.5.

O3 affects CO2 bands

perturbed minus original profile

Legend:
- +15% 0-1000mb
- +15% 0-10mb
- +15% 0-100mb
- +15% 100-1000mb

BT [K] vs Wavenumber [cm⁻¹]

MODIS C6: CO_2 changes over time

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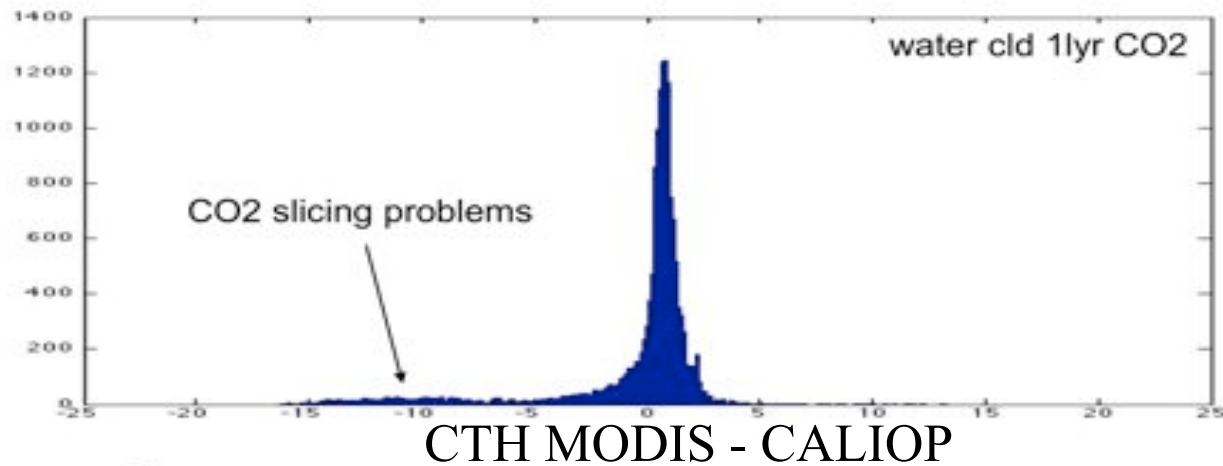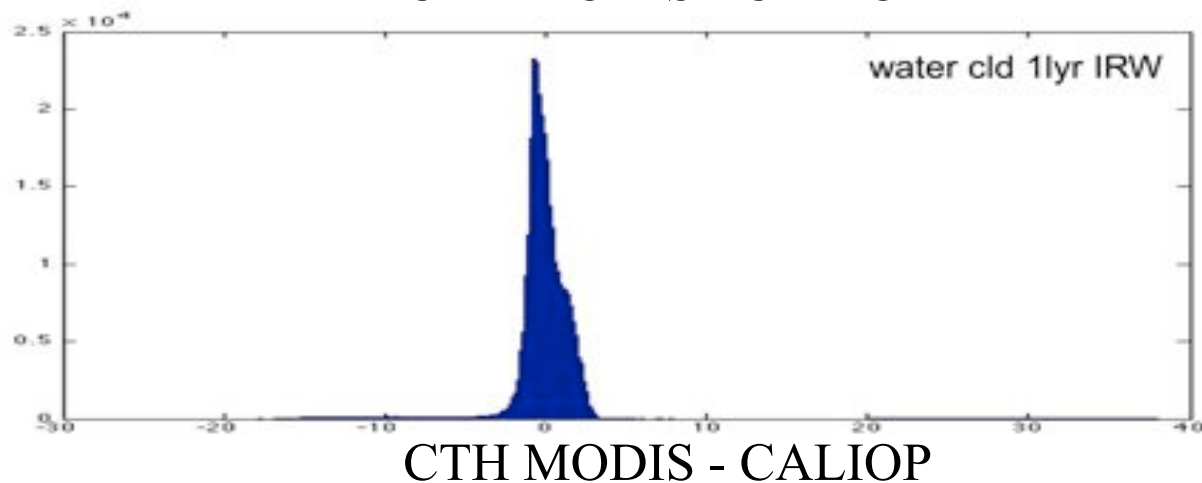
Avoid IRW solutions for ice clouds

Number for
Aug 2006

IRW ice cld 1 lyr

CTH MODIS - CALIOP
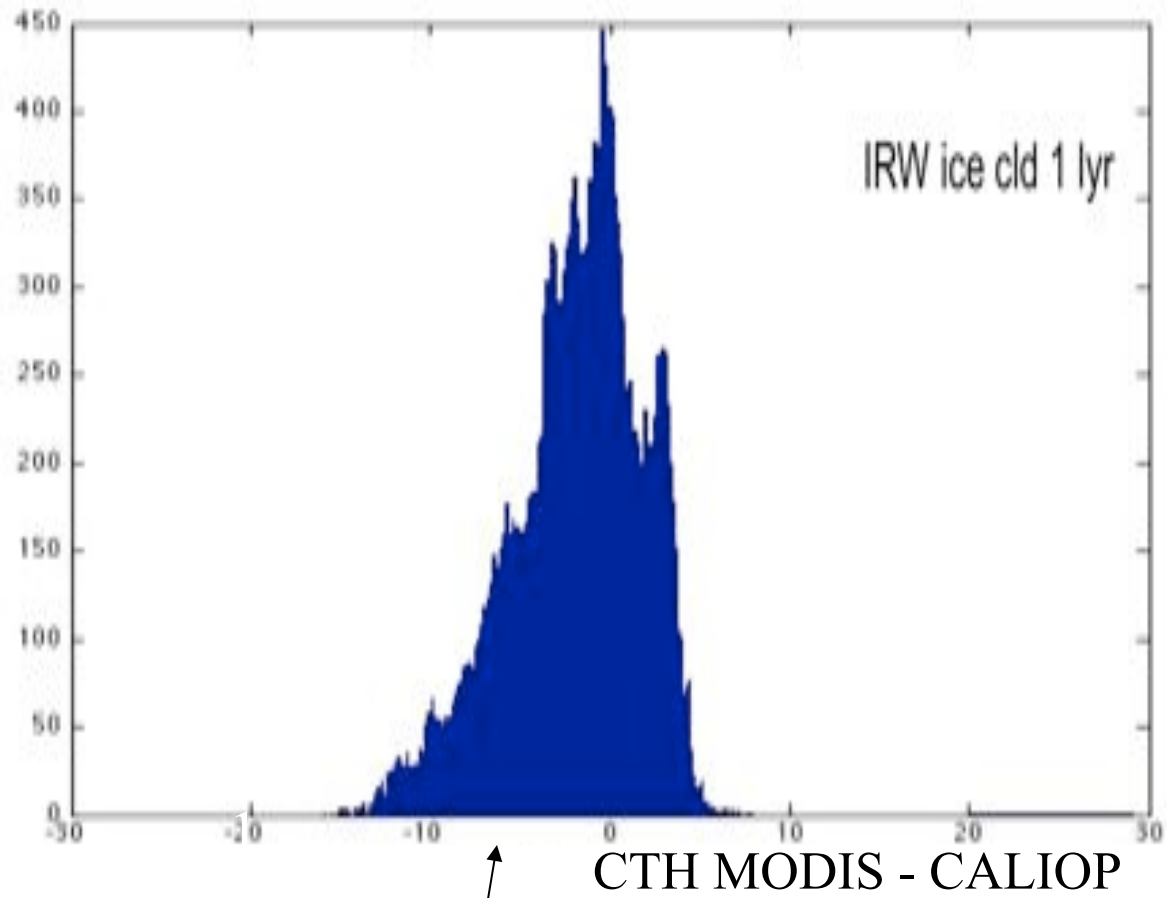
IRW CTHs are too low for ice clouds

Avoid CO2 slicing solutions for water clouds

Number for
Aug 2006

CTH MODIS - CALIOP

Number for
Aug 2006

CTH MODIS - CALIOP

Determine C6 Cloud Phase with Beta Ratio Tests

Collection 5:
   Based on 8.5/11-μm brightness temperatures (BT) and their differences (BTD)

Collection 6:
   Supplement BT & BTD tests with emissivity ratios (b ratio)

   b ratios are based on 7.3, 8.5, 11, 12-μm bands (more on another slide)

      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)

   Use of b 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

The Beta ratio is based on cloud emissivity profiles

A cloud emissivity profile for a single band:

$$e(p) = \frac{(I - I_{clr})}{[I_{ac}(p) + T_{ac}(p)I_{bb}(p) - I_{clr})]}$$

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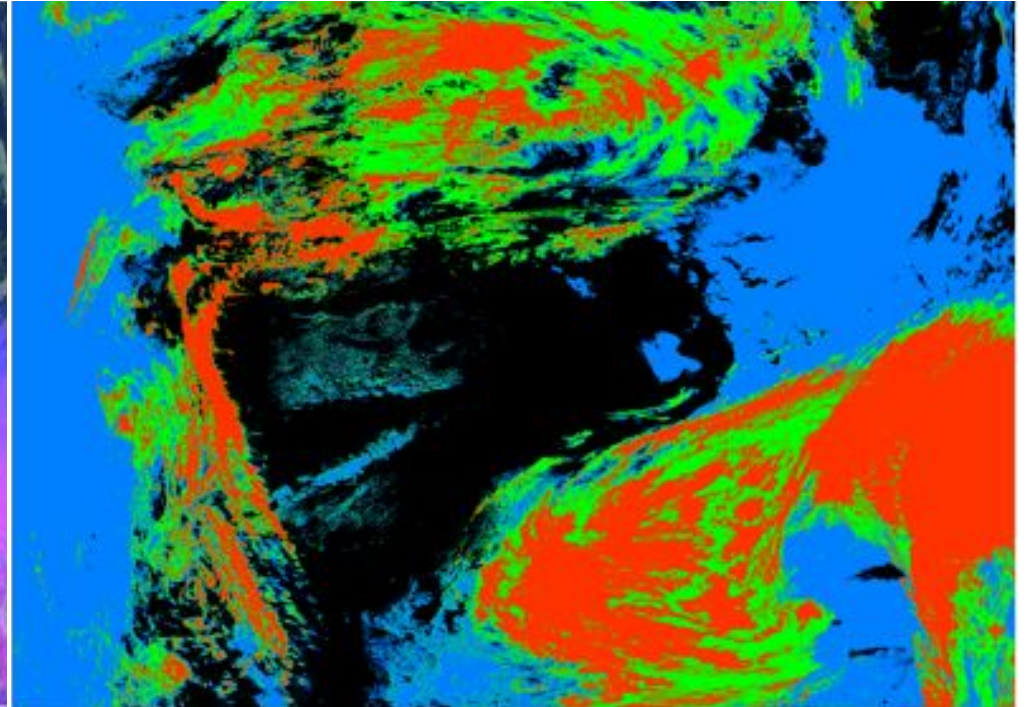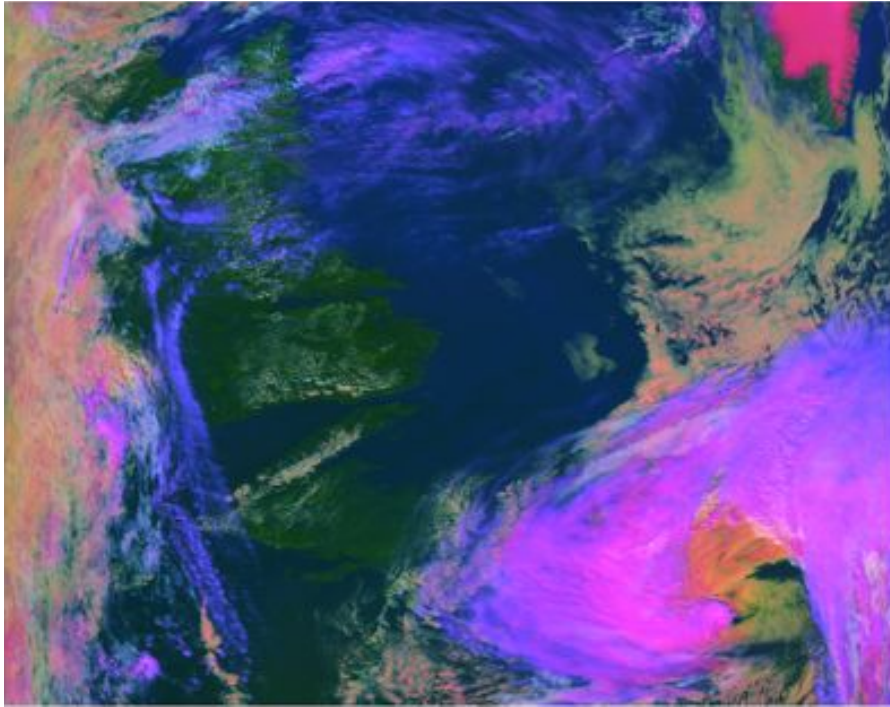$I_{ac}(p)$ = above cloud emission at pressure p
$I_{bb}(p)$ = TOA radiance for opaque cloud at pressure p
$T_{ac}(p)$ = above cloud transmission

$$b_{x,y}(p) = \frac{\ln[1 - e_{c,y}(p)]}{\ln[1 - e_{c,x}(p)]}$$

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

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 mm; Green: 2.1 mm; Blue: 11 mm

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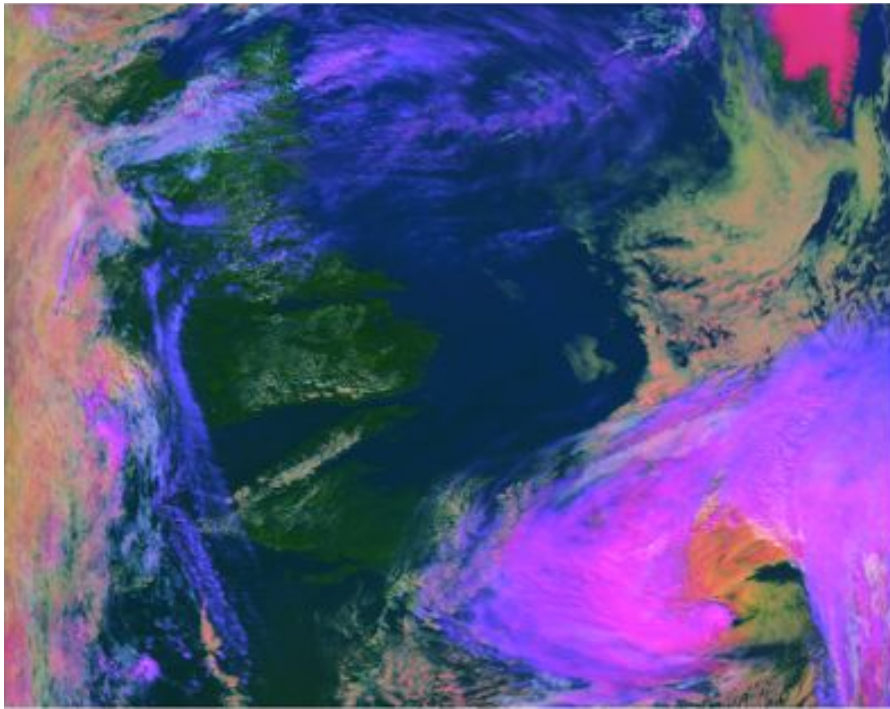Snow/ice: magenta (Southern tip of Greenland)
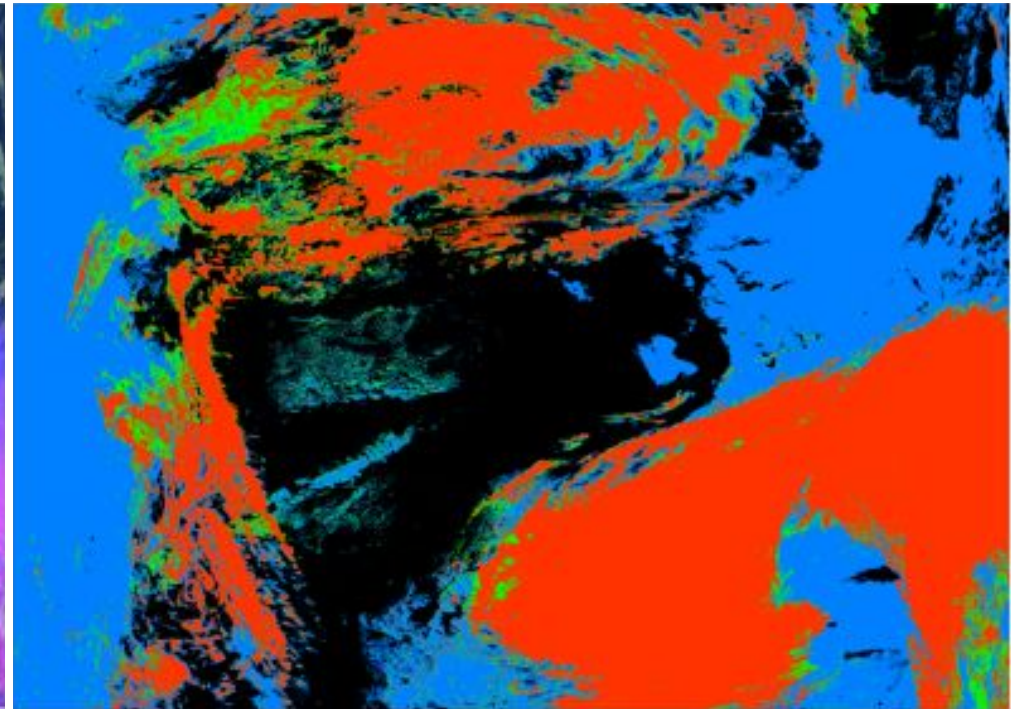Ocean: dark blue
Land: green

Clear   Water   Ice   Unknown

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
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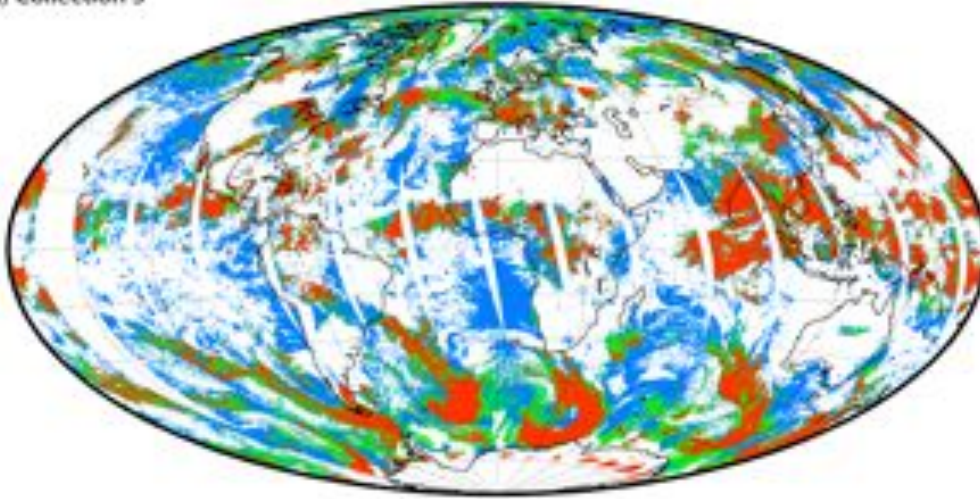

False color image
Red: 0.65 mm; Green: 2.1 mm; Blue: 11 mm

Clear   Water   Ice   Unknown

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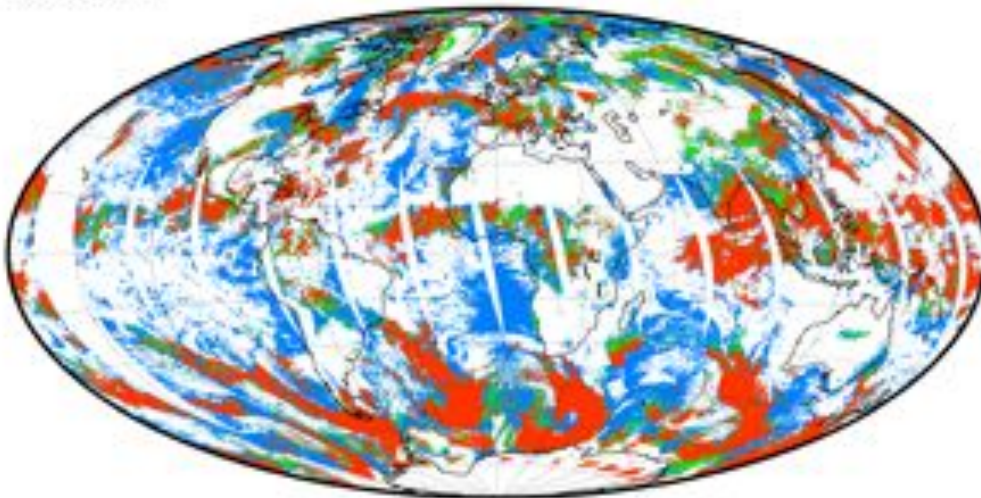phase since there is no justification
for this category

a) Collection 5

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

Water   Ice   Unknown

b) Collection 6

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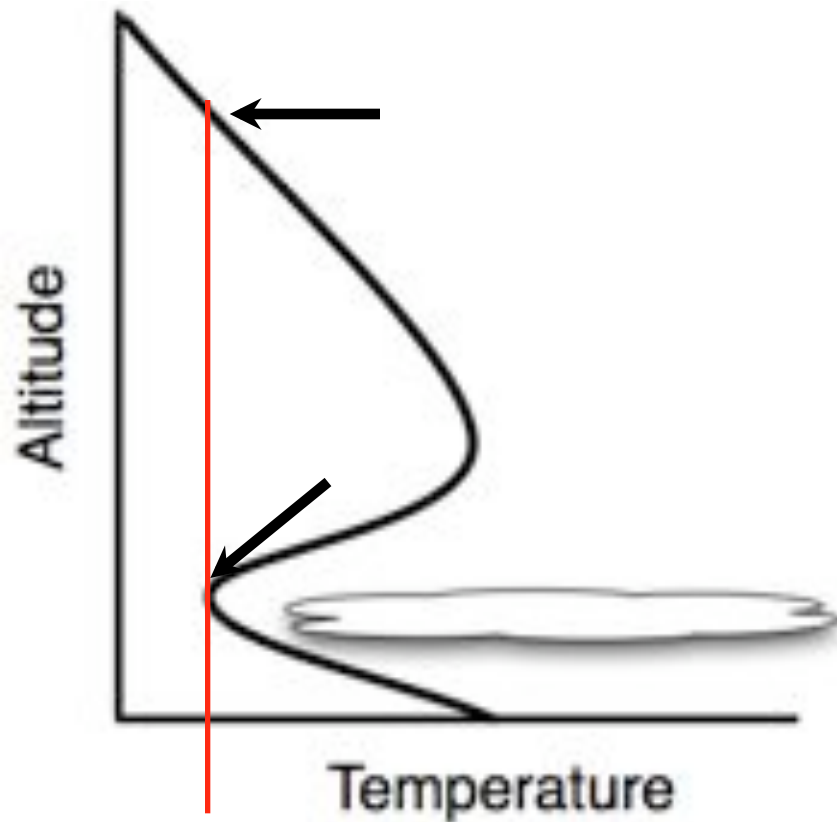phase clouds

MODIS Algorithm Adjustments for Collect 6

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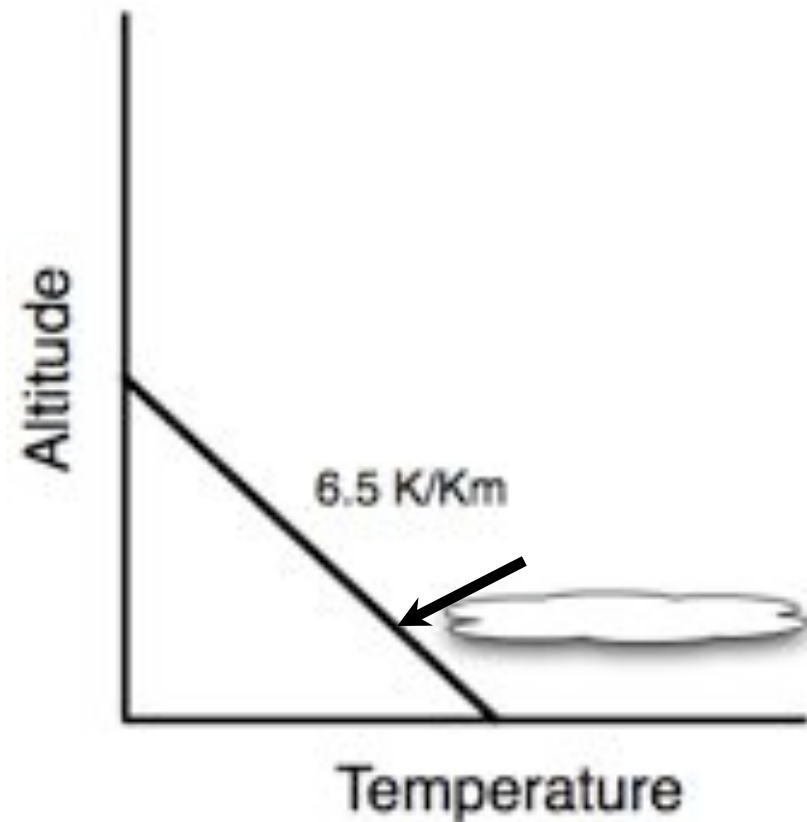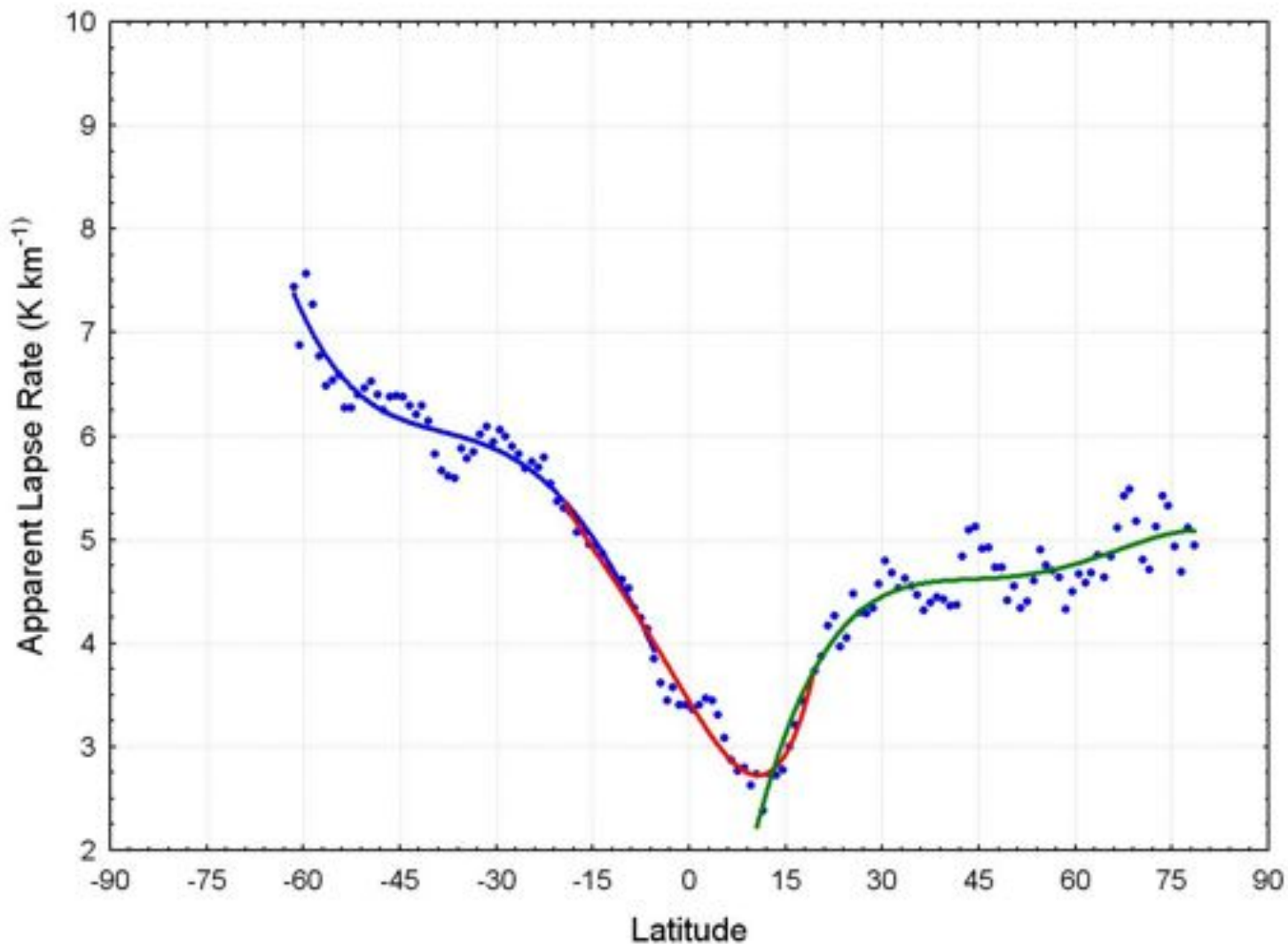
Marine Stratus CTH Over-Estimated

Total Attenuated Backscatter 532 nm
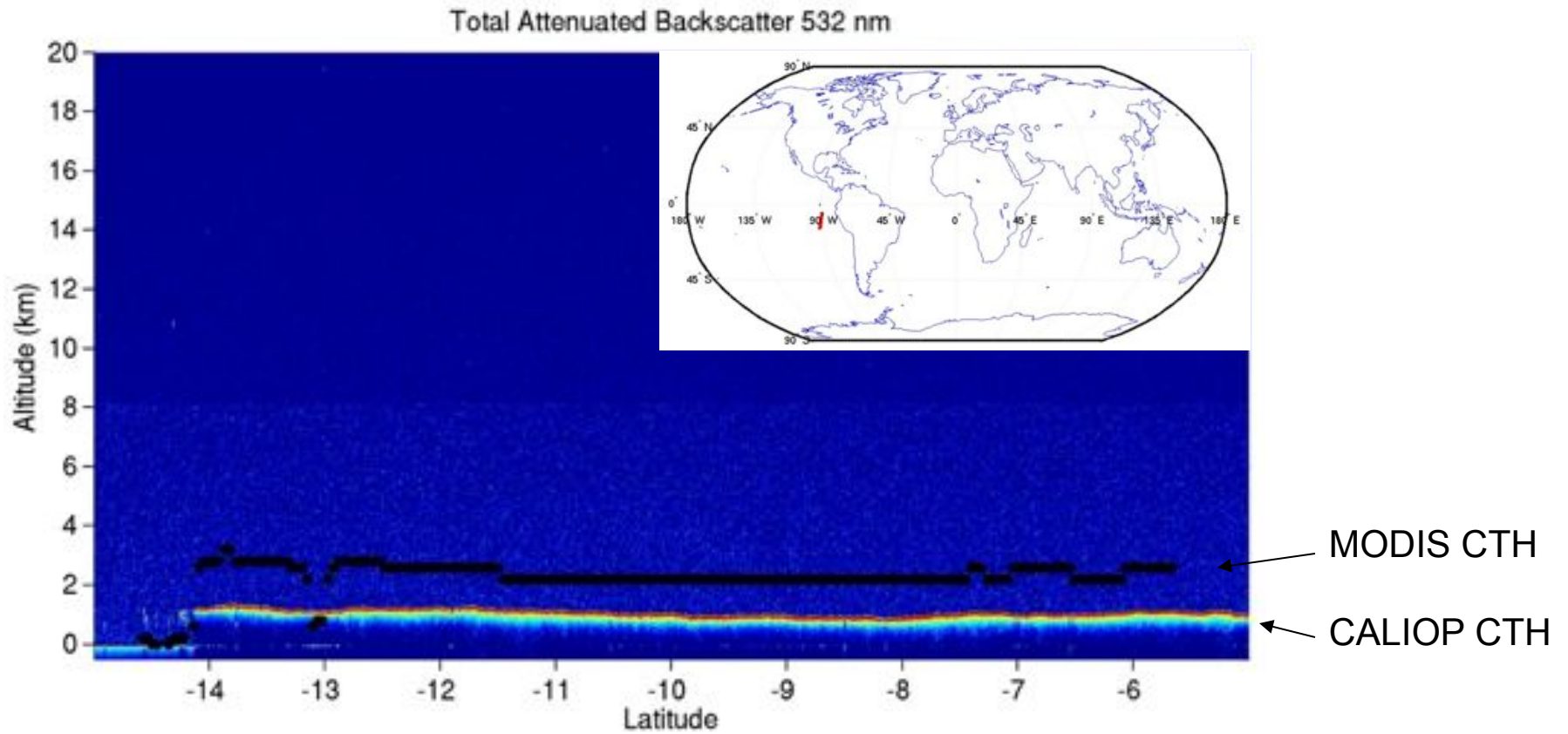
Marine Stratus Correction for Low Level Inversion

Current
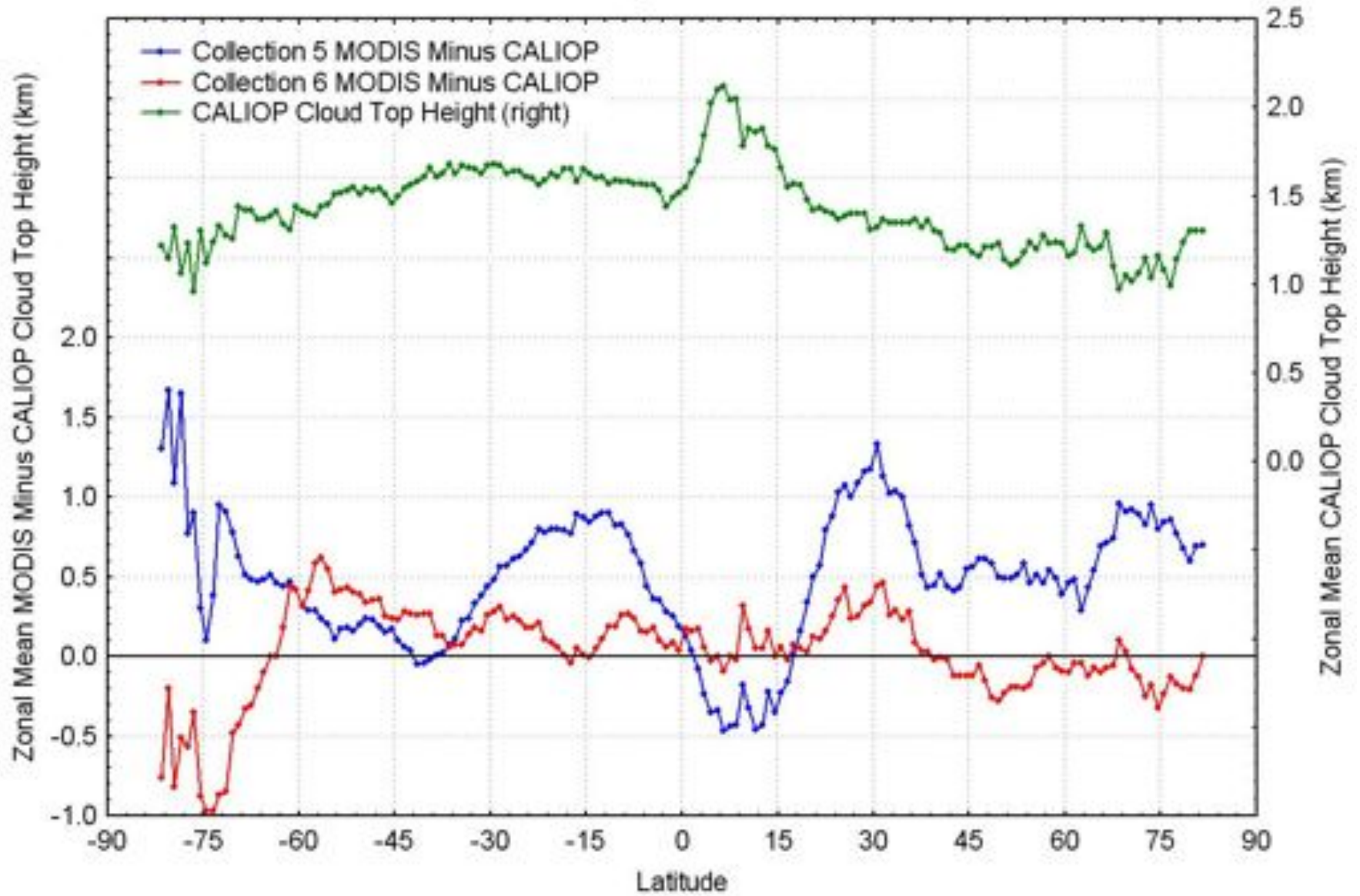
Modified (Minnis 1992)

6.5 K/Km

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.
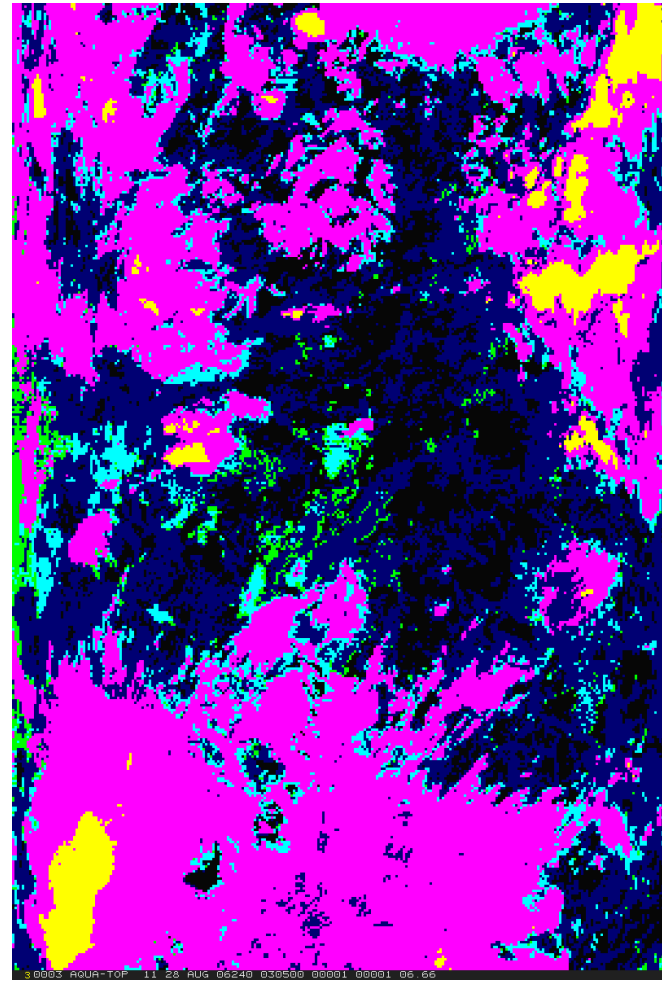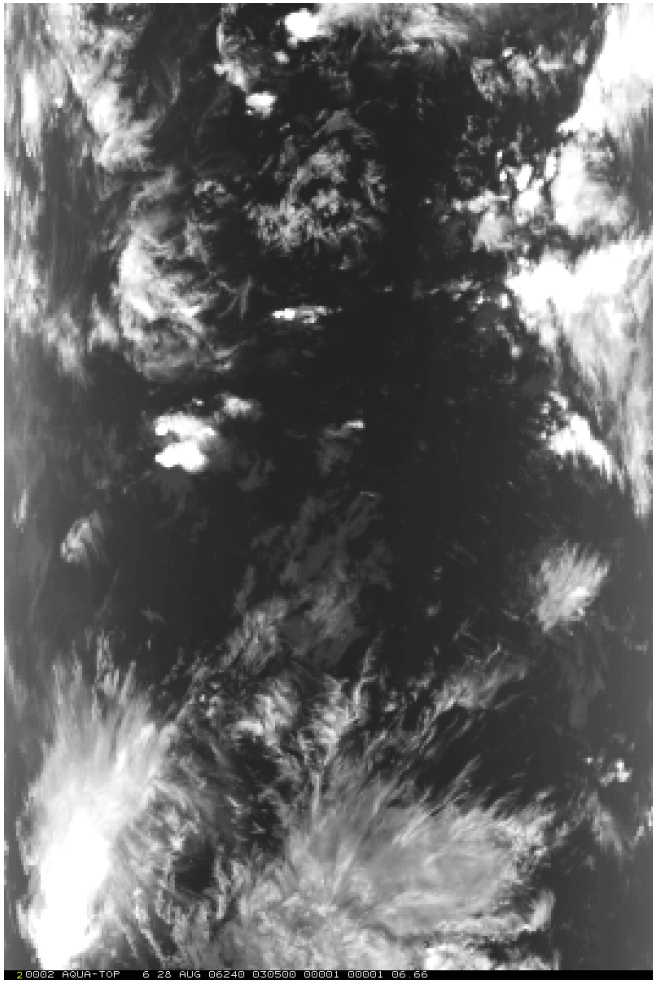
Collocated CALIOP and MODIS Cloud Top Heights
Marine Low Clouds (CALIOP < 3 km)
August 2006

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I. *Add stratospheric cloud flag responding to BT13.9>BT13.3+0.5.*

Stratospheric Cloud Test

Stratospheric clouds are identified when a more opaque band is found to be warmer than a less opaque band indicating detection of a positive lapse rate above an opaque cloud; thus when BT13.9 > BT13.3 + 0.5 K a yellow flag is indicated in the image on the right.

MODIS Algorithm Adjustments for Collect 6

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MODIS Collect 6 improvements over Collect 5 measured by CALIOP for August 2006
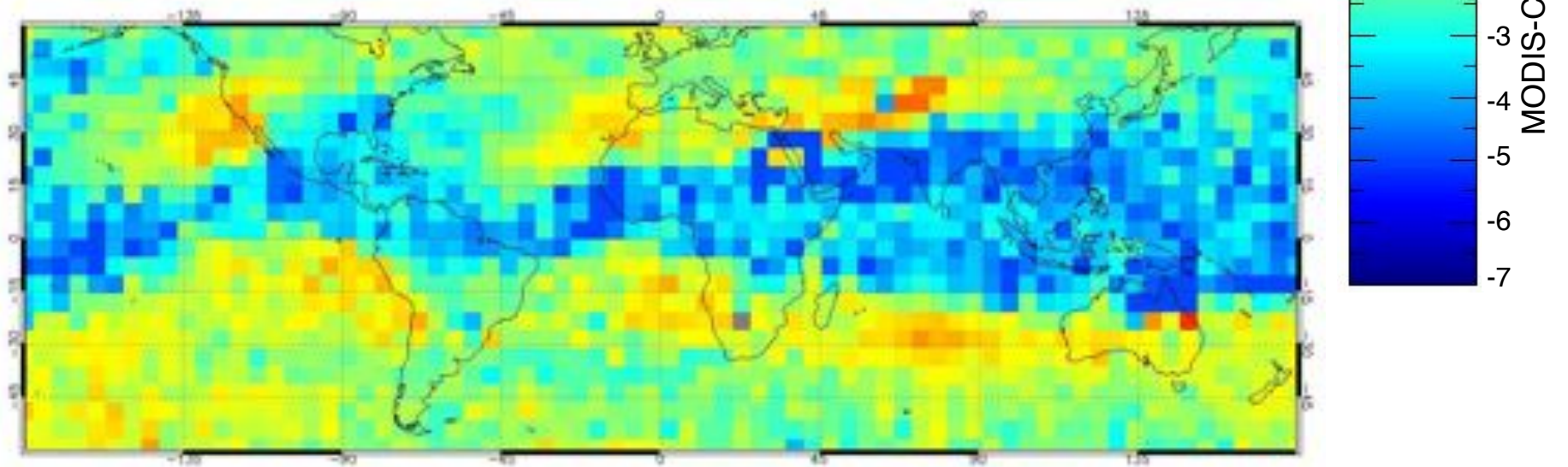
(MODIS–CALIOP) for All Clouds; August 2006
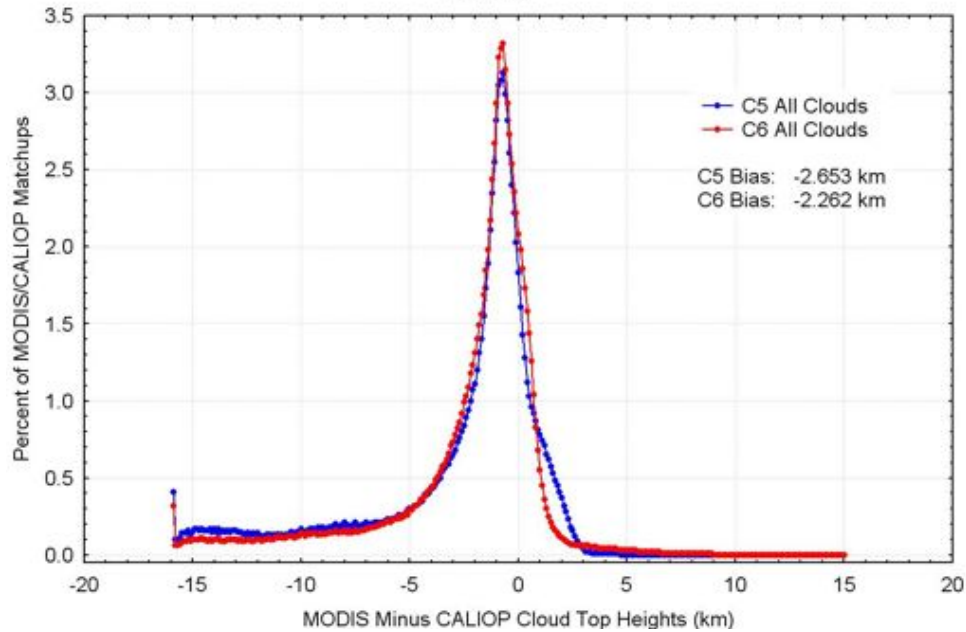Based on Collection 5 MODIS 5-km CTH and Version 3 CALIOP 5-km CTH
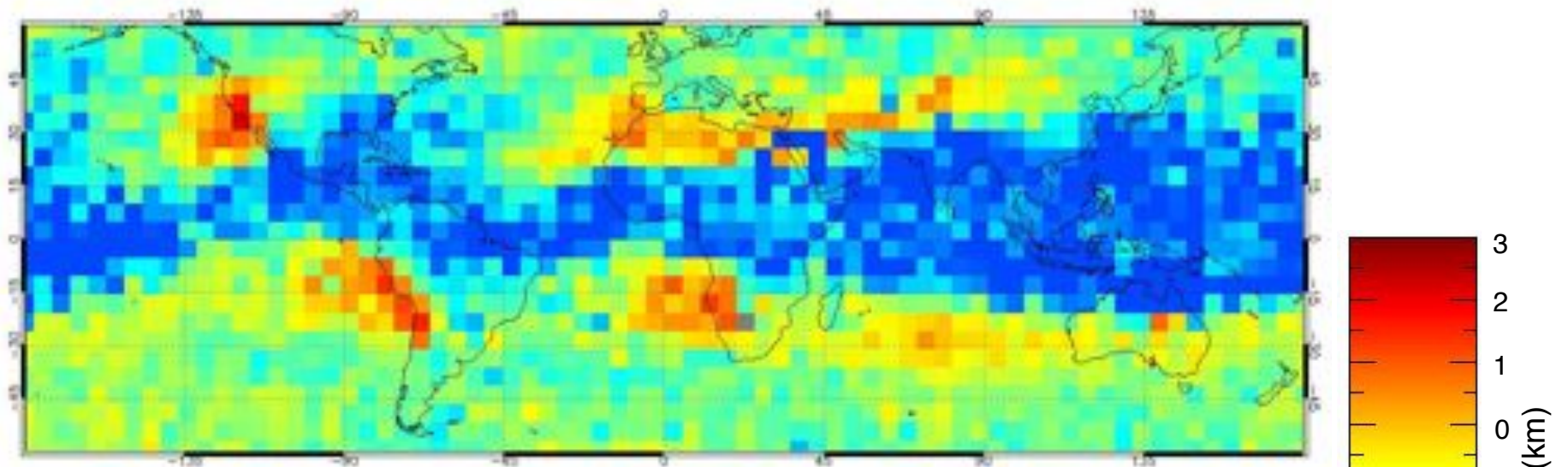
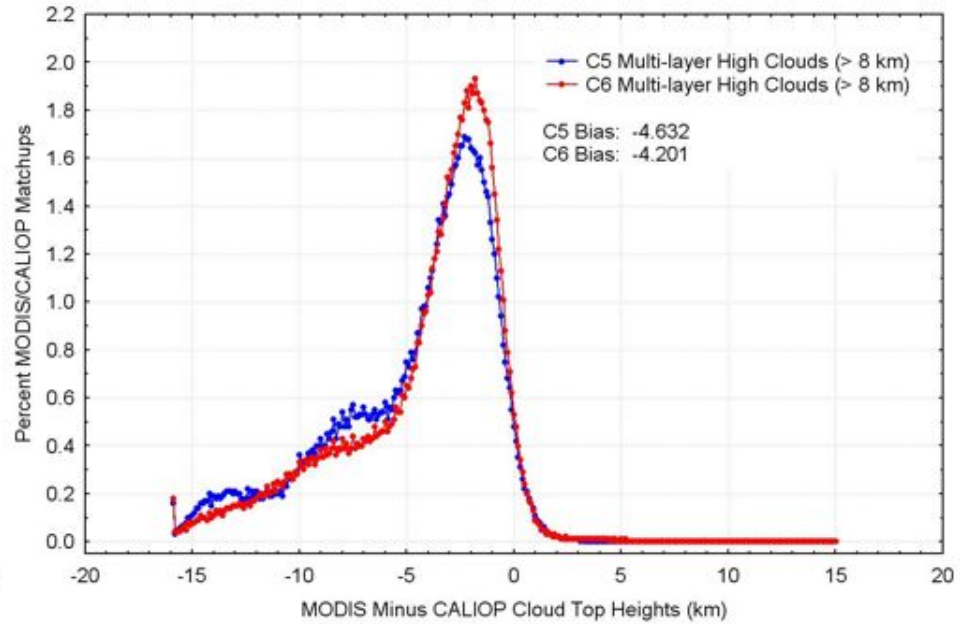(MODIS–CALIOP) for All Clouds for August 2006
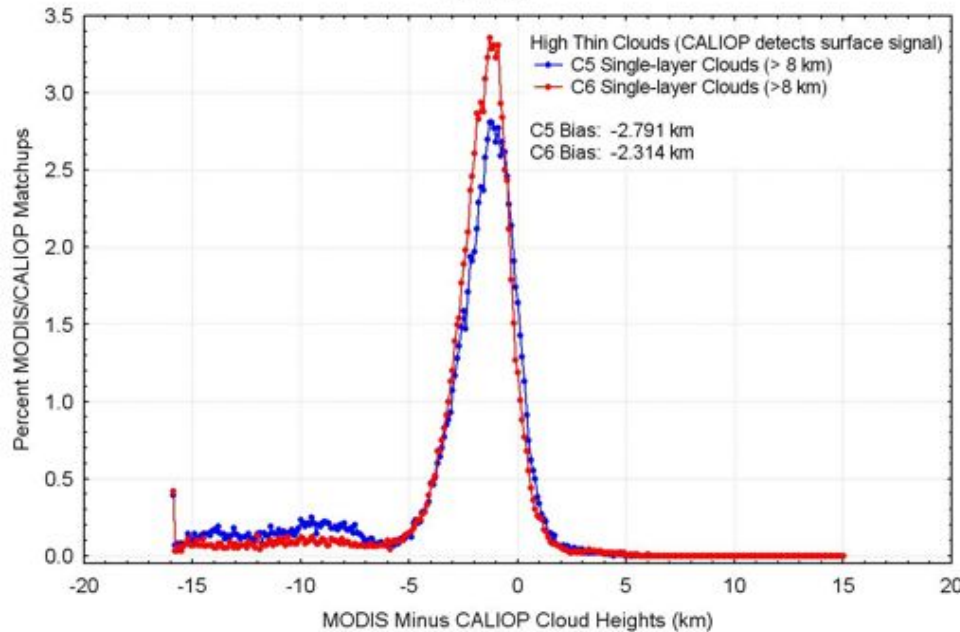Based on Collection 6 MODIS 5-km CTH and Version 3 CALIOP 5-km CTH

MODIS-CALIOP (km)
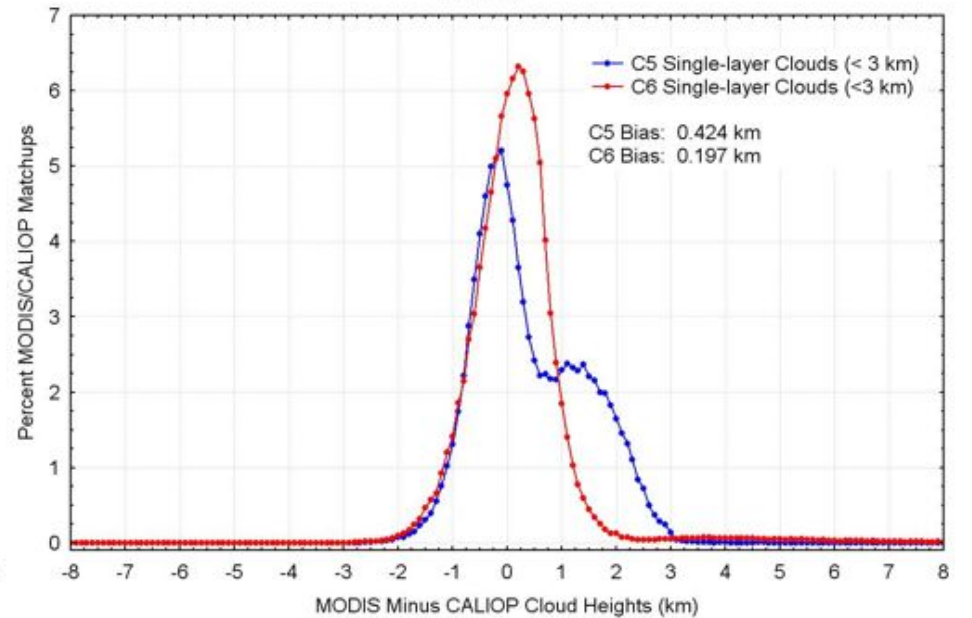
Aqua MOD06CT and CALIOP Cloud Heights
August 2006
60S-60N

C5 All Clouds
C6 All Clouds

C5 Bias: -2.653 km
C6 Bias: -2.262 km

Aqua MOD06CT and CALIOP Cloud Heights
August 2006
60S-60N

C5 Multi-layer High Clouds (> 8 km)
C6 Multi-layer High Clouds (> 8 km)

C5 Bias: -4.632
C6 Bias: -4.201

Aqua MOD06CT and CALIOP Cloud Heights
August 2006
60S-60N

High Thin Clouds (CALIOP detects surface signal)
C5 Single-layer Clouds (> 8 km)
C6 Single-layer Clouds (>8 km)

C5 Bias: -2.791 km
C6 Bias: -2.314 km

Aqua MOD06CT and CALIOP Cloud Heights
August 2006
60S-60N

C5 Single-layer Clouds (< 3 km)
C6 Single-layer Clouds (<3 km)

C5 Bias: 0.424 km
C6 Bias: 0.197 km

Conclusions on CTP Algorithm Adjustments

- The largest cloud height differences results from not using CO_2 slicing (>15 km)
- Reducing the cloud detection threshold produced more high thin cloud retrievals, but also produced erroneously high CO_2 CTH retrievals for low water clouds in the southern Pacific
- CO_2 slicing (IRW) heights should be avoided for water (ice) clouds
- A high bias in marine stratus was identified in the MODIS retrievals; CTH algorithm problems in inversions will be mitigated assuming a wet lapse rate
- Adjusting the spectral response of the CO_2 bands reduced CTH errors
- Selecting the spectral radiance ratio using a top down criteria improved high cloud detection
- Making multiple passes through large data sets was necessary
- Using CALIOP as a reference was invaluable
- Collect 6 Cloud Products should be the ten year reference
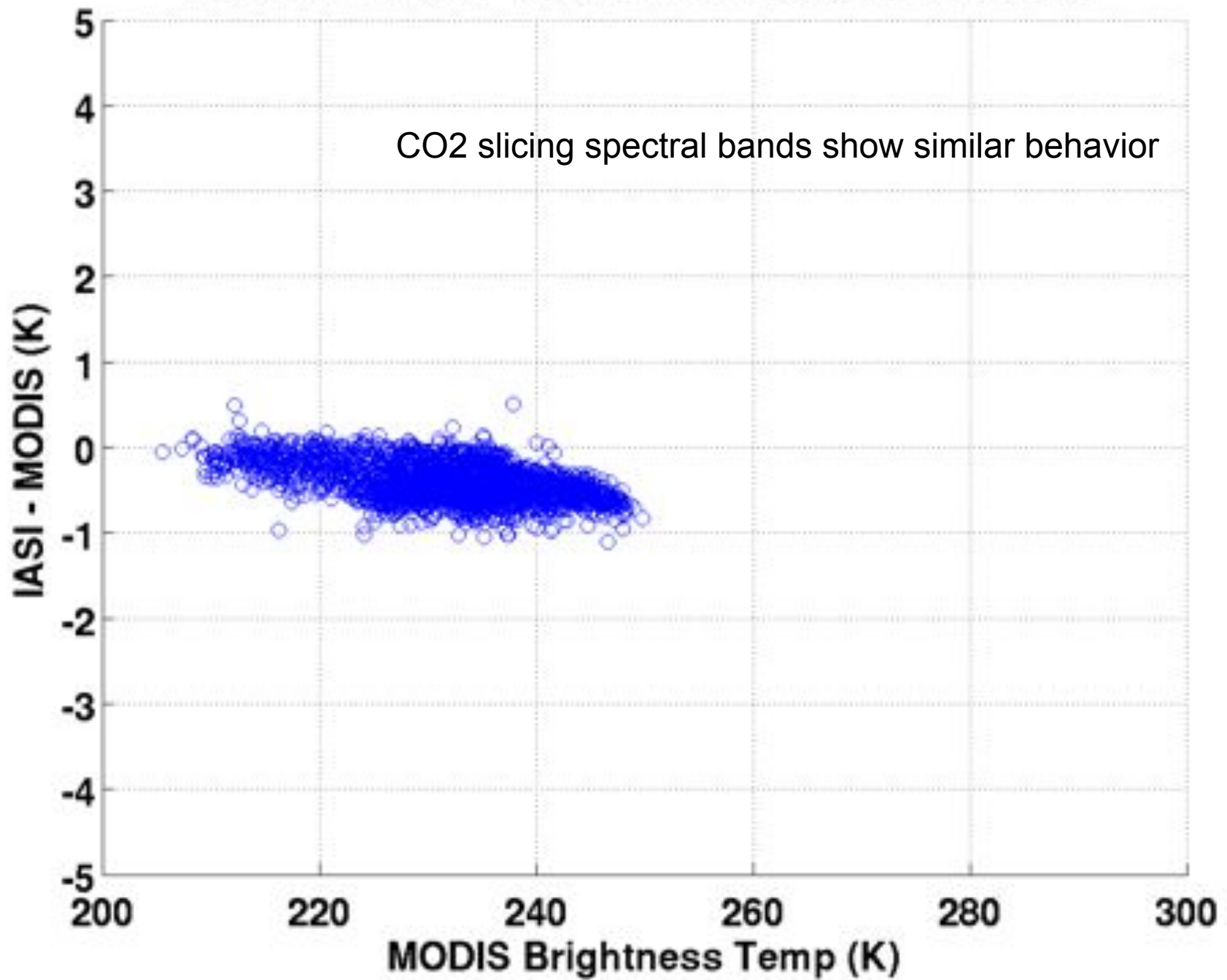
Remaining Actions

(1) Spectral shifts have been implemented for Aqua MODIS.
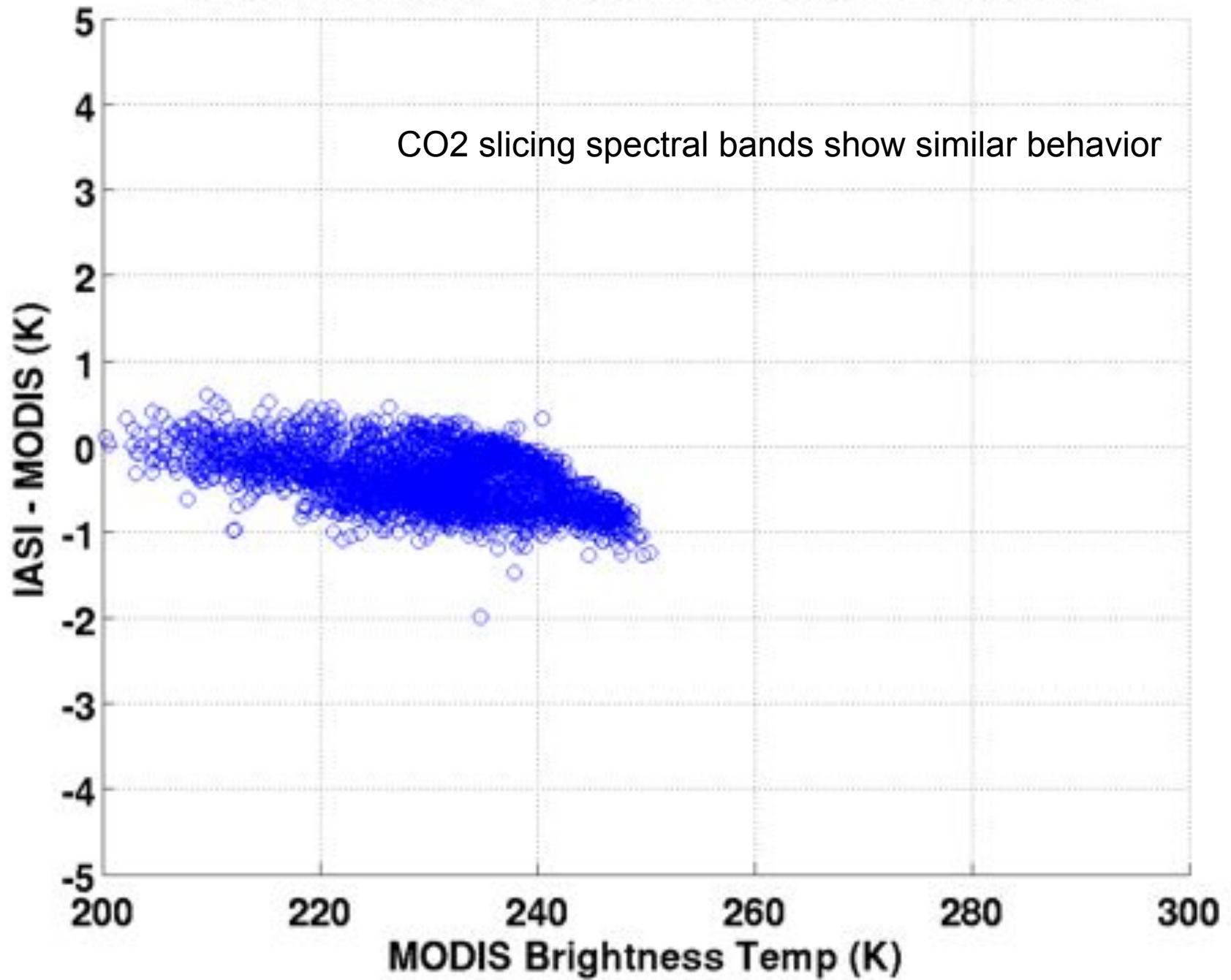Are spectral shifts necessary for Terra MODIS?
Intercomparisons with IASI are beginning to indicate answers.
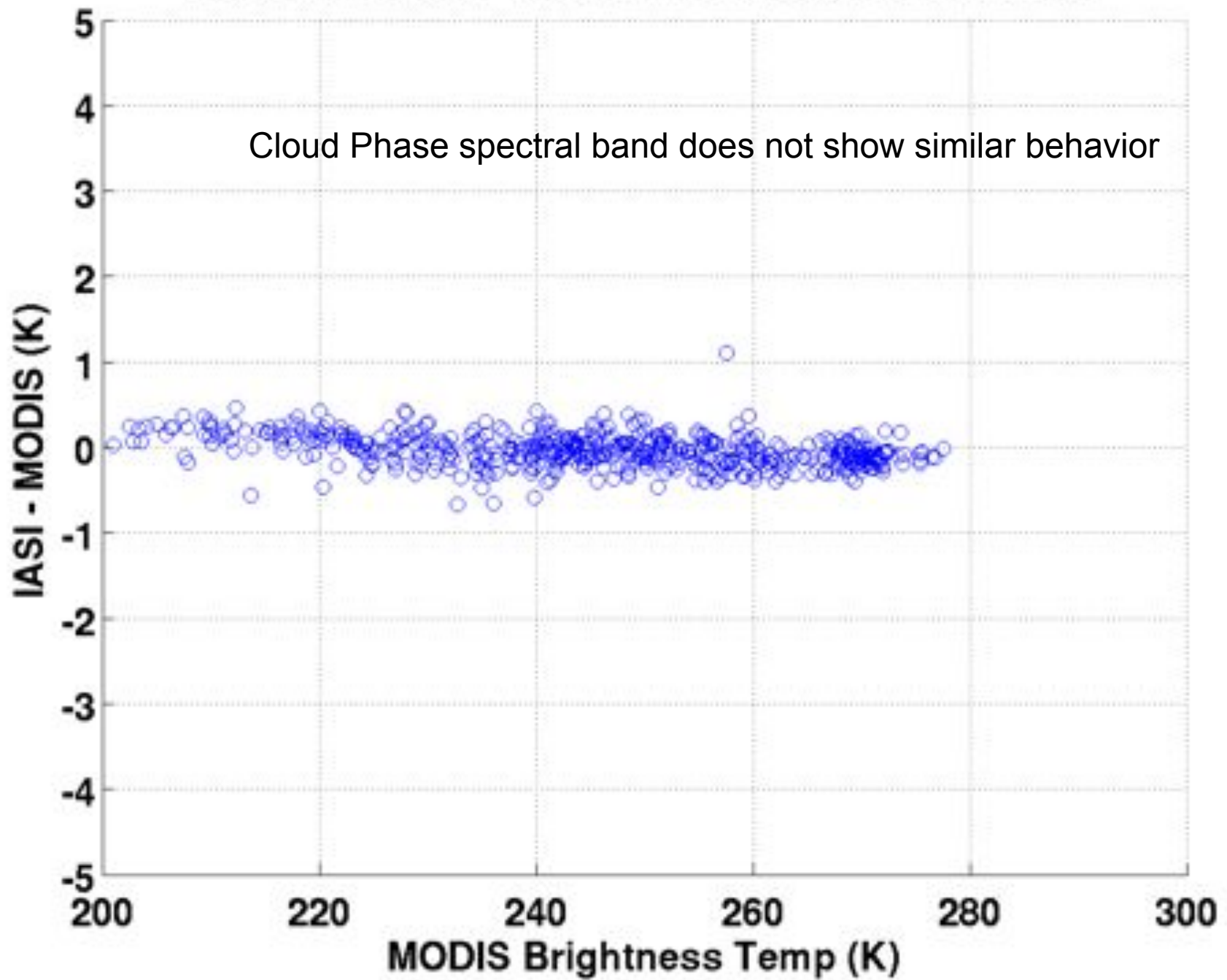
(2) Flag multi-layer cloud situations.

2009 SNOs: IASI - Aqua MODIS Band 35 Det 5 MS 1

CO2 slicing spectral bands show similar behavior

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Cloud Phase spectral band does not show similar behavior

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Cloud Phase spectral band does not show similar behavior