30 Years of HIRS Cloud Observations

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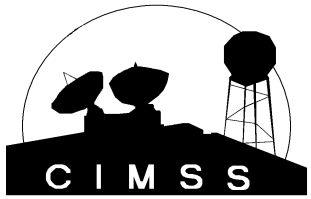
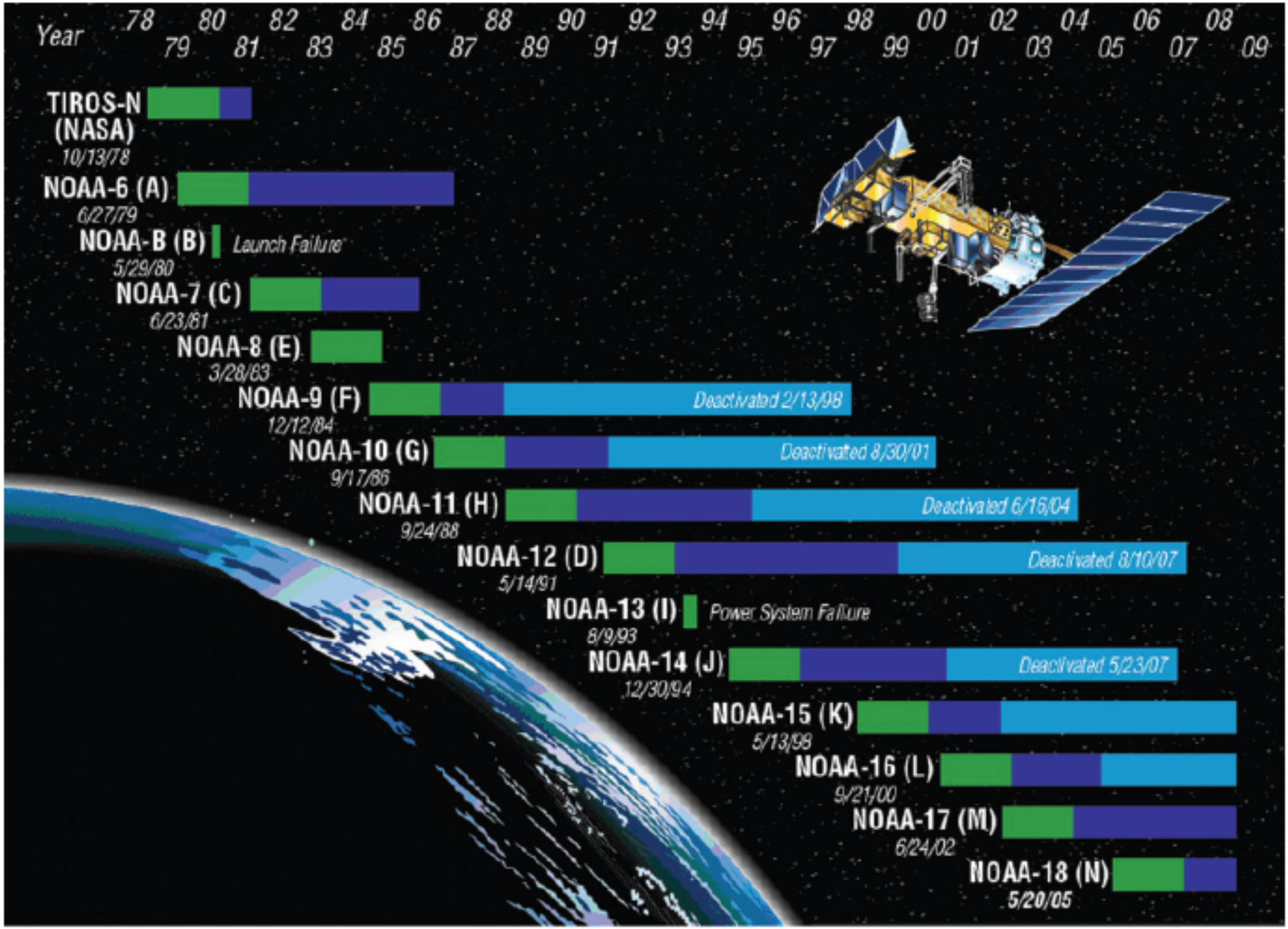


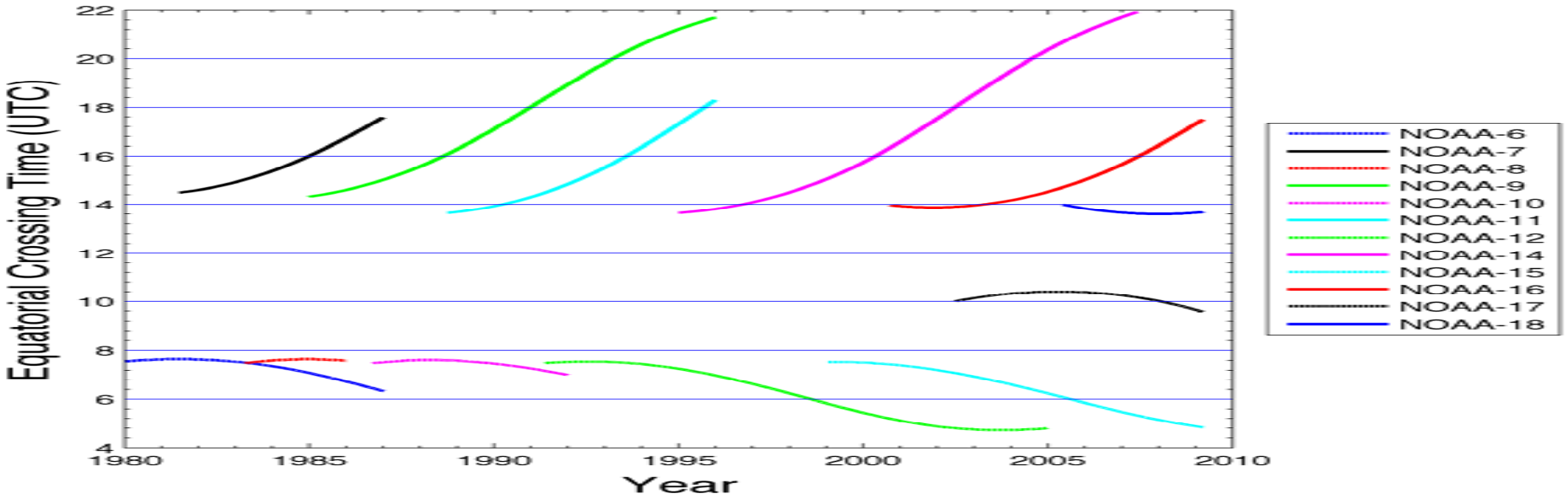
June 2010


Year
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09
TIROS-N (NASA)
10/13/78
NOAA-6 (A)
6/27/79
NOAA-B (B)
Launch Failure
5/29/80
NOAA-7 (C)
6/23/81
NOAA-8 (E)
3/28/83
NOAA-9 (F)
12/12/84
Deactivated 2/13/98
NOAA-10 (G)
9/17/86
Deactivated 8/30/01
NOAA-11 (H)
9/24/88
Deactivated 6/15/04
NOAA-12 (D)
5/14/91
Deactivated 8/10/07
NOAA-13 (I)
8/9/93
Power System Failure
NOAA-14 (J)
12/30/94
Deactivated 5/23/07
NOAA-15 (K)
5/13/98
NOAA-16 (L)
9/21/00
NOAA-17 (M)
6/24/02
NOAA-18 (N)
5/20/05
Expected 2 Year Operational Life
Expected Operational Life (Beyond 2 years)
Expected Backup Operational Life

Cloud measurements have been made from 15 HIRS sensors

morning (8 am LST)	afternoon (2 pm LST)
NOAA 6 HIRS/2	NOAA 5 HIRS
NOAA 8 HIRS/2	NOAA 7 HIRS/2
NOAA 10 HIRS/2	NOAA 9 HIRS/2
NOAA 12 HIRS/2	NOAA 11 HIRS/2I *
NOAA 15 HIRS/3	NOAA 14 HIRS/2I *
NOAA 17 HIRS/3	NOAA 16 HIRS/3
METOP HIRS/4	NOAA 18 HIRS/4 +
	NOAA 19 HIRS/4

HIRS/2I ch 10 at 12.5 um instead of prior HIRS/2 8.6 um. HIRS/3 improved S/N. Asterisk indicates orbit drift from 14 UTC to 18 UTC over 5 years of operation. HIRS/4 has 10 km FOV (improved from previous 20 km FOV). Plus indicates excessive noise in LW channels.



CTPs using CO2 Slicing

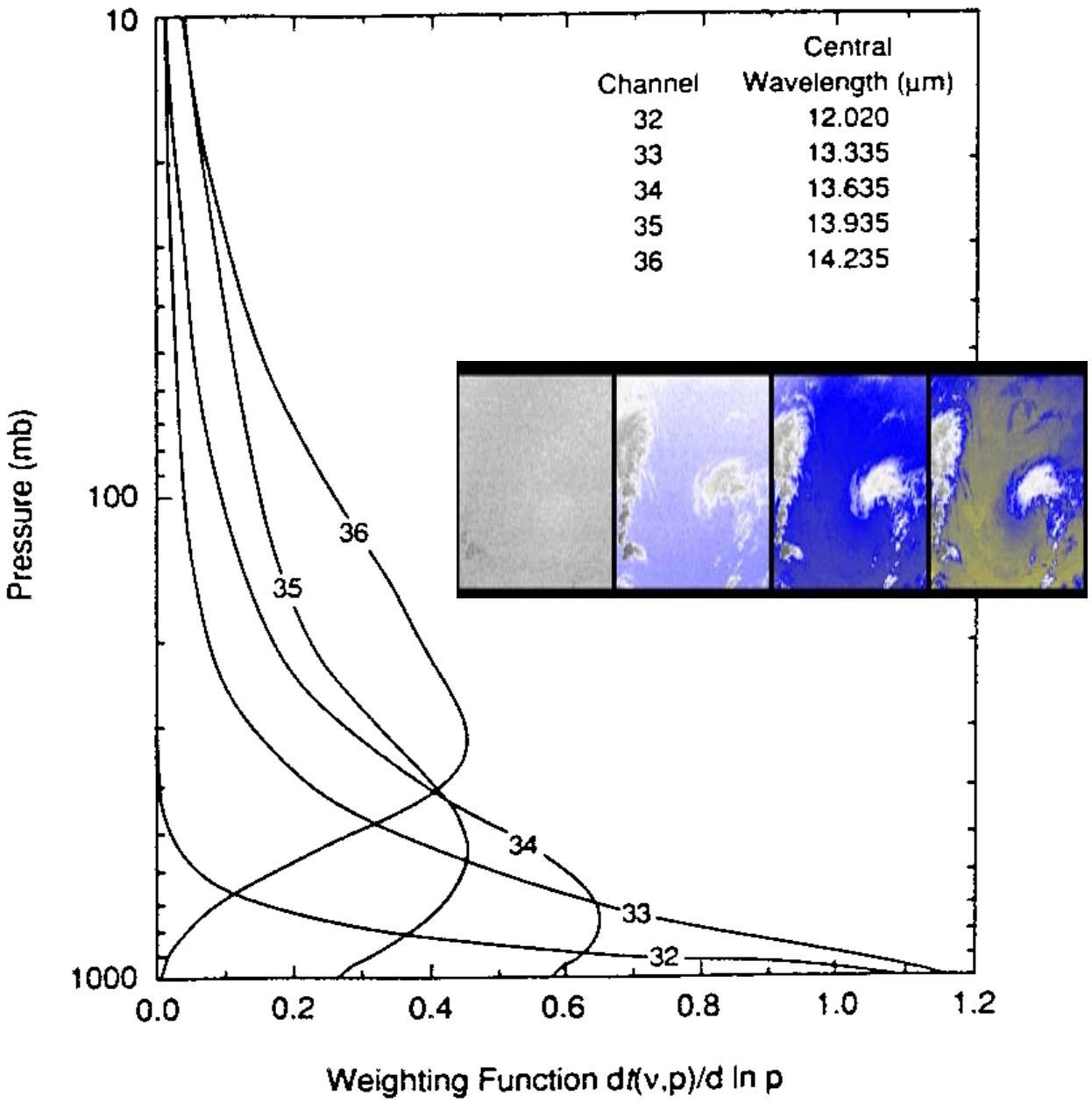
Different ratios reveal cloud properties at different levels

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

Meas **Calc**

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

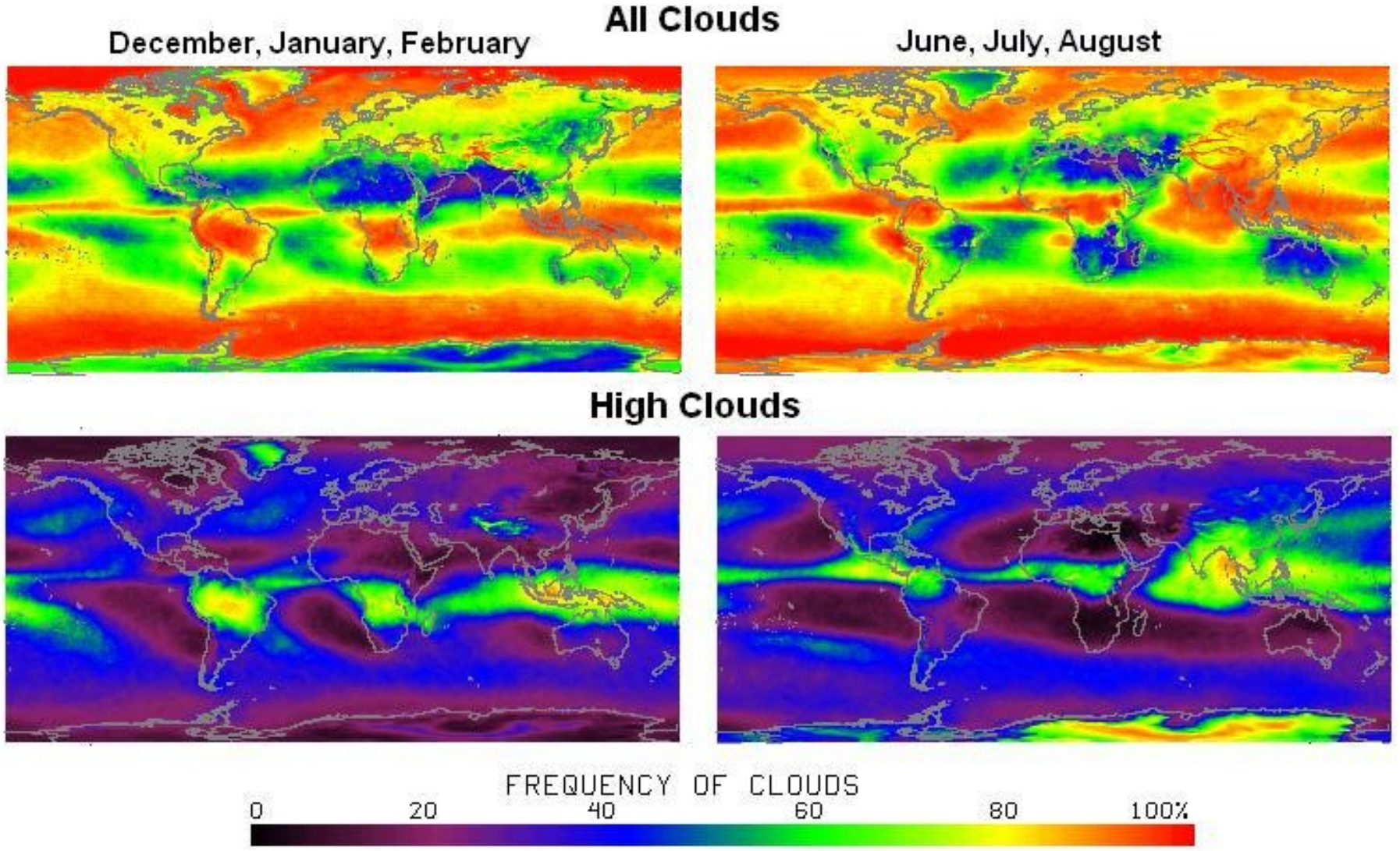
if $(I_\lambda^{clr} - I_\lambda) < \Delta$
then IRW is used



Wylie et al (2005) HIRS Results

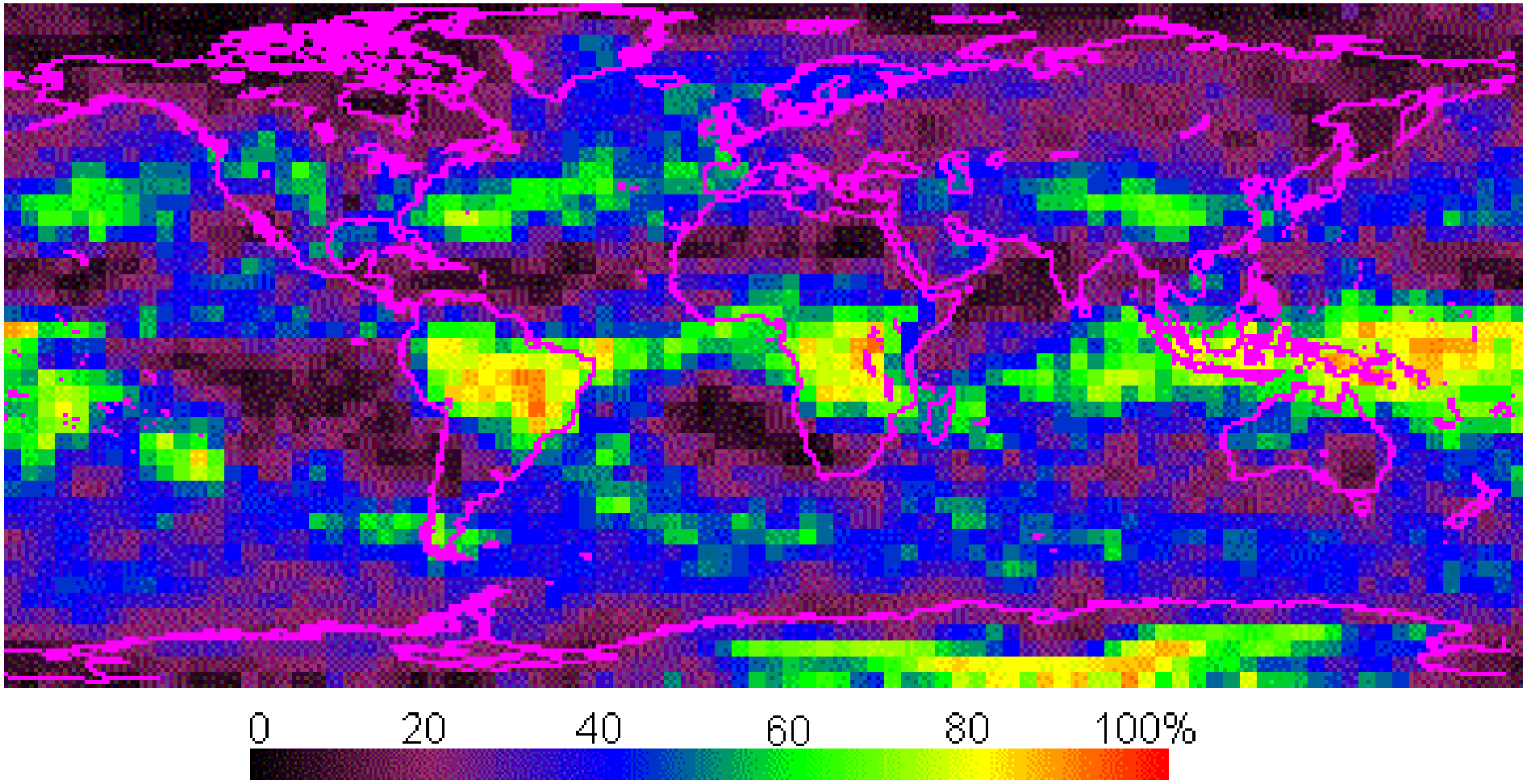
* only near nadir observations from pm orbits processed
* clear sky radiance calculated from NCEP re-analysis
* orbit drift (adjusted to 2 pm)
* constant CO2 (adjusted for 2% less high clouds in 335 ppm vs 380 ppm)

HIRS near nadir (<32 deg) Cloud Observations since 1979

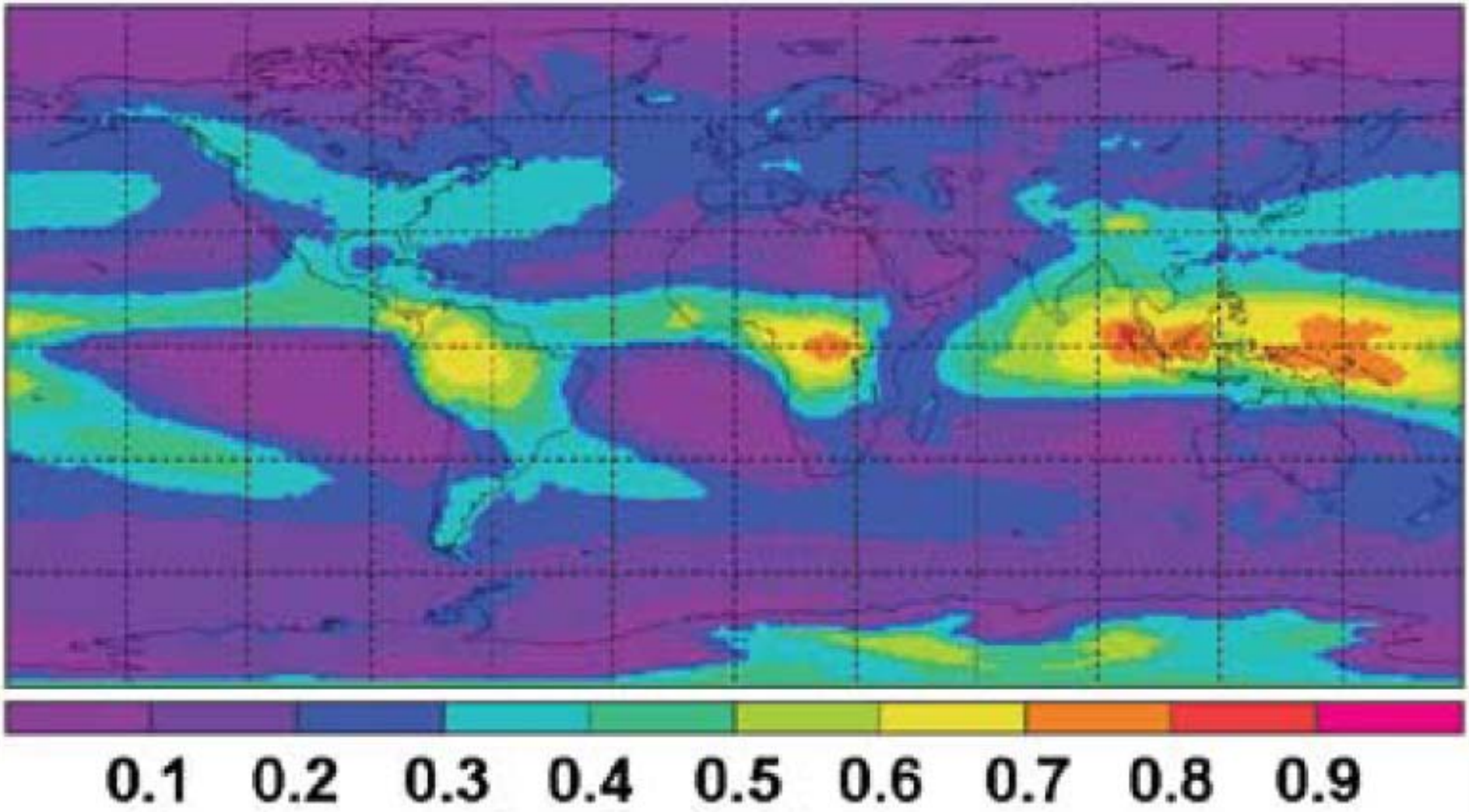


clouds are found in >75% of all observations
global preponderance of semi-transparent high clouds (>33%)
ITCZ shows high frequency of high clouds (> 50%)
more high clouds in summer hemisphere

Wylie et al,
Jour Clim, 2005



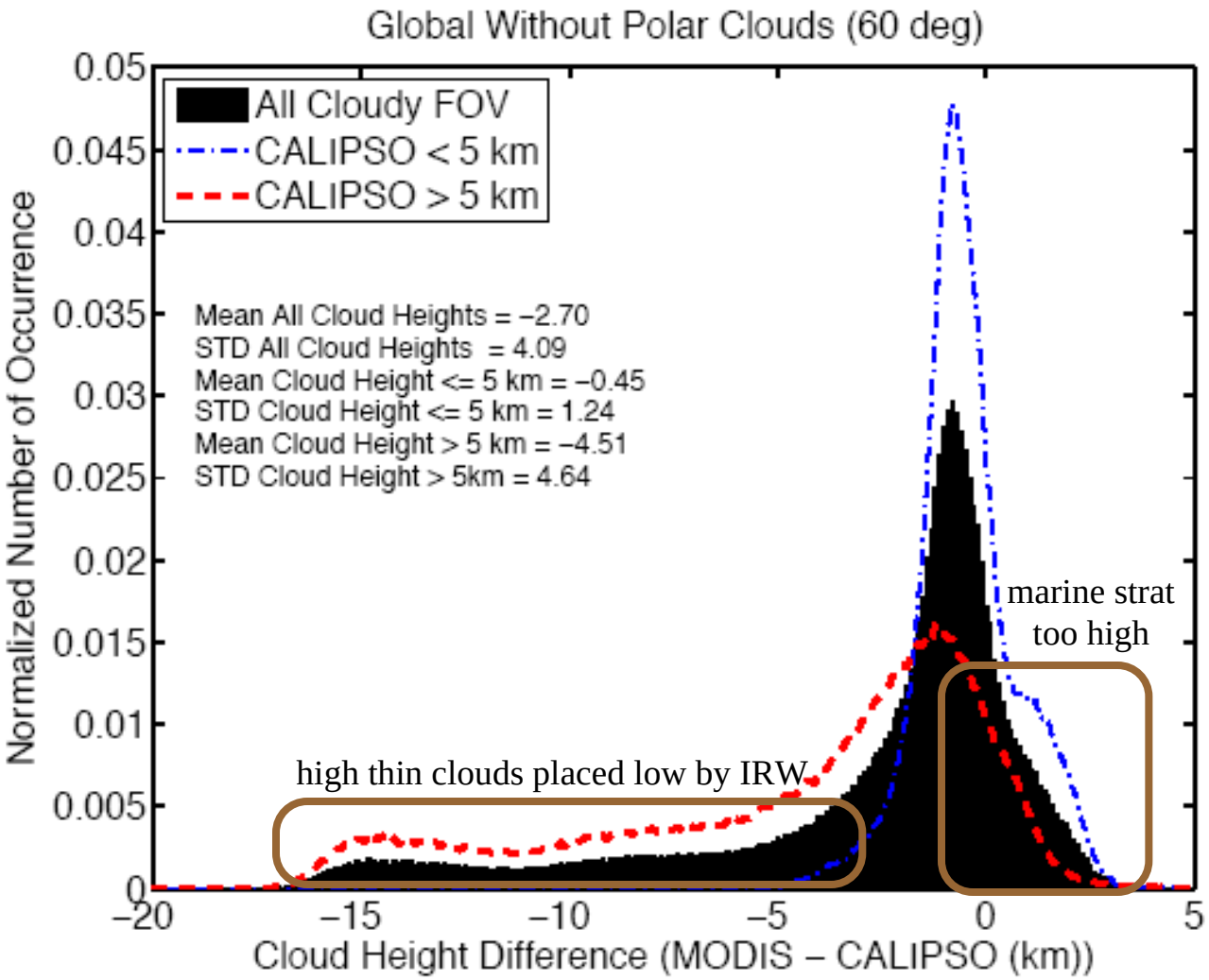
HIRS High Cloud detection over 20 years



AIRS High Cloud detection over 6 years

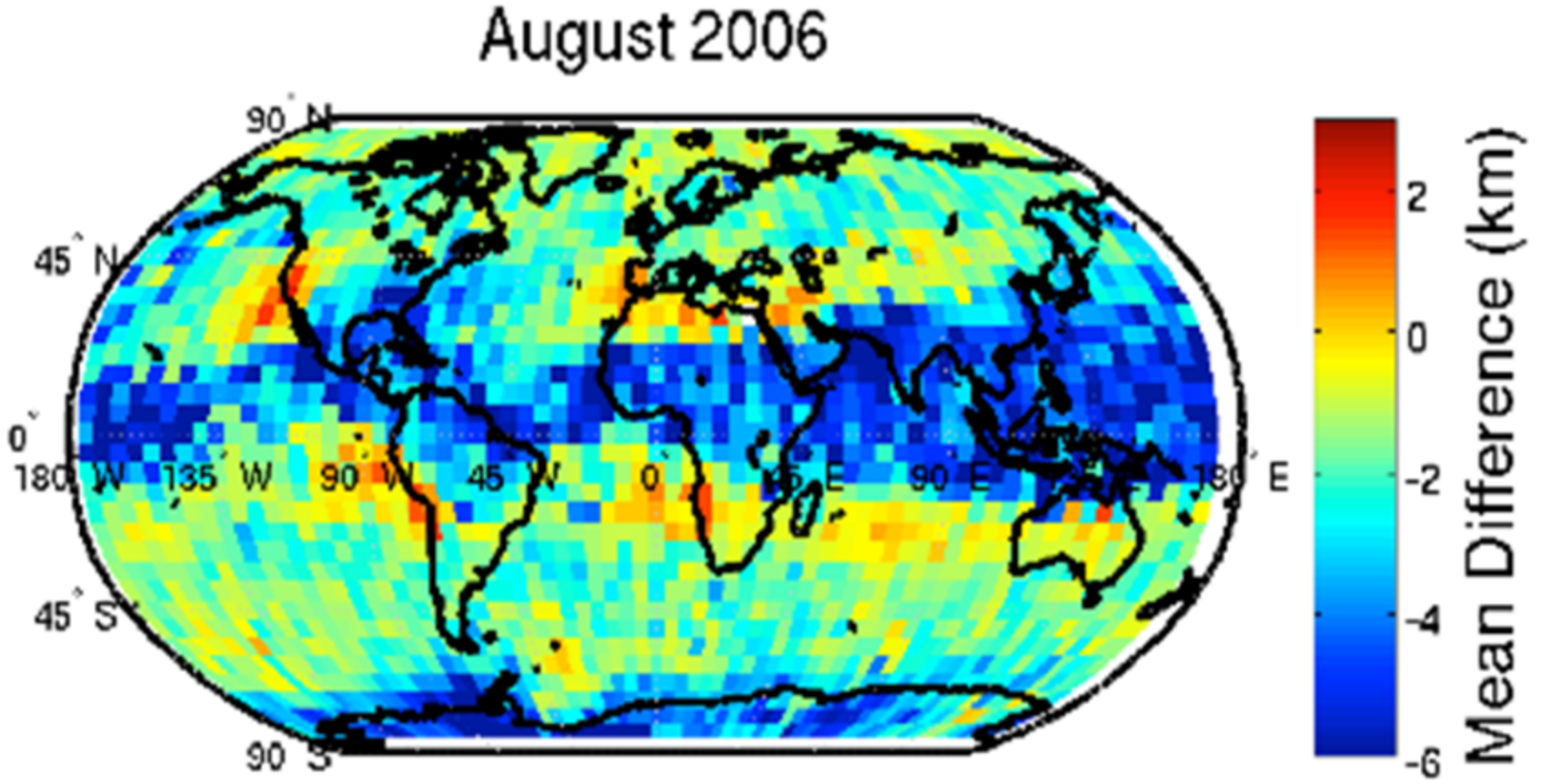
Lessons Learned from Using MODIS and CALIOP Comparisons

Compare MODIS and CALIOP Cloud Properties



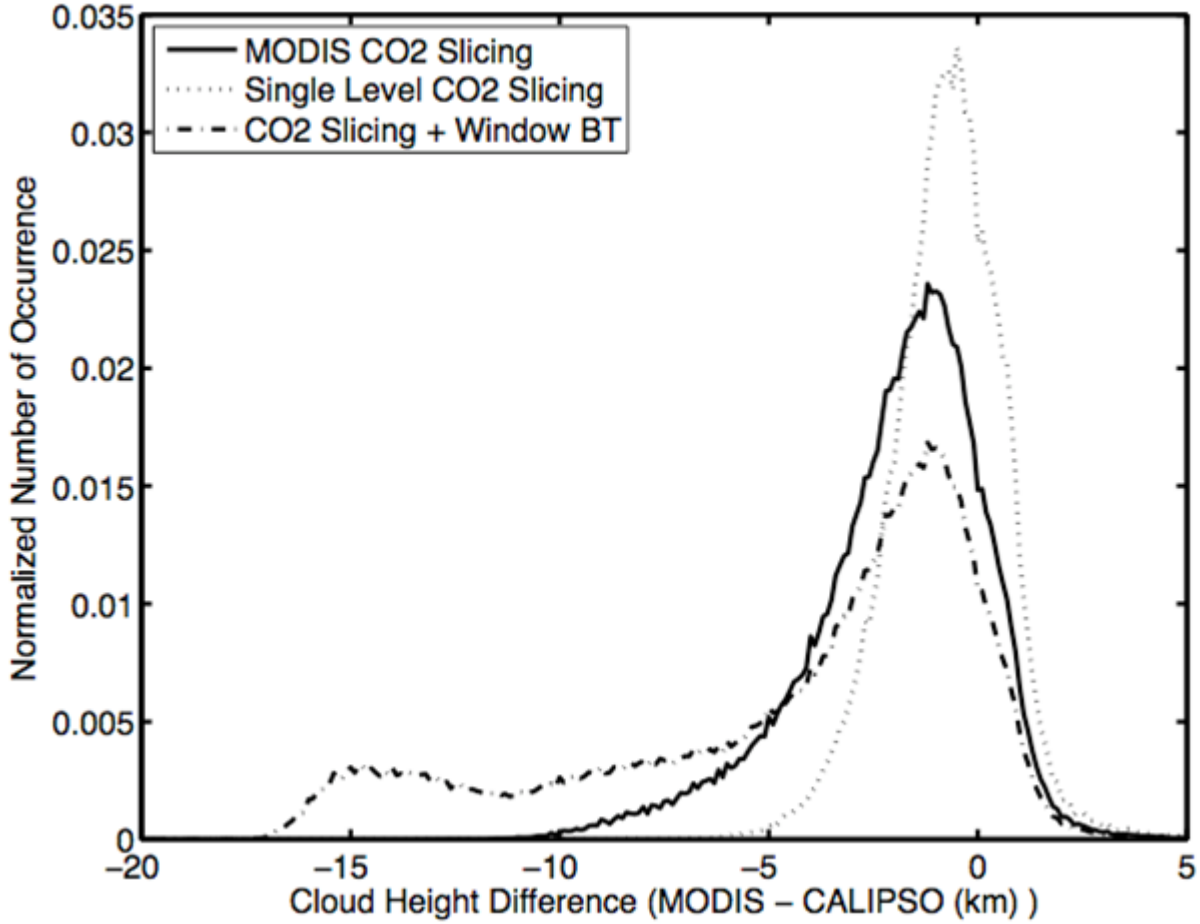
August 2006

MODIS-CALIOP CTH Differences



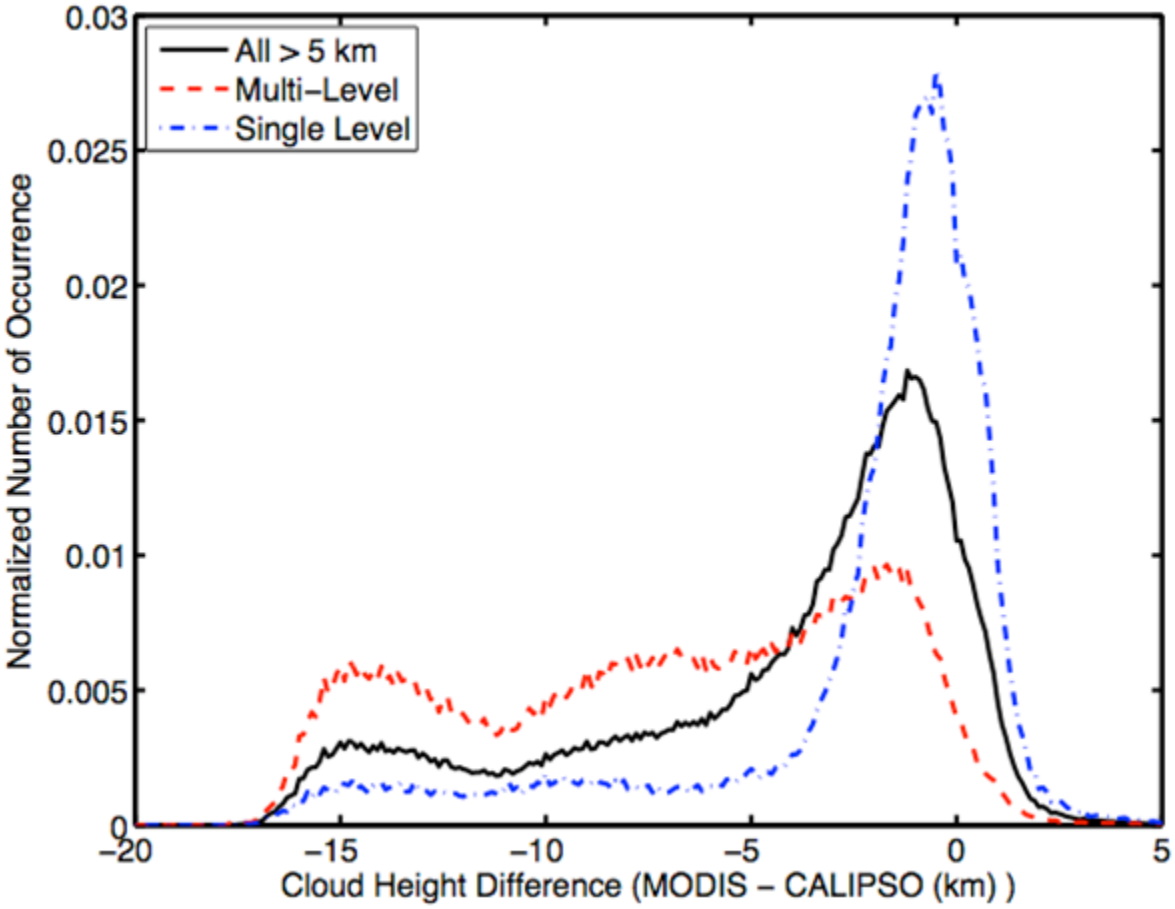
Collect 5 (described in Menzel et al (2008))

Single Level CO2 Slicing CTHs



CO2 slicing does well in single layer clouds– Holz et al (2008)

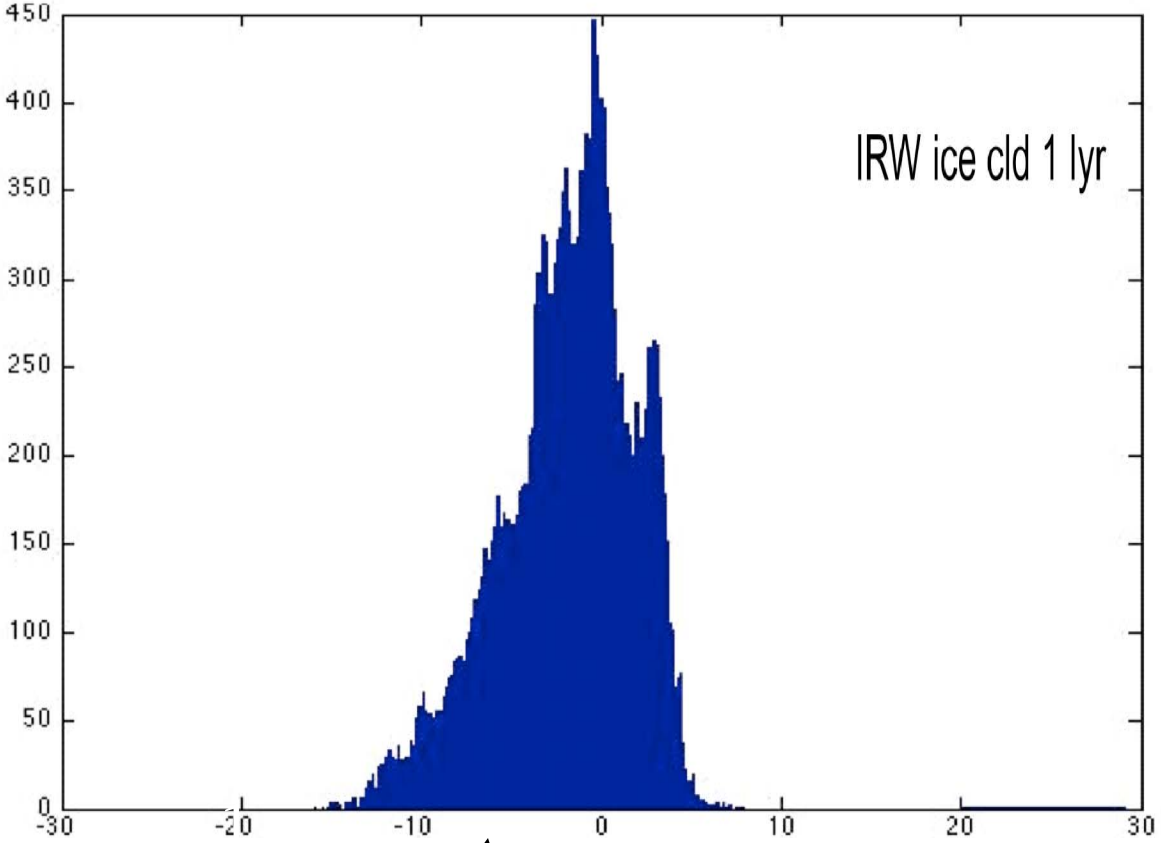
Impact of Multilevel Clouds



CO2 slicing puts CTP in between two cloud layers – Holz et al (2008)

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

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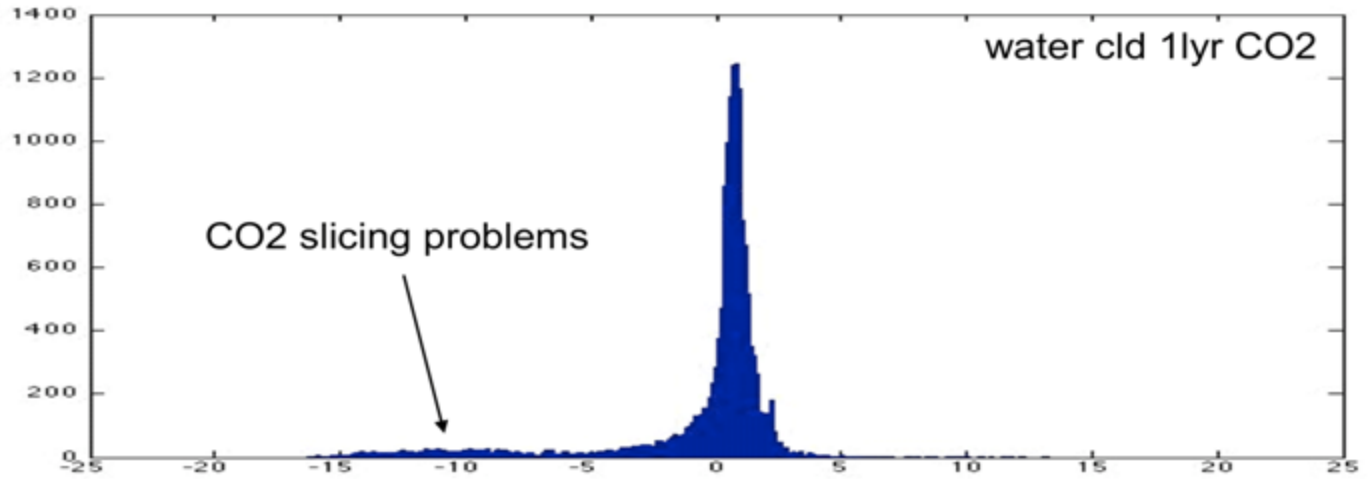
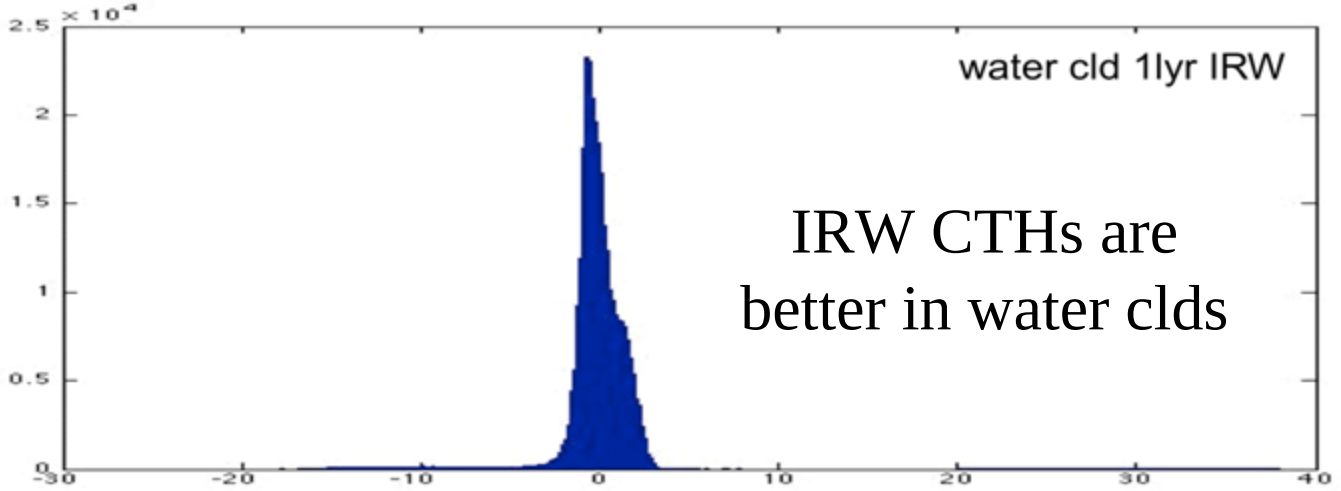


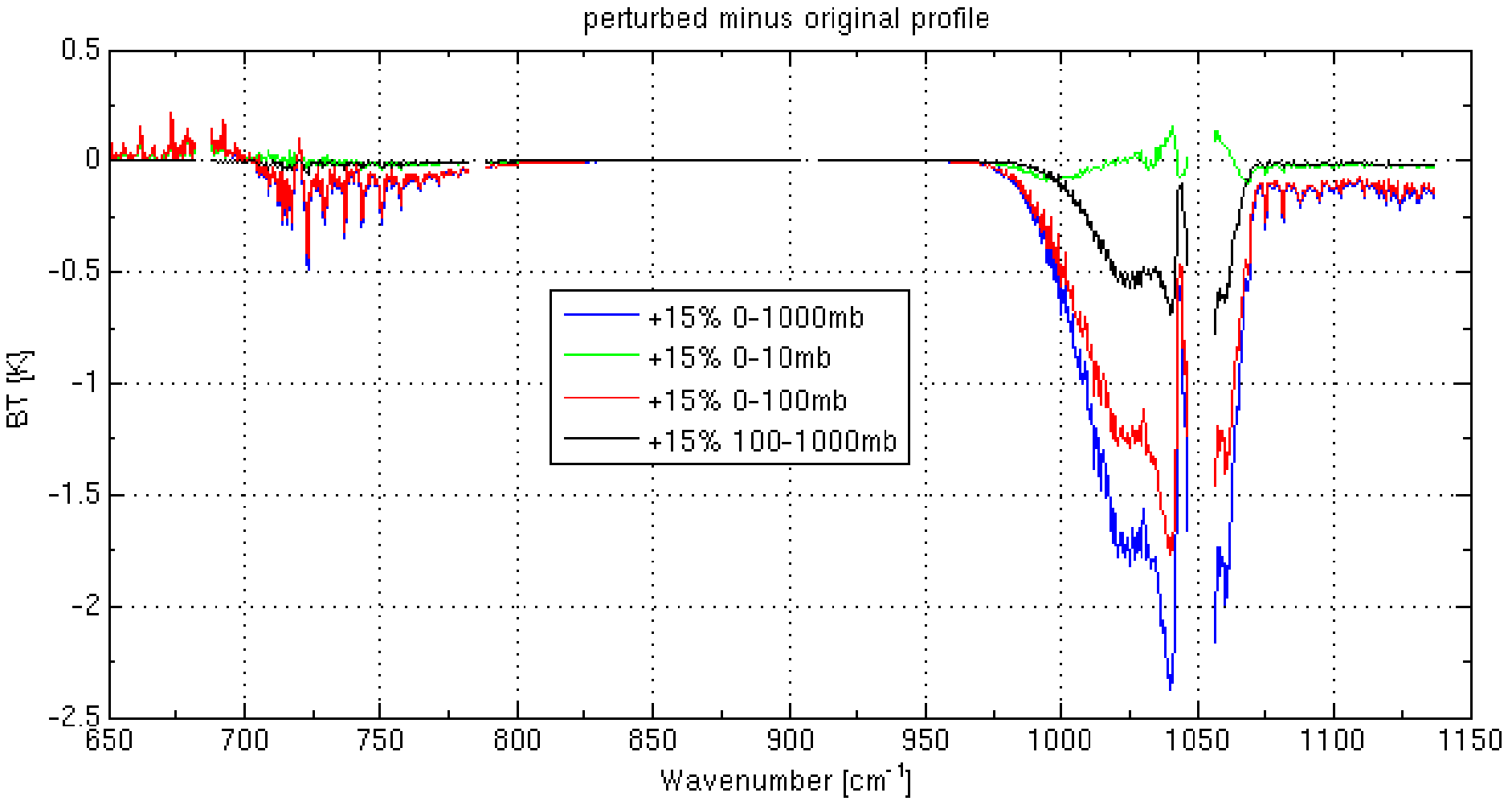
CTH MODIS - CALIOP

Number for Aug 2006

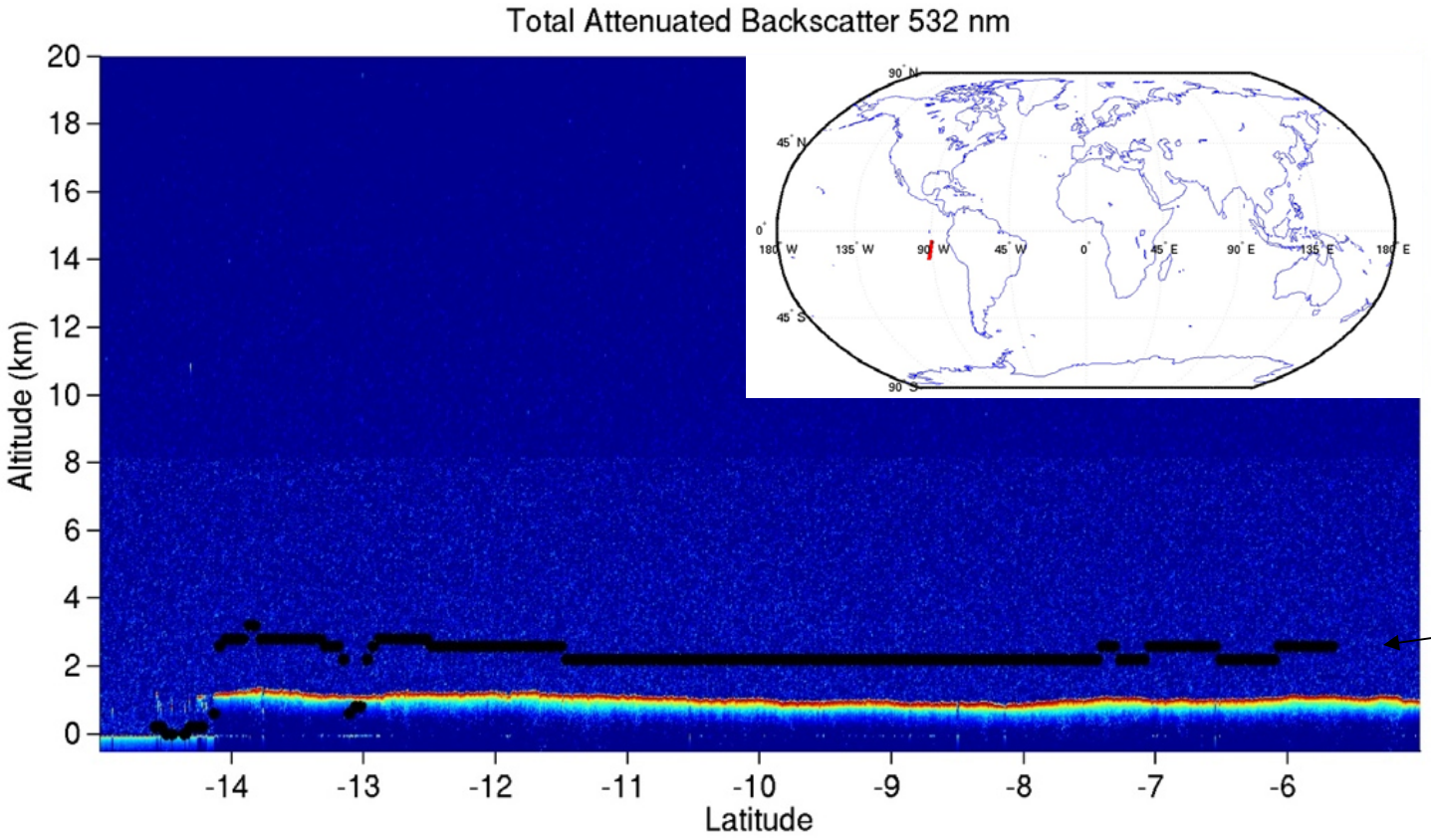


CTH MODIS - CALIOP

O3 affects CO2 bands

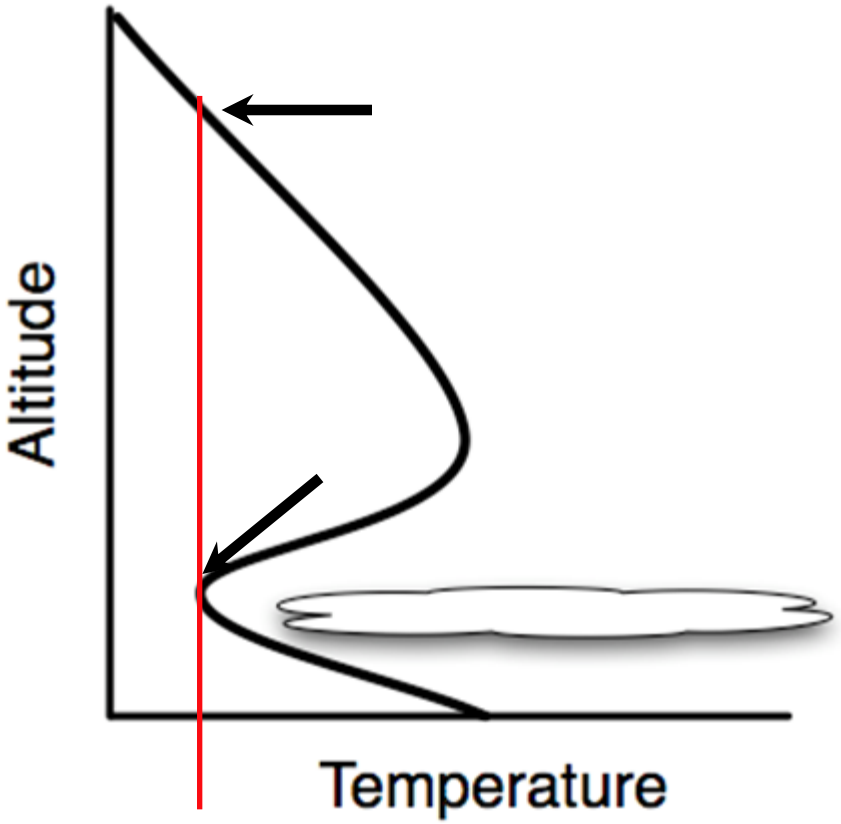


Marine Stratus CTH Over-Estimated

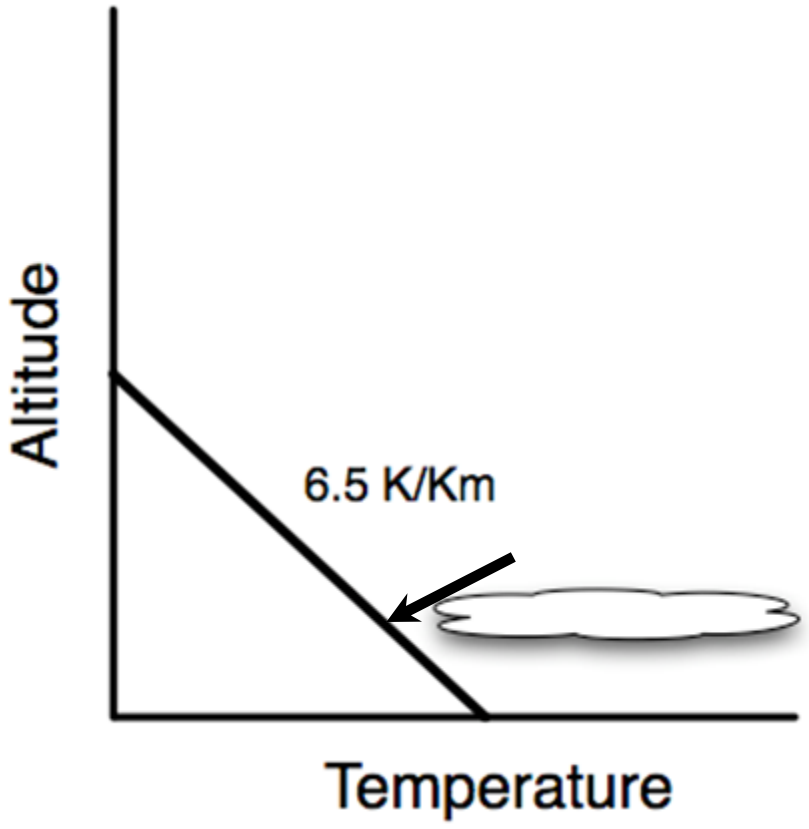


Marine Stratus Correction for Low Level Inversion

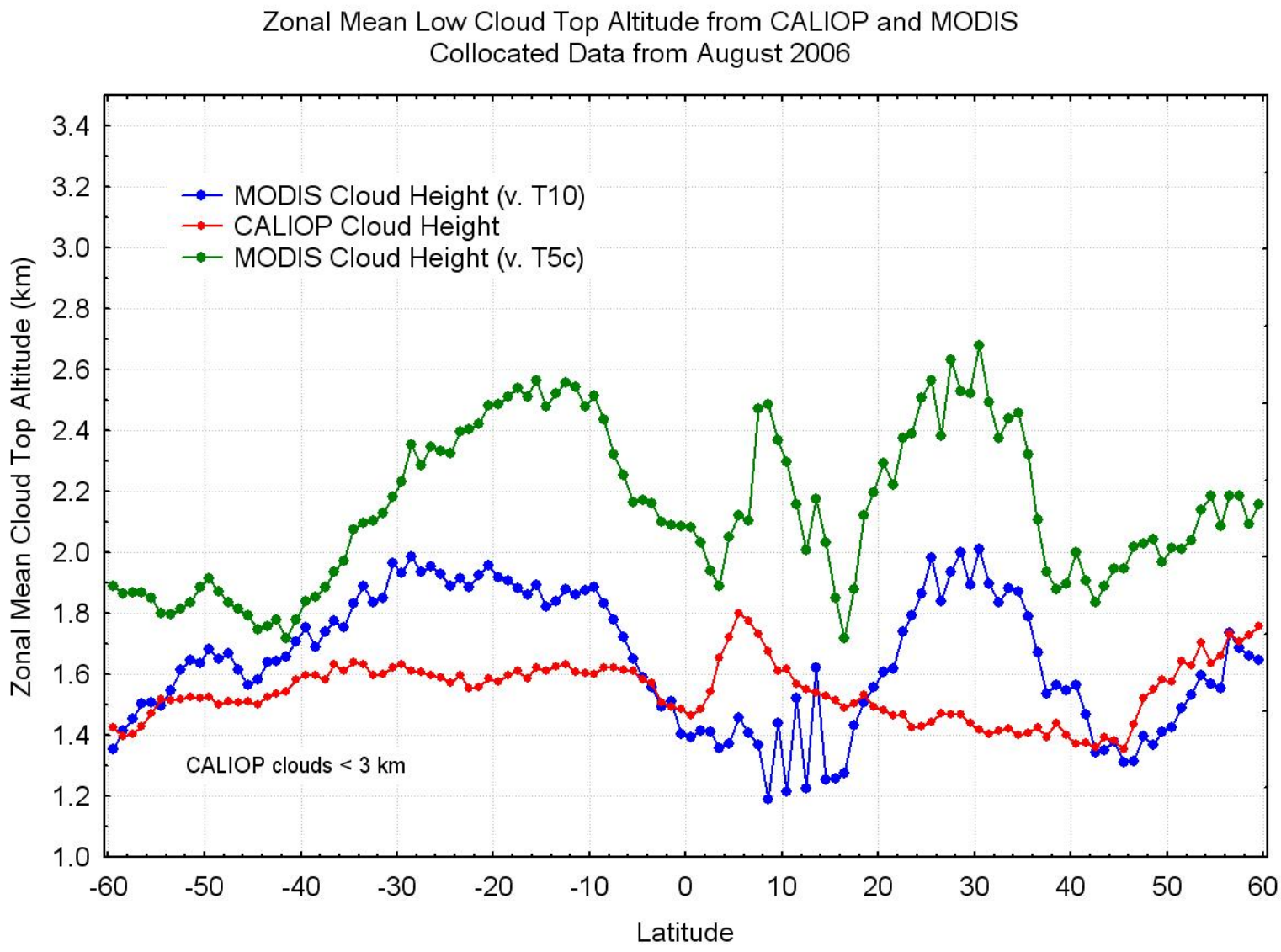
Current

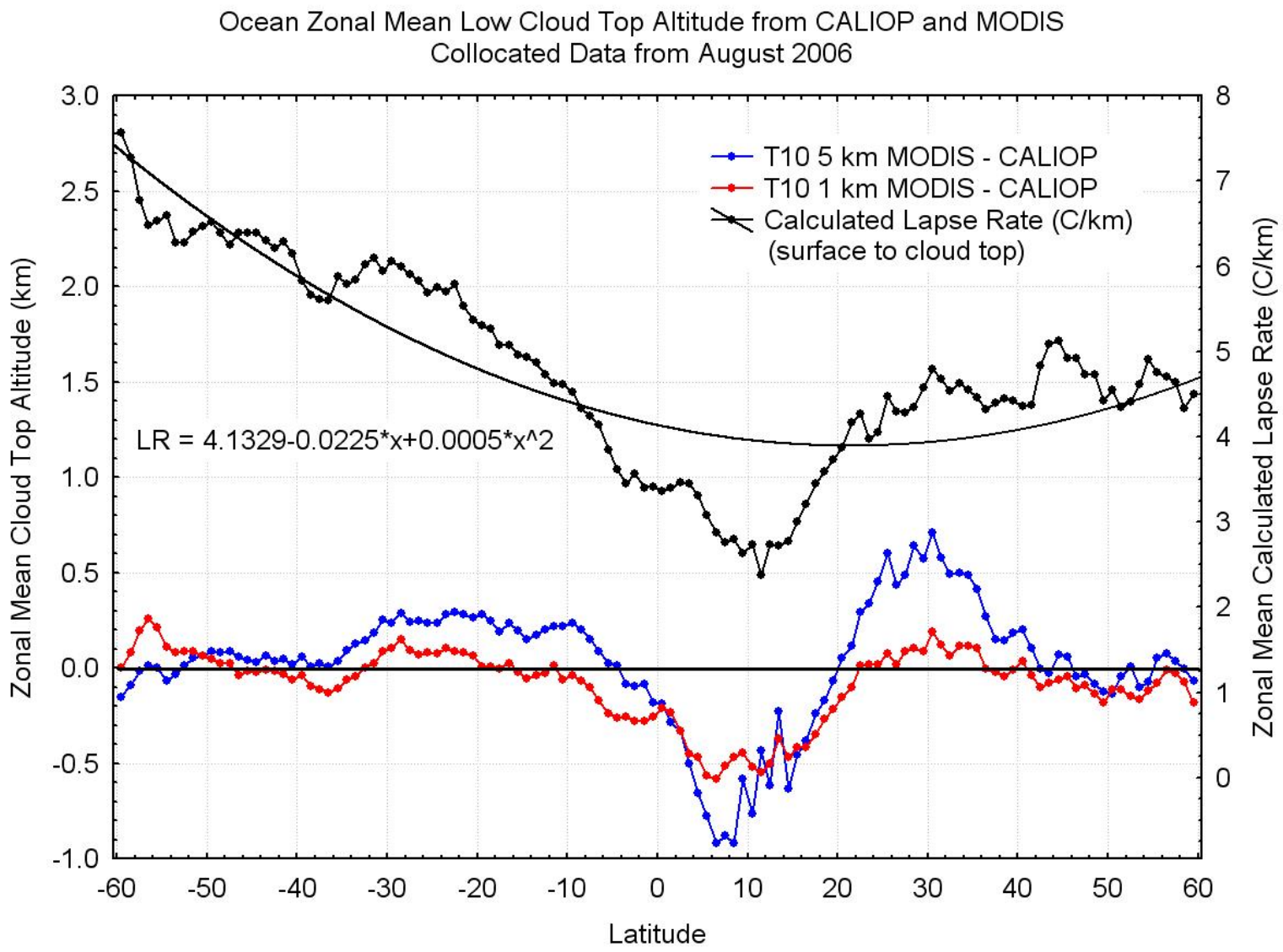


Modified (Minnis 1992)



Averaging through inversion creates 1 to 1 relation of T to p


Zonal Mean Low Cloud Top Altitude from CALIOP and MODIS
Collocated Data from August 2006
MODIS Cloud Height (v. T10)
CALIOP Cloud Height
MODIS Cloud Height (v. T5c)
CALIOP clouds < 3 km
Zonal Mean Cloud Top Altitude (km)
Latitude
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60


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

MODIS Algorithm Adjustments for Collect 6

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

B: Restrict CO2 channel pair solutions to the appropriate portion of troposphere (determined by their weighting functions – 36/35 less than 450 hPa, 35/34 less than 550 hPa, and 34/33 less than 650 hPa).

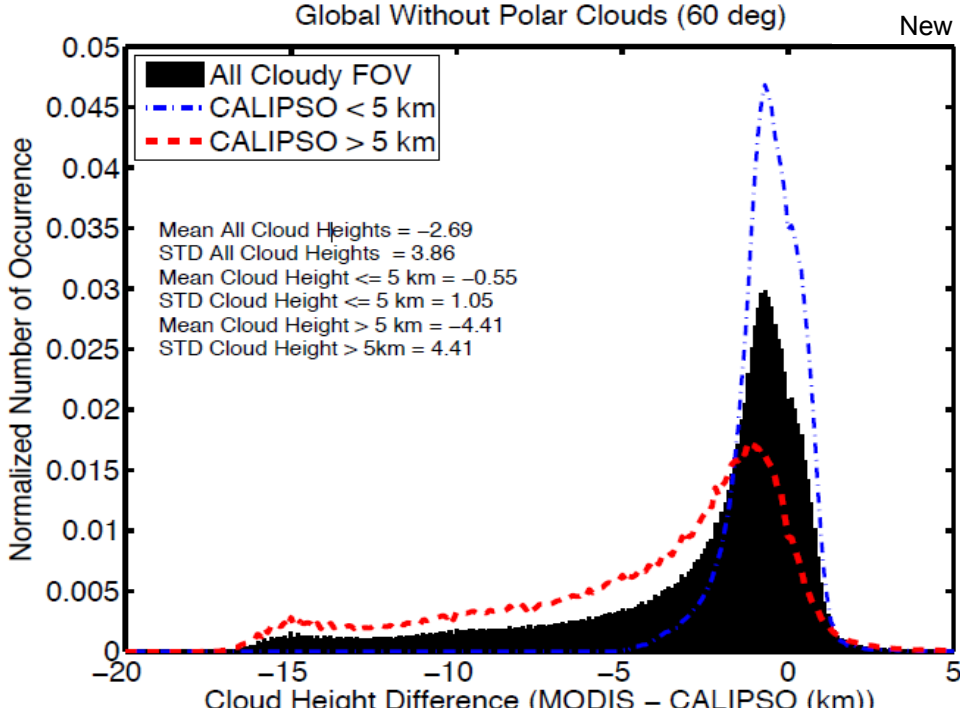
C: Prohibit CO2 slicing solutions for water clouds; use only IRW solution. Avoid IRW solutions for ice clouds; use CO2 slicing whenever possible.

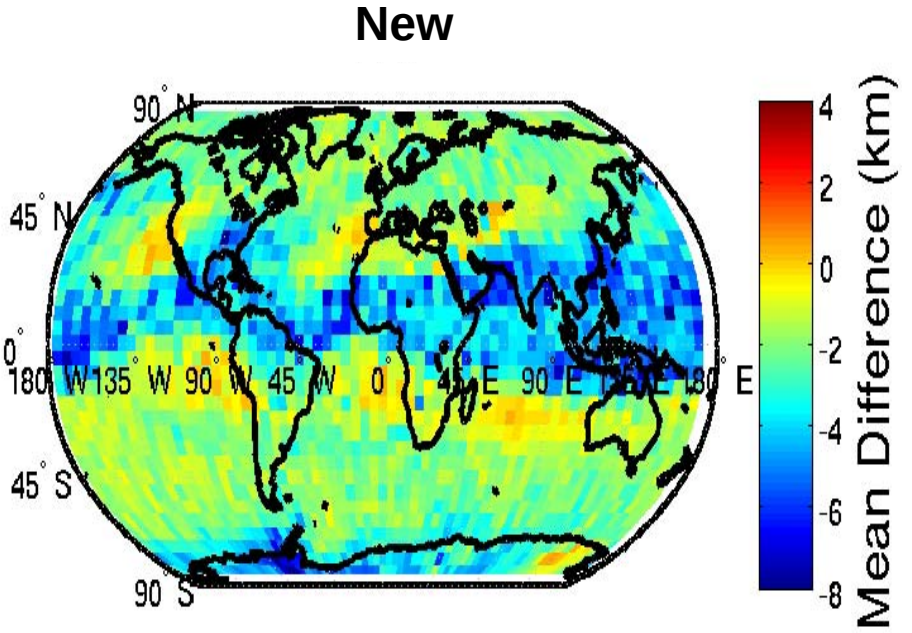
D: Lower the "noise" thresholds (clear minus cloudy radiances required to indicate cloud presence in bands 33 to 36) to force more CO2 slicing solutions for high thin clouds.

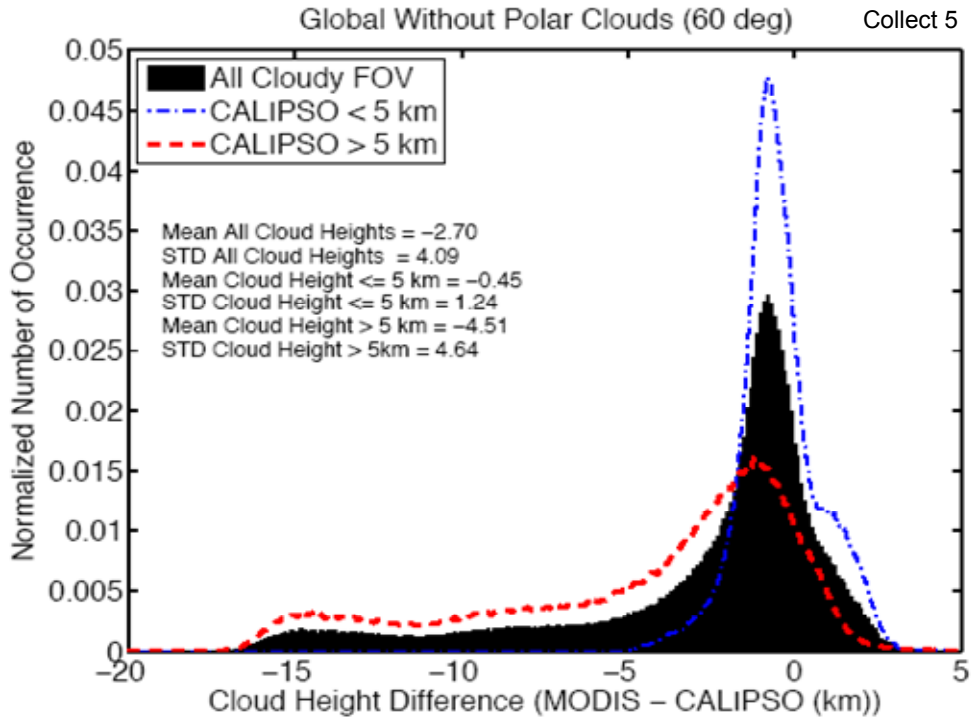
E: Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO2 radiances influenced by O3 profiles are calculated correctly).

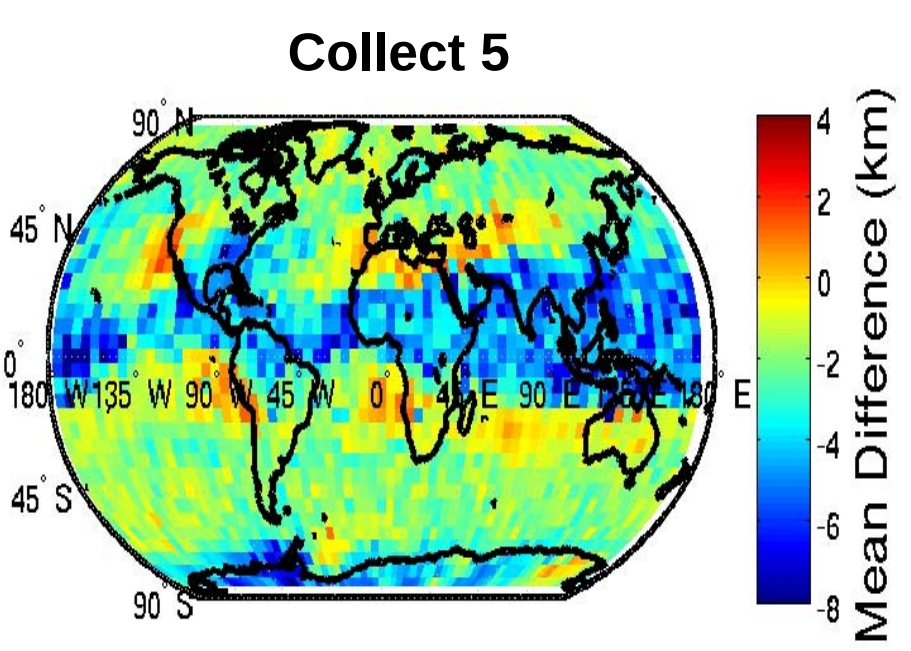
F: Implement Band 34, 35, 36 spectral shifts suggested by Tobin et al. (2005).

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


Global Without Polar Clouds (60 deg)
New
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))


New
90° N
45° N
0°
180°
W135° W 90° W 45° W 0° 45° E 90° E
45° S
90° S
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°
180°
W135° W 90° W 45° W 0° 45° E 90° E
45° S
90° S
Mean Difference (km)

Conclusions on CO2 Slicing CTH Algorithm Adjustments

- The largest cloud height differences results from not using CO2 slicing (>15 km) in high thin clouds
- Selecting the CO2 spectral band radiance ratio with a top down preference improved high cloud detection
- Reducing the cloud detection threshold produced more high thin cloud retrievals, but also produced erroneously high CO2 CTH retrievals for low water clouds in the southern Pacific
- CO2 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 are mitigated assuming a wet lapse rate
- Adjusting the spectral response of the CO2 bands reduced CTH errors
- Making multiple passes through large data sets was necessary
- Using CALIOP as a reference was incredibly valuable

HIRS CO2 Cloud Algorithm Adjustments

Adjustments to HIRS Cloud Processing

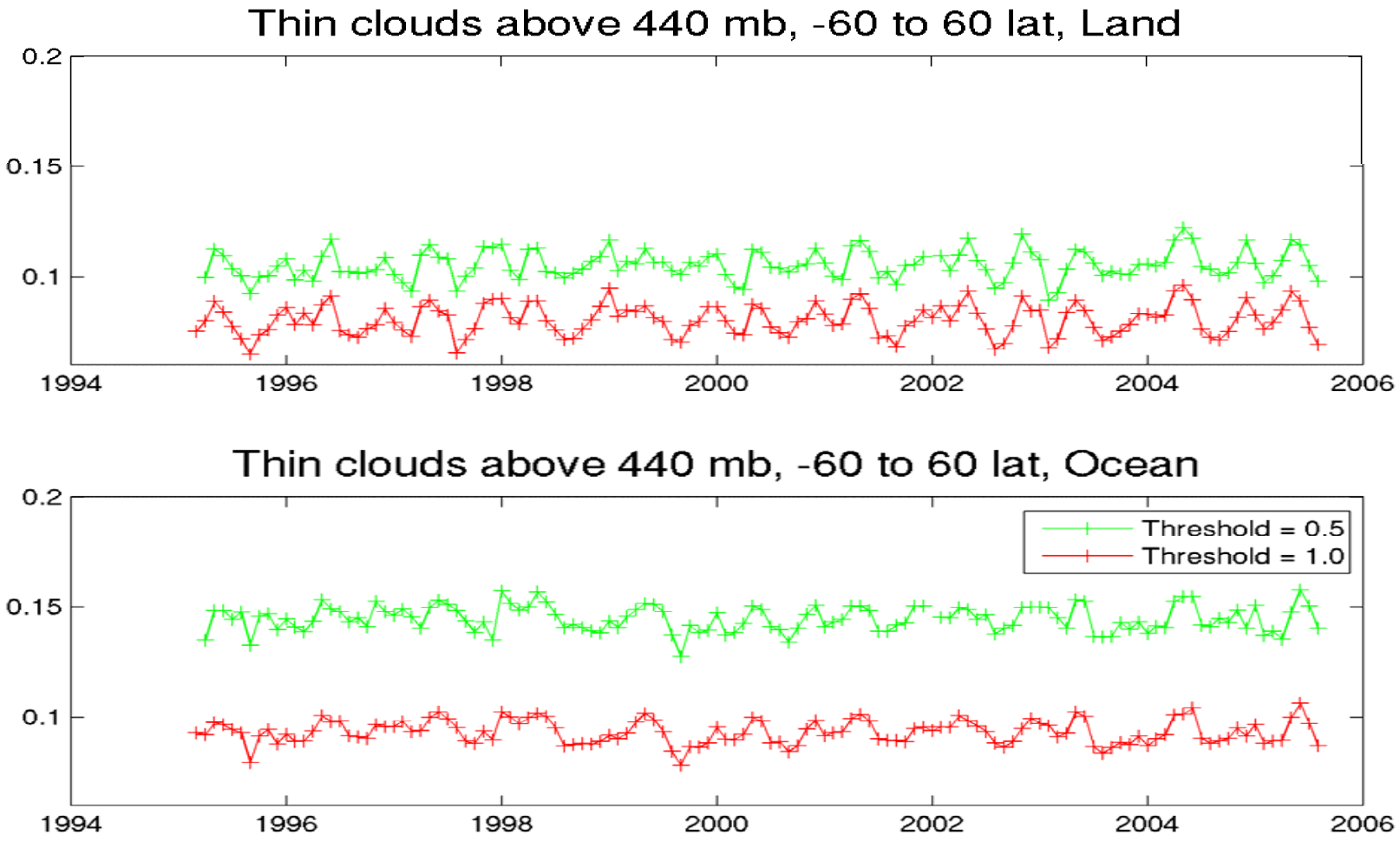
Done

- Use "top-down" method where most opaque channel pair seeing cloud derives CTP
- **Lower the "noise" thresholds** (clear minus cloudy radiances required to indicate cloud presence in CO2 bands) to force more CO2 slicing solutions for high thin clouds.
- Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO2 radiances influenced by O3 profiles are calculated correctly).
- **Implement CO2 spectral band shifts** suggested by comparisons with AIRS
- **Identify stratospheric clouds** when opaque band is warmer than less opaque band
- **Incorporate sinusoidal CO2 increase**

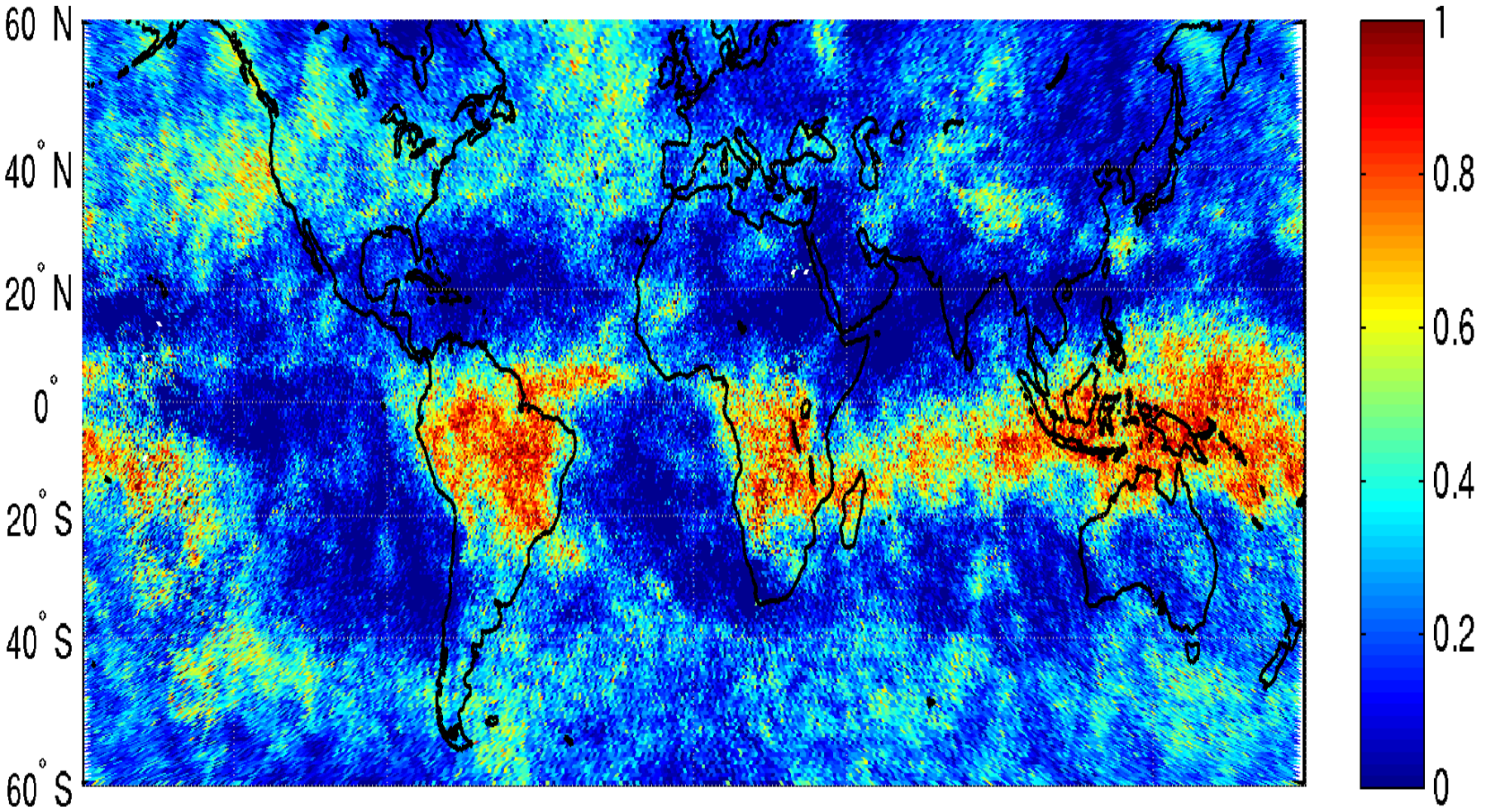
Pending

- Prohibit CO2 slicing solutions for water clouds; use only IRW solution. Avoid IRW solutions for ice clouds; use CO2 slicing whenever possible.
- Restrict CO2 channel pair solutions to appropriate portion of troposphere (determined by their weighting functions).
- Add marine stratus improvement (constant lapse rate in low level inversions)

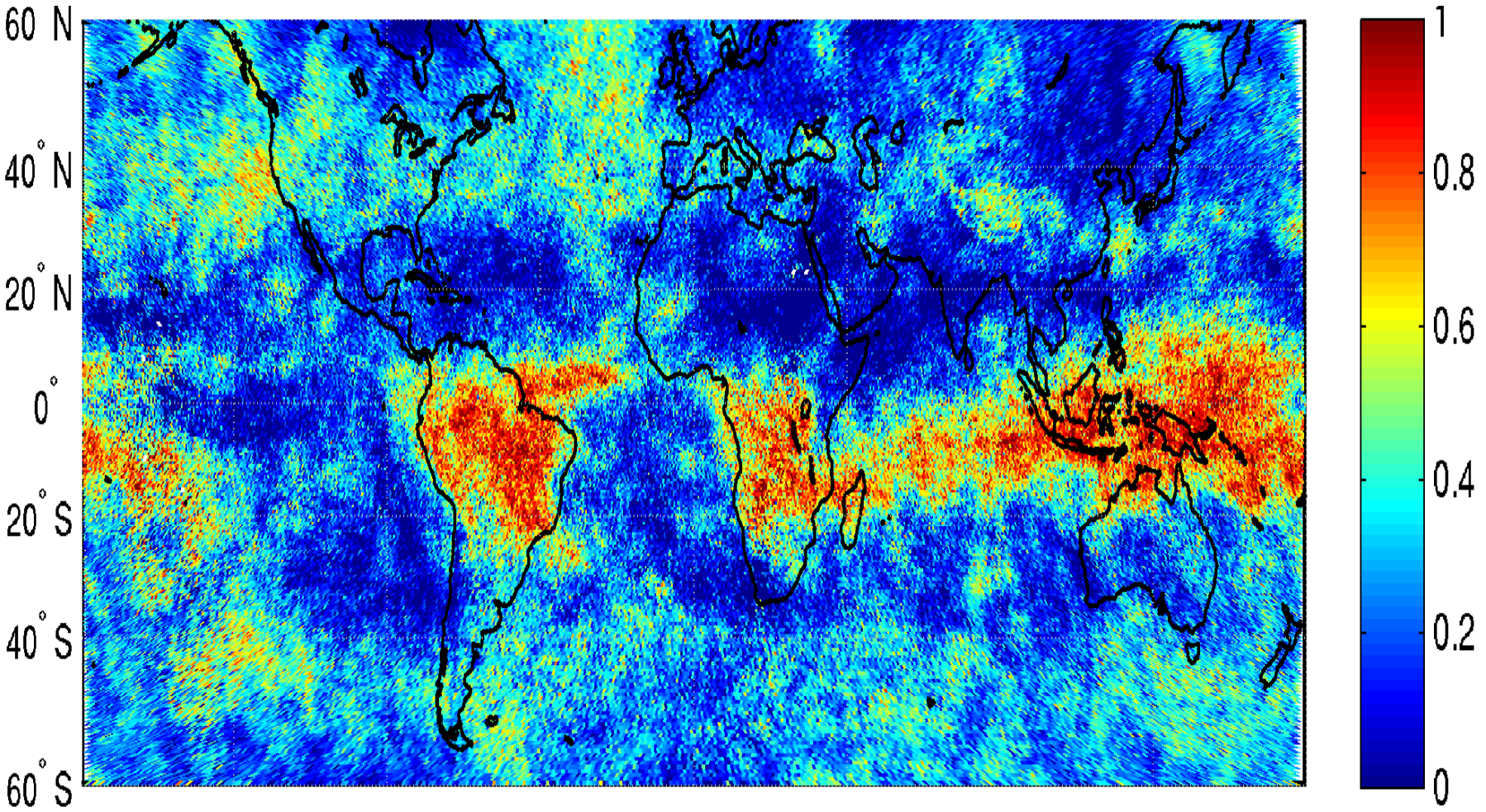
Changing Cloud Detection Threshold



About 5 % of low opaque clouds are correctly defined as high thin clouds when [Rclear – Rcloud] > NEDR threshold is changed from 1.0 to 0.5 mW/m2/ster/cm-1



January 1997 NOAA-14 % of High Cloud Observations NEDR=1.0

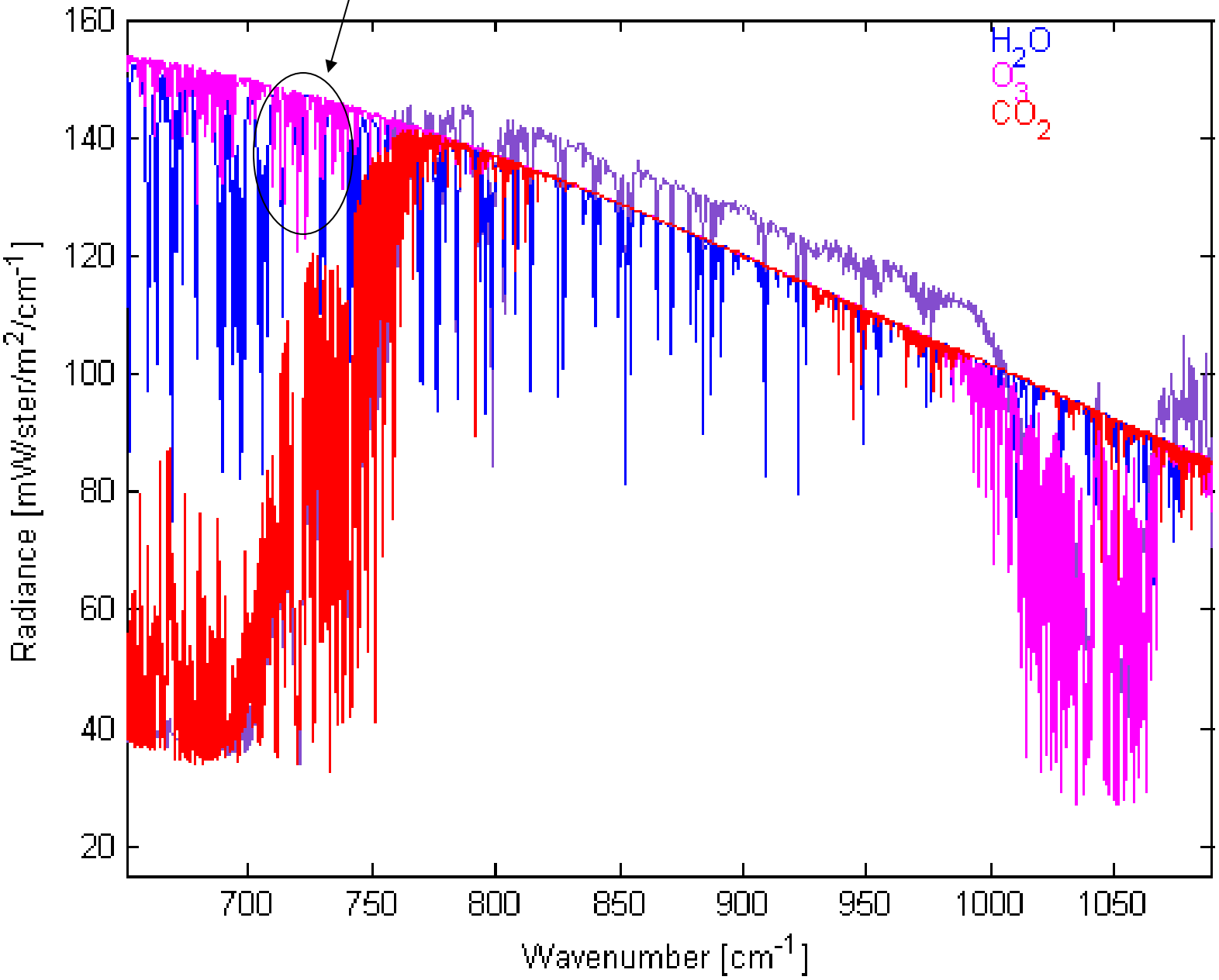


January 1997 NOAA-14 % of High Cloud Observations NEDR=0.5

HIRS global cloud statistics for Jul 1997
60N to 60S over ocean
NEDR=1.0 and 0.5 mW/m2/ster/cm-1

	All Clouds	Thin Clouds NE<0.5	Thick Clouds	Opaque Clouds NE>0.95
IR Optical Depth	0.1<	<0.7	<3	>3
High (<440 hPa)	36 (40)	19 (23)	16 (16)	1 (1)
Mid (440 → 680 hPa)	12 (13)	5 (7)	5 (5)	2 (1)
Low (>680 hPa)	38 (32)	1 (1)	2 (2)	35 (29)
All Clouds	84 (84)	25 (31)	23 (23)	38 (31) %

O3 profile affects CO2 radiances



CO2 Ramp

$F(x) = [\, m\, x + a*\sin(2\pi x/365)] + b$

where

x = # days since 1 Jan 1980

m = 1.5 ppmv / 365

b = 337.5 ppmv

a = 3 ppmv

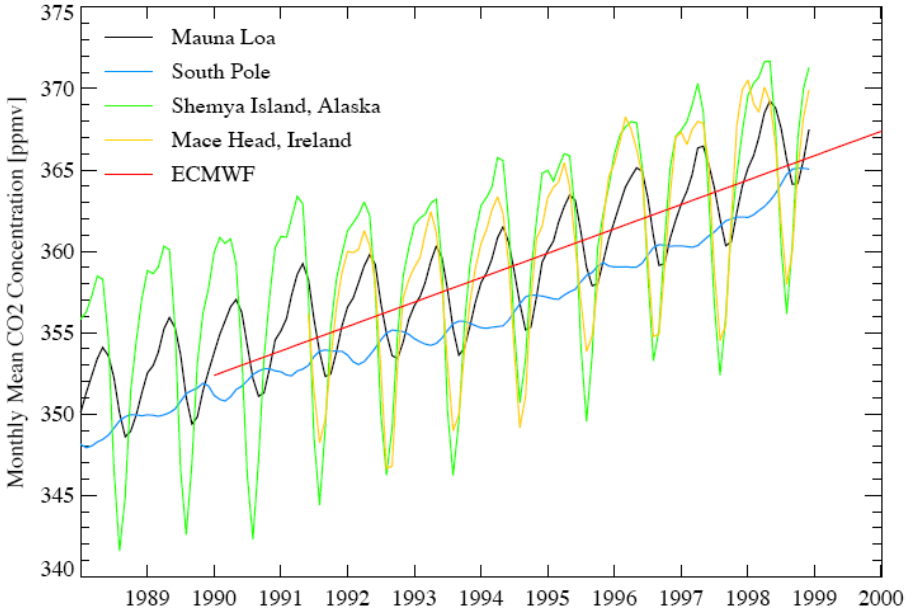
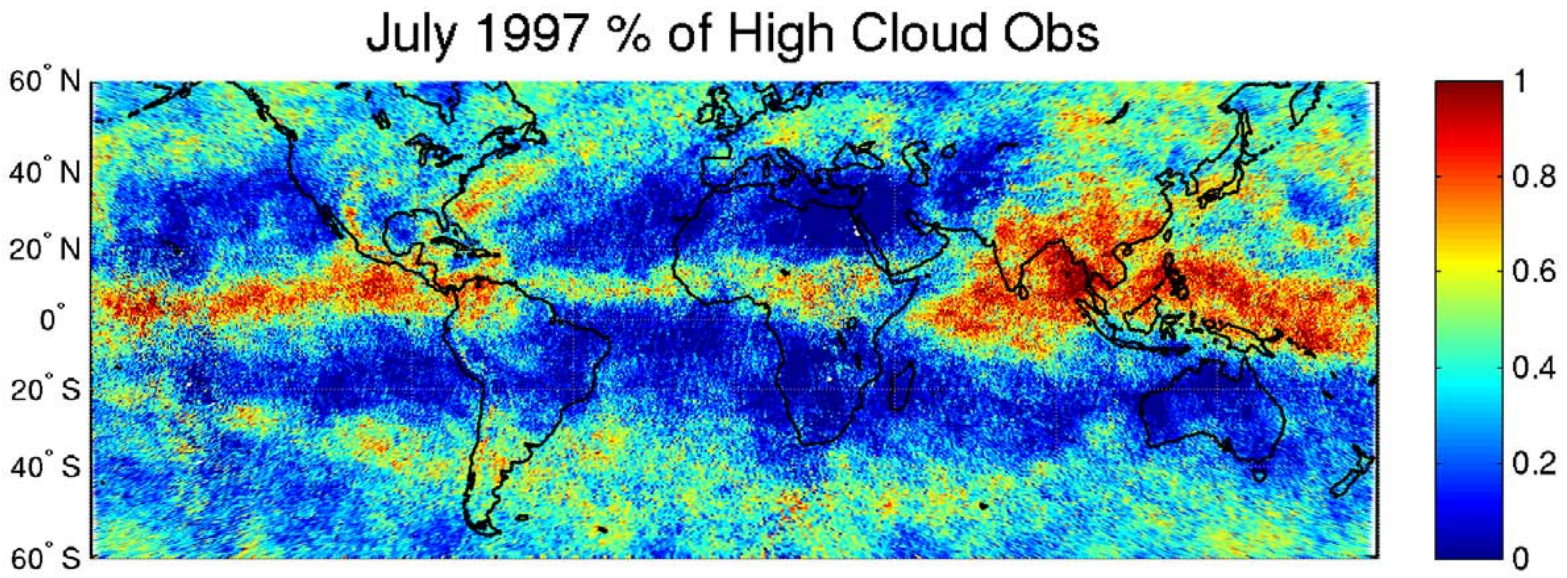
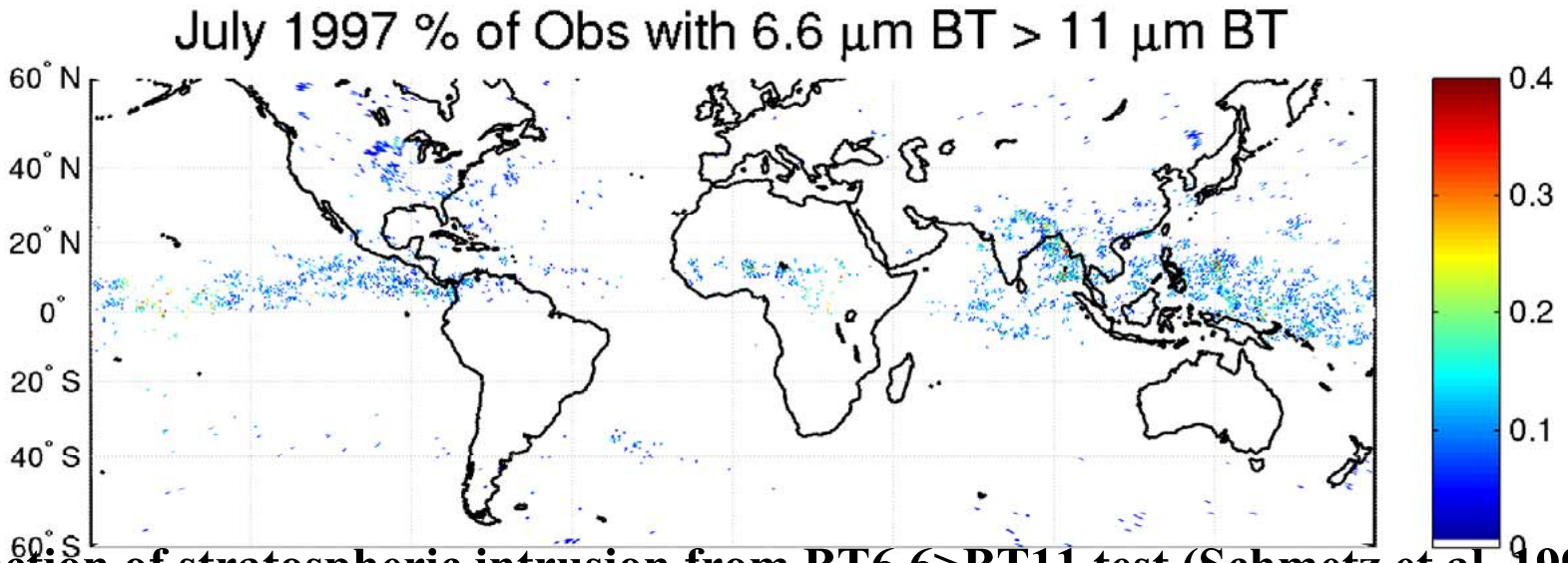


Figure 1. Time series of monthly mean surface CO_2 volume mixing ratios for 4 flask stations. The red line represents the values used by ECMWF. From Engelen et al (2001)

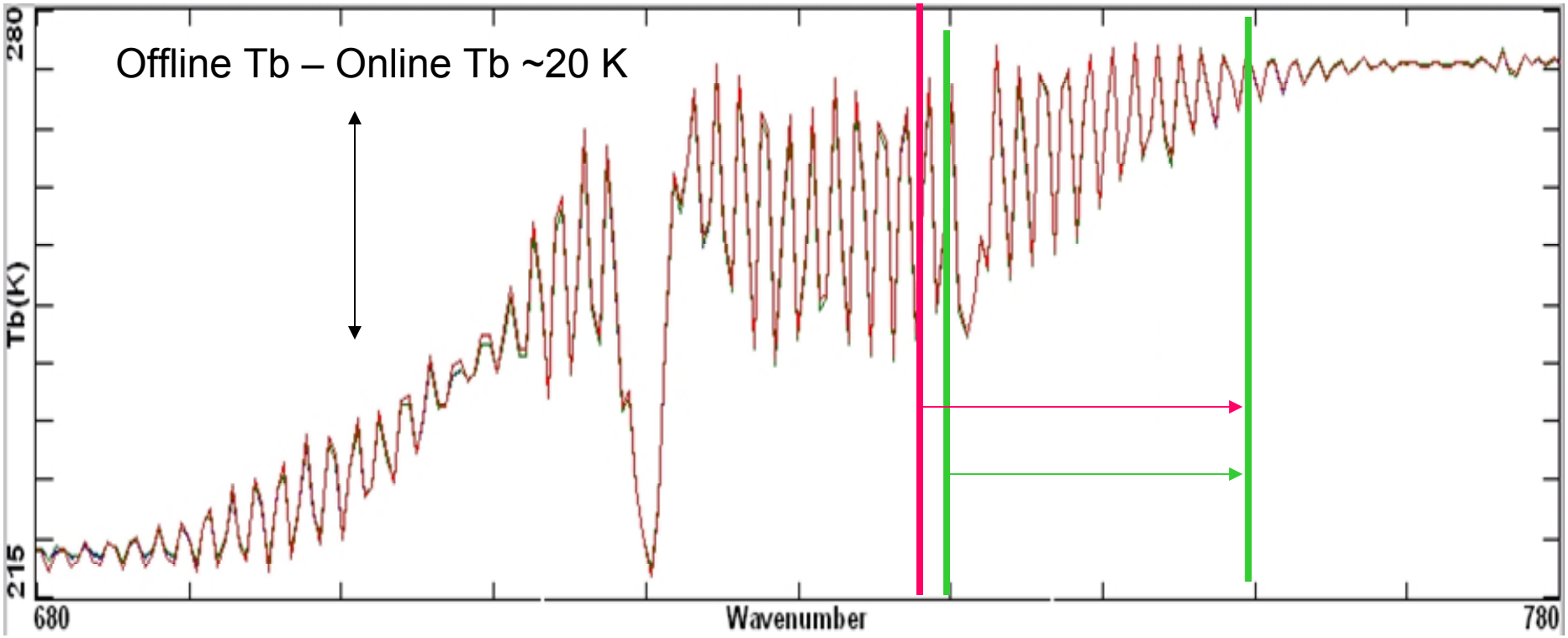
Stratospheric Cloud Identification





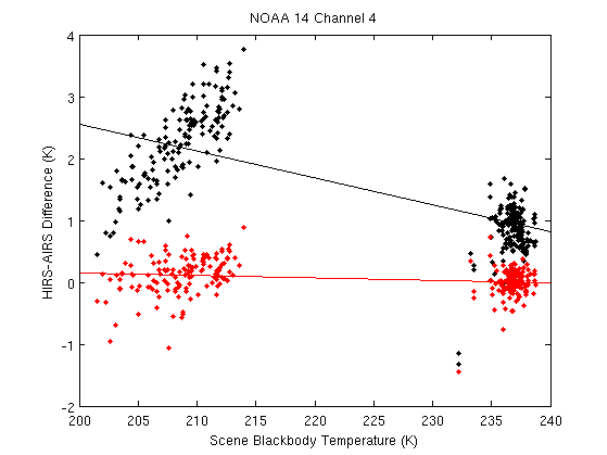
Detection of stratospheric intrusion from BT6.6>BT11 test (Schmetz et al, 1997) will help improve high cloud determination

Using AIRS to Adjust HIRS SRF

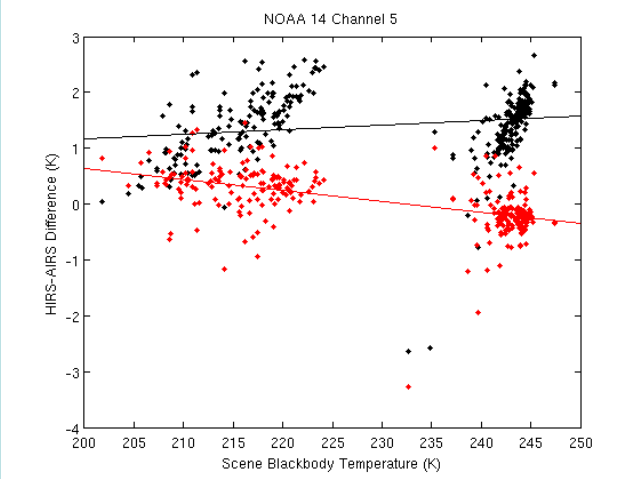


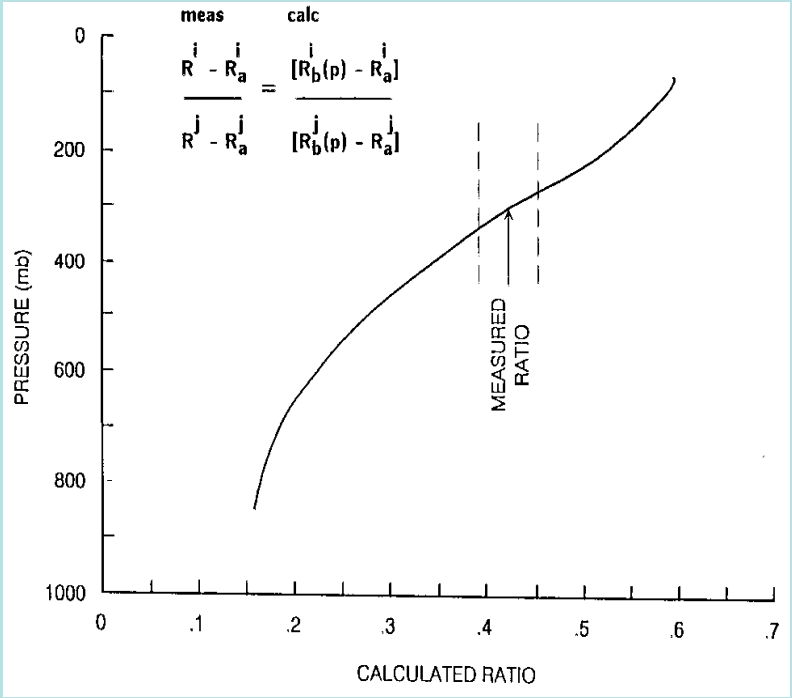
* Bandwidth ~ 20 cm-1 includes roughly 12 peaks and 12 valleys
* Including extra peak implies ΔTb ~ +2 K or ΔR ~ +1 mW/m2/ster/cm-1
* Then calculation of clear sky radiance obs would be off by ΔR
  which would affect determination of Pc
* Warmer clear sky calculation introduces extra false cloud detection

N14 Channel 4



N14 Channel 5





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

$(I_4^{clr} - I_4)$ is too small (wrt to AIRS)

$(I_5^{clr} - I_5)$ is too large (wrt to AIRS)

So cloud forcing ratio 4/5 is too small

as ratio increases, p_c decreases

Spectral Shifts used for N14

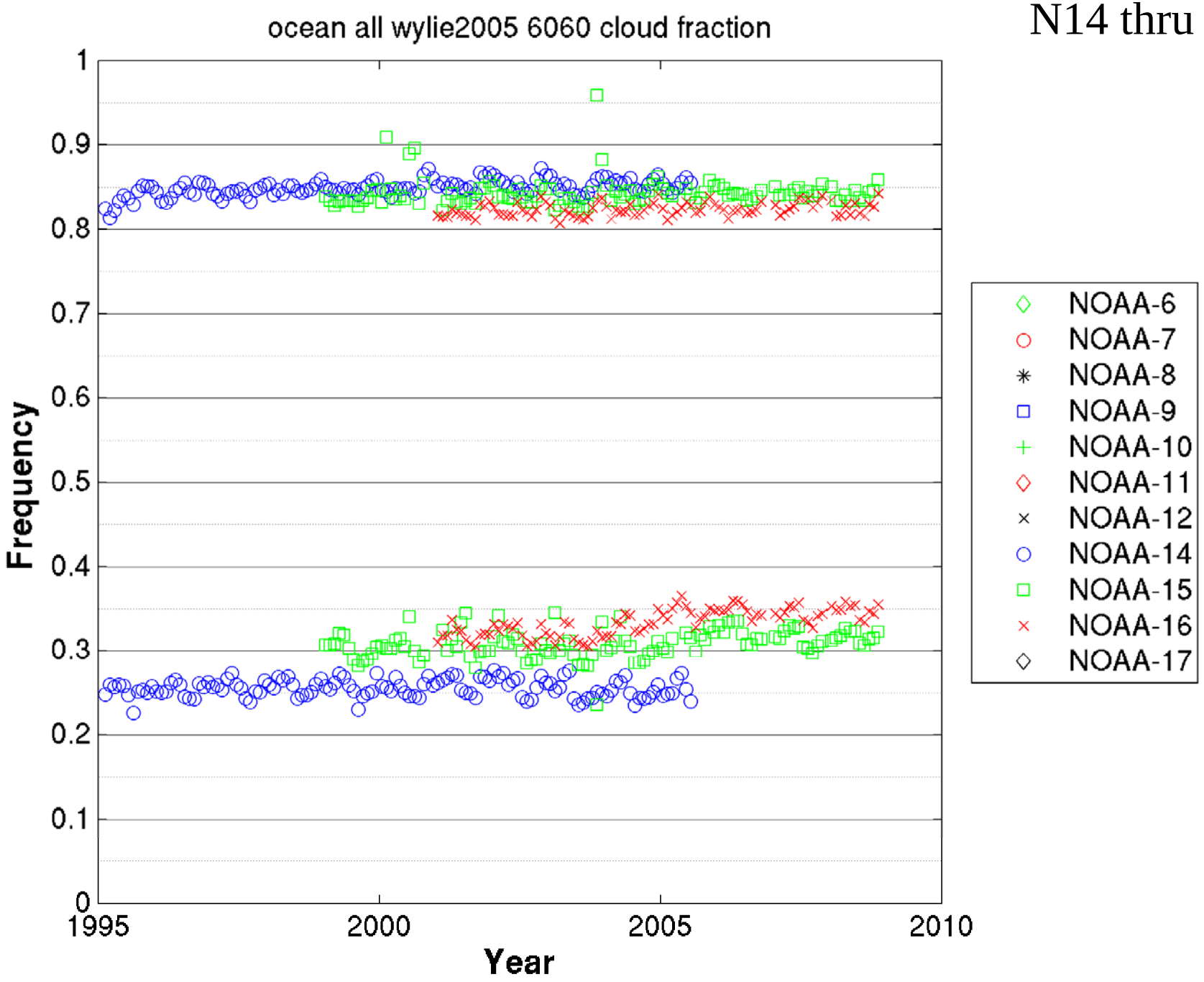
Ch4	14.2um	704 cm-1	+2.0 cm-1
Ch5	13.9	719	+2.5
Ch6	13.6	735	+3.0
Ch7	13.3	750	+1.5

Spectral Shifts used for N15 & N16

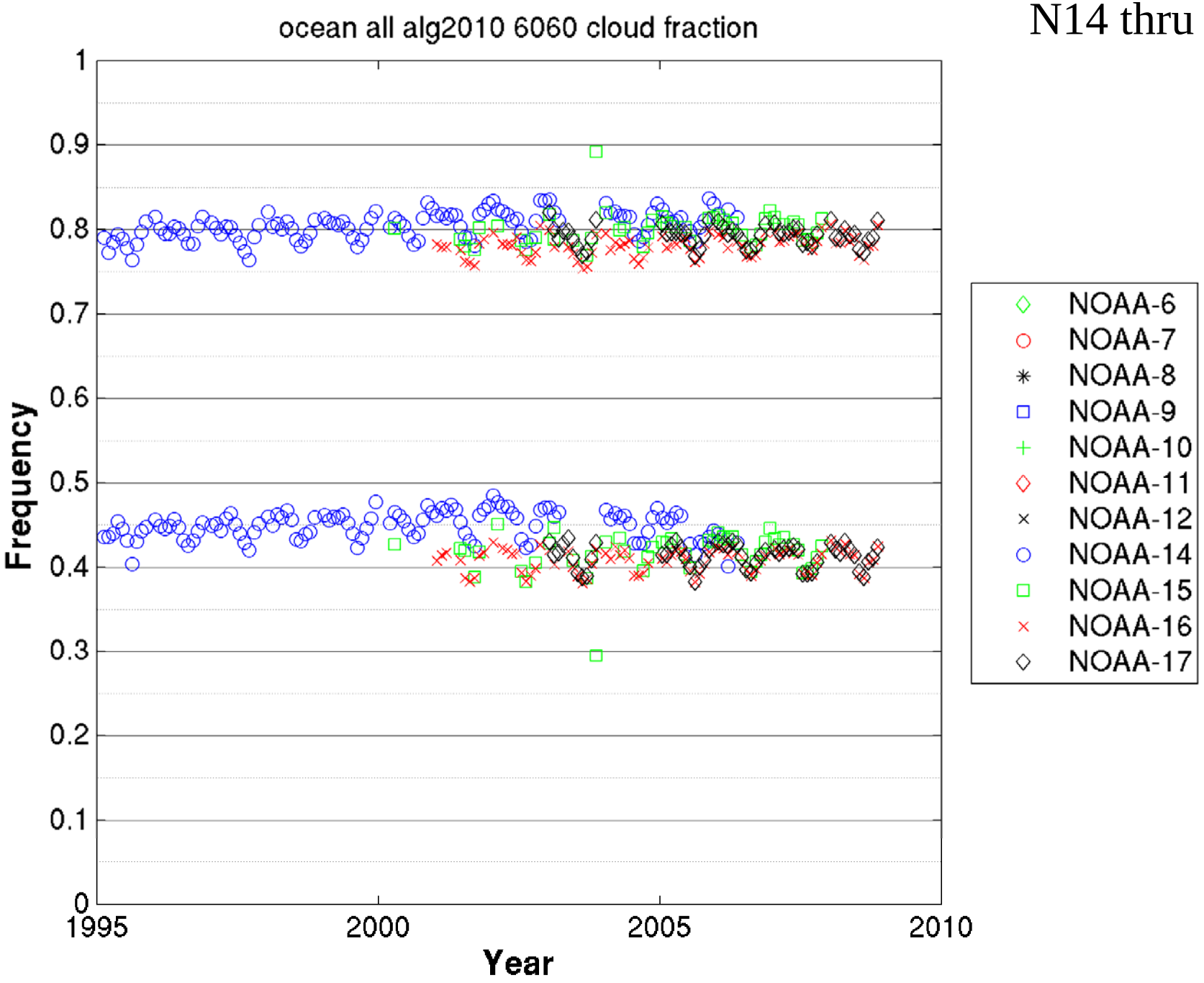
none

HIRS Reprocessing Results

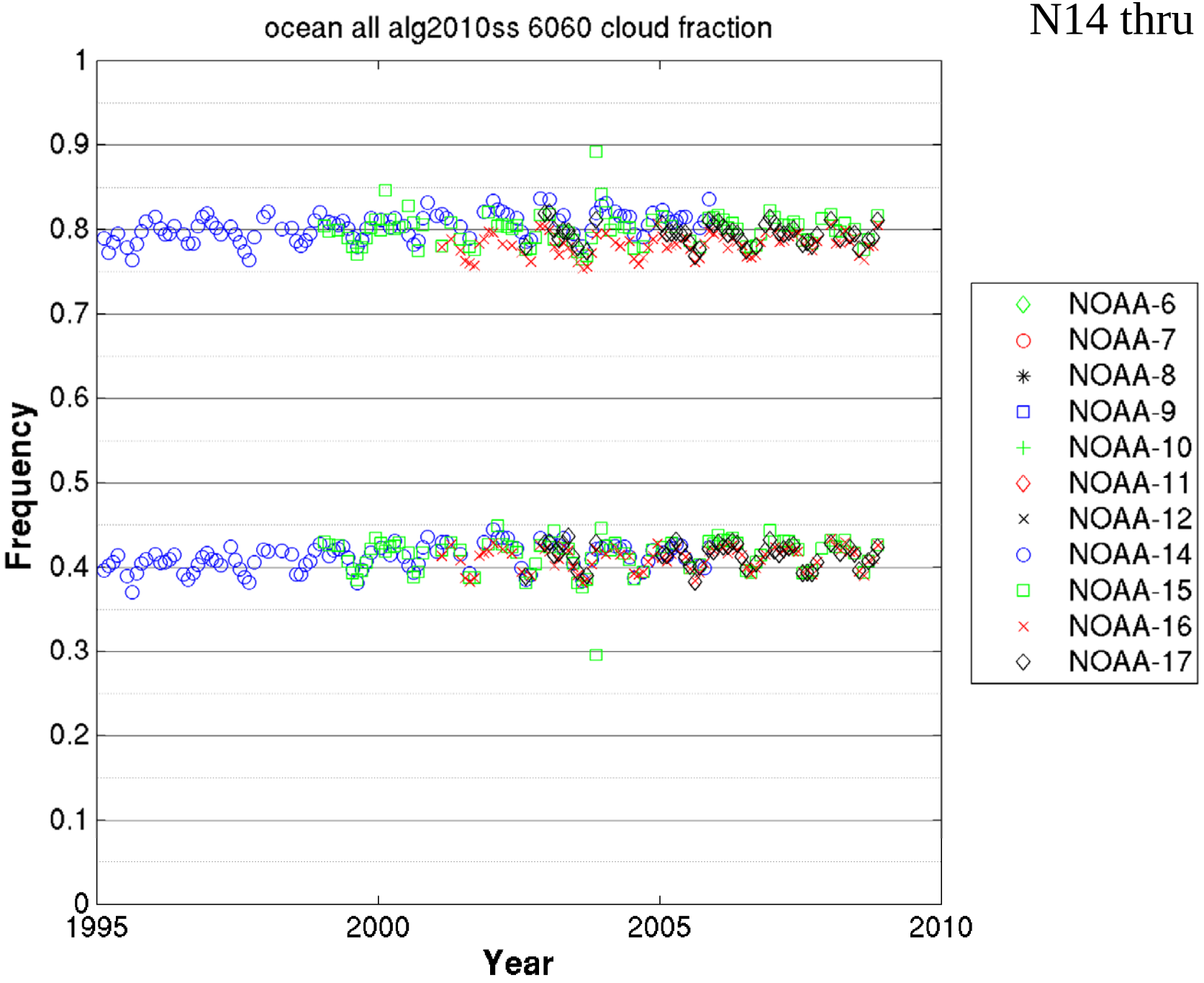
N14 thru N16

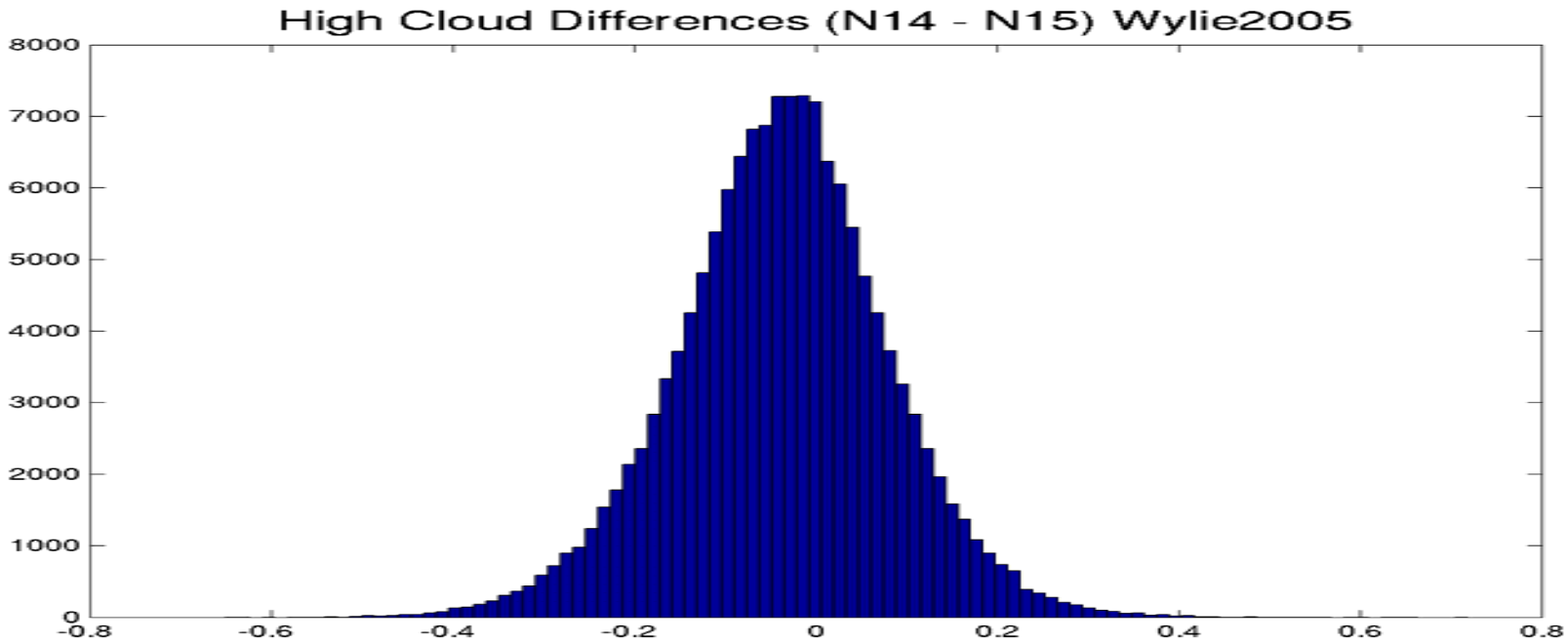

ocean all wylie2005 6060 cloud fraction
Frequency
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1995
2000
2005
2010
NOAA-6
NOAA-7
NOAA-8
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
NOAA-15
NOAA-16
NOAA-17

N14 thru N17

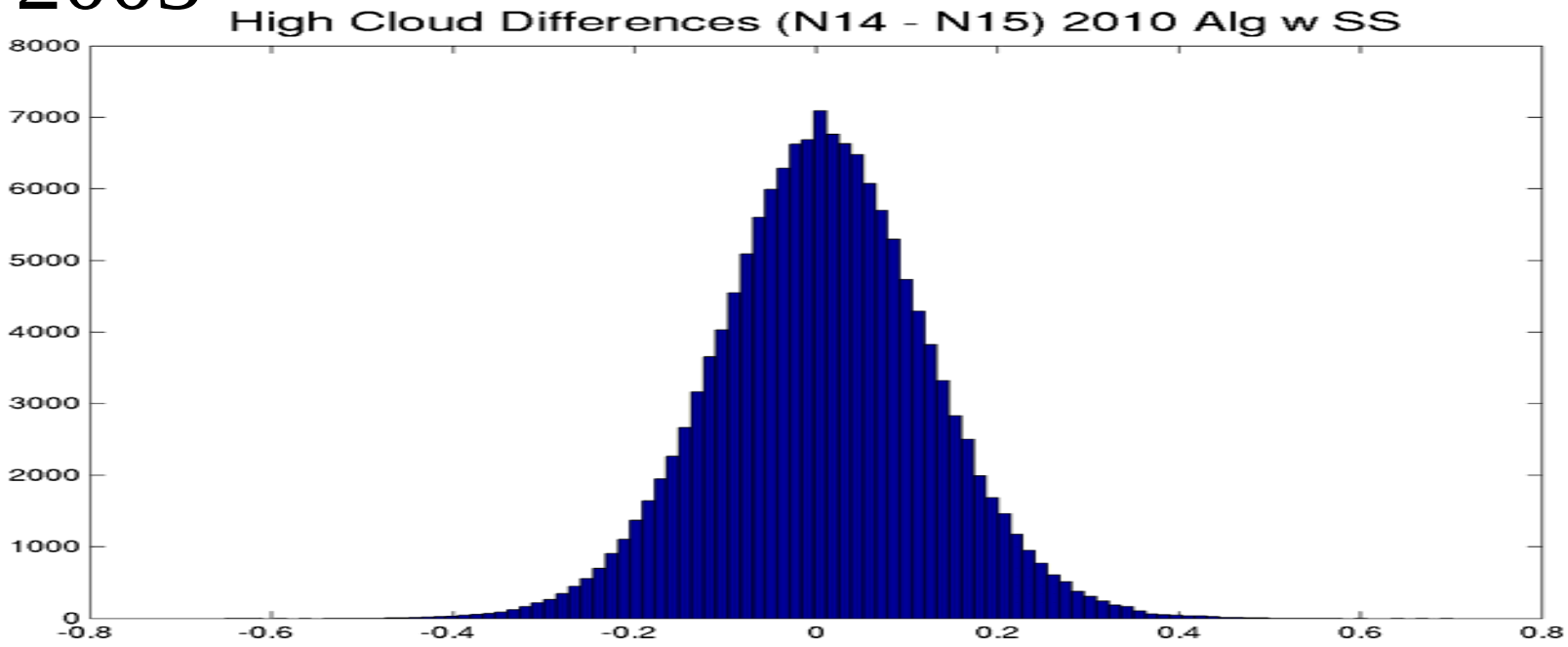

ocean all alg2010 6060 cloud fraction
Frequency
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1995
2000
2005
2010
NOAA-6
NOAA-7
NOAA-8
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
NOAA-15
NOAA-16
NOAA-17

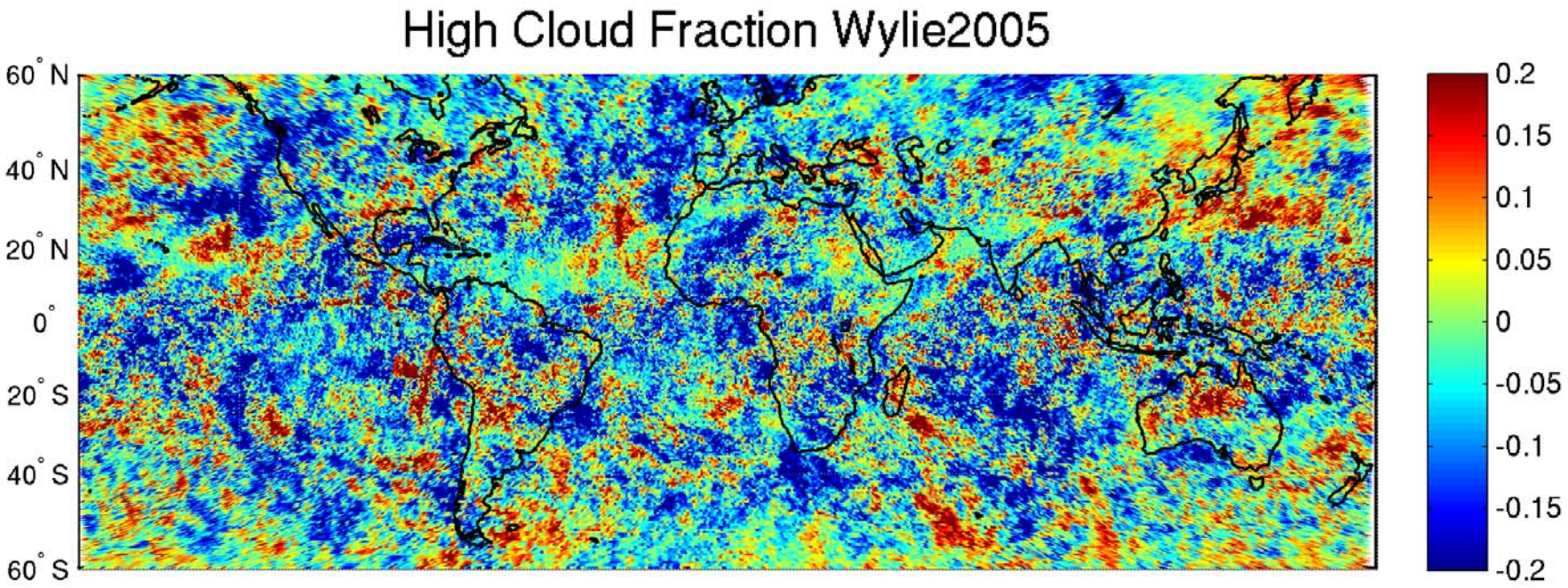
N14 thru N17


ocean all alg2010ss 6060 cloud fraction
Frequency
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1995
2000
2005
2010
NOAA-6
NOAA-7
NOAA-8
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
NOAA-15
NOAA-16
NOAA-17

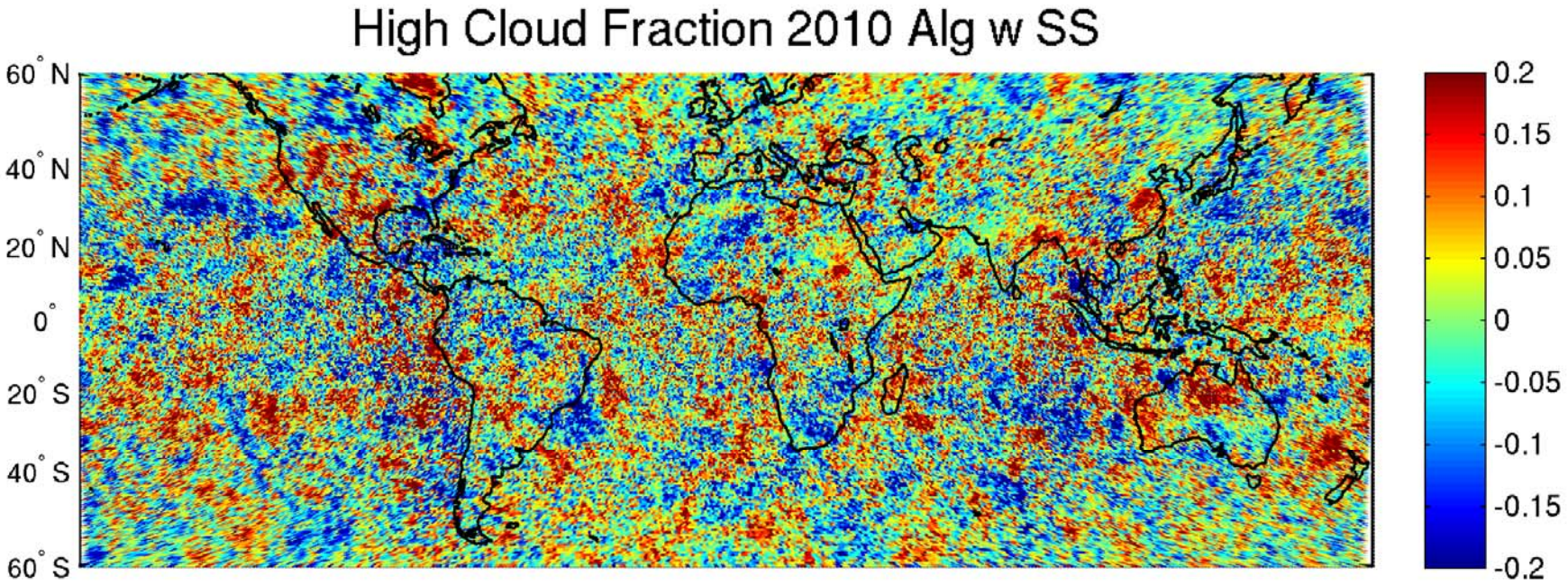

High Cloud Differences (N14 - N15) Wylie2005
8000
7000
6000
5000
4000
3000
2000
1000
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

Jan 2003

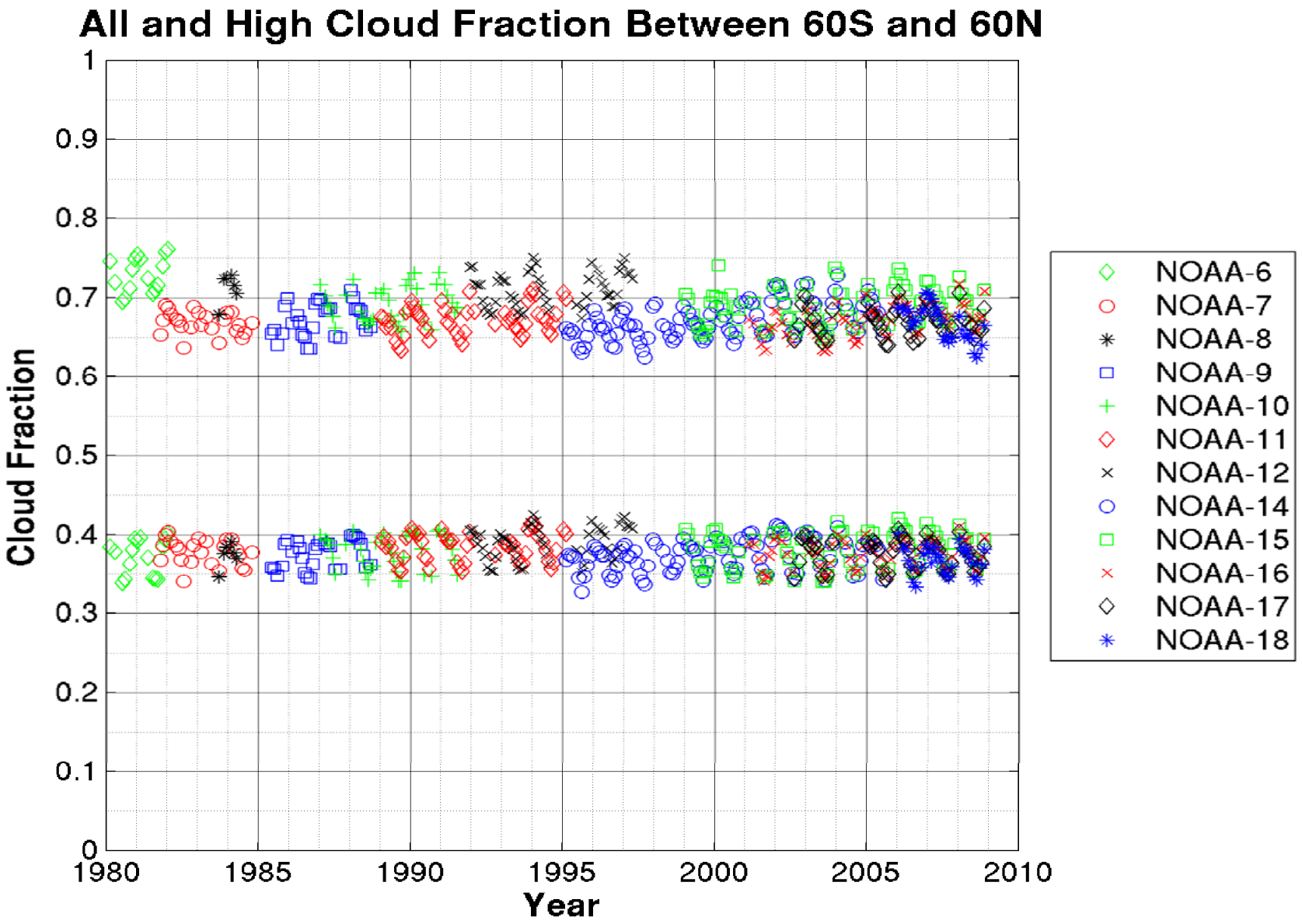

High Cloud Differences (N14 - N15) 2010 Alg w SS
8000
7000
6000
5000
4000
3000
2000
1000
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8



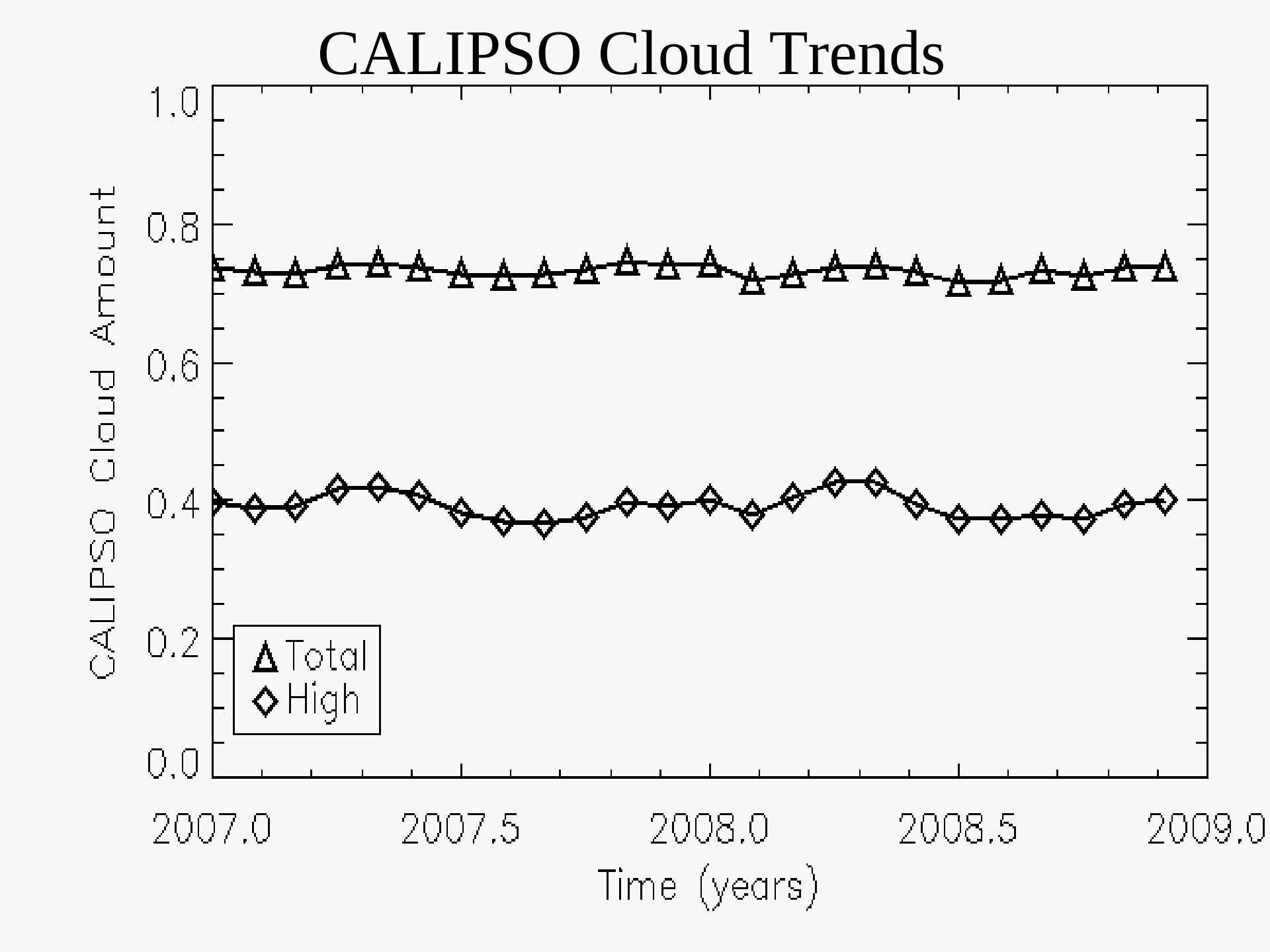
N14 – N15 for Jan 2003

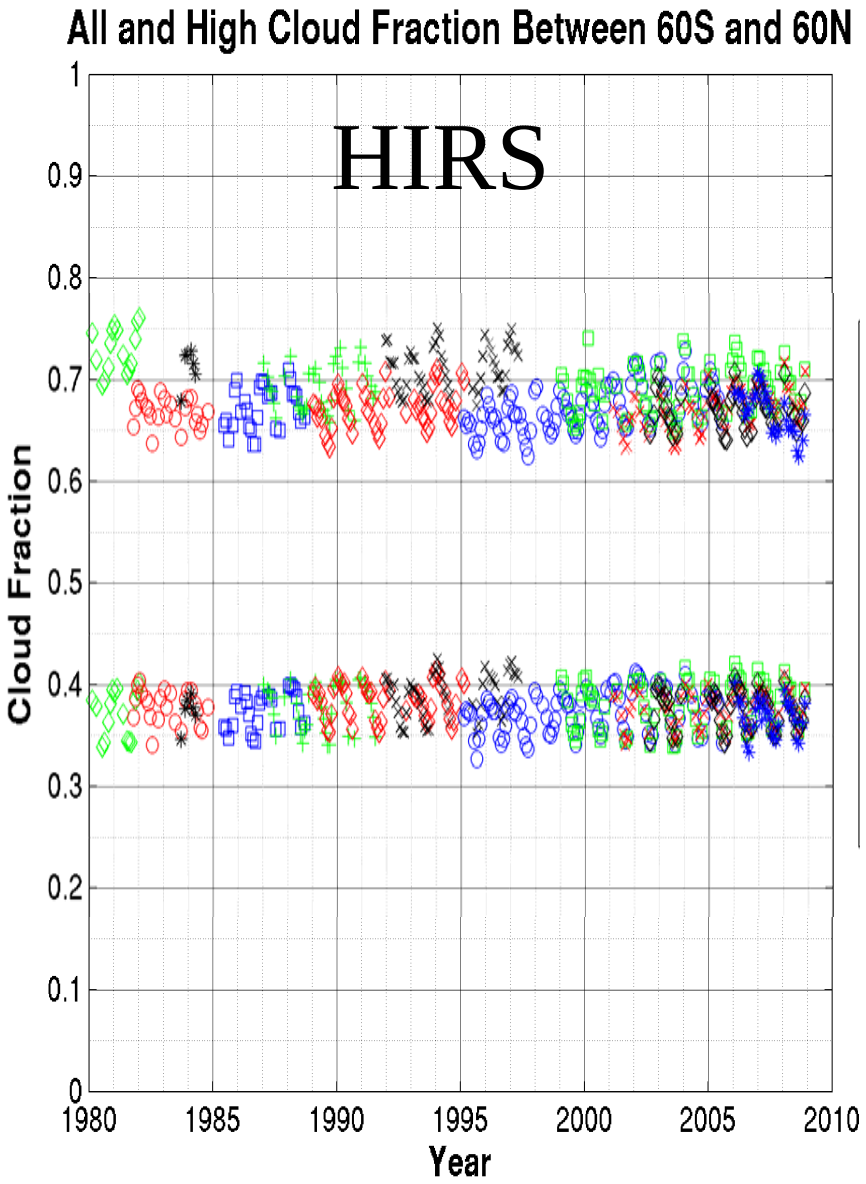


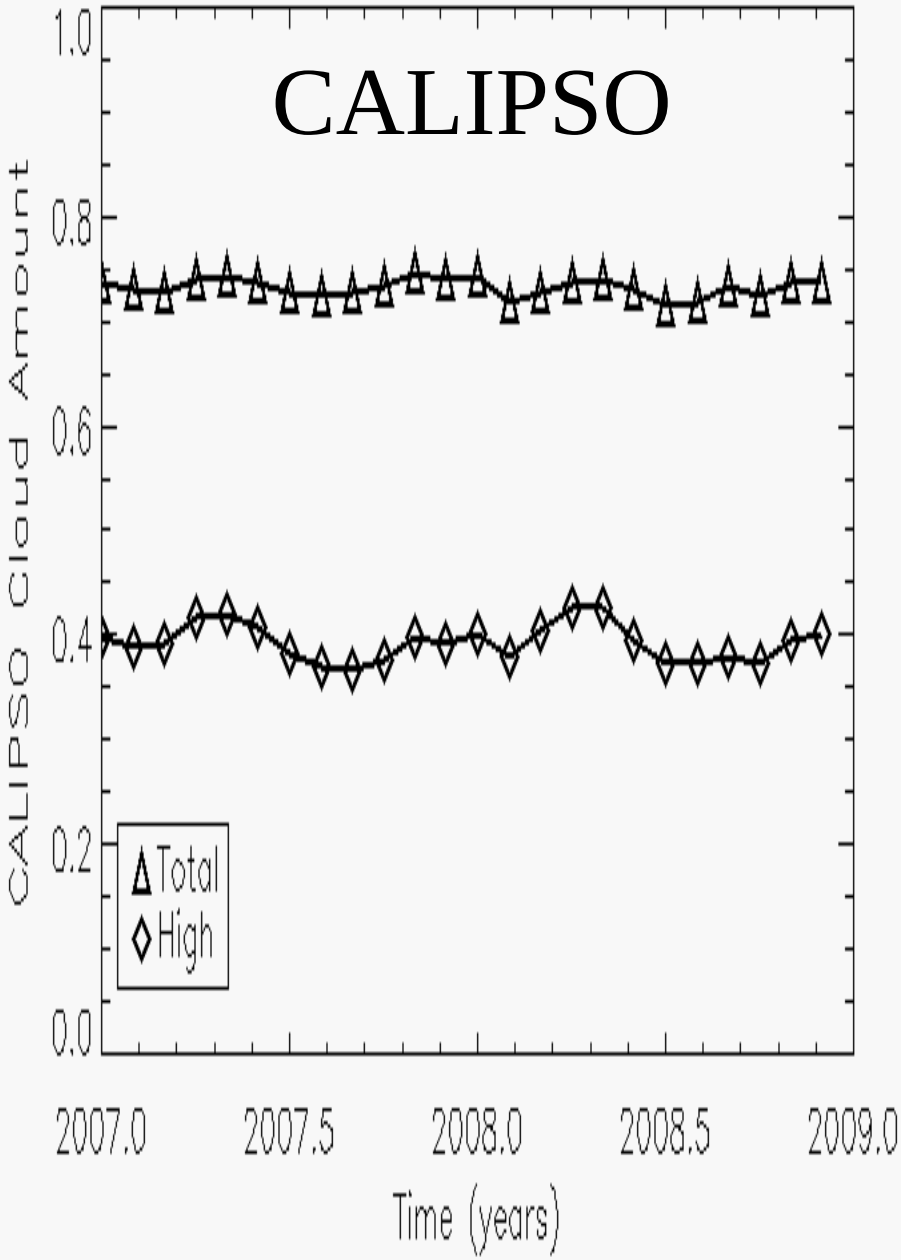
N14 – N15 for Jan 2003

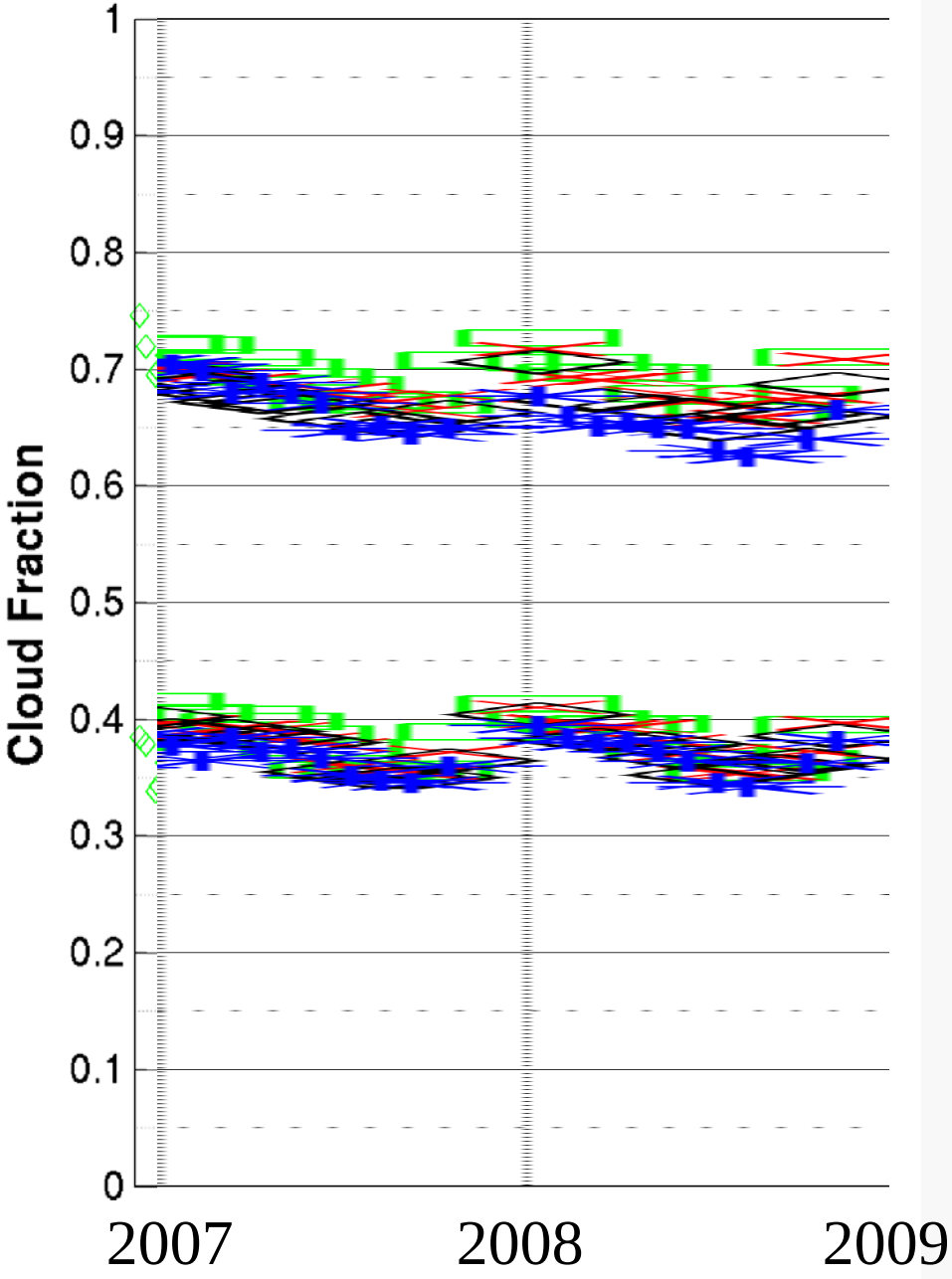


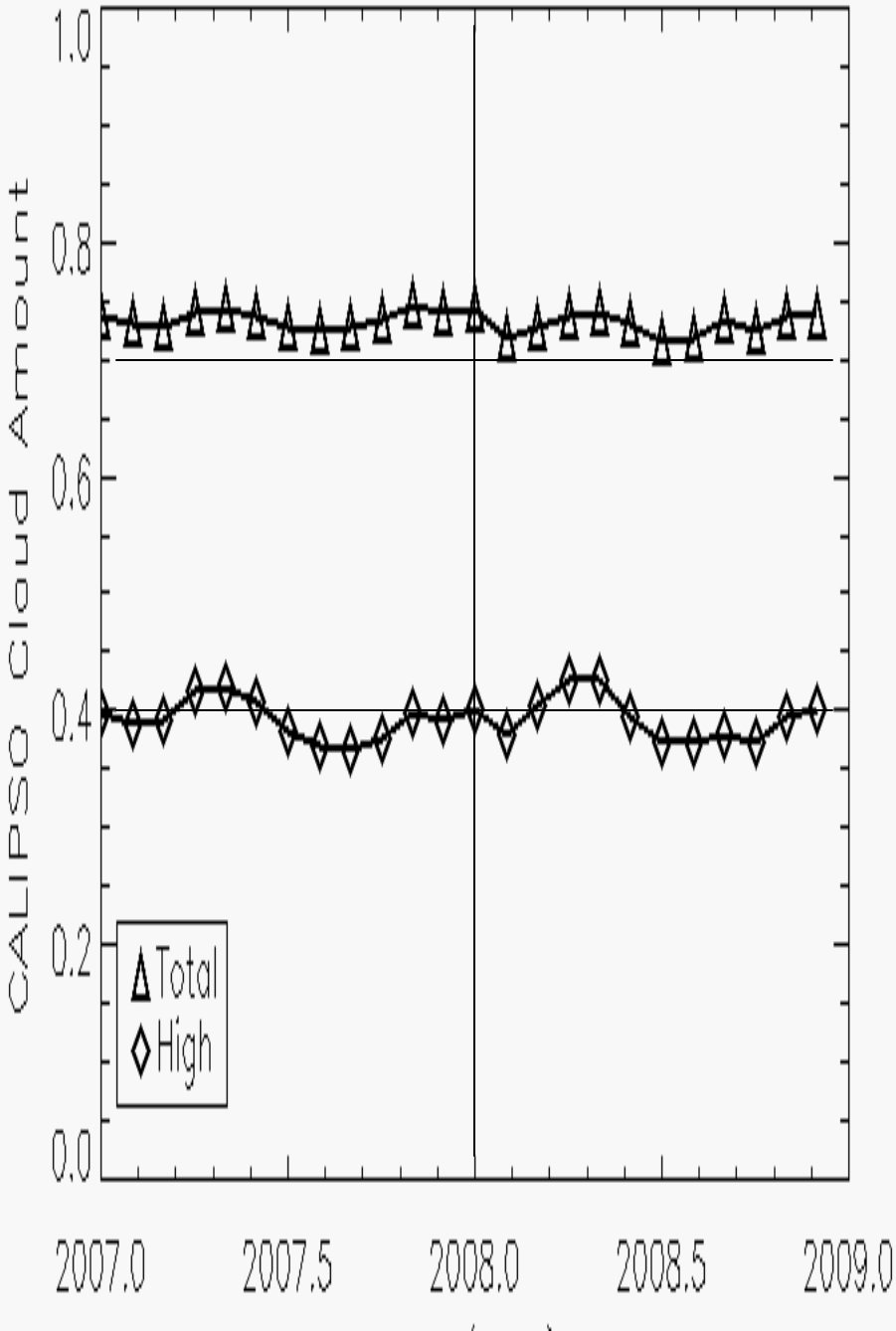
Land plus Ocean


CALIPSO Cloud Trends
1.0
0.8
0.6
0.4
0.2
0.0
CALIPSO Cloud Amount
Total
High
2007.0
2007.5
2008.0
2008.5
2009.0
Time (years)


All and High Cloud Fraction Between 60S and 60N
HIRS
Cloud Fraction
Year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1980
1985
1990
1995
2000
2005
2010


CALIPSO
CALIPSO Cloud Amount
Time (years)
Total
High
0.0
0.2
0.4
0.6
0.8
1.0
2007.0
2007.5
2008.0
2008.5
2009.0


Cloud Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2007
2008
2009


CALIPSO Cloud Amount
1.0
0.8
0.6
0.4
0.2
0.0
Total
High
2007.0
2007.5
2008.0
2008.5
2009.0

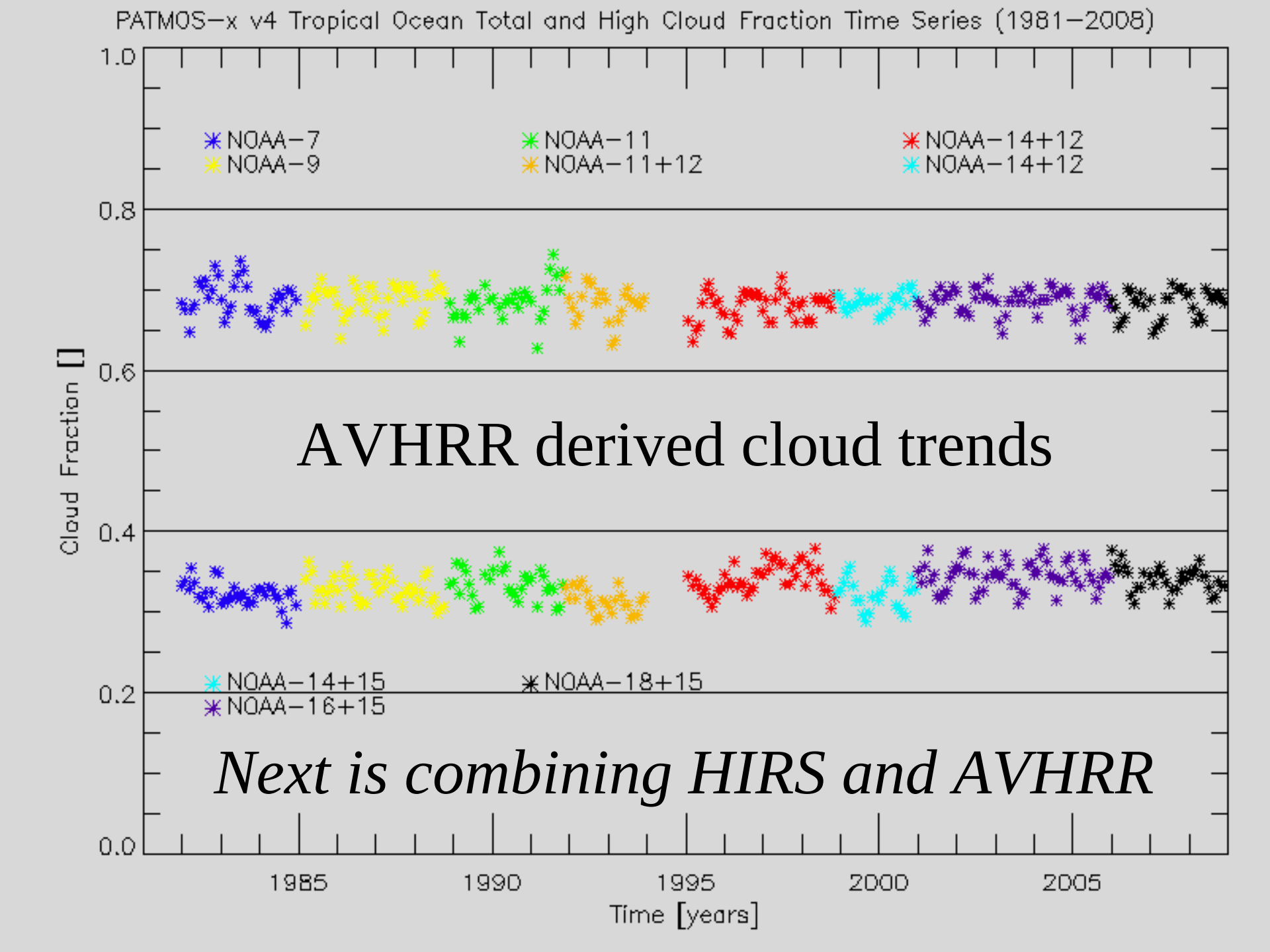
UW HIRS global cloud statistics from December 1978 through December 2009

	All Clouds	Thin Clouds NE<0.5	Thick Clouds	Opaque Clouds NE>0.95
IR Optical Depth	0.1<	<0.7	<3	>3
High (<440 hPa)	40%	22%	15%	3%
Mid (440 → 680 hPa)	12%	5%	6%	1%
Low (>680 hPa)	21%	1%	2%	18%
All Clouds	73%	28%	23%	22%

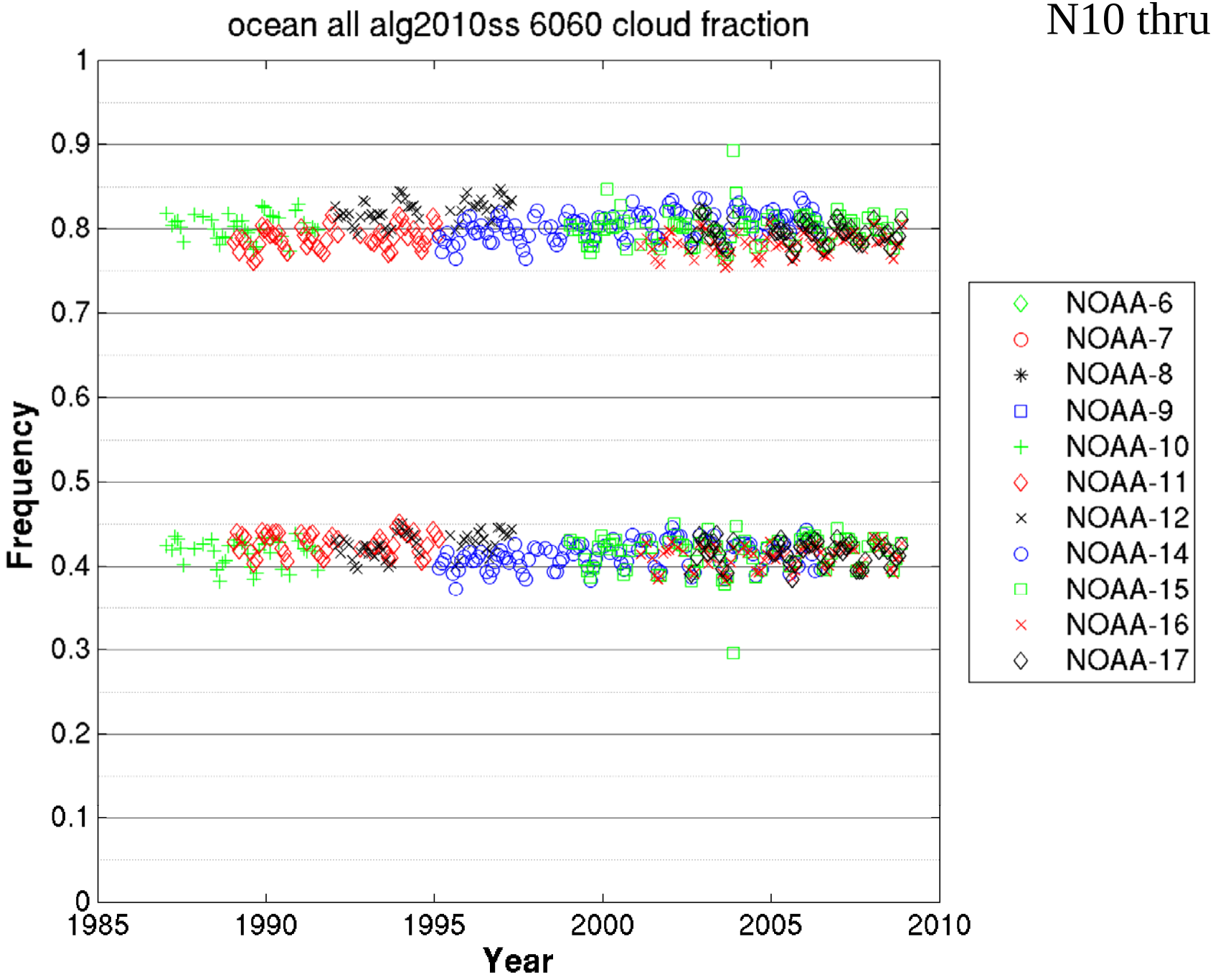
UW HIRS global cloud statistics from December 1978 through December 2009 (corrected for higher cloud obstruction of lower clouds using random overlap assumption)

	All Clouds	Thin Clouds NE<0.5	Thick Clouds	Opaque Clouds NE>0.95
IR Optical Depth	0.1<	<0.7	<3	>3
High (<440 hPa)	40%	22%	15%	3%
Mid (440 → 680 hPa)	20%	8%	10%	2%
Low (>680 hPa)	52%	2%	5%	45%
Clear	27%			

Combining Imager and Sounder Measurements


PATMOS–x v4 Tropical Ocean Total and High Cloud Fraction Time Series (1981–2008)
NOAA–7
NOAA–9
NOAA–11
NOAA–11+12
NOAA–14+12
NOAA–14+12
AVHRR derived cloud trends
NOAA–14+15
NOAA–16+15
NOAA–18+15
Next is combining HIRS and AVHRR
Cloud Fraction []
1.0
0.8
0.6
0.4
0.2
0.0
1985
1990
1995
2000
2005
Time [years]

N10 thru N17


ocean all alg2010ss 6060 cloud fraction
Frequency
Year
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1985
1990
1995
2000
2005
2010
NOAA-6
NOAA-7
NOAA-8
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
NOAA-15
NOAA-16
NOAA-17

Summary

* algorithm adjustments tested with MODIS, halving CO2 slicing threshold, spectral shifts suggested by AIRS, CO2 ramp, stratospheric intrusions,… are producing consistent HIRS/2 to HIRS/3 results
* clouds were found in ~80% (55%) of HIRS observations over ocean (land) since 1995; hi clouds were found in ~40% (33%) over ocean (land)
* two year comparison with CALIPSO shows HIRS is finding most of the high clouds and missing more than 5% of all clouds
* reprocessing of complete HIRS archive with adjusted algorithm using calibration adjustments suggested by SNOs is underway; merging with AVHRR planned
* combined cloud top property retrievals from high spatial and high spectral radiance measurements are still being investigated