Recalibrating HIRS Sensors to Produce a 30 year Record of Radiance Measurements Useful for Cloud and Moisture Trend Analysis

University of Wisconsin-Madison
Space Science and Engineering Center (SSEC)

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Recalibrating HIRS Sensors to Produce a 30 year Record of Radiance Measurements Useful for Cloud and Moisture Trend Analysis

Recalibrating HIRS
Accommodating Orbit Drift
TPW and UTH Trends
CTP Results

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HIRS Recalibration

Mitigating sensor to sensor differences

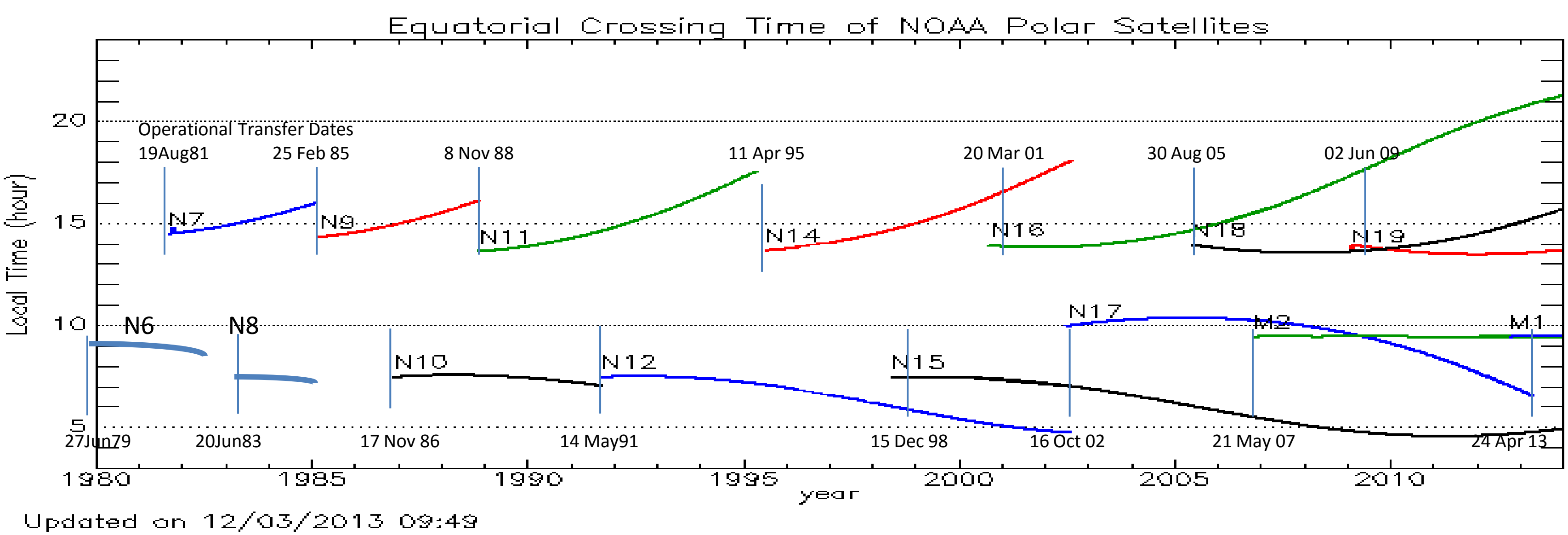
Recalibrating Metop HIRS using IASI

Recalibrating all prior HIRS
using Metop HIRS or IASI as a reference
(at Simultaneous Nadir Overpasses adjust for radiance differences
beyond those caused by known SRF differences)

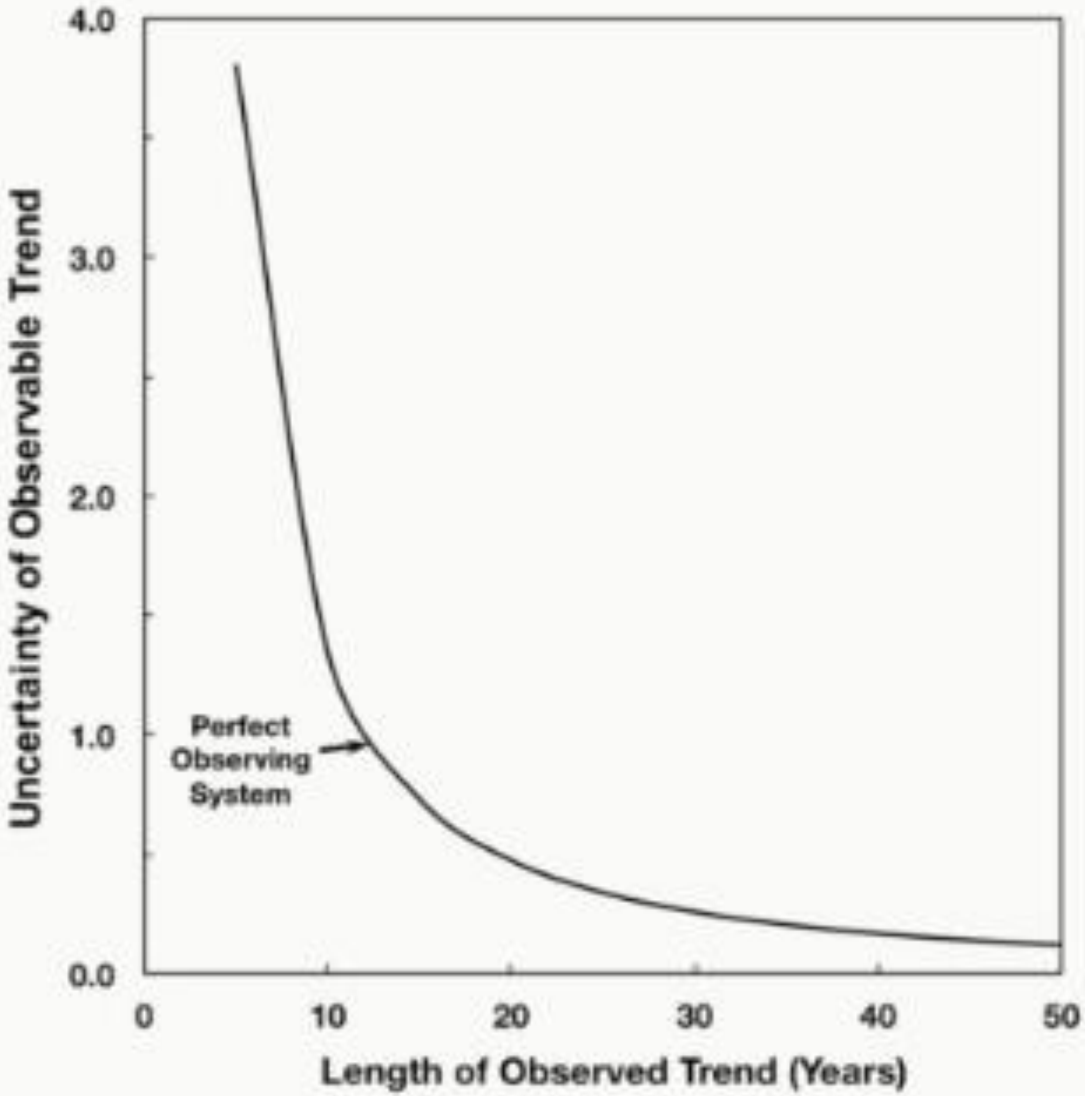
Measurements from 16 HIRS sensors in use for 30+ year cloud study

morning (8 am LST)	Desc Node Times	night (2 am 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-A HIRS/4		NOAA 18 HIRS/4 +
METOP-B HIRS/4		NOAA 19 HIRS/4

Before HIRS/2I ch 10 is at 8.6 um, thereafter it is at 12.5 um. HIRS/3 improved S/N.
* indicates orbit drift from 14 UTC to 18 UTC over 5 years of operation. Before HIRS/4 FOV is 20 km FOV; thereafter it is 10 km. + indicates excessive noise in LW channels. Local Time of descending node equator crossing is shown below along with operational transfer dates.



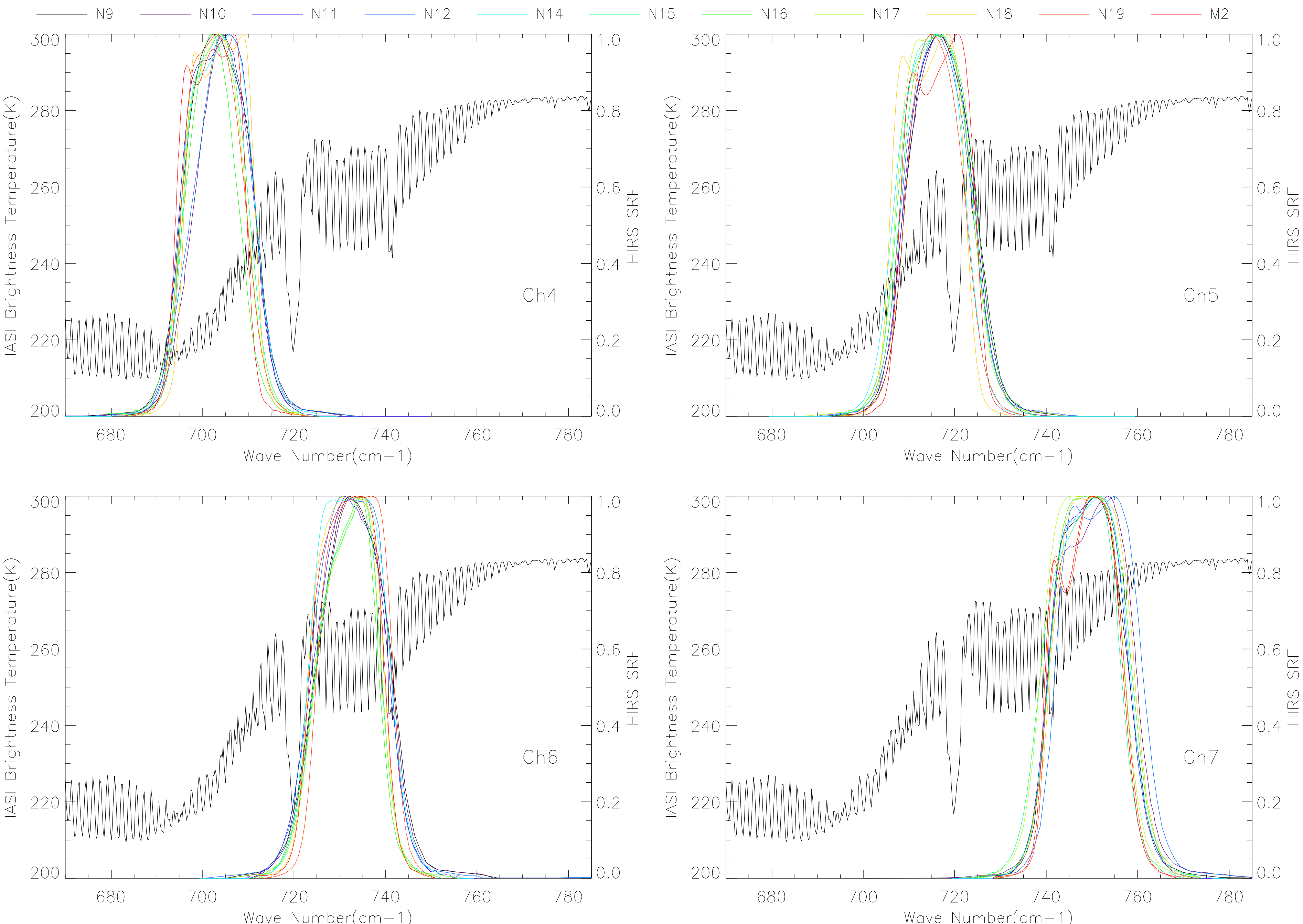
Accuracy Requirements of the Climate Observing System



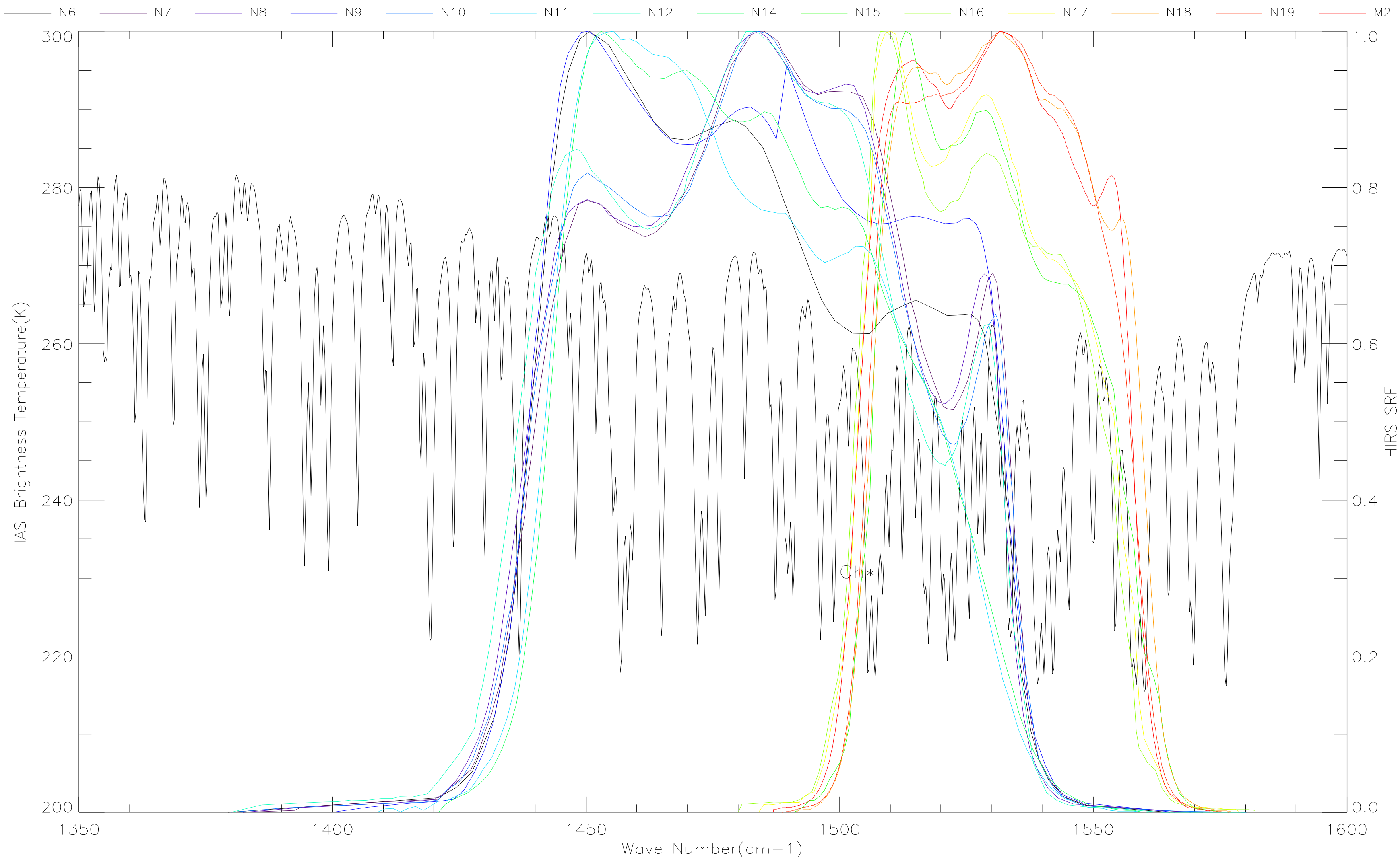
The length of time required to detect a climate trend caused by human activities is determined by:

- *Natural variability*
- *The magnitude of human driven climate change*
- *The accuracy of the observing system*

SRFs of CO2 channels for NOAA/Metop satellites

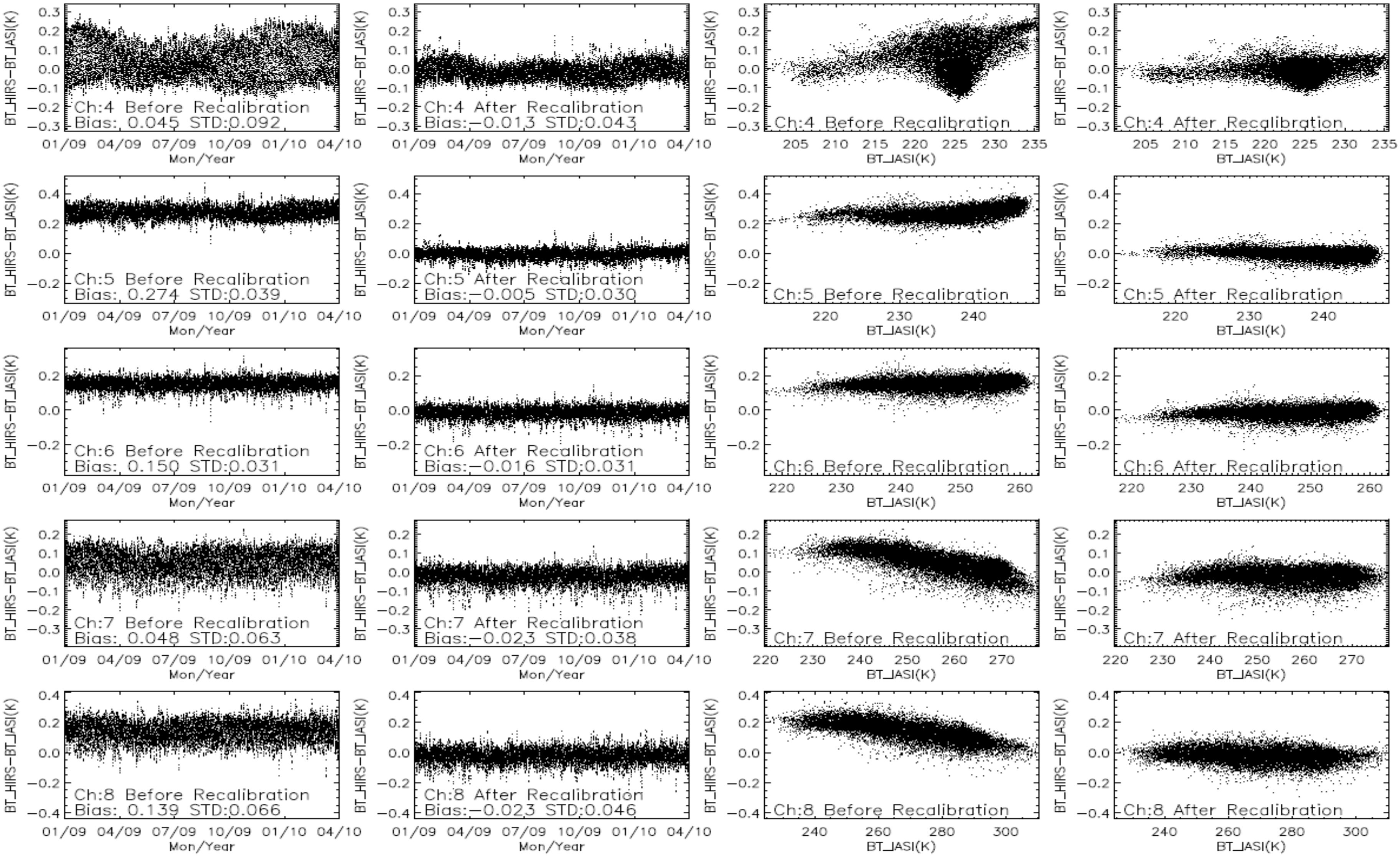


SRF of water vapor channel for NOAA/MetOp satellites



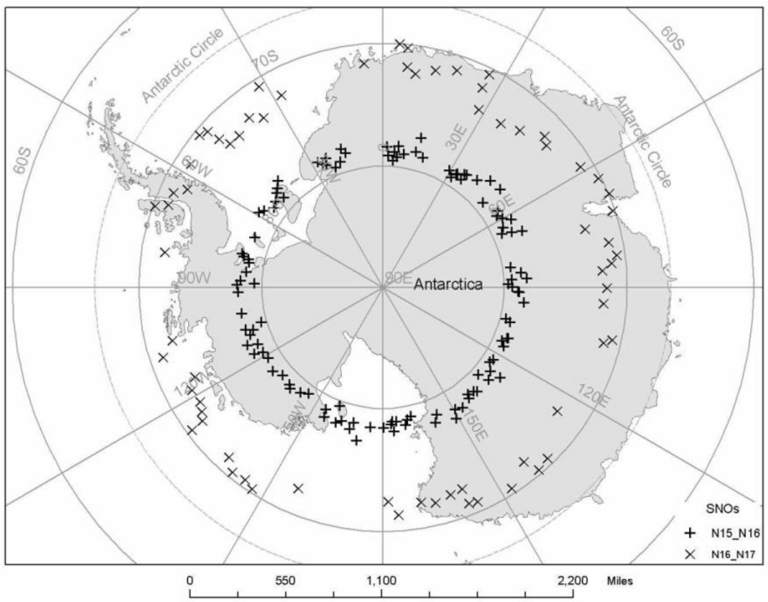
- SRF of HIRS ch12 for NOAA/MetOp satellites (left axis), an IASI spectra (right axis)
- Differences can be seen between HIRS/2, HIRS/3, and HIRS/4

MetOp-A HIRS Recalibration Using IASI

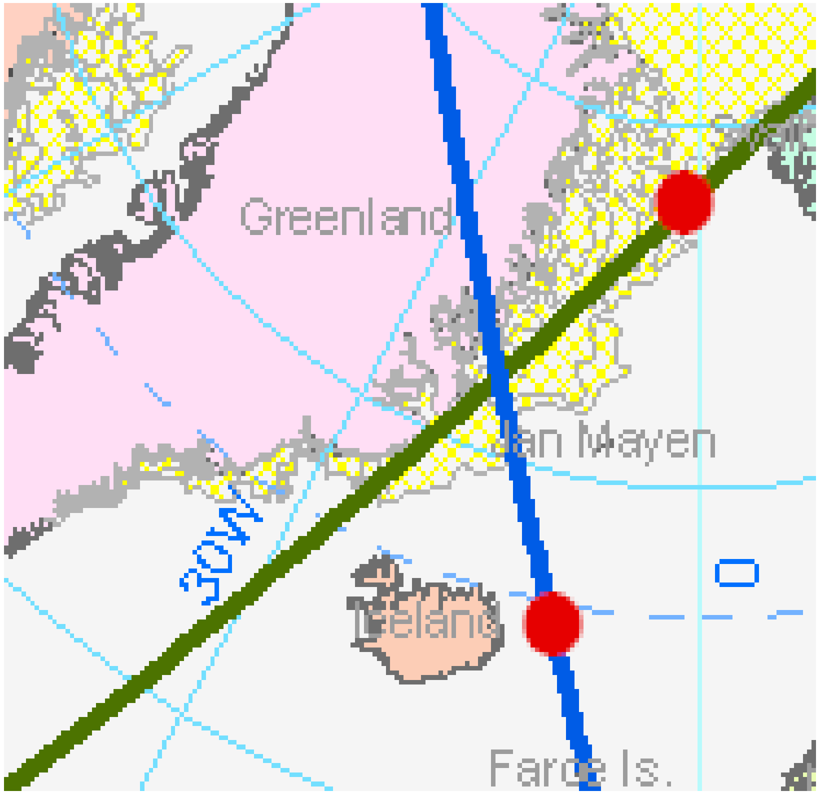


- Corrected of blackbody bias (0.14 K), SRFs (shifted -0.13, 0.09, -0.15 cm-1 for Ch 4, 5, and 7), and calibration non-linearity term.
- Validated with 16 months sampled MetOp data (the fifth orbit of each day)
- Both mean bias and bias variation (both T- and non T-dependent) are significantly reduced (< 0.1K)

Toward an Integrated System for Intersatellite Calibration of POES using the SNO Method



N15 & N16 (+) and
N16 & N17 (X)
SNO locations
from 2000 to 2003



SNO: Simultaneous Nadir Overpass

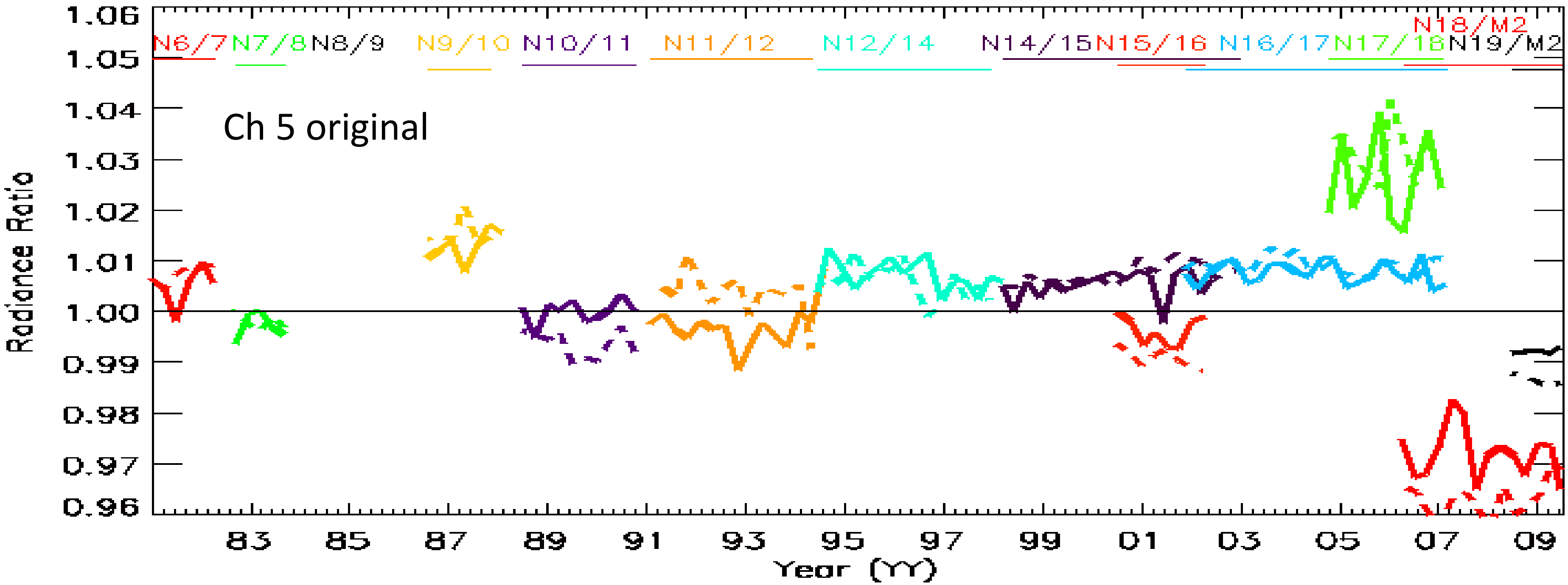
Using Metop-A IASI-HIRS data to estimate SRF shifts implied by HIRS-HIRS SNOs

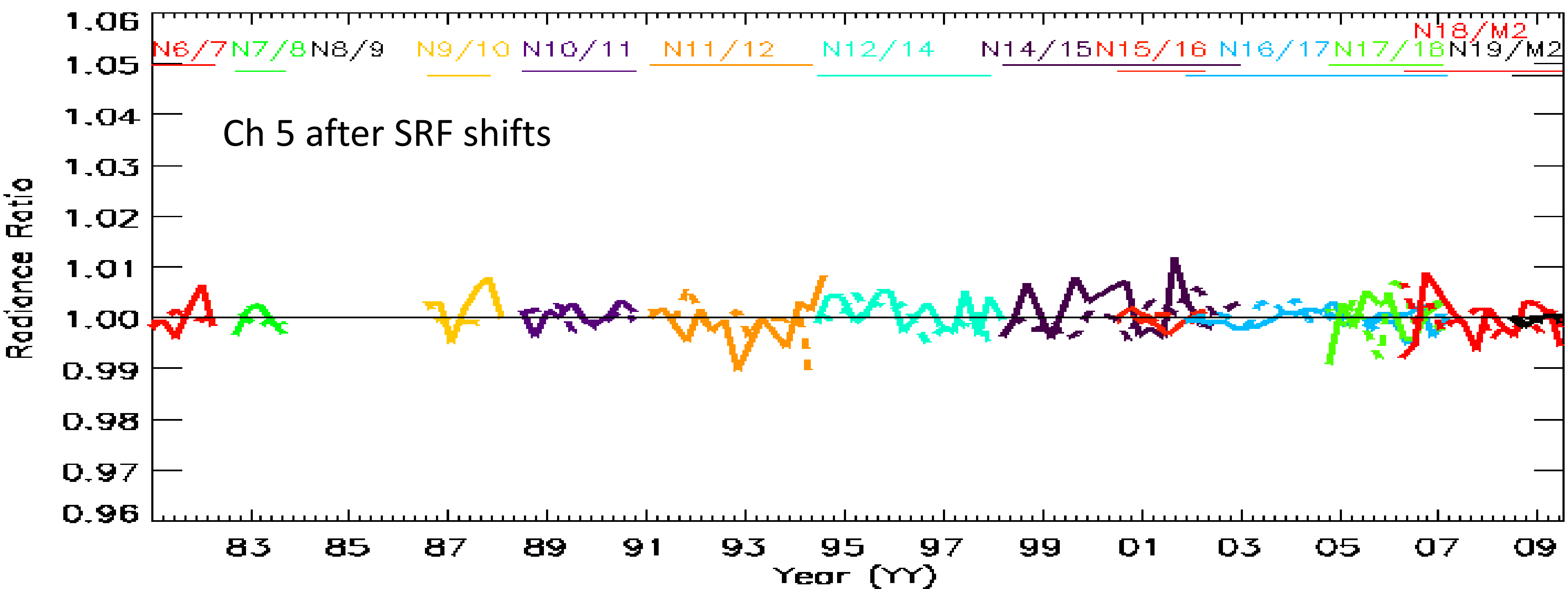
Impact of spectral shift on inter-satellite radiance (or BT) difference depends on atmospheric state at time of measurements

IASI-simulated HIRS data are used to develop linear models to estimate impacts of SRF shifts (and differences) on inter-satellite radiance differences for various atmospheric conditions;

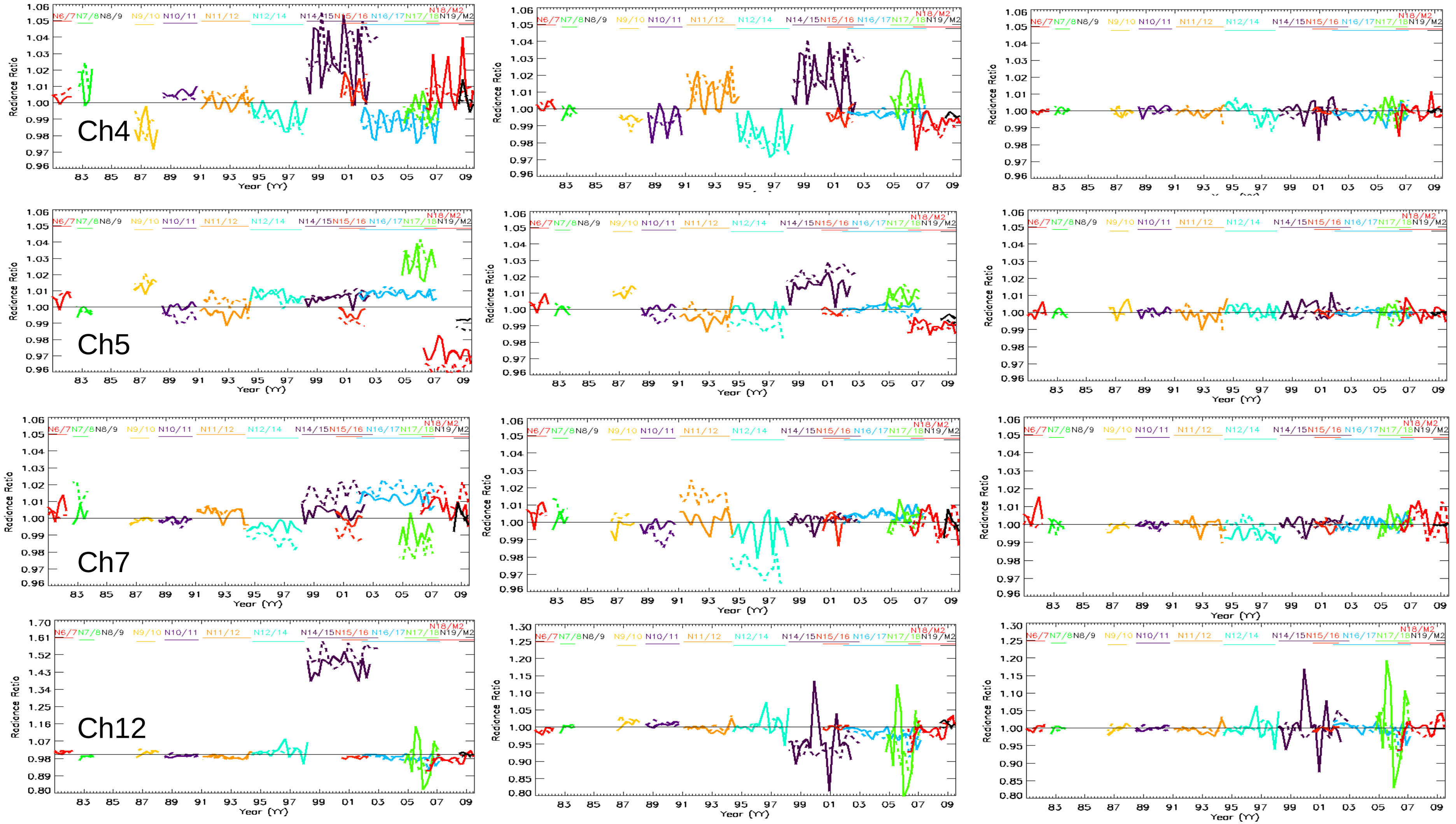
For channel *i* and satellite *m* a shift of *ΔSRF* will produce a radiance change $\Delta R_{im} = \Delta SRF\ [\Sigma_j\ a_{ijm}\ R_{jm} + c_{im}]$

where *j* sums the HIRS CO2 channels 2 – 7, IRW channel 8, and H2O channel 12 (these are used to estimate the atmospheric state for a given SNO)


N6/7 N7/8 N8/9 N9/10 N10/11 N11/12 N12/14 N14/15 N15/16 N16/17 N17/18 N18/M2 N19/M2
Ch 5 original
Radiance Ratio
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
83 85 87 89 91 93 95 97 99 01 03 05 07 09
Year (YY)


N6/7 N7/8 N8/9 N9/10 N10/11 N11/12 N12/14 N14/15 N15/16 N16/17 N17/18 N18/M2 N19/M2
Ch 5 after SRF shifts
Radiance Ratio
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
83 85 87 89 91 93 95 97 99 01 03 05 07 09
Year (YY)

Process of HIRS Inter-satellite Calibration



Original | After known SRF differences | After SRF shifts

- IASI-simulated HIRS data are used to develop linear models to estimate impacts of SRF differences and shifts on inter-satellite radiance biases for various atmospheric conditions
- After accounting for pre-launch SRF differences, inter-satellite biases are recalculated
- Optimized SRF shifts (as large as 4 cm-1) minimize RMS of biases to less than 1%.

CO_2 and H_2O HIRS spectral shifts

	Ch4(14.2)	Ch5(13.9)	Ch7(13.3)	Ch12(6.7)
Hirs2n06 V	0.31	0.7	0.7	1.1
Hirs2n07 V	-0.18	0.1	1.2	-0.46
Hirs2n09 H	0.43	2.66	-0.48	1.1
Hirs2n10 H	0.95	1.56	-0.93	3.0
Hirs2n11 H	1.72	2.05	0.15	4.2
Hirs2n12 H	0.47	2.23	-2.06	4.1
Hirs2n14 H	1.97	3.13	1.22	4.1
Hirs3n15 I	-0.21	0.27	1.01	0.6
Hirs3n16 I	0.22	0.62	0.47	0.8
Hirs3n17 I	0.54	0.72	0.44	-0.3
Hirs4n18 I	-0.71	-0.37	-0.49	3.3
Hirs4n19 I	-0.00	-0.12	0.10	0.7
Hirs4moa I	-0.15	0.10	-0.15	2.2
Hirs4mob I	-1.21	-0.43	-0.54	0.0

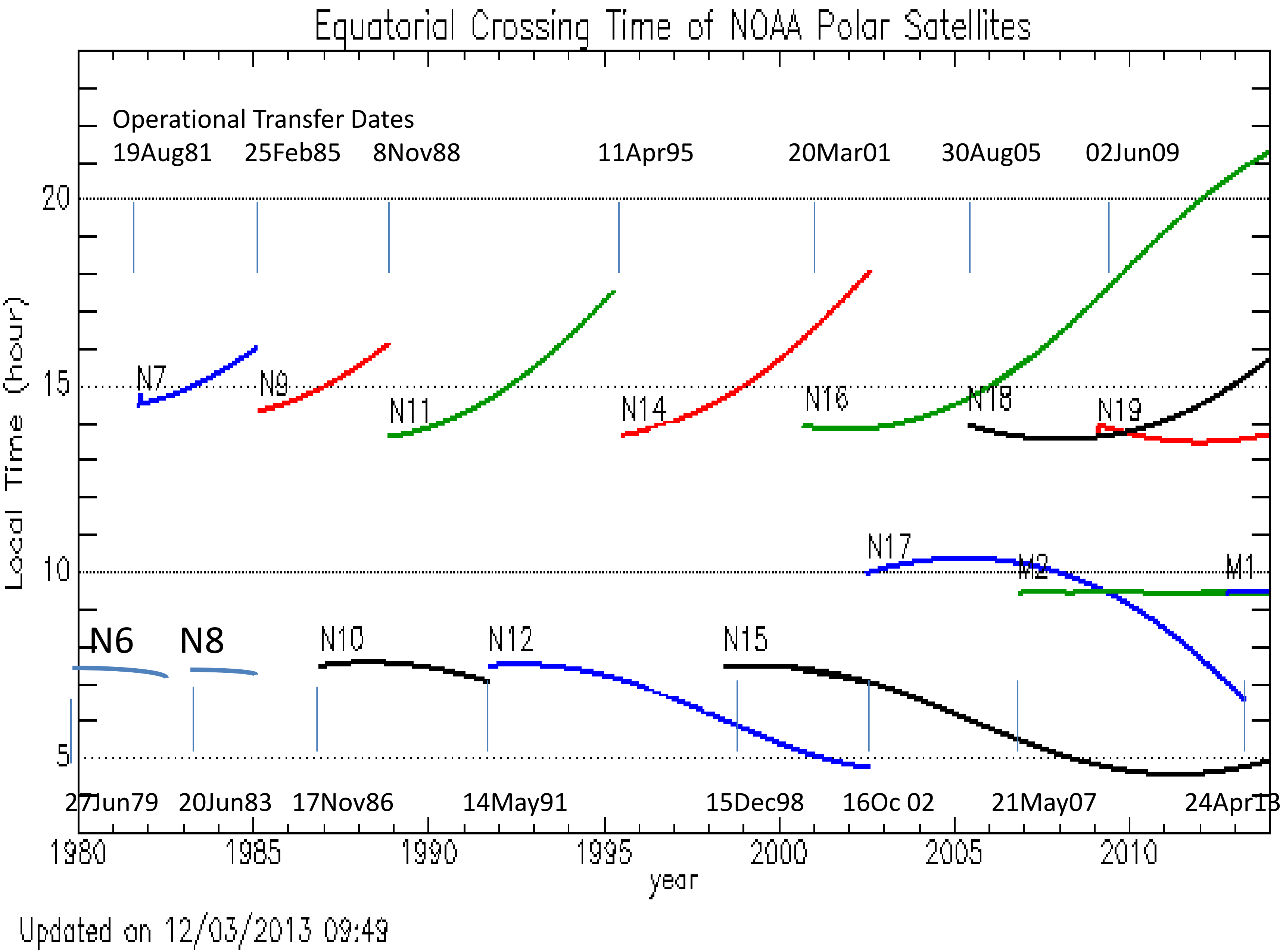
V indicates intercal with VAS, H with later HIRS, and I with IASI directly

Accommodating Orbit Drift

Dividing the day into four segments

(with sunlight before and after noon; without sunlight before and after midnight)

Equatorial Crossing Times / Operational Transfer Dates for NOAA



Dividing the Day into 4 Time Periods

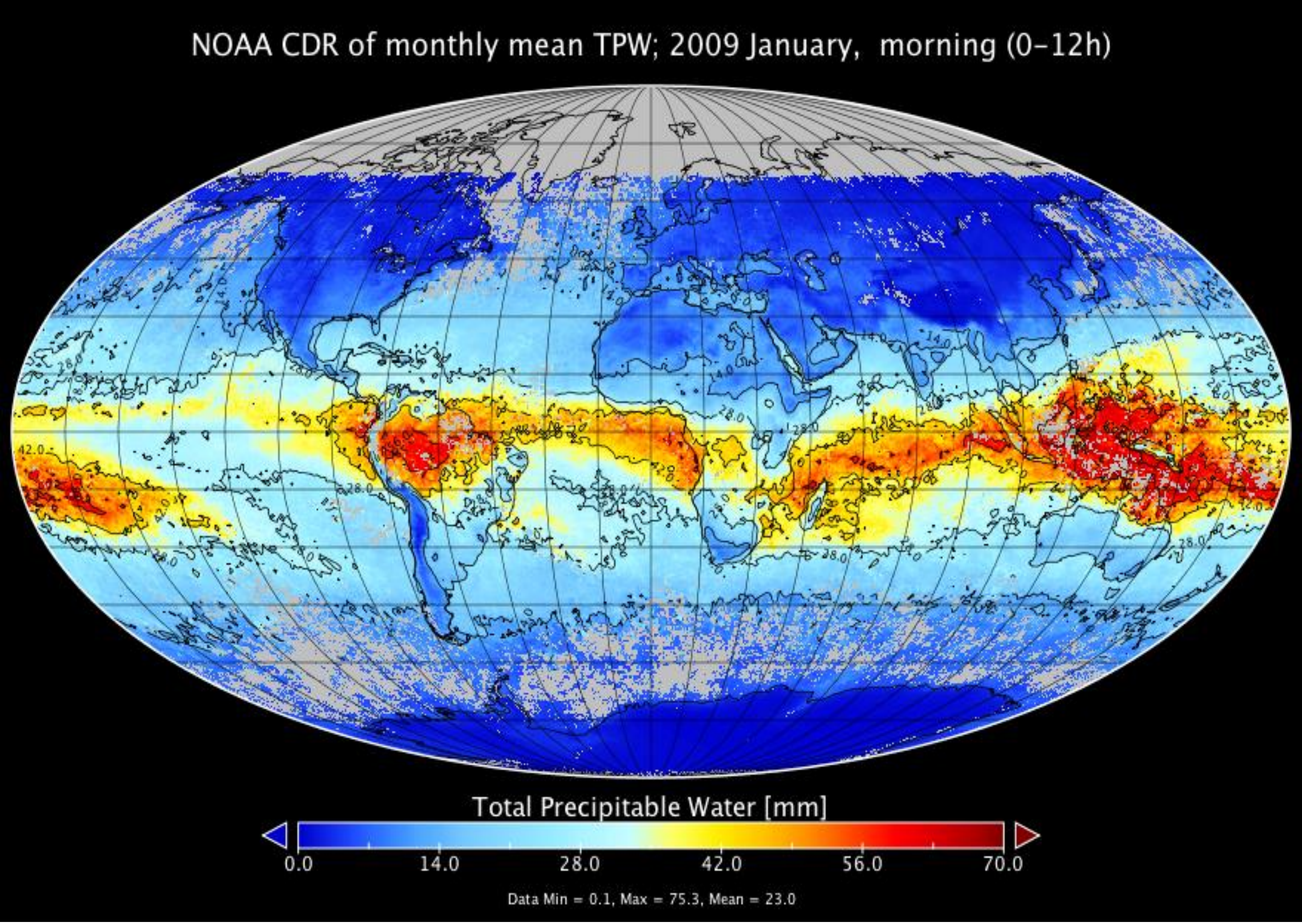
Morning SZA <= 85^o and Local Time Before Noon

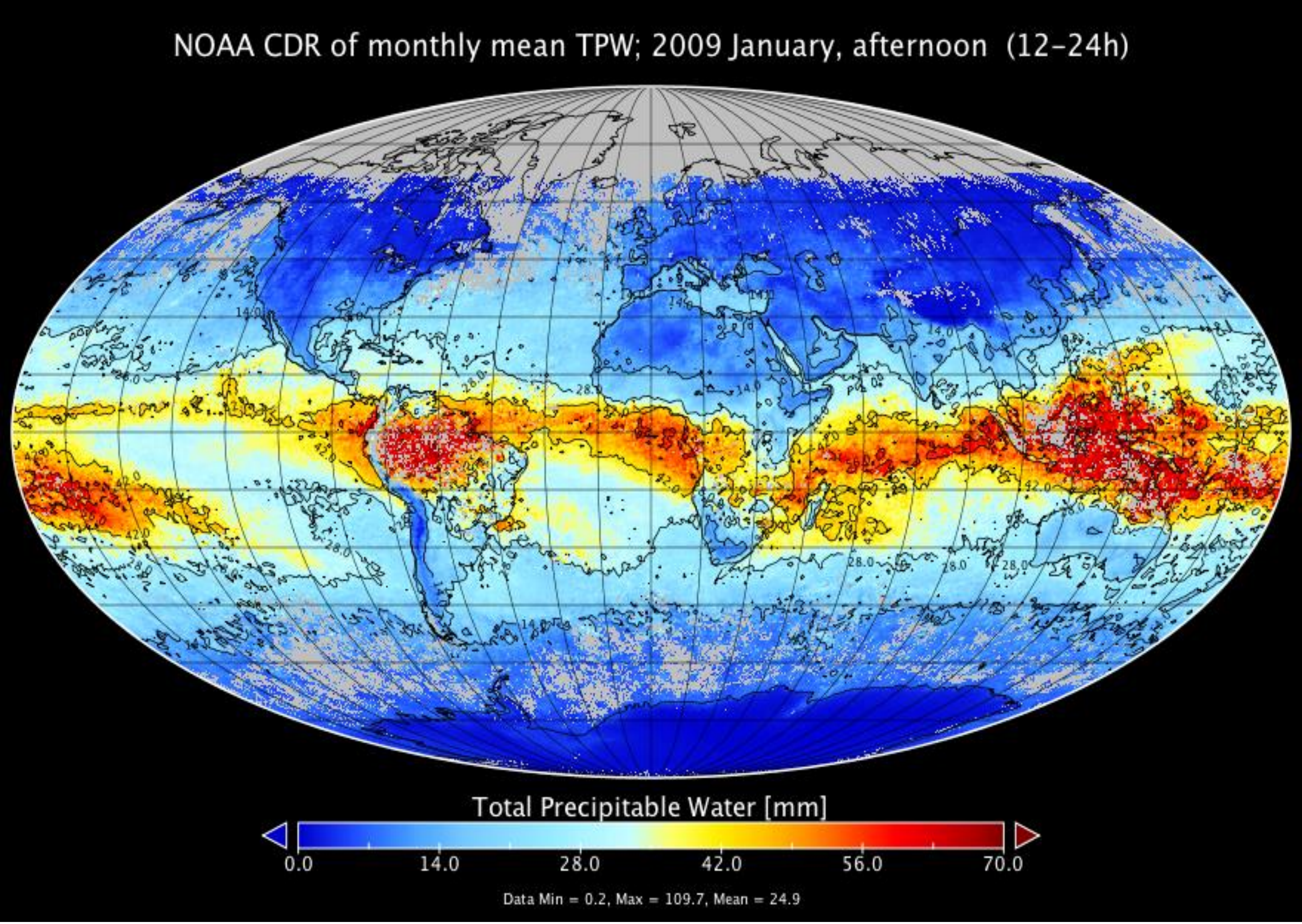
Afternoon SZA <= 85^o and Local Time After Noon

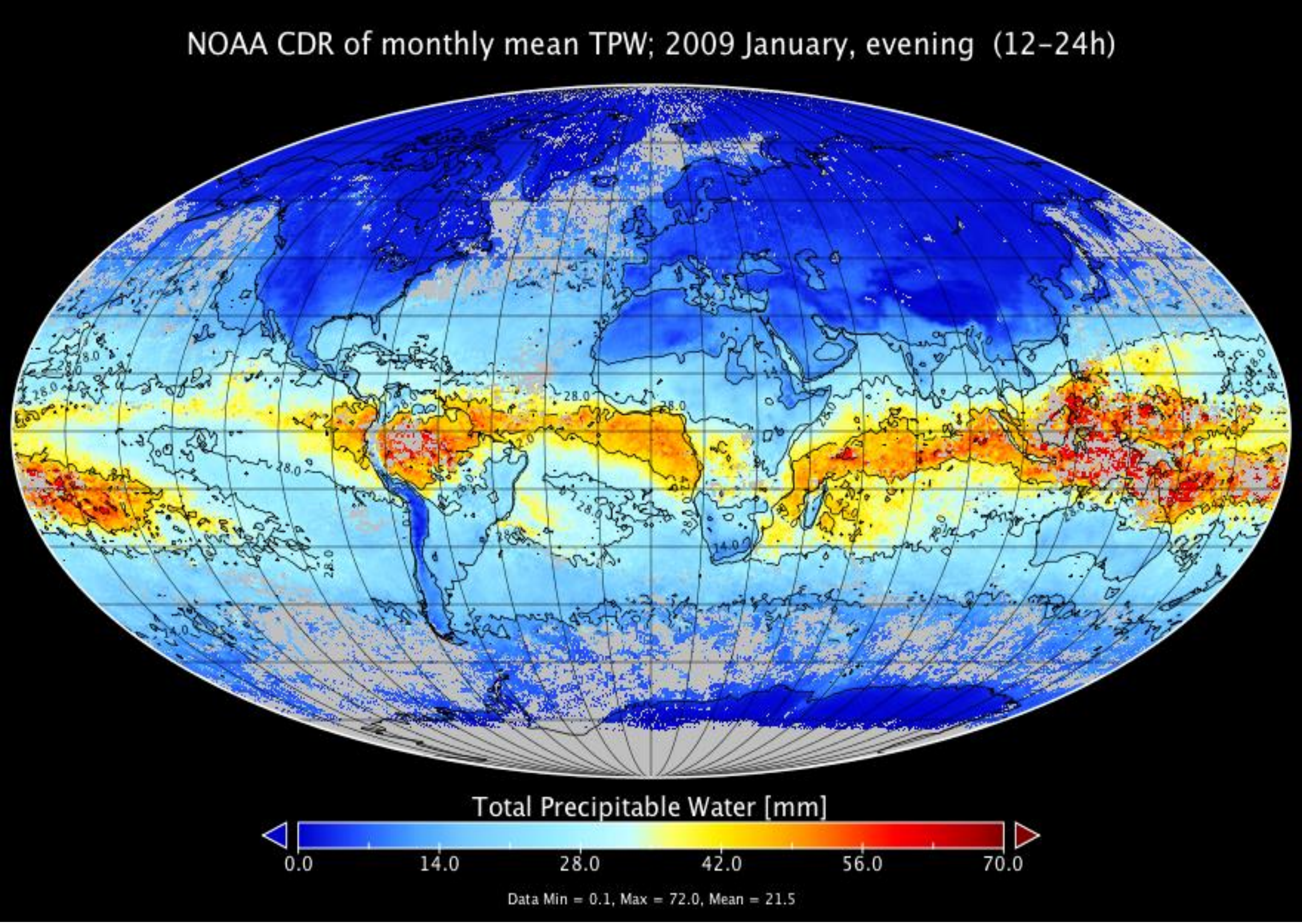
Evening SZA > 85^o and Local Time Before Midnight

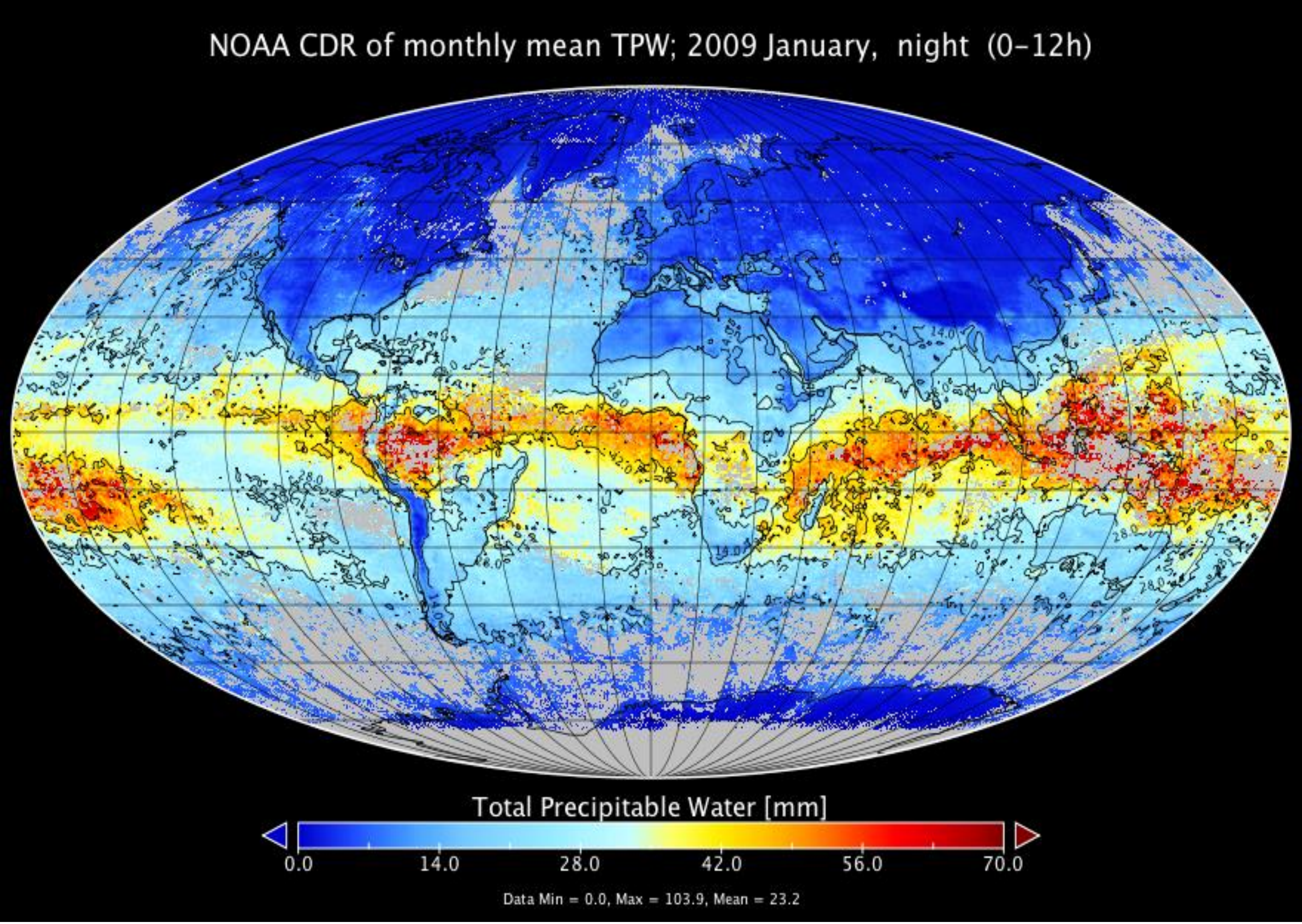
Night SZA > 85^o and Local Time After Midnight

Accounting for and taking advantage of orbit drift


NOAA CDR of monthly mean TPW; 2009 January, morning (0-12h)
Total Precipitable Water [mm]
0.0
14.0
28.0
42.0
56.0
70.0
Data Min = 0.1, Max = 75.3, Mean = 23.0

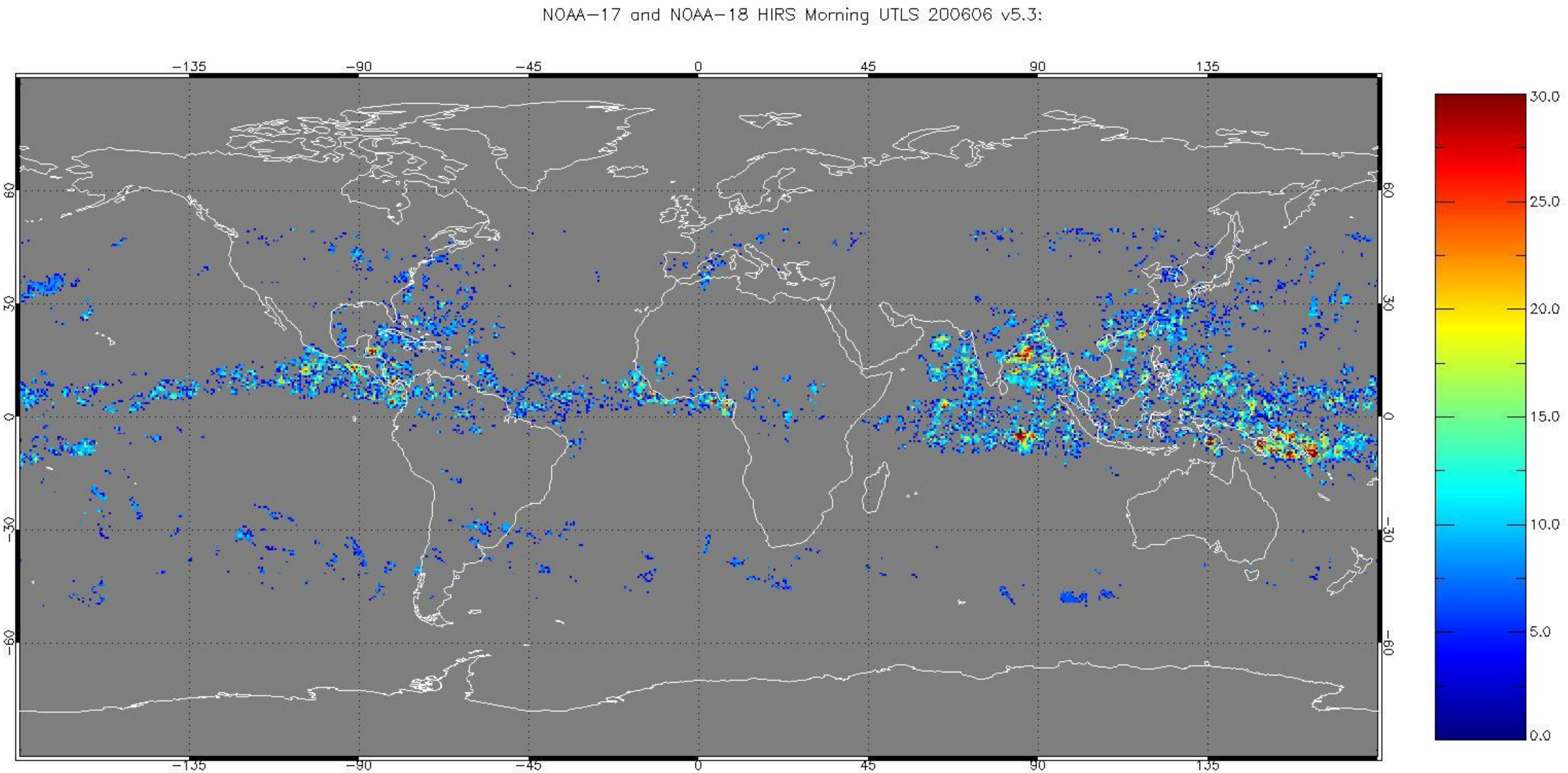

NOAA CDR of monthly mean TPW; 2009 January, afternoon (12-24h)
Total Precipitable Water [mm]
0.0
14.0
28.0
42.0
56.0
70.0
Data Min = 0.2, Max = 109.7, Mean = 24.9


NOAA CDR of monthly mean TPW; 2009 January, evening (12-24h)
Total Precipitable Water [mm]
0.0
14.0
28.0
42.0
56.0
70.0
Data Min = 0.1, Max = 72.0, Mean = 21.5



NOAA CDR of monthly mean TPW; 2009 January, night (0-12h)
Total Precipitable Water [mm]
0.0
14.0
28.0
42.0
56.0
70.0
Data Min = 0.0, Max = 103.9, Mean = 23.2

Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency



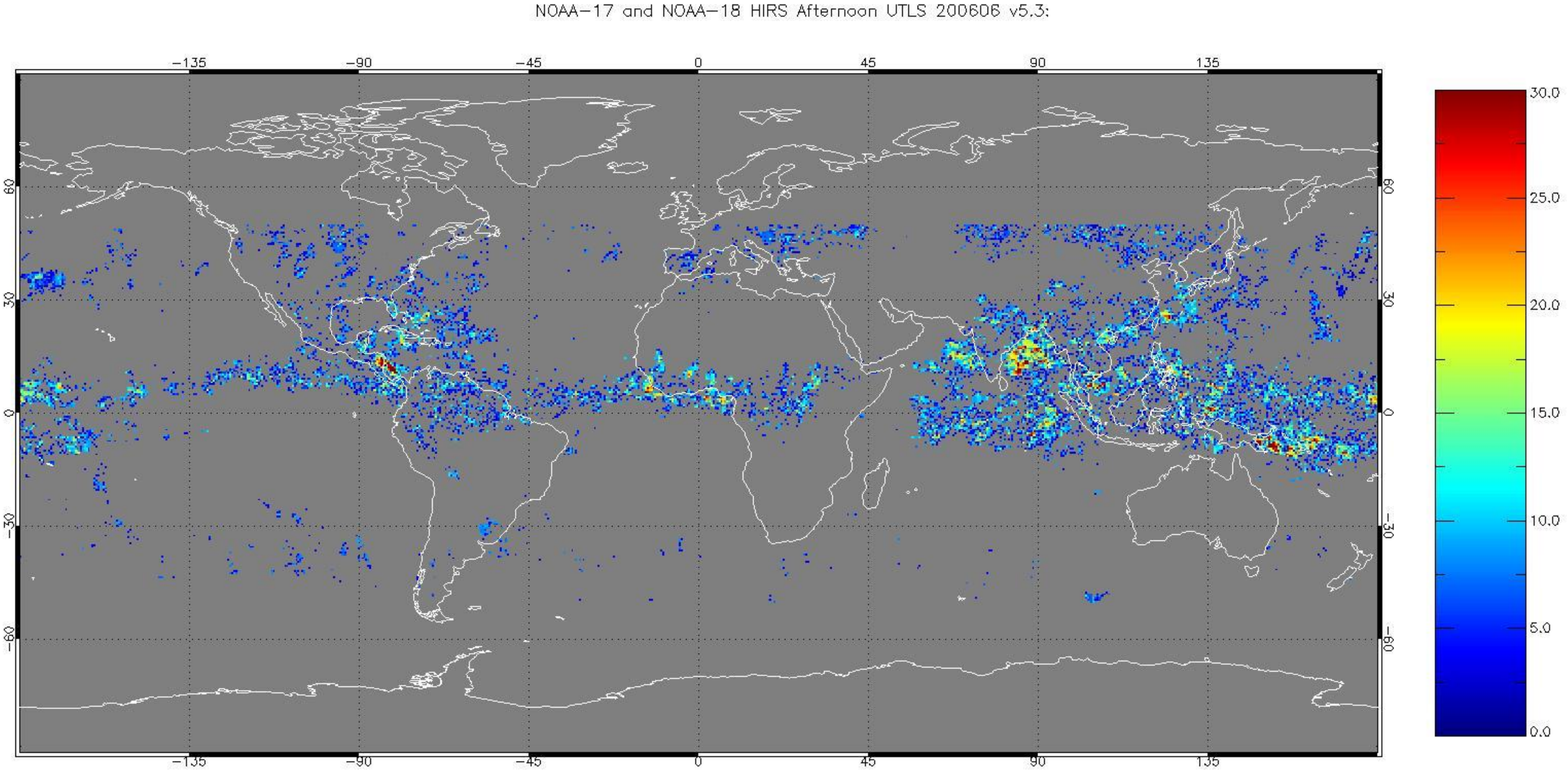
UTLS Frequency in Percent

Morning June 2006

SZA <= 85^{o} and Local Time Before Noon

Spatial Resolution is 0.5^{o} Equal Angle

Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency



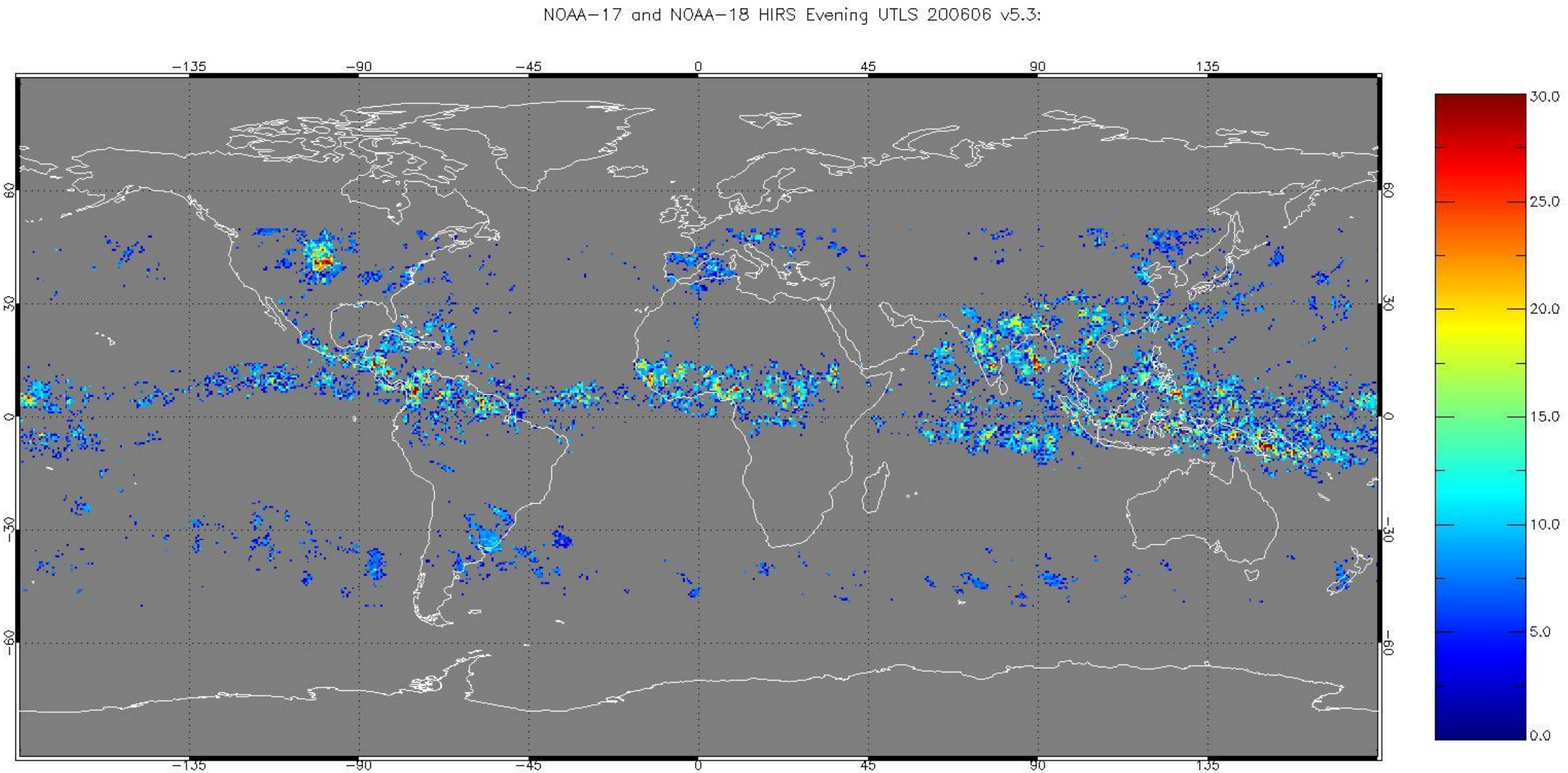
UTLS Frequency in Percent

Afternoon June 2006

SZA <= 85^{o} and Local Time After Noon

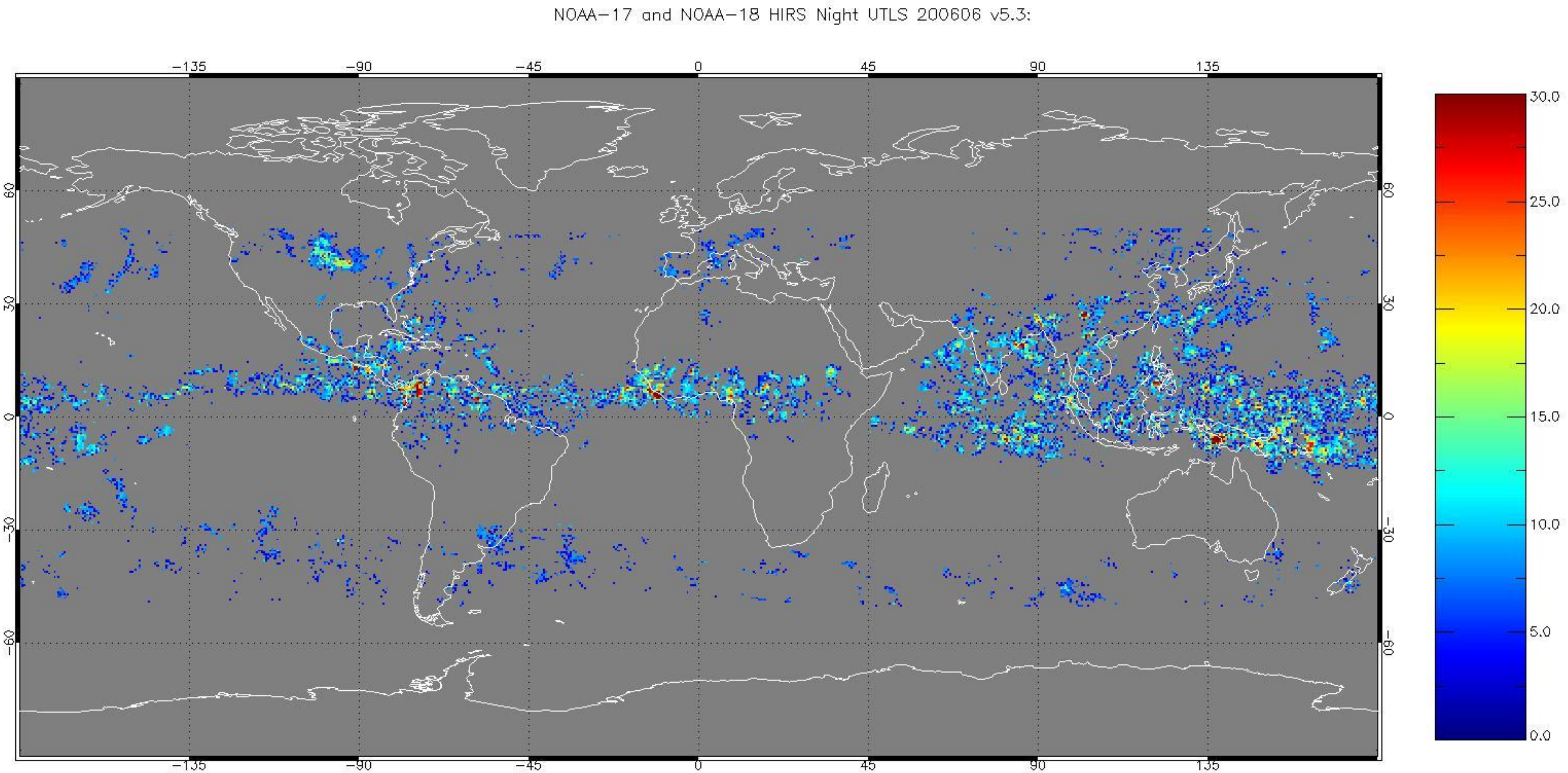
Spatial Resolution is 0.5^{o} Equal Angle

Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency



UTLS Frequency in Percent
Evening June 2006
SZA > 85º and Local Time Before Midnight
Spatial Resolution is 0.5º Equal Angle

Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency



UTLS Frequency in Percent

Night June 2006

SZA > 85^{o} and Local Time After Midnight

Spatial Resolution is 0.5^{o} Equal Angle

HIRS High Cloud Detection Trends

Comparing N11 and N14

CTPs using CO2 Slicing

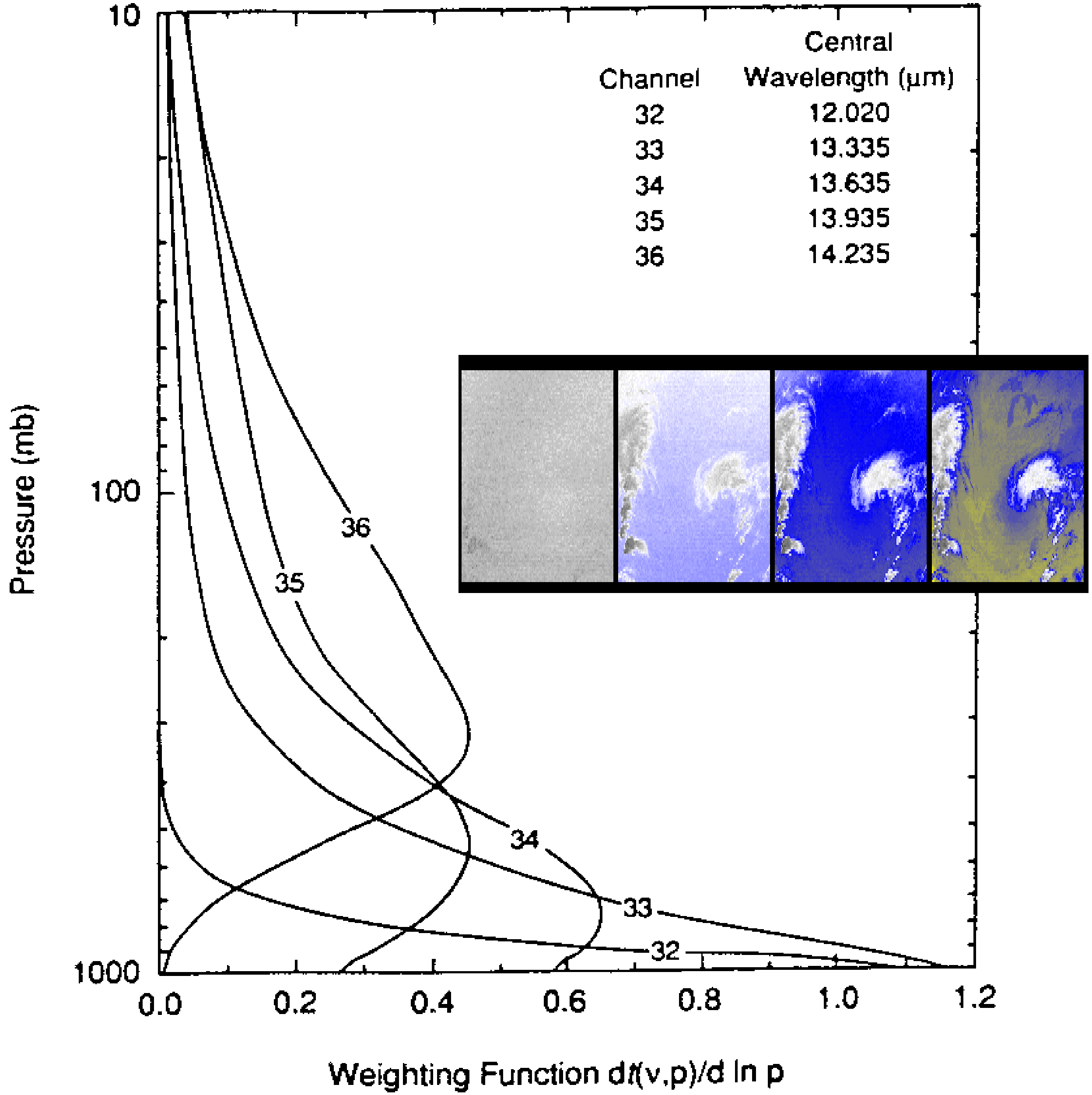
Different ratios reveal cloud properties at different levels

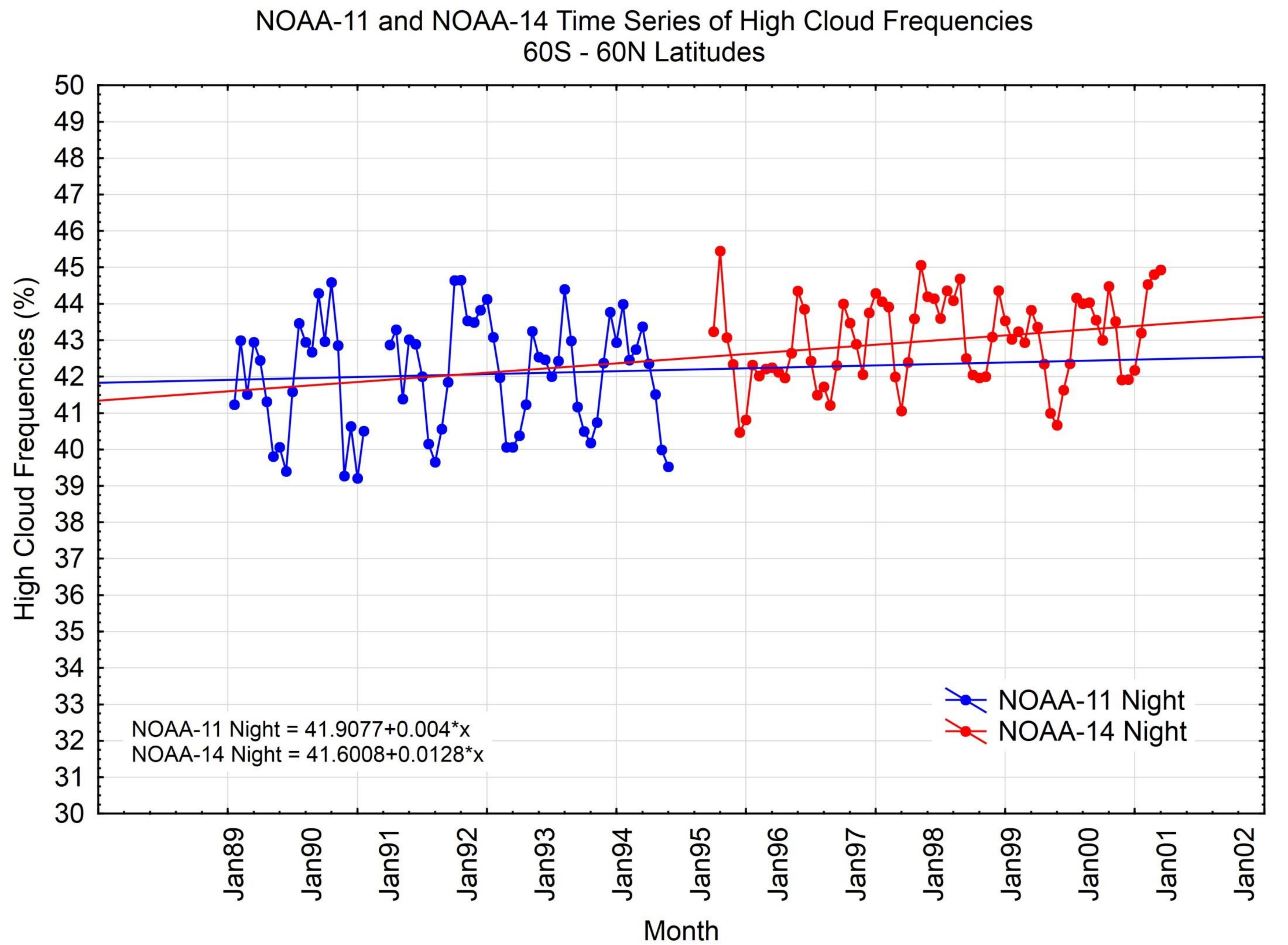
hi - 14.2/13.9
mid - 13.9/13.6
low - 13.6/13.3

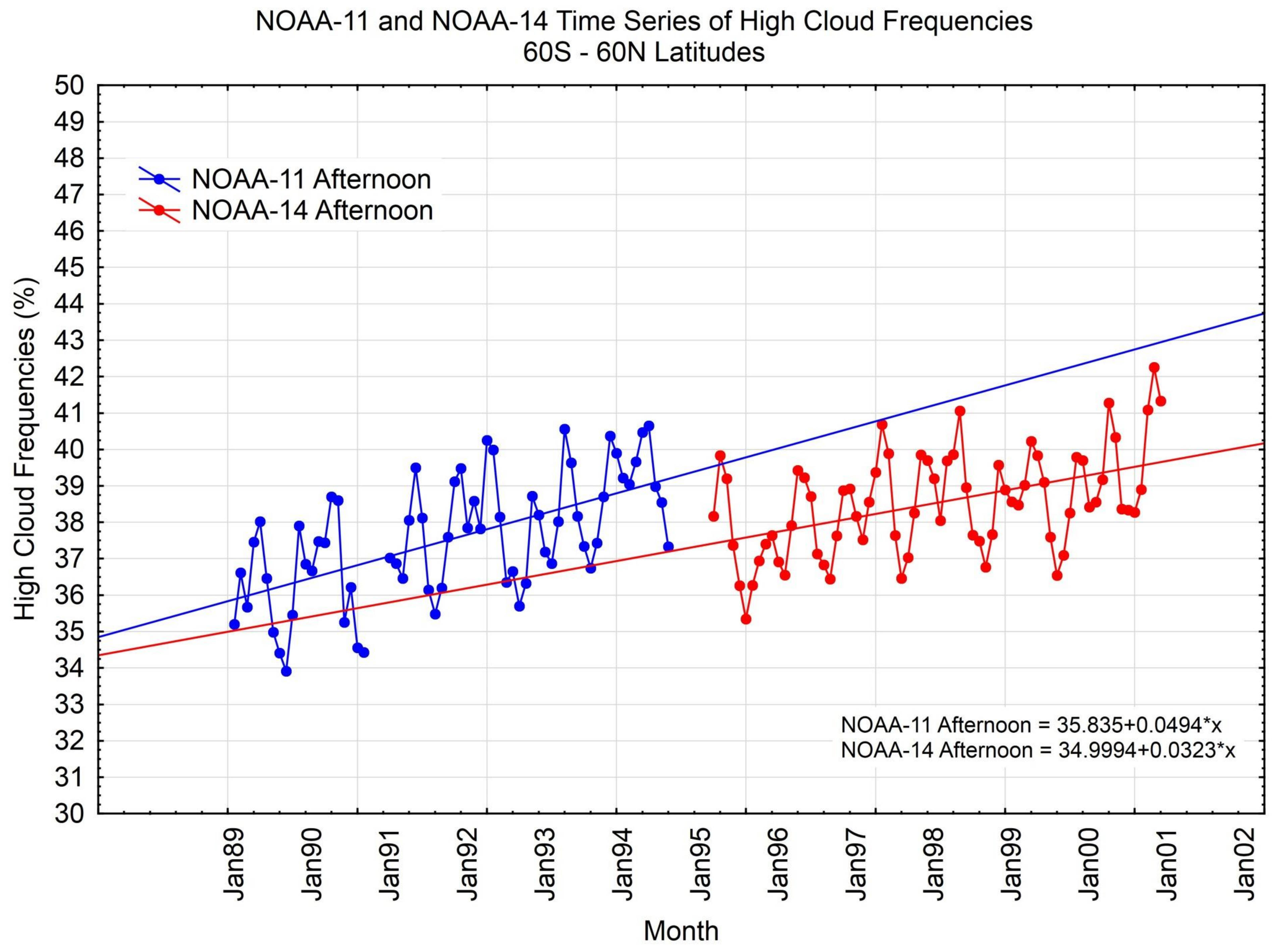
Meas **Calc**

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

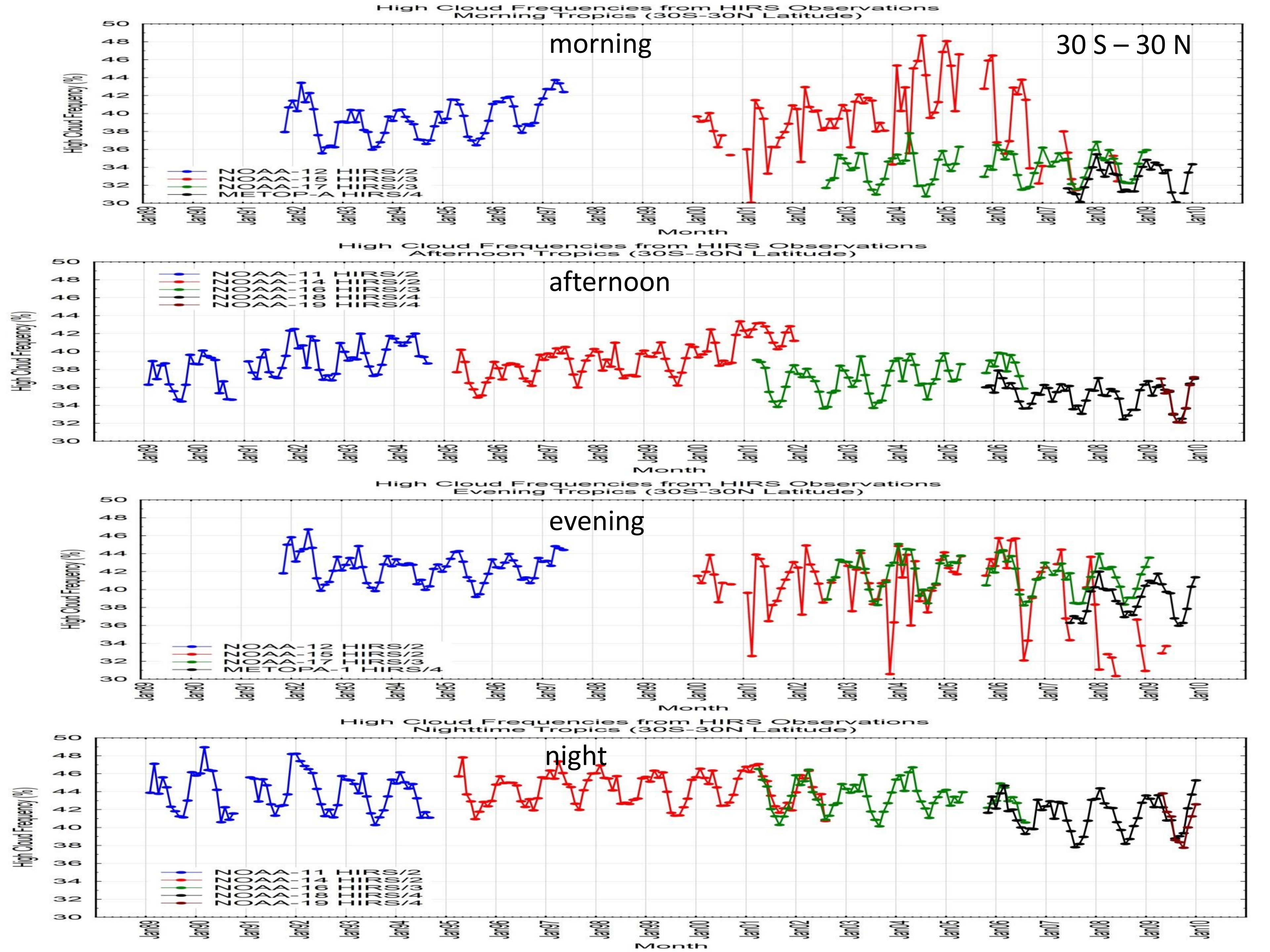
if $(I_{\lambda}^{clr} - I_{\lambda}) < \Delta$
then IRW is used



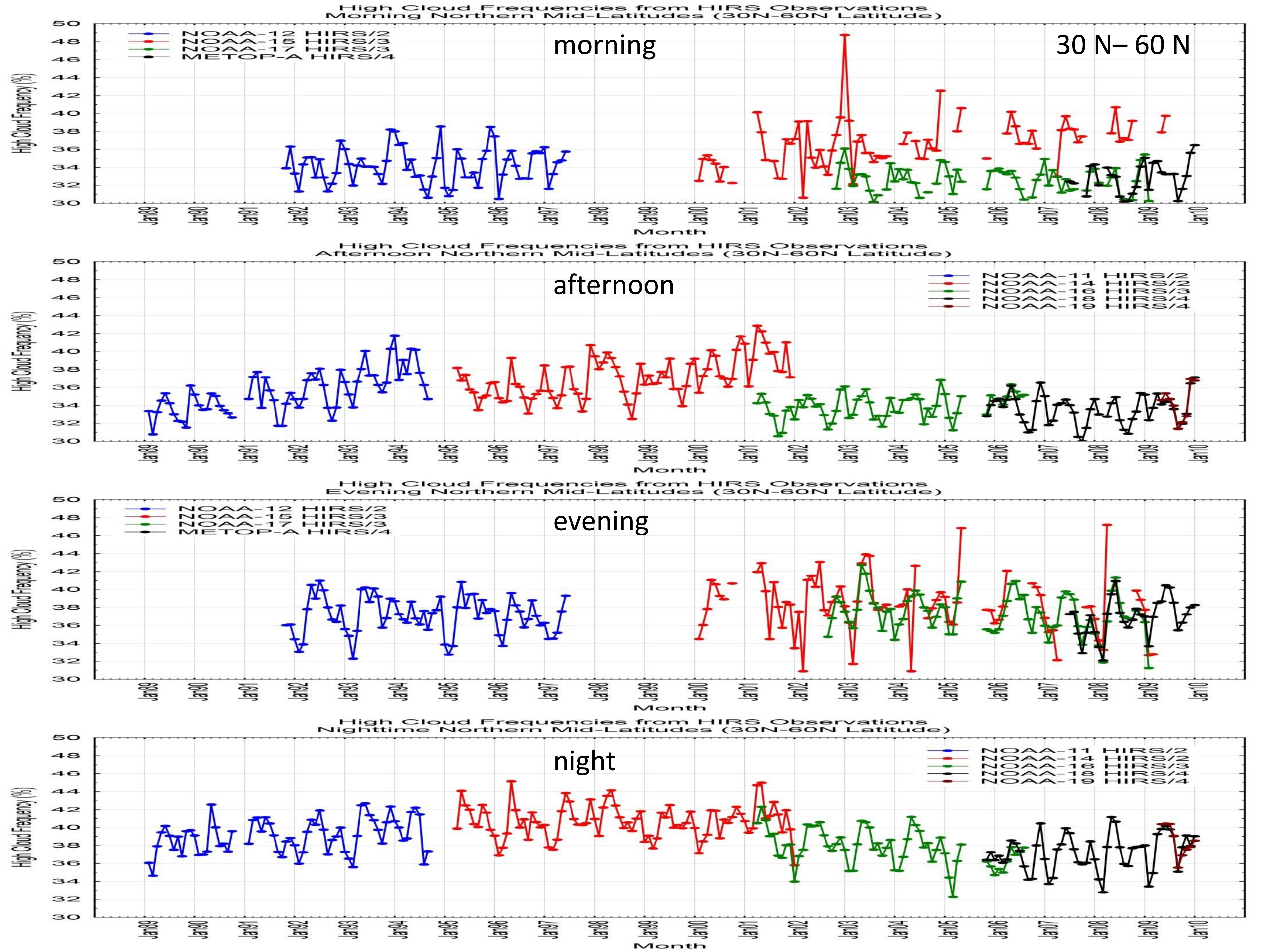

NOAA-11 and NOAA-14 Time Series of High Cloud Frequencies
60S - 60N Latitudes
High Cloud Frequencies (%)
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
Jan89
Jan90
Jan91
Jan92
Jan93
Jan94
Jan95
Jan96
Jan97
Jan98
Jan99
Jan00
Jan01
Jan02
Month
NOAA-11 Night
NOAA-14 Night
NOAA-11 Night = 41.9077+0.004*x
NOAA-14 Night = 41.6008+0.0128*x

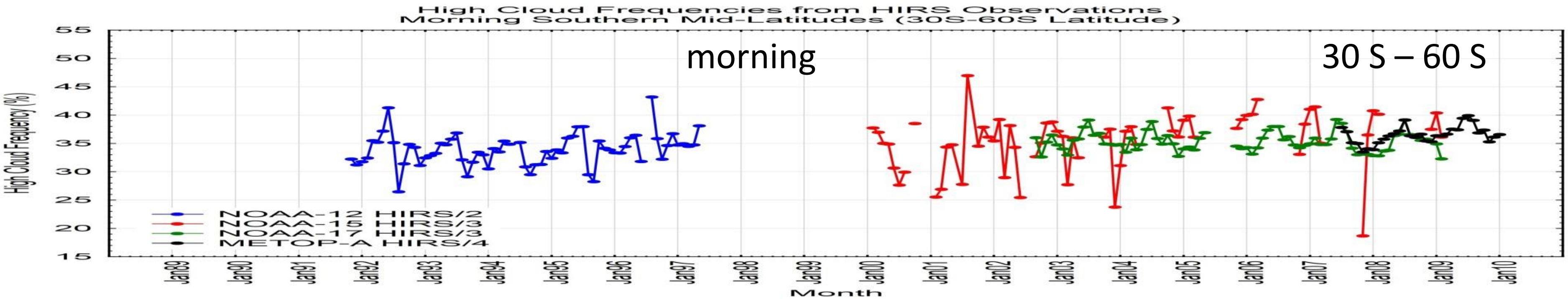


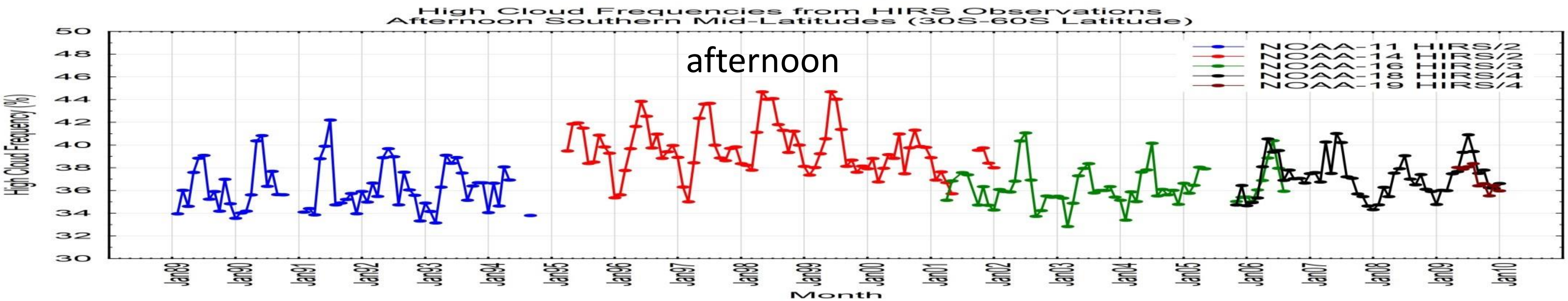
NOAA-11 and NOAA-14 Time Series of High Cloud Frequencies
60S - 60N Latitudes
High Cloud Frequencies (%)
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
NOAA-11 Afternoon
NOAA-14 Afternoon
NOAA-11 Afternoon = 35.835+0.0494*x
NOAA-14 Afternoon = 34.9994+0.0323*x
Jan89
Jan90
Jan91
Jan92
Jan93
Jan94
Jan95
Jan96
Jan97
Jan98
Jan99
Jan00
Jan01
Jan02
Month

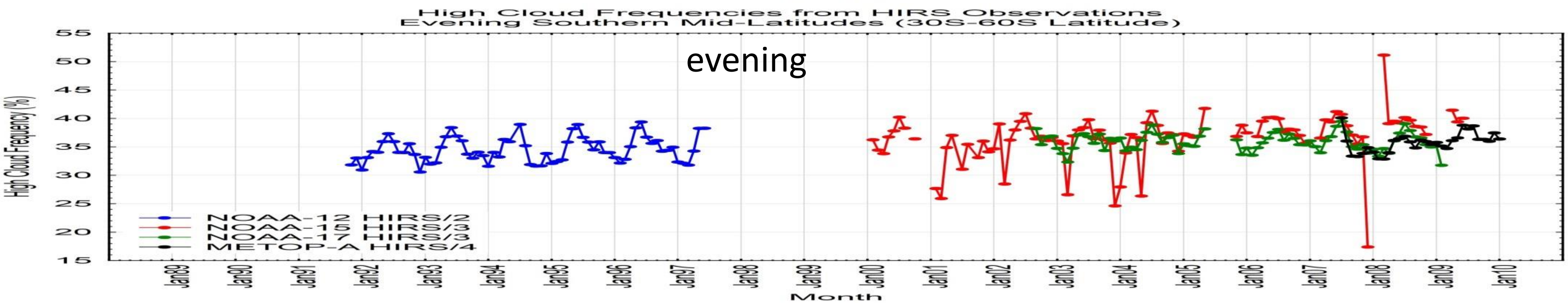


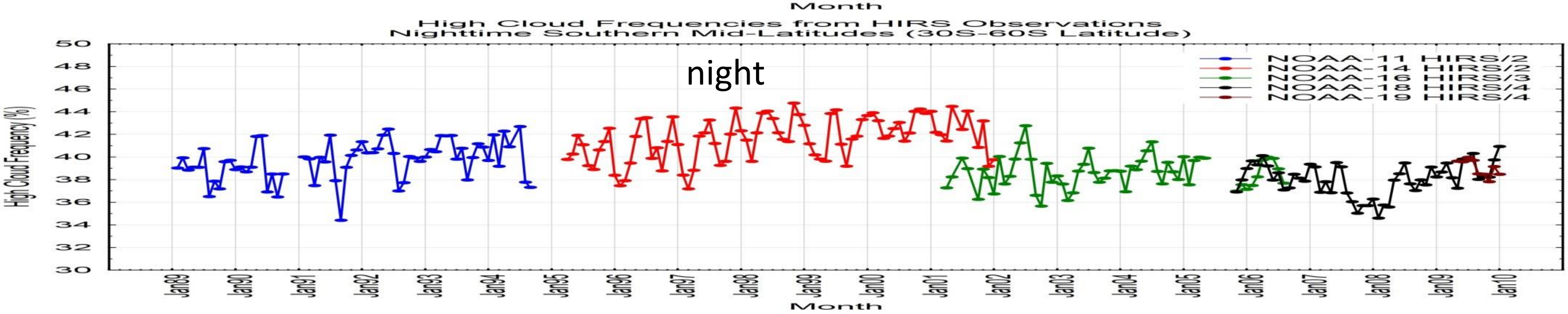
High Cloud Frequencies from HIRS Observations
Morning Tropics (30S-30N Latitude)
morning
30 S – 30 N
NOAA-12 HIRS/2
NOAA-15 HIRS/3
NOAA-17 HIRS/3
METOP-A HIRS/4
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Afternoon Tropics (30S-30N Latitude)
afternoon
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Evening Tropics (30S-30N Latitude)
evening
NOAA-12 HIRS/2
NOAA-15 HIRS/2
NOAA-17 HIRS/3
METOPA-1 HIRS/4
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Nighttime Tropics (30S-30N Latitude)
night
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4
High Cloud Frequency (%)
Month


High Cloud Frequencies from HIRS Observations
Morning Northern Mid-Latitudes (30N-60N Latitude)
NOAA-12 HIRS/2
NOAA-15 HIRS/3
NOAA-17 HIRS/3
METOP-A HIRS/4
morning
30 N– 60 N
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Afternoon Northern Mid-Latitudes (30N-60N Latitude)
afternoon
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Evening Northern Mid-Latitudes (30N-60N Latitude)
NOAA-12 HIRS/2
NOAA-15 HIRS/3
NOAA-17 HIRS/3
METOP-A HIRS/4
evening
High Cloud Frequency (%)
Month
High Cloud Frequencies from HIRS Observations
Nighttime Northern Mid-Latitudes (30N-60N Latitude)
night
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4
High Cloud Frequency (%)
Month


High Cloud Frequencies from HIRS Observations
Morning Southern Mid-Latitudes (30S-60S Latitude)
morning
30 S – 60 S
High Cloud Frequency (%)
Month
NOAA-12 HIRS/2
NOAA-15 HIRS/3
NOAA-17 HIRS/3
METOP-A HIRS/4


High Cloud Frequencies from HIRS Observations
Afternoon Southern Mid-Latitudes (30S-60S Latitude)
afternoon
High Cloud Frequency (%)
Month
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4


High Cloud Frequencies from HIRS Observations
Evening Southern Mid-Latitudes (30S-60S Latitude)
evening
High Cloud Frequency (%)
Month
NOAA-12 HIRS/2
NOAA-15 HIRS/3
NOAA-17 HIRS/3
METOP-A HIRS/4


High Cloud Frequencies from HIRS Observations
Nighttime Southern Mid-Latitudes (30S-60S Latitude)
night
High Cloud Frequency (%)
Month
NOAA-11 HIRS/2
NOAA-14 HIRS/2
NOAA-16 HIRS/3
NOAA-18 HIRS/4
NOAA-19 HIRS/4

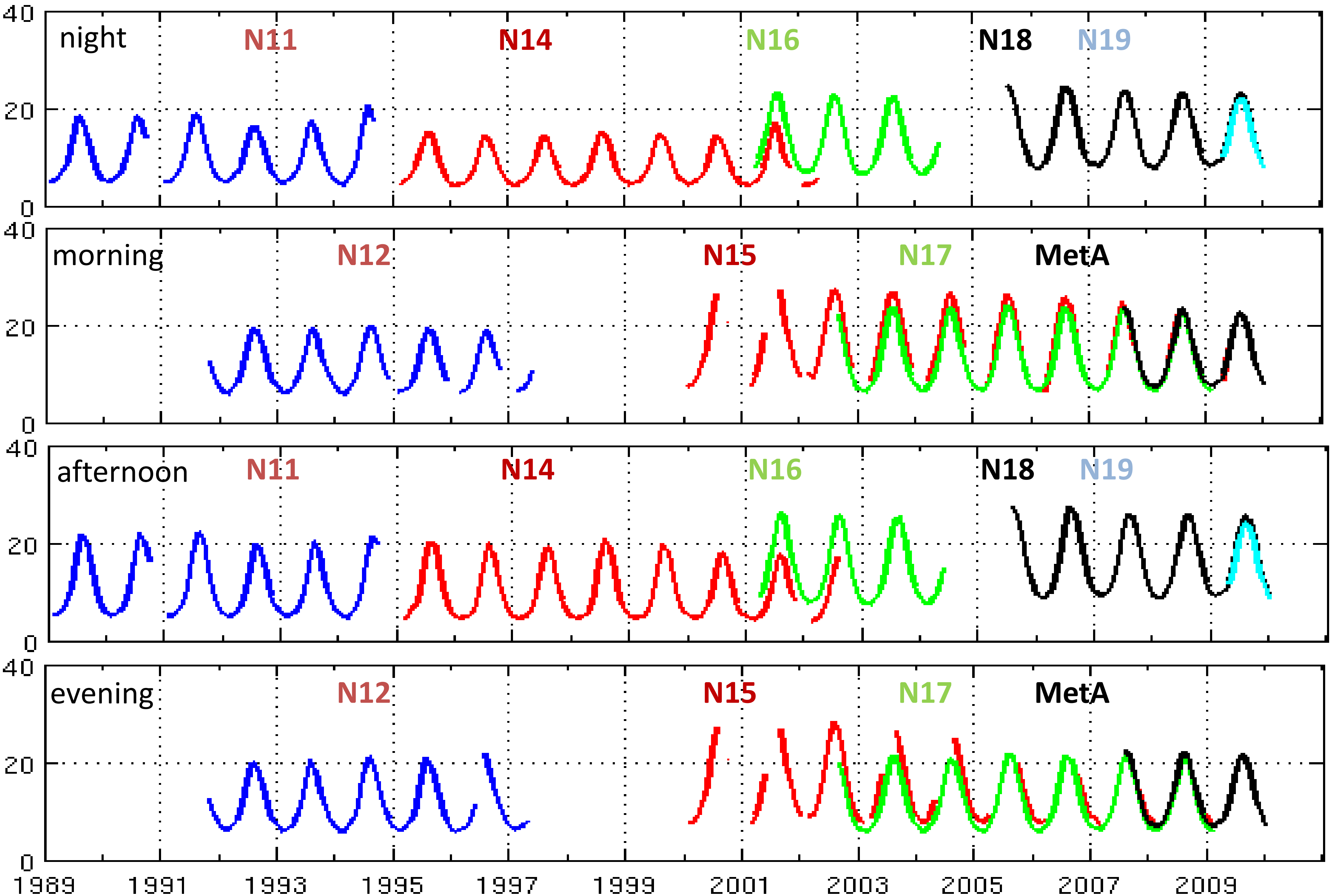
HIRS TPW and UTH Trends

Comparing with Aqua MODIS

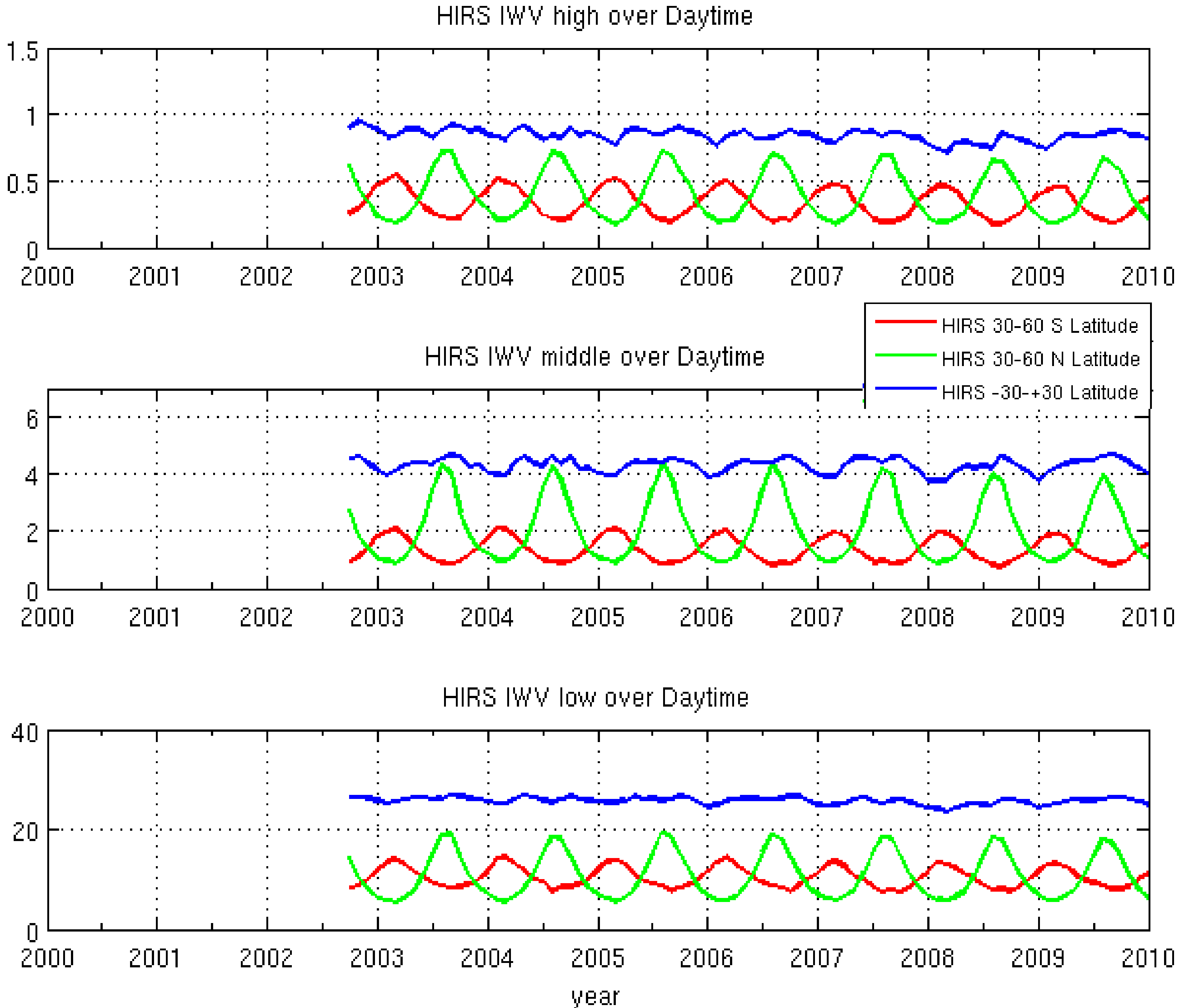
HIRS TPW and UTH

HIRS TPW and UTH is a statistical regression developed from the SeeBor data base (Borbas et al. 2005) that consists of geographically and seasonally distributed radiosonde, ozonesonde, and ECMWF ReAnalysis data. TPW are determined for clear sky radiances measured by HIRS over land and ocean both day and night. The retrieval approach is borrowed from MODIS (Seemann et al. 2003, Seemann et al. 2008). There is strong reliance on radiances from 6.5, 11, 12 μm.

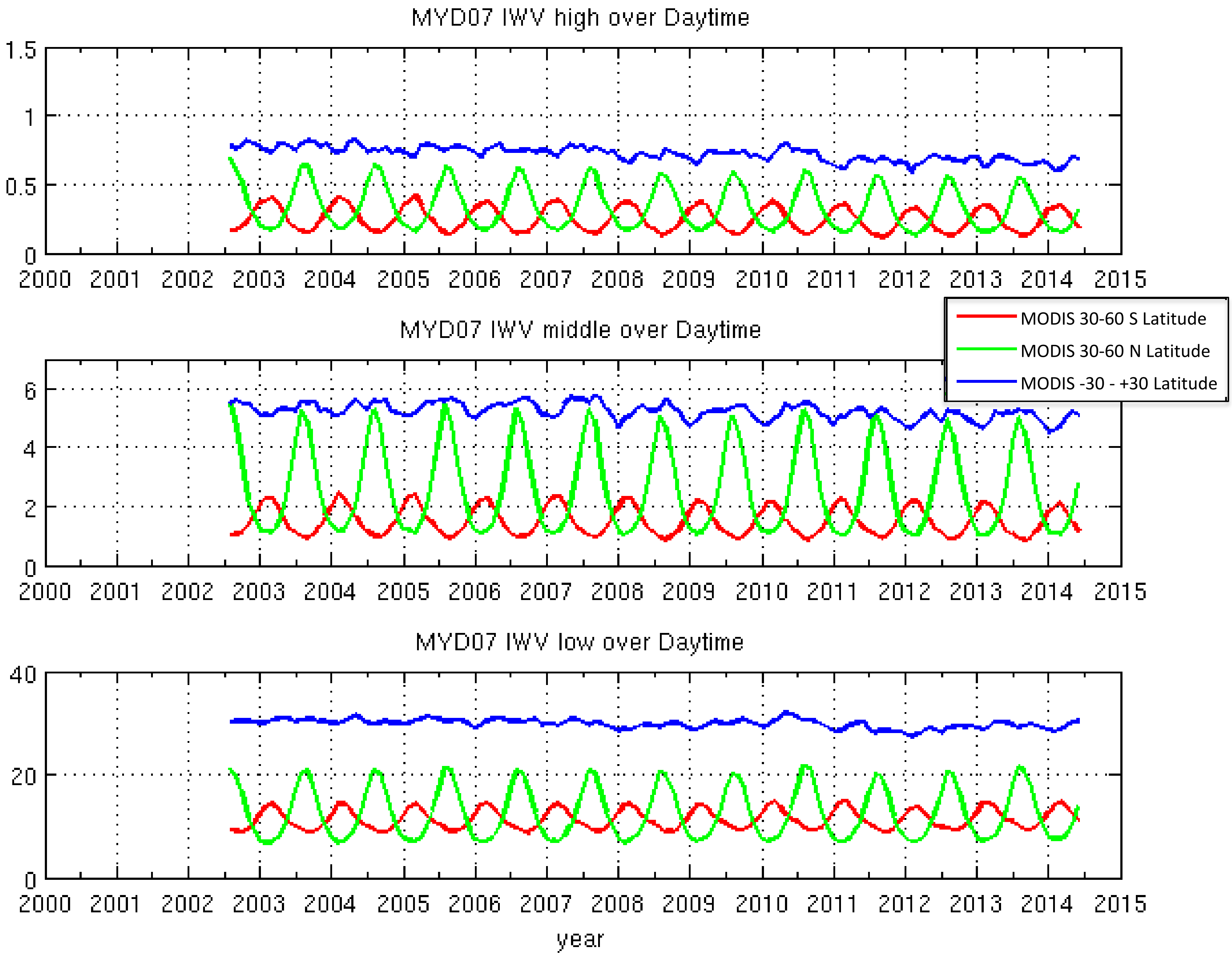
Time series of TPW for Northern Mid-latitudes 1989 - 2010

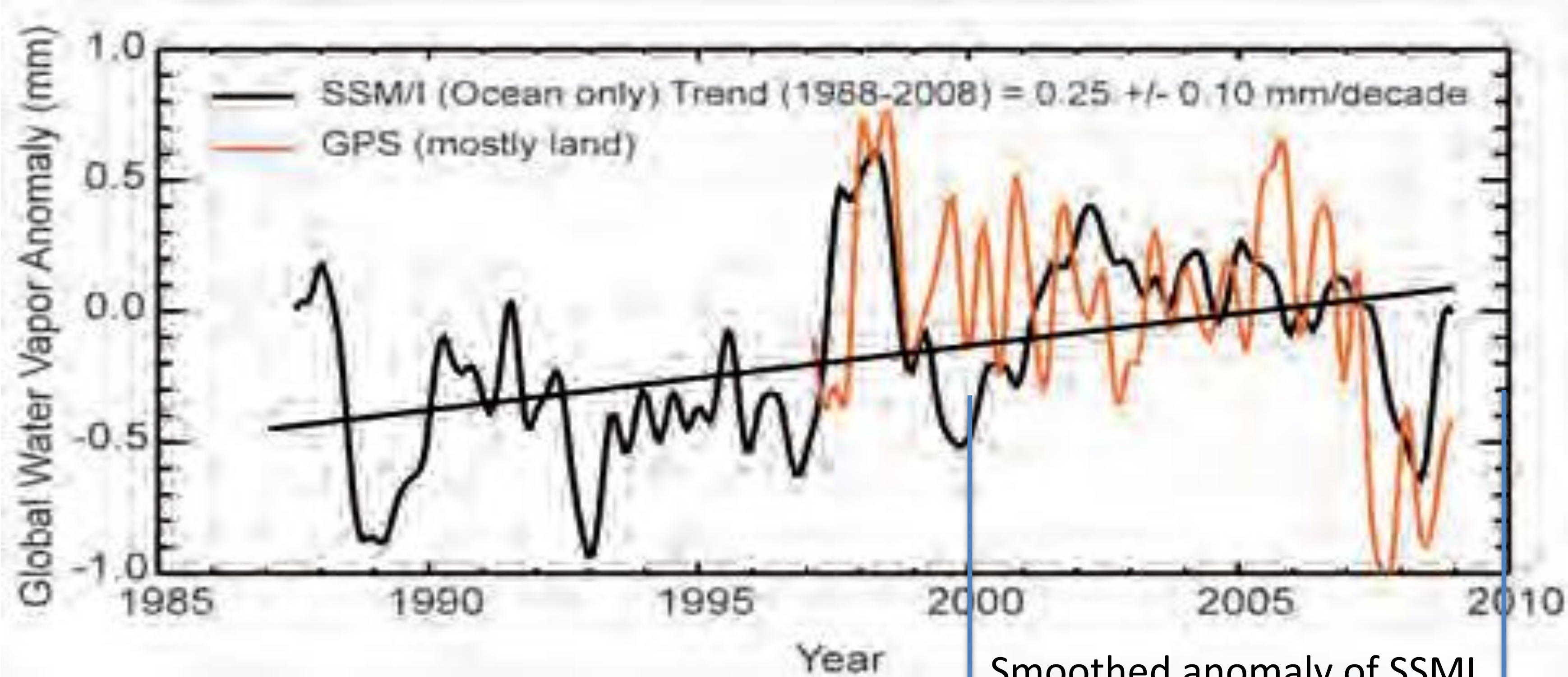


Timeseries of N17/HIRS IWV high, middle and low over Daytime

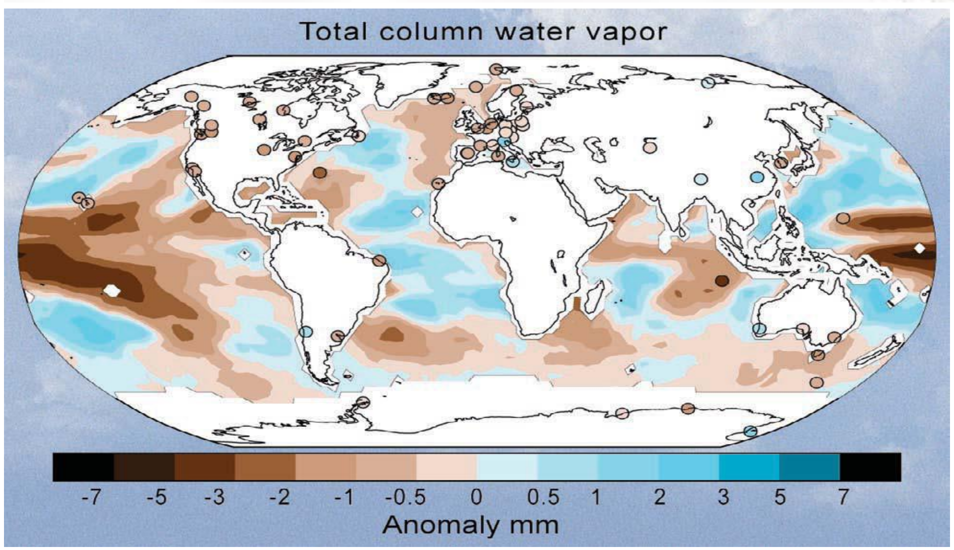


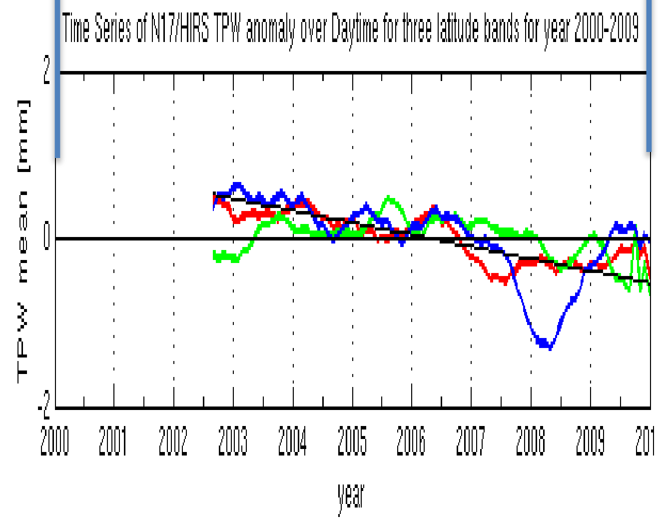
Timeseries of MYD07 IWV high, middle and low over Daytime





Smoothed anomaly of SSMI and HIRS TPW





2008 La Nina Water Vapor 10 yr Anomaly

Conclusions

Regarding Recalibration
* Metop HIRS recalibration using IASI offers best HIRS reference
* Recalibration against reference HIRS mitigates but does not eliminate sensor to sensor differences
* Dividing the day into 4 time periods mitigates but does not eliminate effects of orbit drift

Regarding High Cloud Trends
* HIRS radiance data is being processed with MODIS CO2-slicing algorithm
* Afternoon cloud trends are affected by orbit drift
* Frequency of night time cloud is greater than that in afternoon (cloud mask issue??)
* 10 km FOV (HIRS4) sees fewer clouds than 20 km FOV (HIRS3 & HIRS2)
* N15 remains out of family
* Most HIRS to HIRS comparisons are in good agreement

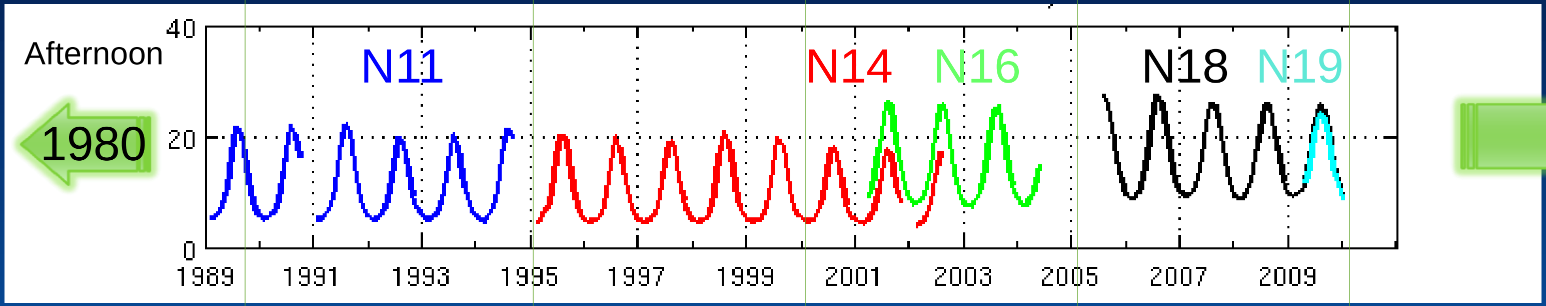
Regarding H2O Trends
* Seasonal TPW cycle is strongest in northern mid-latitudes and weakest in tropics
* Seasonal TPW cycle is stronger in the afternoon than at night
* La Nina decrease in tropical TPW is evident
* Recalibrating IR split window needed to mitigate sensor to sensor TPW issues
* Decrease in TPW from 2002 to 2008 and increase after 2008 is suggested

Overall
* Processing whole HIRS record from 1978 onwards will reveal trends better

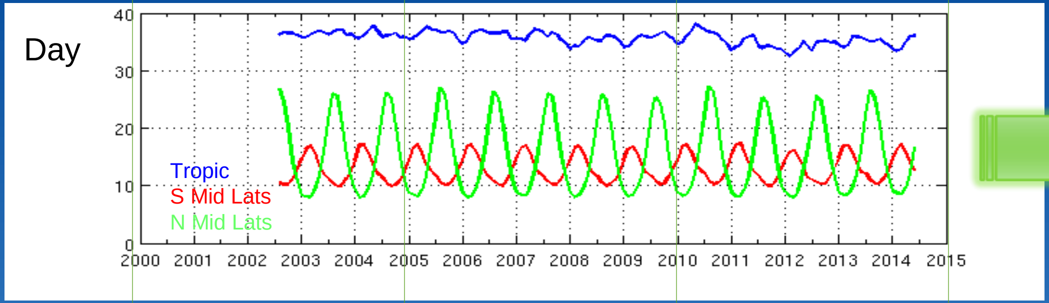
Timeline

1990 2000 2010

HIRS Northern Mid latitude (30N-60N)



Aqua/MODIS Northern Mid latitude (30N-60N - green)



S-NPP/VIIRS Northern Mid latitude (30N-60N – green)