INFERRING THREE DECADES OF GLOBAL CLOUD AND MOISTURE PROPERTIES FROM THE HIRS DATA RECORD

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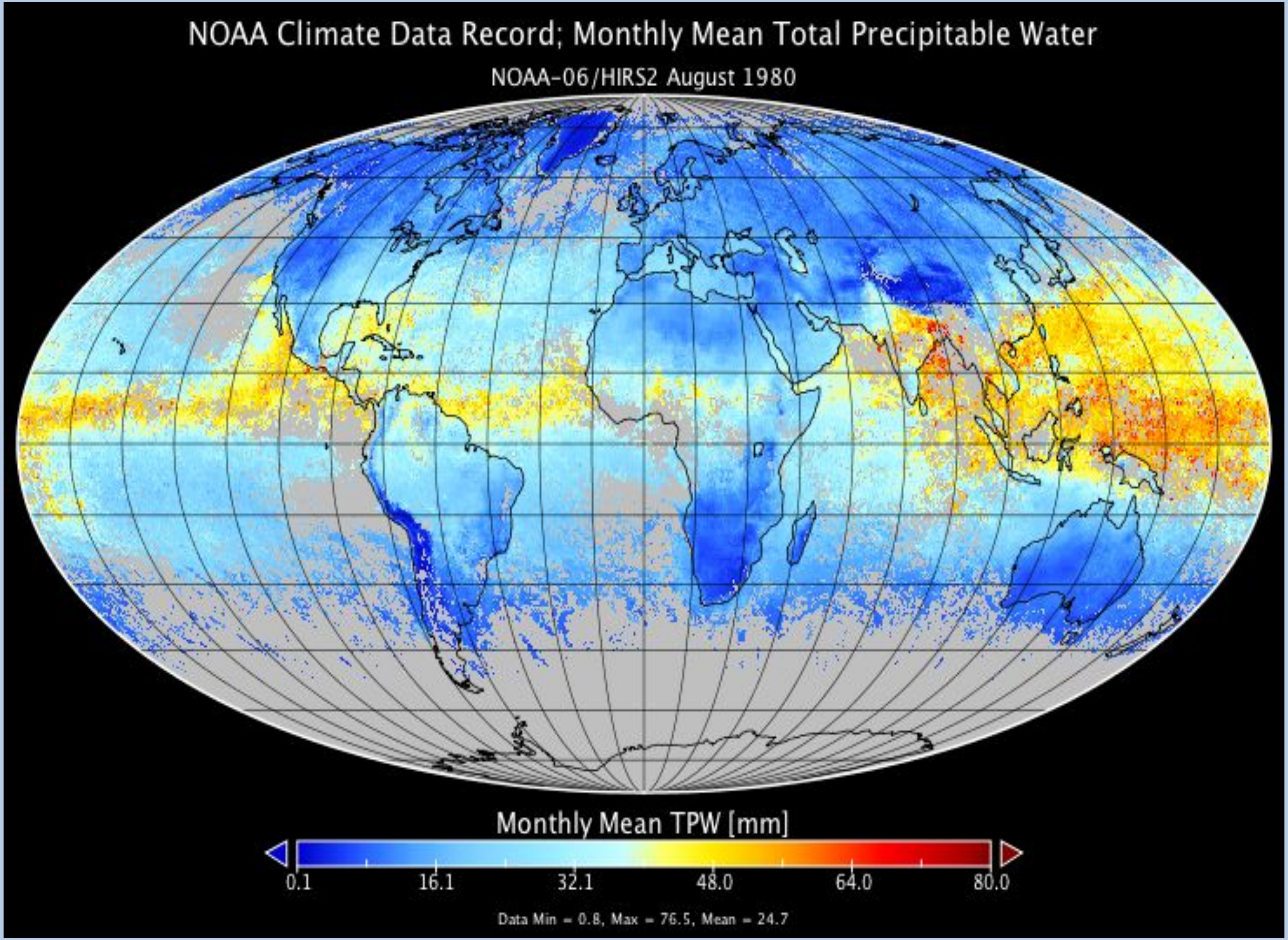
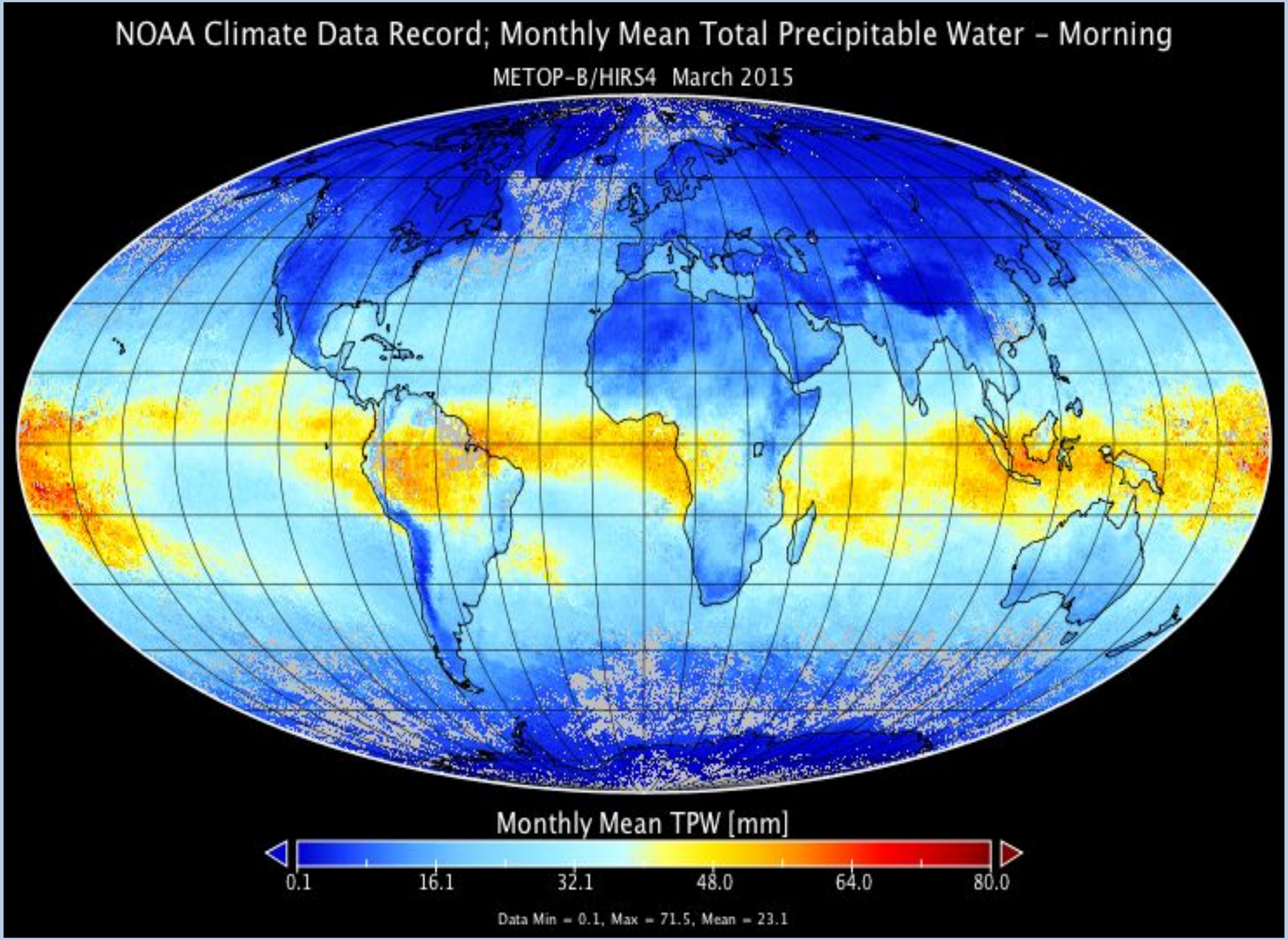
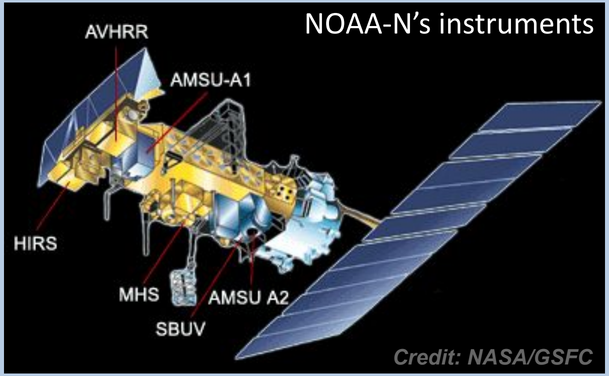

NOAA Climate Data Record; Monthly Mean Total Precipitable Water
NOAA-06/HIRS2 August 1980
Monthly Mean TPW [mm]
0.1
16.1
32.1
48.0
64.0
80.0
Data Min = 0.8, Max = 76.5, Mean = 24.7

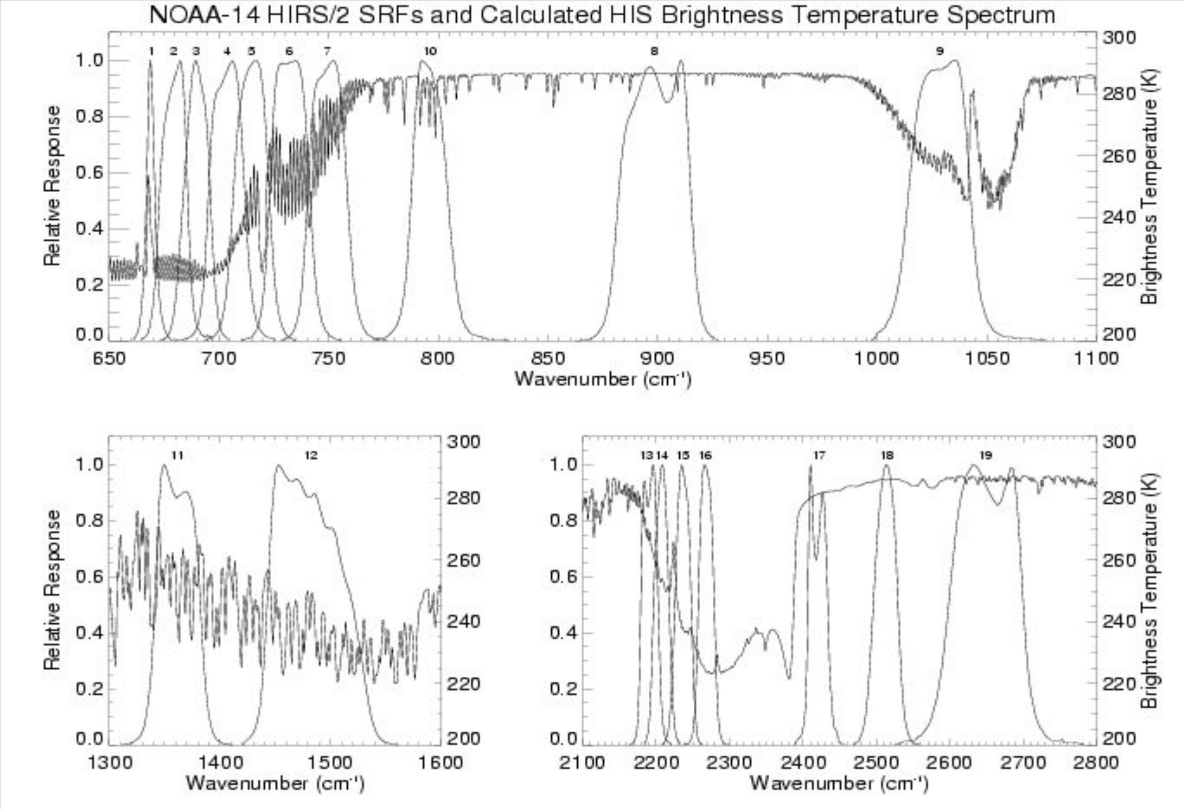

NOAA Climate Data Record; Monthly Mean Total Precipitable Water - Morning
METOP-B/HIRS4 March 2015
Monthly Mean TPW [mm]
0.1
16.1
32.1
48.0
64.0
80.0
Data Min = 0.1, Max = 71.5, Mean = 23.1

HIRS- High-Resolution Infrared Radiation Sounder

- HIRS is a 20-channel infrared scanning radiometer that performs operational atmospheric sounding
- HIRS has 19 infrared channels (3.8–15µm) and one visible channel.
- Channels 1–7 are the CO2 channels; Channel 8 is a window channel, Channel 9 is for ozone, Channel 10 is a split-window channel, and Channels 11 and 12 are water vapor channels.



Spectral Response Functions of NOAA-14/HIRS2 channels

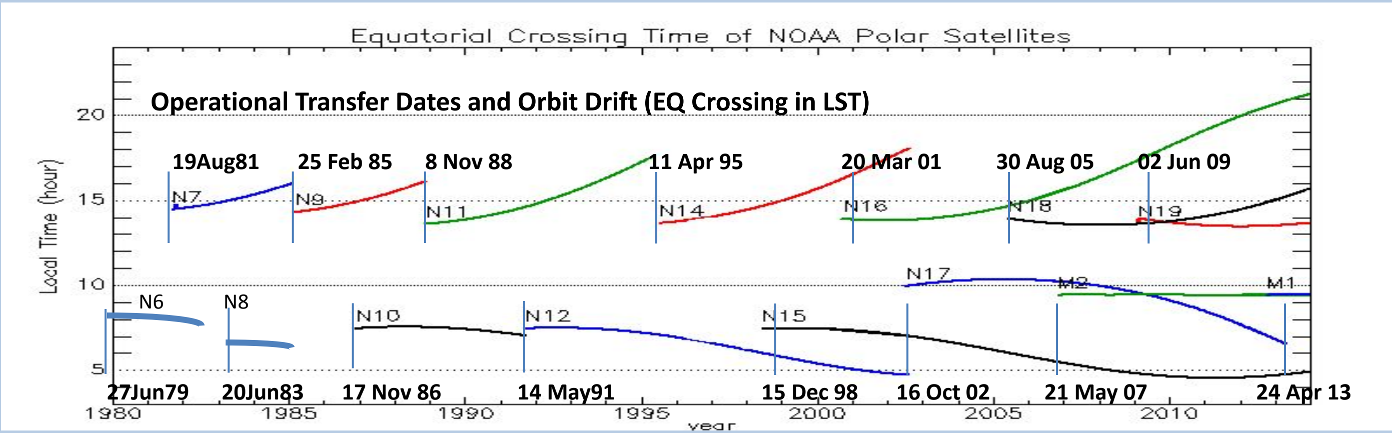


Challenge:

The instrument changes over the last 45 years:

morning (8 am Desc Node)	night (2 am Desc Node)
NIMBUS 6 HIRS – 6/1975	
NOAA 6 HIRS/2 – 6/1979	NOAA 5 HIRS – 10/1978
NOAA 8 HIRS/2 – 3/1983	NOAA 7 HIRS/2 – 6/1981
NOAA 10 HIRS/2 – 9/1986	NOAA 9 HIRS/2 – 12/1984
NOAA 12 HIRS/2 – 5/1991	NOAA 11 HIRS/2I* - 9/1988
NOAA 15 HIRS/3 – 5/1998	NOAA 14 HIRS/2I* - 12/1994
NOAA 17 HIRS/3 – 6/2002	NOAA 16 HIRS/3 – 9/2000
METOP-A HIRS/4 – 10/2006	NOAA 18 HIRS/4 – 5/2005
METOP-B HIRS/4 – 9/2012	NOAA 19 HIRS/4 – 2/2009

Split window change: HIRS & HIRS/2 ch 10 is 8.6 um and HIRS/2I, /3, & /4 is 12.5 um .
Orbit Drift: Asterisk (*) indicates drift from 14 to 18 UTC over 5 years of operational use.
S/N improved in HIRS/3.
FOV improved to 10 km FOV for HIRS/4 (previously 20 km FOV).
HIRS coverage: More than 100 satellite years in HIRS data set.



Dividing the day into four time periods

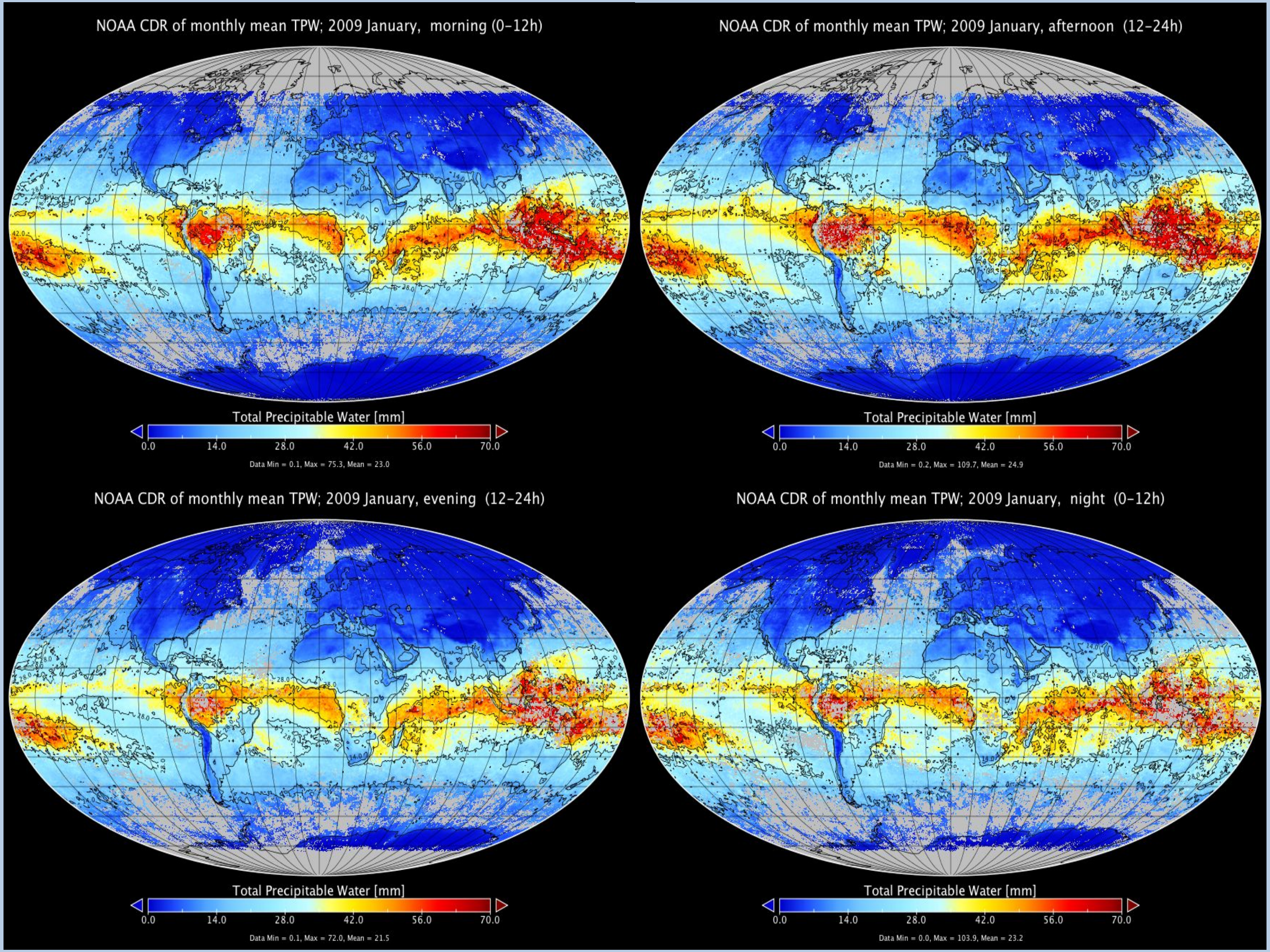
Morning SZA <= 85^0 and Local Time Before Noon

Afternoon SZA <= 85^0 and Local Time After Noon

Evening SZA > 85^0 and Local Time Before Midnight

Night SZA > 85^0 and Local Time After Midnight

Accounting for and taking advantage of orbit drift

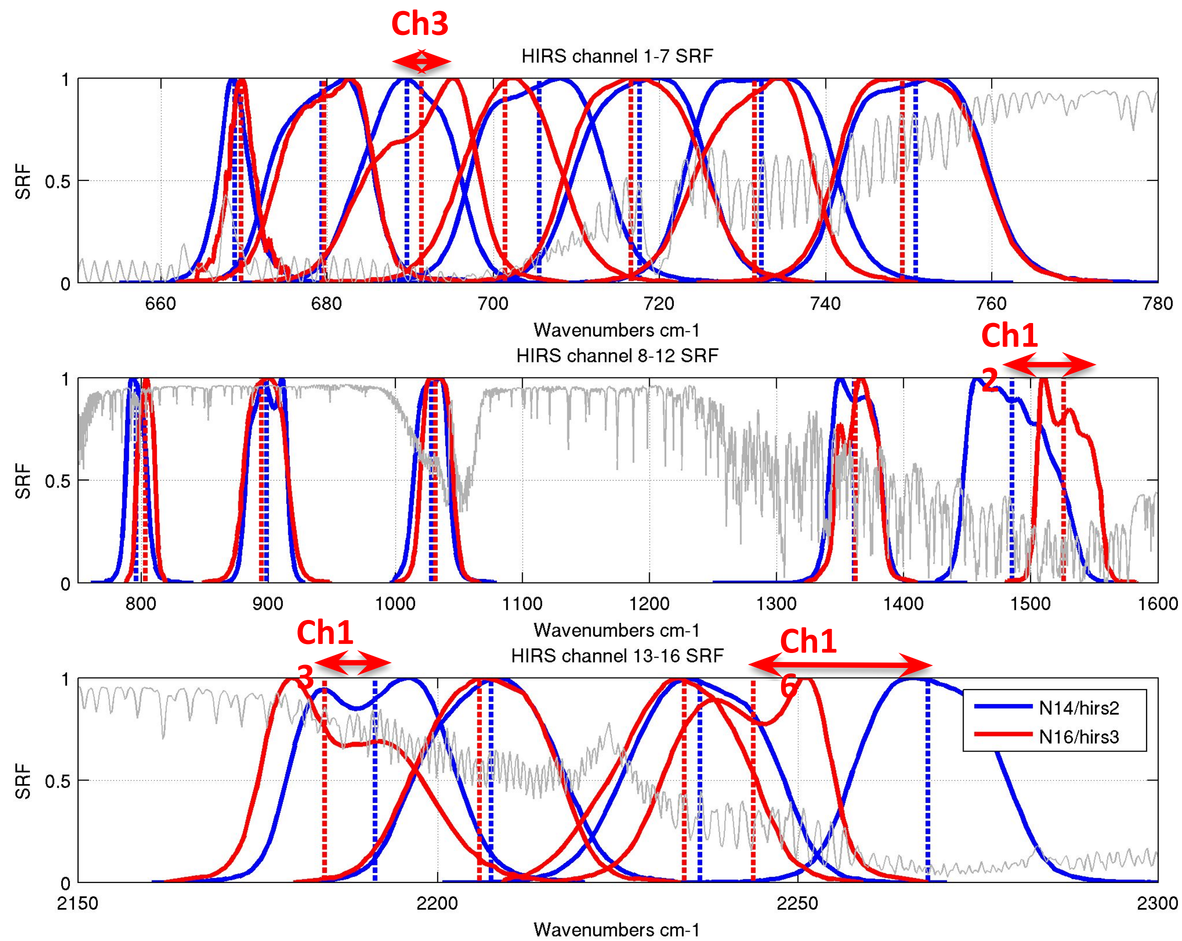


Satellite	Launch Date	Operational Dates - Orbit	
NIMBUS 6	June 12, 1975	August 1975 -March 29, 1983	
TIROS-N	October 13, 1978	Oct 19, 1978-Jan 30, 1980	
NOAA-6	June 27, 1979	Jun 27, 1979-Mar 5, 1983 Jul 3, 1984-Nov 16, 1986	AM
NOAA-B	May 29, 1980	Failed to achieve orbit	
NOAA-7	June 23, 1981	Aug 19, 1981-Jun 7, 1986	PM
NOAA-8	March 28, 1983	Jun 20, 1983-Jun 12, 1984 Jul 1, 1985-Oct 31, 1985	AM
NOAA-9	December 12, 1984	Feb 25, 1985-Nov 7, 1988	PM
NOAA-10	September 17, 1986	Nov 17, 1986-Sep 16, 1991	AM
NOAA-11	September 24, 1988	Nov 8, 1988-Apr 11, 1995	PM
NOAA-12	May 14, 1991	May 14, 1991- Dec 14, 1998	AM
NOAA-13	August 9, 1993	Aug 9, 1993-Aug 21, 1993	
NOAA-14	December 30, 1994	Apr 11, 1995-Mar 19, 2001	PM
NOAA-15	May 13, 1998	Dec 15, 1998-Oct 15, 2002	AM
NOAA-16	September 21, 2000	Mar 20, 2001-Aug 29, 2005	PM
NOAA-17	June 24, 2002	Oct 16, 2002- May 21, 2007	AM
NOAA-18	May 20, 2005	Aug 30, 2005-Jun 01, 2009	PM
NOAA-19	February 06, 2009	Jun 02, 2009- July 2013	PM
MeTop-A	October 19, 2006	May 21, 2007-Apr 23 2013	AM
MeTop-B	September 17, 2012	Apr 24, 2013	AM

15 of 17 HIRS sensors processed in 35+ year study

Comparison of the spectral response functions of channels on HIRS2 and HIRS3

NOAA-14/HIRS2
NOAA-16/HIRS3



*N14: 1, 11, 12, 16 bands are too noisy, not used

HIRS recalibration

- Goal: removing the inter-satellite radiance discrepancies in all the HIRS channels for being able to develop a 45+ year-long consistent HIRS cloud and moisture data record.
- Based on optimizing SRFs (shift) using SNO between the NOAA and METOP satellites.
- IASI is used as a reference because it locates on the same satellite with HIRS4 (METOP M1 and M2) and a well-calibrated HSR instrument.
- Intersatellite SRF shifts are then propagated to the earliest satellites

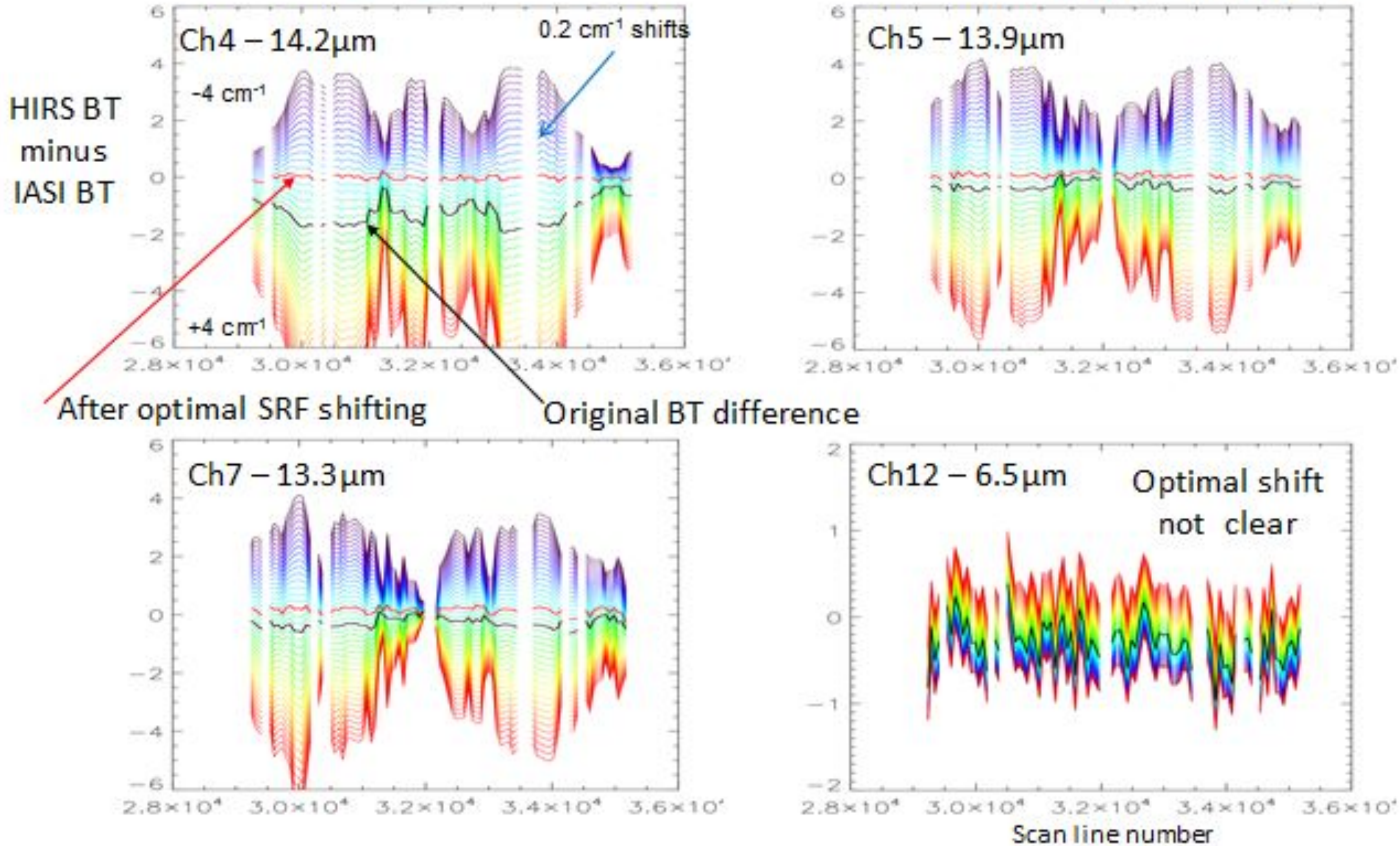
- *Tobin et al. 2006, Chen et al. 2013;Zhang et al. 2021;*

SNO: Simultaneous Nadir Overpass

HIRS vs IASI BT Bias Change with SRF shift

METOP-B 08/01/2013

From Chen and Cao



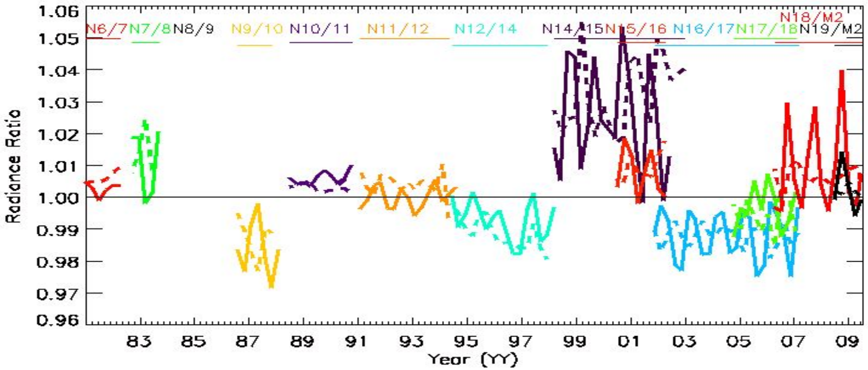
Color represents different wavenumber shifting

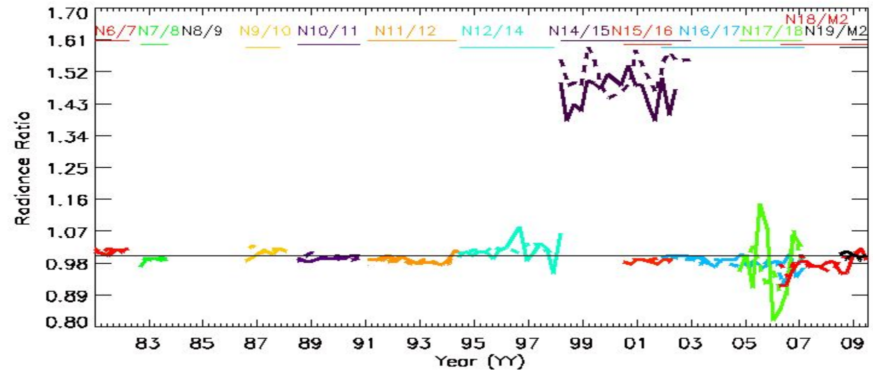
Time series of intersatellite biases of HIRS channel 4 and 12 for NOAA-6 to NOAA-19 (*Chen et al, 2013, JGR-Atmos*)

Band 4 (14.2 μm)

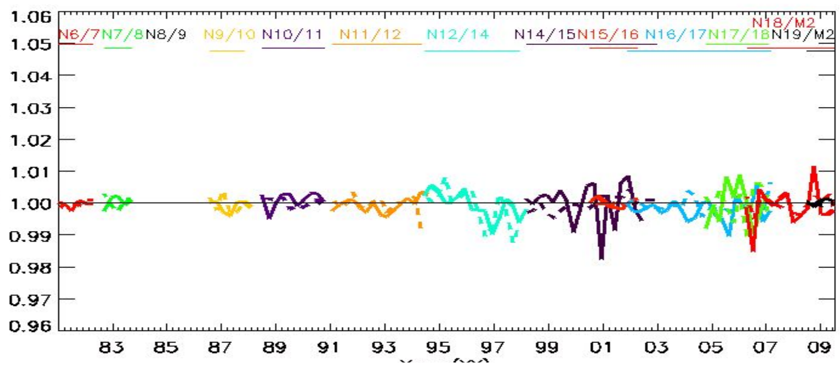
Band 12 (6.7 μm)

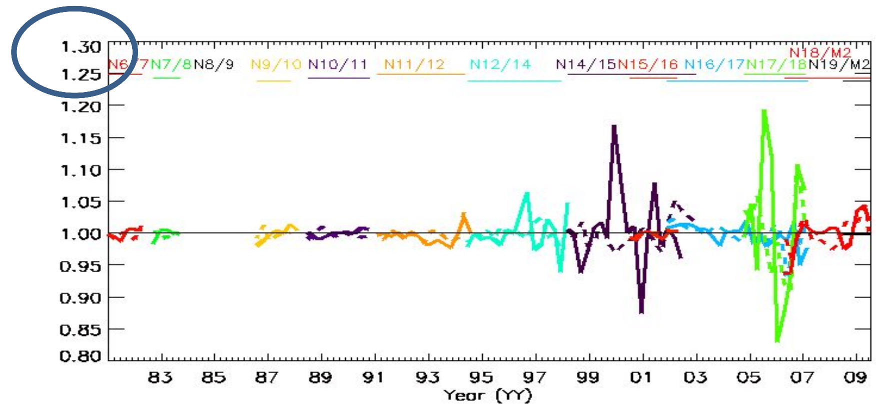
Original SRF





Shifted SRF





Solid: SNO comparisons in the south polar region, Dashed: SNO comparisons in the north polar region

CO2 and H2O HIRS spectral shifts relative to MetOp/M2-IASI

(*Chen et al, 2013, JGR-Atmos, Zhang et al, 2021, Atmosphere*)

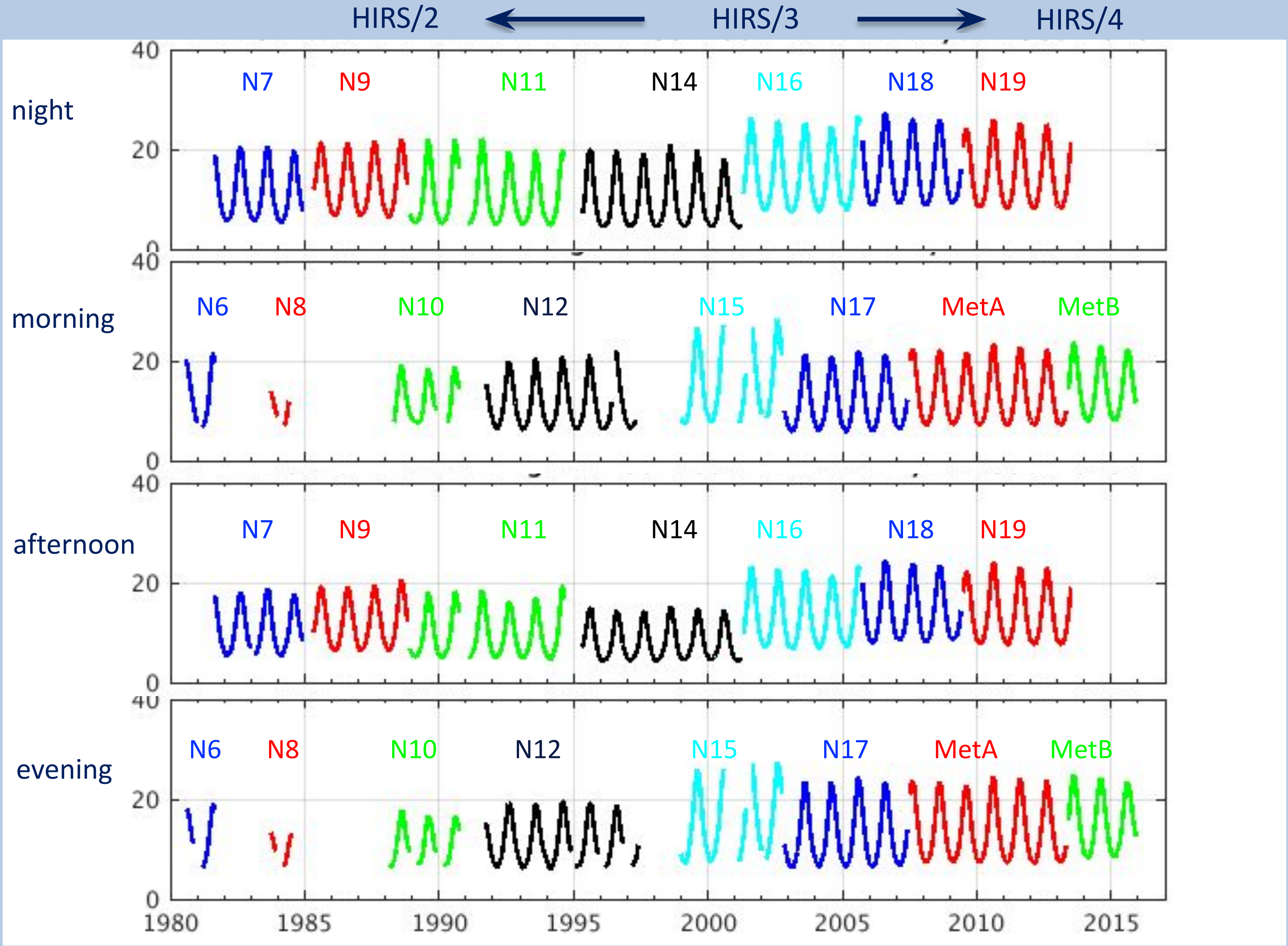
	Ch4(14.2)	Ch5(13.9)	Ch7(13.3)	Ch12(6.7)
Hirs2n06 V	0.31	0.7	0.7	1.1
Hirs2n07 V	-0.18	0.1	1.2	-0.46
Hirs2n09 H	0.43	2.66	-0.48	1.1
Hirs2n10 H	0.95	1.56	-0.93	3.0
Hirs2n11 H	1.72	2.05	0.15	4.2
Hirs2n12 H	0.47	2.23	-2.06	4.1
Hirs2n14 H	1.97	3.13	1.22	4.1
Hirs3n15 I	-0.21	0.27	1.01	0.6
Hirs3n16 I	0.22	0.62	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
Hirs4m2 I	-0.15	0.10	-0.15	2.2
Hirs4m1 I	-1.21	-0.43	-0.54	0.0

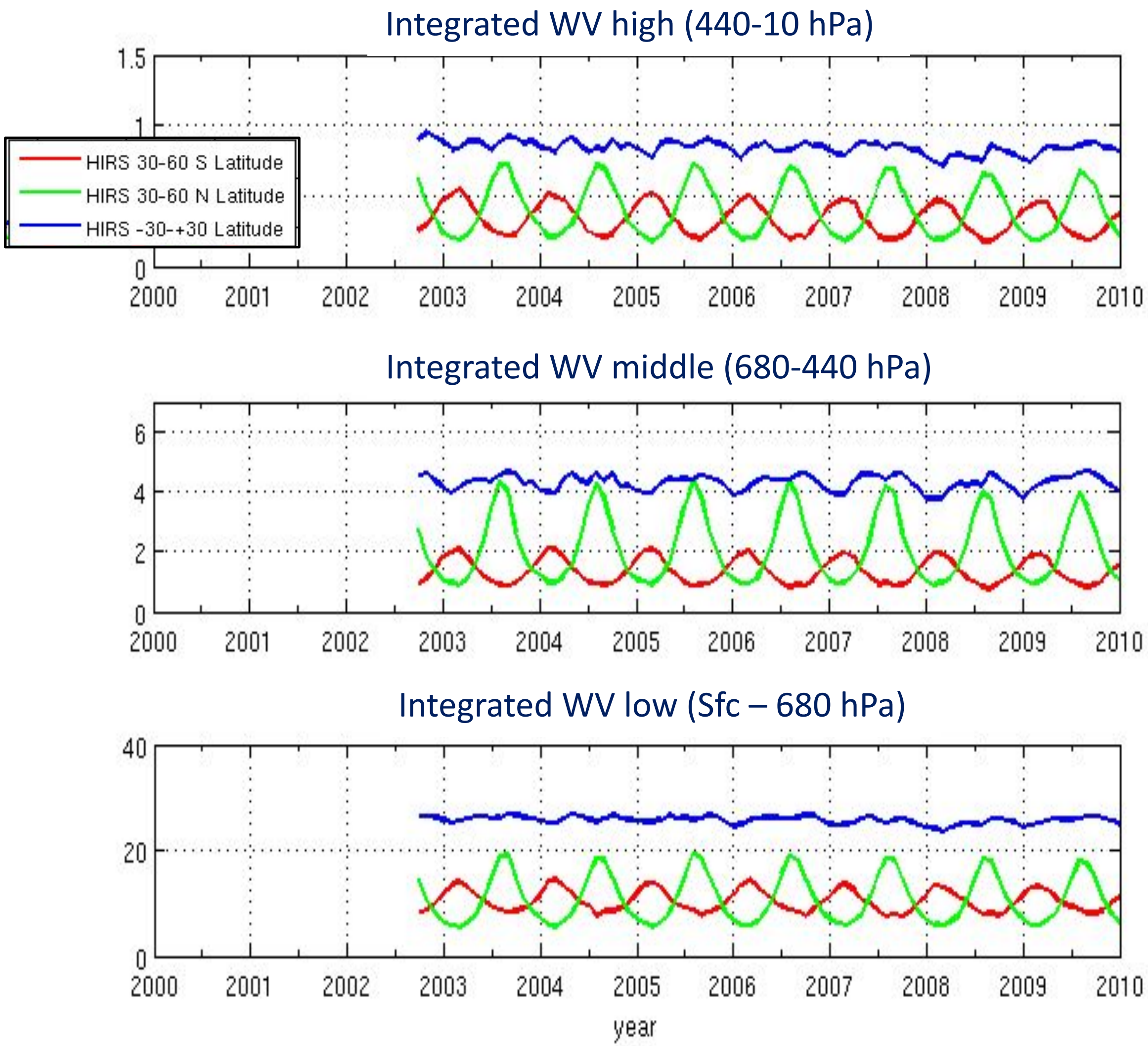
V indicates intercalibration with VAS, H with later HIRS, and I with IASI directly

Tracking Global TPW and UTH for 35 years

- 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 & UTH are determined for clear sky radiances measured by HIRS over land and ocean both day and night.
- The retrieval approach is borrowed from MODIS MOD07 Atmospheric Profile Products *(Seemann et al. 2003, Seemann et al. 2008*).
- There is a strong reliance on radiances from 6.5, 11, 12 µm.
- The AVHRR based PATMOS-x cloud mask is used to characterize HIRS sub-pixel cloud cover.

Time series of HIRS TPW [mm] for Northern Mid-latitudes 1980 - 2016



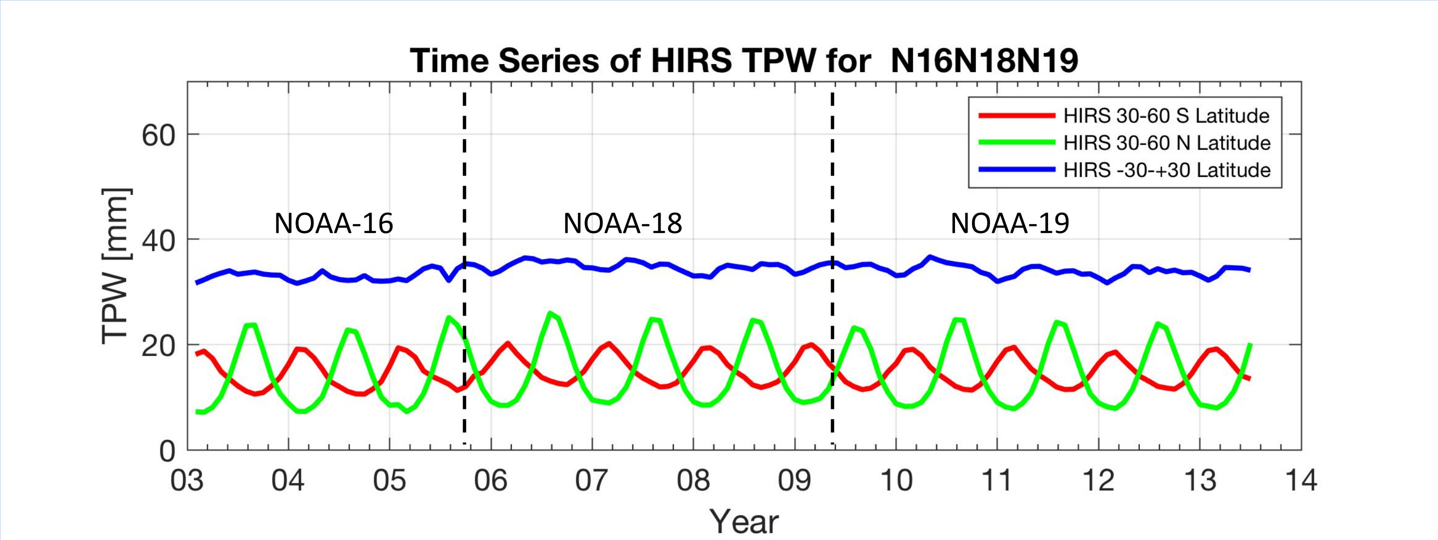


Timeseries of N17/HIRS IWV (mm) high, middle and low at Daytime

TPW & UTH highest in tropics; seasonal TPW and UTH cycle strongest in northern mid-latitudes, weakest in tropics.

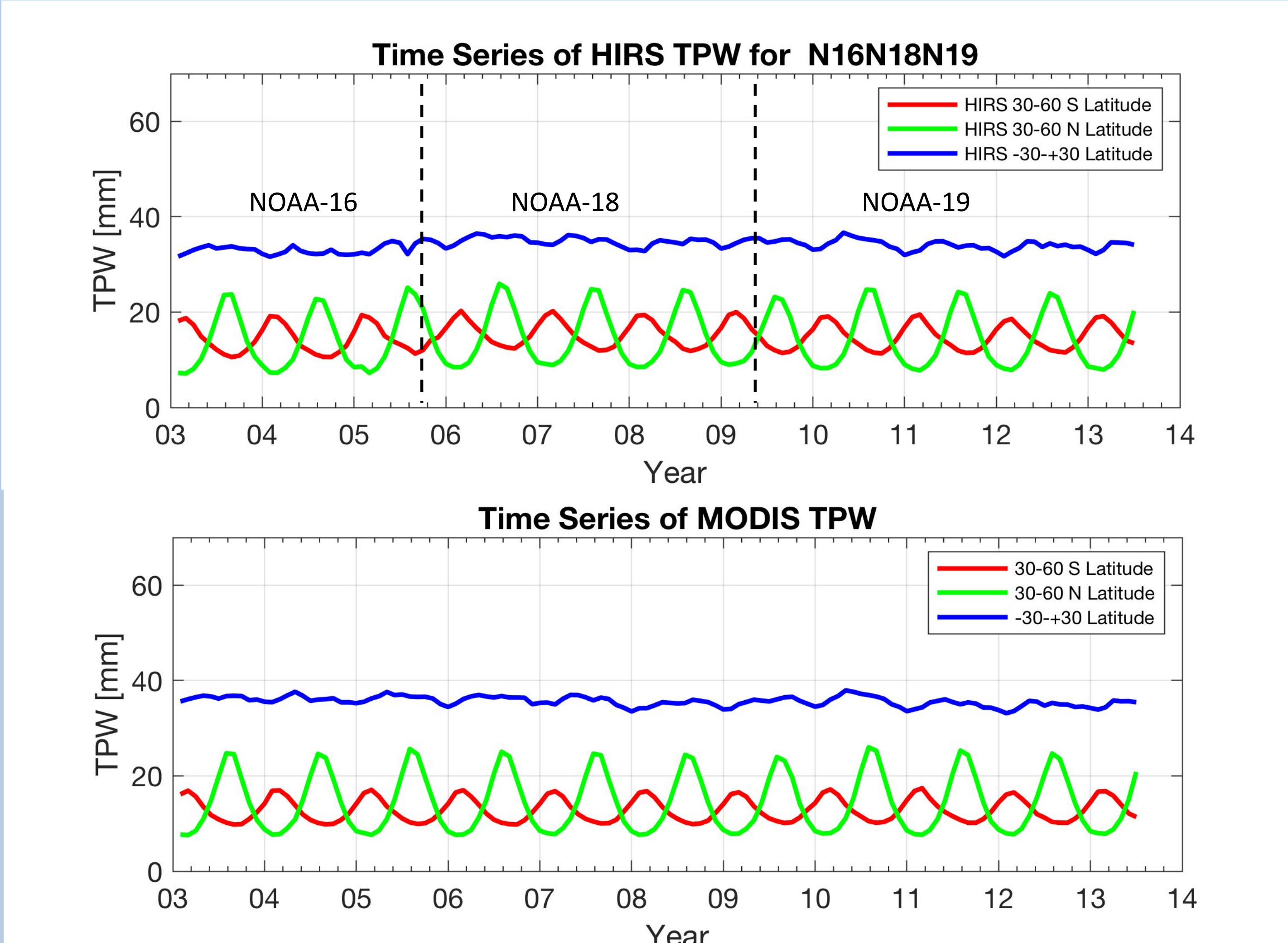
Borbas and Menzel, 2021: Remote Sens, 13(3), 502; doi.org/10.3390/rs13030502

Month to month changes in TPW detection for three latitude bands

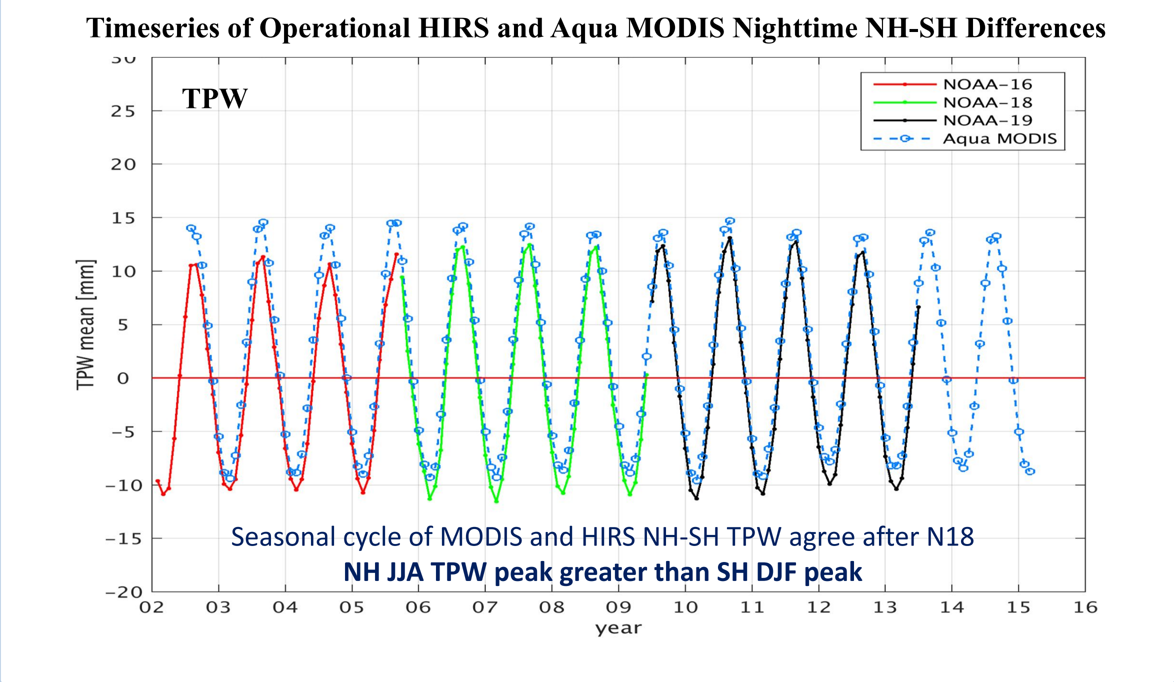


- Tropical TPW stays relatively constant in time (~34 mm)
- Northern mid-latitude TPW maxima are in sync with southern mid-latitude TPW minima;
- northern mid-latitudes have a wetter maximum as well as a drier minimum each year (seasonal change of 17 mm) compared to the southern mid-latitudes (seasonal change of 7 mm).

Month to month changes in TPW detection for three latitude bands



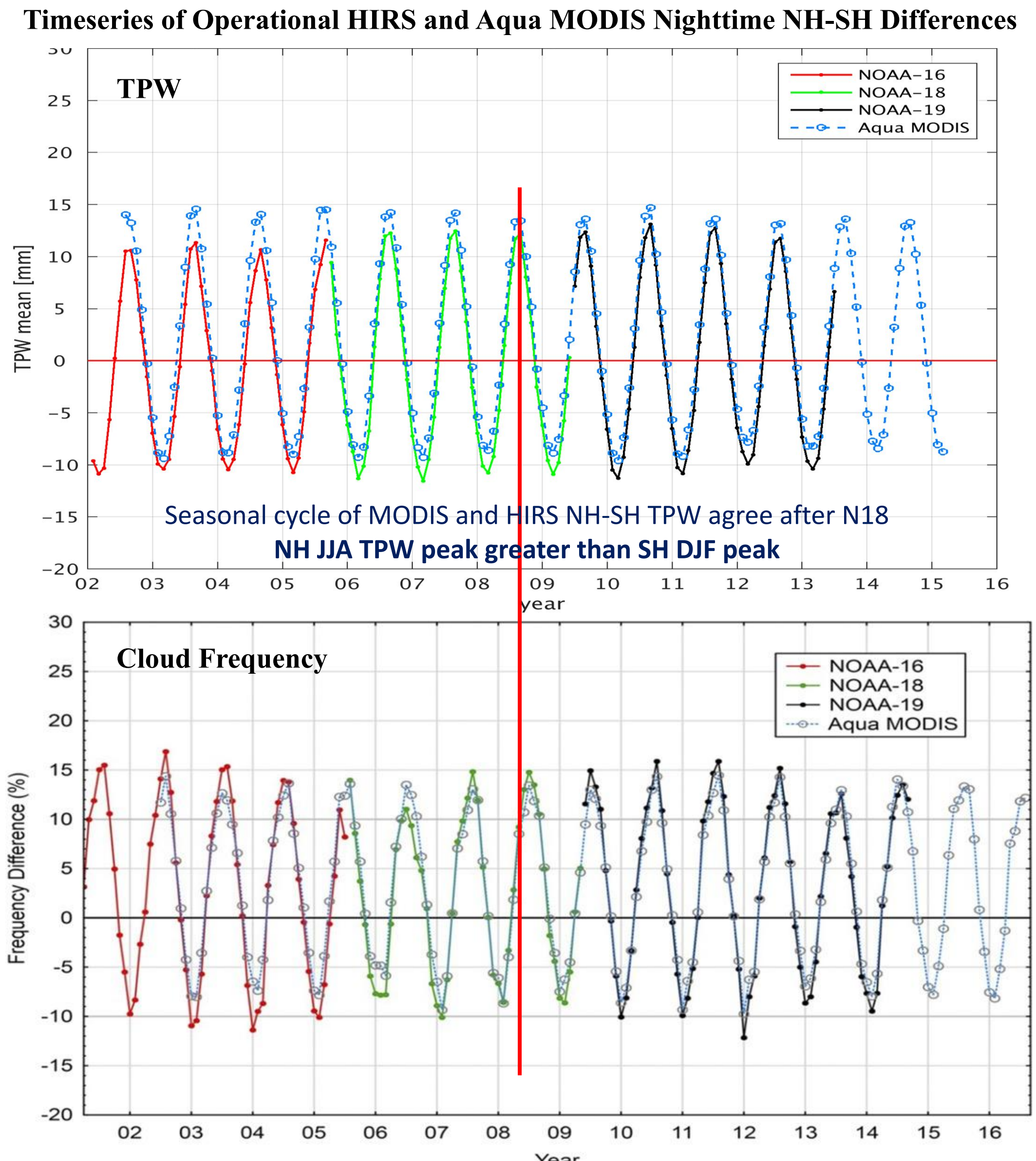
Seasonal Hemispheric Moisture Changes NH-SH



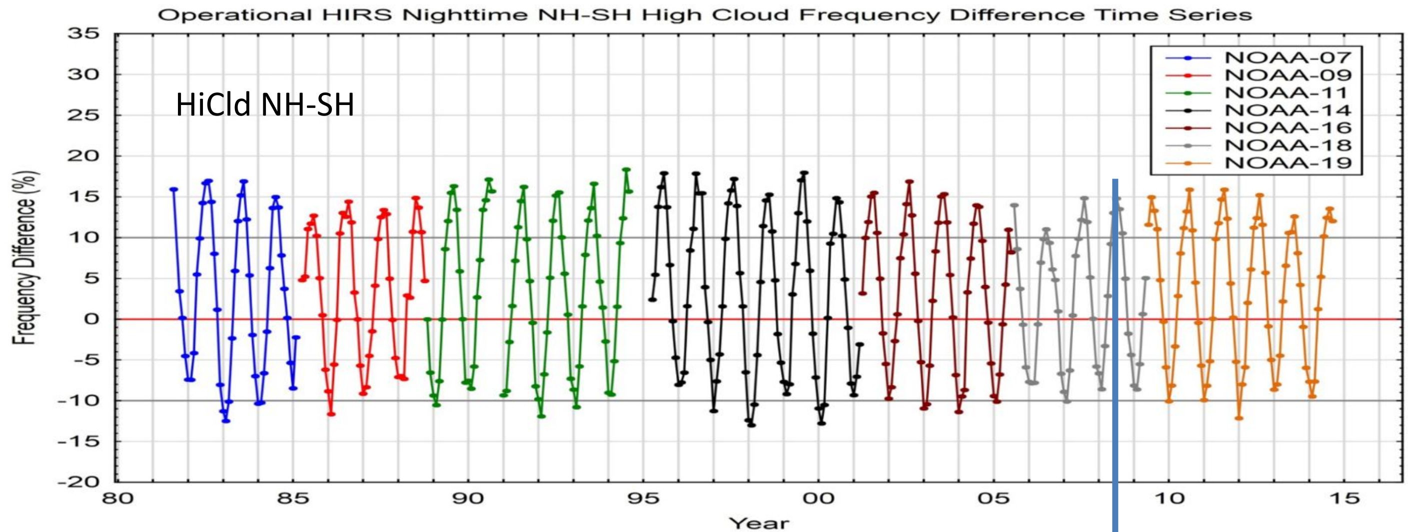
- Agreement with MODIS is best for NOAA 19, and falls off some for NOAA 16.
- NH TPW is greater than that of the SH in the summer by 15 mm and, in winter it is drier by 10 mm, causing hemispheric imbalance.
- This annual seasonal change is repeated throughout the ten-year record.

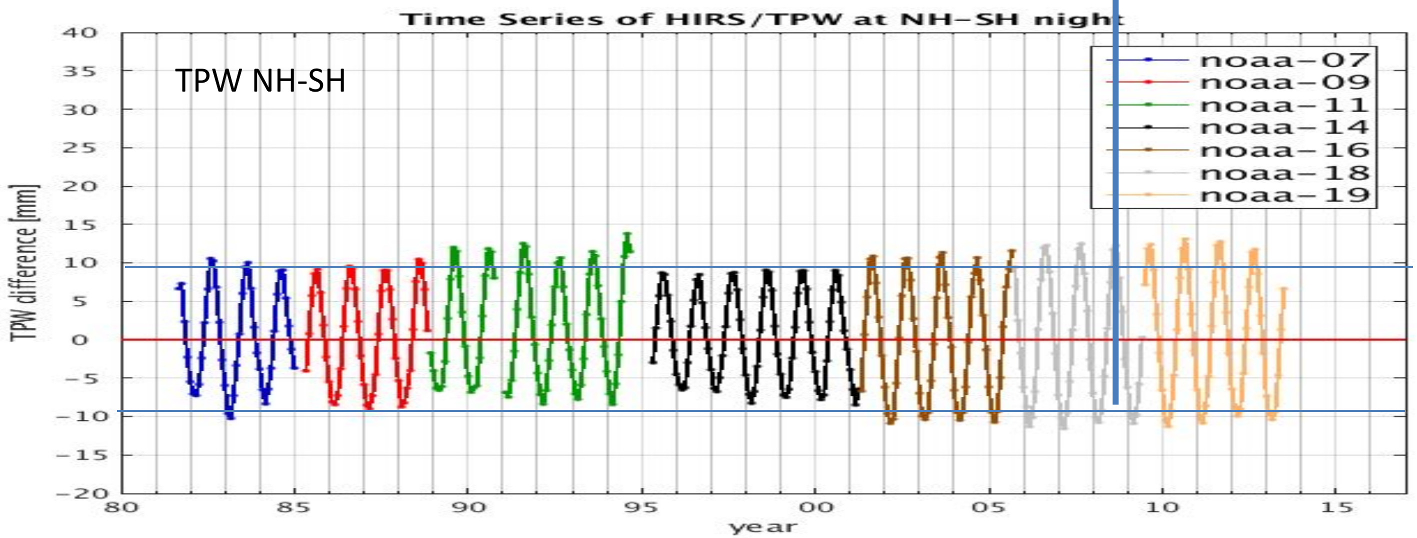
Seasonal Hemispheric Moisture Changes NH-SH

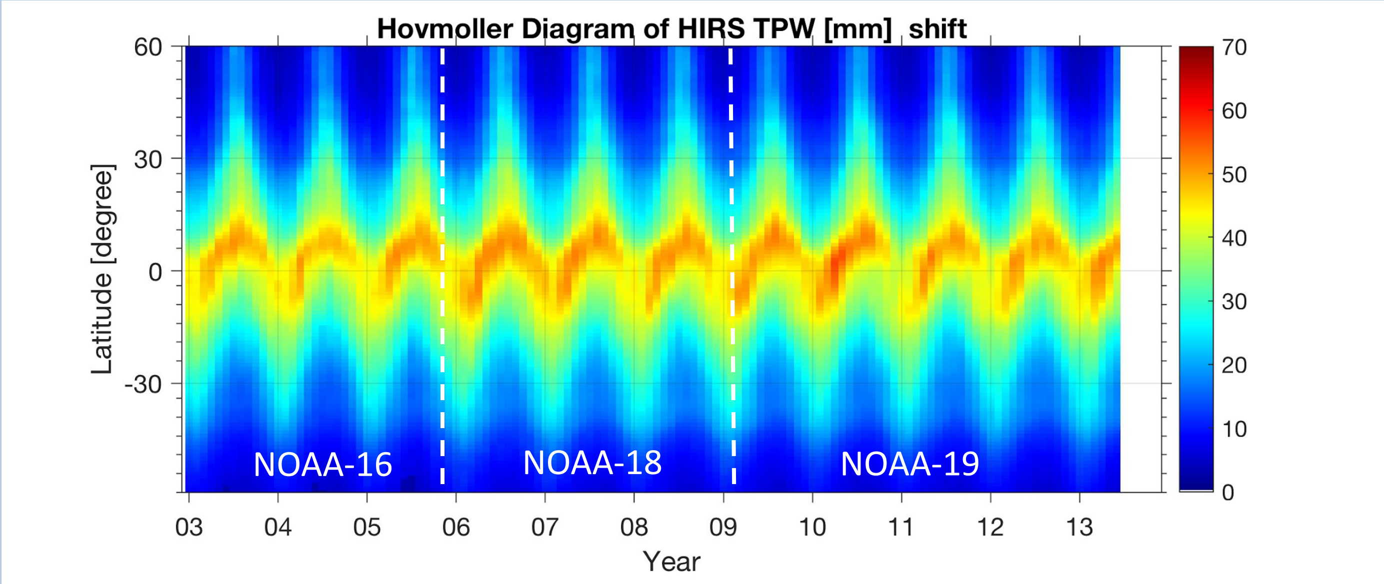
Seasonal Hemispheric high cloud freq Changes NH-SH

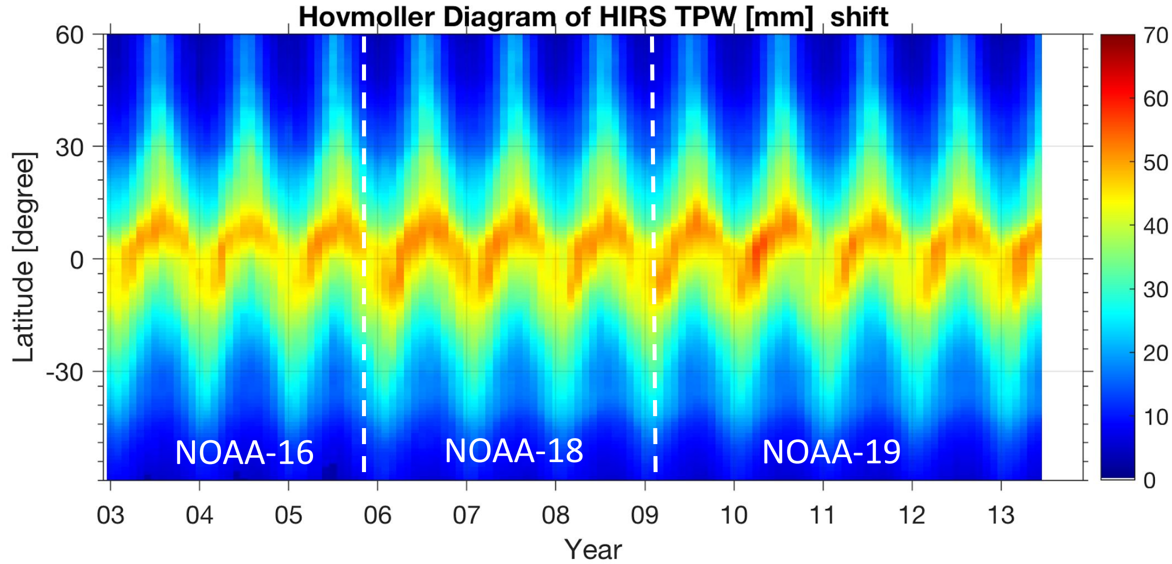


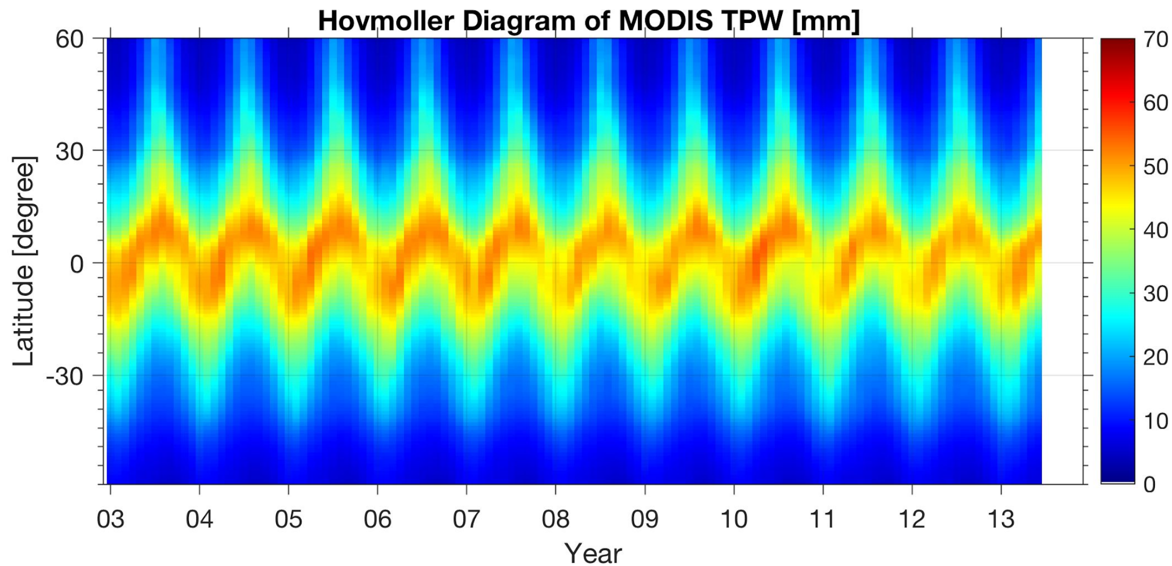
(Frey and Menzel, 2019, JAM)

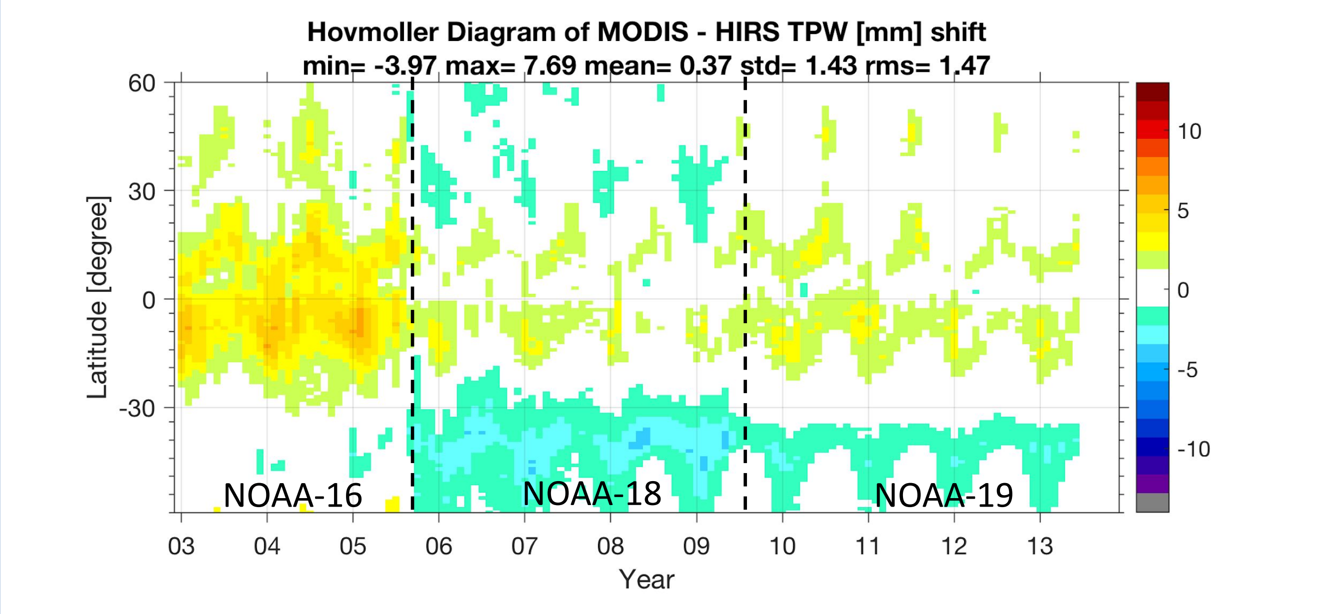

Operational HIRS Nighttime NH-SH High Cloud Frequency Difference Time Series
HiCld NH-SH
Frequency Difference (%)
Year
NOAA-07
NOAA-09
NOAA-11
NOAA-14
NOAA-16
NOAA-18
NOAA-19
35
30
25
20
15
10
5
0
-5
-10
-15
-20
80
85
90
95
00
05
10
15


Time Series of HIRS/TPW at NH−SH night
TPW NH-SH
TPW difference [mm]
year
noaa−07
noaa−09
noaa−11
noaa−14
noaa−16
noaa−18
noaa−19
40
35
30
25
20
15
10
5
0
−5
−10
−15
−20
80
85
90
95
00
05
10
15


Hovmoller Diagram of HIRS TPW [mm] shift
Latitude [degree]
60
30
0
-30
03
04
05
06
07
08
09
10
11
12
13
Year
NOAA-16
NOAA-18
NOAA-19
70
60
50
40
30
20
10
0


Hovmoller Diagram of HIRS TPW [mm] shift
Latitude [degree]
Year
NOAA-16
NOAA-18
NOAA-19
60
30
0
-30
03
04
05
06
07
08
09
10
11
12
13
70
60
50
40
30
20
10
0


Hovmoller Diagram of MODIS TPW [mm]
Latitude [degree]
Year
60
30
0
-30
03
04
05
06
07
08
09
10
11
12
13
70
60
50
40
30
20
10
0



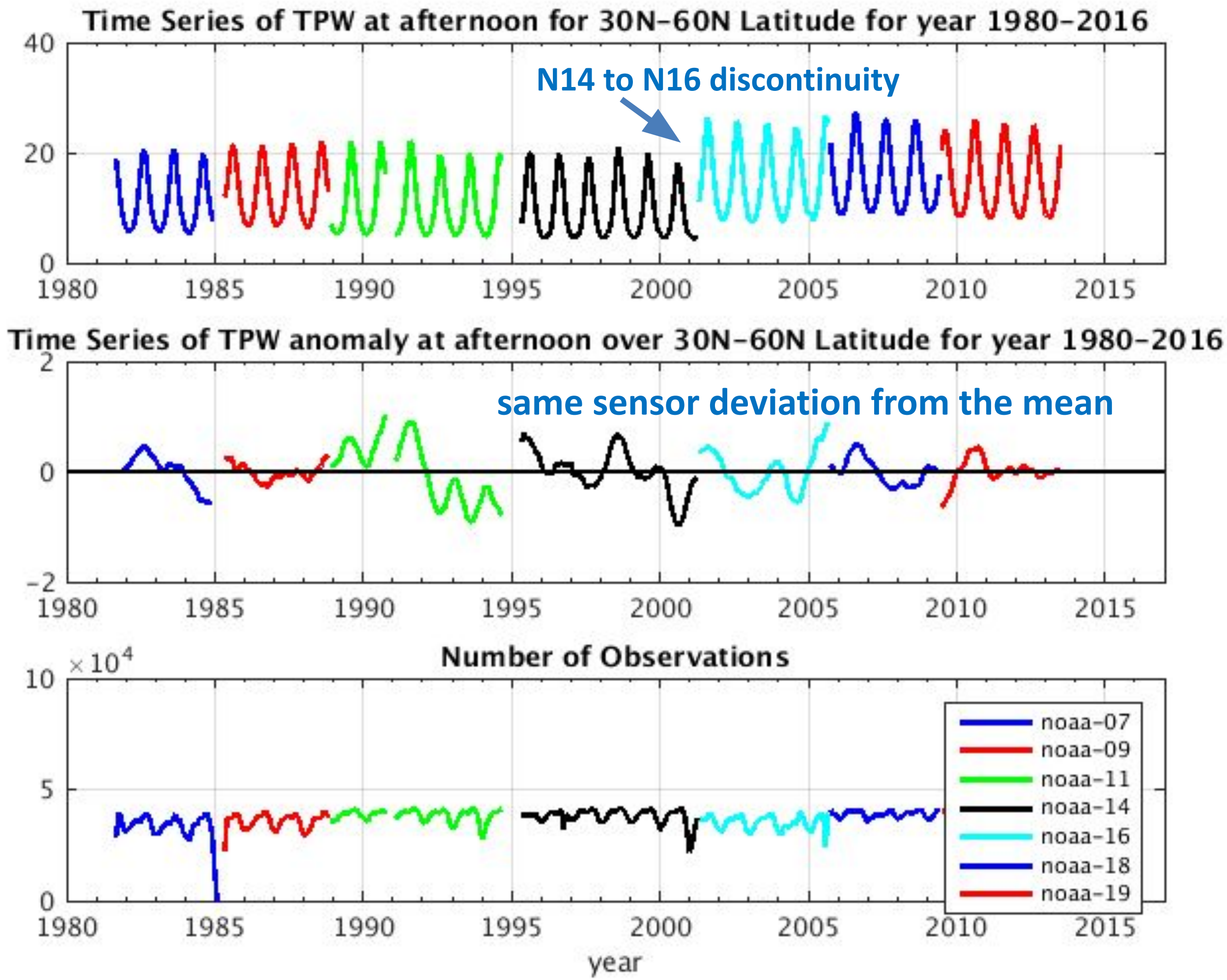
Compared with MODIS,

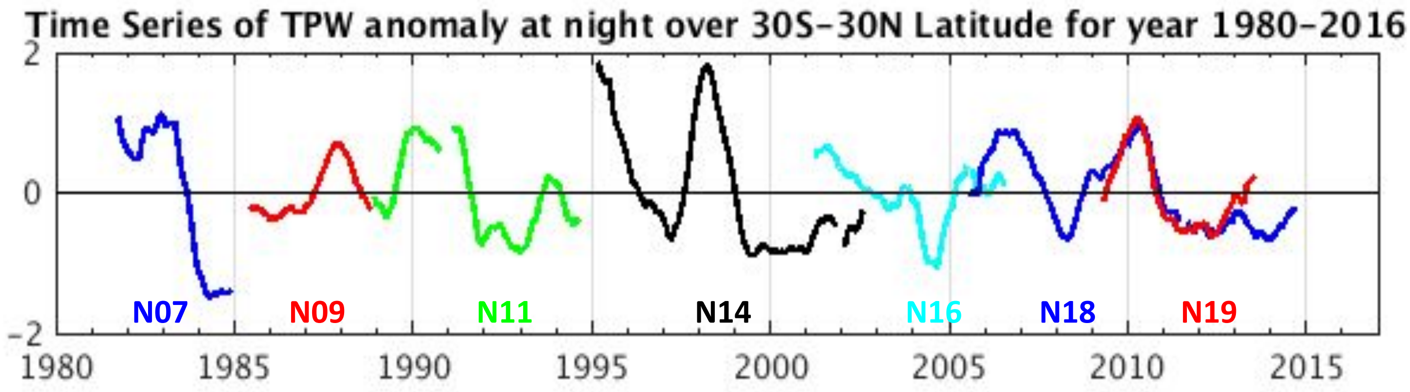
NOAA-16 is too dry in the tropics,

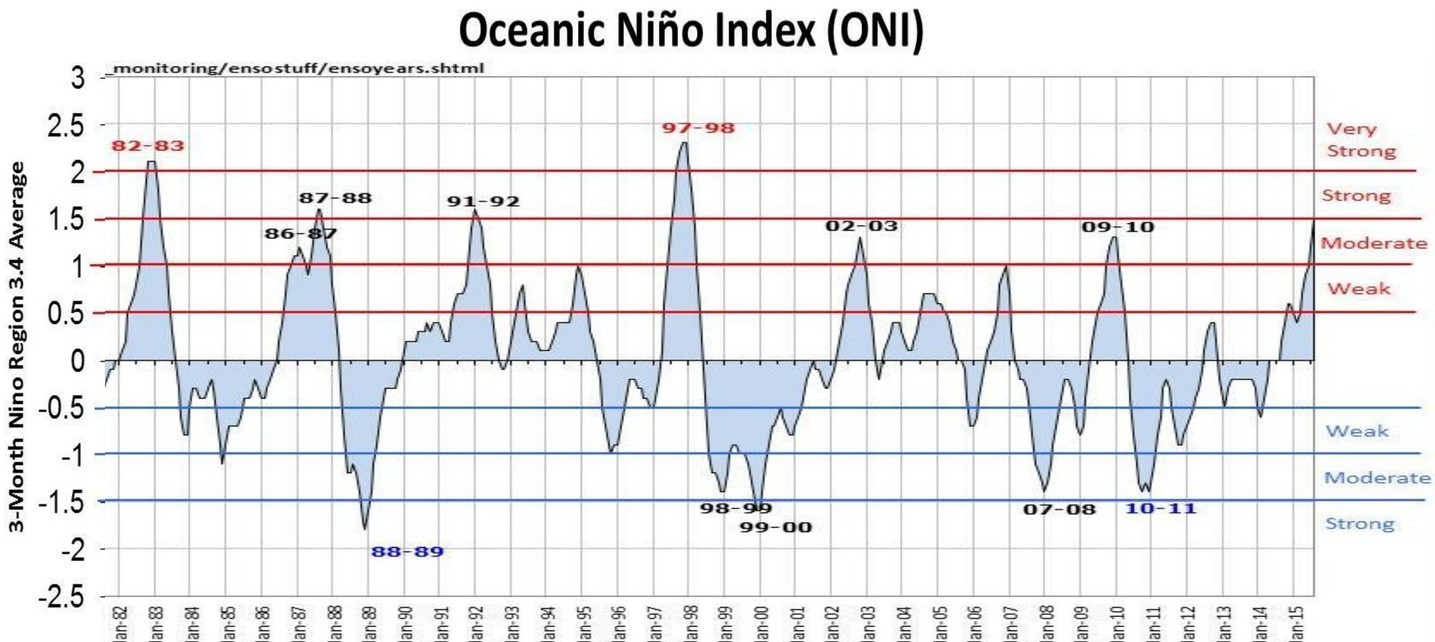
NOAA-18 is too moist in the southern mid-latitudes, and

NOAA-19 agrees the best of the three sensors.

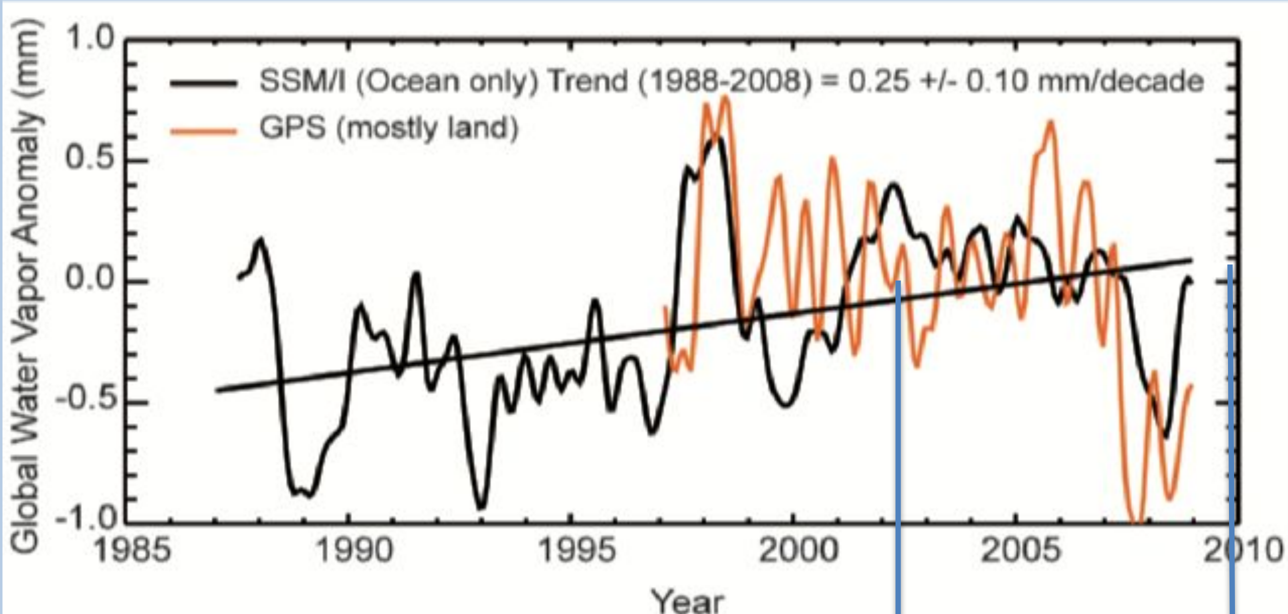
Largest differences mainly occur for NOAA-16, where the larger HIRS3 FOV (18km) is introducing more of a dry bias (~ 2 mm) with fewer clear sky determinations in and around clouds. NOAA-18 and NOAA-19 HIRS4 FOV is 10 km.

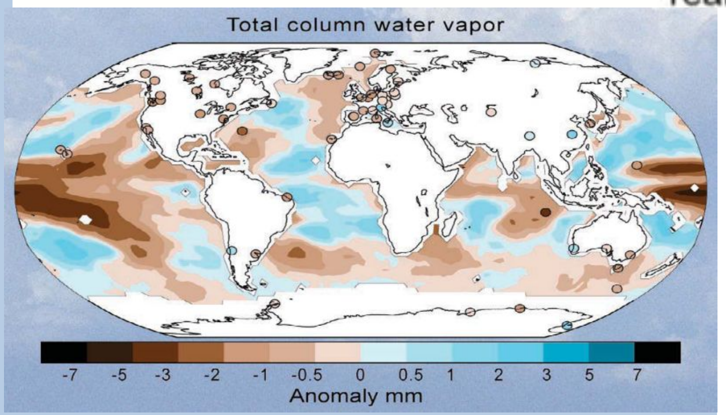

Time Series of TPW at afternoon for 30N-60N Latitude for year 1980-2016
N14 to N16 discontinuity
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Time Series of TPW anomaly at afternoon over 30N-60N Latitude for year 1980-2016
same sensor deviation from the mean
2
0
-2
Number of Observations
$\times 10^4$
10
5
0
year
noaa-07
noaa-09
noaa-11
noaa-14
noaa-16
noaa-18
noaa-19



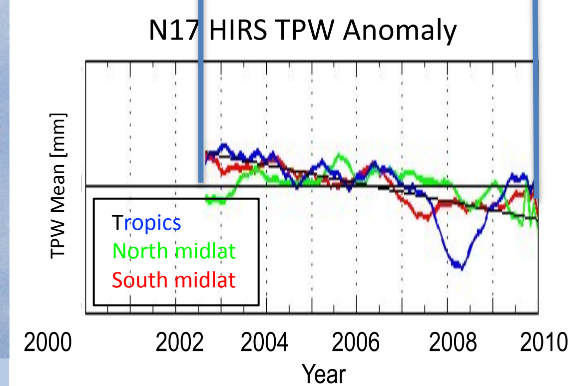


https://origin.cpc.ncep.noaa.gov/products/analysis monitoring/ensostuff/ONIv5.php





2008 La Nina Water Vapor 10 yr Anomaly



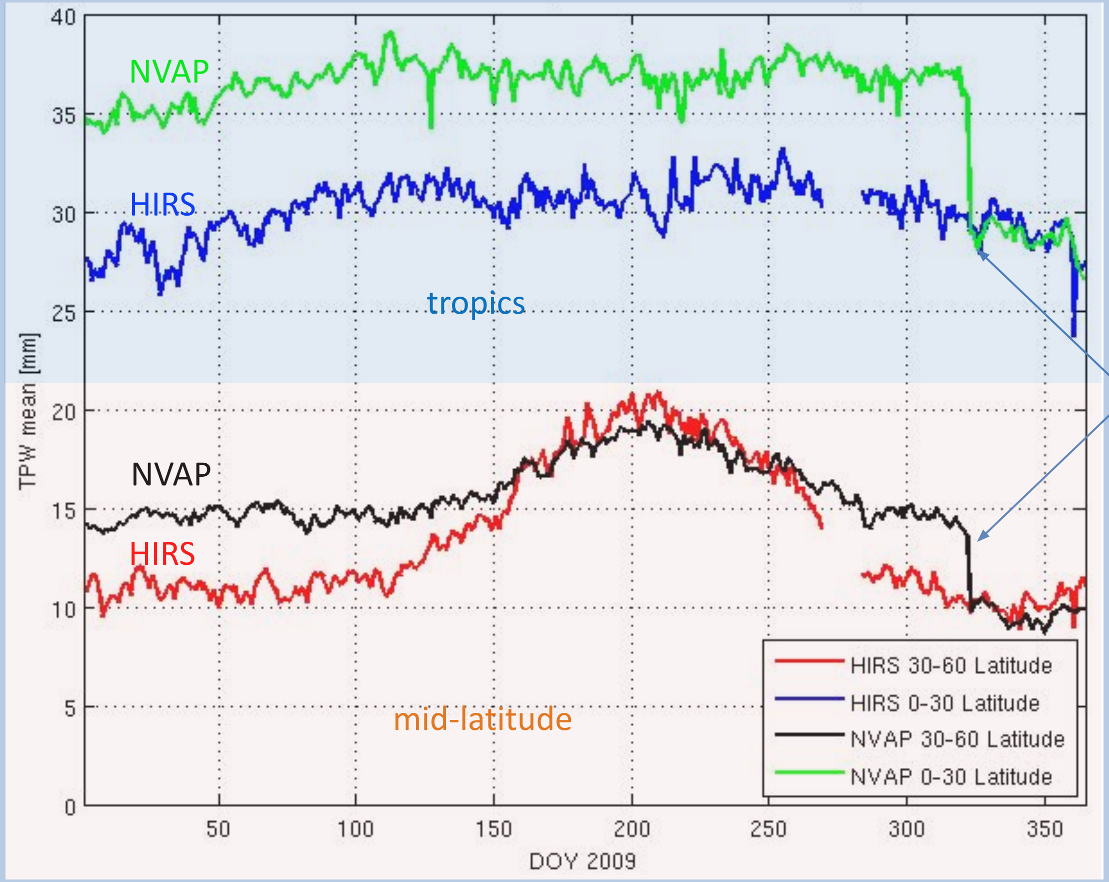
Smoothed anomaly of SSMI (black) and tropical (blue) HIRS TPW agree

State of Climate in 2008

Microwave considerations: comparing IR only METOP-A/HIRS4 TPW (mm) with IR & MW NASA NVAP-M TPW for 2009

MW adds ~7mm in Tropics (~25%)

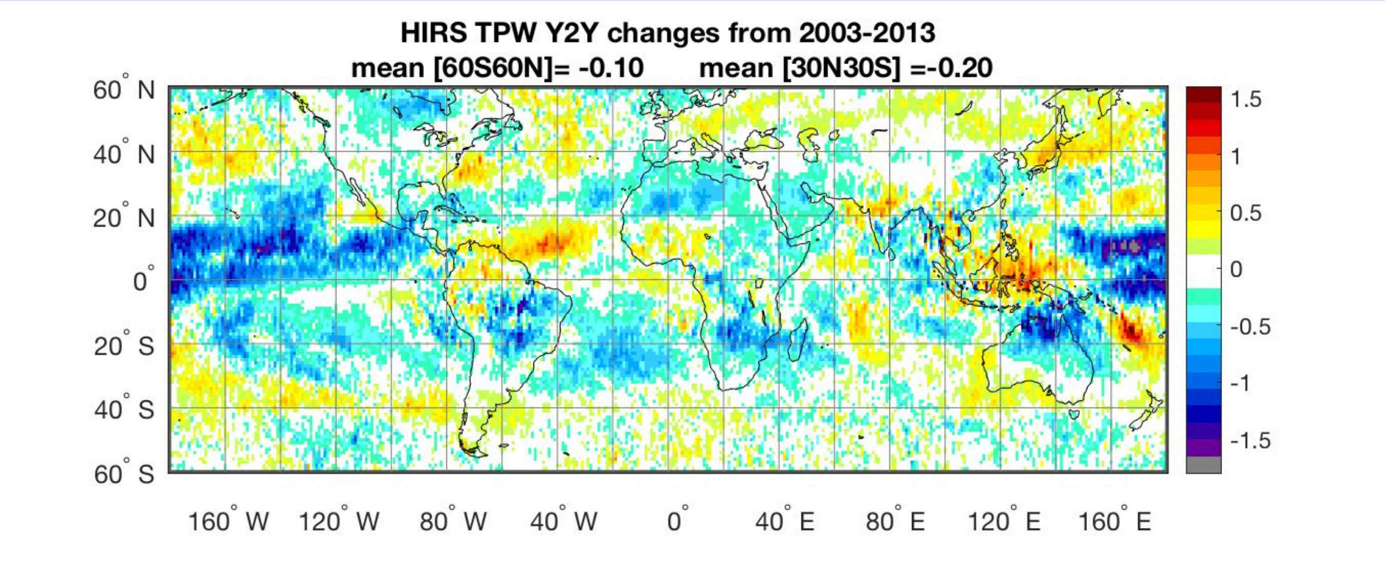
MW adds ~5mm in mid-lat winter (~30%)



MW failed on day 325
NVAP becomes IR only

NVAP-M: Vonder Haar et al. 2012, JGR

Mean year to year change in TPW for 2003-2013

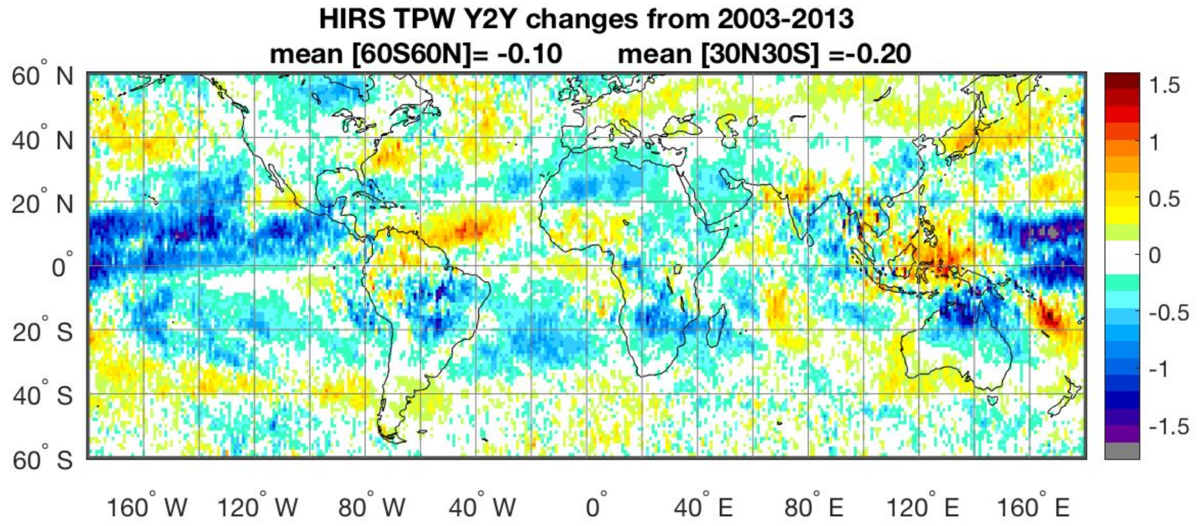


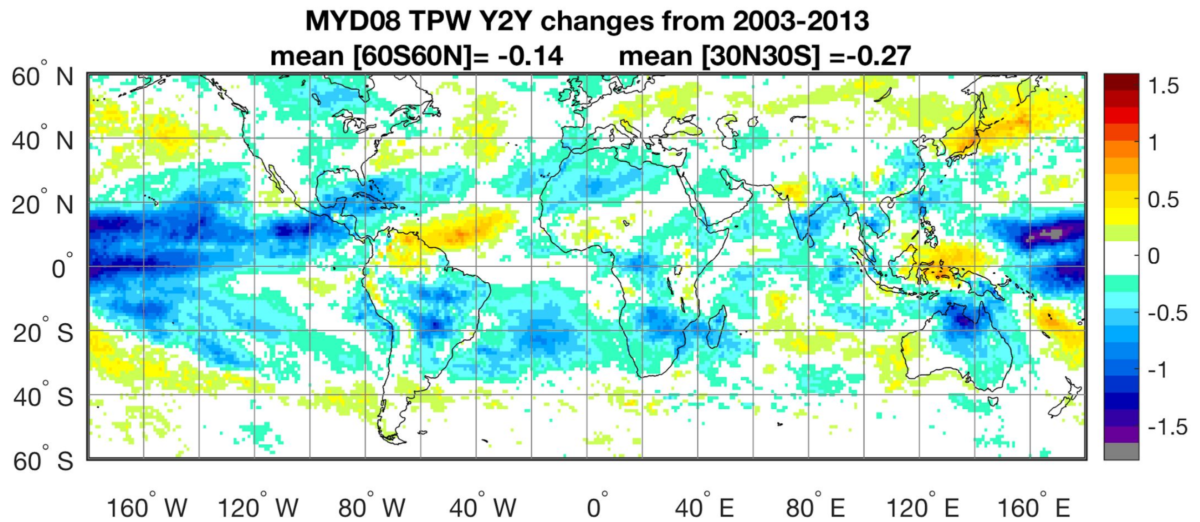
Same sensor detection of TPW differences for the same month from one year to the next is computed separately for all twelve months and then aggregated over the years 2003–2013; averages are taken over all months to infer mean changes.

Coherent changes greater than the standard deviation of the monthly changes for each instrument (1.3 mm for HIRS) should be considered significant.

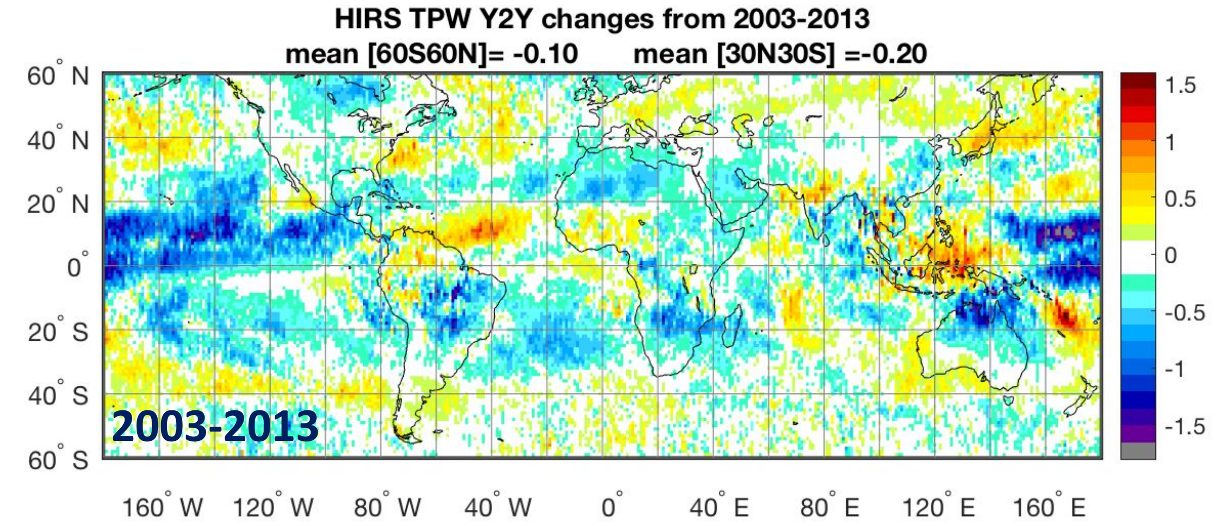
Geographical distribution of decrease is noticeable over the Equatorial Pacific Ocean for these ten years.

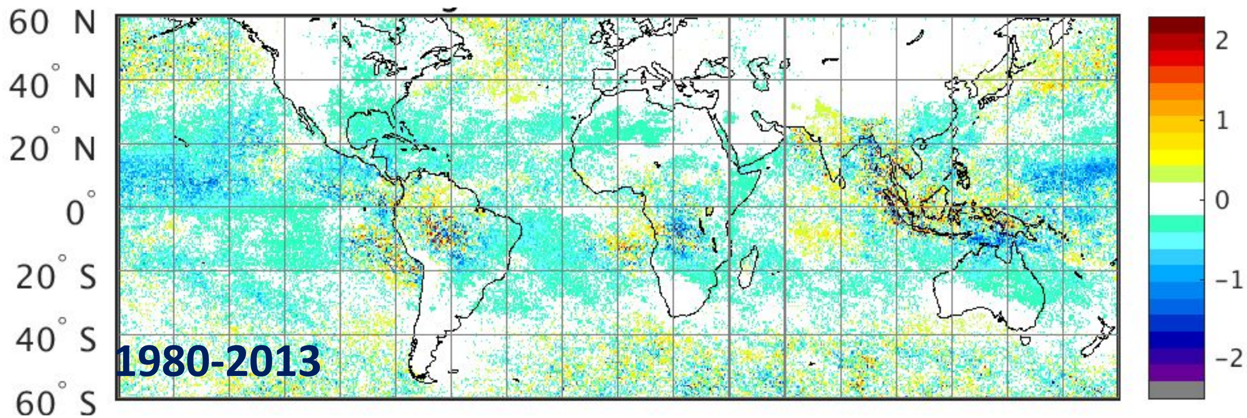
Mean year to year change in TPW for 2003-2013





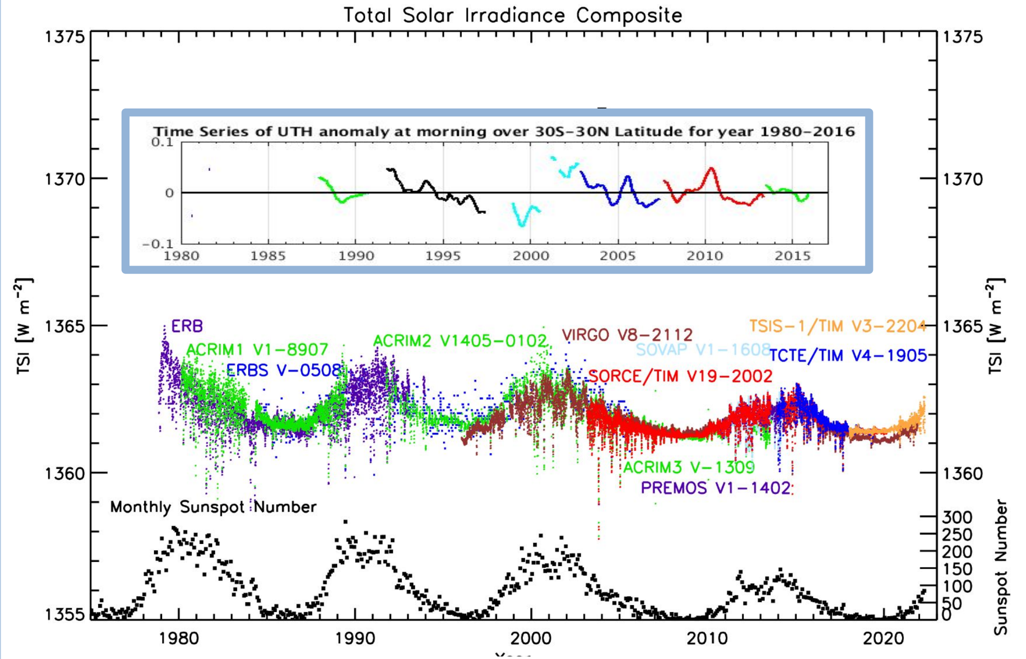
Mean year to year change in TPW for HIRS





Summary

- 35 years of cloud and moisture properties have been processed from the historical HIRS data record
- More work needs to be done to make them a more coherent dataset
- Extend them by adding the very first satellite (TIROS-N) and METOP-B as long as it is possible to cover 45 years of data
- The 45-year data record will provide a possibility to study if there is any connection between the HIRS UTH and the solar cycle (Total Solar Irradiance)



https://spot.colorado.edu/~koppg/TSI/#TSI_data

G.Kopp, 05 May, 2022