Uncertainty of Atmospheric Temperature Trends Derived from Satellite Microwave Sounding Data

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Community Reactions to Our Studies on "Uncertainty of AMSU-A Derived Atmospheric Temperature Trend….."

WWW.THEGUARDIAN.COM by John Abraham, November 7, 2014

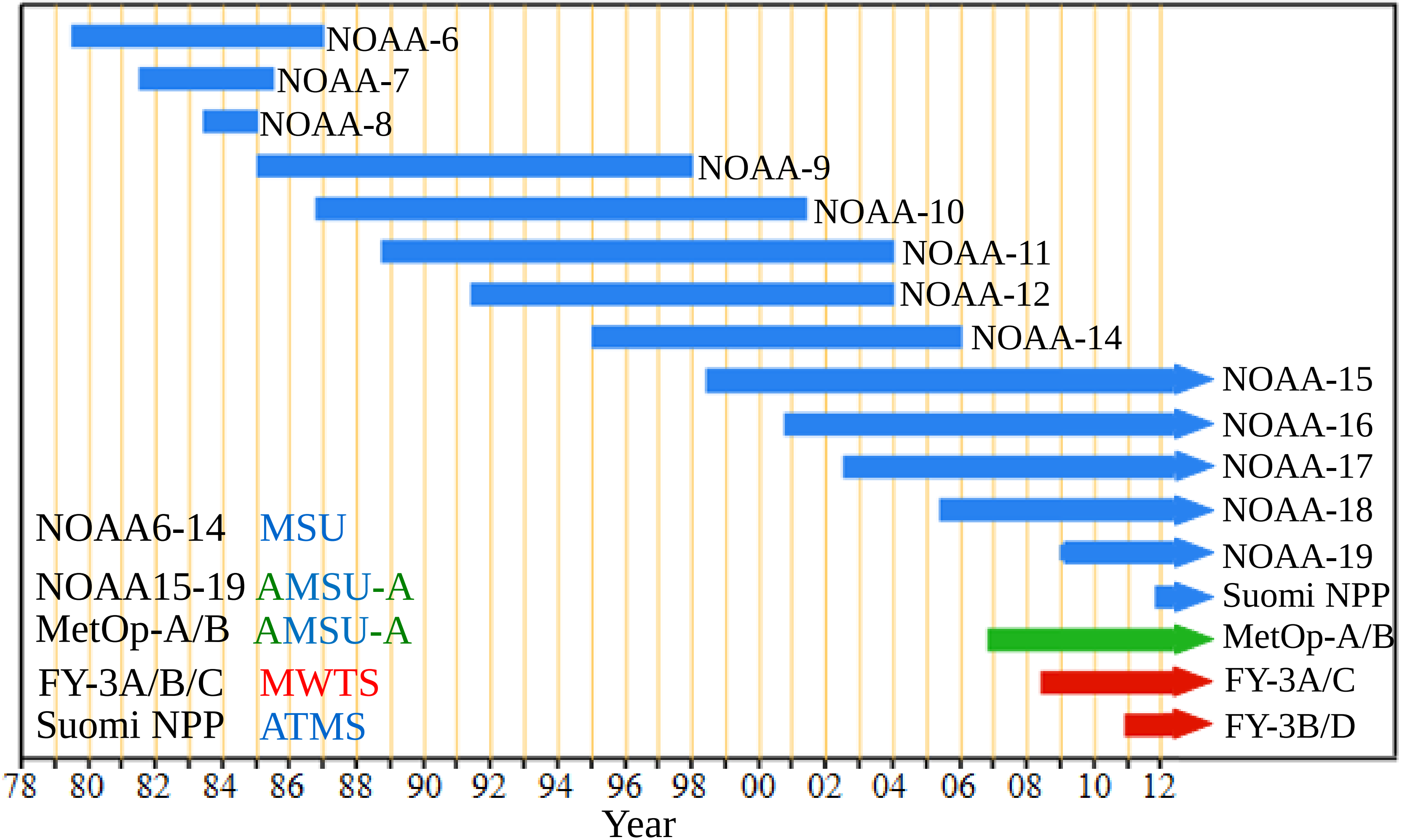
A new study questions the accuracy of satellite-based temperature measurements: "The recent flatness in satellite temperatures as surface temperatures continue to rise has presented a quandary for scientists. Are both results real? Is there some reason they diverge? Is one measurement more accurate than the other? This is one of the areas of very active research. A contribution to this question appeared last week by researcher Fuzhong Weng and his colleagues. The paper, published in *Climate Dynamics*, claimed to find the reason for much of that difference – the authors report that the satellite trends could be off (too cold) by perhaps 30%....Dr. Roy Spencer who works….." **http://www.theguardian.com/environment/climate-consensus-97-per-cent/2014/nov/07/new-study-disputes-satellite-temperature-estimates**

WWW.REPORTINGCLIMATESCIENCE.COM by Leon Clifford, October 24, 2014

Cloud Depress Satellite Warming Trend Says Study**:** "Measurements of the temperature of the atmosphere made by satellites may be underestimating the global warming trend by as much as 30 per cent, according to research. Satellites measure atmospheric temperature using microwave sensors but rain-bearing clouds scatter microwaves and this has the effect of depressing the apparent atmospheric temperature, says Fuzhong Weng, a senior research scientist with the US National Oceanic and Atmospheric Administration (NOAA)…….Weng's findings are disputed by climate scientist John Christy…." **http://www.reportingclimatescience.com/news-stories/article/clouds-depress-satellite-warming-trend-says-study.html**

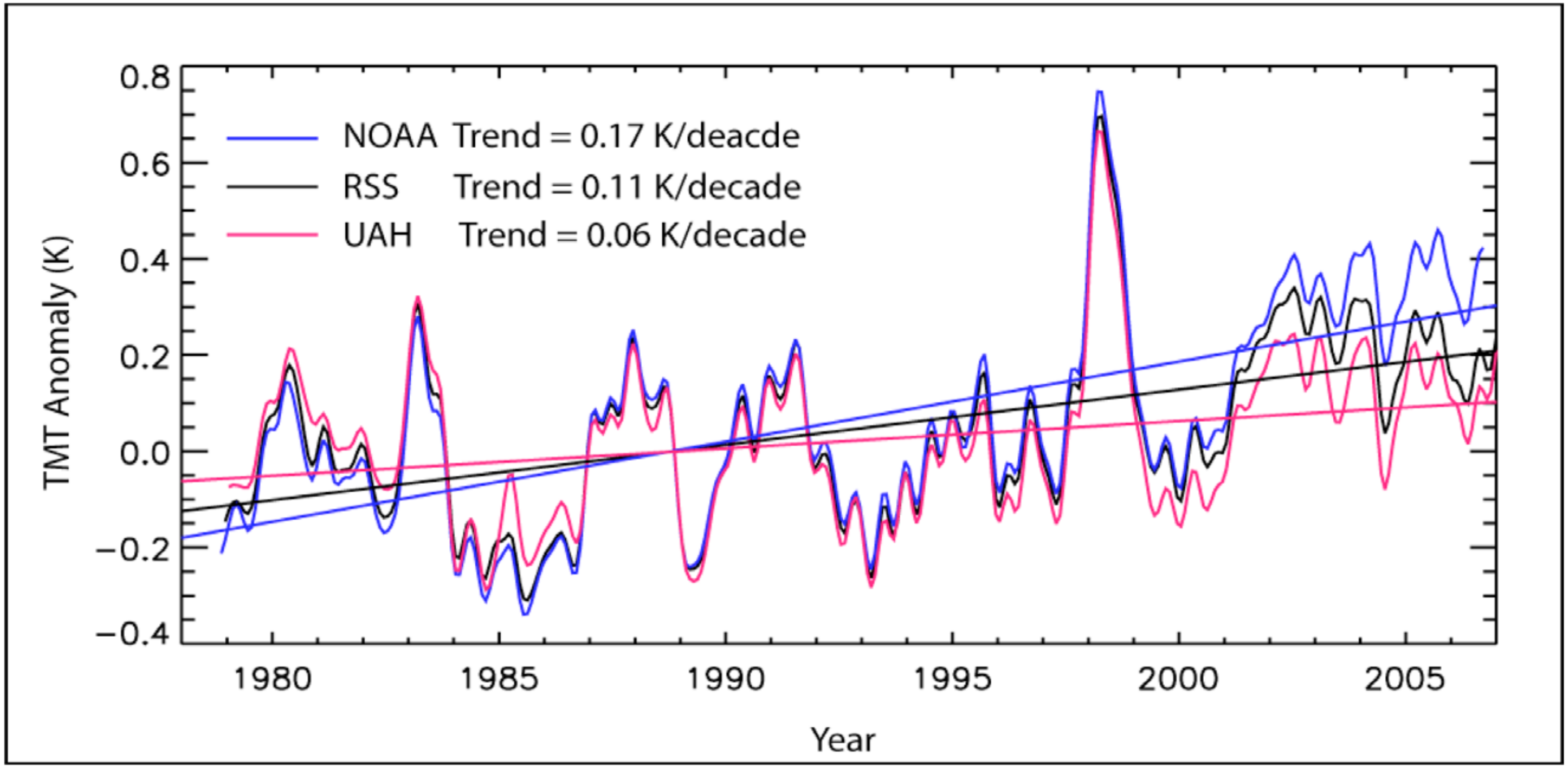
Citation: Weng, F., X. Zou and Z. Qin, 2014: Uncertainty of AMSU-A derived temperature trends in relationship with clouds and precipitation over ocean ,*Climate Dynamics,* September 2014, Volume 43, Issue 5-6, pp 1439-1448 DOI 10.1007/s00382-013-1958-7

USA, Europe and China Operational Weather Satellites



Three MSU Groups Derived Different Global Tropospheric Temperature Trend

Example: Middle Tropospheric Temperature.



Stratospheric Observations and Modeling Trends due to for Ozone, GHG and Water Vapor Changes

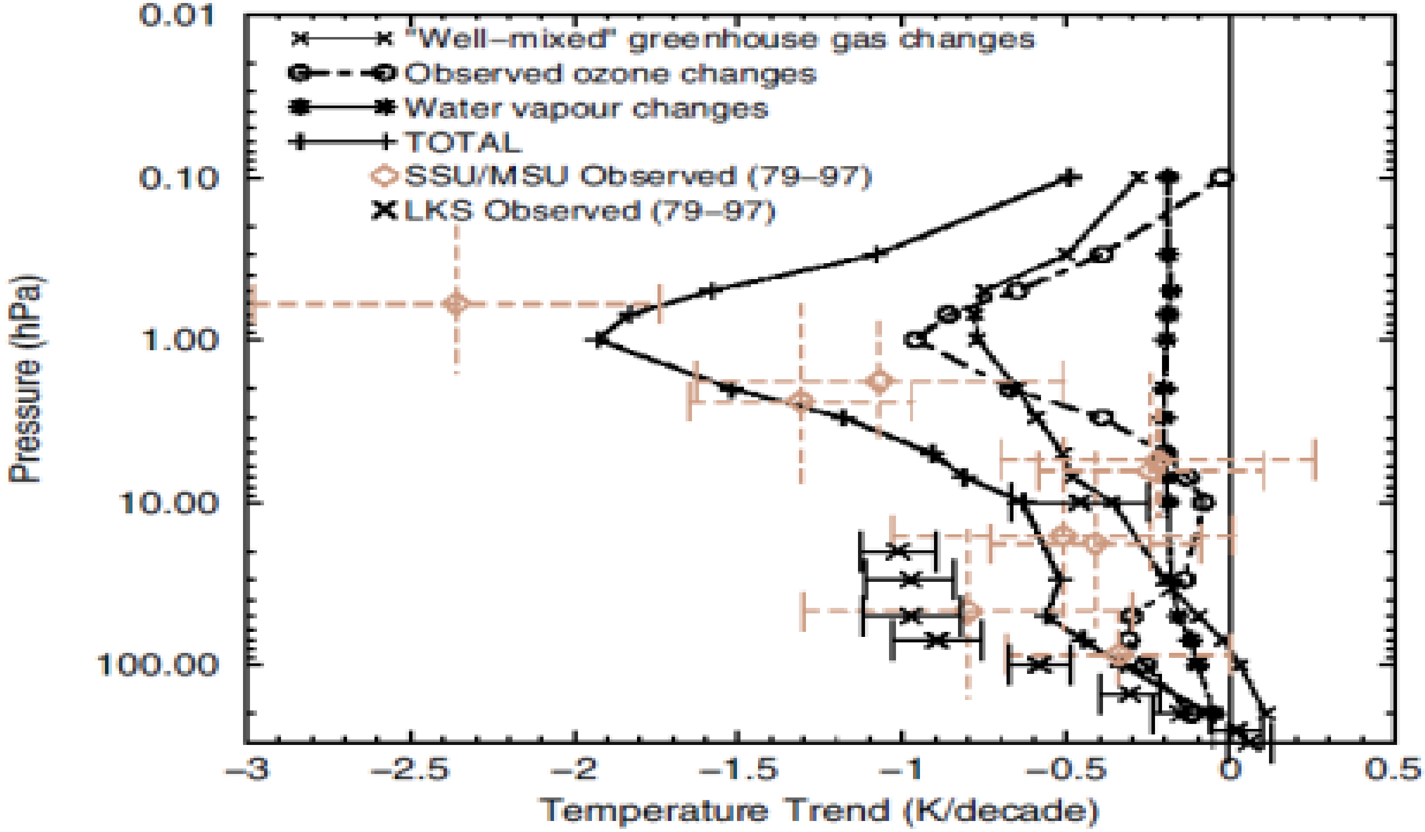
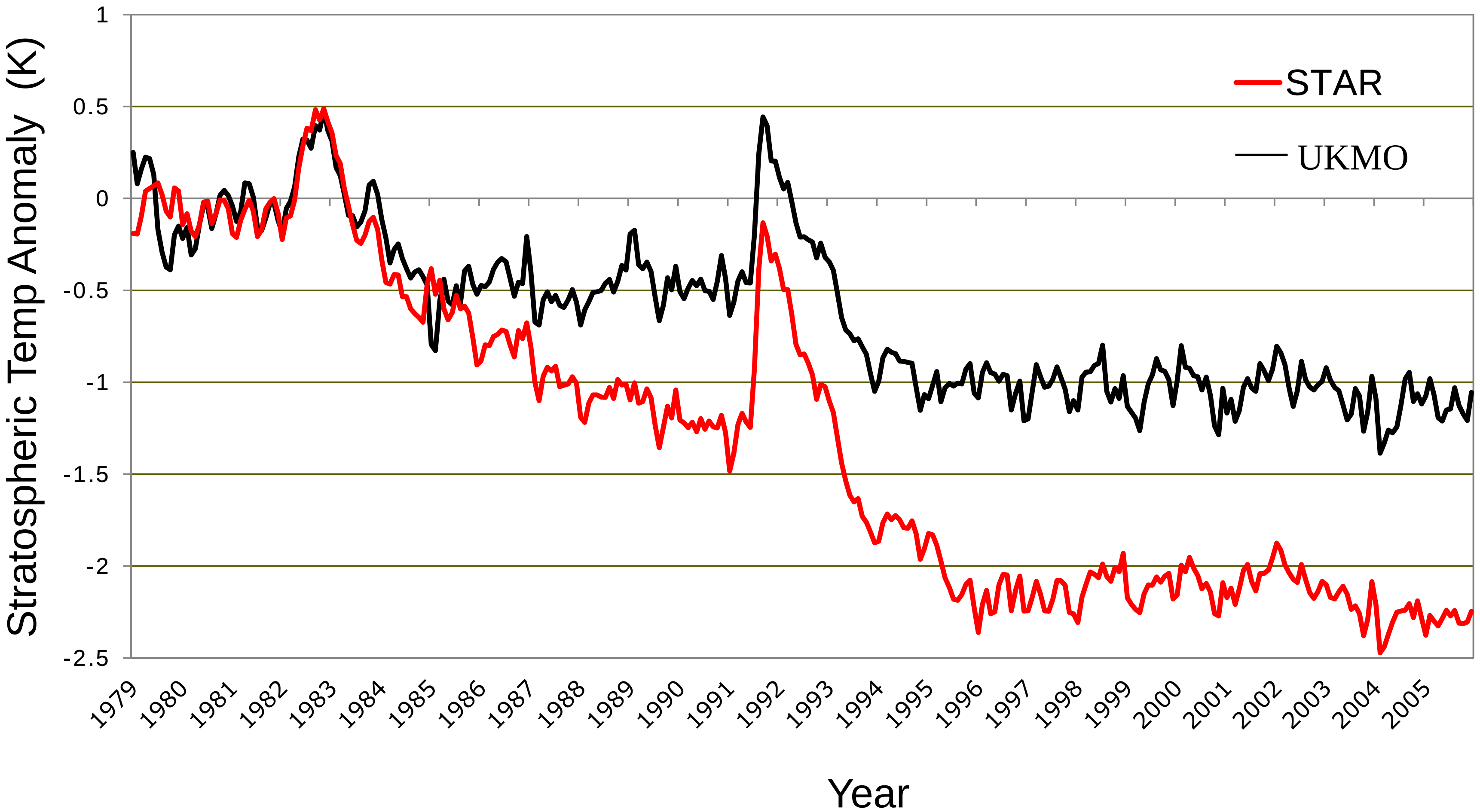


Figure 5. Global- and annual-mean temperature trends for the period approximately 1980–2000, from an average of the model results for the imposed height-resolved ozone trends (Fig. 1) and greenhouse gases (Fig. 2); the water vapour results are the Imperial College IGCM Halogen Occultation Experiment (HALOE) trends in Fig. 3. The satellite trends from the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU), and the radiosonde trends from Lanzante *et al.* (2003a,b; LKS) are also shown. The 2-sigma error bars in the observations are included; the vertical bars are intended to give the approximate altitude range sensed by the particular satellite channel.

Shine (2003)

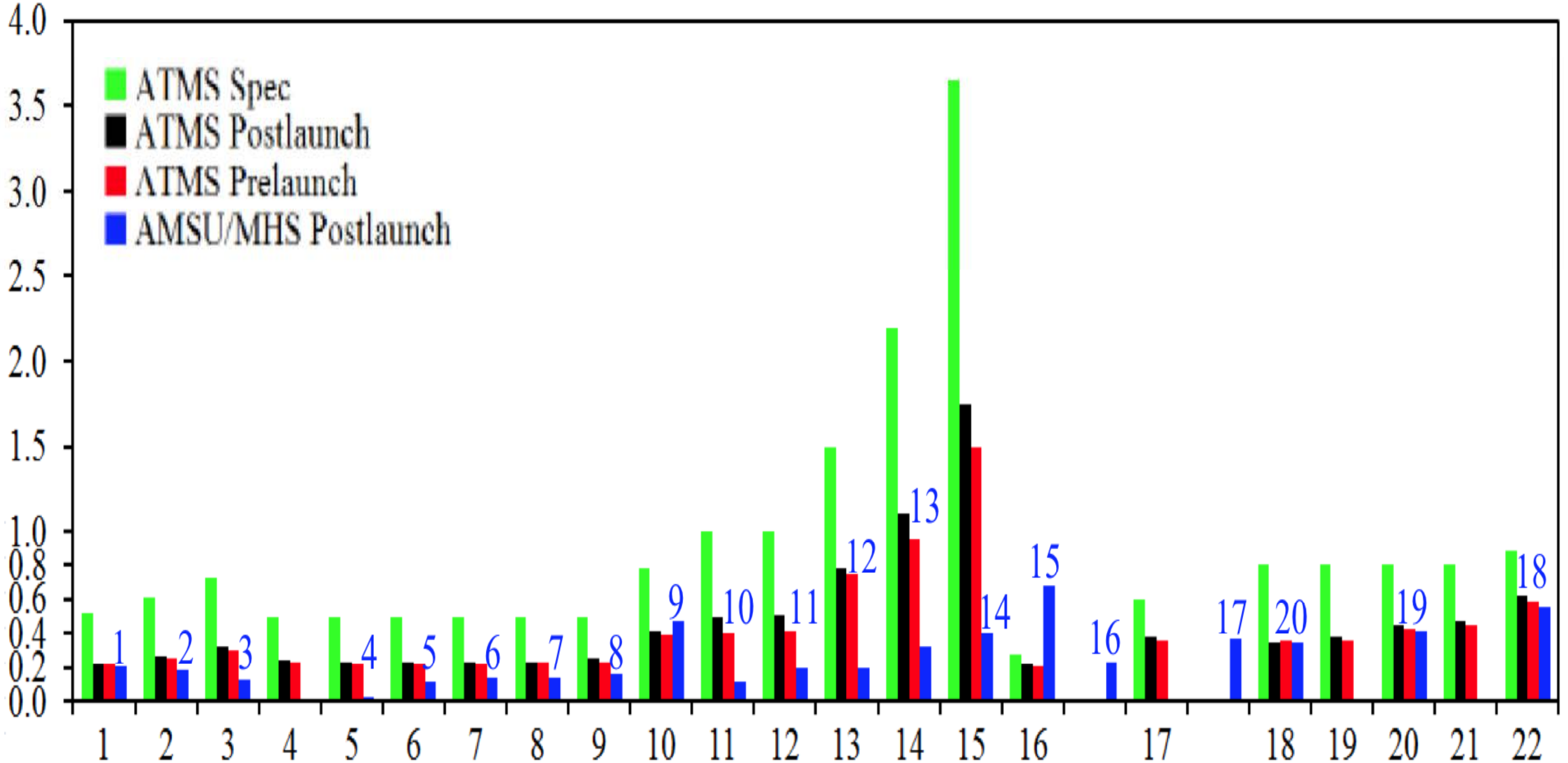
Two SSU Groups Derived Different Global Stratospheric Temperature Trends



Community Efforts on Uses of Satellite Data for Atmospheric Trend Studies

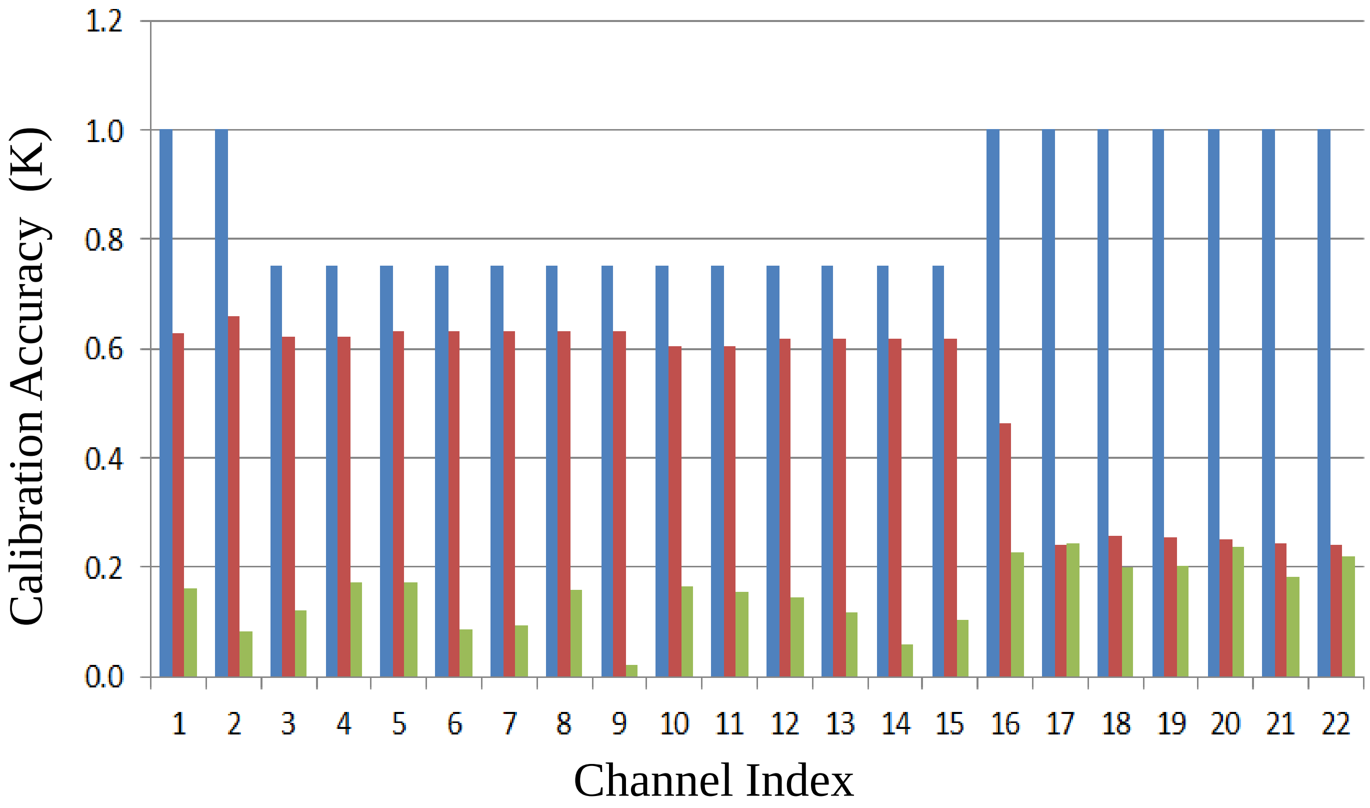
- Understand the calibration anomalies from each MSU instrument and their impacts on atmospheric temperature trends
- Cross-calibrate all the historical MSU data through SNO
- Correct the effects of satellite orbit drifts on tmeperature trend
- ***Develop on-orbit calibration standard for microwave sounding instruments***
- ***Make spatially and spectrally consistent satellite microwave sounding data***
- ***Understand the physical process such as clouds and precipitation and its impacts on the trend***
- ***Examine the trends of satellite retrieved temperature***

ATMS Channel Noise Characterization



All Channels are within Specifications (Weng et al., 2012, JGR)

ATMS Pre-launch Calibration Accuracy



Red – Calibration accuracy from a nominal data, Green – values obtained from prelaunch Thermal Vacuum (TVAC), and Blue – specification

ATMS Calibration Accuracy Assessment Using GPS RO

- Time period of data search:

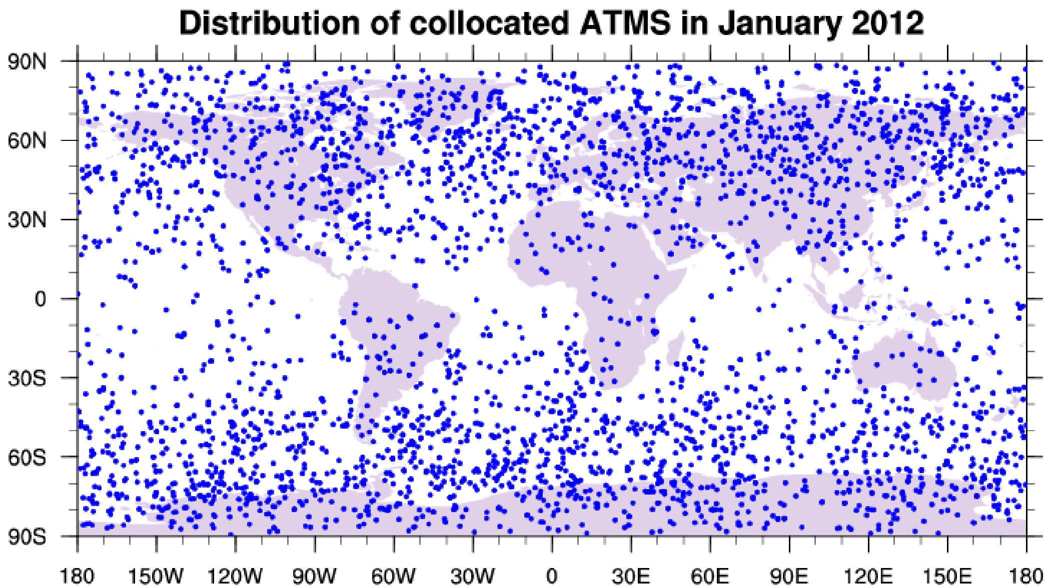
  January, 2012

- Collocation of ATMS and COSMIC data:

  Time difference < 0.5 hour

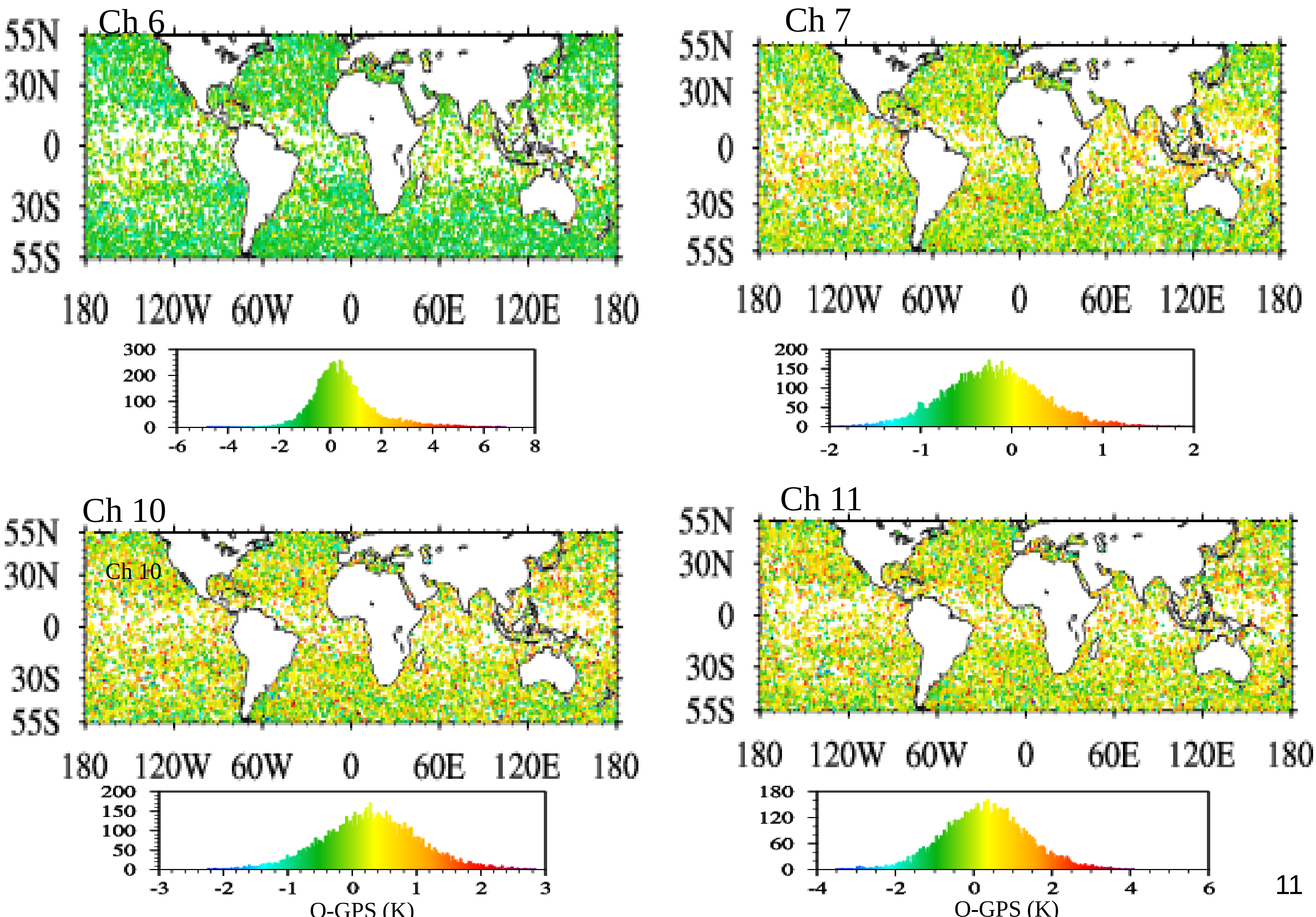
  Spatial distance < 30 km

(GPS geolocation at 10km altitude is used for spatial collocation)

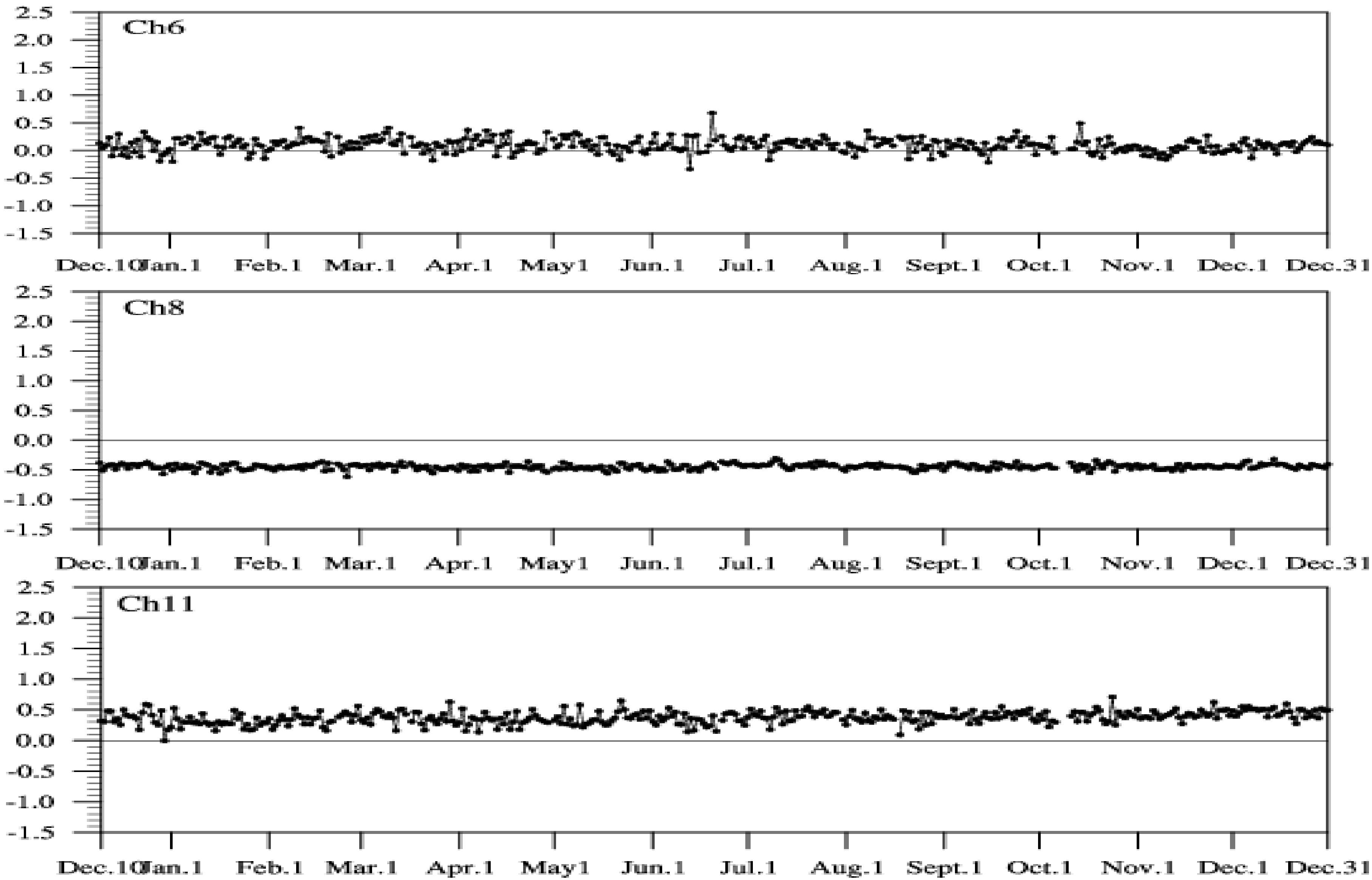


3056 collocated measurements

ATMS Bias Obs (TDR) - GPS Simulated



ATMS Bias Obs - Sim (GPS RO)

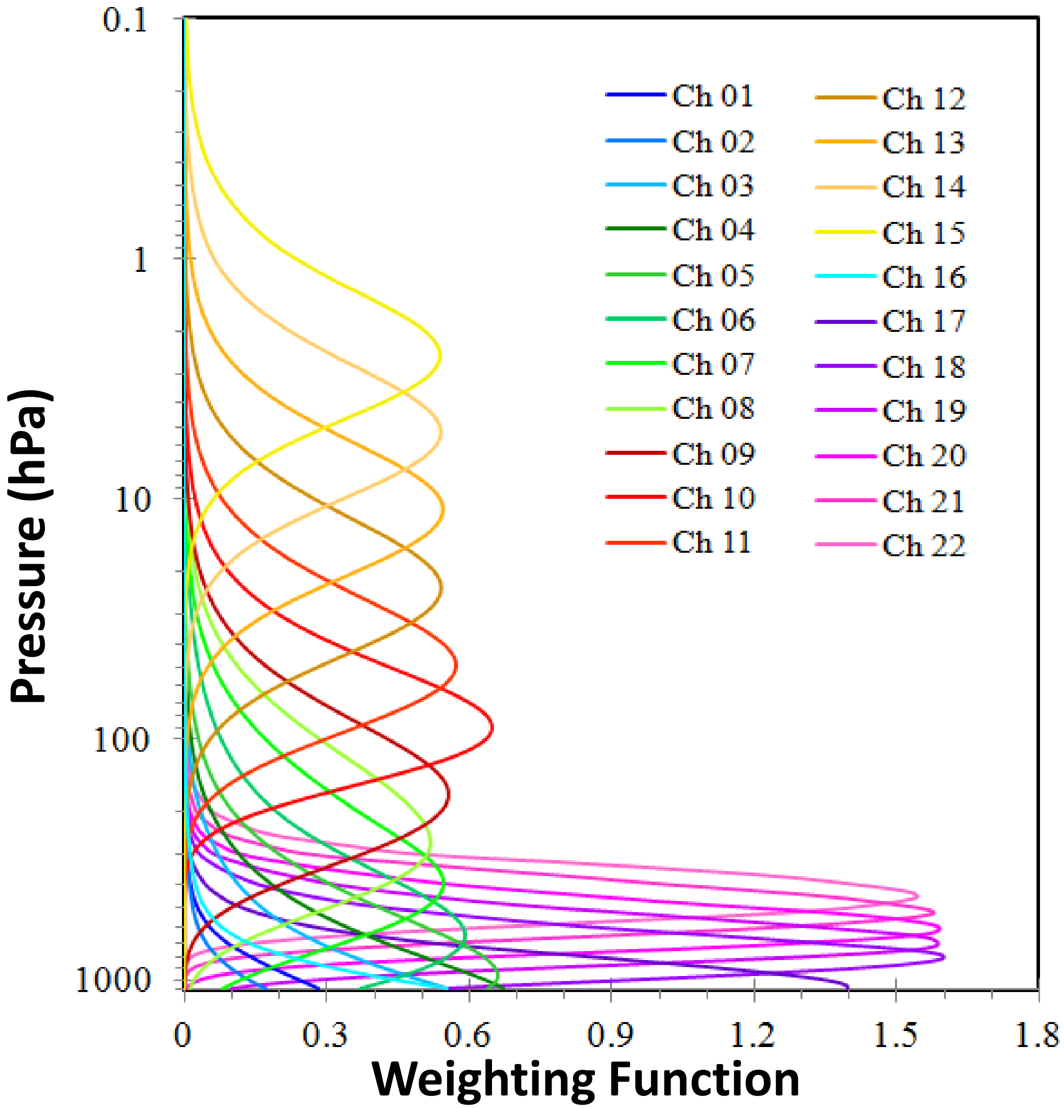


Slide courtesy of Lin Lin

MSU			AMSU/MHS			ATMS		
Ch	**GHz**	**Pol**	**Ch**	**GHz**	**Pol**	**Ch**	**GHz**	**Pol**
			1	23.8	QV	1	23.8	QV
			2	31.399	QV	2	31.4	QV
1	50.299	QV	3	50.299	QV	3	50.3	QH
						4	51.76	QH
			4	52.8	QV	5	52.8	QH
2	53.74	QH	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
			6	54.4	QH	7	54.4	QH
3	54.96	QH	7	54.94	QV	8	54.94	QH
			8	55.5	QH	9	55.5	QH
4	57.95	QH	9	fo = 57.29	QH	10	fo = 57.29	QH
			10	fo ± 0.217	QH	11	fo±0.3222±0.217	QH
			11	fo±0.3222±0.048	QH	12	fo± 0.3222±0.048	QH
			12	fo ±0.3222±0.022	QH	13	fo±0.3222±0.022	QH
			13	fo± 0.3222±0.010	QH	14	fo±0.3222 ±0.010	QH
			14	fo±0.3222±0.0045	QH	15	fo± 0.3222±0.0045	QH
			15	89.0	QV			
			16	89.0	QV	16	88.2	QV
			17	157.0	QV	17	165.5	QH
						18	183.31 ± 7	QH
						19	183.31 ± 4.5	QH
			19	183.31 ± 3	QH	20	183.31 ± 3	QH
			20	191.31	QV	21	183.31 ± 1.8	QH
			18	183.31 ± 1	QH	22	183.31 ± 1	QH

- Exact match to AMSU/MHS
- Only Polarization different
- Unique Passband
- Unique Passband, and Pol. different from closest AMSU/MHS channels

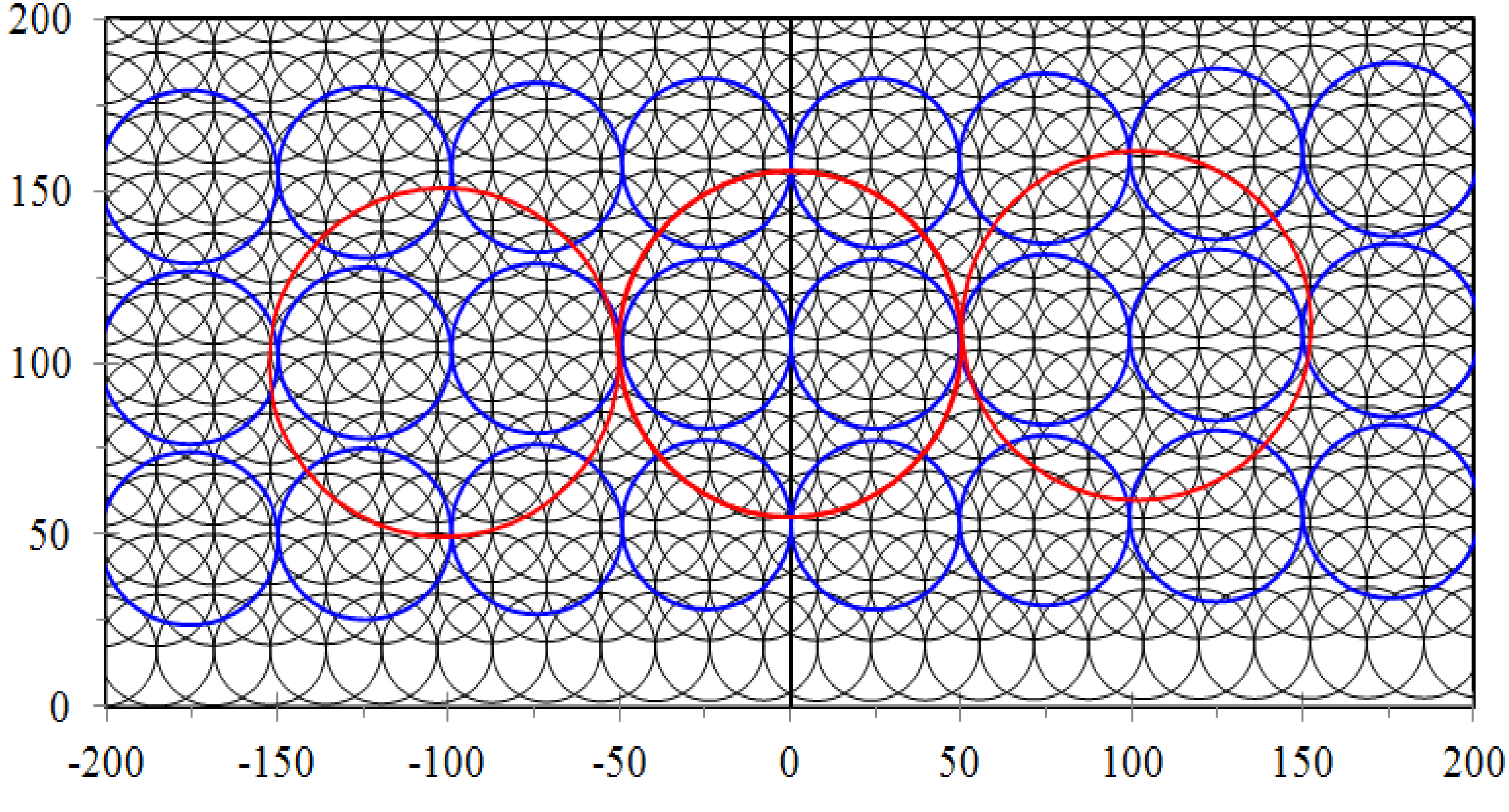
ATMS Weighting Functions



Three Generations of Microwave Sounding Instruments from MSU to AMSU/MHS to ATMS

ATMS Field of View Size for the beam width of 2.2º – black line

ATMS Resample to the Field of View Size for the beam width of 3.3º- blue line



ATMS Resampling Algorithm

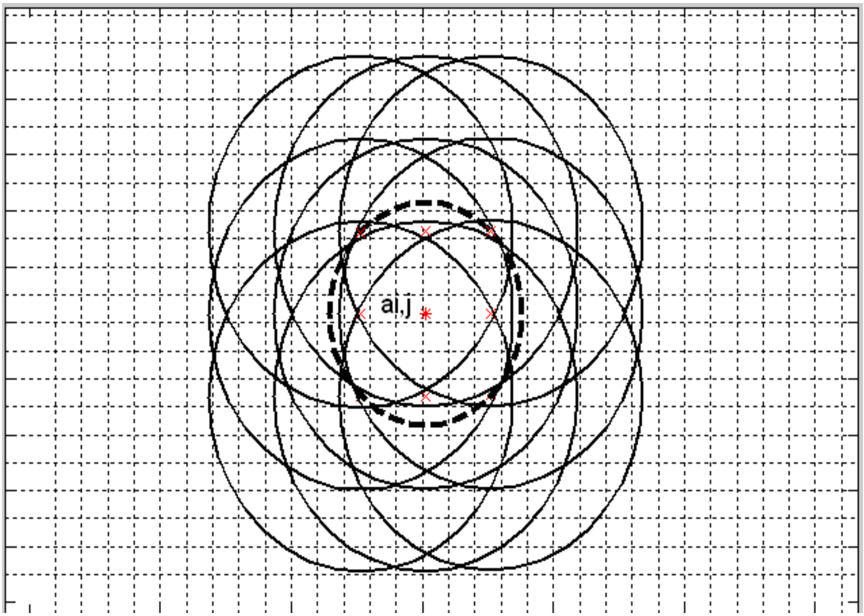
$$T_b^{BG}(k) = \sum_{i=-N_{ch}}^{N_{ch}} \sum_{j=-N_{ch}}^{N_{ch}} w(k+i, j) T_b^{ATMS}(k+i, j)$$

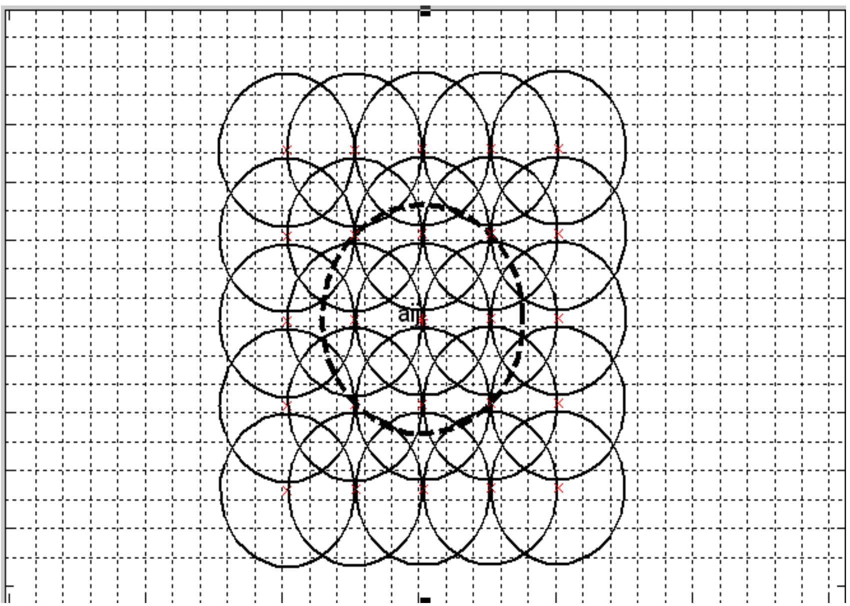
$$w(k+i, j) - \text{B-G coefficients}$$

$$N_{ch} = \begin{cases} 1 & \text{Channels 1 - 2} \\ 2 & \text{Channels 3 -16} \end{cases}$$

Stogryn, A., 1978: Estimates of brightness temperatures from scanning radiometer data. *IEEE Trans. Ant. & Prop.*, AP-26, 720-726.

Backus-Gilbert (BG) Methodology for Consistent AMSU-A and ATMS Resolution



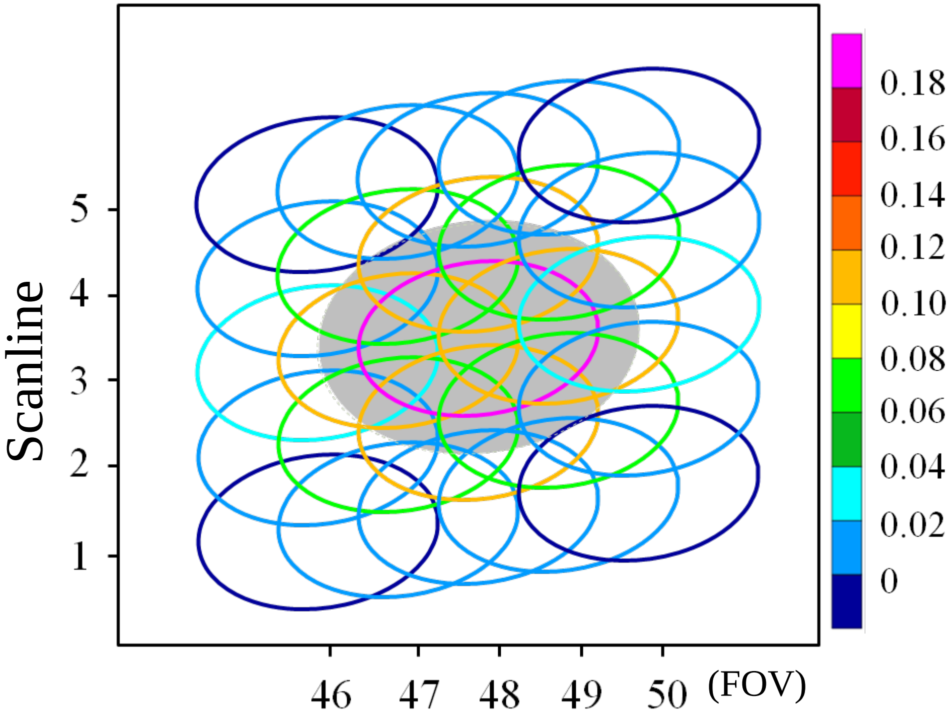


ATMS 5.2 degree beam width: 3 × 3 FOVs used for AMSU-A 3.3 degree beam width

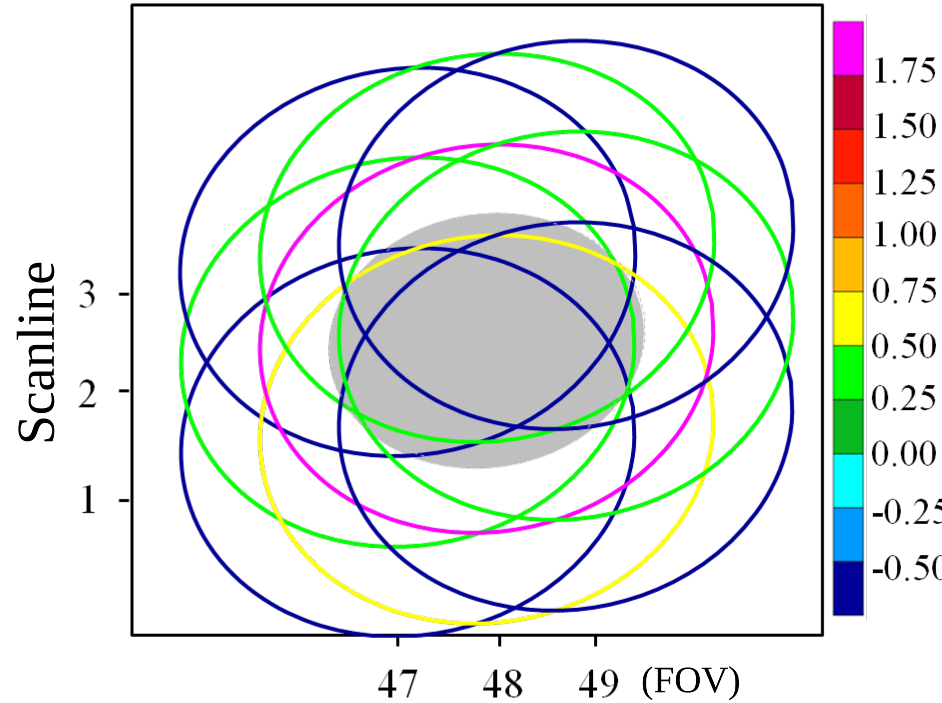
ATMS 2.2 degree beam width: 5 × 5 FOVs used for AMSU-A 3.3 degree beam width

Backus-Gilbert (BG) Methodology for Consistent AMSU-A and ATMS Resolution near Nadir

ATMS Channels 3-16



ATMS Channels 1-2

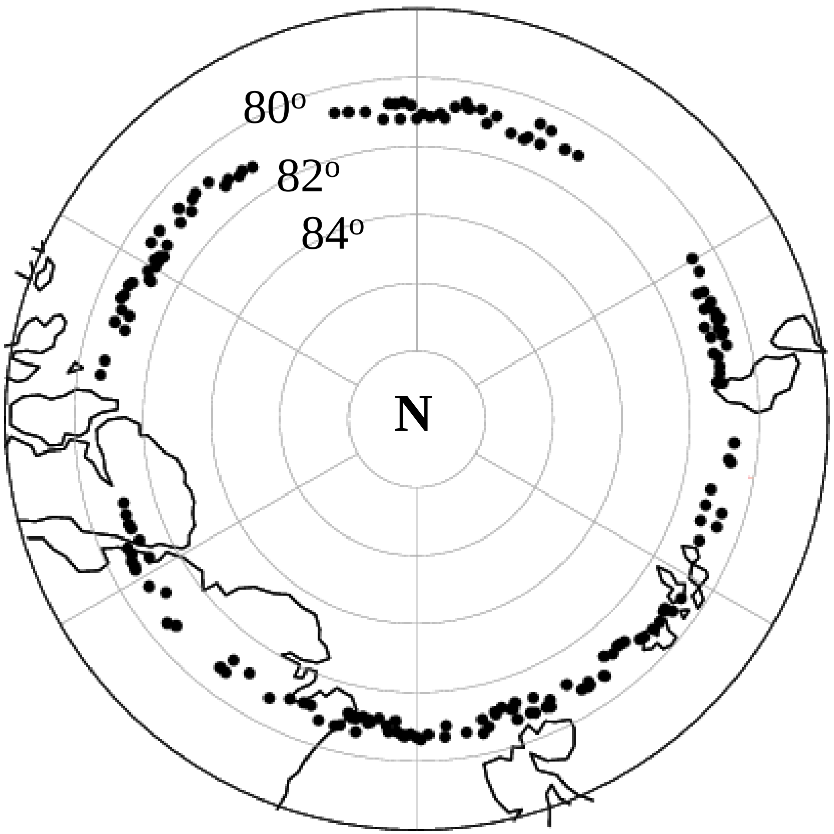


An effective AMSU-A target FOV: output of BG remap (shaded in gray)

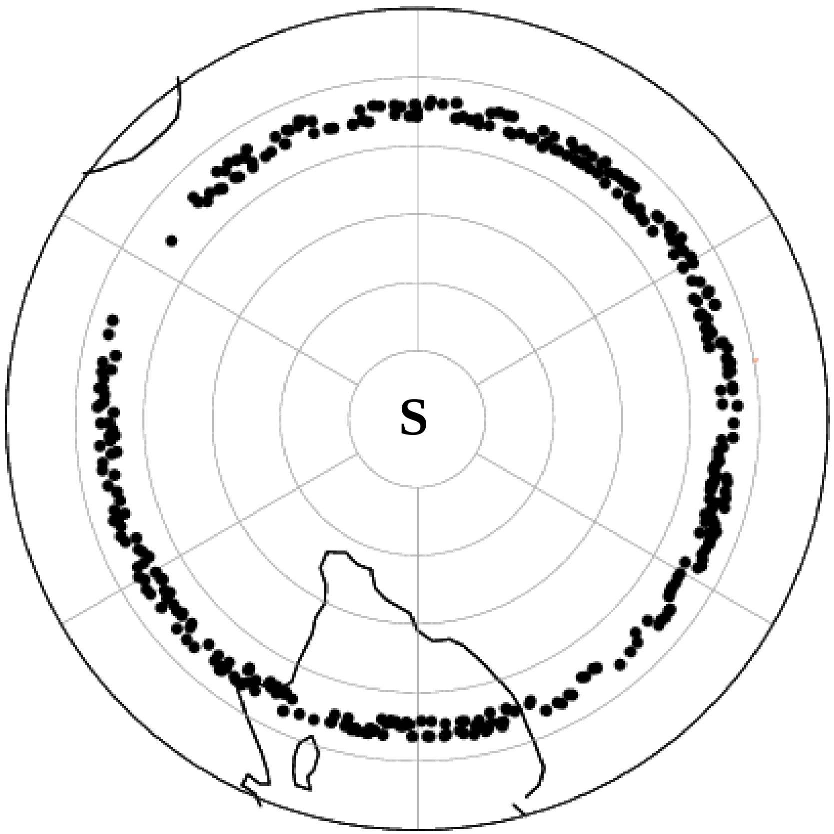
ATMS effective FOVs: Circles with colors indicating the magnitude of BG coefficients

Further Characterization of Bias between Resample ATMS vs. AMSU using SNO Data

Northern Hemisphere



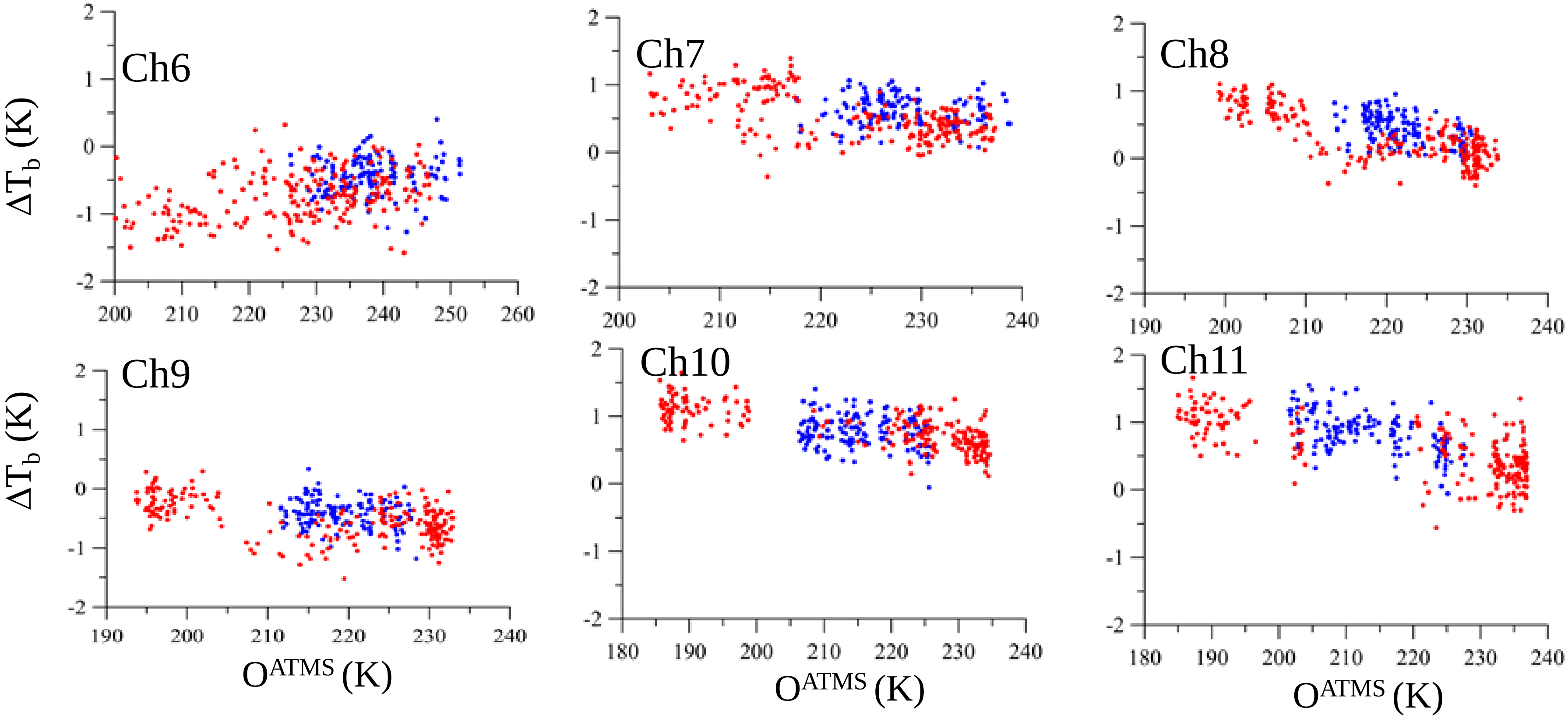
Southern Hemisphere

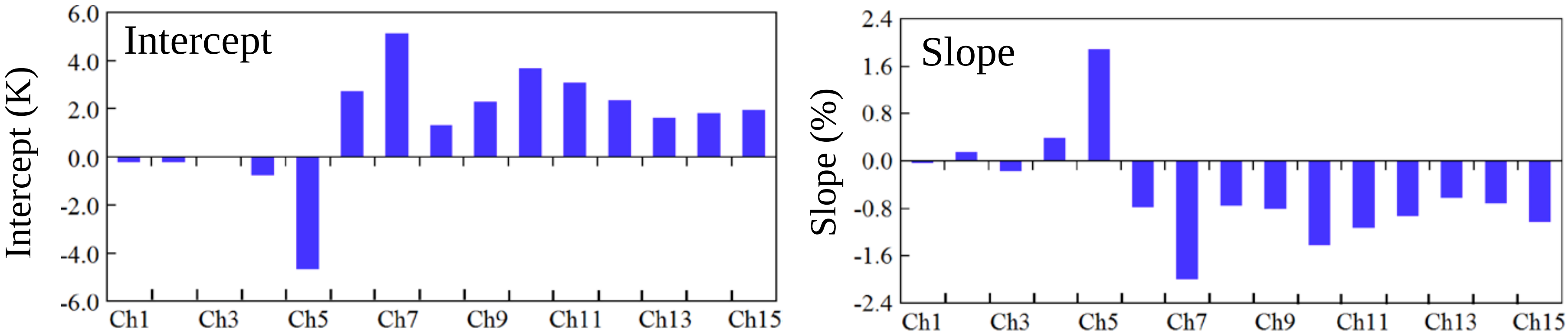


Time Period: January 1, 2012 - March 31, 2013

Collocation Criteria: 15 km and 60 seconds

Scatter Plots of $\Delta T_b (= O^{ATMS} - O^{NOAA\text{-}18})$
(Blue :Arctic and Red: Antarctic)

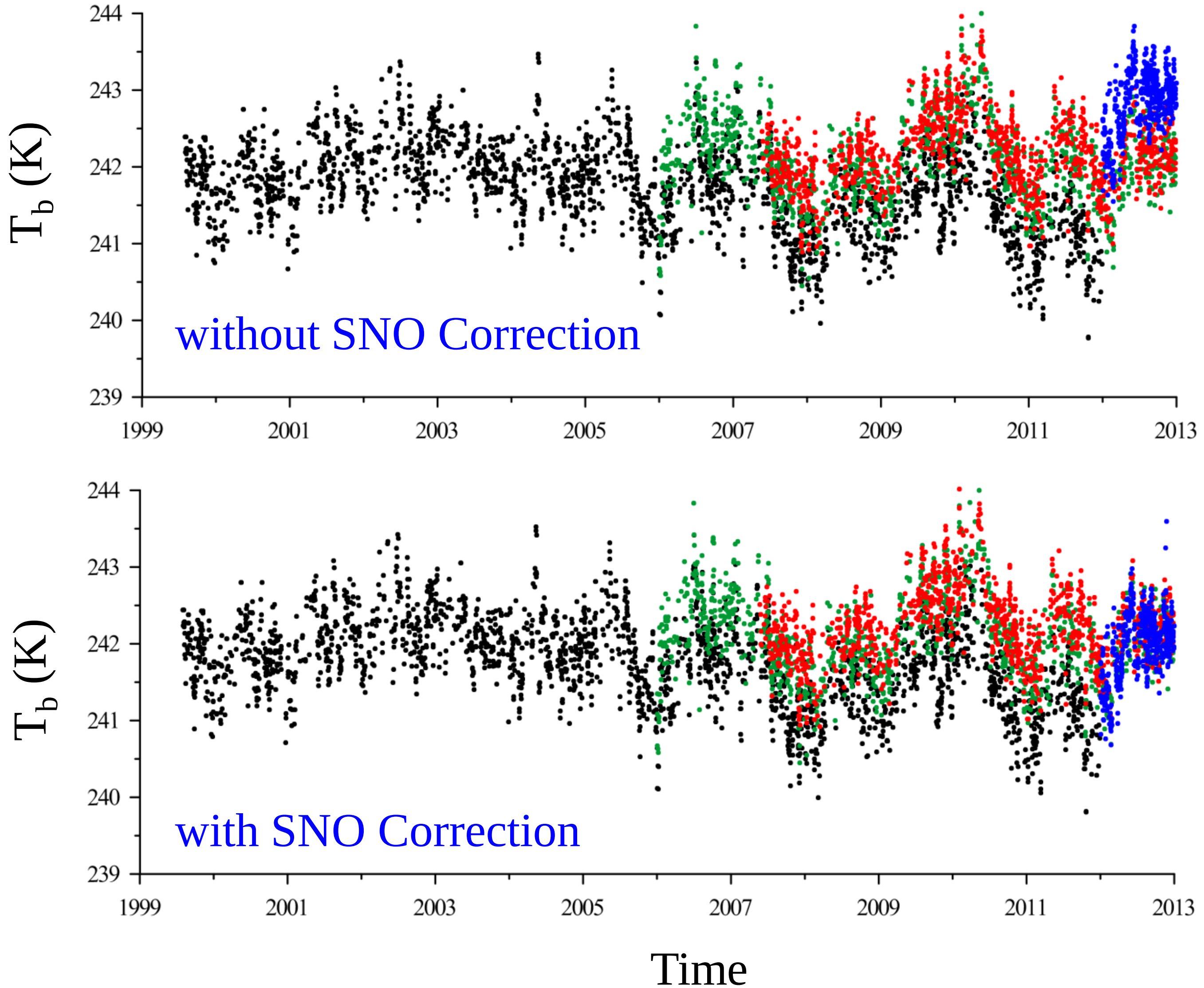




Bias between Resample ATMS and AMSU-A

Channel	ATMS remap minus NOAA-18 AMSU-A		
	mean	intercept	slope
1	-0.25	-0.22	-0.0002
2	0.08	-0.20	0.0015
3	-0.35	-0.01	-0.0016
5	0.15	-0.74	0.0039
6	-0.29	-4.66	0.0189
7	0.99	2.73	-0.0077
8	0.70	5.12	-0.0199
9	-0.30	1.31	-0.0074
10	0.58	2.29	-0.0079
11	0.59	3.66	-0.0141
12	0.60	3.06	-0.0112
13	0.26	2.35	-0.0092
14	0.18	1.61	-0.0061
15	0.08	1.82	-0.0070
16	-0.05	1.95	-0.0102

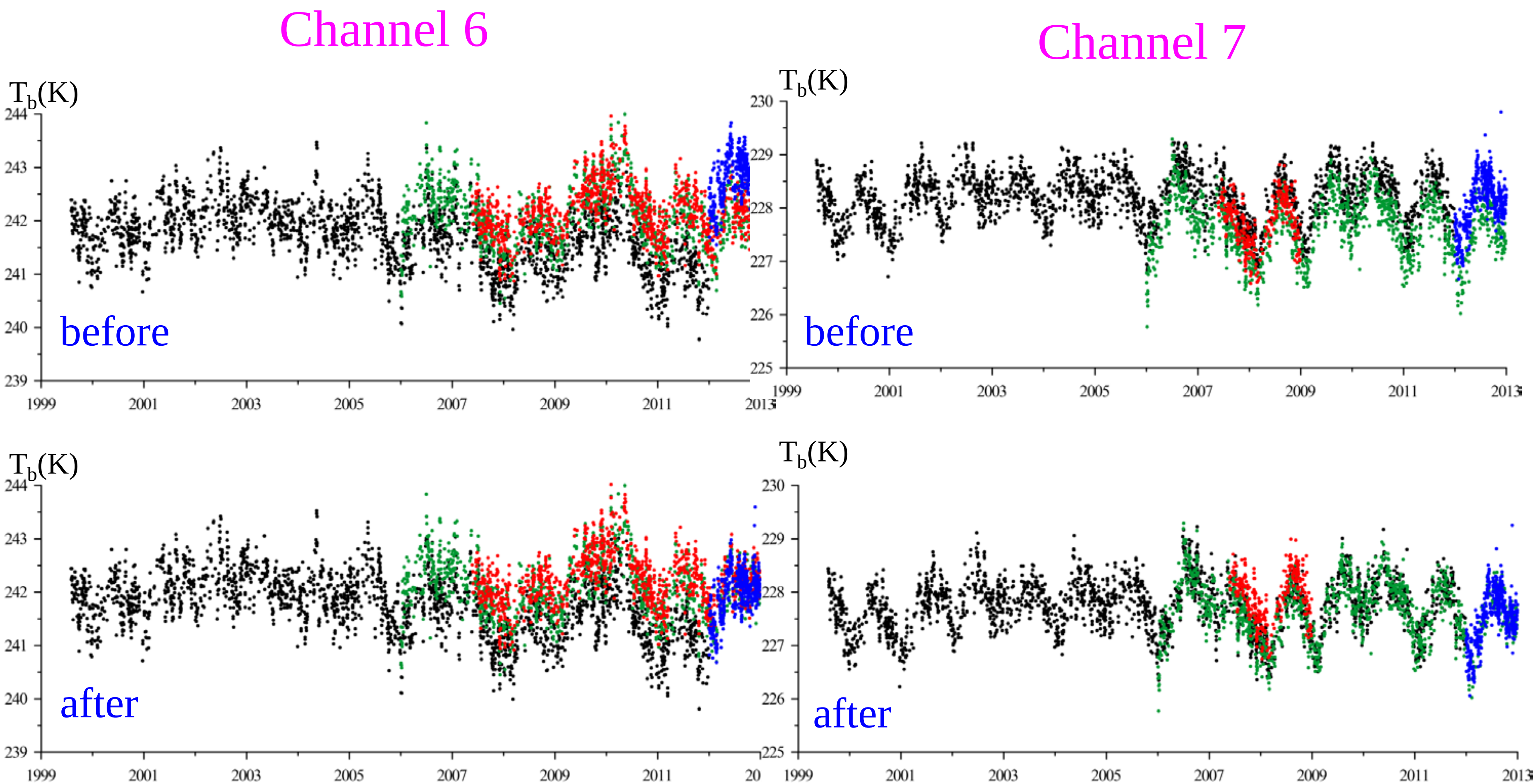
Temporal Evolution of Channel 6 Observation



NOAA-15
NOAA-18
MetOp-A
SNPP

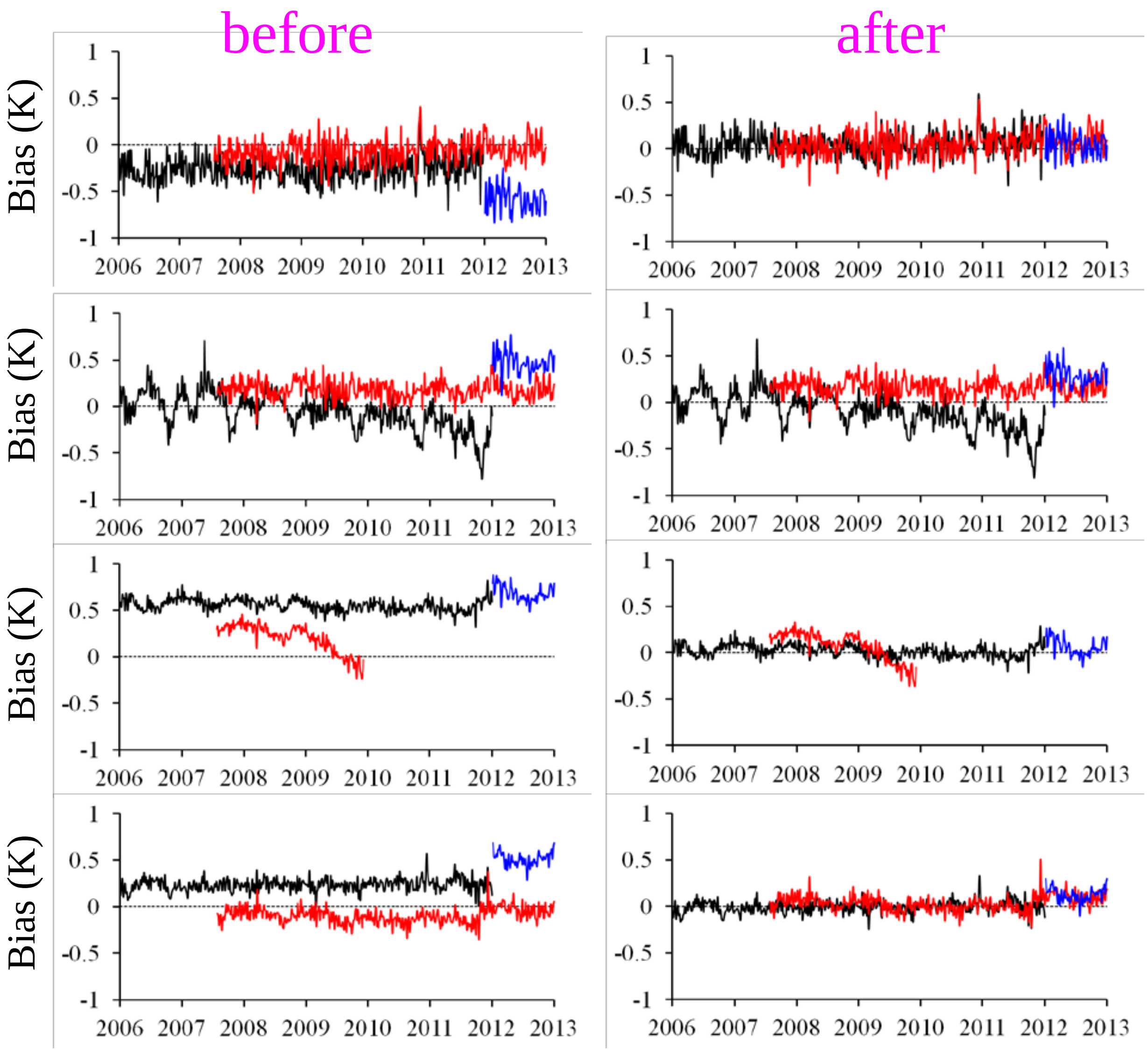
nadir
clear-sky
(2S-2N)
(80W-100W)

Data from NOAA-15, NOAA-18, MetOp-A, SNPP



Nadir only, clear-sky, (2S-2N), (80W-180W)

Biases in the Tropics (NOAA-15, NOAA-18, MetOp-A, SNPP)



ATMS channel 6

ATMS channel 7

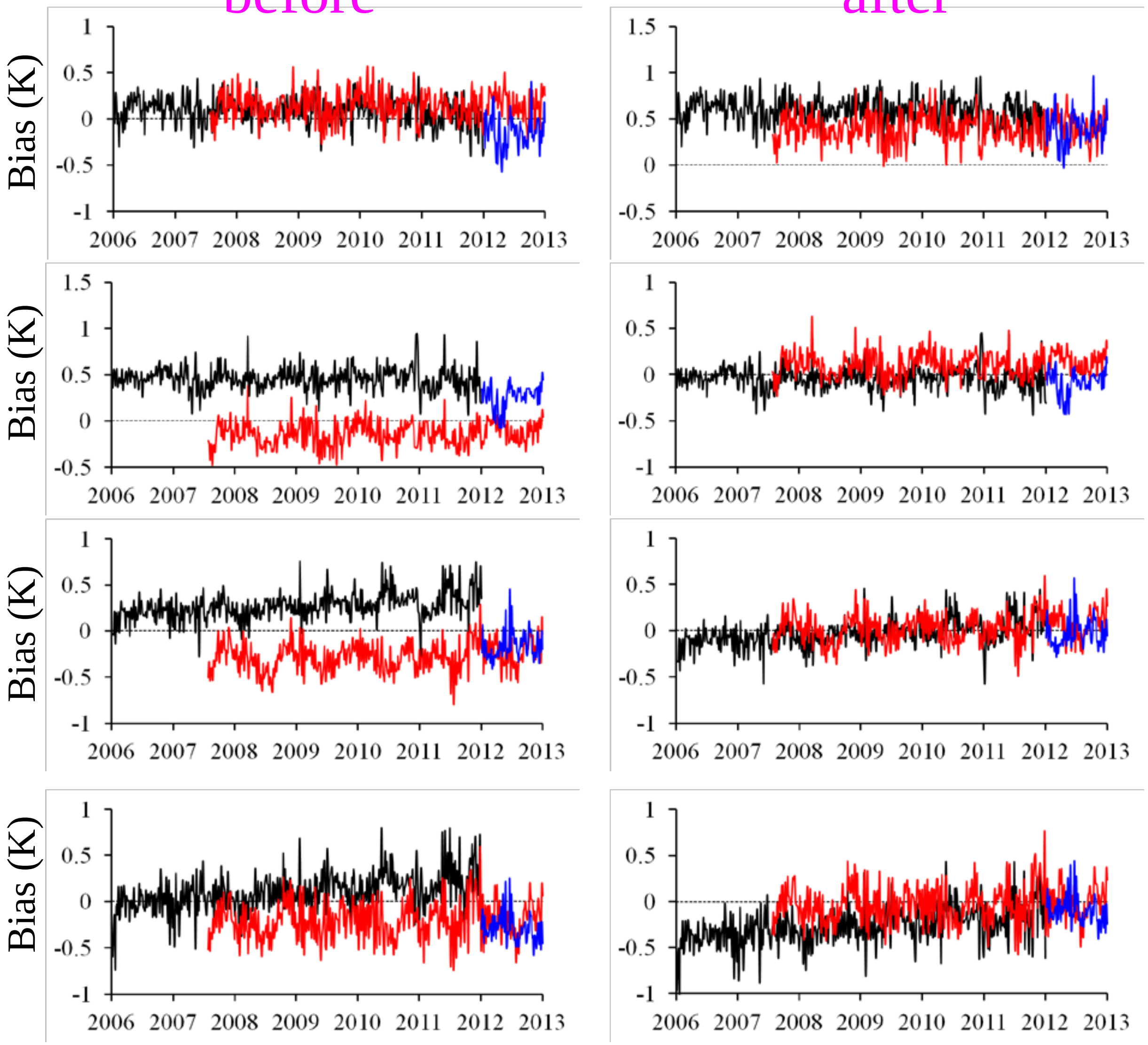
ATMS channel 8

ATMS channel 9

NOAA-18 is subtracted. The pentad data set within ±30º latitudinal band.

Biases in the Tropics (NOAA-15, MetOp-A, SNPP)

before | after



ATMS channel 10

ATMS channel 11

ATMS channel 13

ATMS channel 14

NOAA-18 is subtracted. The pentad data set within ±30° latitudinal band.

Satellite Datasets and Its Quality Control

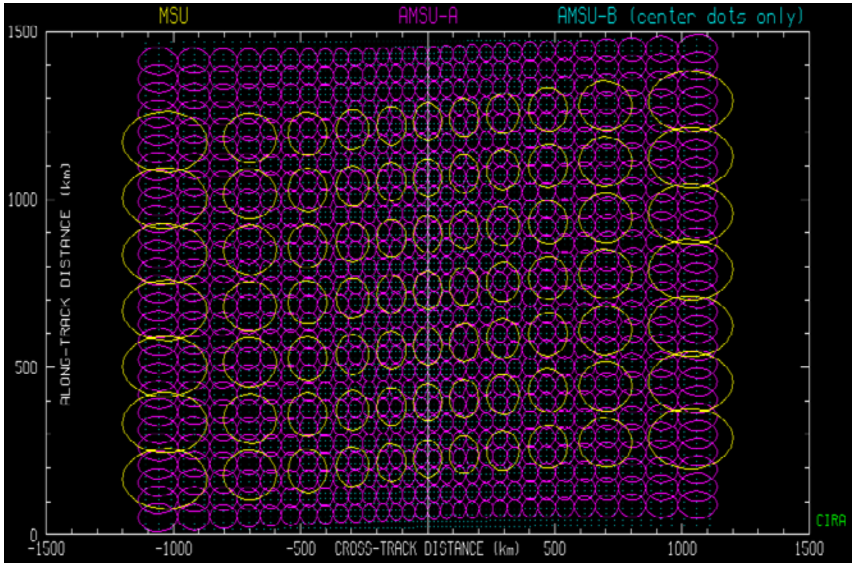
• NOAA-15 AMSU-A data which include 15 channels: Ch1-23.8 Ghz, Ch2-31.4 GHz, Ch15-89 GHz, Ch3-14: 50-60 GHz

• AMSU-A scans across the track with 30 field of views

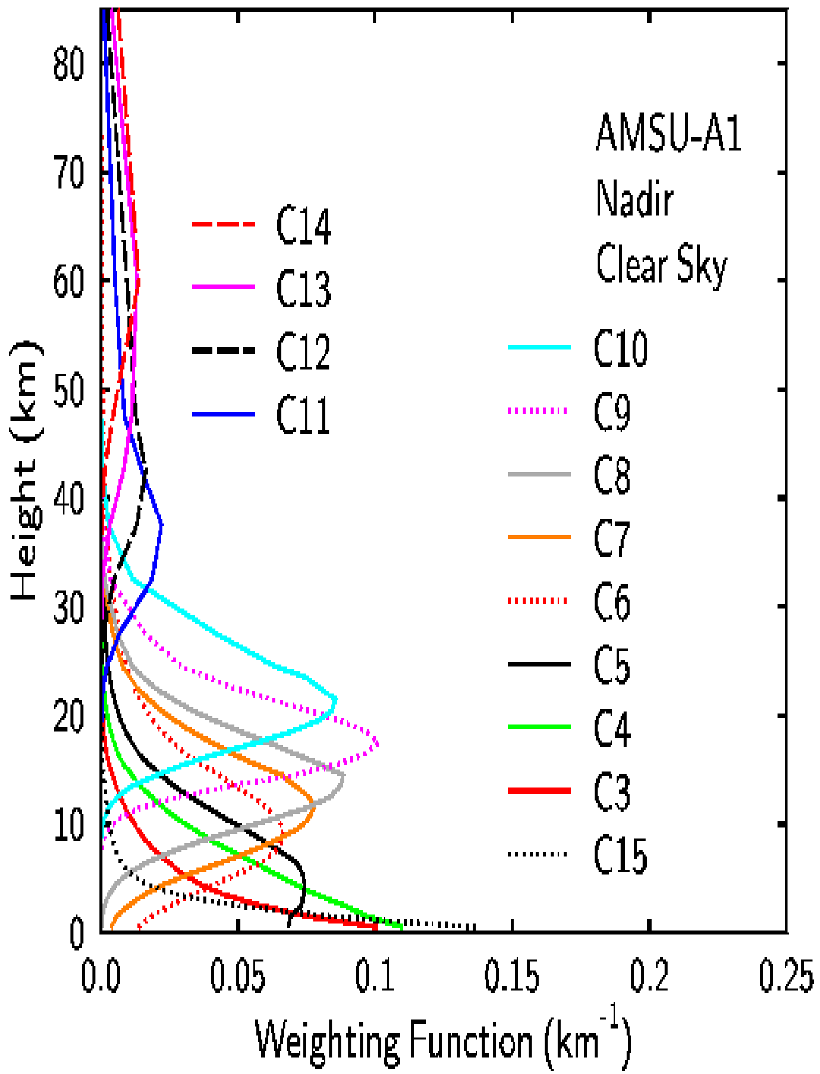
•It has a longest time-series (16 years) from single NOAA satellite

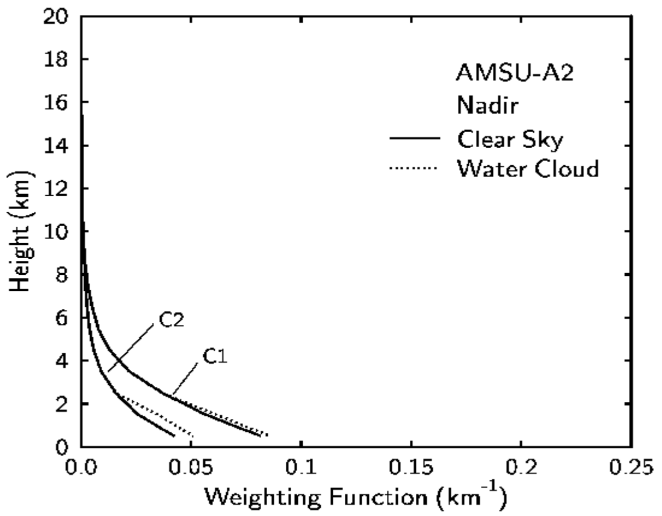
• There are quite larger orbit drifts in local passing time

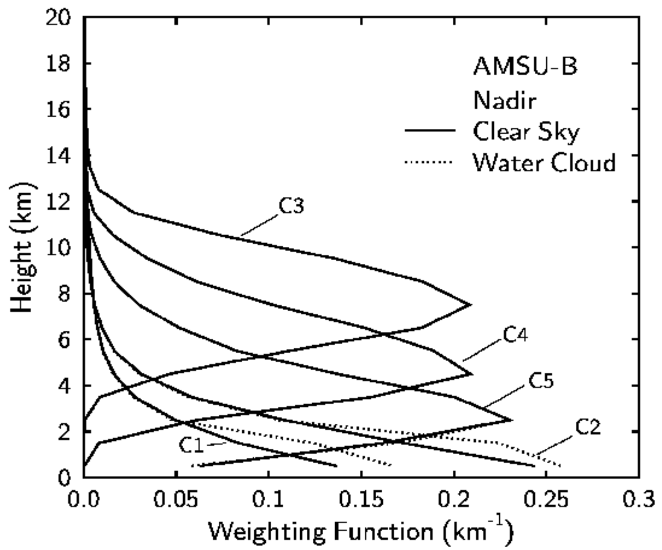
• Satellite observations near oceanic data are used



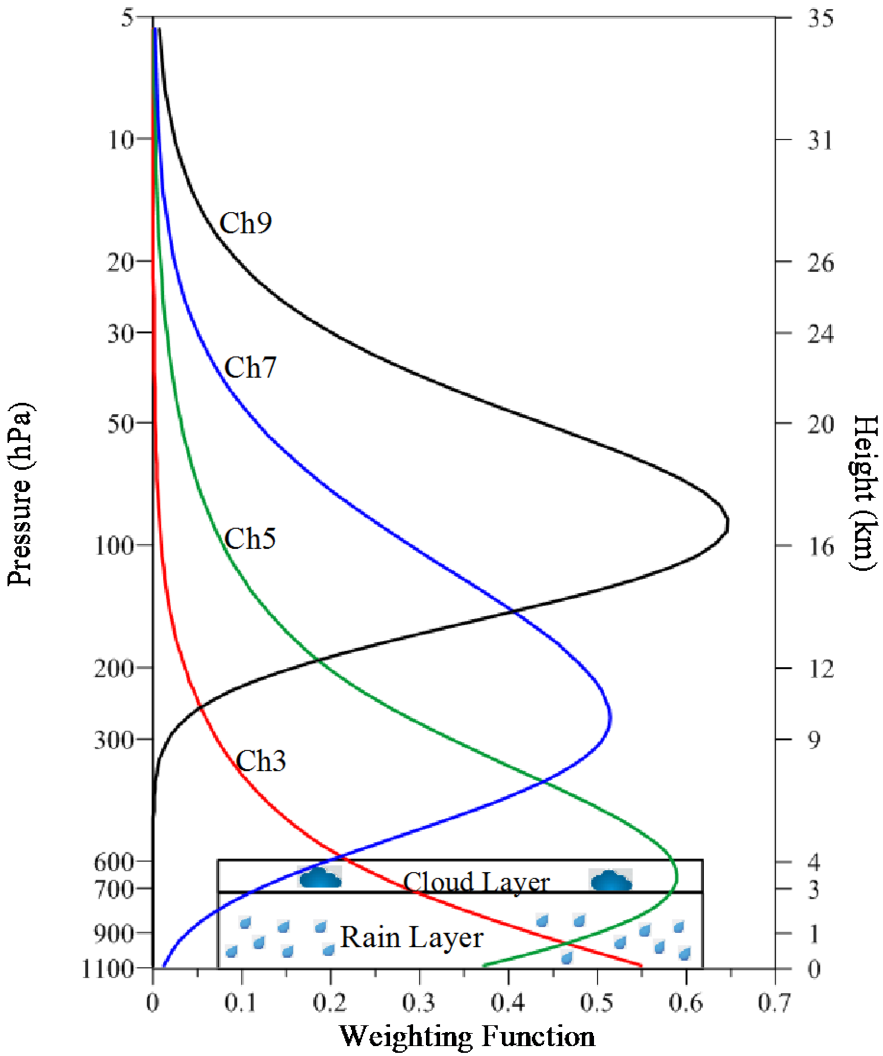
AMSU Weighting Functions



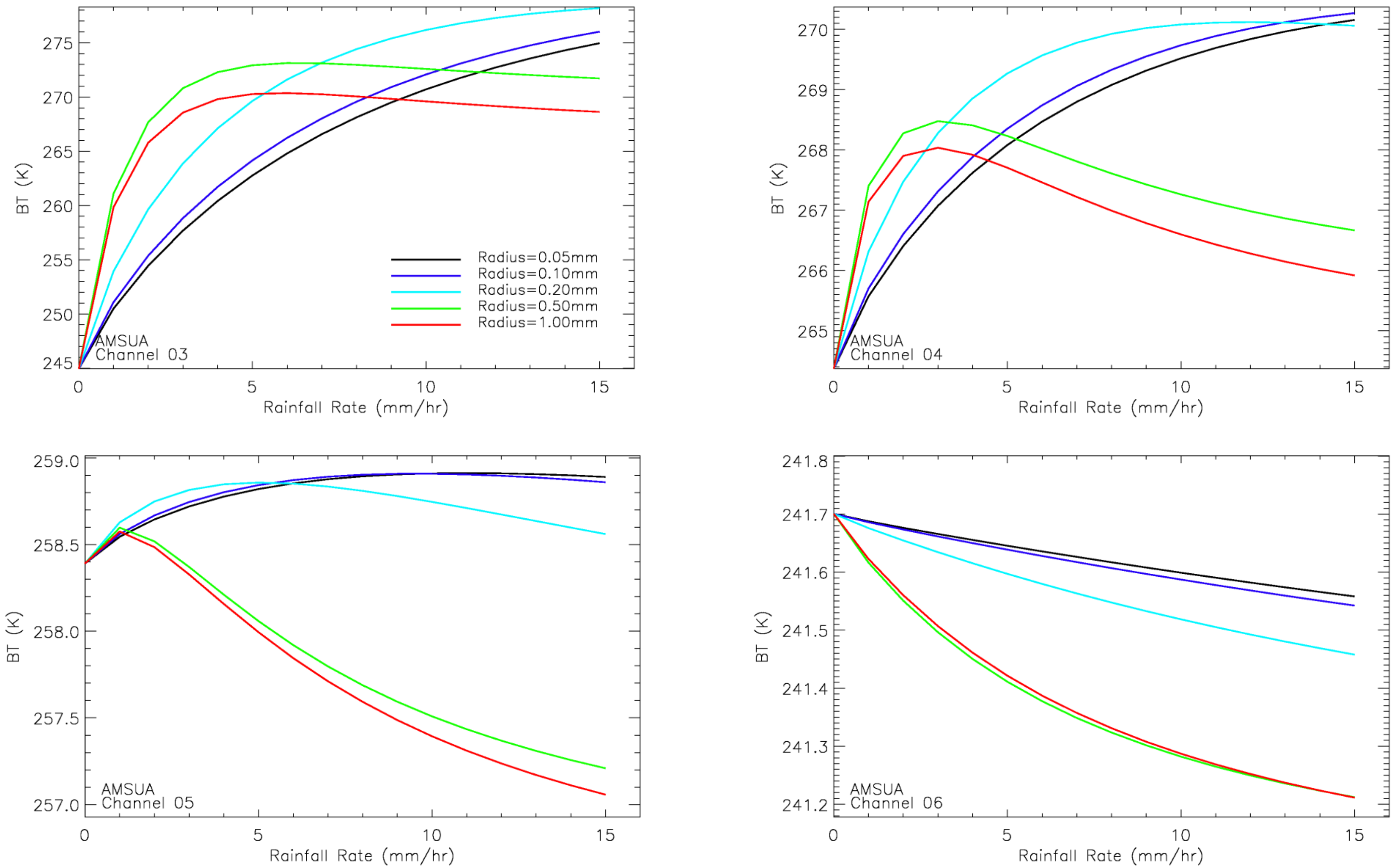




New Analysis of Atmospheric Temperature Trend from MSU and AMSU



Cloud Effects on AMSU Brightness Temperature



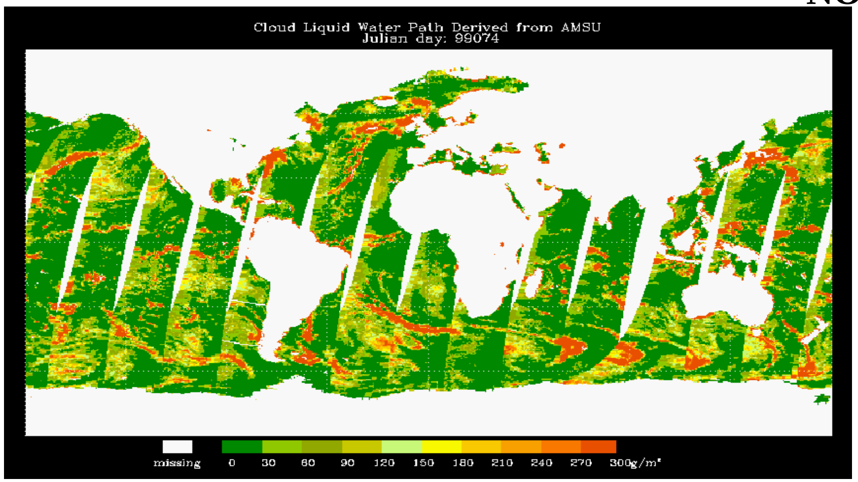
Assume a stratiform rainfall with intermediate rainfall rate: A cloud layer about 0.8 km depth below the freezing level with liquid water path of 0.5 kg/m2, and the raindrops all below the non-precipitating cloud layer and the rainfall rates unchanged vertically. Emissivity set to 0.5.

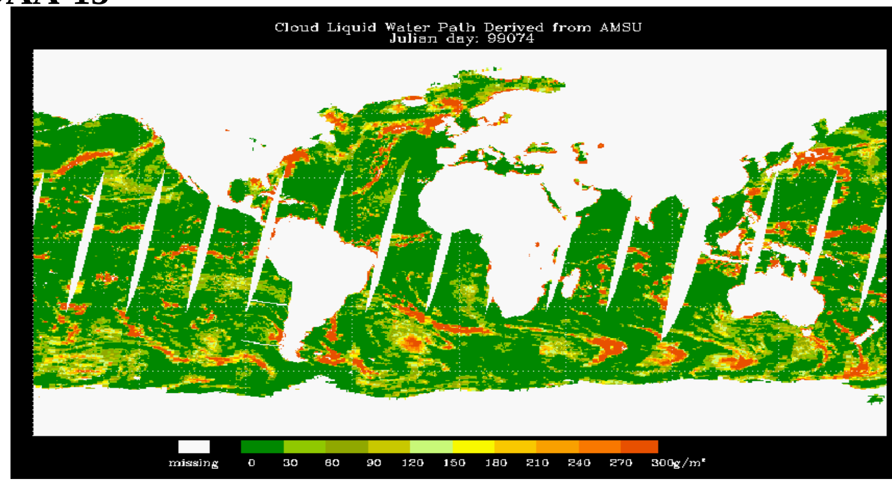
AMSU Cloud Liquid Water

Before Asymmetry Correction

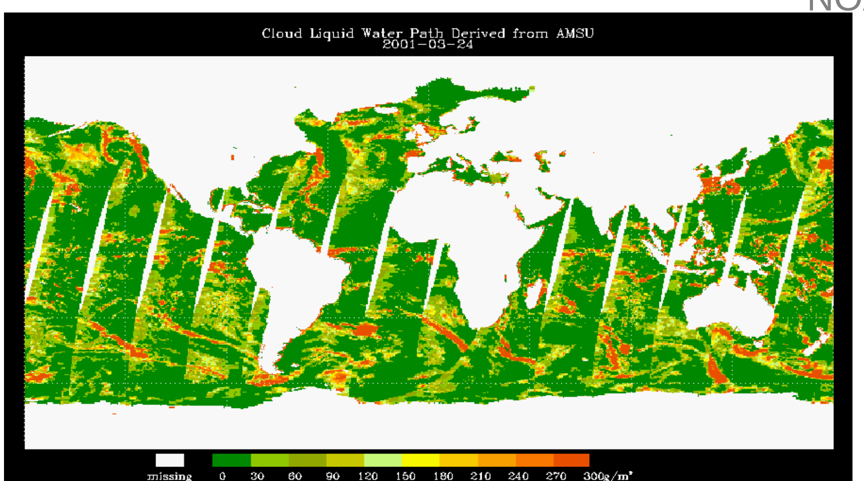
NOAA-15

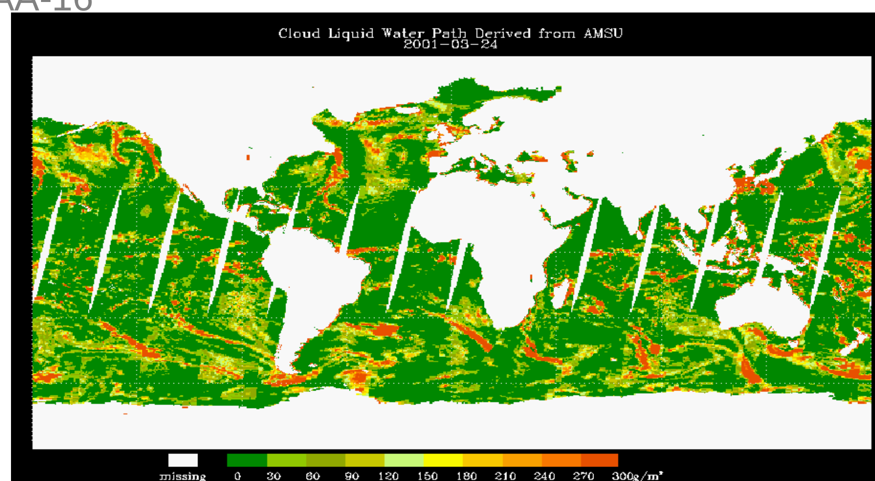
After Asymmetry Correction



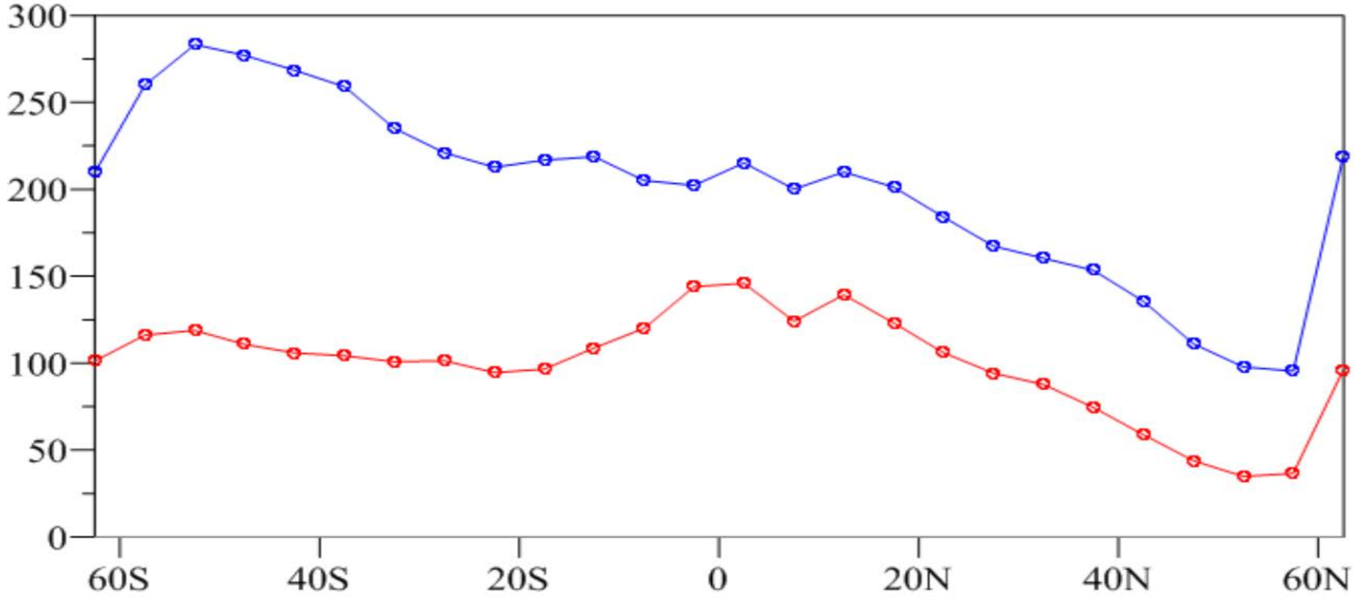


NOAA-16



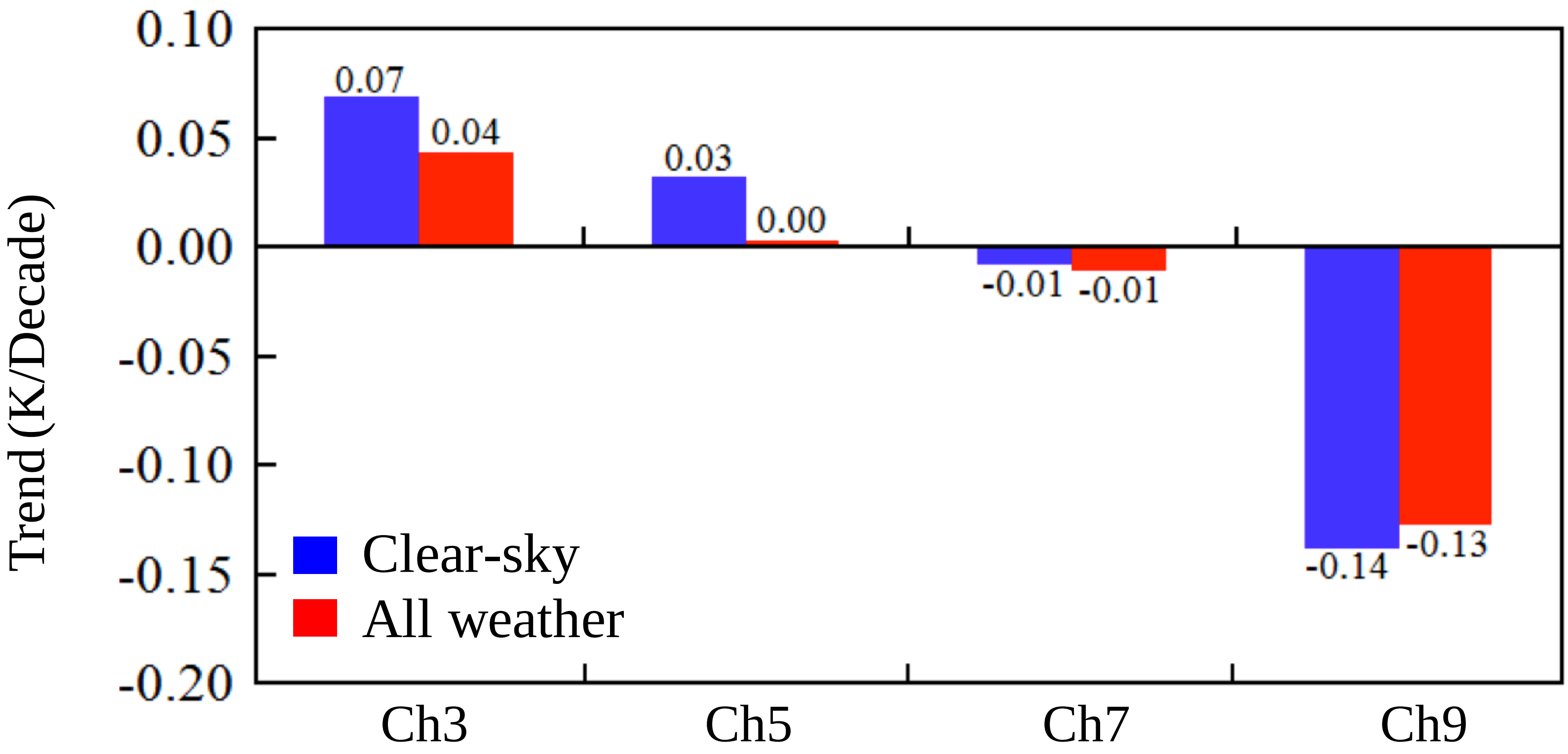


Population of AMSU-A Channel 5
Clear (red) and All Sky Measurements (blue)



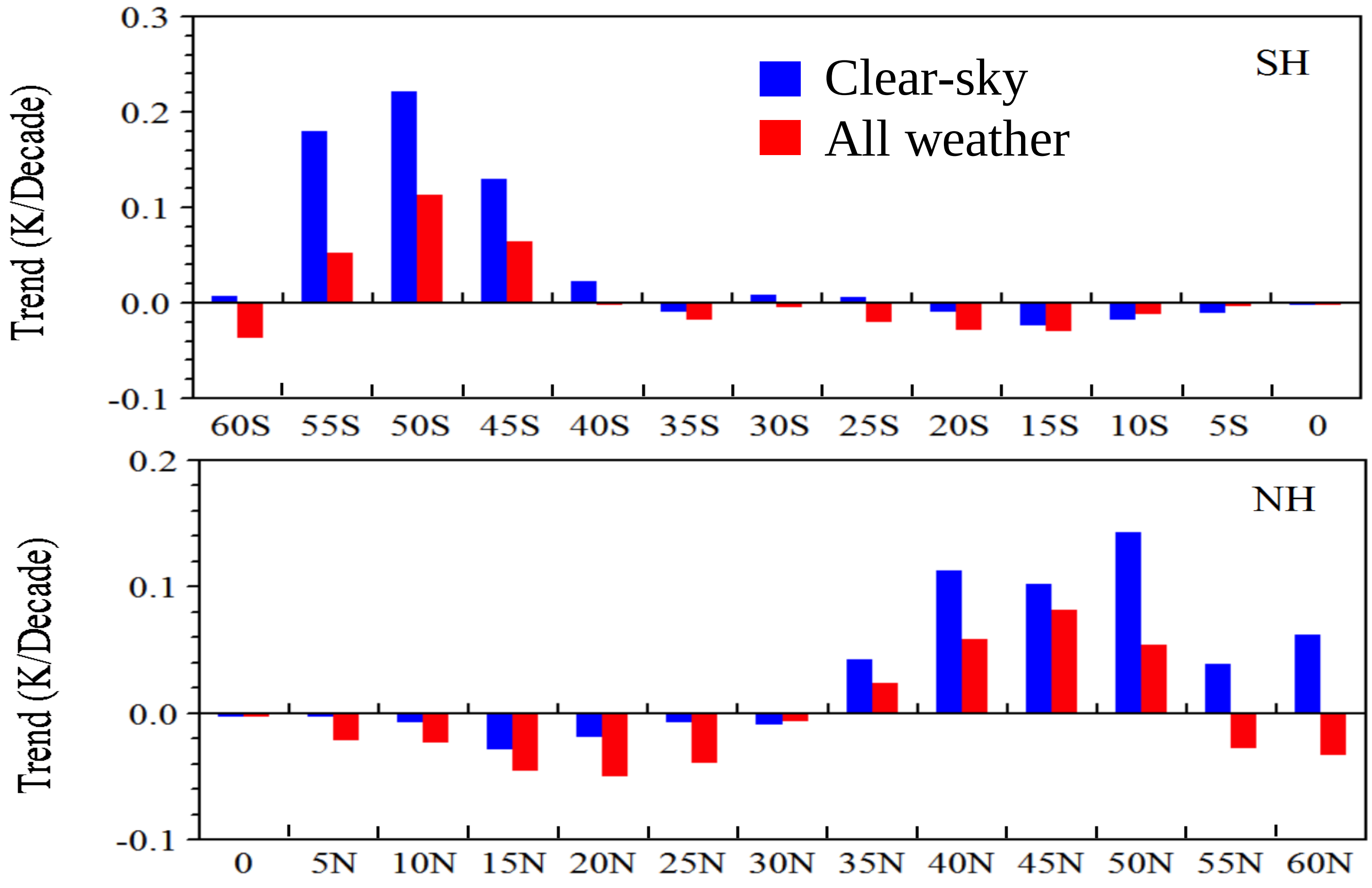
Annual mean daily data count at 5.0 degree resolution latitudinal band for NOAA-15 channel 5 FOV 15 and 16 in 2008 with LWP < 0.5 kg/m^2 (blue line) and LWP < 0.01 kg/m^2 (red line). All the AMSU data for the region north of 60N and 60S are included in the first and last point on the curve.

Cloud Impact on MSU/AMSU Derived Trends

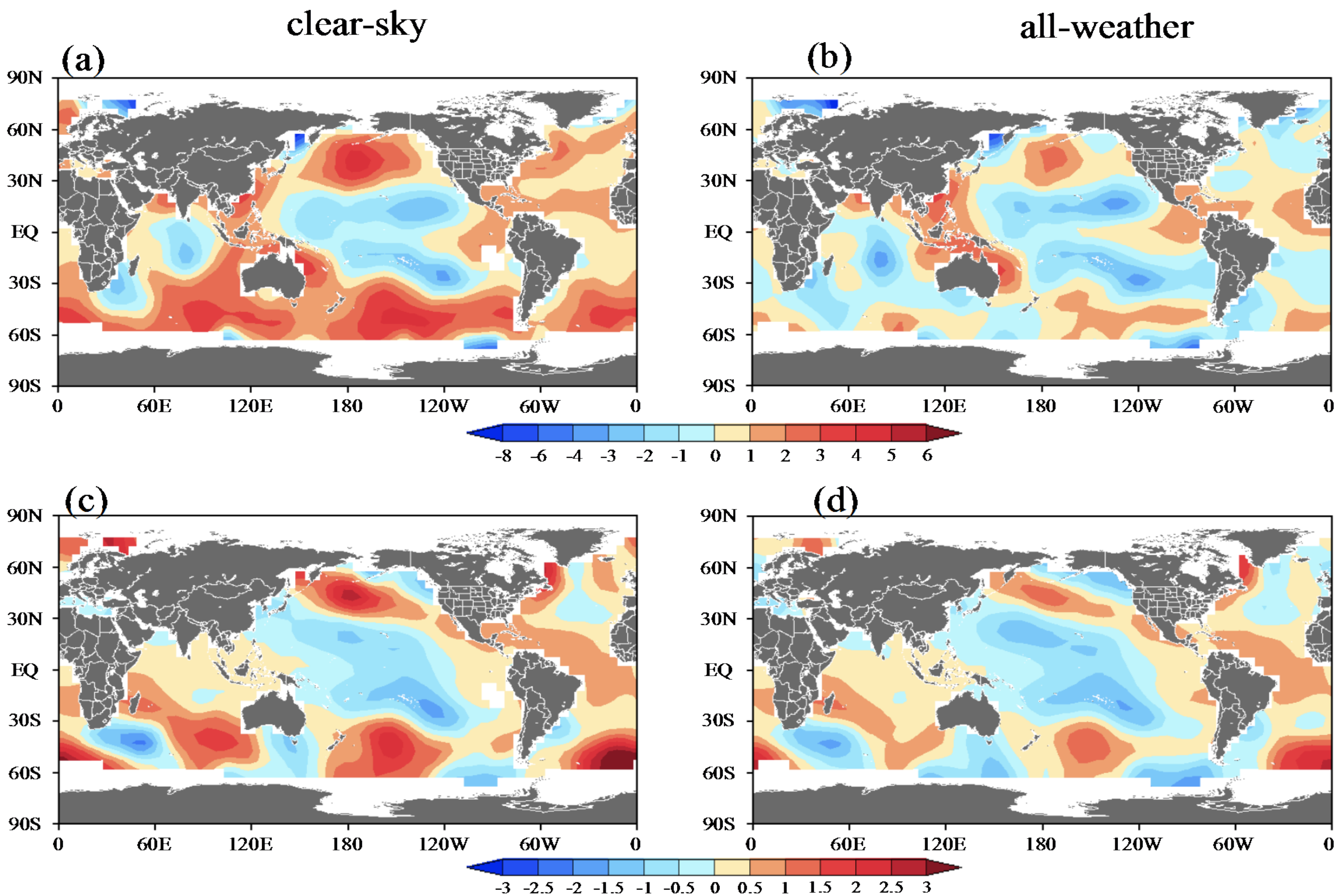


Weng, F. X. Zou and Z. Qin, 2013: Uncertainty of AMSU-A derived temperature trends in relationship with clouds and precipitation. *Clim. Dyn.*, DOI 10.1007/ s00382-013-1958-7.

Cloud Impacts on MSU/AMSU Channel 5 Derived Trends in South and North Hemispheres



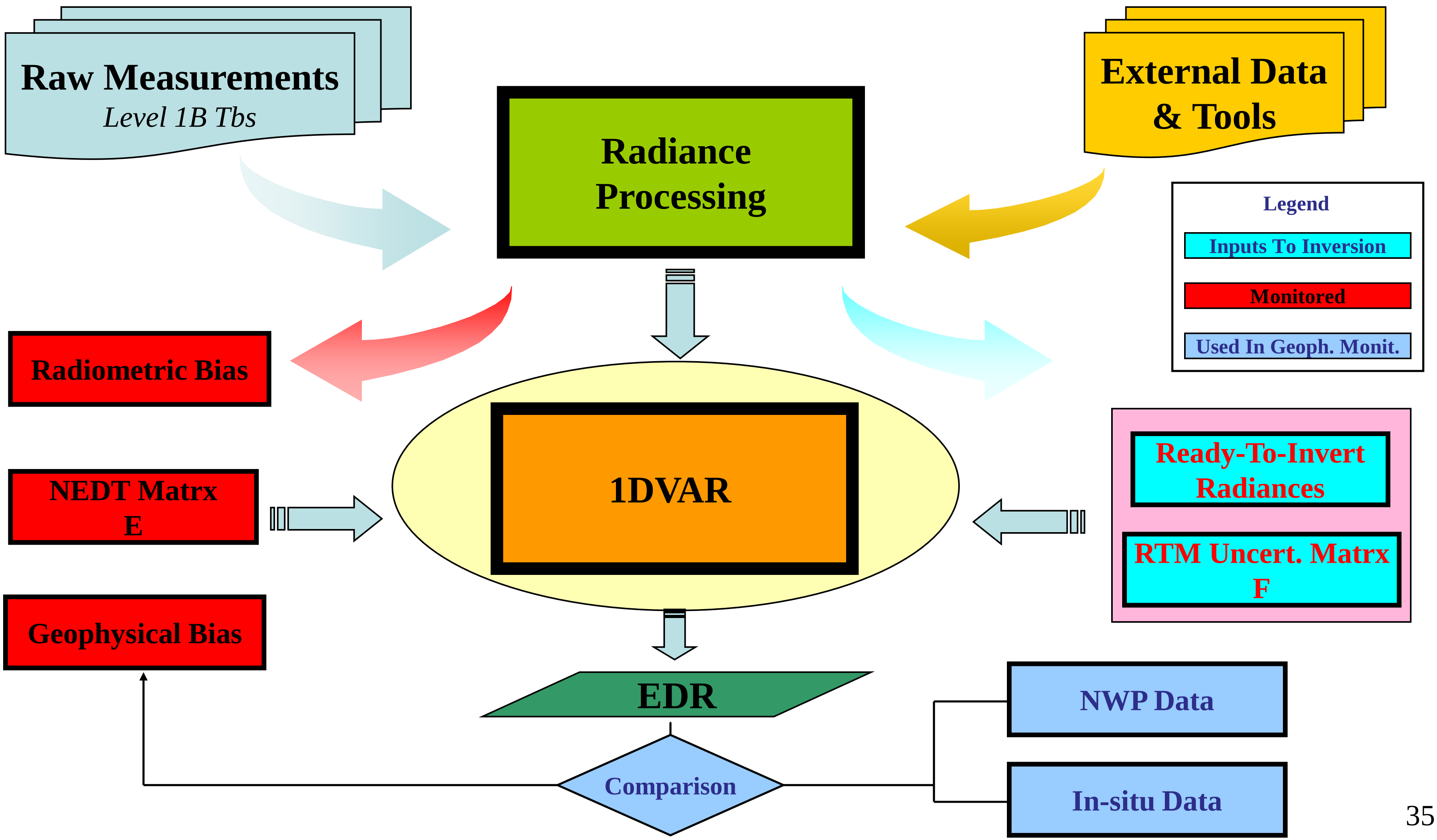
Regional Contribution to the Global Trend from Clear-Sky and All Weather AMSU-A Data



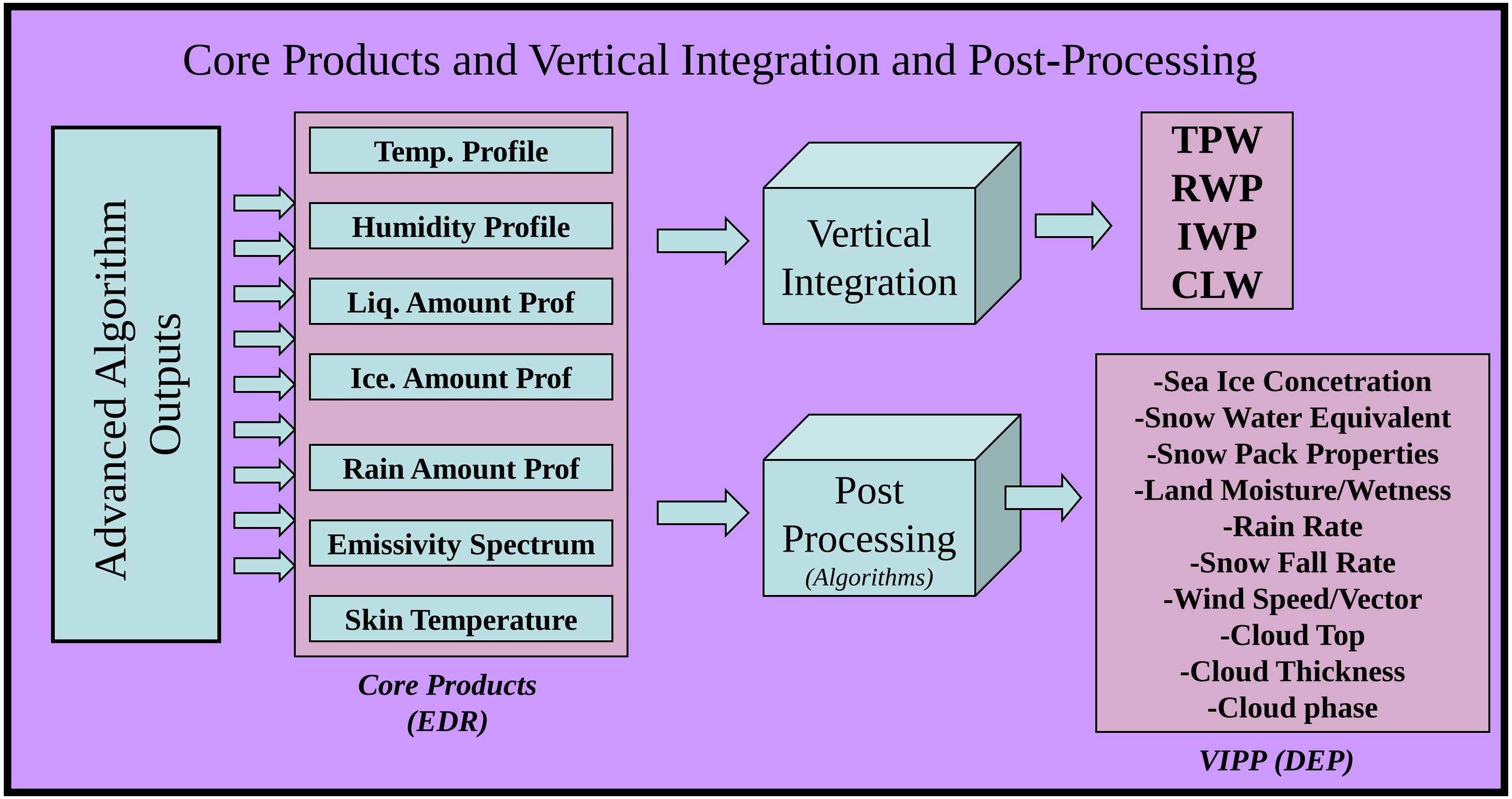
Ch3

Ch5

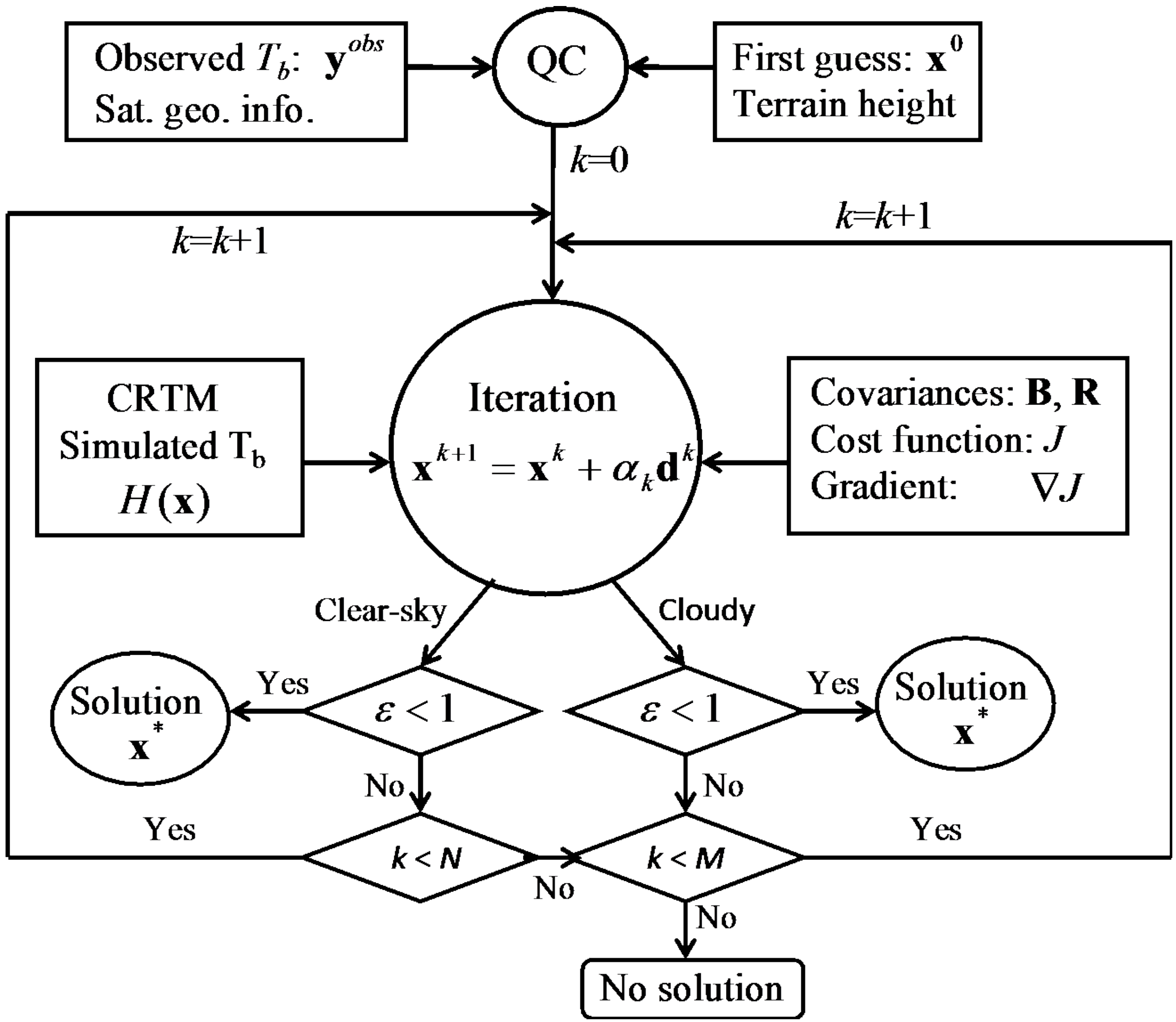
Microwave Integrated Retrieval System (MIRS)



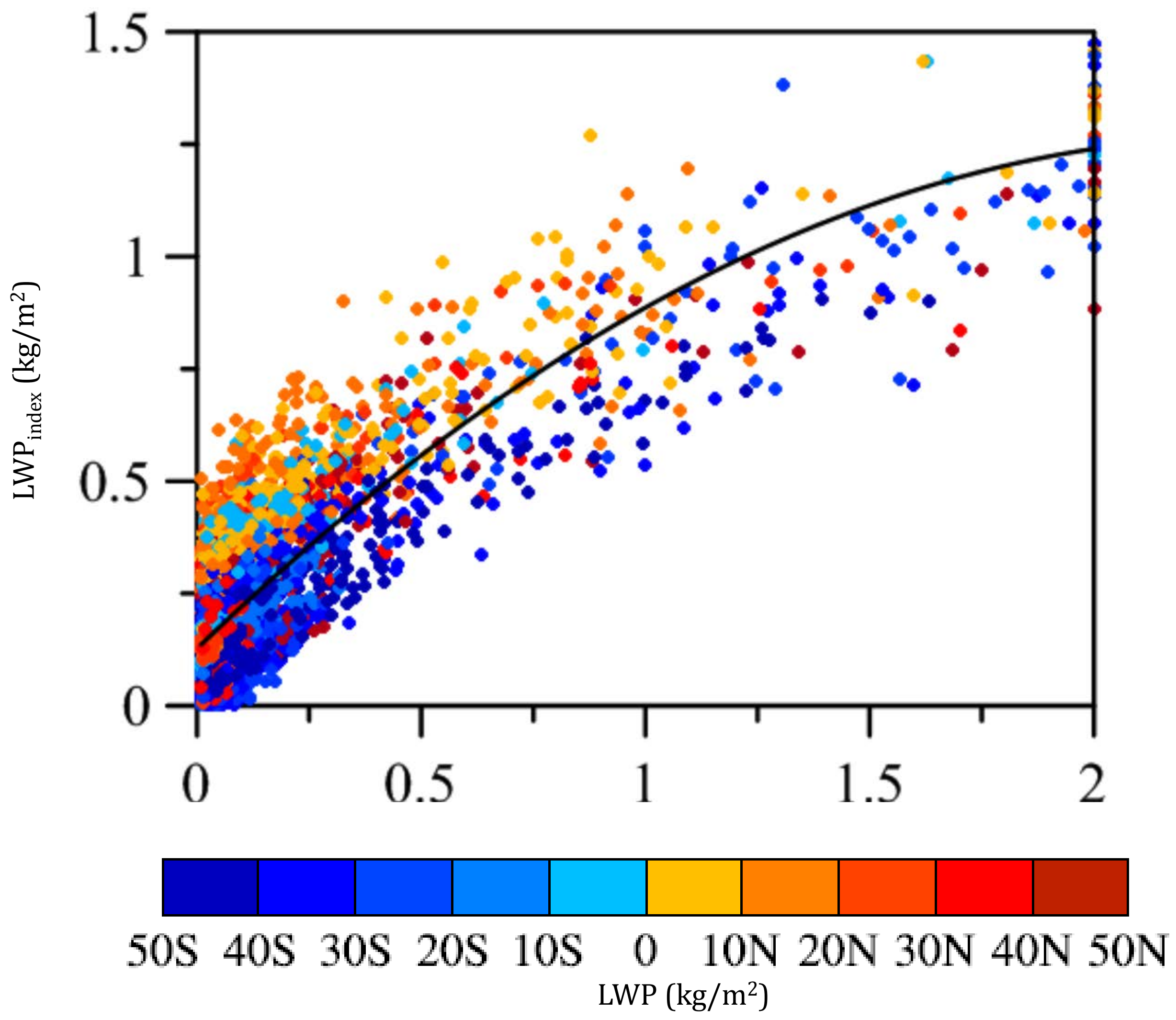
MIRS Post-processing Flow Chart



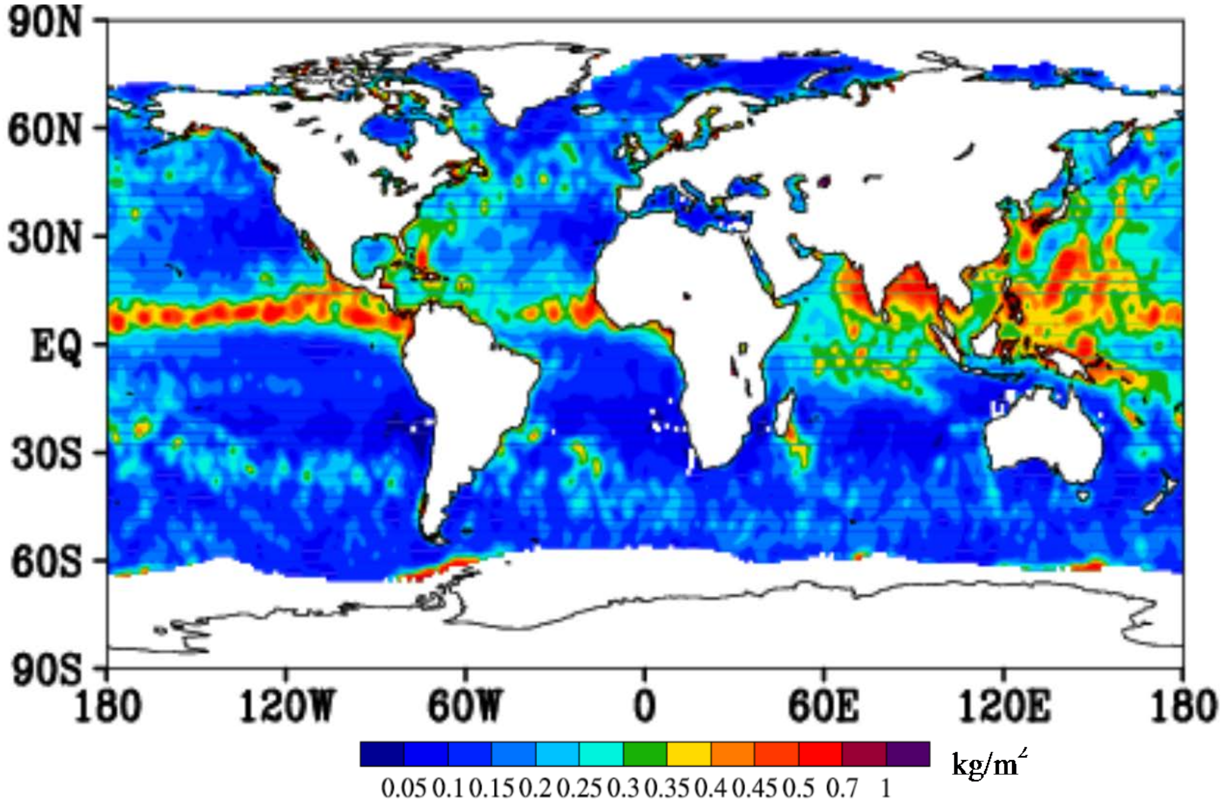
One-Dimension Variational Retrieval



Uses of MSU Channel 1 and 2 for Cloud Detection

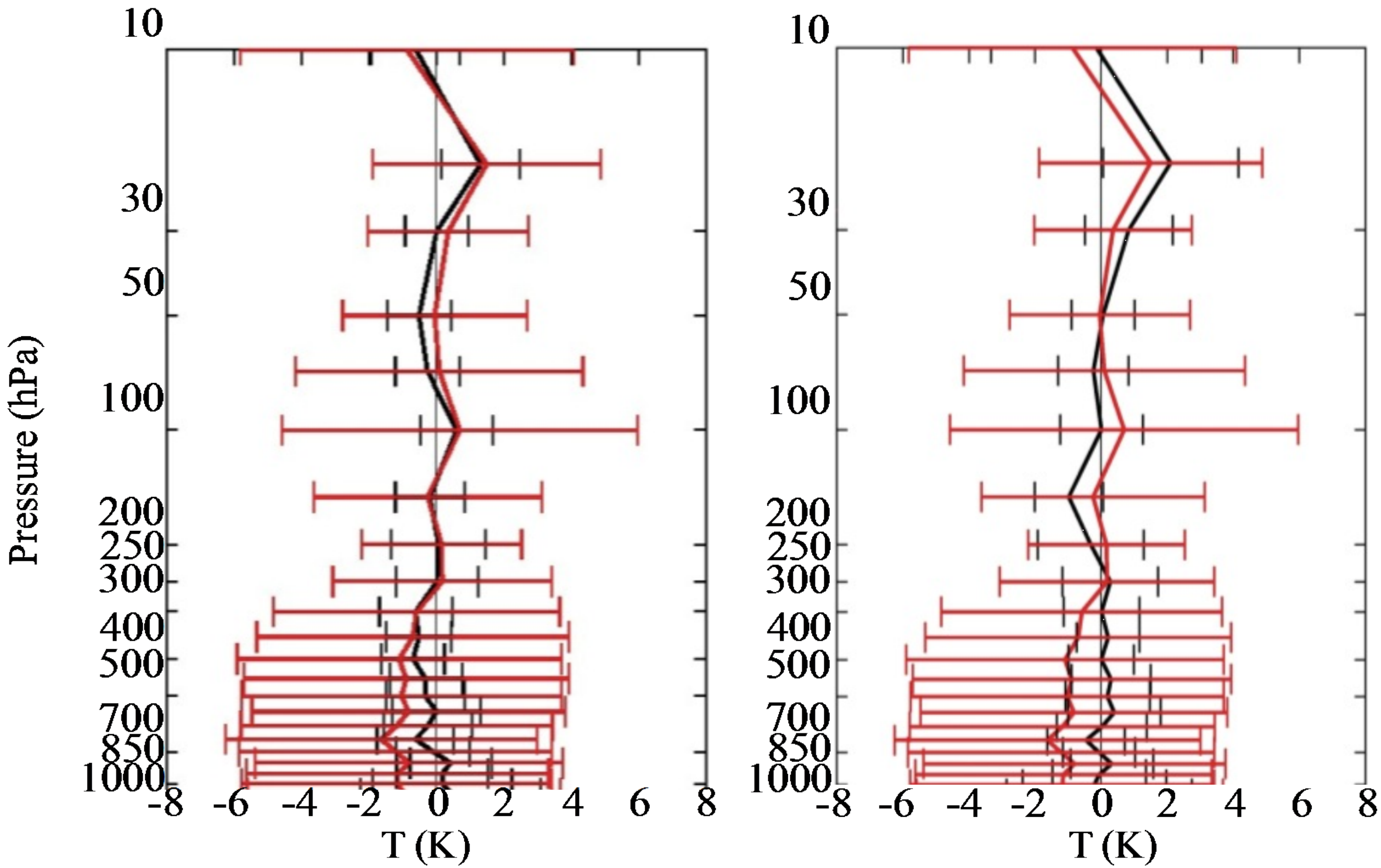


Detection of Clouds from MSU like Instruments



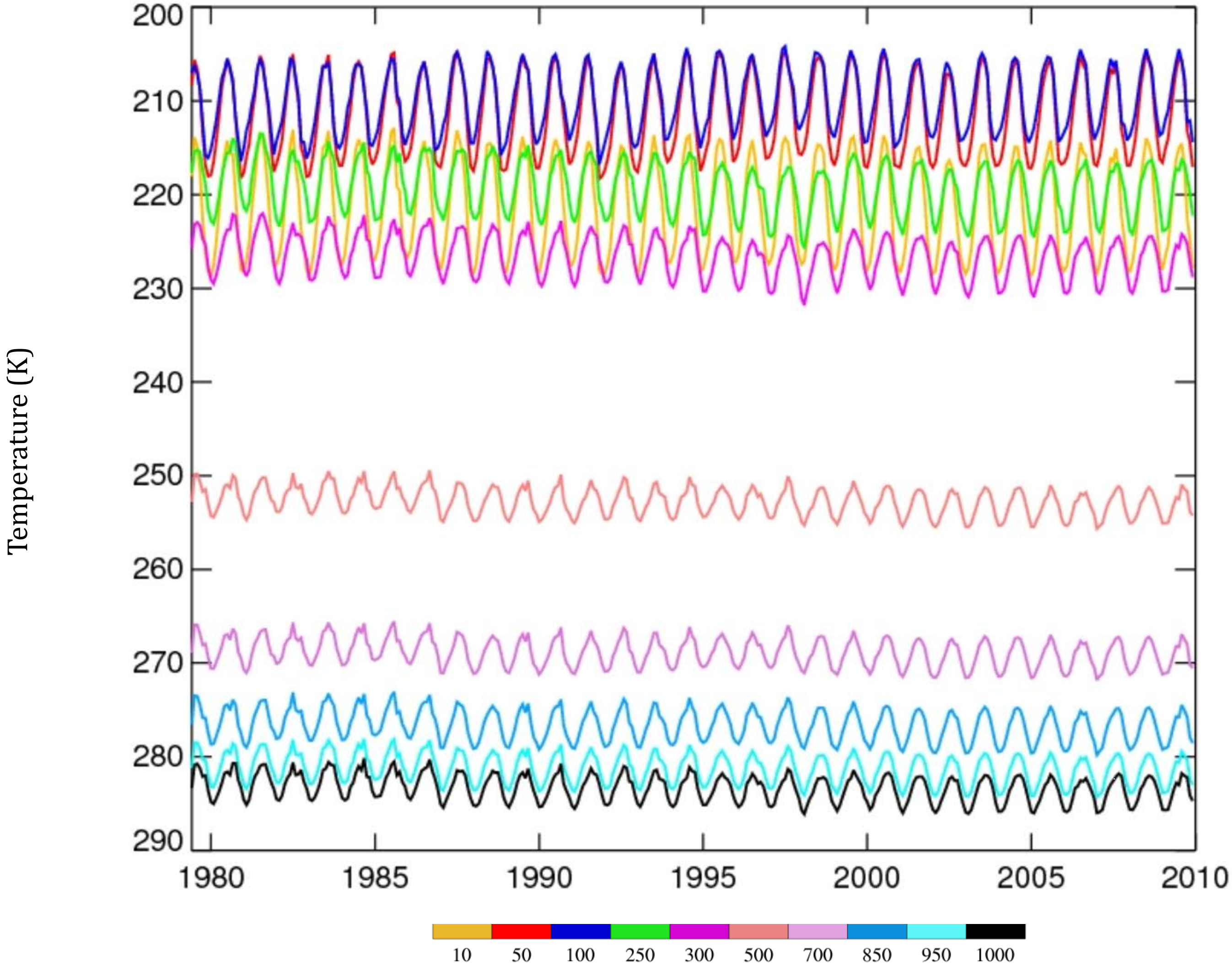
Scatter plot of LWP index derived from MSU-like AMSU-A channels 3 and 5 using equation (4) (y-axis) and LWP derived from AMSU-A channels 1 and 2 for nadir only over ocean on August 1, 2011. The black line represents a parabolic fitting: $LWP_{index}= -0.16*LWP^2 + 0.87*LWP+0.15$. (b) Global distribution of monthly mean cloud LWP_{index} (unit: kg/m^2) within $1^o \times 1^o$ grid box over ocean in August 2011.

Error Profiles from MSU Temperature Retrieval as Compared with GPSRO Data

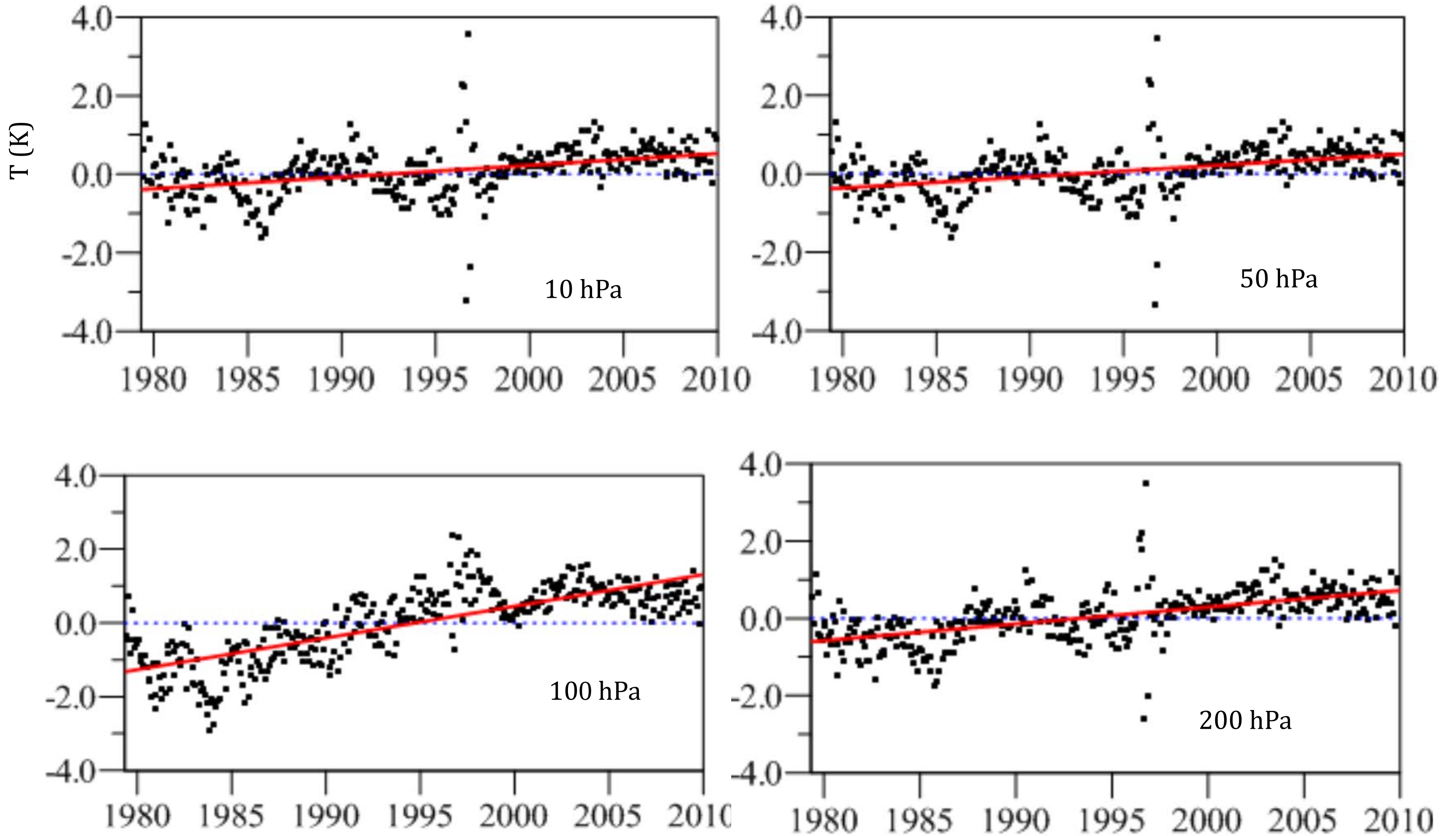


Mean error (solid) and RMS errors (horizontal bar) of atmospheric temperature profiles from the initial guess (red) and the 1D-Var retrievals (black) verified with COSMIC GPS RO data during June 1-10 in 2008-2011. Collocation criteria in time and space are set to be one hour and 50 km, respectively. (a) Only AMSU-A channels 3, 5, 7 and 9 are assimilated. (b) All AMSU-A channels are assimilated

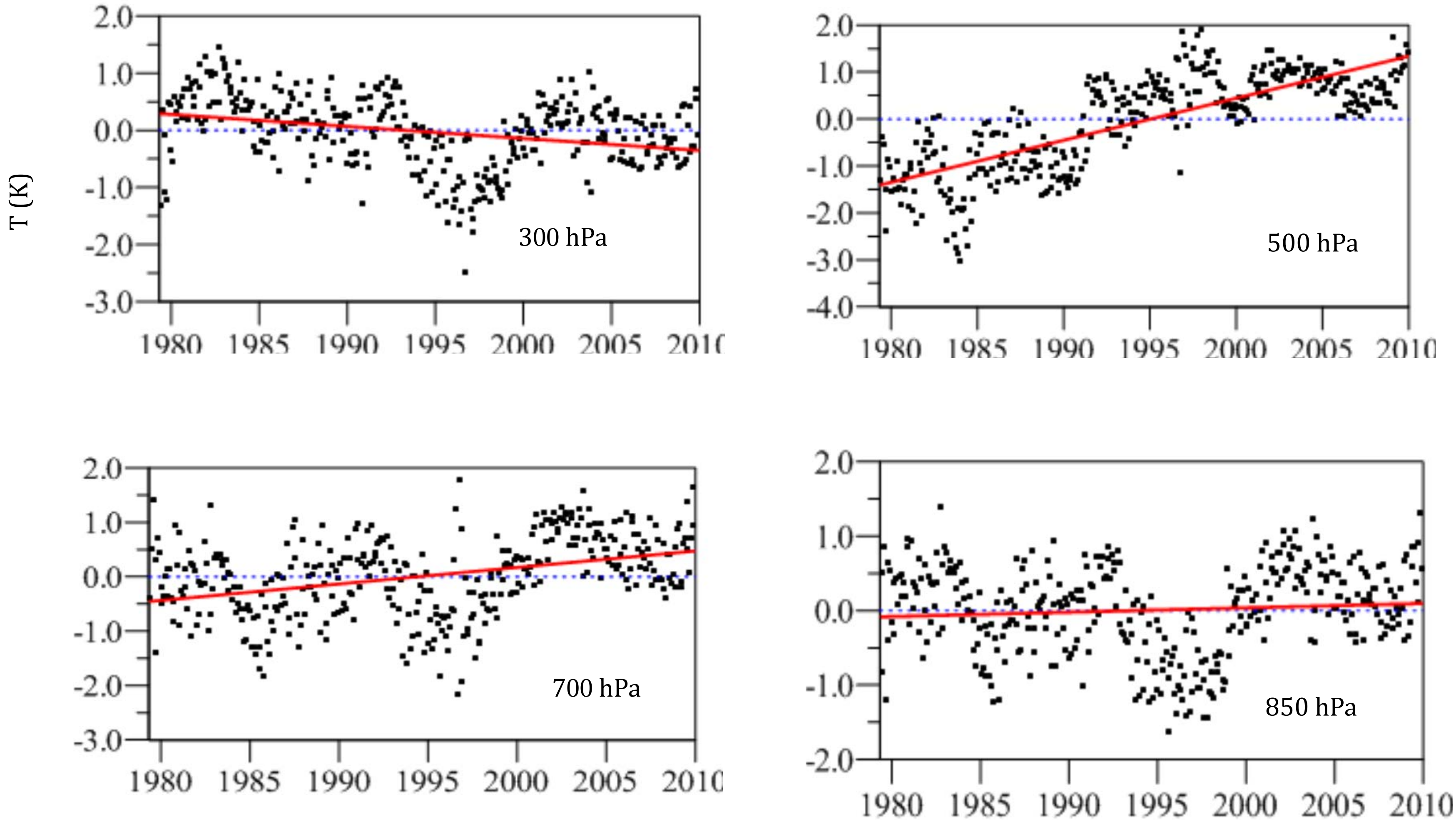
Mean Temperature Trends from 1980 to 2010 at Different Pressure Levels



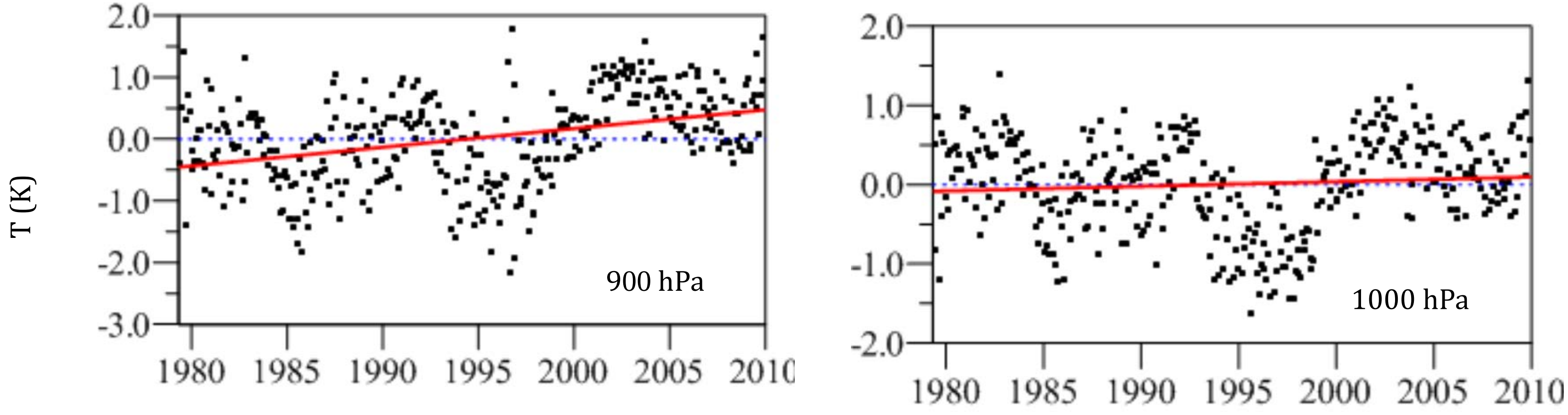
Mean Temperature Trends from 1990 to 2010 at Different Pressure Levels (1/3)



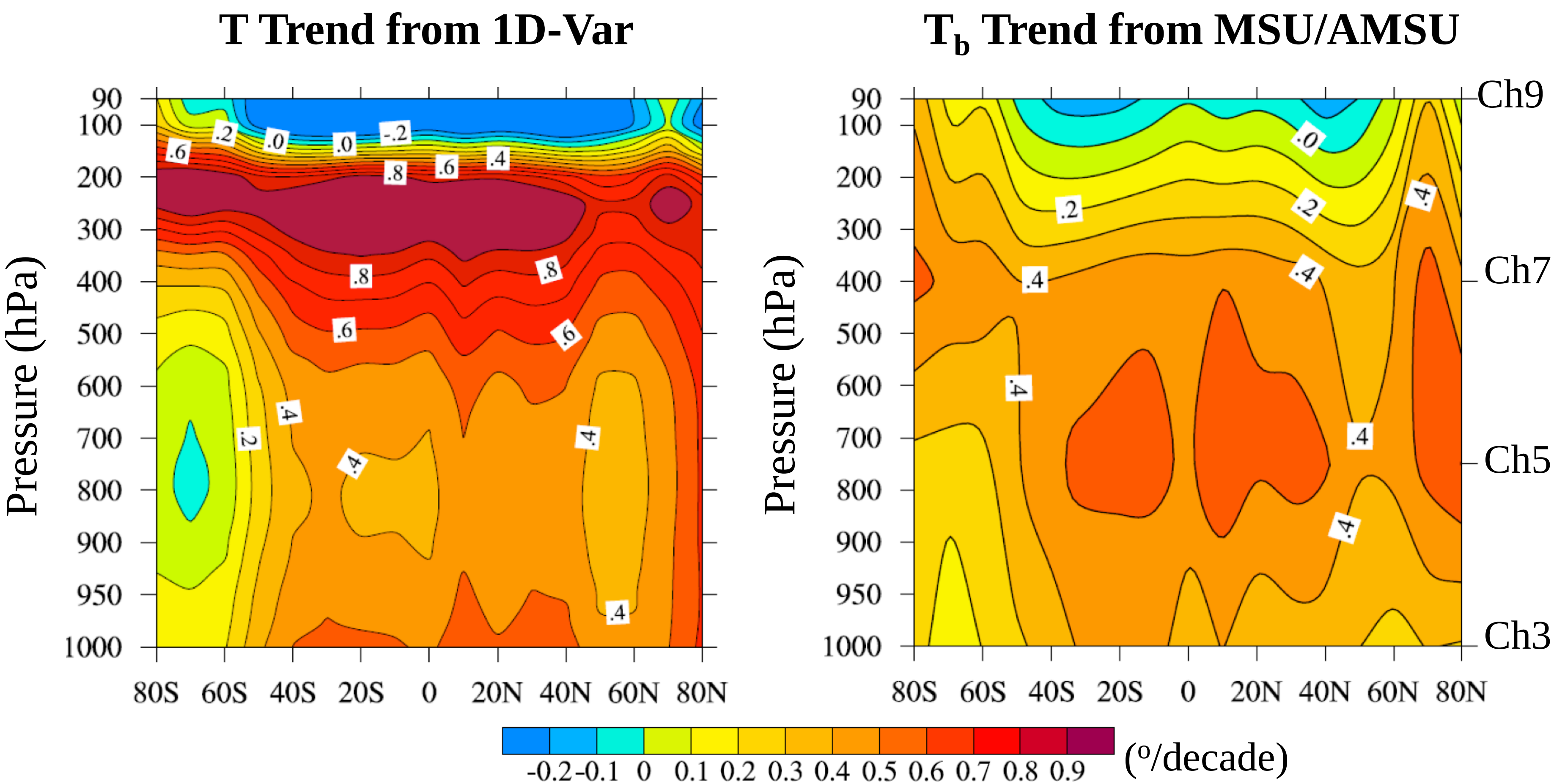
Mean Temperature Trends from 1990 to 2010 at Different Pressure Levels (2/3)



Mean Temperature Trends from 1990 to 2010 at Different Pressure Levels (3/3)



1D-Var Derived Temperature Trend



Weng, F. and X. Zou, 2013: 30-year atmospheric temperature trend derived by one-dimensional variational data assimilation of MSU/AMSU-A observations. *Clim. Dyn.*, DOI: 10.1007/s00382-013-2012-5.

Summary and Conclusions

- Satellite measurements have become critical mass in global observing systems for both weather and climate applications

- For creating the climate data records from historical satellite instruments such as MSU, AMSU and ATMS, robust algorithms are required for calibration and data harmonization

- The scattering from precipitating clouds at 50-60 GHz primarily affects the AMSU derived tropospheric trends in both radiance and physical temperature spaces

- Atmospheric temperature trends derived satellite radiance data could be significantly different, compared to those in radiance space

- A significant atmospheric warming near tropopause is found from MSU-1dvar and is more consistent with the climate modeling results with doubling CO_2.

More details can be found in

Zou, X., F. Weng and H. Yang, 2014: Connecting the time series of microwave sounding observations from AMSU to ATMS for long-term monitoring of climate change, *J. Ocean Atmos. Tech.*, (in press)

Yang, H. and X. Zou, 2014: Optimal ATMS remapping algorithm for climate research. *IEEE Trans. Geo. Remote Sensing*, in press

Weng, F., X. Zou and Z. Qin, 2014: Uncertainty of AMSU-A derived temperature trends in relationship with clouds and precipitation. *Clim. Dyn.*, DOI 10.1007/ s00382-013-1958-7.

Weng, F. and X. Zou, 2013: 30-year atmospheric temperature trend derived by one-dimensional variational data assimilation of MSU/AMSU-A observations. *Clim. Dyn.*, DOI: 10.1007/s00382-013-2012-5.

Qin, Z., X. Zou, and F. Weng, 2012: Comparison between linear and nonlinear trends in NOAA-15 AMSU-A brightness temperatures during 1998–2010, *Clim. Dyn.*, 10.1007/s00382-012-1296