NOAA MSU/AMSU Radiance FCDR

—Methodology, Production, Validation, Application, and Operational Distribution

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Outline

- ❑ Introduction
- ❑ Methodology
- ❑ Data Production
- ❑ Validation
- ❑ Application
- ❑ Operational Distribution

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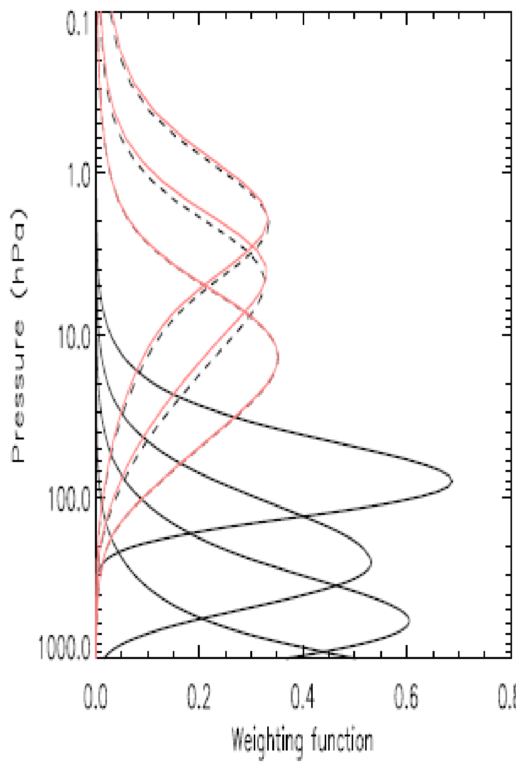
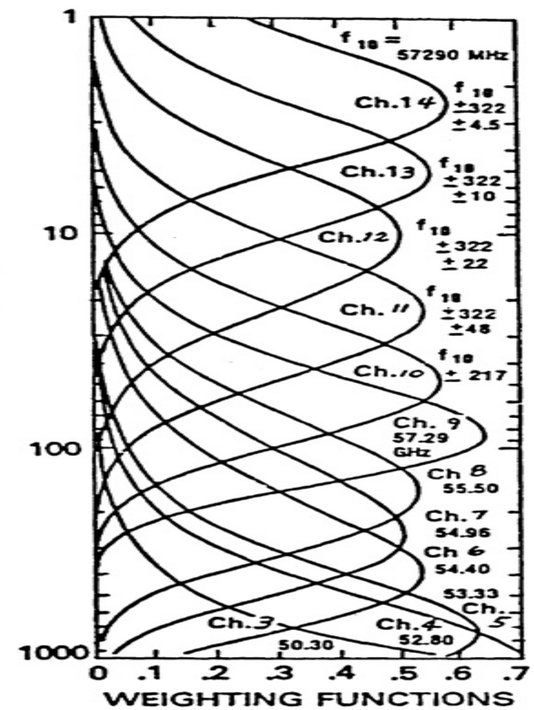
MSU/AMSU Sounding Instruments

- MSU/AMSU covering time period from 1979-present
- Have a total of 19 channels
- Generally, each channel has its own characteristics for calibration
- Involving 15+ satellites

MSU; 1978-2007



AMSU; 1998-present



Left: Weighting functions for the MSU and SSU instruments, where the black curve represent the MSU weighting functions and the dashed and red curves are the SSU weighting functions for different time period, showing a shift due to an instrument CO_2 cell pressure change; Right: Weighting functions for AMSU-A. All weighting functions are corresponding to nadir or near-nadir observations.

Operational Calibration Versus Inter-Calibration

- Operational calibration of MSU/AMSU provides quality controlled level-1b data to produce level-1c radiance data. These activities includes, but are not limited to, lunar contamination correction, antenna pattern correction, determining nonlinearity using pre-launch lab testing data, quality assurance. Calibration coefficients from operational calibration are saved in level-1b files

- Operational calibrated MSU/AMSU radiances were widely used in NWP and climate renalaysis data assimilations

- Post-launch inter-satellite calibration examines long-term satellite biases left over from operational calibration, and then develops algorithms to remove these biases

- Post-launch inter-calibration support FCDR development

Fundamental Challenges

- Historical data, no SI-traceable standards to verify results
- No stable microwave target to verify results
- No other observations for global validation

➢ We need to develop self-consistent, hopefully consensus, best-practice algorithms for FCDR and TCDR development based on improved physical and engineering understanding of the instrument and sampling issues

Outline

- Introduction
- Methodology—Integrated Microwave Inter-Calibration Approach (IMICA)
- Data Production
- Validation
- Application
- Operational Distribution

IMICA Methodology

- Physically based approach to remove satellite biases
- Use simultaneous nadir overpass as applicable
- Use global ocean means as applicable—diurnal drift effects are small, so calibration errors emerge
- Use CRTM simulations as applicable
- Develop consistent FCDRs for climate applications

Calibration Equation—based on observational principles and allowing inter-calibration

Nonlinear Calibration: one set of calibration coefficients for all scan positions

$$R = R_L - \delta R + \mu Z$$

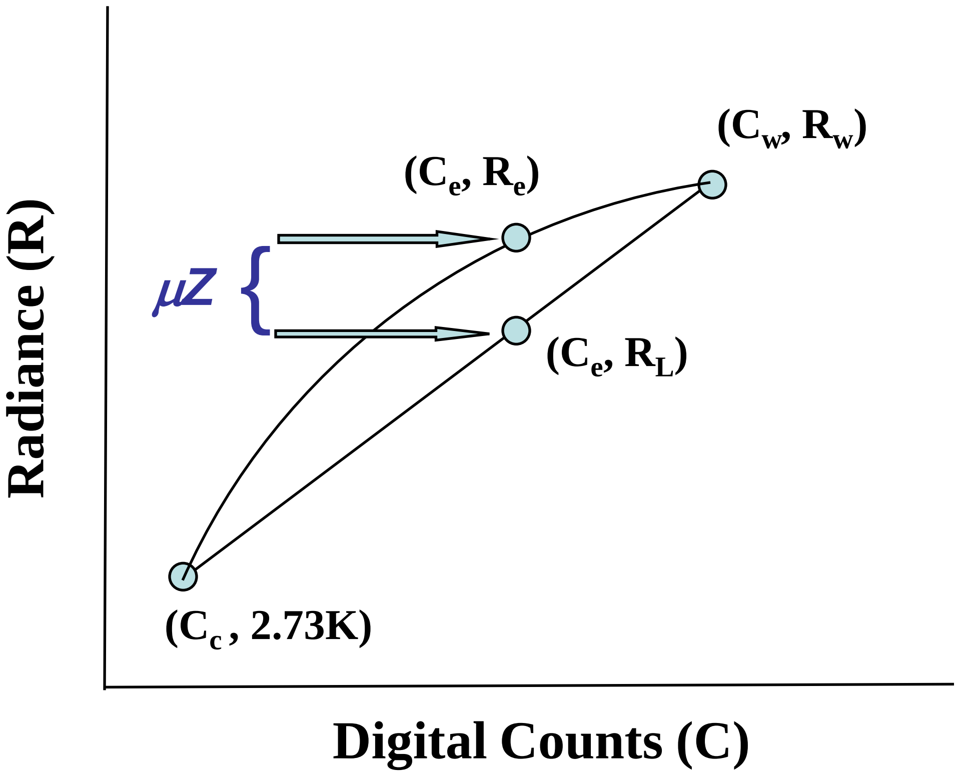
R_L is the linear calibration term

$$R_L = R_c + S(C_e - C_c)$$

S ⟶ Slope

***Z* is the quadratic nonlinear term**

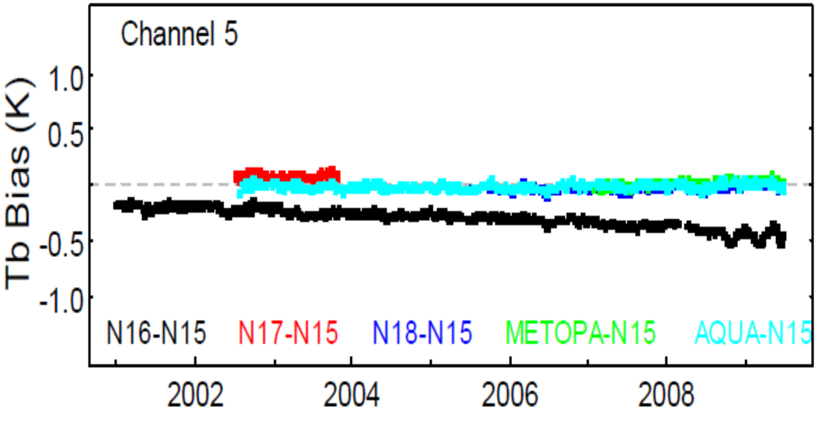
$$Z = S^2 (C_e - C_c)(C_e - C_w)$$

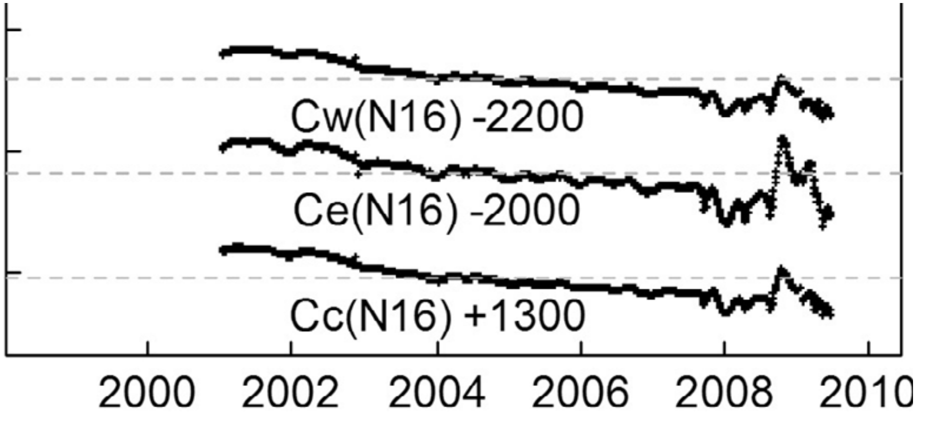


Bias Types I and II: Constant bias and relatively stable bias drift

Global ocean mean inter-satellite difference time series showing NOAA-16 had a relatively stable drift

NOAA-16 raw counts drifted for all Earth and target views, suggesting degradation of certain parts



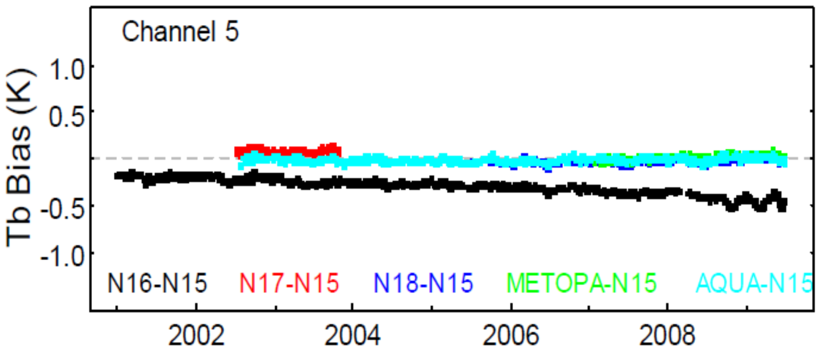


Solution

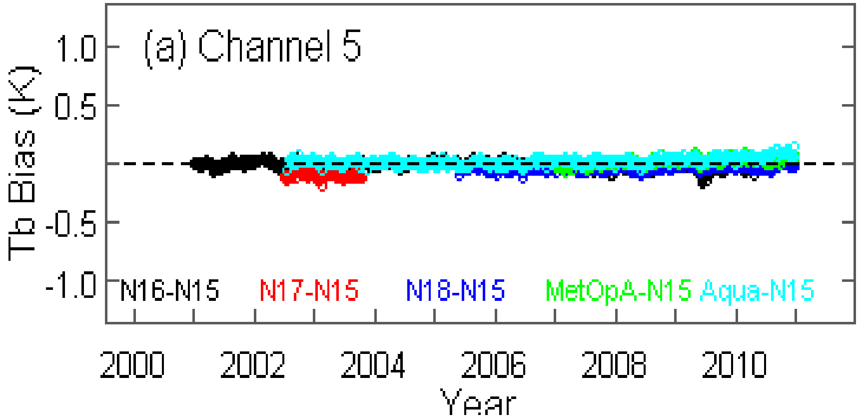
Simply allowing calibration offset to change with time linearly had nicely removed the NOAA-16 drifts

$$R = R_L - \delta R + \mu Z$$

$$\delta R = \delta R_0 + \alpha (t - t_0)$$

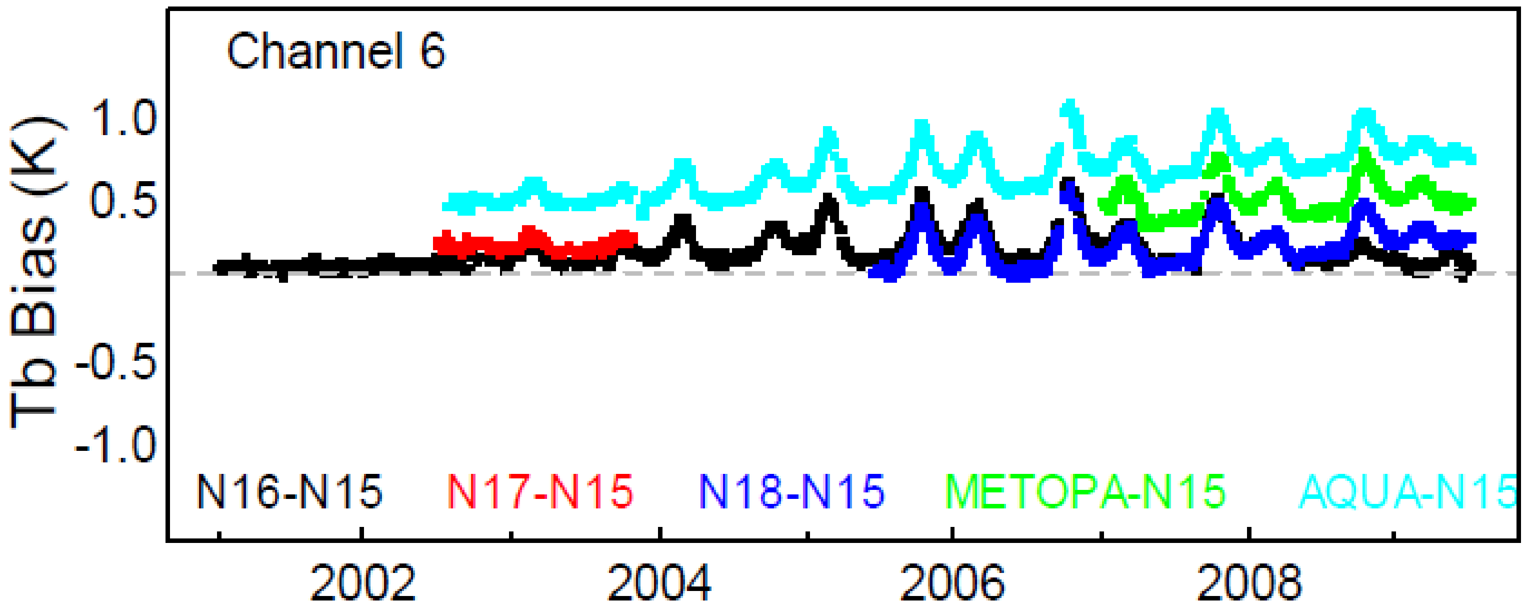


Before Inter-calibration



After inter-calibration

Bias Type III: Instrument Temperature Related Atmospheric Temperature Variability – much more complicated

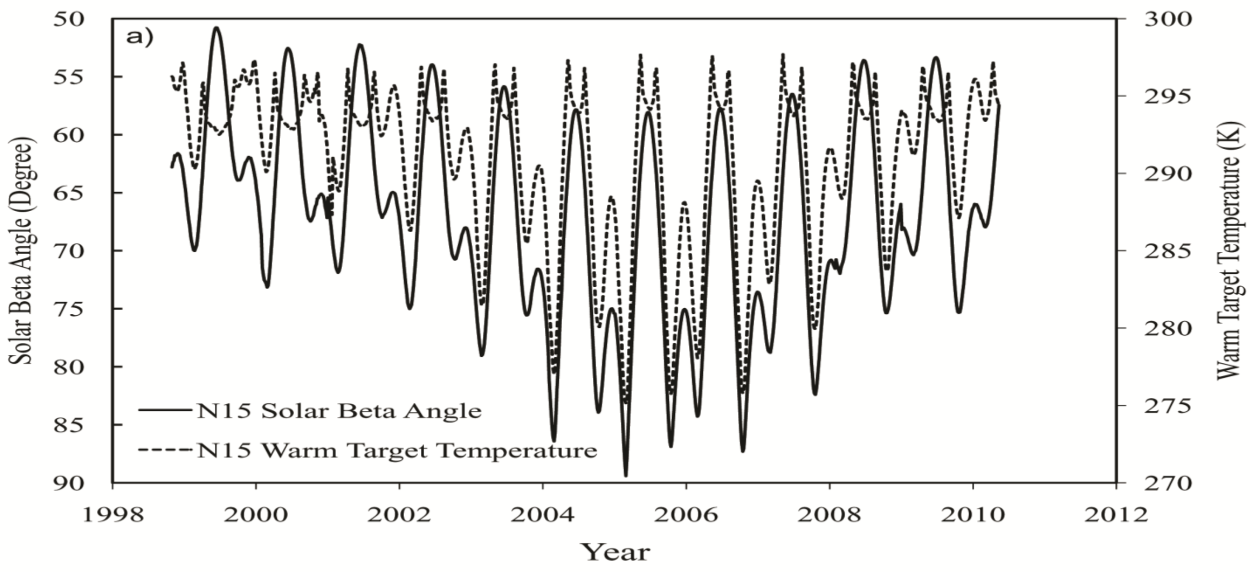


* Ocean mean inter-satellite difference time series for AMSU-A channel 6

* NOAA-15 has a instrument temperature related variability

Solar Heating Related Instrument Temperature Variability

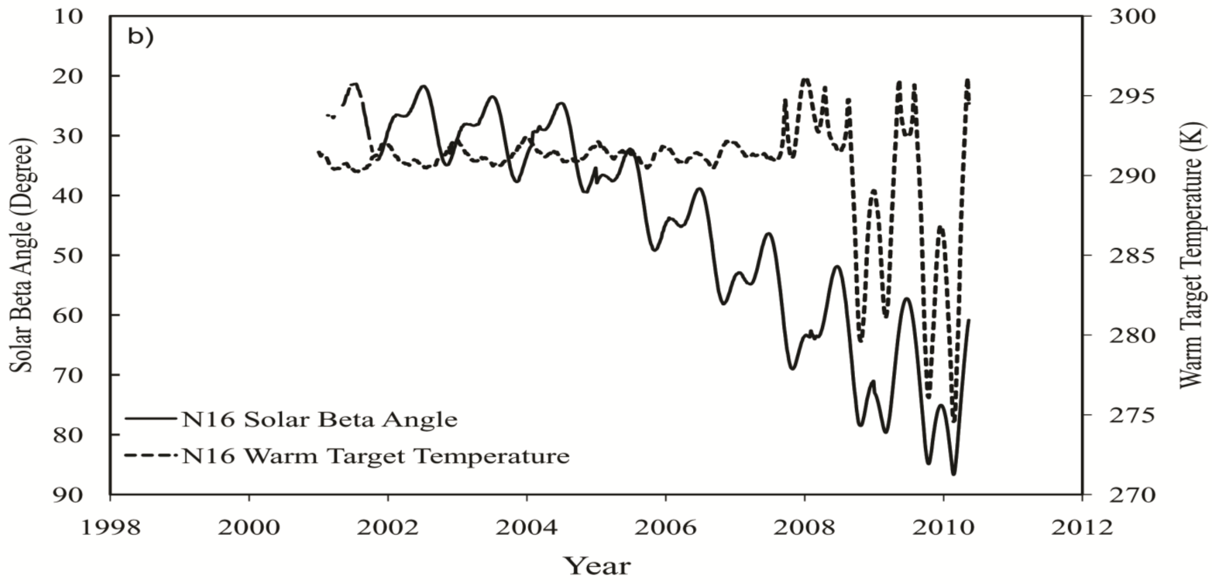
NOAA-15 Case



Warm Target temperature highly correlated with Solar Beta Angle
Correlation Coefficient==0.85

Solar Heating Related Instrument Temperature Variability

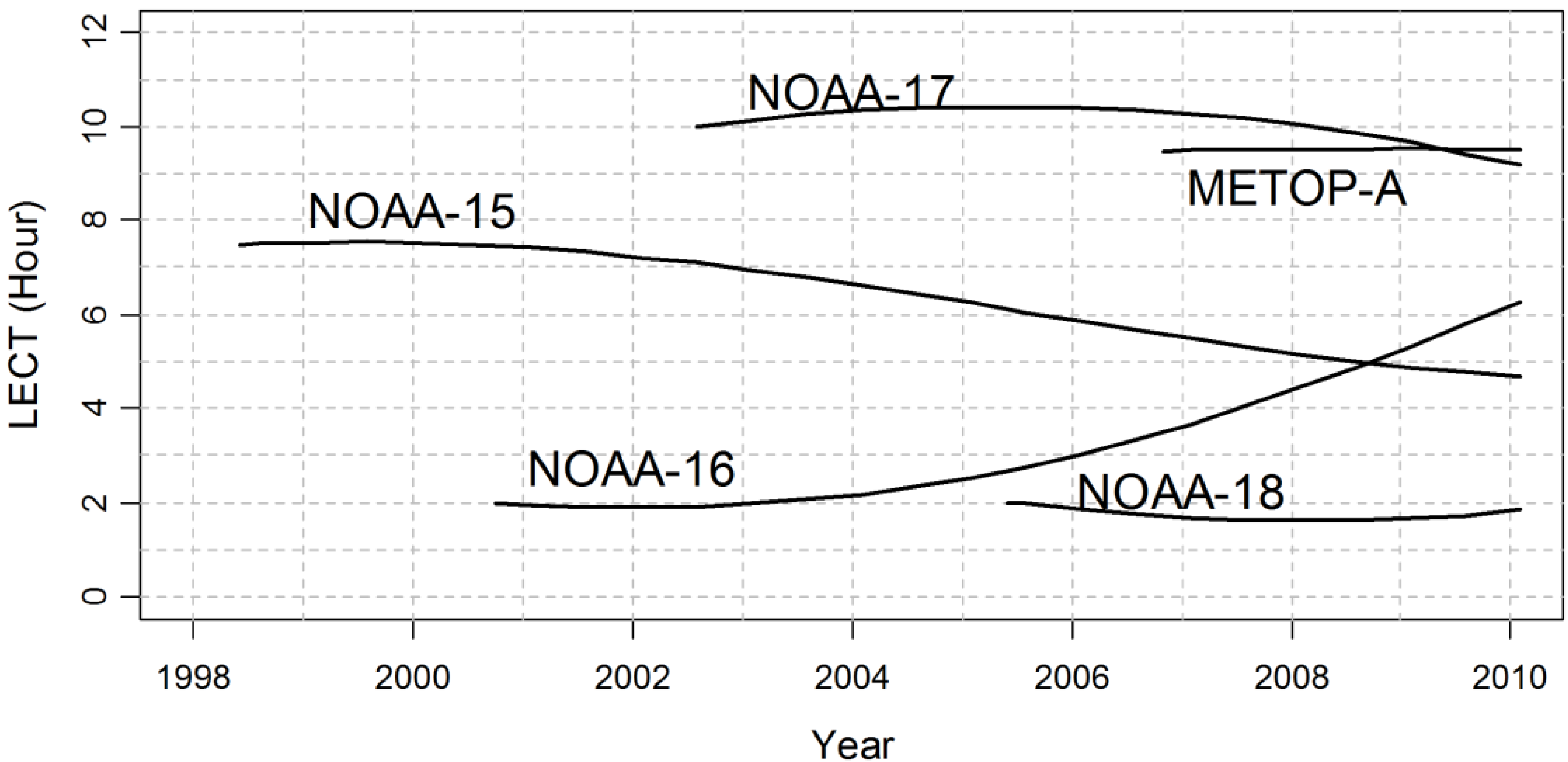
NOAA-16 Case



Warm Target temperature NOT correlated with Solar Beta Angle before 2007

Solar shield played a role in protecting the instrument from solar radiation before 2007

AMSU-A Orbit Information



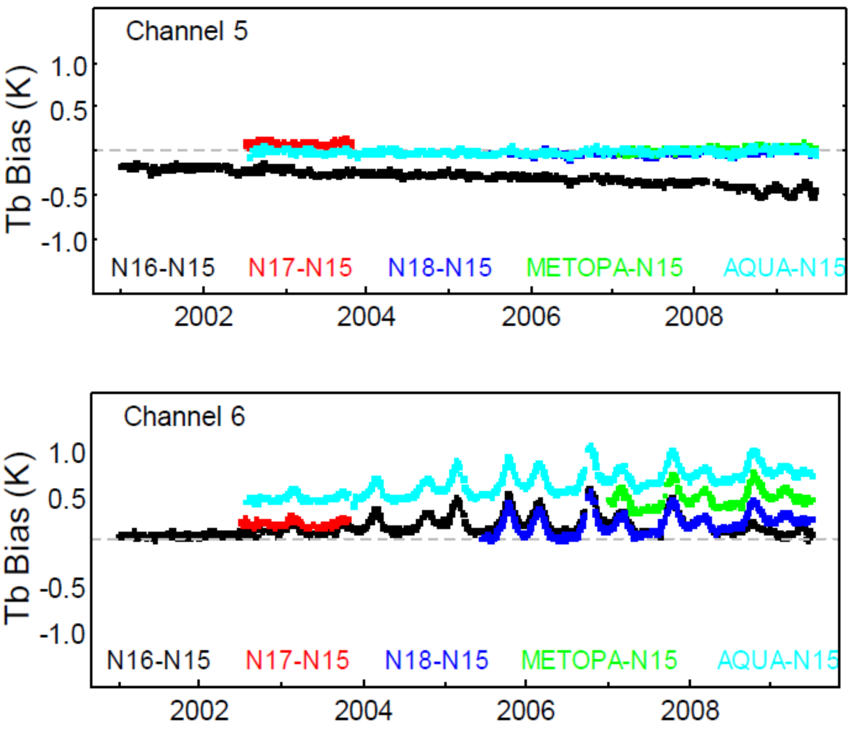
Local Equator Crossing Time of the Descending Orbits of the NOAA and MetOp-A satellites

Solar Heating Has Different Effect on Different Channels

- ❑ NOAA-15 solar heating signals do not show up in channel 5 and other inter-satellite difference time series--suggesting weak calibration nonlinearity

- ❑ NOAA-15 solar heating signals show up in channel 6 inter-satellite difference time series—suggesting strong nonlinearity

- • NOAA-16 has large long-term Tb bias drift, also channel dependent



Algorithm for Removal of Solar-heating Induced Instrument Temperature Variability

- Theoretically, one specific value of μ exist that can completely remove instrument temperature signals:

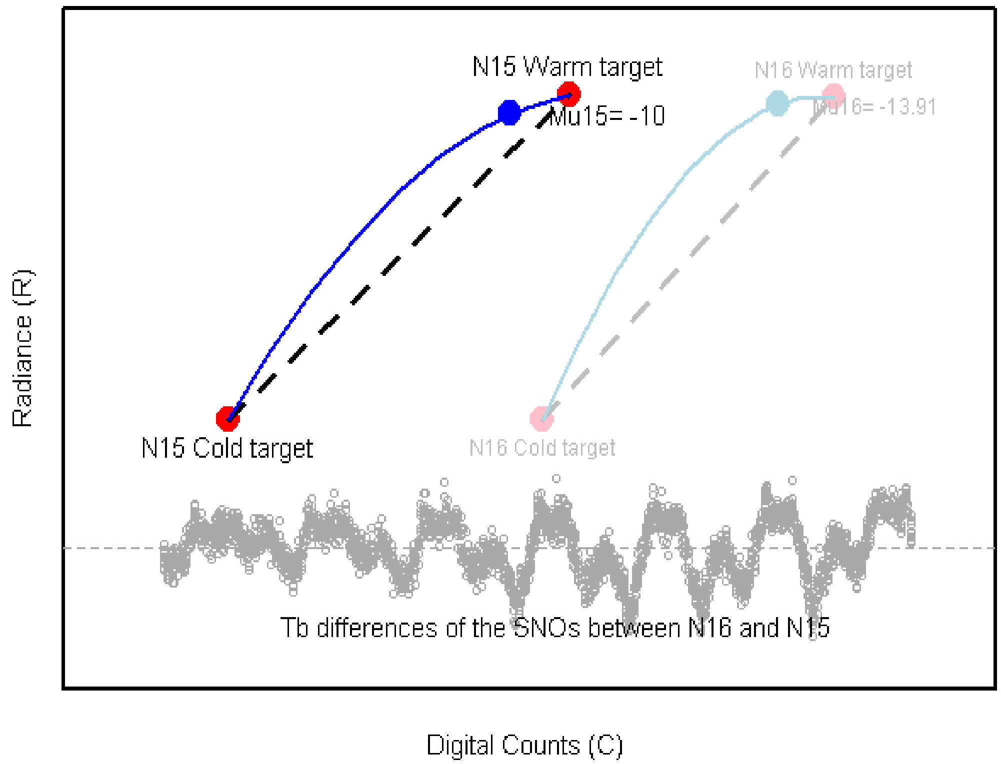
$$R = R_L - \delta R + \mu Z$$

⇓

$$\overline{R'T_w'} = \overline{R_L'T_w'} + \mu \overline{Z'T_w'}$$

⇓

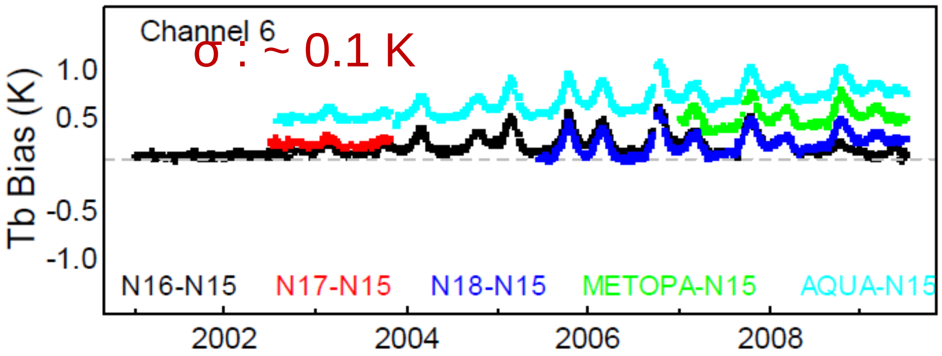
$$\mu = \mu_c = -\frac{\overline{R_L'T_w'}}{\overline{Z'T_w'}}$$



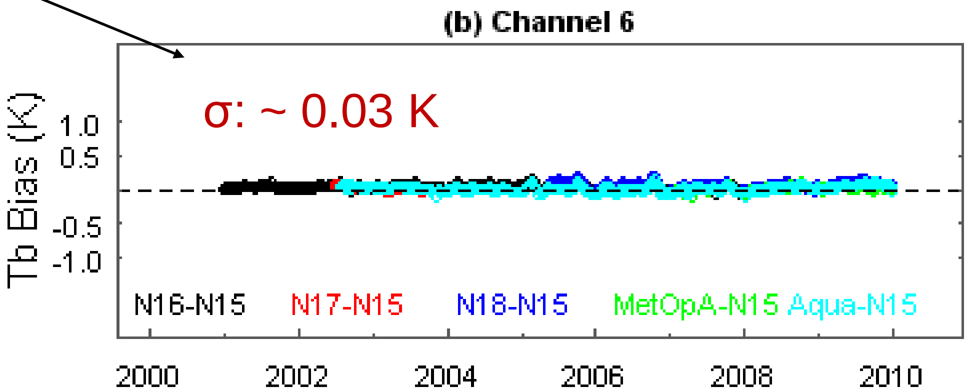
Before and After Inter-Satellite Calibration AMSU-A CH6

- NOAA-15 CH6 has strong calibration nonlinearity
- Time-dependent level 1c calibration coefficients for NOAA-15/16 are introduced
- After recalibration, inter-satellite differences close to zero
- Recalibrated trend is expected to be different from NOAA-15

NOAA operational calibrated inter-satellite difference time Series (Before Inter-satellite calibration); Ocean Mean



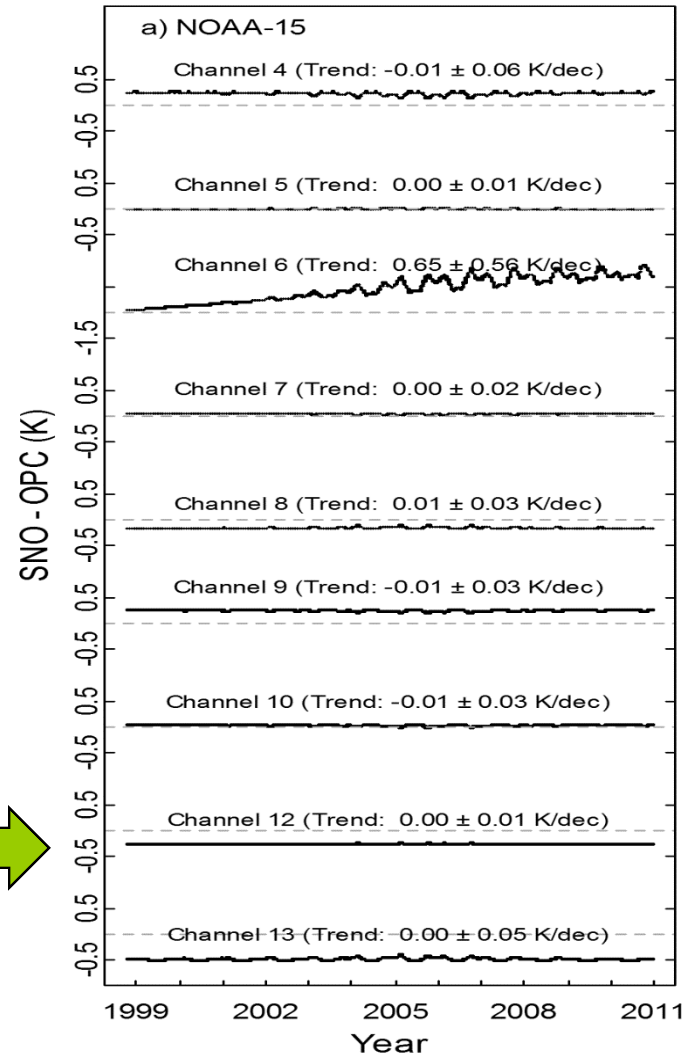
Inter-satellite difference time series after SNO Inter-satellite calibration, AMSU-A CH6



Operational Versus Inter-Satellite Calibration—NOAA-15

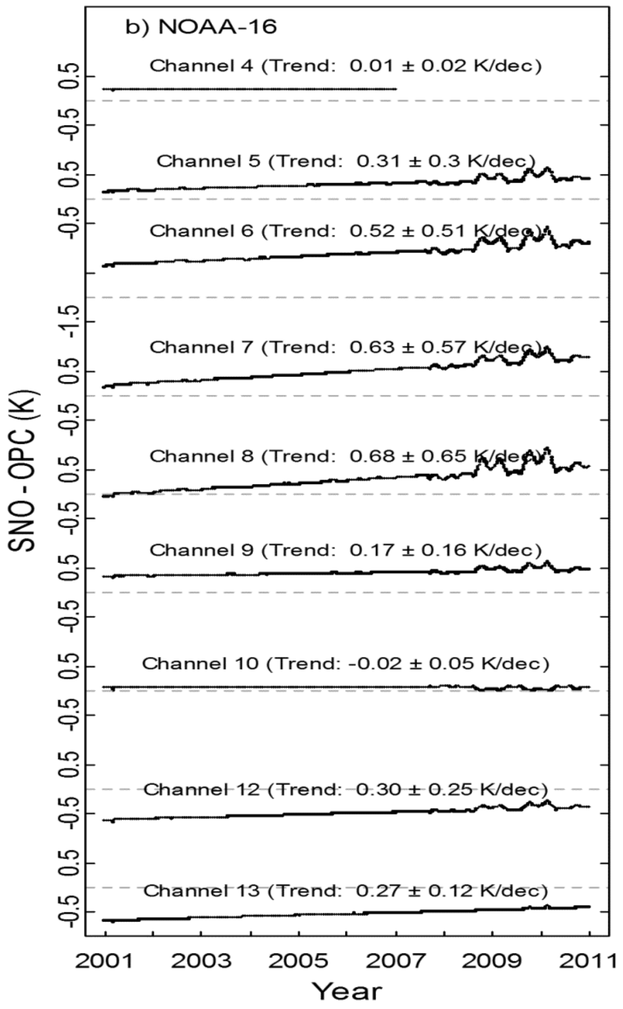
- The pre-launch and post-launch calibrated data have no relative bias drifts for most channels for NOAA-15
- Suggesting that most AMSU-A channels don't have bias drifts for pre-launch calibration

Global mean brightness temperature difference time series between pre-launch and post-launch calibrations. SNO denotes post-launch calibration using SNO method; OPC refers to pre-launch operational calibration (plot from Zou and Wang 2011)



Operational Versus Inter-Satellite Calibration—NOAA-16

- The pre-launch and post-launch calibrated data show remarkable relative bias drifts for most channels for NOAA-16
- Suggesting that most AMSU-A channels suffered bias drifts for pre-launch calibration



Global mean brightness temperature difference time series between pre-launch and post-launch calibrations. SNO denotes post-launch calibration using SNO method; OPC refers to pre-launch operational calibration (plot from Zou and Wang 2011)

Discussion/Summary for Bias Type III

Root-causes for instrument temperature variability in radiances:

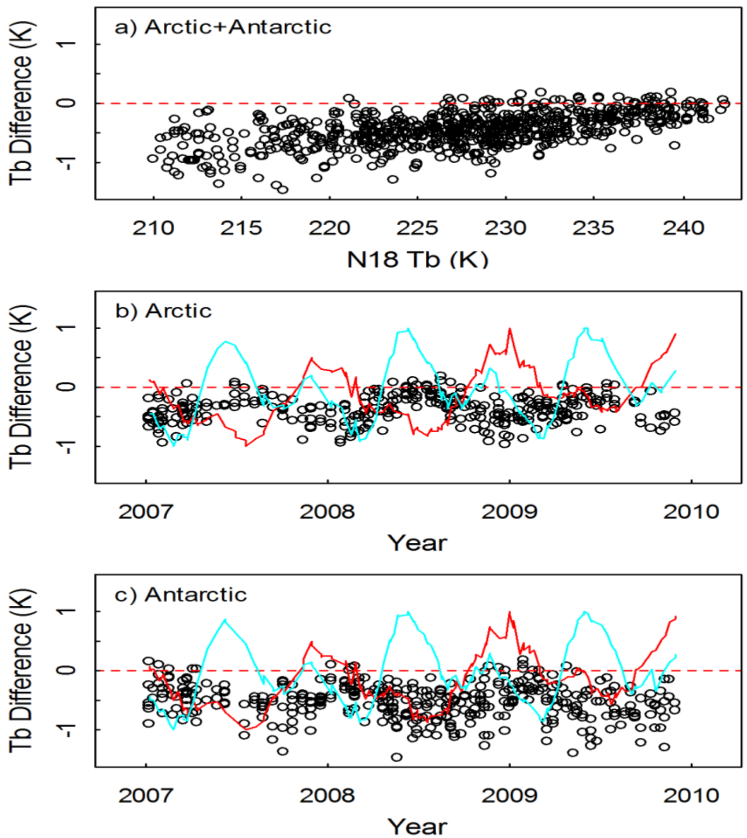
- Combination of orbital drifts and inaccurate calibration equations— e.g., all MSU channels, NOAA-15 AMSU-A channel 6, most NOAA-16 channels after 2008,…

Not all channels suffer such variability; situations recalibrations are not needed:

- Orbit not drifting--- e.g, AQUA, NOAA-18,…
- Orbit drifting, but channel is high linear and thus pre-launch linear calibration is sufficient accurate --- e.g., most NOAA-15 channels
- Orbit drifting, but solar shield did a good job in protecting the instrument from solar radiative heating--- e.g., NOAA-16 before 2008

Bias Type IV: Scene Temperature Dependent Biases

Root causes: Inaccurate calibration nonlinearity

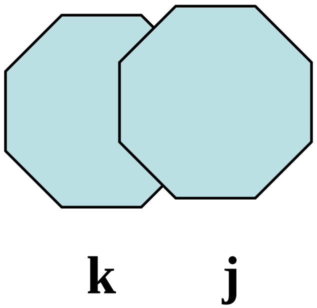


SNO scatter and time series for AMSU-A channel 7 between NOAA-15 and NOAA-18

Solution: find accurate nonlinear calibration coefficients using SNOs

$$R_k = R_{L,k} - R_{0k} + \mu_k Z_k$$

$$R_j = R_{L,j} - R_{0j} + \mu_j Z_j$$



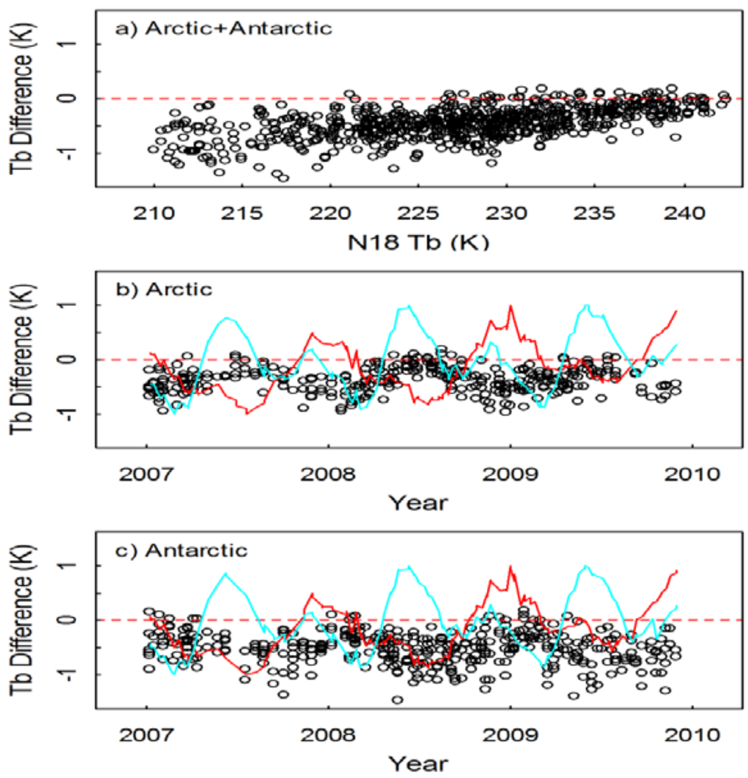
$$\Delta R = \Delta R_L - \delta R_0 + \mu_k Z_k - \mu_j Z_j$$

Radiance Error Model for SNO Matchup K and J

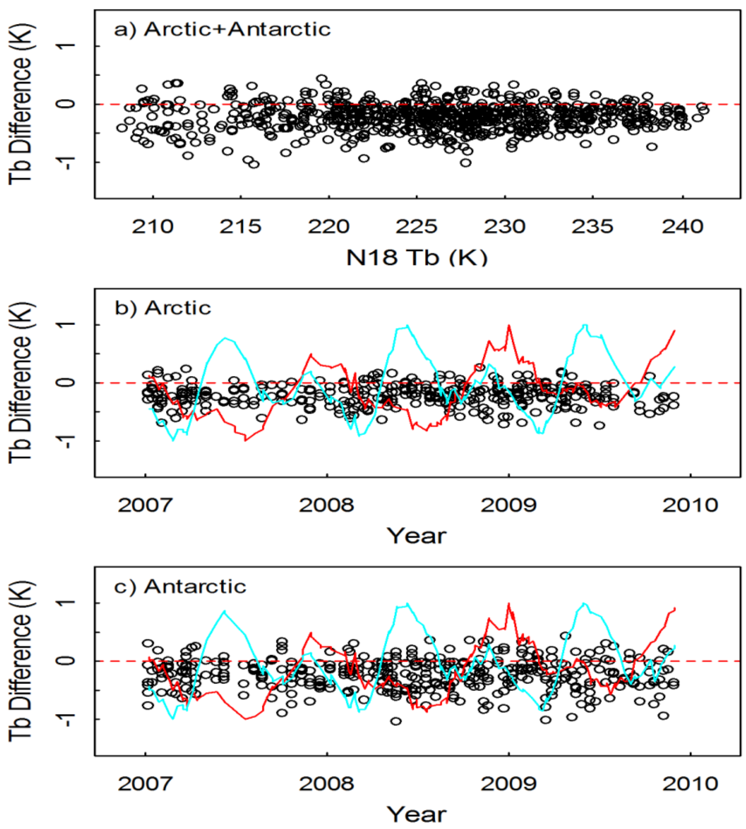
$$\delta\mu \approx \mu_j - \mu_k$$

Inaccuracy leads to scene temperature dependent biases

Removal of Scene Temperature Dependent Biases

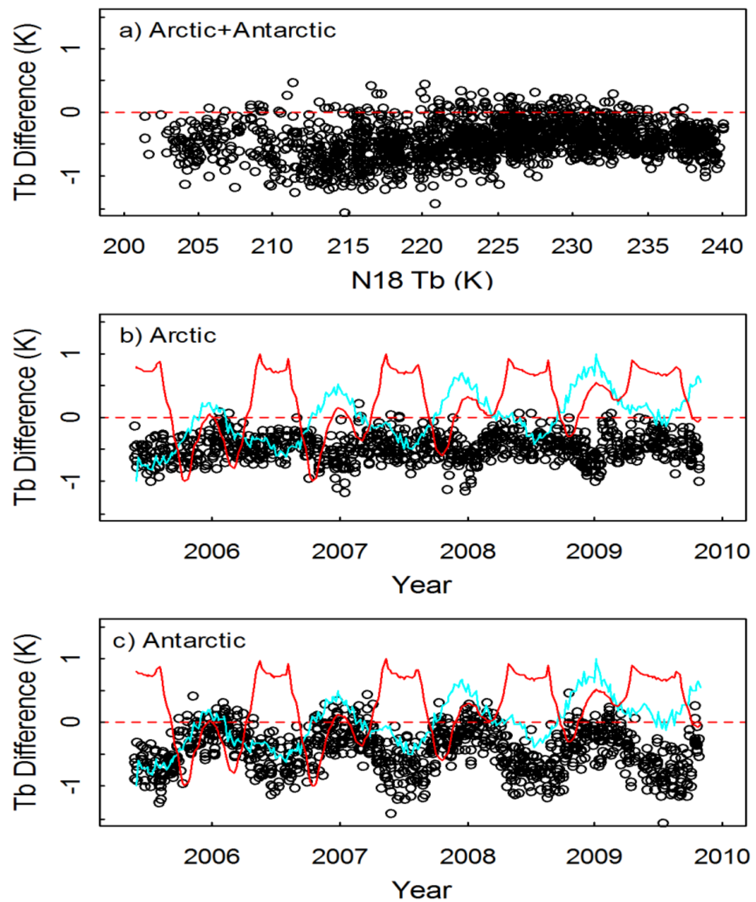


Before inter-calibration



After non-linear calibration

Bias Type V: Channel Frequency Shift



SNO scatter and time series for AMSU-A channel 6 between NOAA-15 and NOAA-18

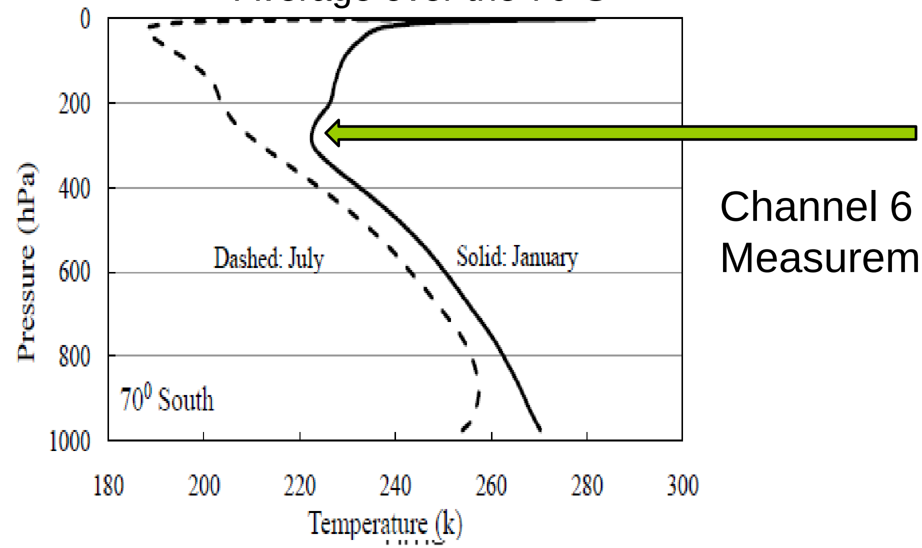
Lapse Rate Climatology

- The averaged lapse rate around 350 hPa being steeper in winters (July) than in summers (January).

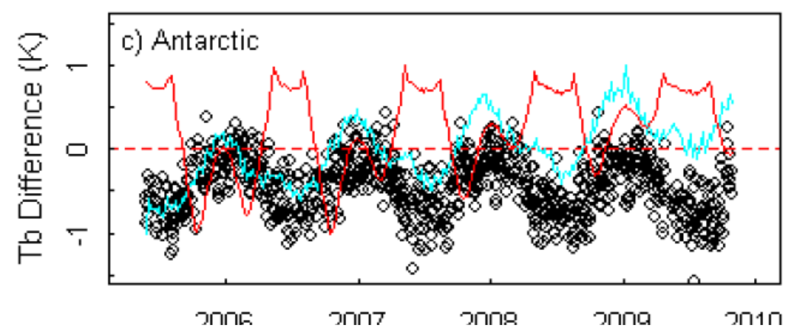
- Time series with winter values being at the negative side of the summer values when the frequency shift is positive (weighting function peaking higher than prelaunch measured), and the other way around for negative frequency shift.

➢ NOAA-15 should have a positive frequency shift

Average over the 70^0S



Channel 6 Measurement



NOAA-15 Minus NOAA-18

Pre-launch Measured Frequencies for AMSU-A Channel 6

- Measured frequency differences between different satellites are within 0.5 MHz.
- These errors are so small that they wouldn't result in noticeable T_b differences between satellites (0.01K)

➢ Practically, these measured channel frequencies can be considered as the same for different satellites

➢ The shift is a post-launch error

Frequency characteristics for AMSU-A Channel 6 from Mo [1996; 2006; 2007]. Units are in MHz.

	Measured Channel Frequency (Specification =54400 for all satellites)
NOAA-15	54399.53
NOAA-16	54399.78
NOAA-18	54400.97
MetOp-A	54400.07

Differences for all pairs: 0.5 MHz

Methods to Determine the Actual Channel Frequency

- ❑ Use NOAA Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) to simulate NOAA-15 observations at its SNO sites relative to NOAA-18

- ❑ Use NASA MERRA reanalysis surface data and atmospheric profiles (temperature, humidity, ozone, cloud liquid water, trace gases etc.) as inputs to the CRTM

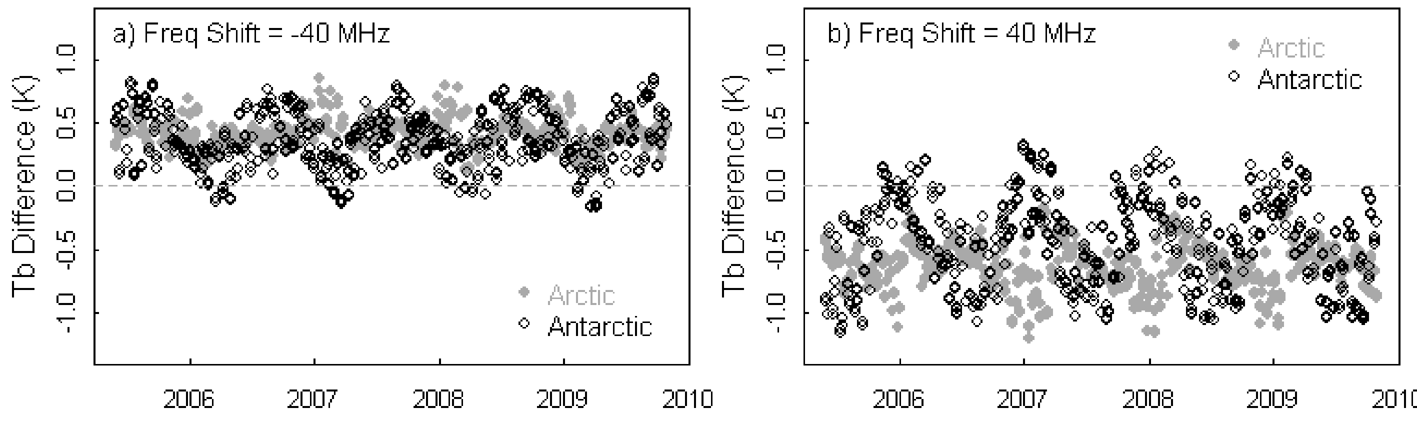
- ❑ MERRA data were interpolated into the N15-N18 SNO sites before being used by CRTM

- ❑ Select different frequency shift values (*df*) in the simulation experiments

- ❑ Analyze $\delta T_b(\text{N15}, df) = T_b(\text{N15}, f_m + df) - T_b(\text{N15}, f_m)$

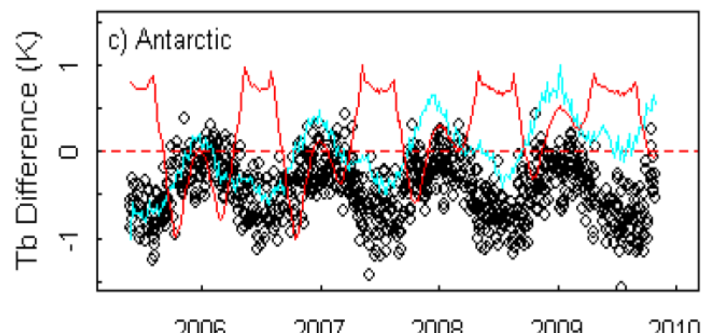
***f_m* : Measured Channel Frequency Value**
***df*: Frequency Shift**

Experimental Results



Simulated δTb (N15, *df*)

- Comparisons between simulations and observed N15-N18 SNO data confirms a positive frequency shift in the NOAA-15 channel 6 relative to its measured frequency value

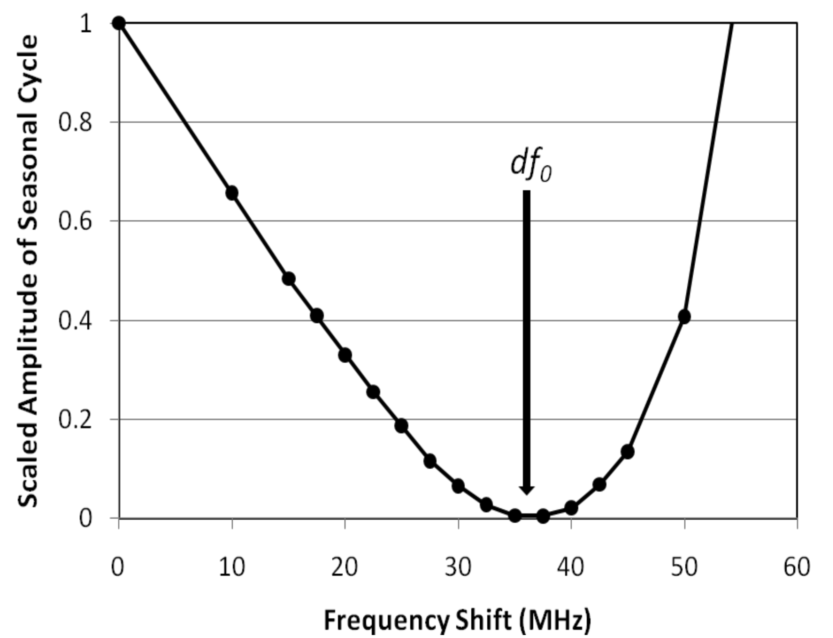


Observed SNO time series over the Antarctic between NOAA-15 and NOAA-18

Determine the Final Channel Frequency Value

- Examine $\Delta Tb'$, which is the T_b differences between NOAA-15 and NOAA-18 at their SNO sites when NOAA-15 T_b is adjusted by its simulated frequency shift
- We expect the seasonal cycles in $\Delta Tb'$ disappear when ***df*** equals to the actual channel frequency shift'
- The seasonal cycles can be measured by the amplitude, which should be equal to zero for ***df***=actual channel frequency shift

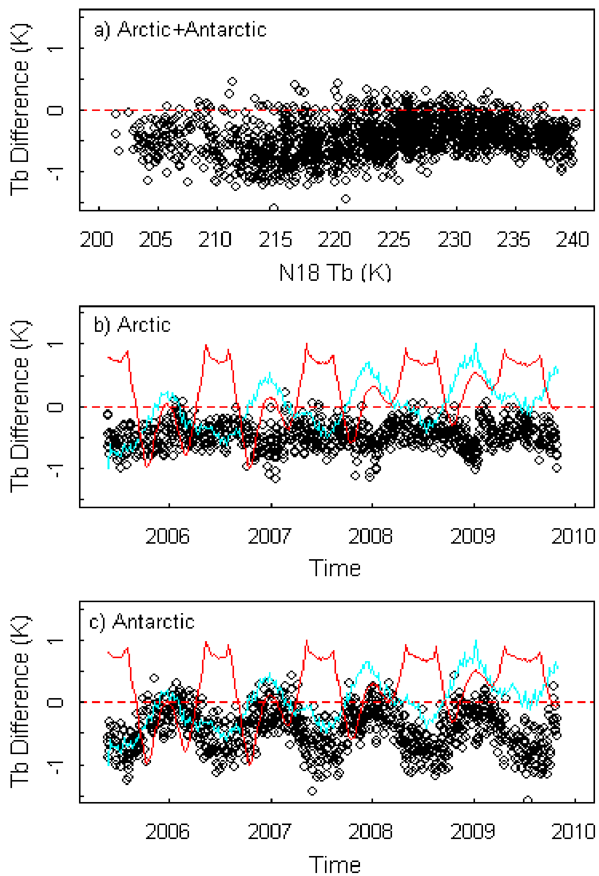
$$\Delta T_b' = T_b(N15) - \Delta T_b^s(N15, df) - T_b(N18)$$



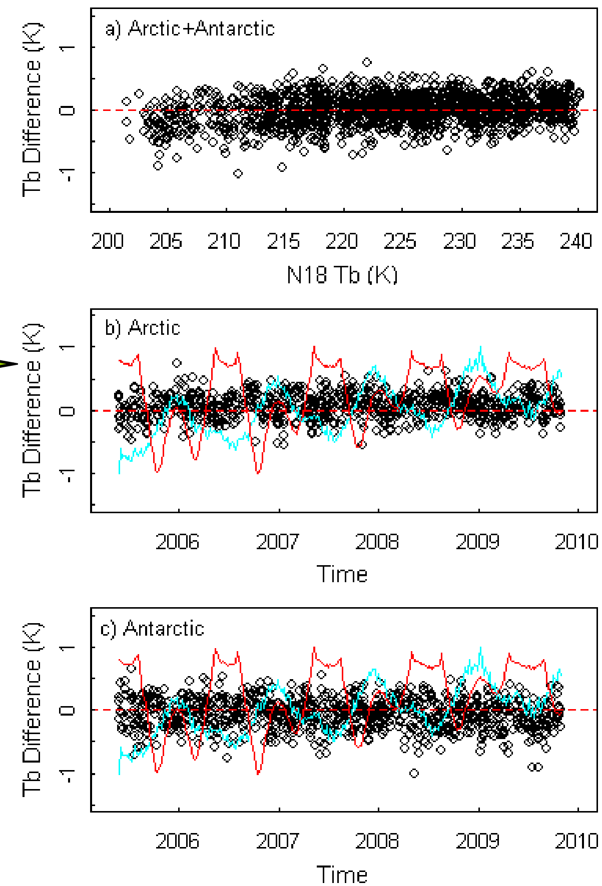
$df_o = 36.25 \pm 1.25$MHz

$f_a = f_m + df_o = 54435.73 \pm 1.25$ MHz

SNO time series after correction of frequency shift



Channel 6 of NOAA-15 vs NOAA-18
Before Frequency adjustment



Channel 6 of NOAA-15 vs NOAA-18
After NOAA-15 Frequency adjustment

Data Production

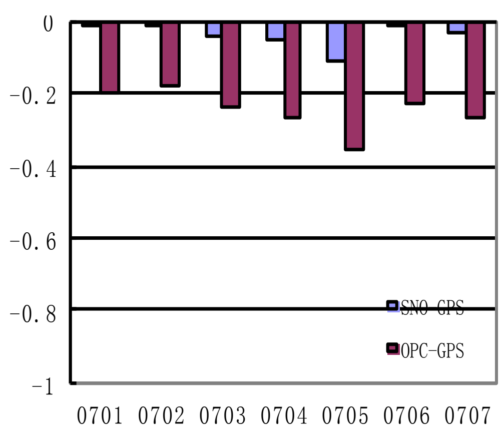
- Determine calibration coefficients and channel frequency shifts offline channel by channel (multiple years of work)
- Use SNOs, global ocean means, and CRTM simulations, and other tools as needed in the process
- Reprocess Level-1b data--use new calibration coefficients to generate a new set of Level-1c radiances for all channels
- Use quality control inherited in level-1b files and do other quality assurance procedure

Validation

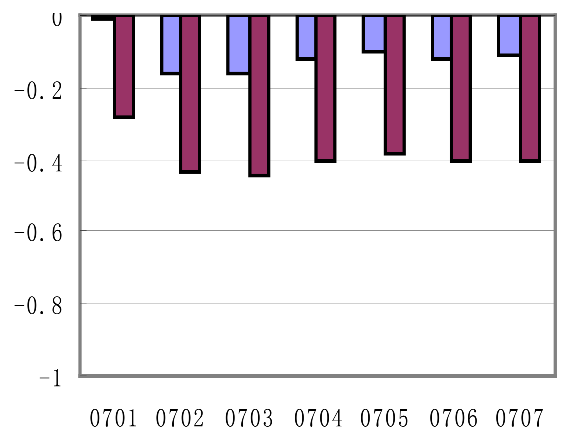
- SI-traceable standards unavailable to validate accuracy of datasets
- Even if SI-traceable standards were available in the future, it can only validate ongoing data; for historical data, accurate inter-satellite calibration algorithm will always be required for them to meet standards
- No datasets can globally verify the MSU/AMSU FCDR for the entire period
- Accuracy maybe established by comparing with operational calibrated radiances
- Use GPSRO for validation for certain period and certain channels
- Reanalysis bias correction scheme to validate inter-satellite biases
- Need more user involvement in the validation processes

Validation—compare with GPSRO

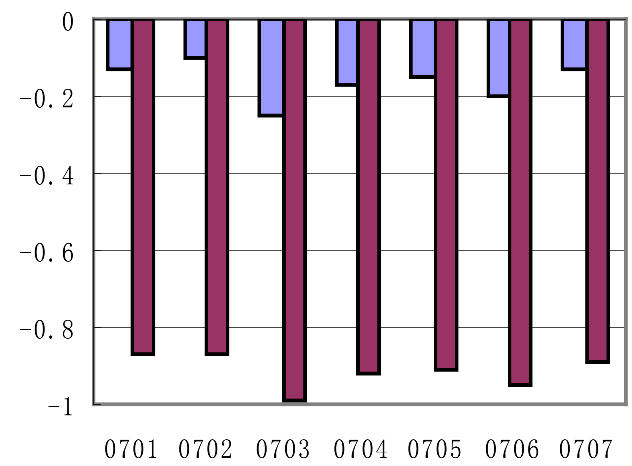
channel 9 biases for AMSU-GPSRO(COSMIC) for randomly selected period January-July, 2007



NOAA-15



NOAA-16

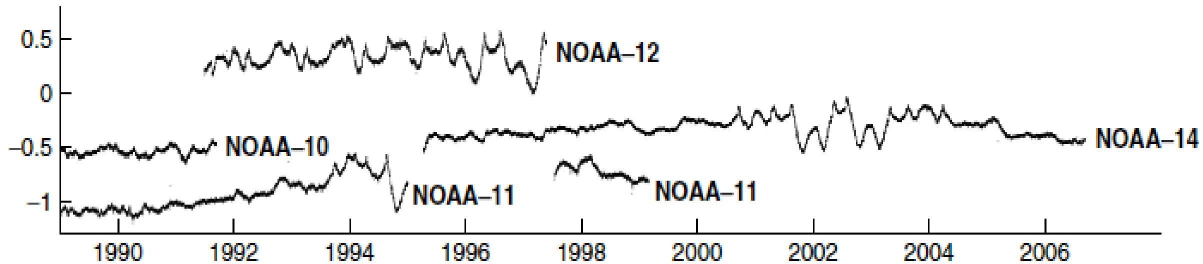


NOAA-18

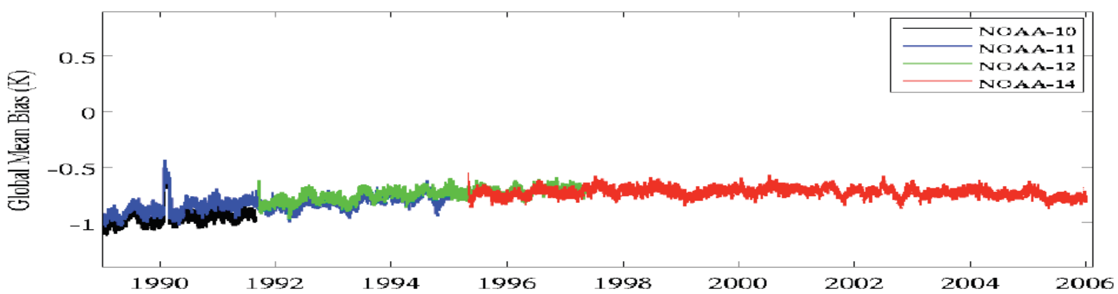
For all three satellites, biases between IMICA calibrated and GPSRO (blue) were consistently small; while those between OPC calibrated and GPSRO (Brown) are different for different satellites and sometimes very large (NOAA-18)

Reanalysis Bias Correction—IMICA calibrated data exhibited consistent bias corrections

ERA-interim Bias Correction Pattern

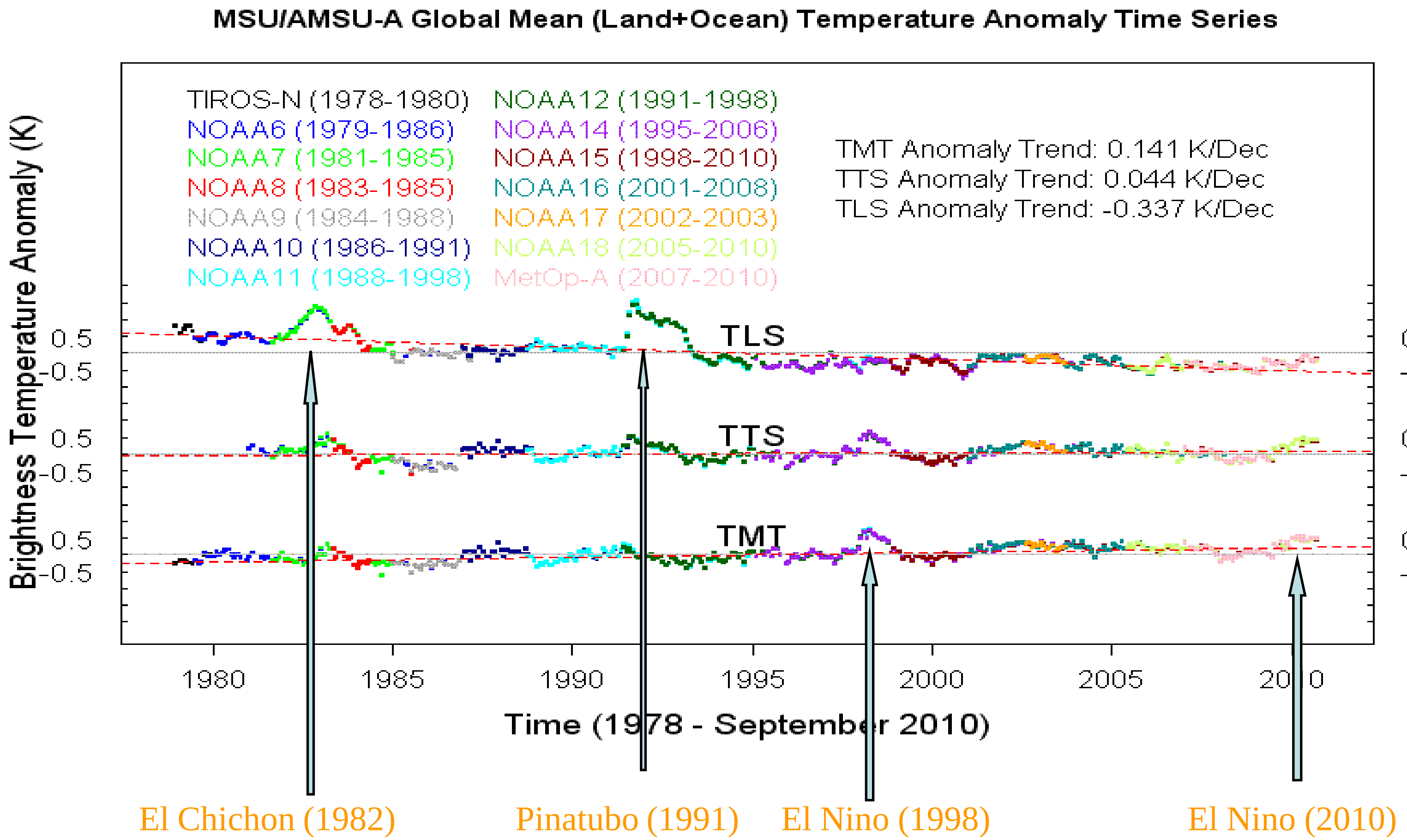


NASA MERRA Bias Correction Pattern



Global mean 12-hourly variational bias estimates (K) for MSU channel 2 radiance data from NOAA-10, NOAA-11, NOAA-12, and NOAA-14 . The upper panel is from ERA-Interim (Dee and Uppalla, 2009) and the lower panel is from MERRA. The latter uses the NOAA/STAR SNO cross-calibrated MSU data. Plot from Dee 2010.

Applications: Develop merged MSU/AMSU time series for climate change monitoring



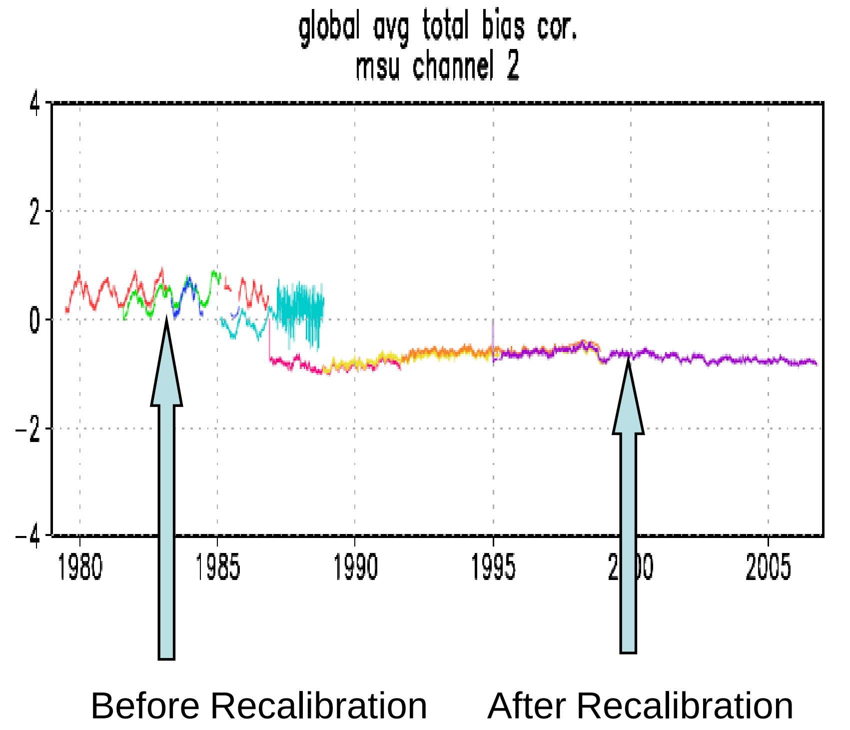
Monthly and global-mean temperature anomaly time series, 'operationally' updated every month

Applications: Improve consistencies in Climate Reanalyses

- Recalibrated MSU level-1c data were assimilated into NCEP CFSR and NASA MERRA reanalysis systems

- Bias correction pattern for recalibrated MSU data are much smoother, since instrument errors were removed before assimilation

- Need to adjust the absolute values of the recalibrated MSU/AMSU data so that the absolute value of the bias correction is close to zero



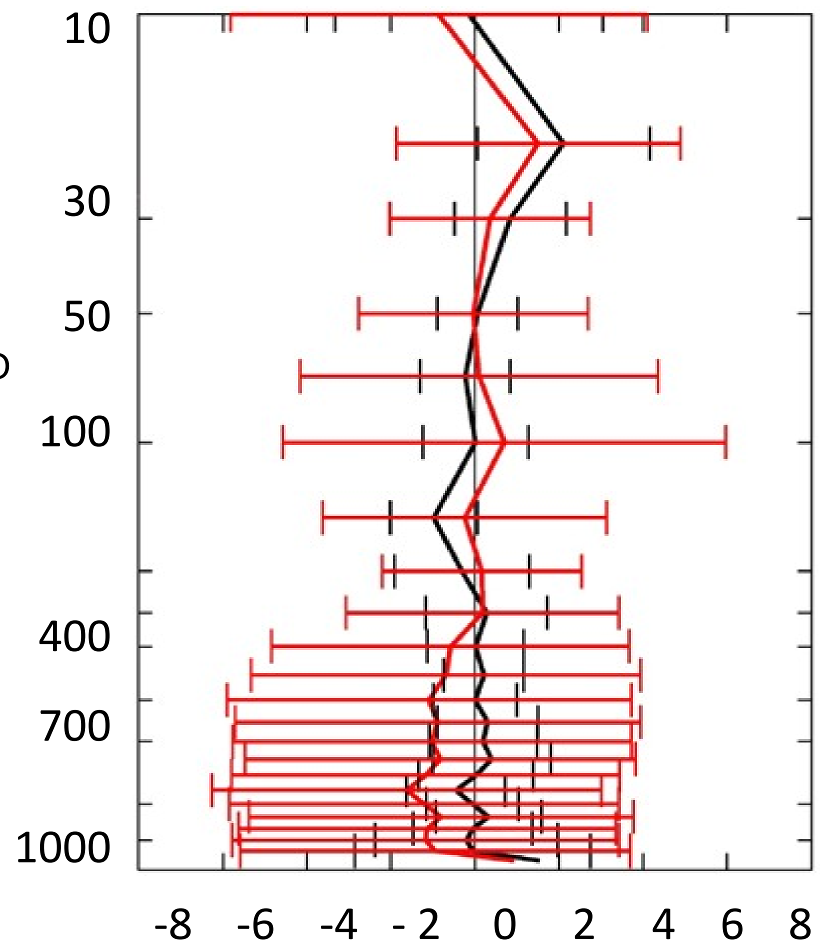
MSU Channel 2 bias correction patterns in NCEP CFSR reanalysis from 1978-2007. Recalibrated MSU data after 1987 were assimilated into CFSR (plot from Saha et al. 2010)

Applications: Develop level temperature CDRs using 1-DVAR

Red: initial guess biases

Black: retrieval biases

Biases against GPSRO



Weng et al. 2013

Input to an 1-DVAR system to develop level temperature time series for temperature change monitoring

Applications: Improve NWP forecasting?

- Channel frequency in radiative transfer models (e.g., CRTM) used in NWP data assimilation system need to be changed

- Impact need to be demonstrated for NWP as well as reanalyses

Operational Distribution

- NCDC website:
  http://www.ncdc.noaa.gov/cdr/operationalcdrs.html
- Data name: AMSU Brightness Temperature--NOAA
  - Use Agreement, FTP, Algorithm Description, Data Flow Diagram, Maturity Matrix

- Data name: MSU Brightness Temperature--NOAA
  - Use Agreement, FTP, Algorithm Description, Data Flow Diagram, Maturity Matrix

- AMSU updated every month

GSICS Demonstration

- Looking for collaboration with GSICS for further user applications and improvement of the datasets

References

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