# Development of climate data record from MSU/AMSU/SSU observations

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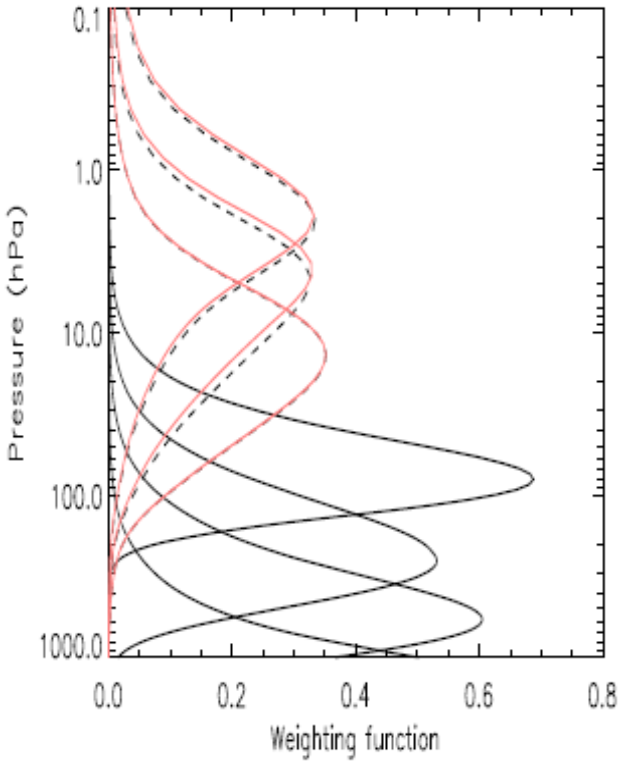
# Purposes

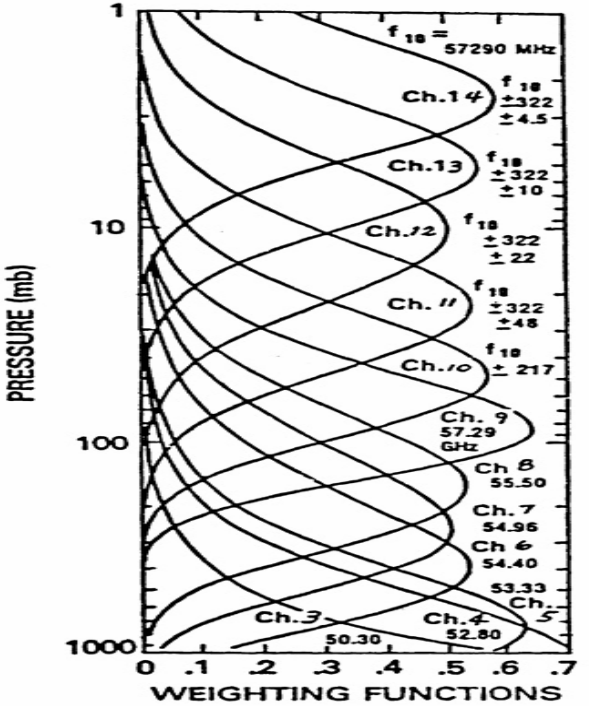
- Develop consistent radiance Sensor Data Record (SDR) to support modeling reanalysis activities and consistent satellite retrievals
- Develop consistent atmospheric temperature thematic climate data record (TCDR) for climate service support – climate change research, climate change monitoring, validating climate model simulation…

# MSU/AMSU/SSU channels

MSU+SSU; 1978-2007




AMSU; 1998-present

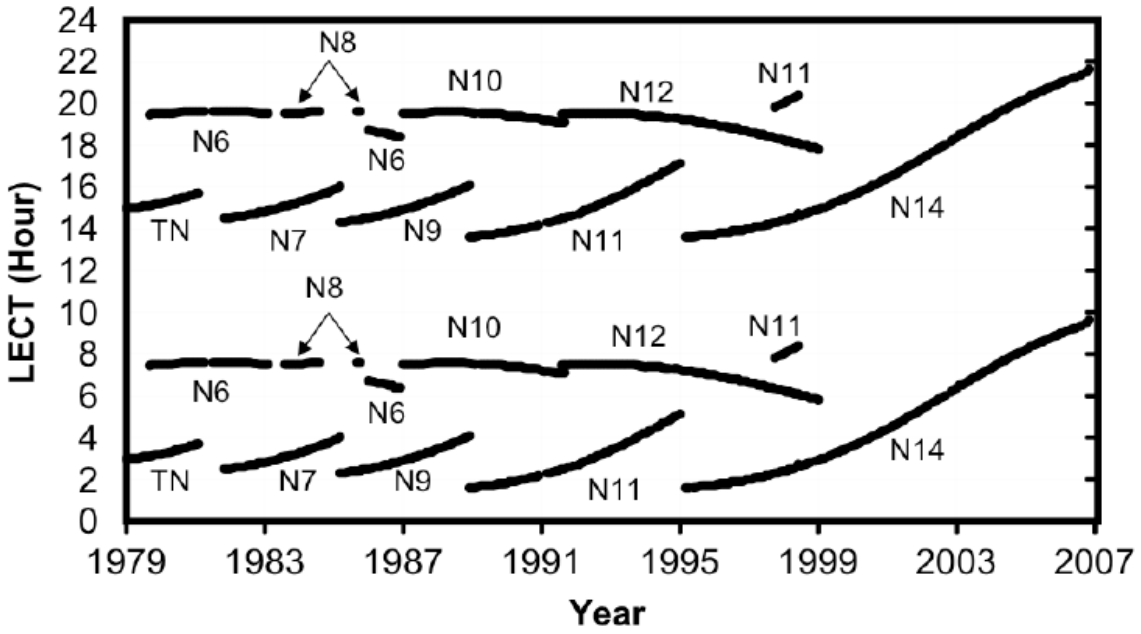



Left: Weighting functions for the MSU and SSU instruments, where the black curve represent the MSU weighting functions and the dashed and red curves are the SSU weighting functions for different time period, showing a shift due to an instrument $CO_2$ cell pressure change; Right: Weighting functions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

# MSU Radiance SDR and Atmospheric Temperature TCDR

1978.11-2007.5

(TIROS-N through NOAA-14)

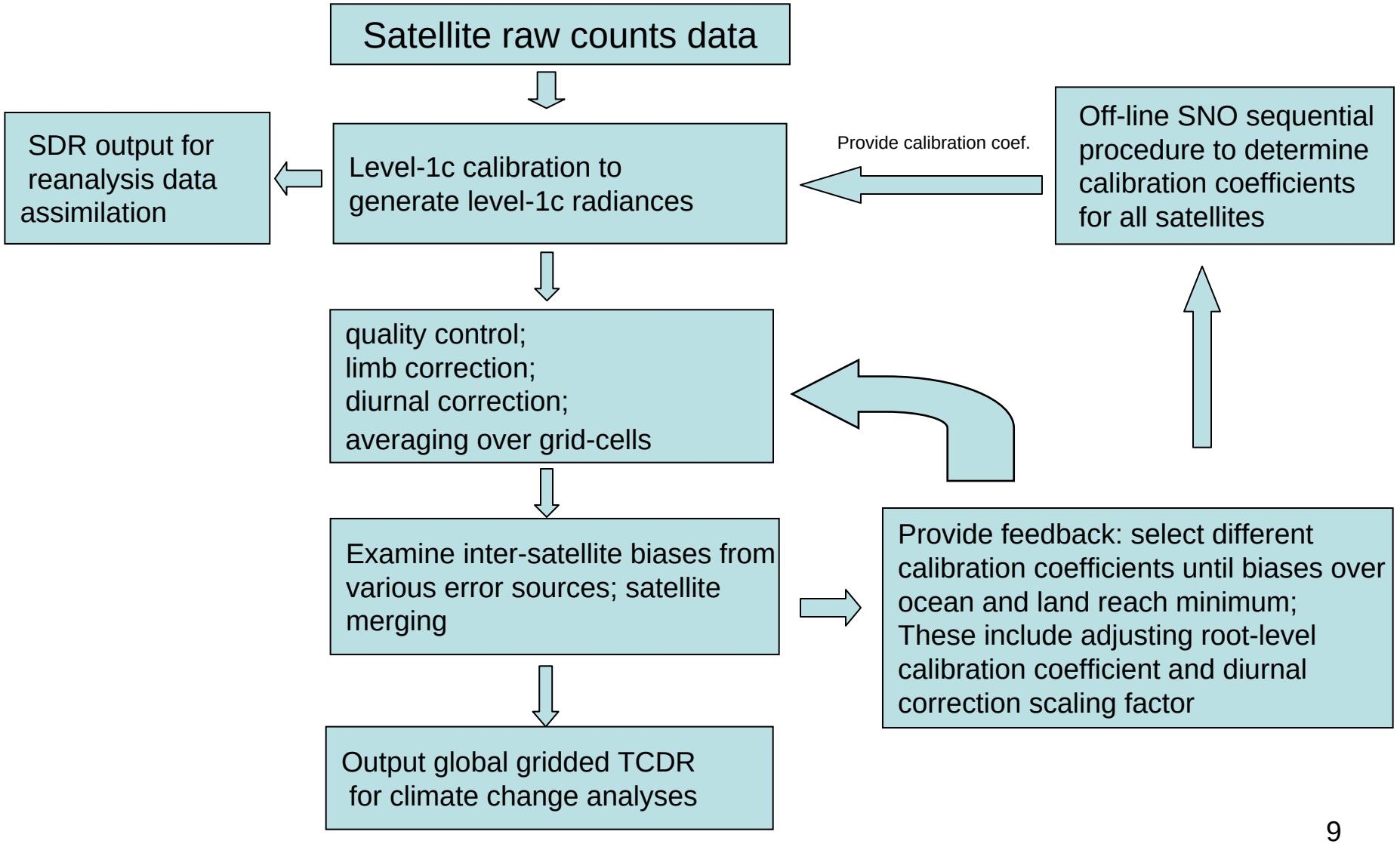


# Issues on the MSU CDR Development

- No SI-traceable standards
- Uncertainty 0.3-0.7K
- Short overlaps between NOAA-9 and NOAA-10
- Lat/Lon and time dependency in biases
- Orbital-Decay
- Antenna Pattern

- Orbital-drift related warm target contamination due to high nonlinearity
- Diurnal drift effect
- Residual bias correction

# STAR MSU/AMSU CDR Development System

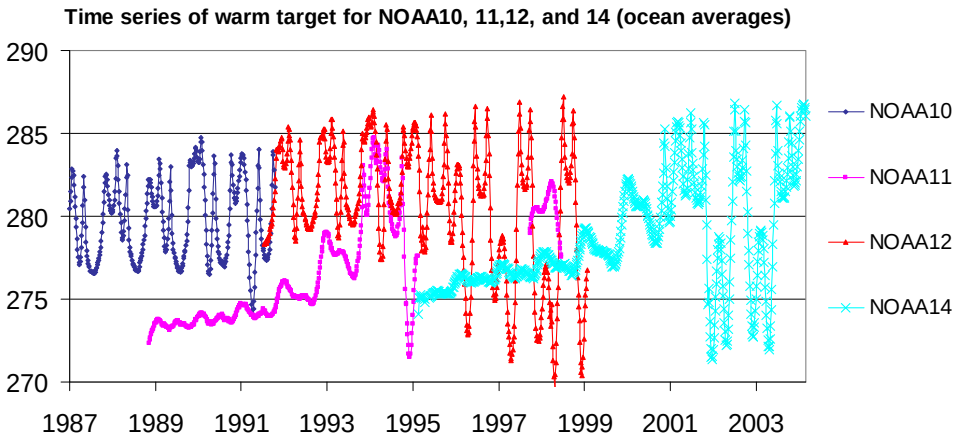


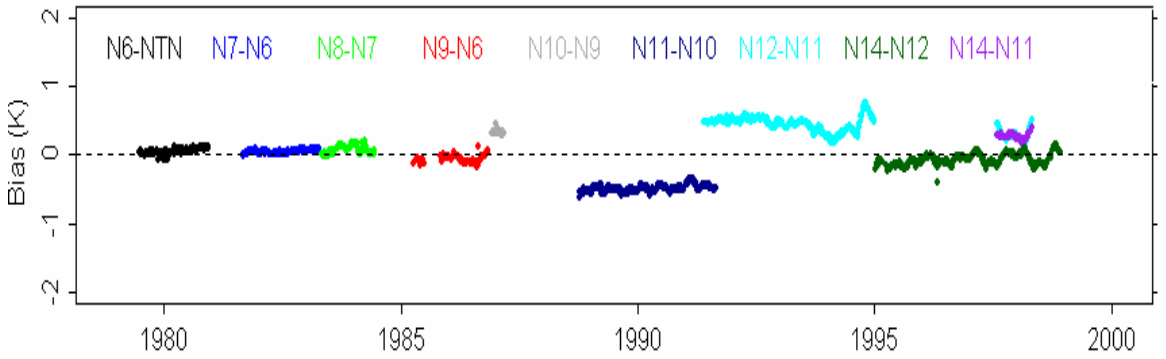
# Key points

- Ocean and land processed separately to decouple warm target and diurnal drift errors
- Ocean for instrument warm target errors
- Land for sampling diurnal drift errors
- Use simultaneous nadir overpasses (SNOs) for level-1c calibration to remove warm target errors
- SNO dynamic range is NOT a big issue for temperature channels, although it is a big problem for water vapor channels
- Reference satellite is NOT a big problem: NOAA-10 is selected as a reference in a sense that only its constant offset is assumed to be zero; all other parameters (e.g., nonlinear coefficients) were determined from inter-calibration procedure which are independent from reference satellite

# Warm Target Problem

Warm target temperature time series




MSU Ch2 global ocean mean Tb difference time series

# Warm target errors due to inaccurate calibration nonlinearity

**Nonlinear Calibration**

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

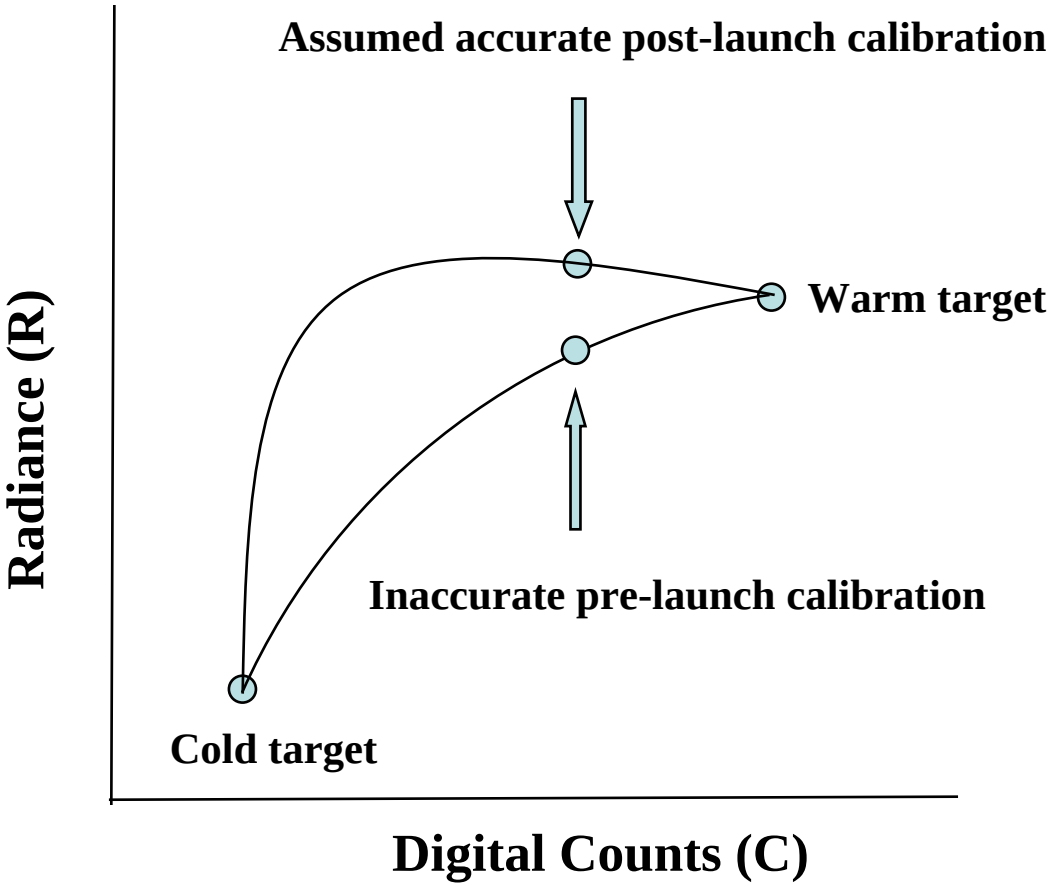
**Linear Term**

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

S ⟶ Slope

**nonlinear Term**

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



# SNO determines calibration nonlinearity

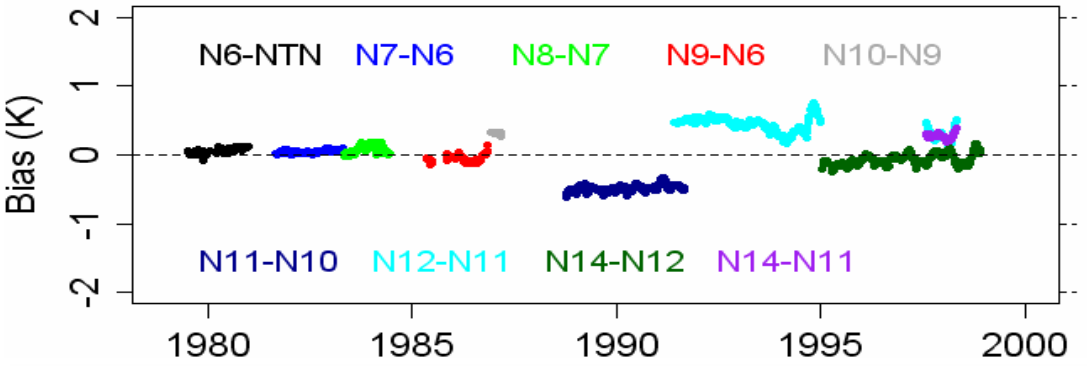
- **Use SNO regression to derive more accurate calibration nonlinearity**

Ch2 examples

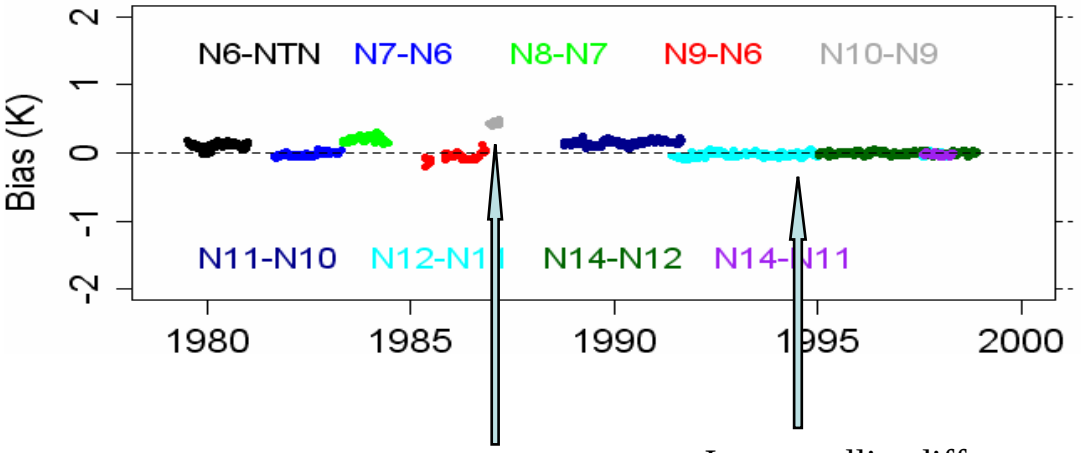
| satellites | Nonlinear calibration coefficients determined by post-launch SNOs (Zou et al. 2006) | Nonlinear calibration coefficients determined by pre-launch lab testing (Mo et al. 2001) |
|---|---|---|
| N10 | 6.25 | 4.9-5.1 |
| N11 | 9.59 | 6.6-7.7 |
| N12 | 6.77 | 3.1-3.3 |
| N14 | 7.46 | 3.2-3.4 |

# Impact on inter-satellite differences

***Intersatellite biases for NOAA operational calibration (ch2 5-day and global ocean-mean)***



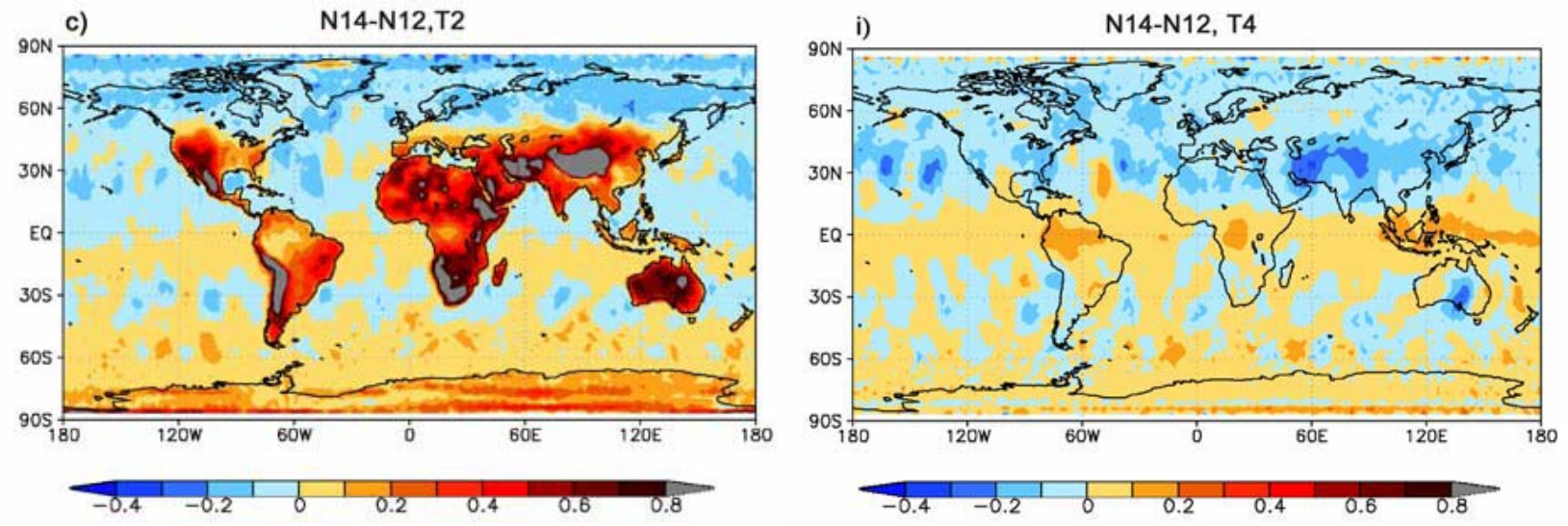

***Intersatellite biases after SNO calibration***




Short overlap problem

Inter-satellite differences dramatically reduced

# Inter-satellite Bias Pattern after SNO Calibration




- After instrument errors are removed, inter-satellite bias patterns show diurnal drift errors
- Diurnal drift over oceans are NOT important for ch2
- Diurnal drift for ch4 are NOT important globally

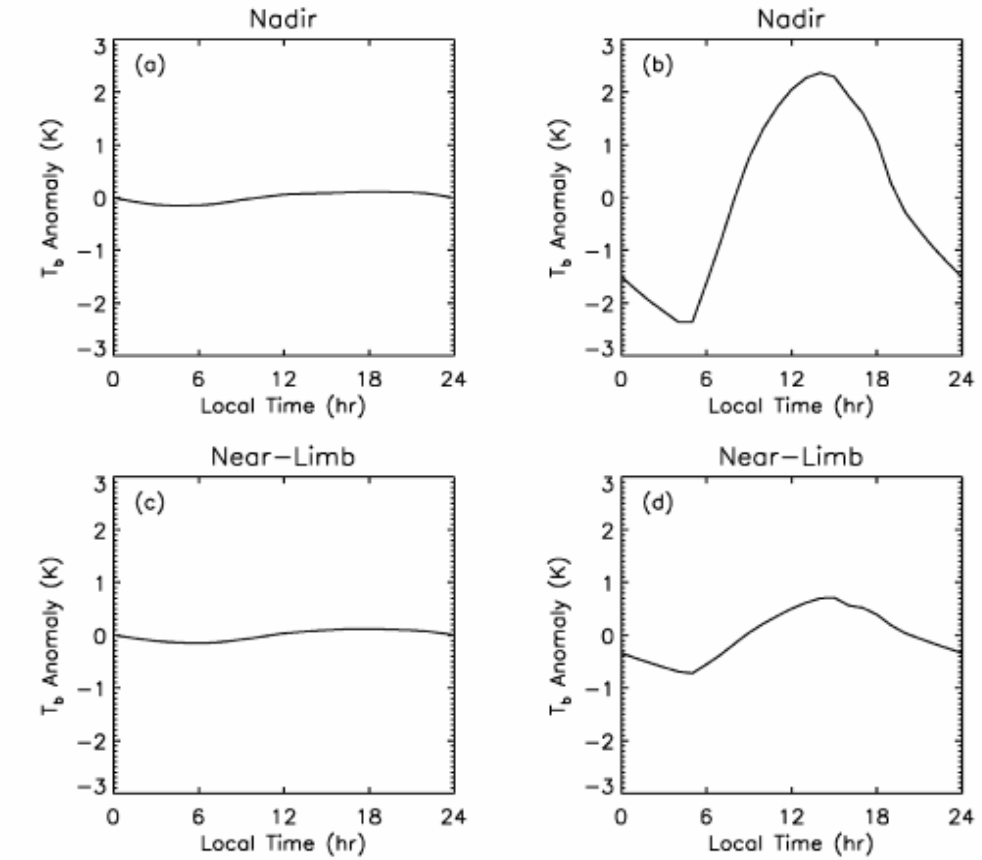
# Diurnal Drift Correction

- Adjust observations at different time to a standard local noon time using diurnal anomaly look-up tables

- Diurnal anomaly dataset developed by Remote Sensing Systems (RSS) is adopted, which is based on NCAR community climate model simulation

- A scaling factor is introduced to take into account the uncertainty in the simulated diurnal anomaly dataset. The scaling factor was determined by minimizing inter-satellite differences over land

# Diurnal Anomaly Examples

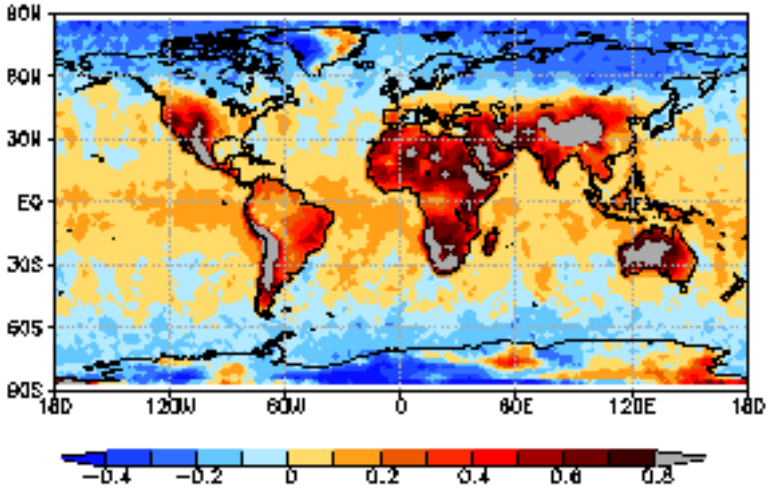



Tropical Pacific (1.25$^0$N, 180$^0$W)  Western USA (39$^0$N, 114$^0$W)

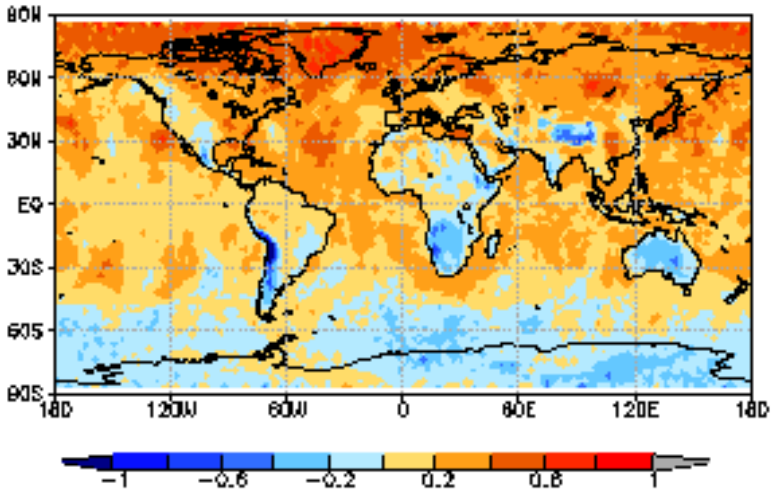
MSU ch2 for the month of June (plot from Mears et al. 2003)

# Impact of Diurnal Drift Correction

No diurnal drift correction




With diurnal drift correction

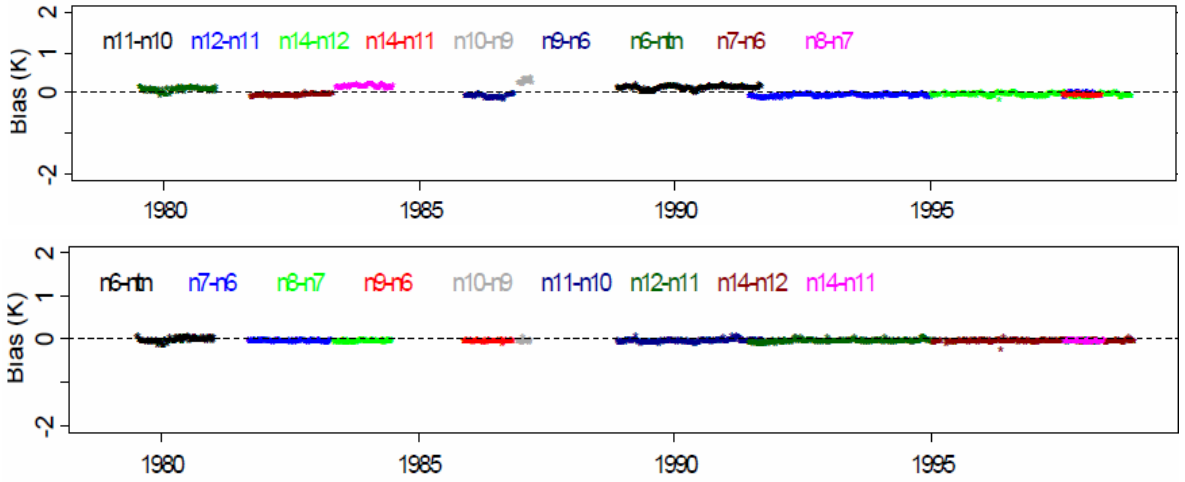



Channel 2 intersatellite bias pattern between NOAA-11 and NOAA-10 (NOAA-11 minus NOAA-10) during 10/1988-08/1991 with and without diurnal drift correction

# Residual Bias Correction

**After SNO calibration but before residual bias correction**

**After residual bias correction**




MSU Channel 2 Tb difference time series over ocean

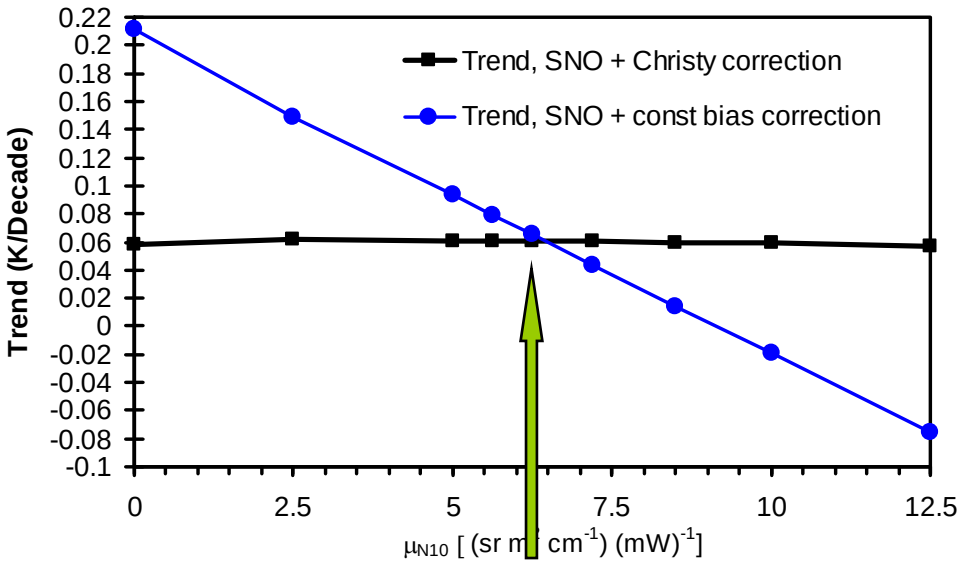
- Constant bias correction
- Relate the inter-satellite biases linearly to warm target temperature variation (Christy et al. 2000)
- Simultaneously solve multi-satellite regression equations to obtain correction coefficients

# Trend Stability Test

- Constant bias correction results in trend to be linearly dependent on calibration coefficients

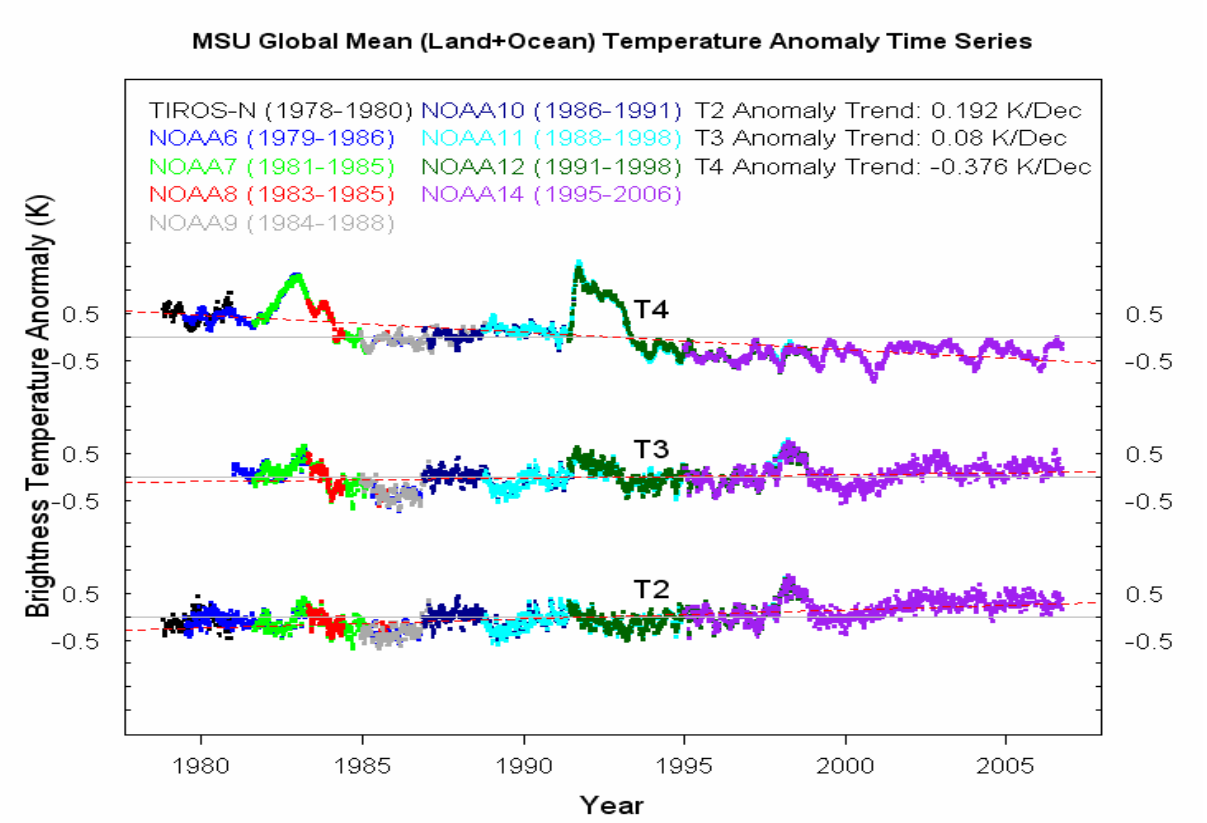
- Combination of SNO calibration at level-1c plus physically-based empirical correction such as Christy correction at level-3 results in stable trends for all channels

Trends versus calibration coefficient (MSU Ch3)




SNO calibration point

# MSU Global Mean Time Series



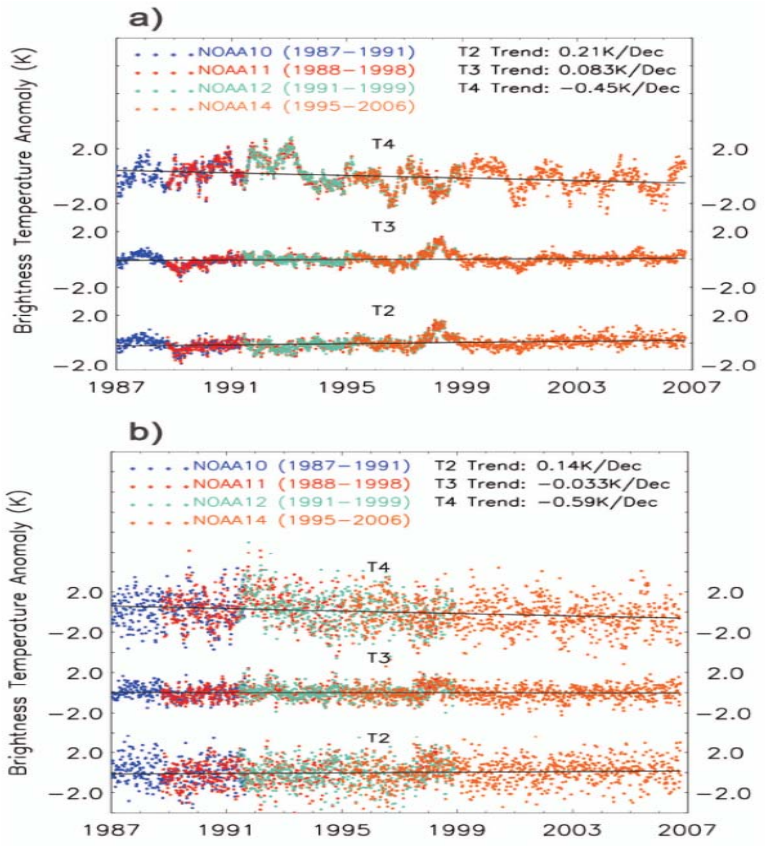

Global mean anomaly time series after inter-calibration and bias correction

# Recalibrated MSU TCDR, Version 1.2

- Residual bias correction applied for each grid-cell to make sure inter-satellite biases were removed completely
- Created well-merged gridded temperature products
- Available products:

  Mid-tropospheric temperature ($T_2$)
  Upper-tropospheric temperature ($T_3$)
  Lower-stratospheric temperature ($T_4$)

- Global monthly and pentad with $2.5^0$x$2.5^0$ grid resolution
- Available for downloading from http://www.star.nesdis.noaa.gov/smcd/emb/mscat/mscatmain.htm




Temperature anomaly time series and trends for geographic locations of (a) (6.250W, 6.250S) and (b) (6.250W, 31.250S) after various bias corrections were made. See text for definition of $T_2$, $T_3$, and $T_4$.

# MSU/AMSU Inter-Satellite Calibration

AMSU: NOAA-15 through NOAA-18 and MetOp-A
(1998-present)

NOAA-19 and NASA AQUA are not included yet

# Orbital Drifts of AMSU Satellites

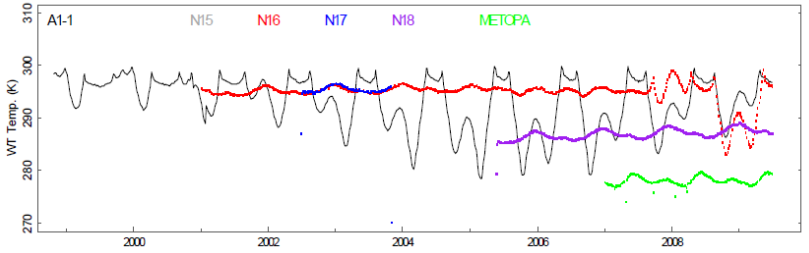
| Satellites | Launch Date | LECT at lunch | Drift as of June 2009 since launch (approximately) |
|---|---|---|---|
| MetOp-A | October 2006 | 0930 Descending | No change |
| NOAA-18 | MAY 2005 | 1400 Ascending | - 0.5 hours |
| NOAA-17 | JUNE 2002 | 1000 Descending | - 0.5 hours (up and down) |
| NOAA-16 | SEPT 2000 | 1400 Ascending | + 2.5 hours |
| NOAA-15 | MAY 1998 | 0730 Descending | - 2.5 hours |

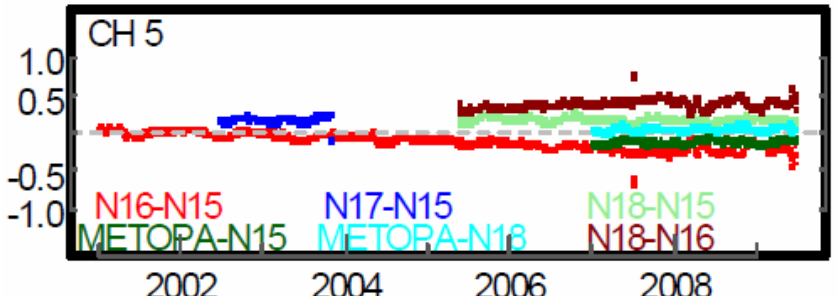
# AMSU warm target and inter-satellite biases

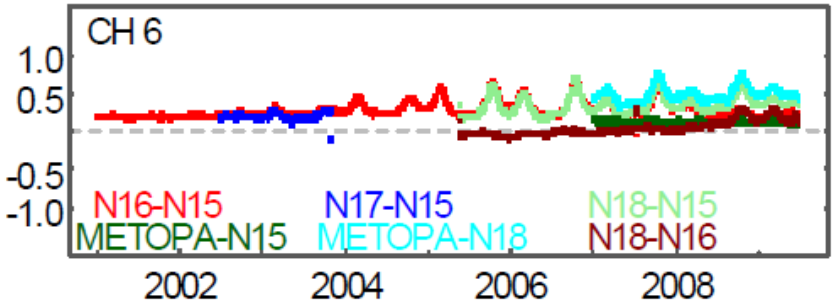
- NOAA-15 has large warm target temperature variability

- Warm target errors not obvious in inter-satellite difference time series for most channels--suggesting weak calibration nonlinearity; however, this is channel dependent. High nonlinearity seen for channel 6 on NOAA-15

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

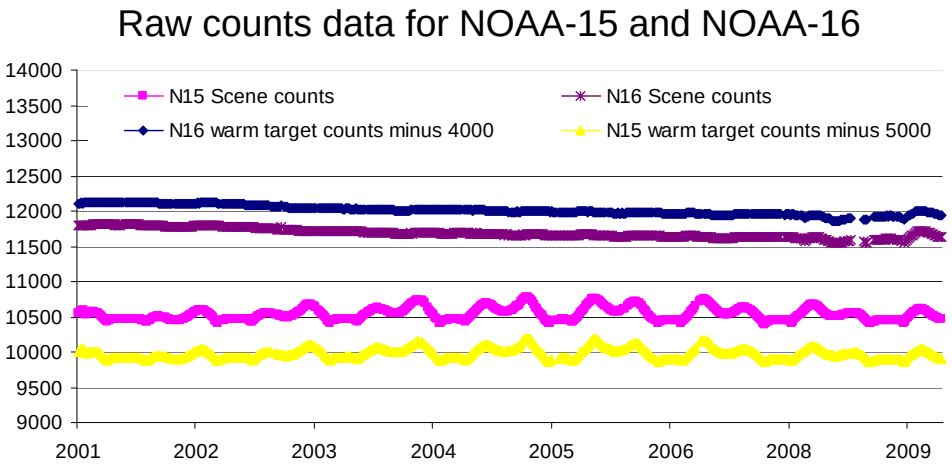


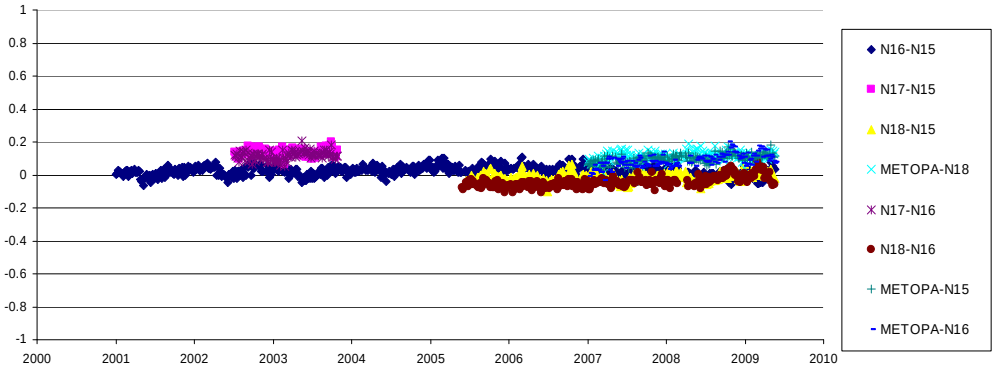



# Eliminating NOAA-16 Bias Drift

- Time-dependent calibration coefficients introduced to remove bias drift in NOAA-16

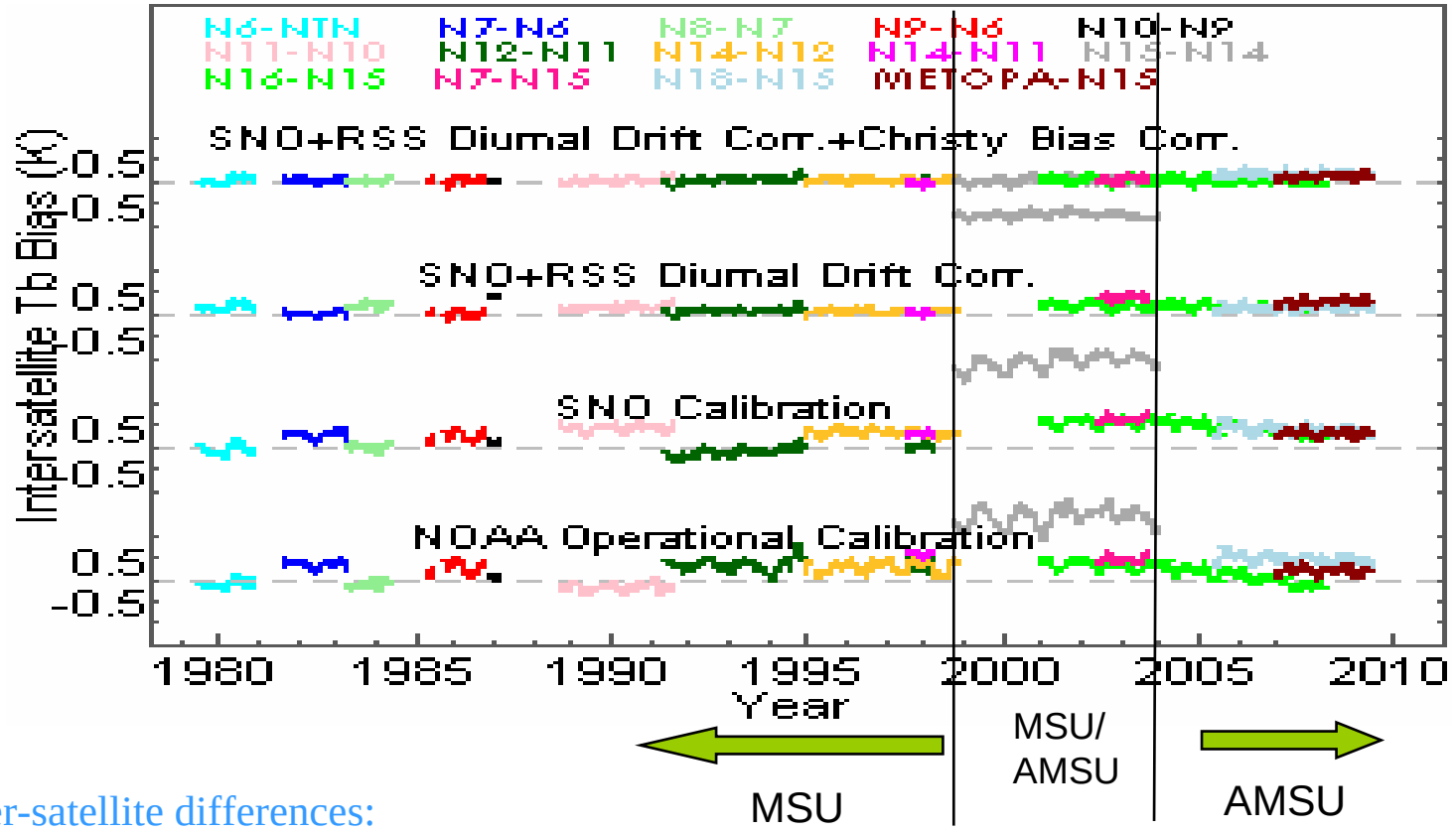



Ch5 inter-satellite biases after SNO inter-calibration



# Merging of MSU and AMSU channels

Inter-satellite differences over land for MSU ch2 and AMSU ch5




inter-satellite differences:
Pre-launch: Biases=0.5-1K; sigma=0.1-0.15 K
Post-launch: Biases=0;  sigma=0.02-0.03 K

# CDR Consistency Test

- Ocean-mean trend should be most reliable – diurnal drift errors are negligible, only instrument (warm target) errors need to be corrected
- Robust scheme for warm target error removal – double correction
- Trends over land should be compatible with ocean – the atmosphere should be well mixed in long-term climate change process
- Average of the spatial trend pattern should be consistent with global-mean merging – a test if spatial bias correction procedure works well
- Adding more satellites should not affect the trend

# Trends Over Land and Ocean

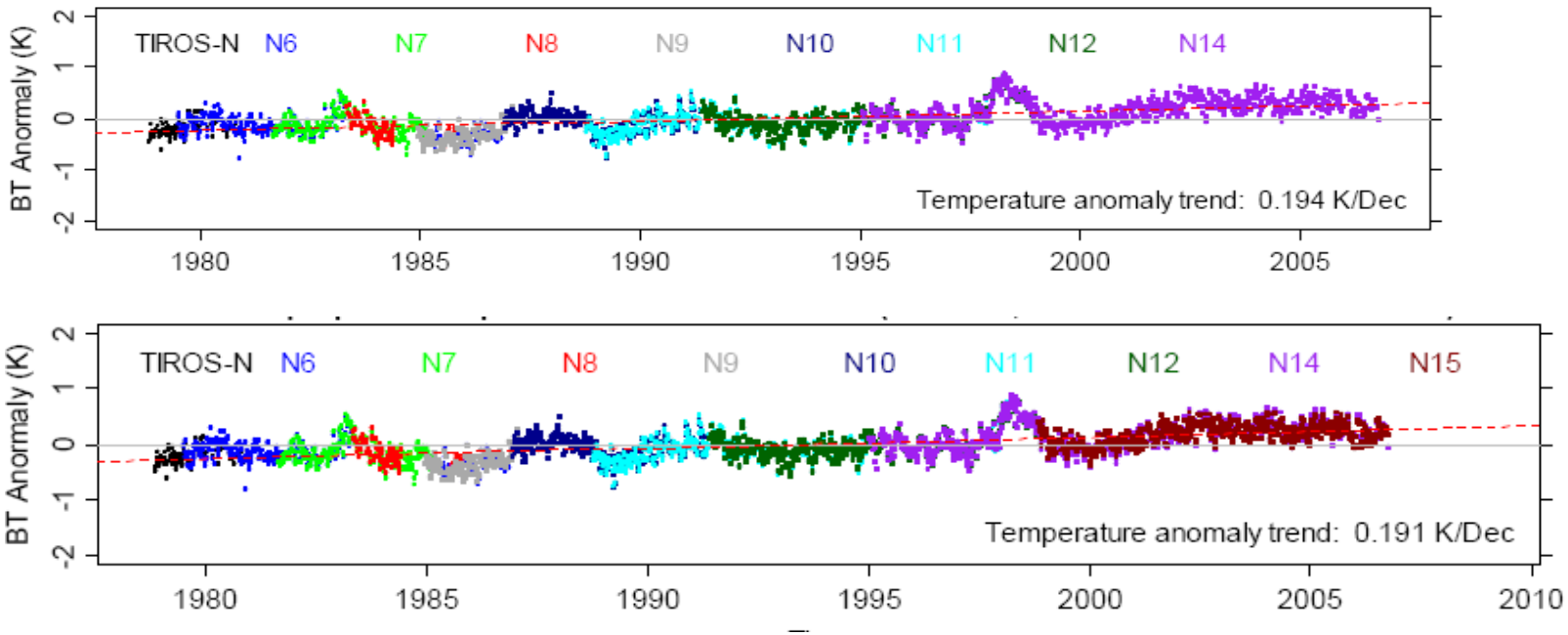
Channel 2 trend from 1978.11-2006.9, Unit in K/decade

| | | |
|---|---|---|
| Without diurnal correction | Global Mean | 0.149 |
| | Ocean Mean | 0.172 |
| | Land Mean | 0.093 |
| With diurnal correction | Global Mean | 0.184 |
| | Ocean Mean | 0.180 |
| | Land Mean | 0.194 |

- Trend over land is compatible with ocean
- Diurnal adjustment has negligible effect on trend over ocean

# Consistency Test by Adding AMSU

MSU2/AMSU5—mid-tropospheric temperature



# SSU Recalibration/Reprocessing

- 1978.11-2007.5
- TIROS-N through NOAA-14
- No SSU on NOAA-10 and NOAA-12

# Measurement Principle

- Use pressure modulation technique to measure atmospheric radiation from $CO_2$ 15-μm $v_2$ band
- A cell of $CO_2$ gas is placed in the instrument's optical path with its pressure changed in a cyclic manner
- An interference filter allows only 15-μm band to pass through
- Weighting function determined by the pressure
- Three different pressures to give three different weighting function

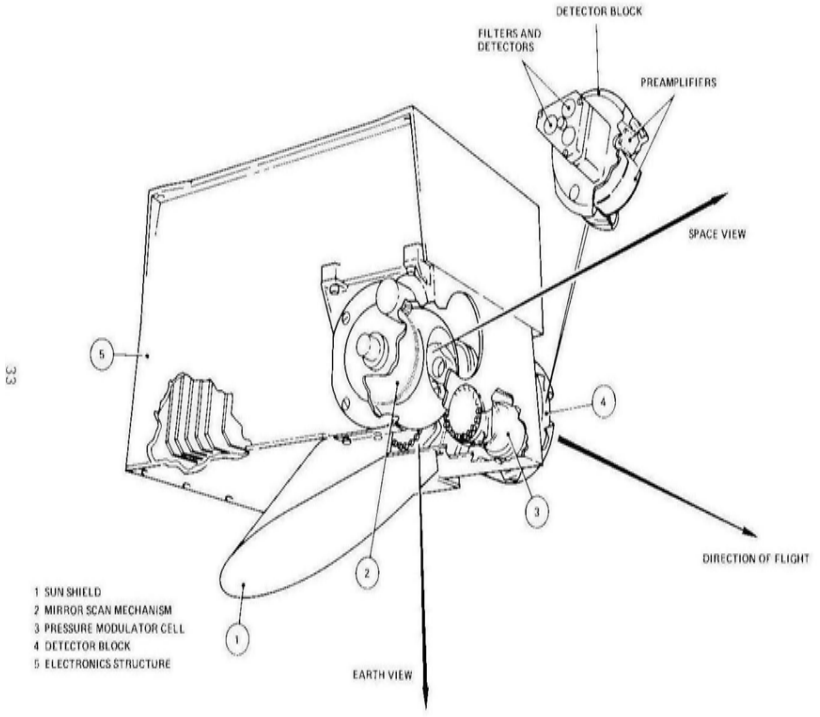



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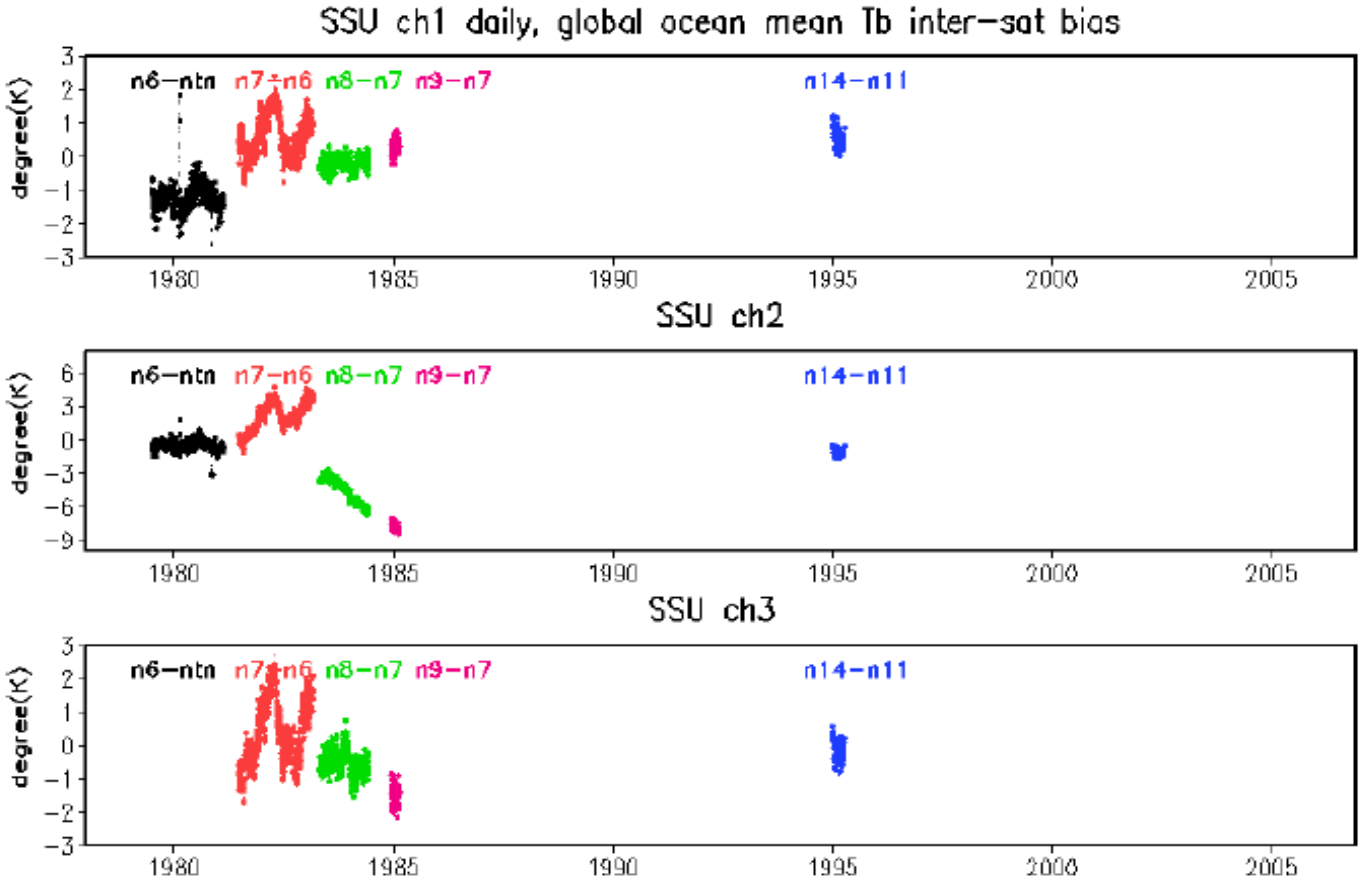
Figure 9.--The complete SSU, showing the views to earth and to space

# SSU Tb Difference Time Series

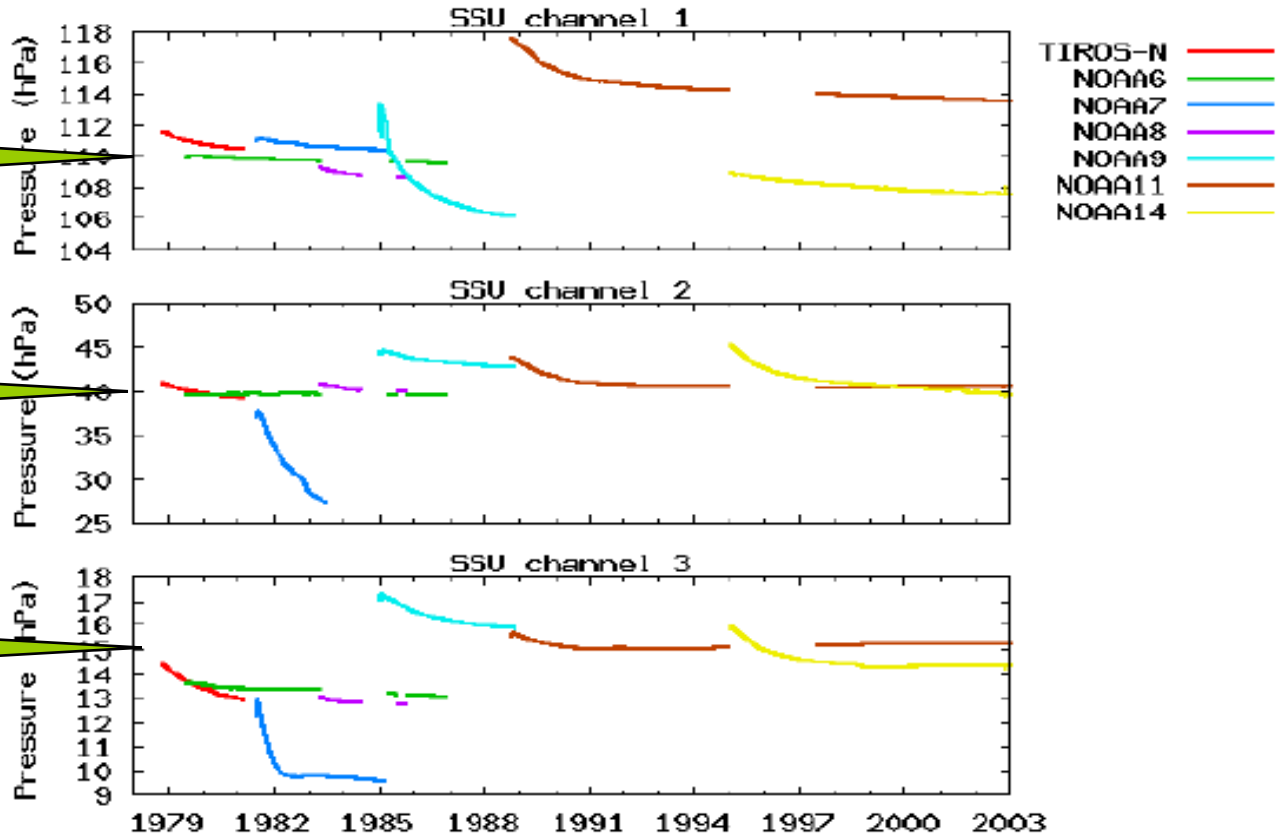


# Gas leaking in $CO_2$ cell

Ideal setting: 110mb

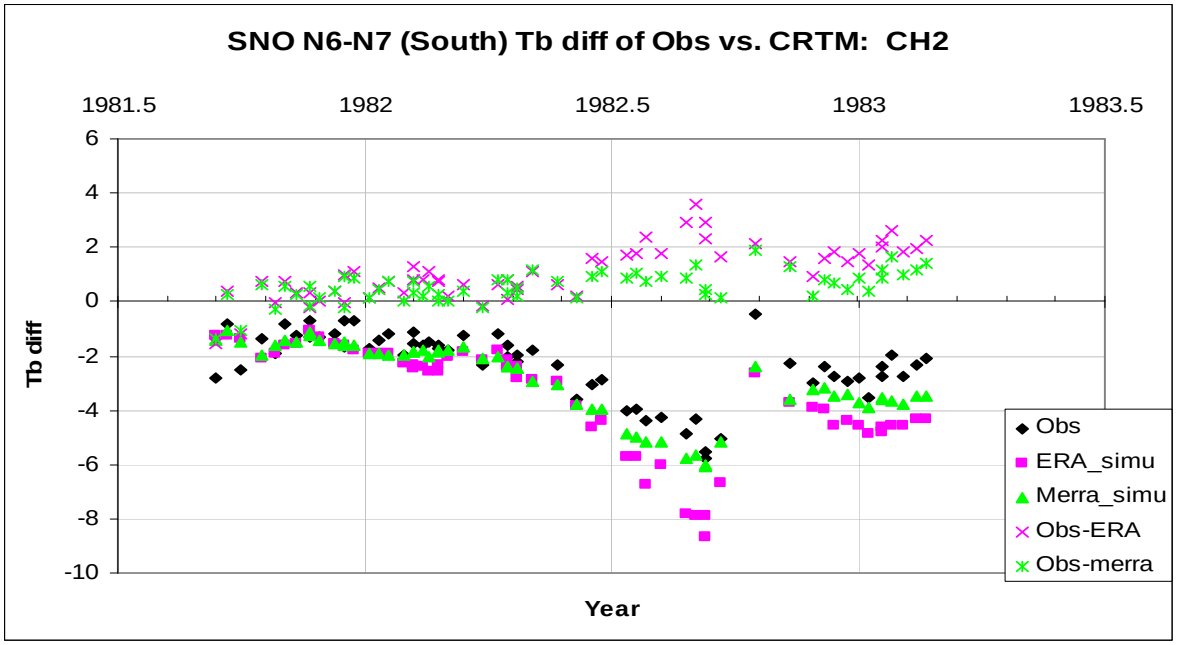
Ideal setting: 40mb

Ideal setting:15 mb




Note the pre-launch settings: ch1: 110mb; ch2: 35mb; ch3: 10mb

# SNO biases – Observation vs Simulation

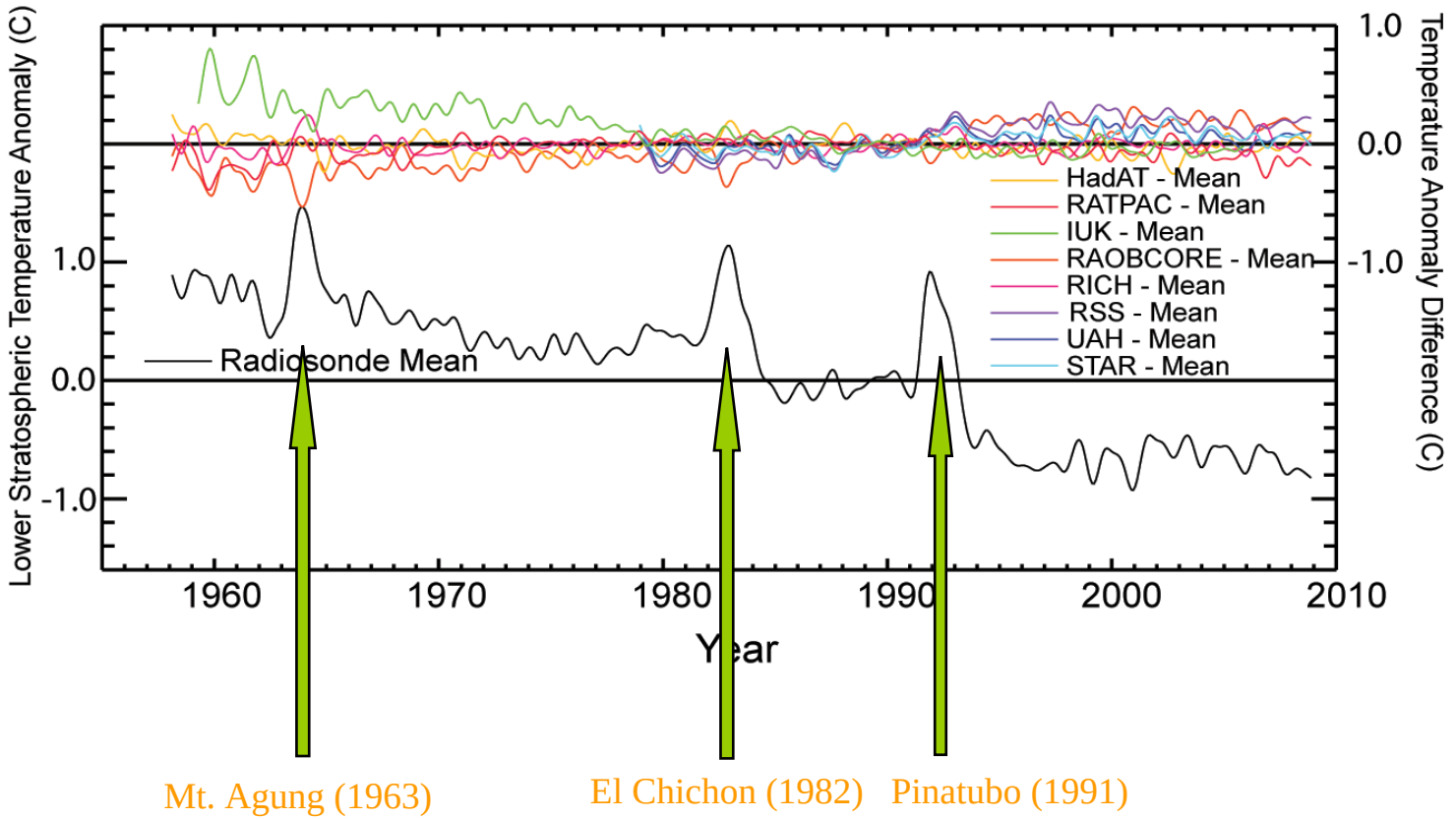



Brightness temperature differences (K) between NOAA-6 and NOAA-7 at the Antarctic SNO sites for their overlapping period from 1981 to 1983. The black dots represent the measured (pre-launch calibrated) radiances, the pink dots are simulated radiances using CRTM plus ERA-40 reanalyses with the $CO_2$ leaking effect included. The green dots are simulated radiances using CRTM plus MERRA reanalyses. The differences between simulations and the 'observation' may suggest a calibration error other than the $CO_2$ leaking effect, reanalysis errors, or CRTM error.

# Inter-Comparison

- Same CDR but developed by different groups
- Same CDR but from other satellite observations
- Reanalysis
- Radiosonde
- Climate model simulations
- Observations of other variables

# MSU/RAOB Inter-Comparison




RAOB equivalent MSU $T_4$ versus satellite MSU $T_4$ (lower-stratospheric temperature) time series

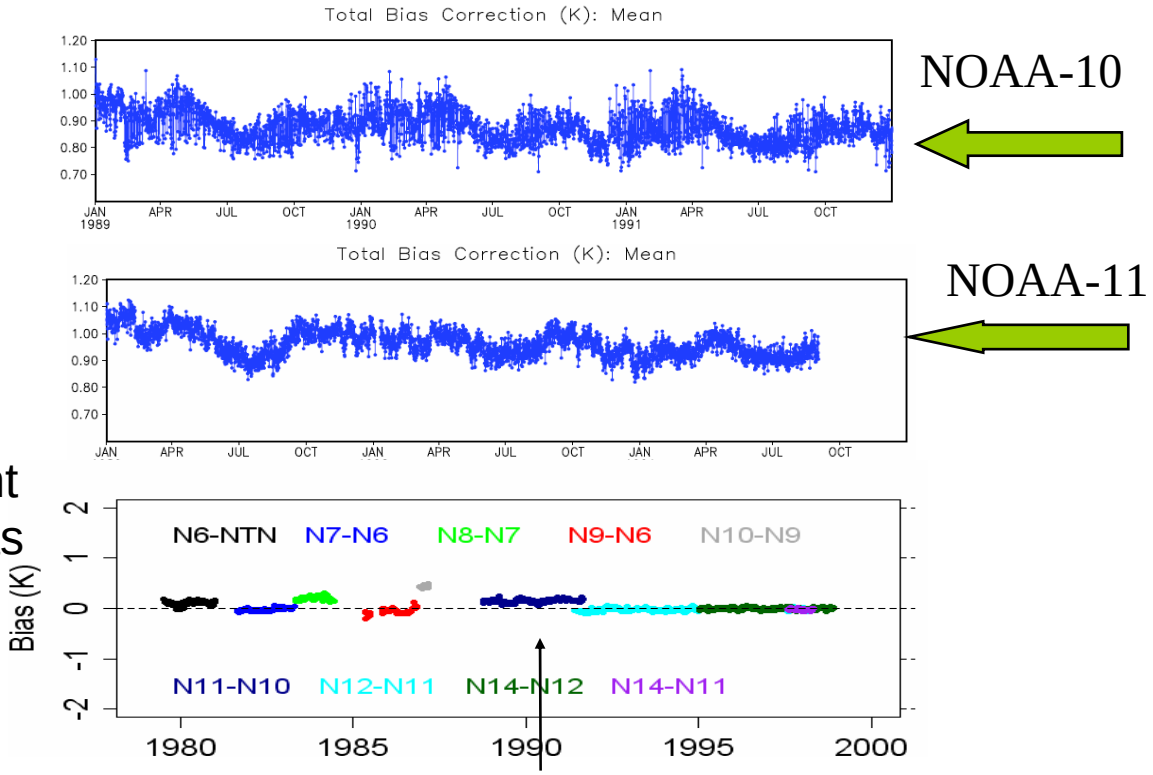
(plot from Peterson and Baringer, BAMS, 2009)

# MSU/Reanalysis Comparison

- Recalibrated MSU radiances being assimilated in the NASA MERRA and NCEP CFSRR reanalyses

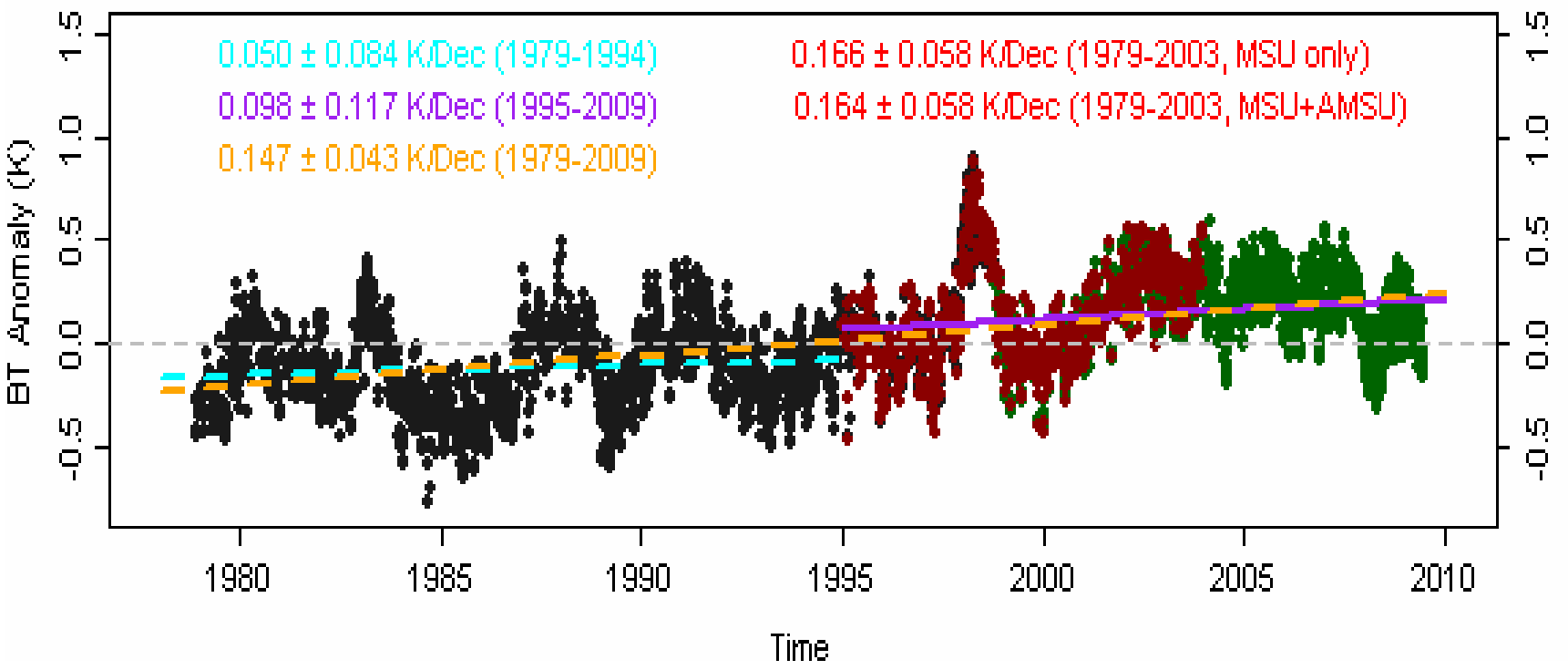
- Comparison of reanalysis bias correction and inter-satellite bias correction help to understand both instrument calibration and reanalysis bias correction procedures

NASA MERRA Reanalysis bias correction



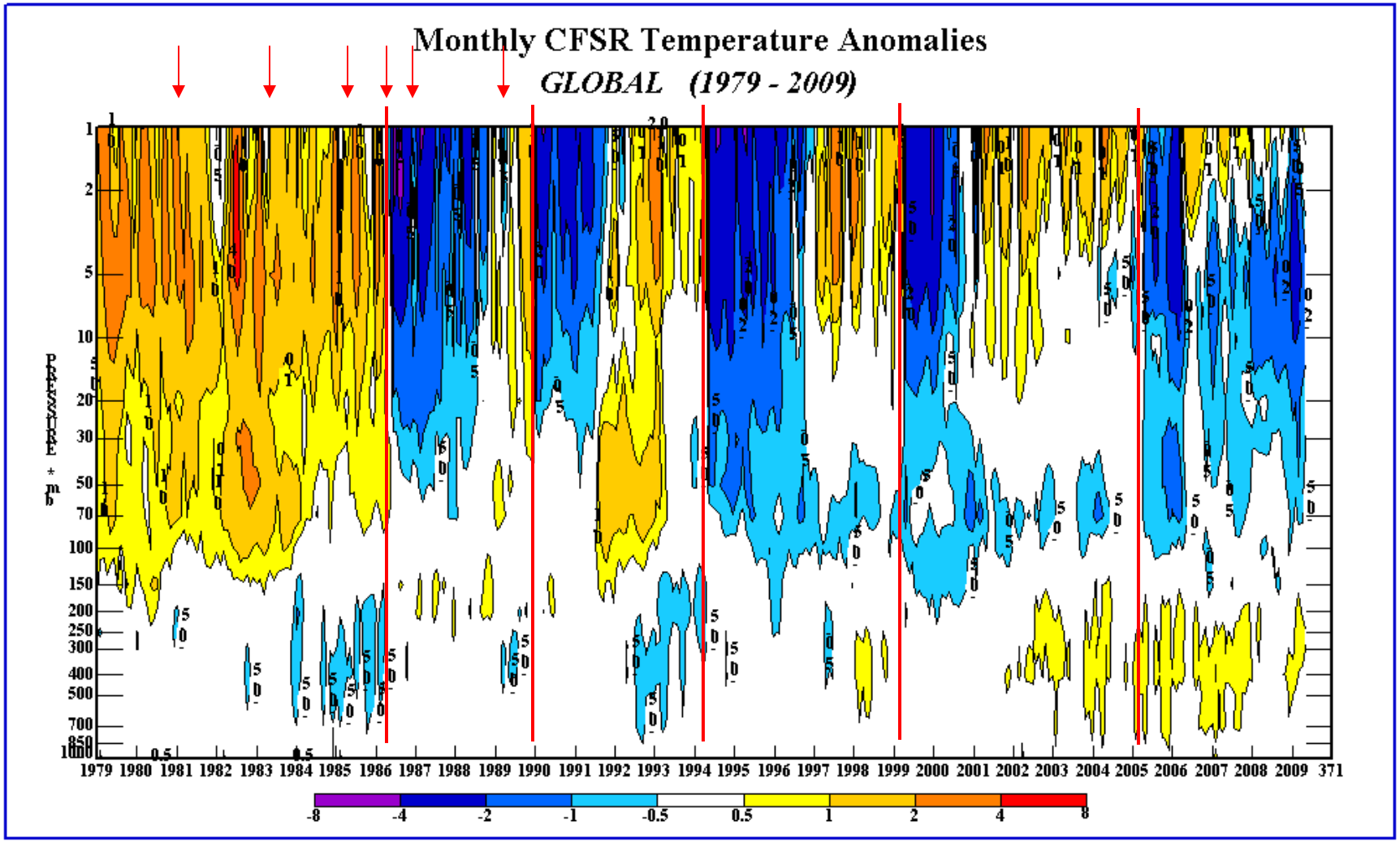

STAR inter-calibrated satellite difference

# Merged MSU/AMSU time series




- Five-day and global-mean MSU channel 2 and AMSU channel 5 temperature anomaly time series (Zou and Wang, 2009)
- MSU include TIROS-N through NOAA-14;
- AMSU include NOAA-15 through NOAA-18 and MetOp-A

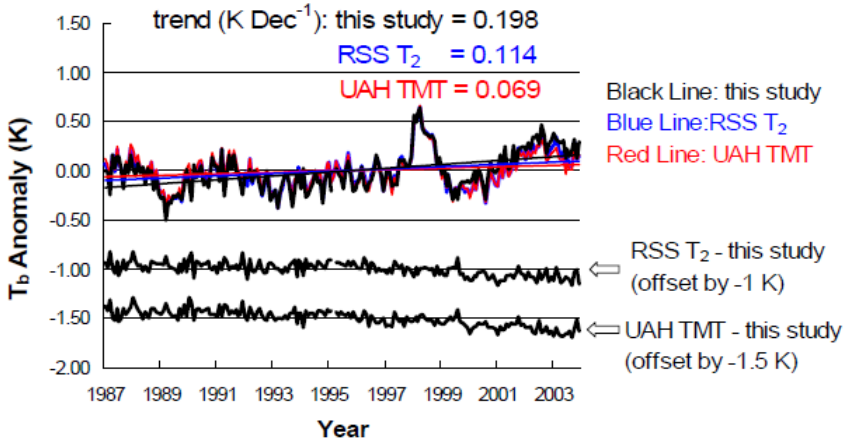
# Global mean temperature anomalies from NCEP CFSRR reanalysis



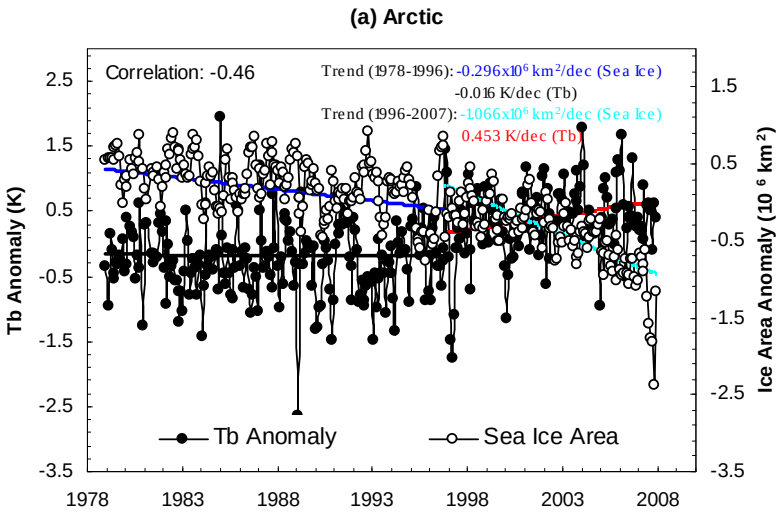

Plot from C. Long et al. 2009, NCEP Climate Meeting

# CDRs Between Different Groups

Comparisons with MSU/AMSU CDRs derived by UAH and RSS groups (Zou et al. 2006)




Comparisons with sea ice melting trend (Wang and Zou, 2009)




Sea ice observations are from Comiso et al, 2008, which are derived from SMMR/SSMI/AMSR-E observations

# Conclusion and ongoing work

- Well-intercalibrated 28-year (1978-2006) MSU radiance CDR is generated for reanalysis data assimilation which accounts for warm target errors
- Well-merged 28-year MSU deep-layer atmospheric temperature TCDR is generated for climate change research
- AMSU channels 5, 7, 9 for NOAA-15 to NOAA-18 and MetOp-A have been inter-calibrated
- Merged MSU/AMSU (1978-present) deep-layer atmospheric temperature CDR will be online in a few months
- SSU recalibration and CDR development is ongoing
- Collaborating with science team members to compare MSU/AMSU/SSU CDRs with other data sources from RAOB, Reanalysis, climate model simulations, GPSRO, etc.

# References


- Zou, C.-Z., M. Goldberg, Z. Cheng, N. Grody, J. Sullivan, C. Cao, and D. Tarpley (2006), Recalibration of microwave sounding unit for climate studies using simultaneous nadir overpasses, J. Geophys. Res., 111, D19114, doi:10.1029/2005JD006798
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Thank You!