NOAA Satellites and Information

National Environmental Satellite, Data, and Information Service

Tropospheric Temperature Trend Derived from MSU when Calibrated using Simultaneous Nadir Overpasses

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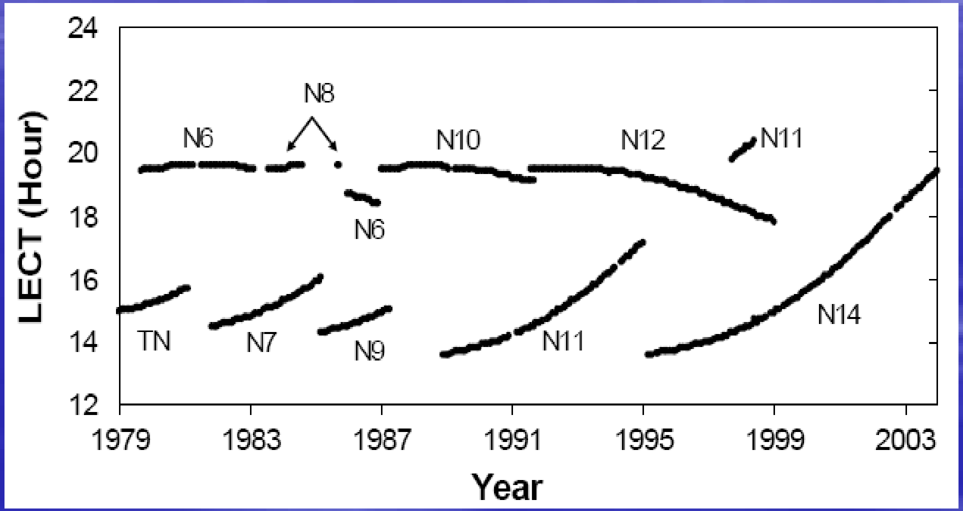
- Simultaneous nadir overpass matchups
- Inter-calibration using SNOs
- Trend results
- On-going work and future plans

I. Background

NOAA MSU Satellites

- Each satellite has
  a life cycle of a few years
- Each satellite overlaps
  With other satellites
- LECT gradually changes
  With time–
  orbital drift phenomenon
- Merging these satellites
  is a non-trivial task



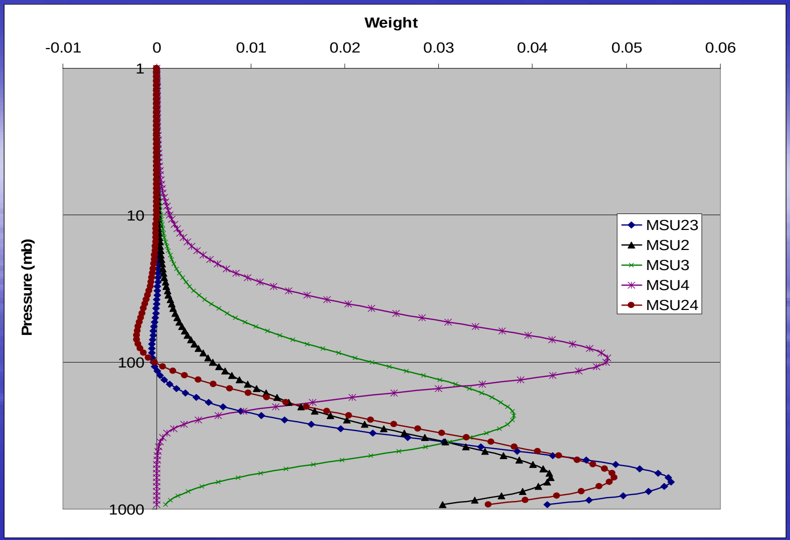
Satellite Local Equator Crossing Time (LECT) vs time

- Global change includes surface and atmospheric components

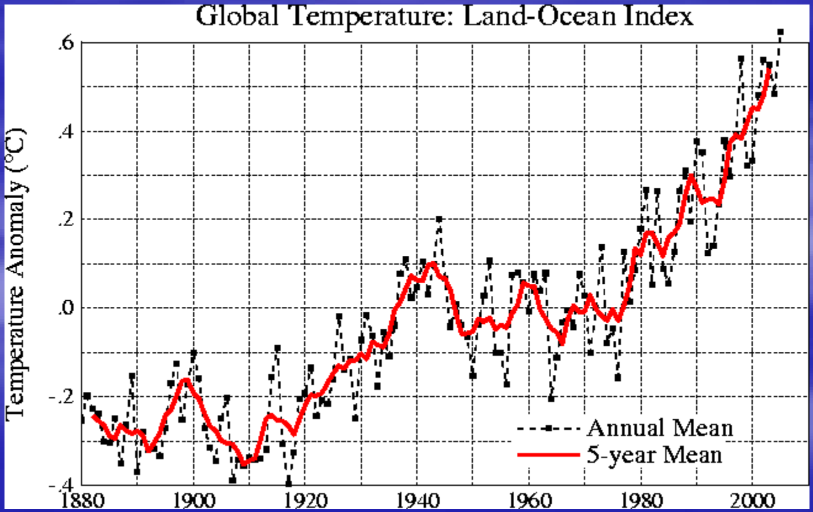
- Surface trend is more reliable due to higher density of observational network

- Radiosondes are sparse for atmosphere observations and subject to regional and temporal errors due to differences in observational practices

- MSU observations to the rescue



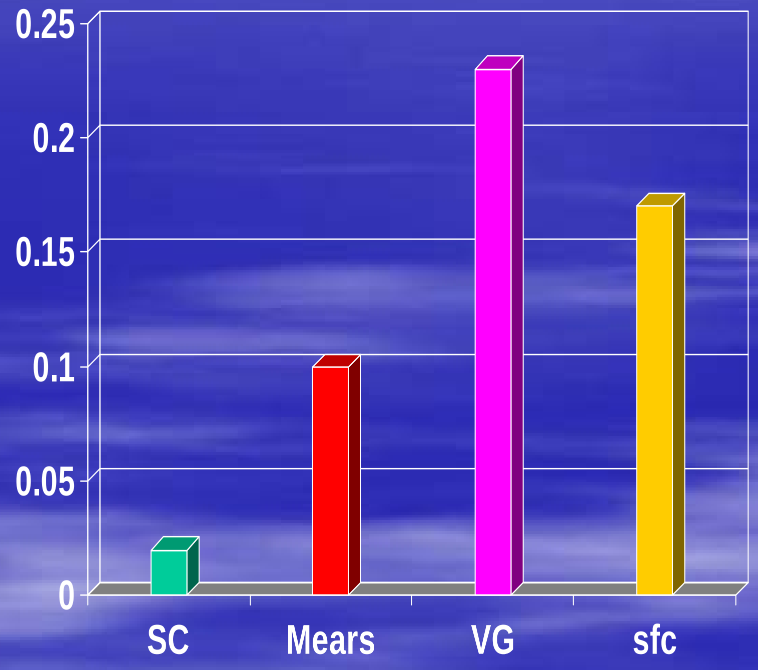
MSU weighting functions for Channel 2, 3, 4, combined 2&4, 2&3 (Courtesy of Mitch Goldberg)



Surface station temperature time series (Hansen et al. 2001)

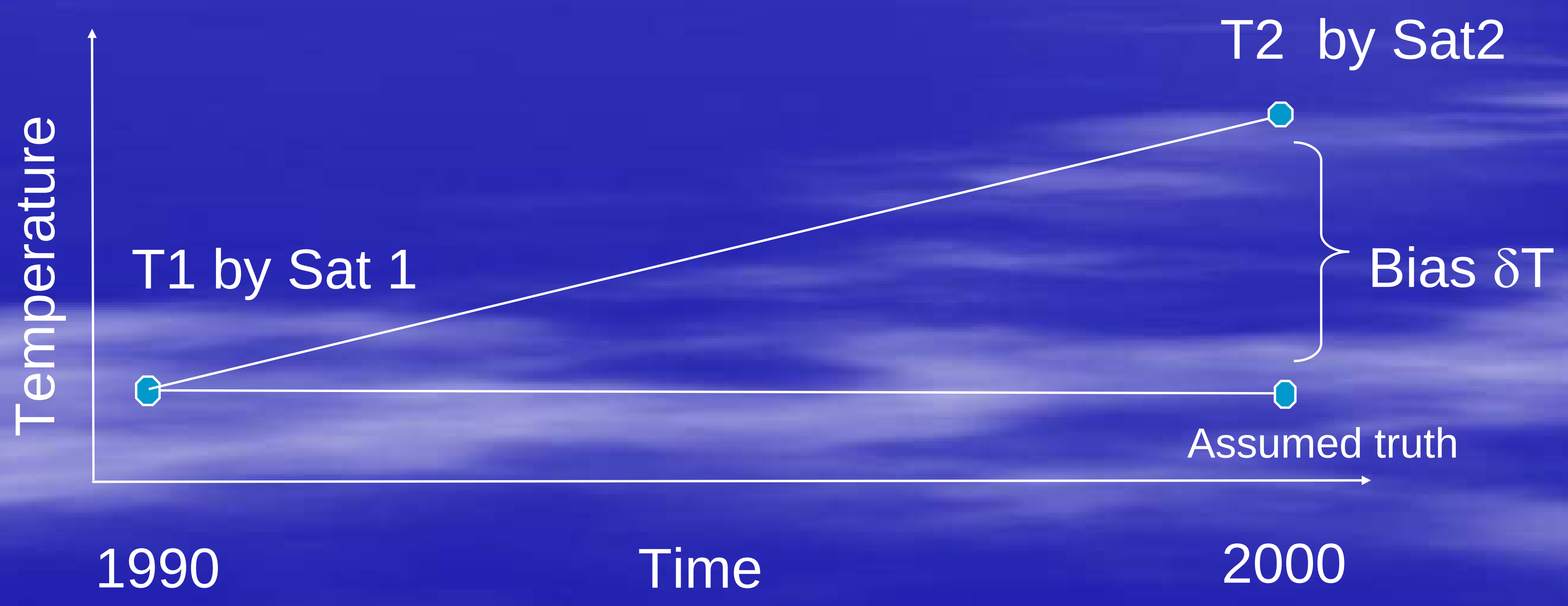
Past MSU CH 2 Trend Studies

- Spencer and Christy (1992): 0.02 K Dec^{-1}, 1979-1988
- Christy et al. (2003): 0.02 K Dec^{-1}, 1979-2002
- Prabhakara et al. (2000): 0.13 K Dec^{-1}, 1980-1999
- Mears et al. (2003, 2005): 0.10 K Dec^{-1}, 1979-2001
- Vinnikov and Grody (2003): 0.22-0.26 K Dec^{-1}, 1979-2002
- Grody et al. (2004) 0.17 K Dec^{-1}, 1979-2002
- Vinnikov et al. (2006): 0.20 K Dec^{-1}, 1978-2004

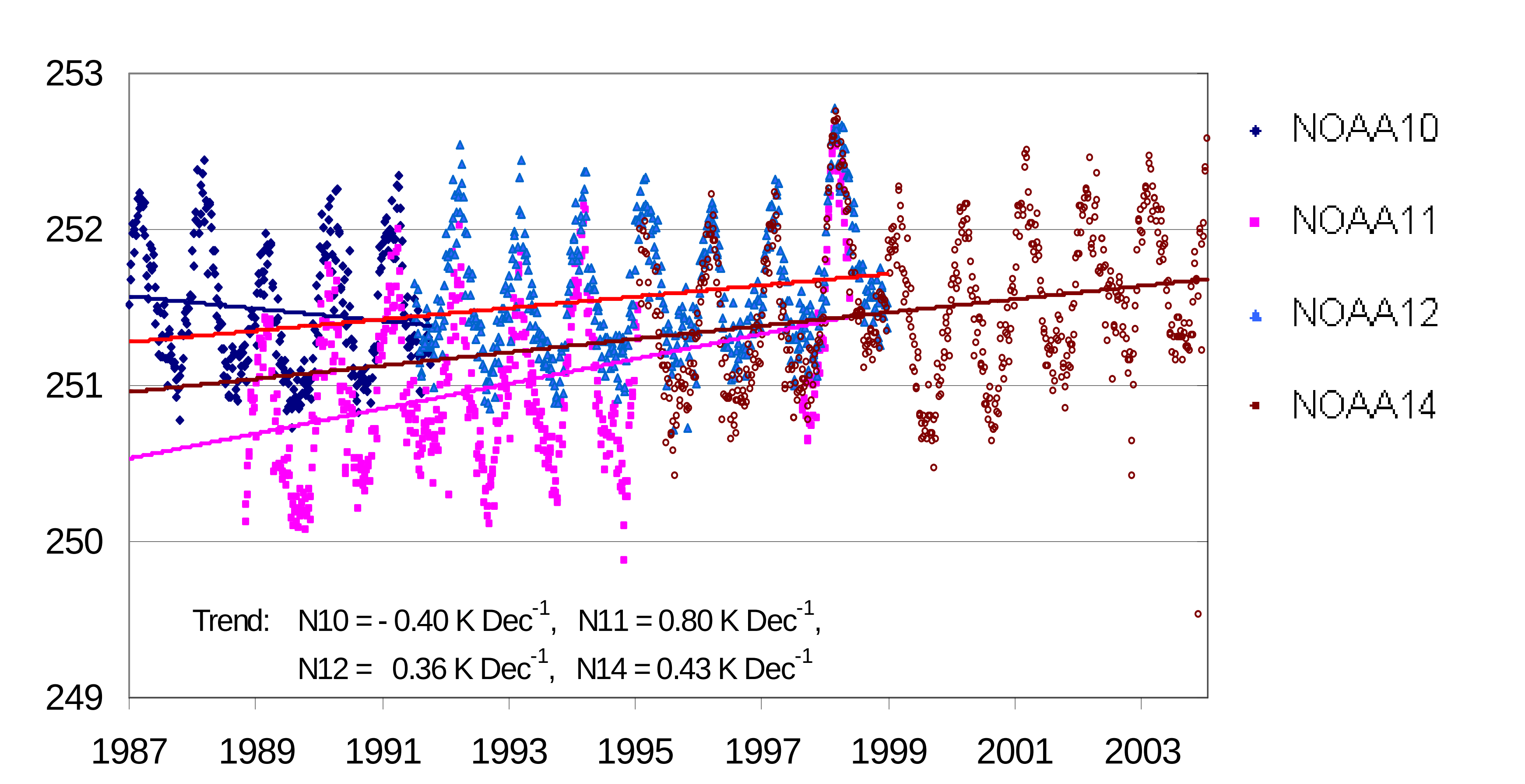


Fake Trend Problem--Bias

- **A bias of 0.1 K is sufficient to lead to different conclusion**



Fake Trend Problem--Bias



5-day and global-ocean-averaged time series for NOAA 10,11,12, and 14 obtained from NESDIS operational calibration algorithm

Fake Trend Problem —Warm Target contamination

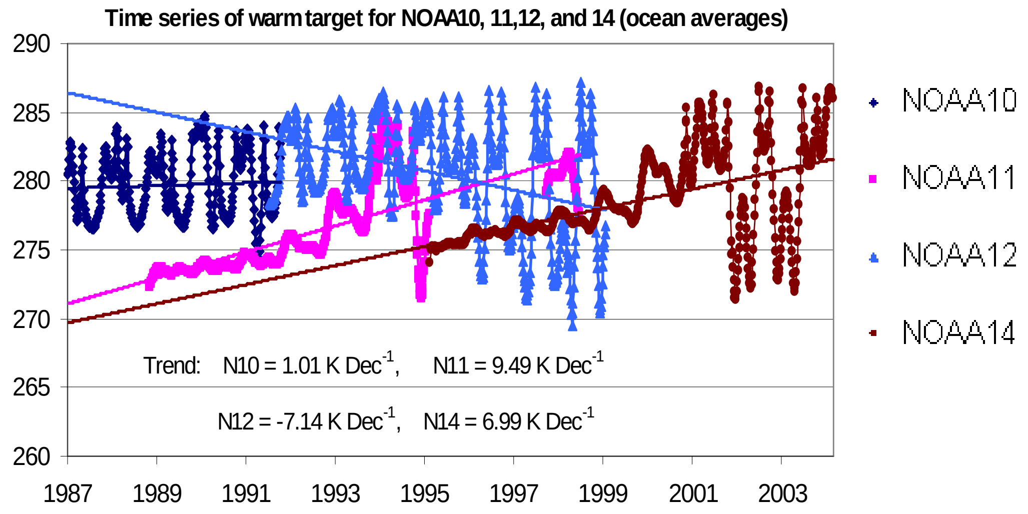
$T_b = T_b\ (T_w, T_r)$

T_w → Warm target temperature

T_r → Weighted temperature from surface and atmosphere

$$\frac{dT_b}{dt} = \frac{\partial T_b}{\partial T_w}\frac{\partial T_w}{\partial t} + \frac{\partial T_b}{\partial T_r}\frac{\partial T_r}{\partial t}$$

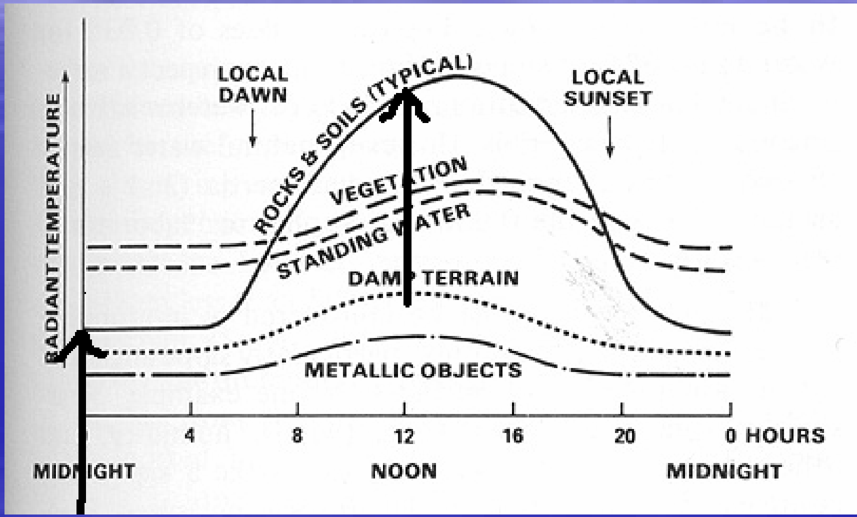
- Require $\dfrac{\partial T_b}{\partial T_w} = 0$

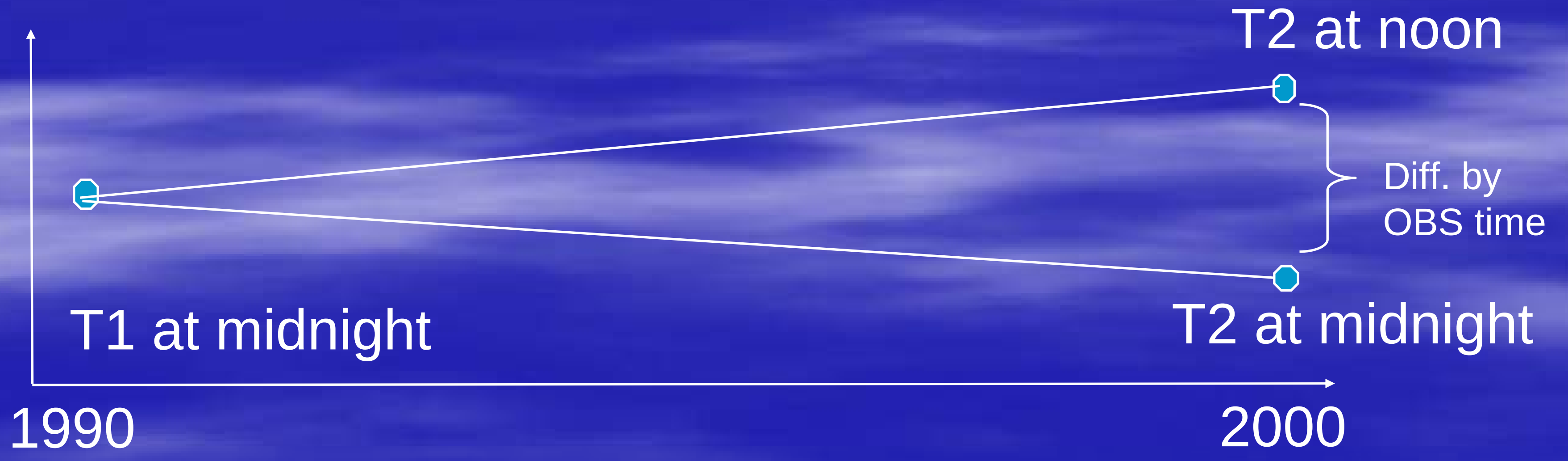


Fake Trend Problem —Diurnal Cycle Effect

- **Ascending plus descending reduce the effect**

- **Effect is small over oceans 0.01 K /decade (Mears et al.)**





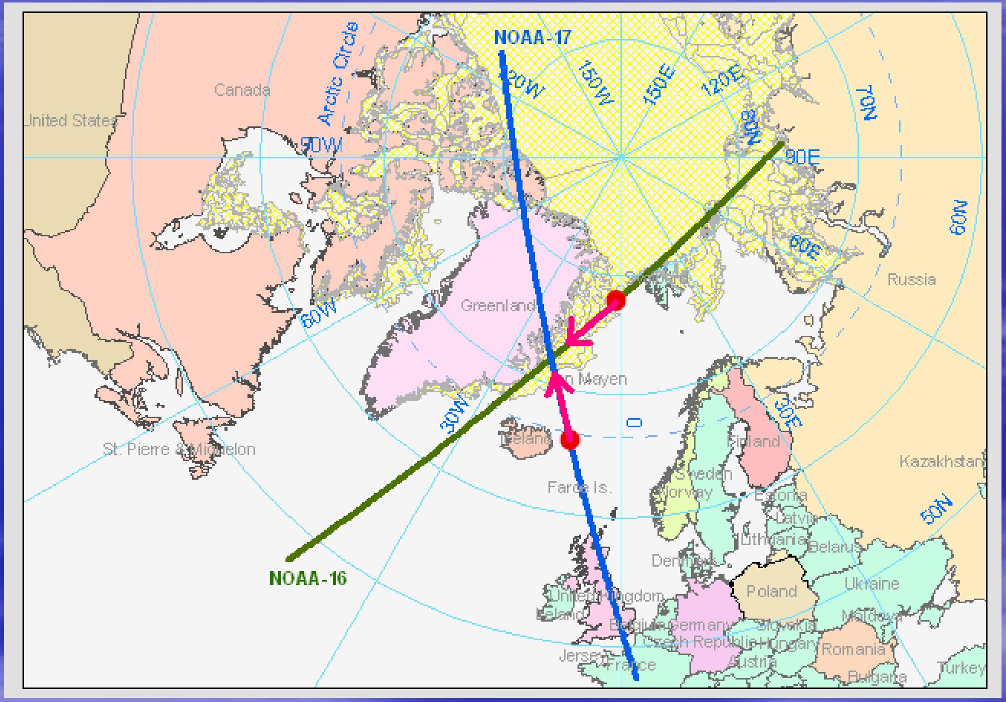
II. SNO Error Characteristics

SNO Definition

Method to find SNO matchups:

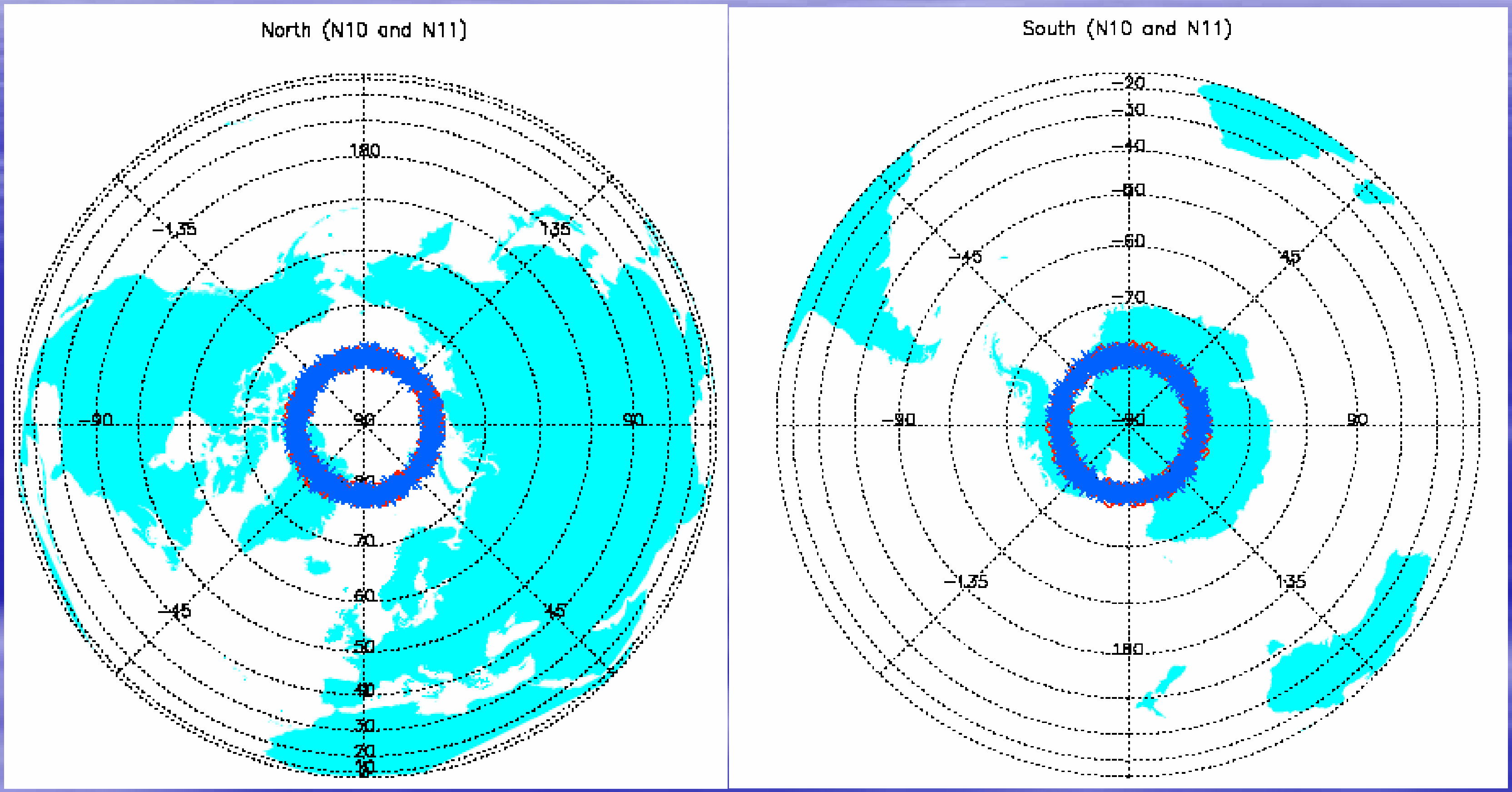
- **Use Cao's (2004) method to find the orbits that have intersections**

- **Use time and location information in the 1B file to determine simultaneity between two pixels**



Schematic viewing the overpasses between two NOAA satellites

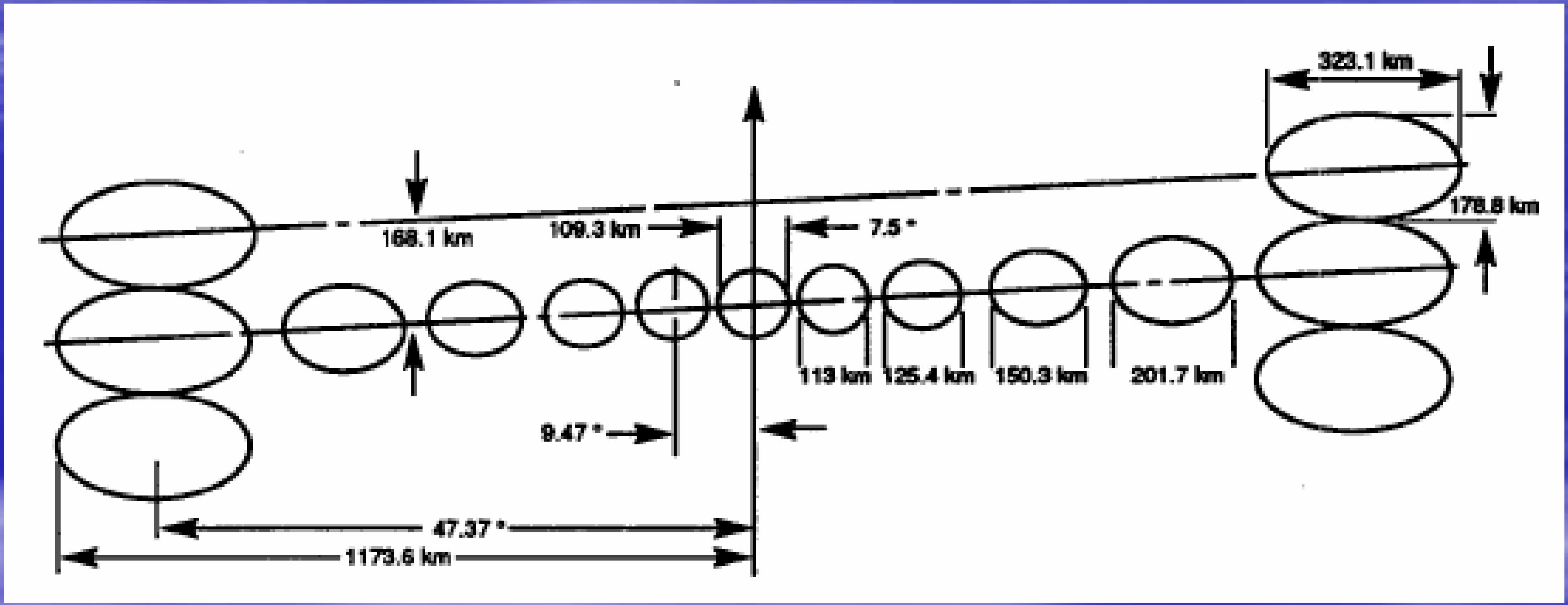
SNO Locations



SNO Temperature range for CH. 2: 200-250 K

Global temperature range for CH. 2: 200-260 K

MSU Scan Pattern



MSU Scan Pattern and footprint sizes

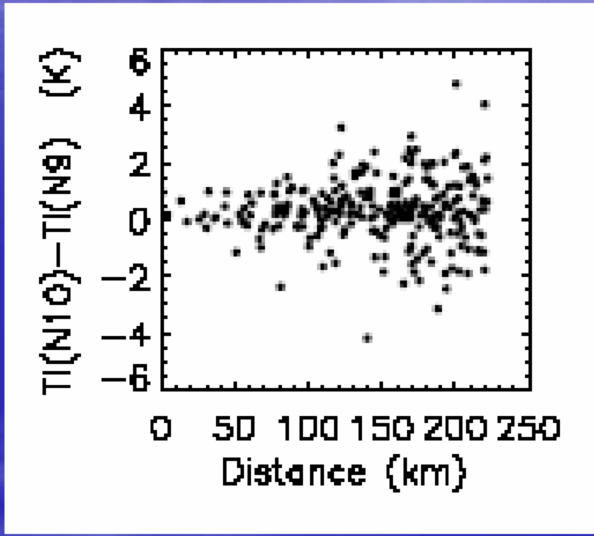
SNO Bias Characteristics

- T_b difference gets larger when the SNO pixel distance gets larger

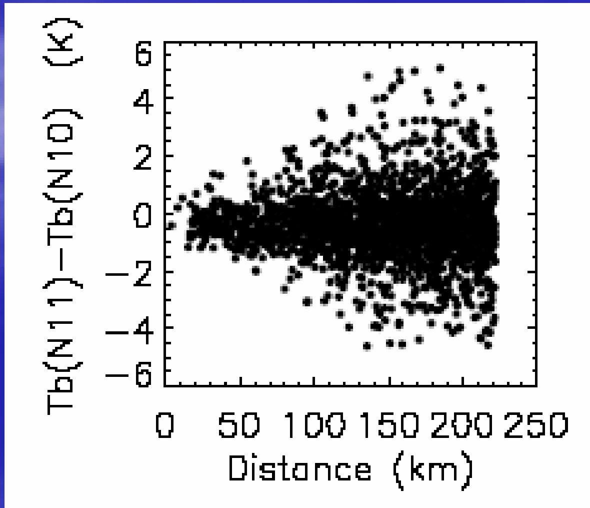
- SNO numbers increase with the distance

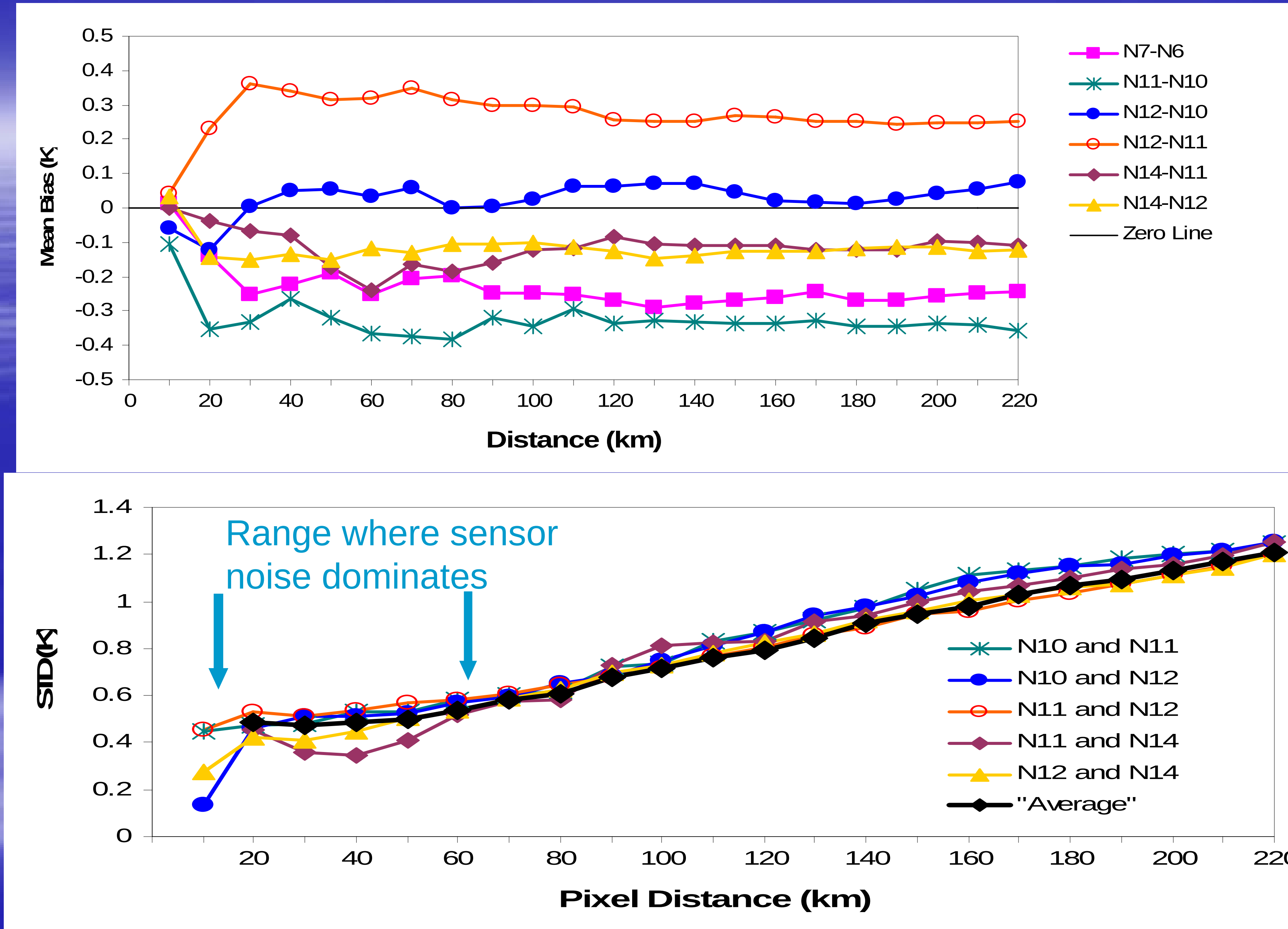
- Different satellite pairs have different SNO numbers because of different overlap period

NOAA 9 and NOAA 10

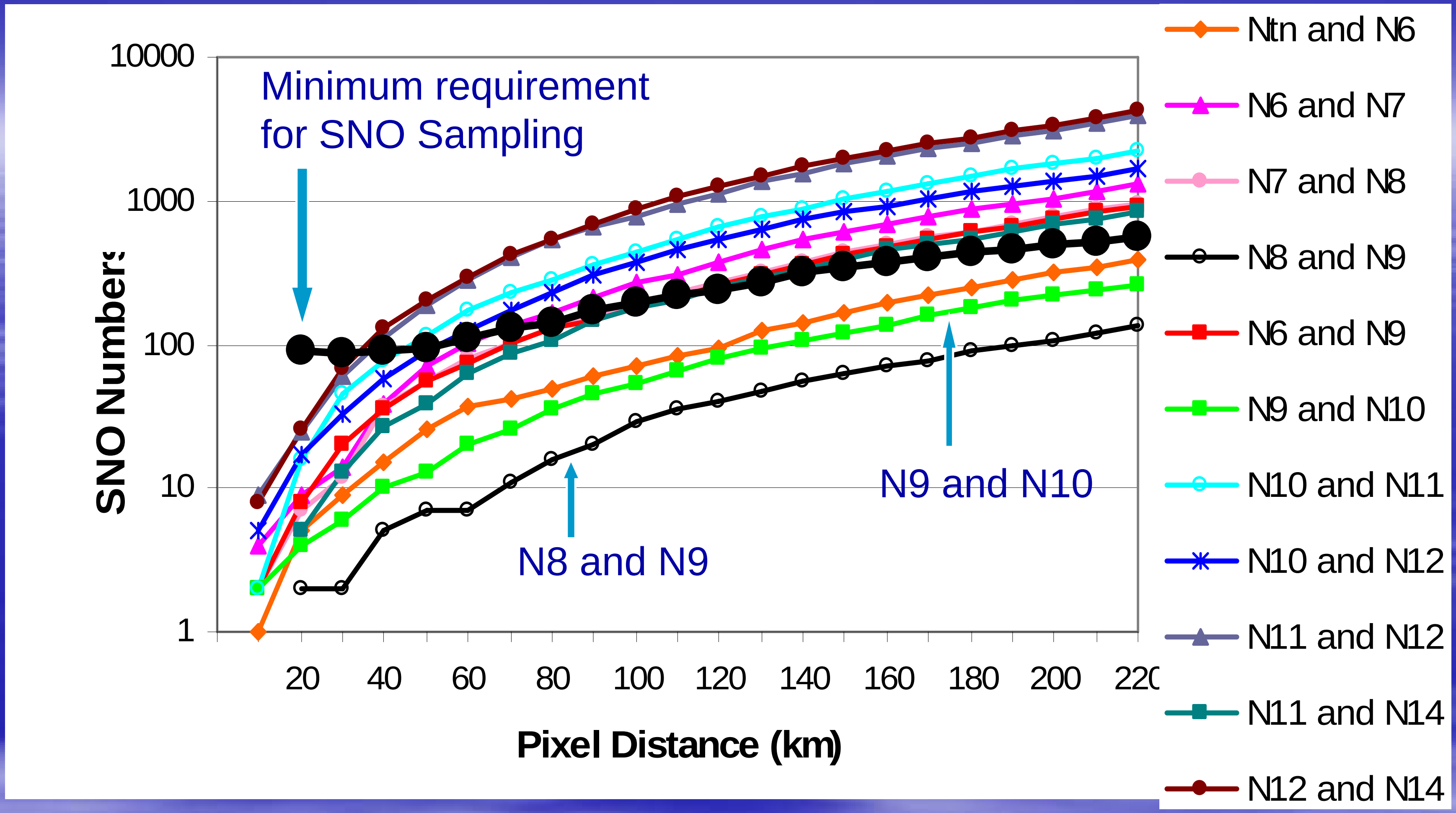


NOAA 10 and NOAA 11





STD and biases of channel 2 brightness temperature differences between satellite pairs versus center distance of the nadir overpass pixels. (a) Biases (b) STD . Linear calibration algorithm at level 0 is used.



SNO numbers vs center distance of nadir pixels for all satellite pairs

$$N_m = \left(\frac{z_{\eta/2}\,\sigma}{\Omega}\right)^2$$

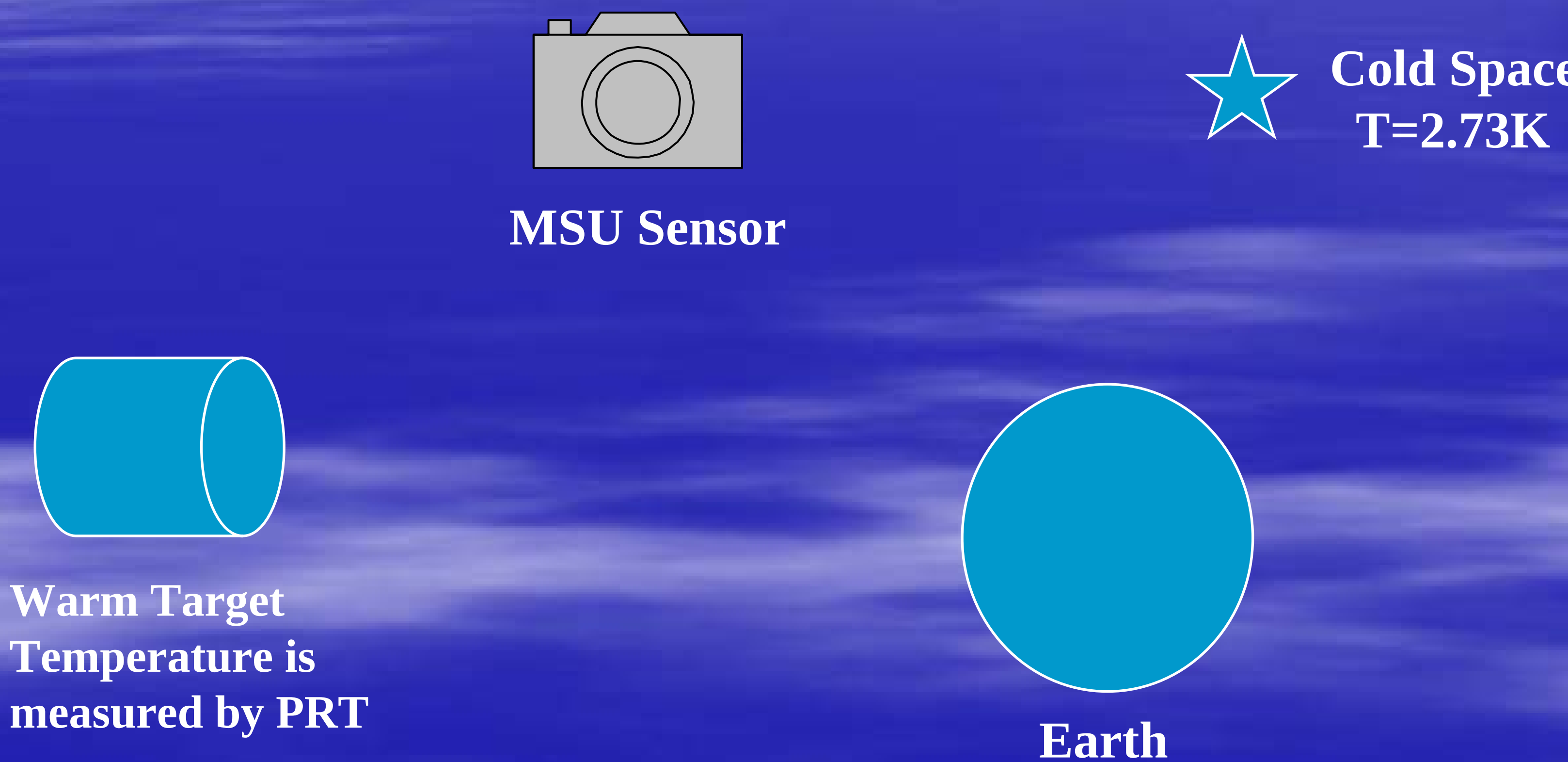
$z_{\eta/2}$=1.96 for 95% confidence level

σ= standard deviation

Ω=0.1 K, tolerance or error bar in the bias statistics

III. Calibration Method

MSU In-Orbit Calibration Process



Conceptual diagram of MSU observational procedure

Level 0 Calibration Equation

Linear Calibration

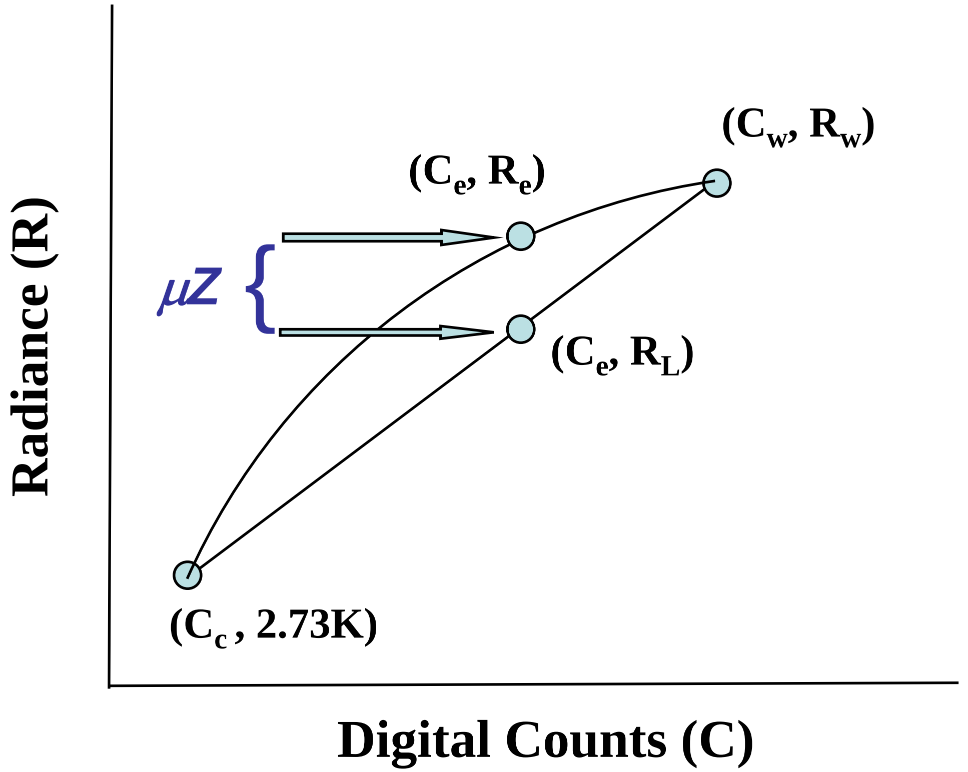
$$R_L = R_c + S(C_e - C_c)$$

S ⟶ Slope

Nonlinear Calibration (Mo 1995)

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

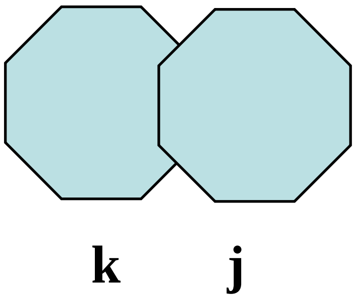
$$Z = S^2 (C_e - C_c)(C_e - C_w)$$



SNO Radiance Error Model

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

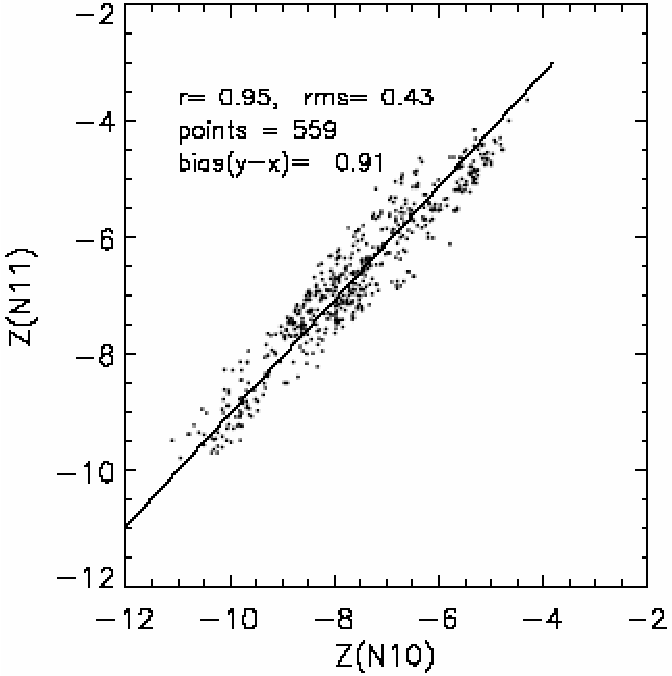
$$R_j = R_{L,j} - \delta R_j + \mu_j Z_j$$



Radiance Error Model for SNO Matchup K and J :

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

$$Z_j = \beta Z_k + \alpha$$



SNO Radiance Error Model

Final Regression Equation:

$$\Delta R_L = a_0 - a_1 Z_k$$

$$a_1 \approx \mu_j - \mu_k$$

$$a_0 \approx \delta R_k - \delta R_j$$

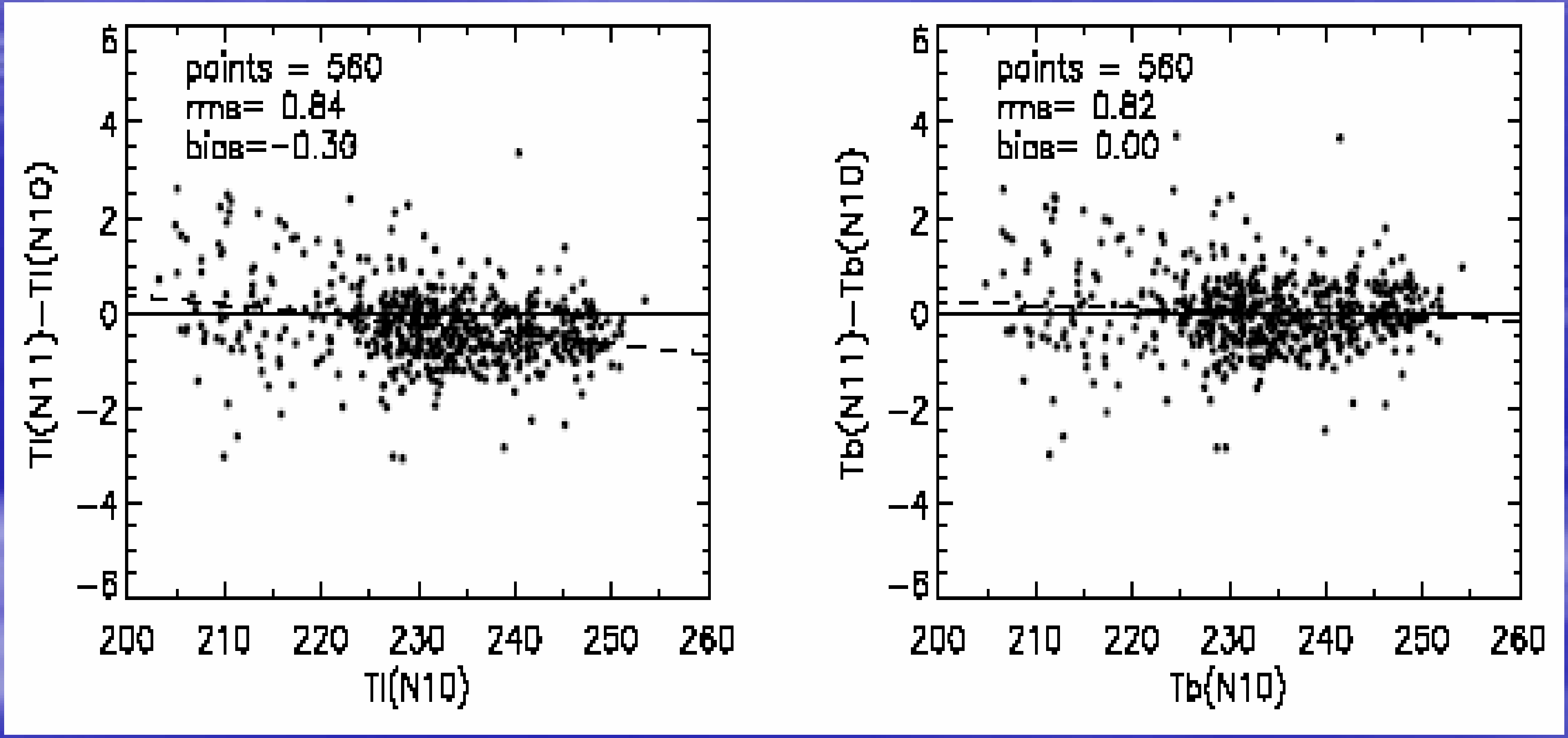
- Since absolute values of μ cannot be obtained reliably from SNO, one of the two satellites must be chosen as a reference satellite. Here NOAA 10 is chosen as a reference satellite and its pre-launch calibration values is temporally used for calibration.

- Final μ will be determined by requiring the contamination by the warm target temperature to be zero.

SNO Nonlinear Calibration—Bias Removal

Linear Calibration

Nonlinear calibration using SNO



Scatter plots showing effects of the nonlinear calibration on the error statistics and distribution of the brightness temperature differences between NOAA 10 and NOAA 11.

SNO Sequential Calibration Procedure

- Assuming NOAA 10 as the reference satellite and using its pre-launch coefficient for reference
- Obtain calibrated radiance (1b) for NOAA 10
- Compute NOAA 11 coefficients from regressions of N11-N10 SNO
- Obtain calibrated radiance (1b) for NOAA11
- Repeat above procedure for NOAA 12 with calibrated NOAA 11 as references

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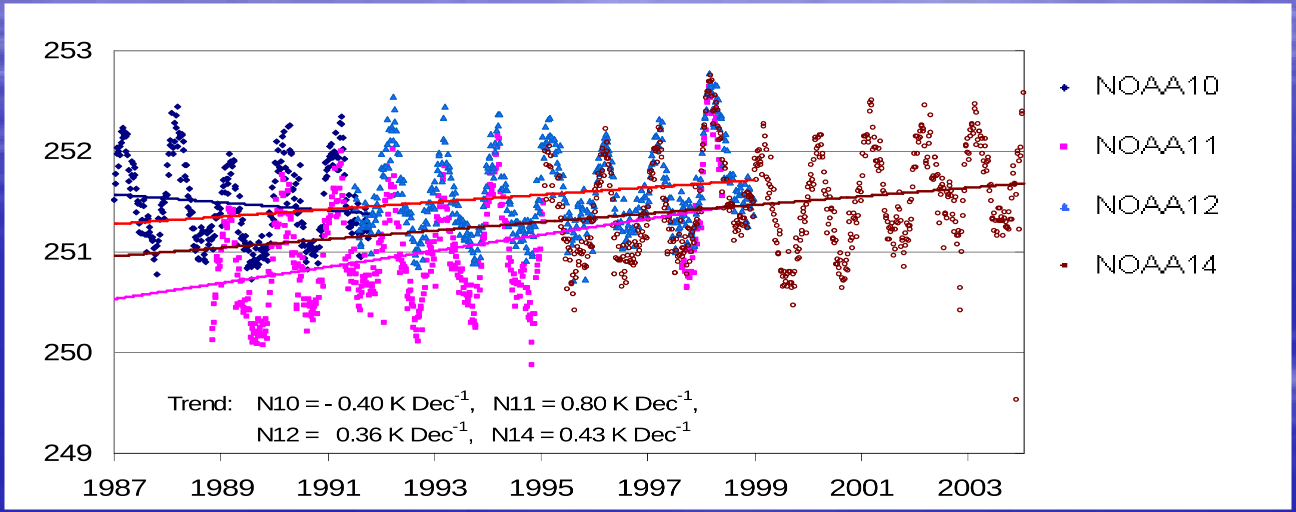
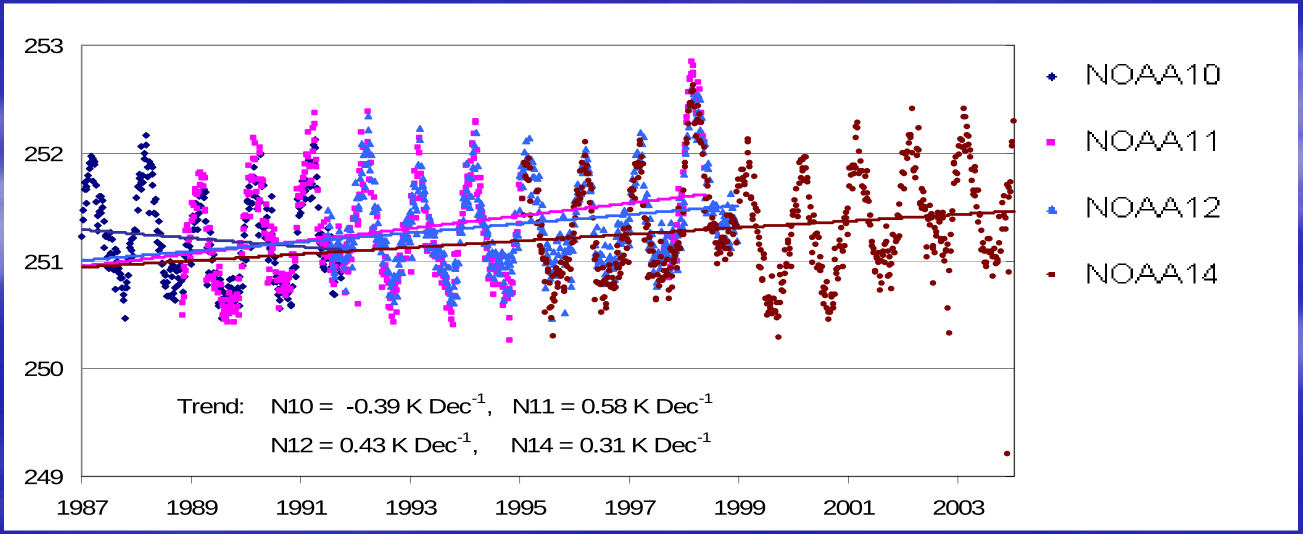
Effect on time series

Time series with NESDIS operational calibration



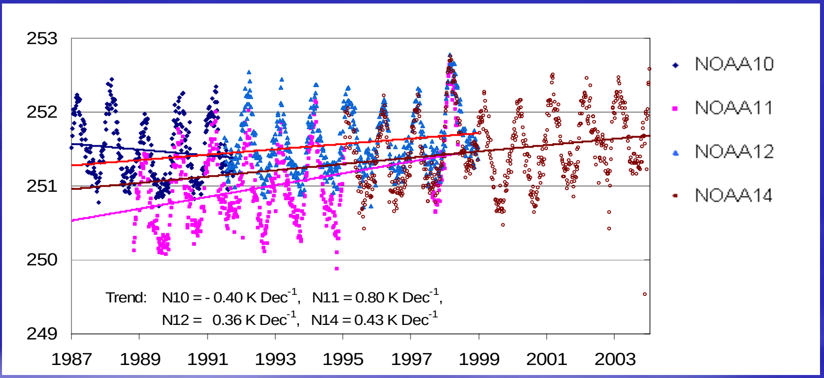
Time series with SNO nonlinear calibration



IV. Trend Results

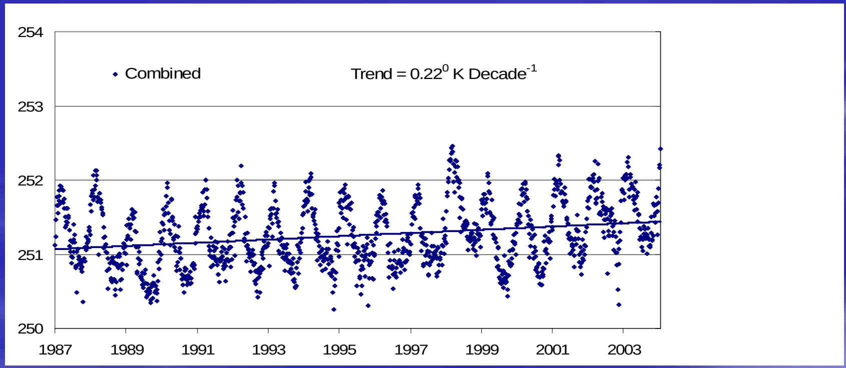
Trend With Simple Bias Removal

- Small inter-satellite biases still exist
  Solution: simply subtract biases to obtain merged time series.

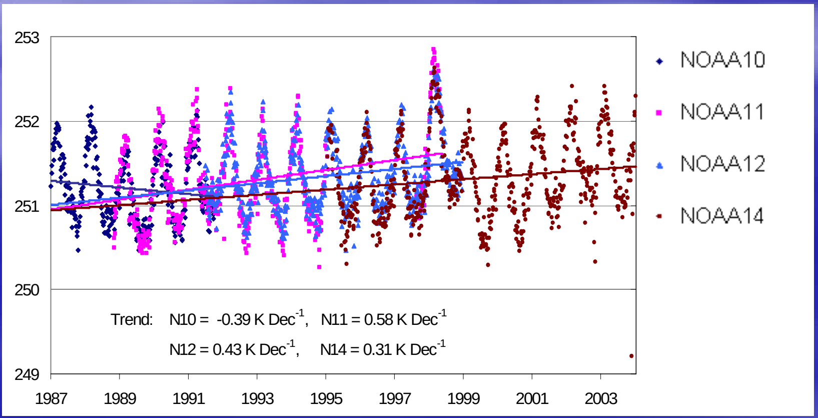


NESDIS Operational Calibration

0.22 K Dec^{-1}

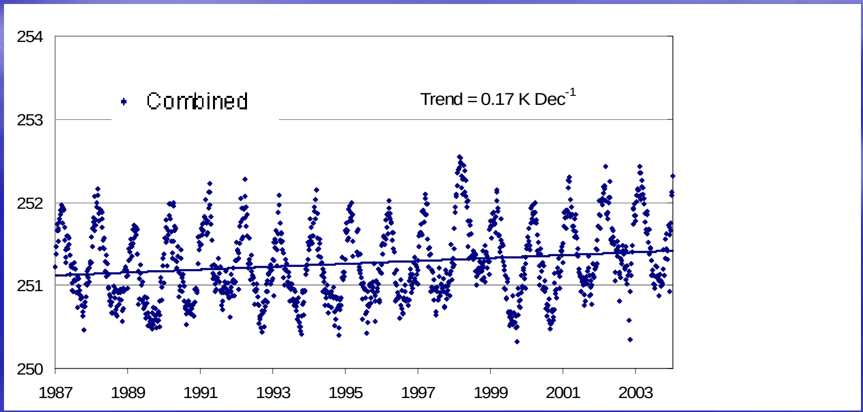


(Vinnikov and Grody, 2003)



SNO calibration

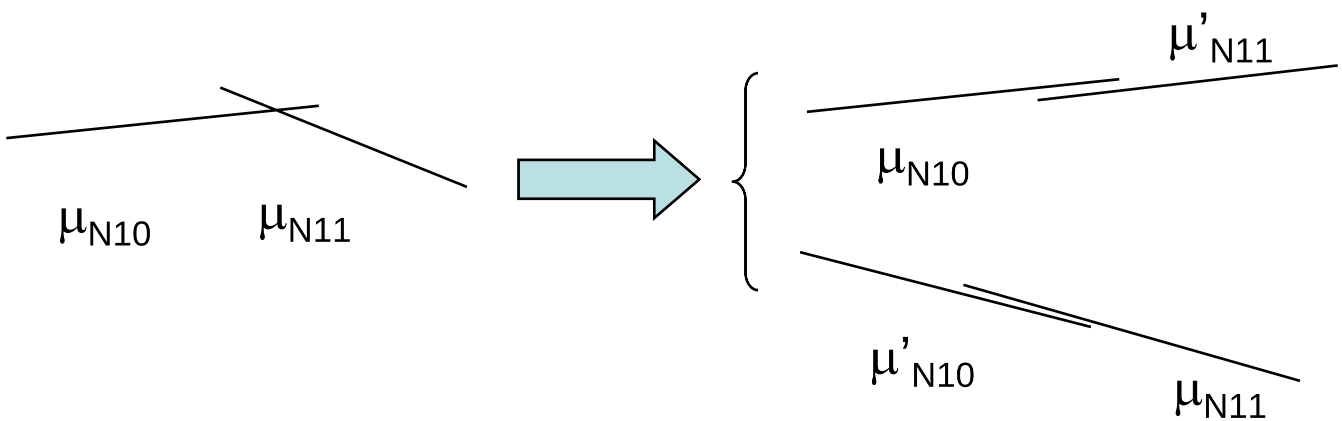
0.17 K Dec^{-1}



Reference satellite problem

Trend is determined by μ: $R = R_L - \delta R + \mu Z$

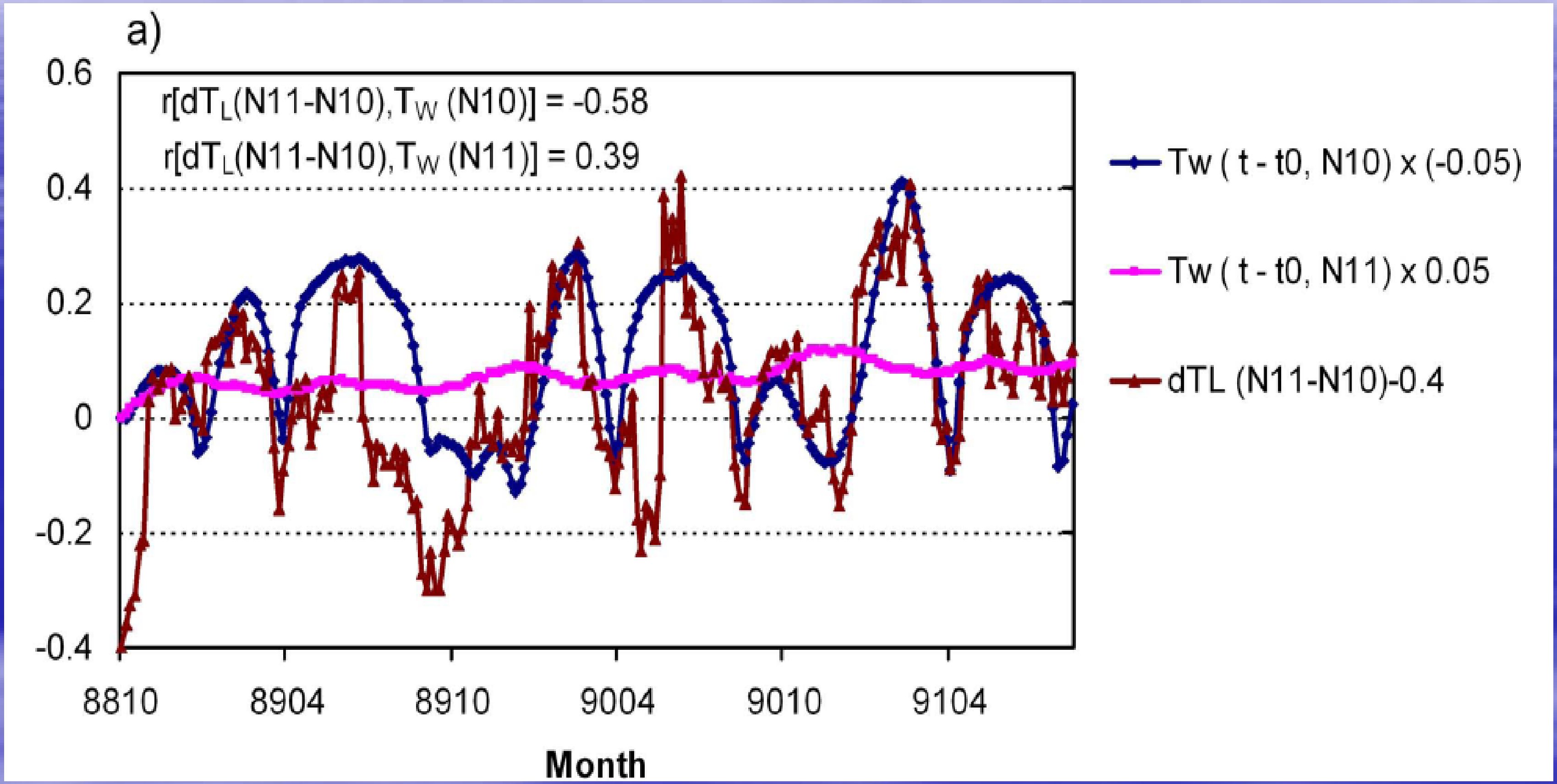
$$\Rightarrow \quad \frac{\partial T}{\partial t} = \frac{\partial T_L}{\partial t} + \mu \frac{\partial Z}{\partial t}$$



Solution: $a_1 \approx \mu_j - \mu_k$

- Selection of different reference satellite is equivalent to conducting sensitivity experiments for the μ parameter of a single reference satellite

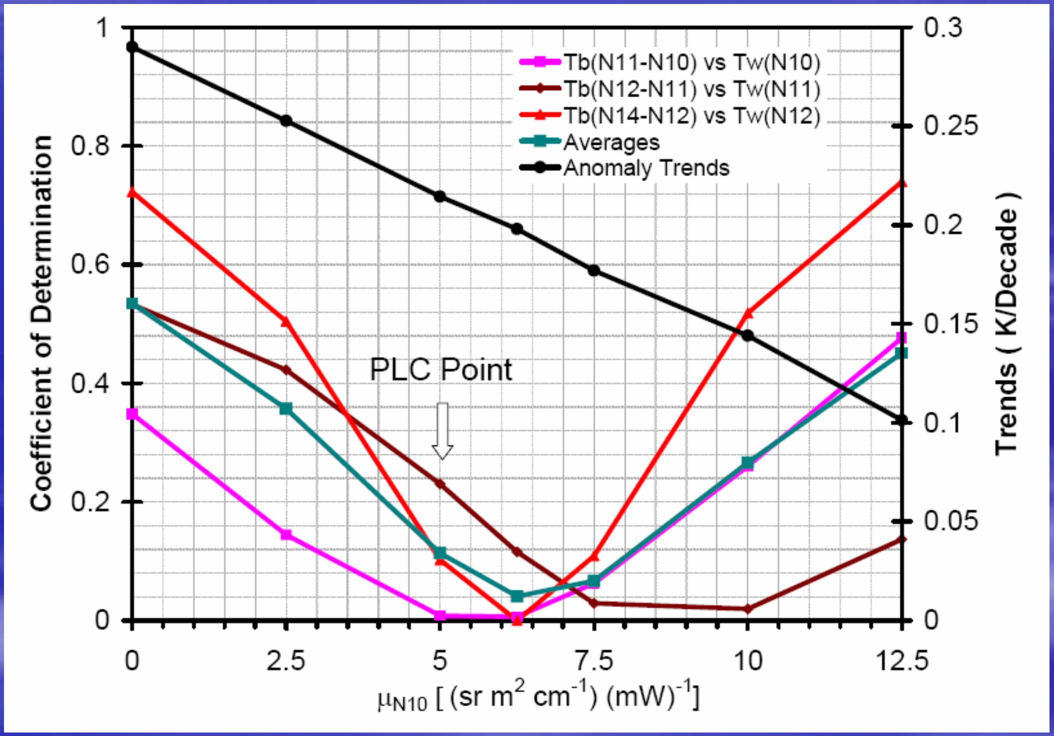
Warm Target Contamination



Brown Line: T_b differences between NOAA 10 and 11
Blue Line: T_w of NOAA 10
Pink Line: T_w of NOAA 11

Fixing Reference Satellite Problem by Removing T_w Contamination

- μ_{N10} small or large, large warm target temperature contamination
- When μ_{N10} is 25% larger than its pre-launch value, averaged warm target temperature contamination reaches a minimum (4%)
- Corresponding trend is 0.198 ± 0.02 K Dec^{-1}
- Degree of freedom about 30, correlation is significant at 95% when r^2>13%



Explaining T_w Contamination Removal

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

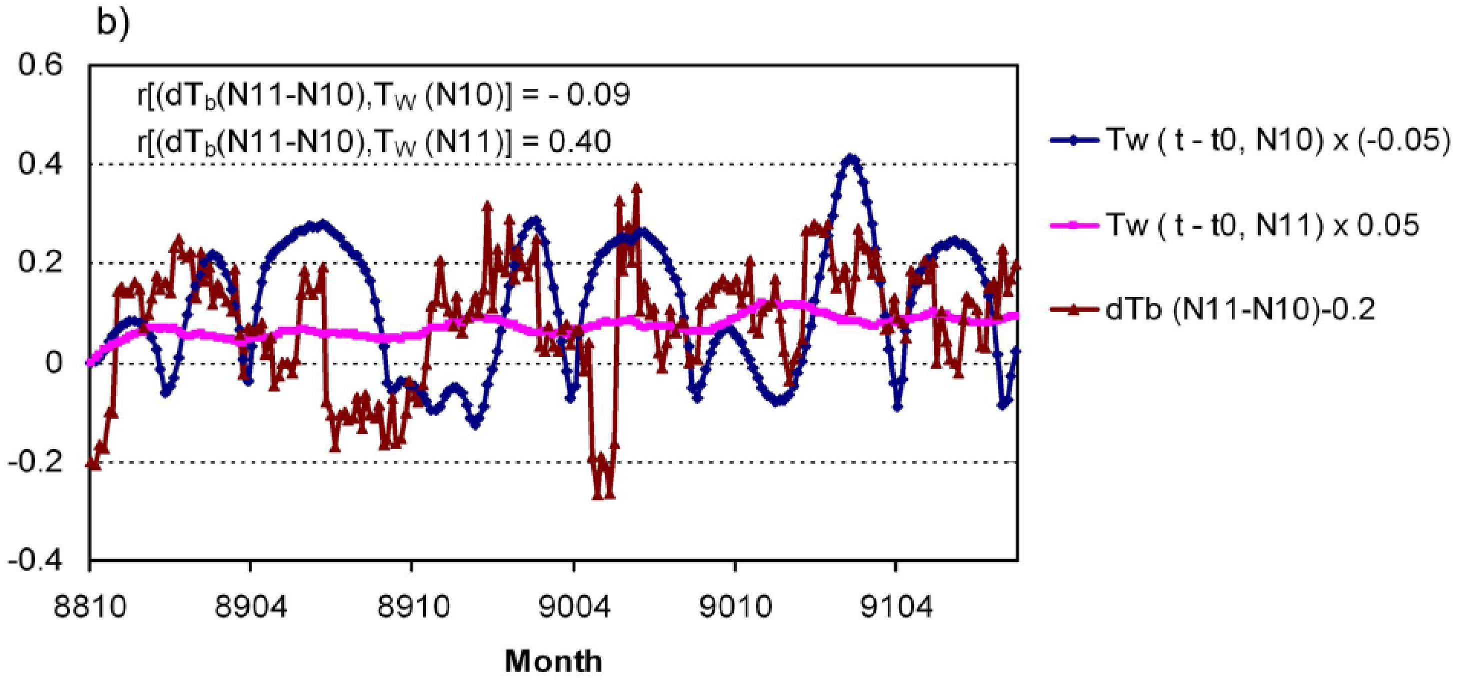
$$\overline{R' T_w'} = \overline{R_L' T_w'} + \mu \overline{Z' T_w'}$$

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

Then $$\overline{R' T_w'} = 0$$

Overlapping Satellites *j* *k*	T_B(j-k) vs *Tw* (j) Linear	T_B(j-k) vs *Tw* (j) U_{N10}=0	T_B(j-k) vs *Tw* (j) U_{N10}=5	T_B(j-k) vs *Tw* (j) U_{N10}=6.25	T_B(j-k) vs *Tw* (j) U_{N10}=10	T_B(j-k) vs *Tw* (j) U_{N10}=12.5
N10 N11	-0.59	-0.59	-0.09	0.08	0.51	0.69
N11 N12	-0.82	-0.73	-0.48	-0.34	0.14	0.37
N12 N14	-0.88	-0.86	-0.33	0.00	0.72	0.87

T_b Difference When T_w Contamination Removed



Summary on SNO Calibration

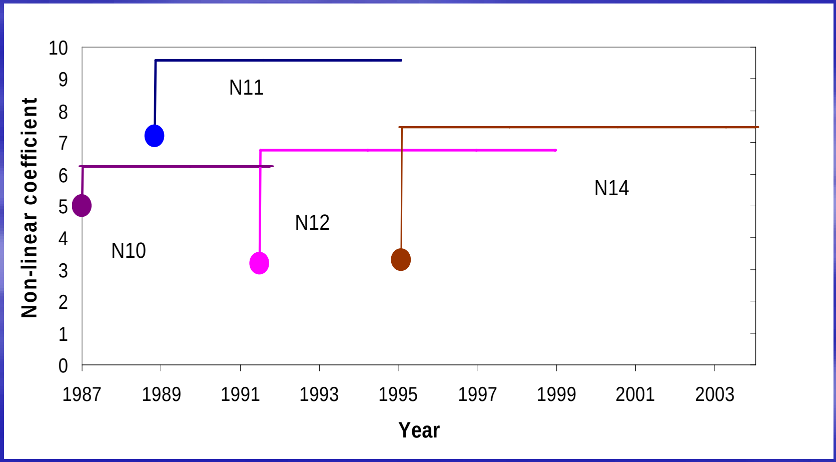
- **SNO to accurately determine the calibration coefficient differences between satellites**

→ results in ZERO inter-satellite biases for SNO
→removes temperature-dependent non-uniformity in biases
→ Greatly reduce inter-satellite biases for gridded dataset
(0.05 to 0.1 K for SNO calibration,
0.5 to 0.7 K for NESDIS operational algorithm)

- **Remove warm target contamination to determine absolute values of calibration coefficients and trend**

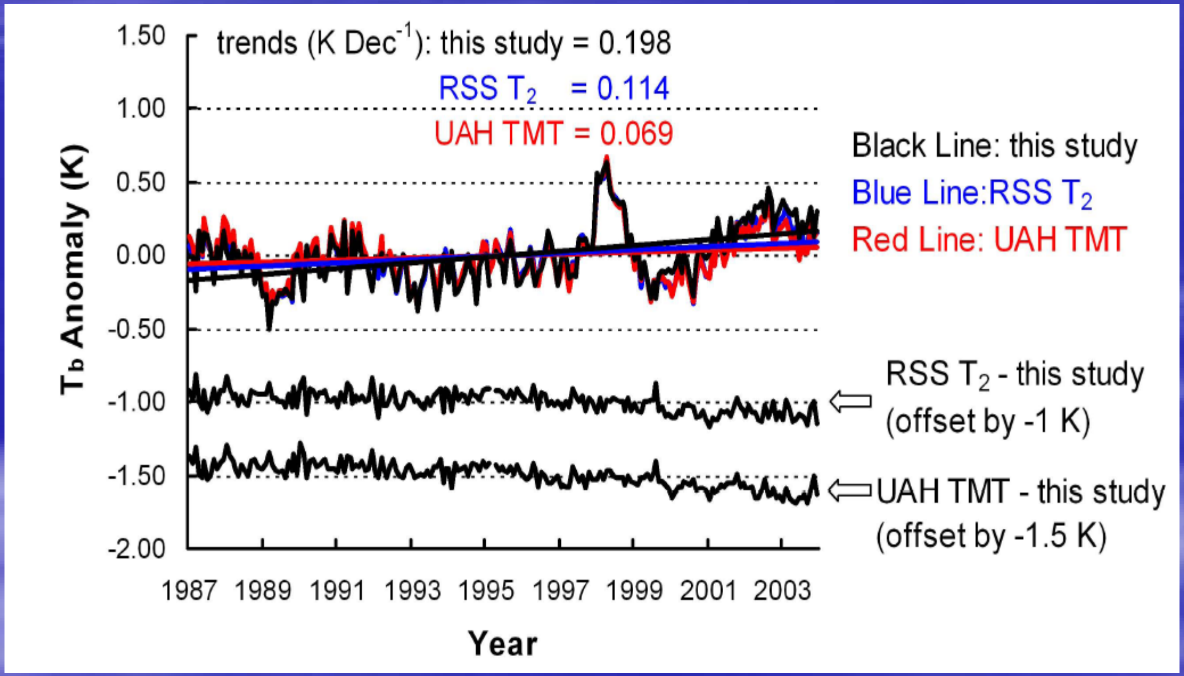
→Post-launch coefficients larger than Pre-launch values

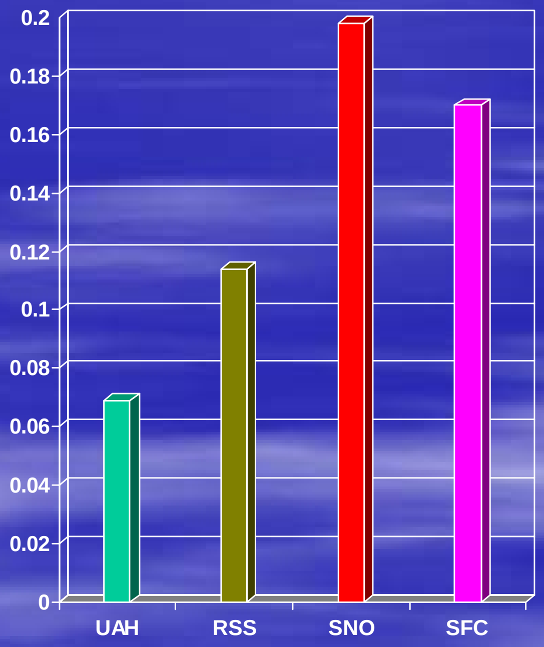
Satellite Pairs *k* *j*	a_0	a_1
N11 N10	-2.925	-3.177
N12 N11	2.572	2.254
N14 N12	-1.282	-1.393



Dots: Pre-launch values
Line: SNO calibration values.

Final anomaly trend

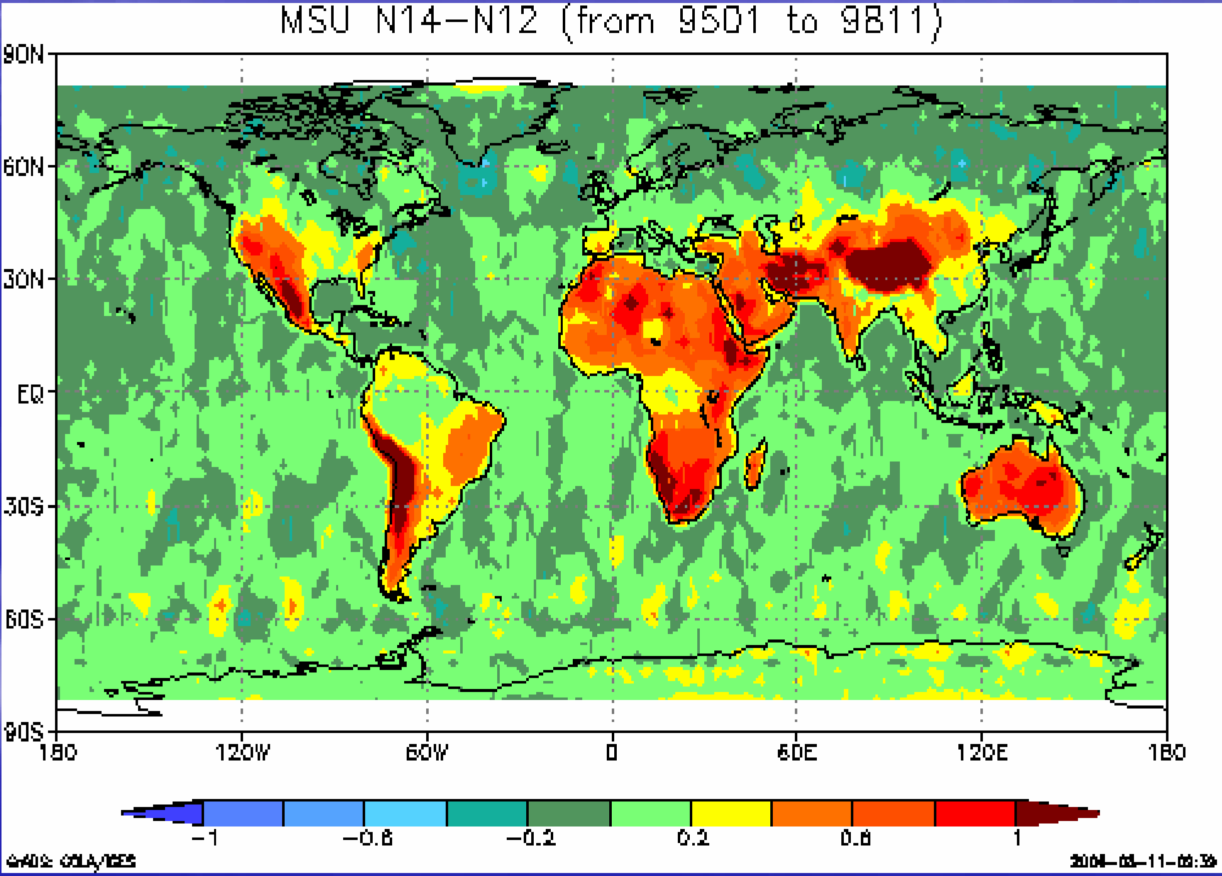




V. On-going work and plans

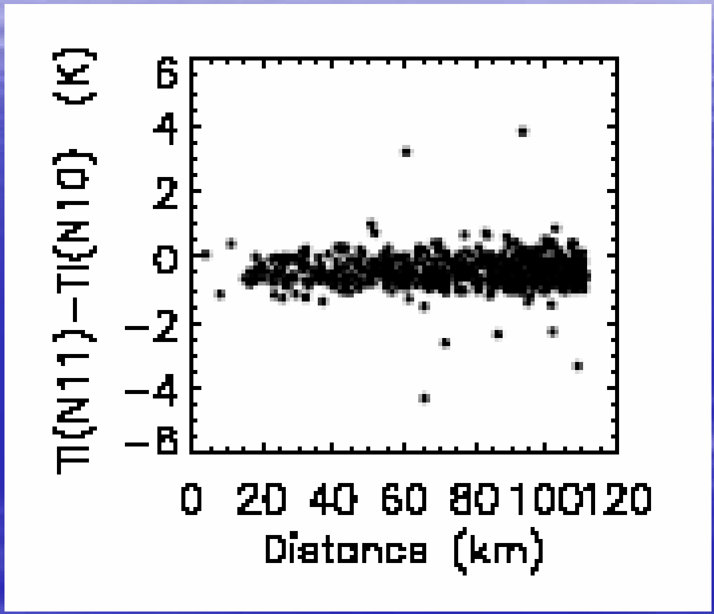
Spatial Distribution of Biases

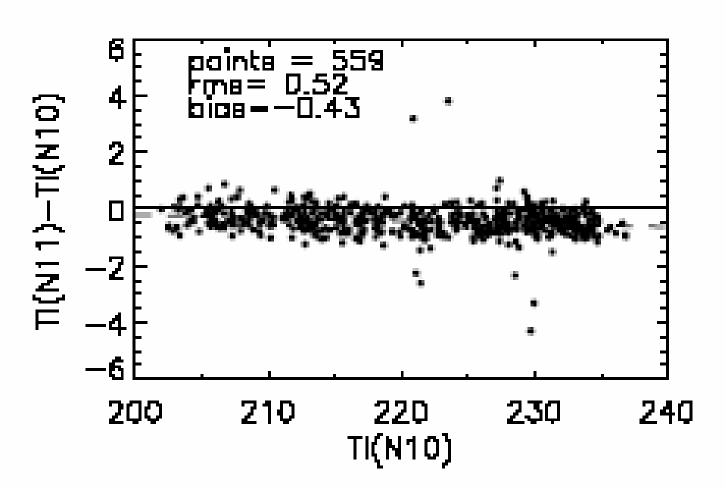
- Ocean OK
- Land needs diurnal cycle corrections



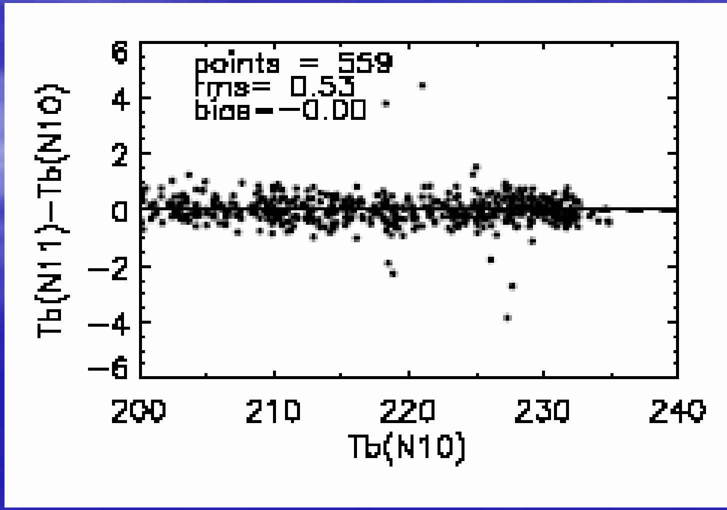
Extends to Different Channels

- MSU Channel 3 bias-distance relationship weaker
- SNO nonlinear calibration also removes biases
- Working on combined Ch 2 and 3 trends



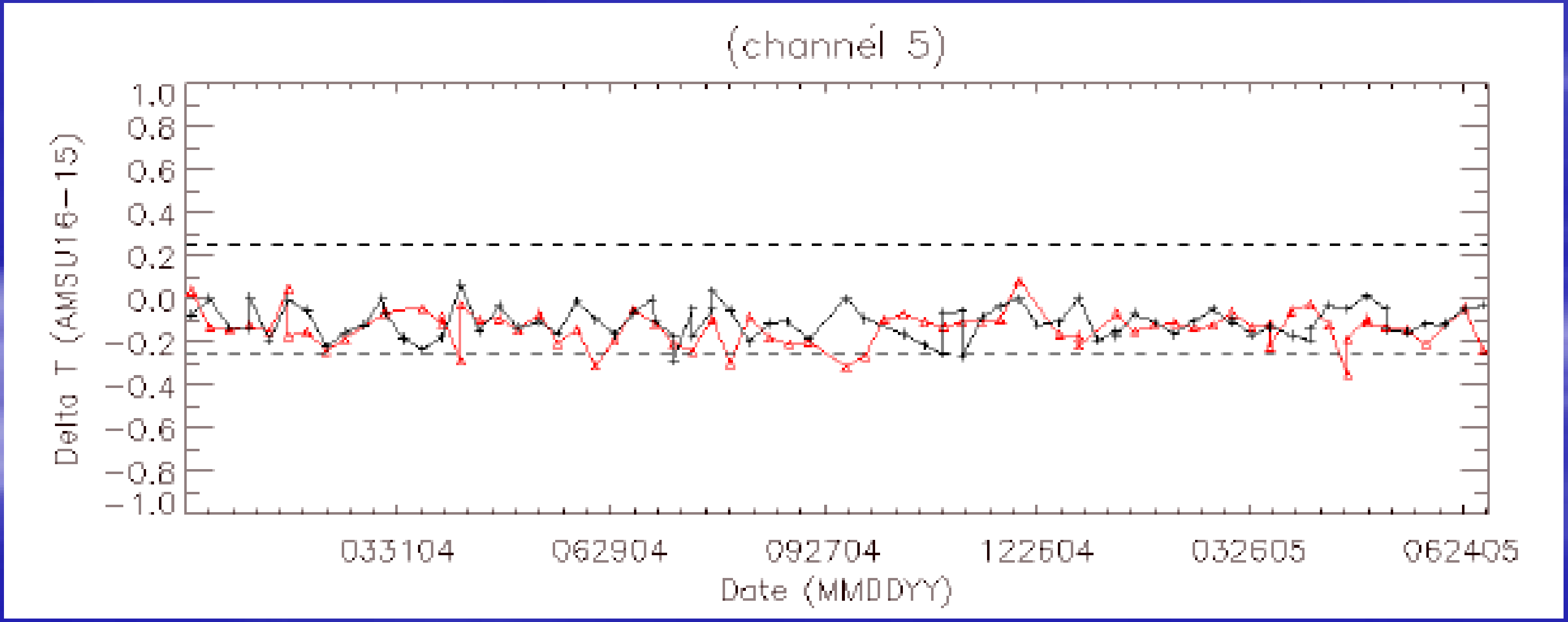


After SNO Calibration



Connect MSU with AMSU

- AMSU biases found
- AMSU has different frequency and resolutions



Time series of SNO biases for Ch. 5 between NOAA 15 and 16 (Courtesy of C. Cao)

Impact on Reanalysis

- Assimilate Merged MSU 1b to NASA MERRA Reanalysis (Modern Era Retrospective-analysis for research and Application) system – Emily Liu
- Impact on all reanalysis variables
- Possibly resolve diurnal cycle problem

Compare With Other Observations

- Radiosonde
- GPS Radio Occultation

Conclusion

- A SNO calibration procedure is developed and a unique set of calibration coefficient is found
- The coefficients remove warm target contamination and biases
- MSU channel 2 ocean trend after bias and warm target contamination removal is 0.20 K Dec^{-1}
- Global tropospheric trend will be available when diurnal cycle and stratospheric cooling effects are removed

END