MSU channel 2 brightness temperature trend when calibrated using simultaneous nadir overpasses

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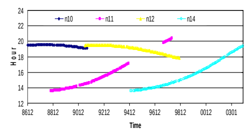
1. Purpose

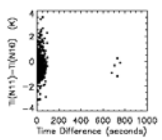
- To re-calibrate MSU observations at level 0 using simultaneous nadir overpasses
- To generate well-calibrated and well-merged multi-satellite MSU 1B data for use by the climate community
- To investigate the MSU trend derived from the well-merged 1B dataset
- To compare with previous trend studies and identify problems with previous use of the MSU data
- To provide a guidance on the future use of MSU data
- To provide the climate community an observed reference on the tropospheric temperature trend

2. SNO dataset



The local equator crossing time (LECT) of the ascending orbit of NOAA satellites

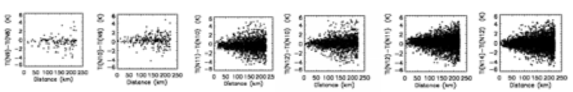
Schematic viewing the overpasses between two NOAA satellites



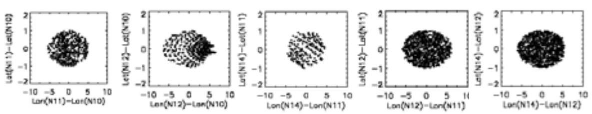
Relationship of the Channel 2 Tb differences between NOAA 10 and 11of the nadir pixels versus time window for the SNO dataset. The maximum spatial distance for the SNOs is set to be 111 km. Note that when the time difference is larger than about 100 seconds, not many SNO data pairs can be found.

Overlap period and SNO numbers of the nadir pixels for different overlap satellites.

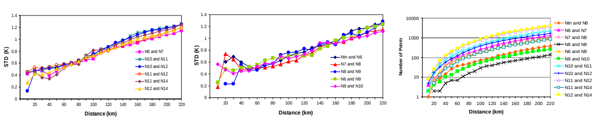
Overlap Satellites	TN-N6	N6-N7	N7-N8	N8-N9	N6-N9	N9-N10	N10-N11	N10-N12	N11-N12	N11-N14	N12-N14
Overlapping Period	01/80-12/80	08/81-12/82	05/83-05/84	07/85-08/85	11/85-10/86	12/86-02/87	10/88-08/91	06/91-08/91	06/91-12/94	08/97-04/98	01/95-11/98
SNO Number	86	329	232	37	217	67	562	470	980	203	1078



Scatterplot of the brightness temperature difference versus the center distance between two nadir pixels of the overpass satellites for some selected overlaps. The pixel center distance has been extended to 222 km from 111km and the time window is still set to be 100 sec. The brightness temperature is computed using the linear calibration equation.



Latitudinal difference vs longitudinal difference for the SNO pairs for some satellite overlaps. Unit is in degree



(a) (b) (c)

STD of channel 2 brightness temperature differences between satellite pairs versus center distance of the nadir overpass pixels. (a) Satellite pairs that have a well defined relationship, (b) satellite pairs that do not show well defined SDT-distance relationship for smaller distance due to sampling size problems, and (c) SNO numbers used in the STD computation for a corresponding distance.

3. Calibration algorithm

$$R_l = R_c + S(C_e - C_c) \qquad (1) \rightarrow \text{Linear calibration equation;}$$

$R_l \rightarrow$ Earth-view radiance by linear calibration

$R_c \rightarrow$ Cold Space Radiance, fixed value; $C_c \rightarrow$ cold space raw counts; $C_e \rightarrow$ Earth-view raw counts;

$$S = \frac{R_w - R_c}{C_w - C_c} \qquad (2) \rightarrow \text{slope;}$$

$R_w \rightarrow$ Blackbody target radiance; $C_w \rightarrow$ Blackbody target raw counts

$$R_e = R_l - \delta R + u\, S^2 (C_e - C_c)(C_e - C_w) = R_l - \delta R + uZ \qquad (3) \rightarrow \text{nonlinear calibration equation;}$$

$R_e \rightarrow$ Earth-view radiance by nonlinear calibration;

$\delta R \rightarrow$ constant offset; $u \rightarrow$ nonlinear calibration coefficient

4. Calibration with SNO dataset

$$R_j(t_j, \mathbf{X}_j) = R_j^{'}(t_j, \mathbf{X}_j) + \varepsilon_j \quad \rightarrow \text{observed radiance R by satellite j at time and location } (t_j, \mathbf{X}_j)$$

$$R_k(t_k, \mathbf{X}_k) = R_k^{'}(t_k, \mathbf{X}_k) + \varepsilon_k \quad \rightarrow \text{observed radiance R by satellite k at time and location } (t_k, \mathbf{X}_k)$$

$R^{'} \rightarrow$ error free measurement; $\varepsilon \rightarrow$ noise;

Taking differences

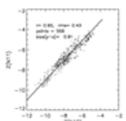
$$\Delta R = R_k^{'}(t_j, \mathbf{X}_j) - R_j^{'}(t_j, \mathbf{X}_j) + \varepsilon_k - \varepsilon_j + \Delta R(\Delta t, \Delta \mathbf{X})$$

Using (3)

$$\Delta R_l - \Delta\delta R + u_k Z_k - u_j Z_j = \varepsilon_k - \varepsilon_j + \Delta R(\Delta \mathbf{X}) \qquad (4) \rightarrow \text{Error equation for any SNO data pairs}$$

We solve $\Delta\delta R = \delta R_k - \delta R_j, u_k, and\ u_j$ using regression method; however, colinearity between $Z_k\ and\ Z_j$ has to be considered (see figure). With colinearity, only $\Delta\delta R\ and\ \Delta u = u_k - u_j$ can be reliably obtained from regression method. Therefore, $\delta R\ and\ u$ for reference satellite have to be determined *a priori* from pre-launch calibration.

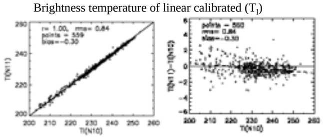
Here $\delta R = 0\ and\ u = 5$ for reference satellite NOAA 10.



Scatterplot showing relationships of the Z factor between NOAA 10 and NOAA 11 for their SNO data pairs. Unit for Z and ζ is 10^{-6} $(mW)^2$ (sr m^2 $cm^{-1})^{-2}$. The regression coefficients for the fitting line is expressed as

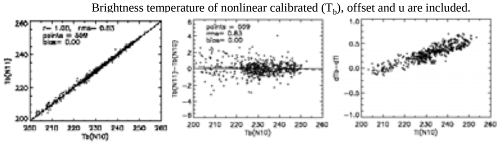
$$Z_j = \beta Z_k + \alpha$$

Brightness temperature of linear calibrated (T_l)



(a) (b)

Brightness temperature of nonlinear calibrated (T_b), offset and u are included.



(c) (d) (e)

Scatter plots showing effects of the nonlinear calibration on the error statistics and distribution of the brightness temperature difference between NOAA 10 and NOAA 11. (a) SNO data between T_l (N10) and T_l (N11); (b) SNO data between T_l (N10) and T_l (N11)-T_l (N10). (c) SNO data between T_b(N10) and T_b(N11); (d) SNO data between T_b(N10) and T_b(N11)- T_b(N10); (e) SNO data of versus ΔT_b-ΔT_l versus T_l (N10).

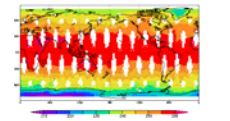
Calibration coefficients for different satellites obtained by the sequential adjusting process using the SNO datasets when NOAA 10 is assumed to be the reference satellite. Units for δR and U are 10^{-5} (mW) (sr m^2 cm^{-1}) $^{-1}$ and (sr m^2 cm^{-1}) (mW) $^{-1}$, respectively.

	Case 1: U for NOAA 10 is obtained simultaneously with NOAA 11 by OLR		Case 2: U for NOAA 10 is determined from pre-launch information	
Satellites	δR	U	δR	U
N10	0	-3.985	0	5
N11	-3.219	-0.912	-2.558	8.308
N12	-0.627	-3.112	-0.254	5.584
N14	-2.525	-1.400	-0.834	6.308

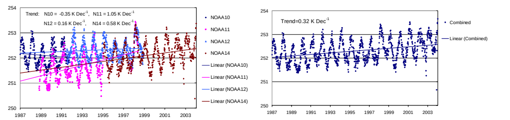
Non-variant quantities ($\Delta\delta R + \alpha U_j$) and ($U_k - \beta U_j$) obtained from regression of SNO using Eq. (28). Units for δR and U are 10^{-5} (mW) (sr m^2 cm^{-1}) $^{-1}$ and (sr m^2 cm^{-1}) (mW) $^{-1}$, respectively.

Satellite Pairs k j	$\Delta\delta R + \alpha U_j$	$U_k - \beta U_j$
N11 N10	-2.925	8.177
N12 N11	2.572	-2.254
N14 N12	-1.282	1.393

5. Results

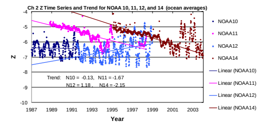


Five-day averages of ascending and descending orbits for NOAA 11 for the period of October 1-5, 1988. Pixels 5, 6, and 7 are used in generating the pentad data

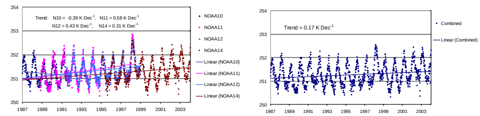


(a) (b)

Time series and trend for the pentad dataset of the global ocean-averaged MSU channel 2 brightness temperature for NOAA 10, 11, 12 and 14 with linear calibration algorithm. (a) Individual time series and trend for NOAA 10, 11, 12 and 14. (b) Combined time series and trend for NOAA 10, 11, 12 and 14. The mean biases between different satellites has been removed with NOAA 10 as the reference satellite.

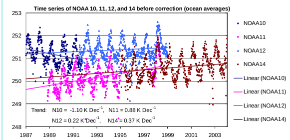


Global ocean-averaged pentad time series and trend of the nonlinear Z term for NOAA 10, 11, 12, and 14. Unit for Z is 10^{-6} $(mW)^2$ (sr m^2 $cm^{-1})^{-2}$.



(a) (b)

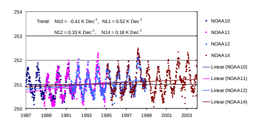
Time series and trend for the pentad dataset of the global ocean-averaged MSU channel 2 brightness temperature for NOAA 10, 11, 12 and 14 with nonlinear calibration algorithm. (a) Individual time series and trends for NOAA 10, 11, 12 and 14. (b) Combined time series and trend for NOAA 10, 11, 12 and 14. The mean biases between different satellites as shown in Table 6 have been removed with NOAA 10 as the reference satellite



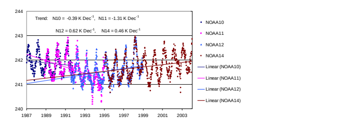
Time series and trend for the pentad dataset of the global ocean-averaged MSU channel 2 brightness temperature for NOAA 10, 11, 12 and 14 with NESDIS operational calibration algorithm.

Mean biases of the global ocean-averages between two satellites during their overlap periods for both linear calibration and nonlinear calibration for Case 2. Biases are computed with the spatial-first and time-second method for computing the global mean.

Overlapping Satellites J k	Overlap Period	Pentad data Number	Bias (K) for linear cal $(k-j)$	Bias (K) for nonlinear cal (Case 2) $(k-j)$
N10 N11	10/88- 08/91	213	-0.605 (b_1)	0.059
N10 N12	06/91- 08/91	19	0.198	0.169
N11 N12	06/91- 12/94	261	0.646 (b_2)	0.064
N12 N14	04/95- 11/98	267	-0.343 (b_3)	-0.148



Pentad time series and trend for the global ocean-averaged MSU channel 2 brightness temperature for NOAA 10, 11, 12 and 14 calibrated by Grody et al. (2004) calibration algorithm. The nonlinear adjustment is directly on the global ocean-averaged pentad time series with linear calibration at level 0. **Combined trend is 0.19 K/Decade.**



Pentad time series of the global ocean-averaged MSU channel 2 brightness temperature for NOAA 10, 11, 12 and 14 with Christy et al. (2004) empirical calibration algorithm. The adjustment is directly on the global ocean-averaged pentad time series with linear calibration at level 0. **Combined trend is 0.02 K/Decade.**

6. Summary and Future work

- Use new nonlinear calibration equation to convert raw counts to radiance. Coefficients for reference satellite are determined by pre-launch calibration but non-reference satellites are determined by post-launch SNO data.
- Very-well calibrated and merged MSU channel 2 data are generated. Biases for pentad global ocean-averages are on the order of 0.05 to 0.1 K between satellite pairs, compared to 0.5 to 1 K with NESDIS operational algorithm.
- Global ocean trend with this merged dataset is **0.17-0.20 K/Decade**, consistent with surface temperature trend.

Reference: Zou,C.-Z., M. Goldberg, Z. Cheng, N. Grody, J. Sullivan, C. Cao, and D. Tarpley, 2005:MSU channel 2 brightness temperature trend when calibrated using simultaneous nadir overpasses, to be submitted as NOAA Technical Report. Email: Cheng-Zhi.Zou@noaa.gov

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