Diurnal drift correction in the NESDIS/STAR MSU/AMSU atmospheric temperature climate data record

Cheng-Zhi Zou and Wenhui Wang

Center for Satellite Applications and Research, NOAA/NESDIS, Camp Springs, Maryland, USA

ABSTRACT

NESDIS/Center for Satellite Applications and Research (STAR) has been reprocessing and recalibrating observations from the Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) to generate atmospheric temperature climate data record (CDR). To obtain reliable atmospheric temperature trends from the dataset, diurnal drift errors due to orbital drift must be removed from the time series. This adjustment is especially important for the MSU/AMSU mid-tropospheric temperature product over land where diurnal-drift effect is large. In this study, we applied the diurnal anomalies developed by the Remote Sensing Systems (RSS) to the STAR MSU/AMSU atmospheric temperatures CDR and examined how the correction affects the trend and intersatellite biases over land. A scaling factor was introduced to multiply the RSS diurnal anomalies to account for uncertainties in the dataset. The results show that the diurnal drift has negligible effect on the mid-tropospheric temperature trends over oceans, which is consistent with previous investigations. However, the trend over land is very sensitive to the magnitude of the scaling factor. The final scaling factor was determined by minimizing intersatellite temperature differences over land. The trend values corresponding to such a scaling factor for the 28-year (1979-2006) merged MSU T_2 time series are 0.193 K/Decade over the global land and 0.180 K/Decade over the global ocean. The global mean T_2 trend is 0.183 K/decade.

Keywords: MSU/AMSU dataset; MSU/AMSU atmospheric temperature trend; satellite intercalibration; satellite merging; diurnal-drift adjustment.

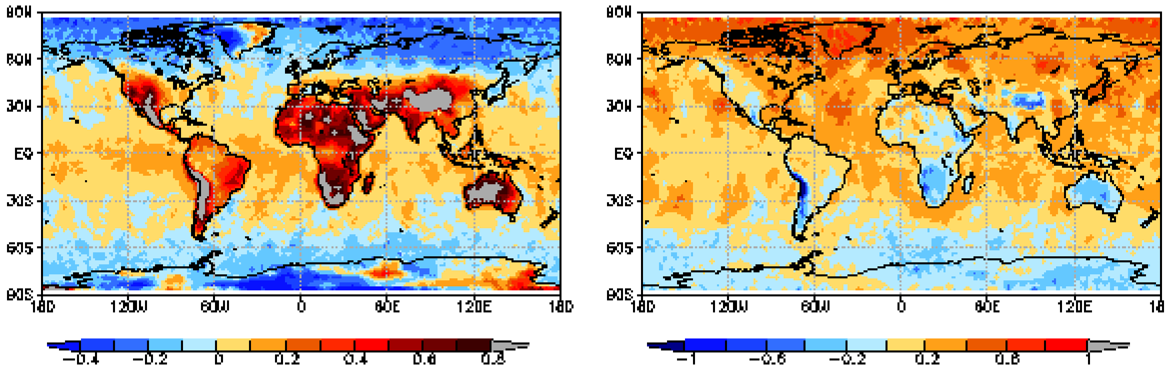
1. INTRODUCTION

The Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) on board the NOAA polar-orbiting satellites have provided critical global atmospheric temperature measurements for the past 30 years for long-term climate monitoring and research. However, reprocessing and recalibration aimed at reducing various calibration errors are required to generate consistent climate data record (CDR) and derive reliable climate trend from these measurements. Previous investigations indicated that the MSU/AMSU atmospheric temperature trend values are affected by at least four factors: diurnal-drift errors, warm target contamination, quality control, and short overlaps between NOAA-9 and NOAA-10. The error correction methods for the warm target contamination and short overlap problems have been developed in our previous investigations (Zou et al. 2006, 2009; Zou 2008). In this study, we focus on removal of diurnal-drift errors.

2. DIURNAL-DRIFT INDUCED ERRORS IN THE MSU/AMSU TEMPERATURE TIME SERIES

The diurnal drift errors originated from satellite orbital-drift. Specifically, the orbital-drift resulted in a change of local observation time, or diurnal-drift that, if not corrected, may introduce false long-term temperature trend by bringing diurnal trend in it (Trenberth and Hurrell 1997; Christy et al. 1998, Mears et al. 2003). Diurnal dirft errors can be seen from both the intersatellite difference maps and trend maps. Figure 1a shows the spatial distribution of intersatellite biases of the MSU channel 2 temperature (T_2) between NOAA-11 and NOAA-10 during 10/1988-08/1991. The T_2 time series represents the deep-layer mid-tropospheric temperature and the product was generated based on a simultaneous nadir overpass (SNO) intercalibration method (Zou et al. 2006, 2009) in which the warm target errors were removed in the root level (level-1c) calibration of scene temperature. The time series is composed of 5-day averaged, seven near-nadir, SNO-calibrated and limb-corrected brightness temperature binned in 2.5^0 by 2.5^0 grid boxes (Zou et al. 2009). Since warm target errors have been removed at the root-level and the same limb-correction scheme was used for all different satellites, the intersatellite biases mainly reflect differences in observation time between two satellites due to orbital-drifts. The figure shows that the T_2 biases are within ±0.2 K over the ocean and the bias values depend on latitudes. This indicates the diurnal-drift effect being small over oceans. However, large biases on the order of 1 K were found over land, showing diurnal differences in observation time between the two satellites are important there.

Figure 1b further shows the 28-year (1979-2006) T_2 trend pattern without the diurnal-drift correction. It is seen that consistent warming trend were observed over the global oceans (except at the southern ocean). However, inconsistent cooling trends were found over much of the land areas, yielding a clear contrast between land and oceans. For instance, the Australia continent has a clear cooling trend but all of its surrounding oceans has a warming trend. The cooling trends over land were artificial effects resulting from the un-corrected large intersatellite biases over land as seen in Figure 1a. These plots indicated that diurnal-dirft correction is very important for obtaining reliable T_2 trend over land.



(a) (b)

Figure 1 (a) Spatial disttribution of the intersatellite T_2 biases between NOAA-11 and NOAA-10 (NOAA-11 minus NOAA-10) during 10/1988-08/1991; (b) Spatial trend pattern for MSU T_2 for 1979-2006 without diurnal-drift correction.

3. DIURNAL-DRIFT CORRECTION IN THE STAR MSU TEMPERATURE CDR

A general technique for removing the diurnal-drift errors is to adjust the scene radiances at different observation time from different satellites to the common 12-noon local time before binning them for averaging. This adjustment yields a trend and intersatellite difference at the 12-noon local time and thus observation time differences are eliminated. This process is expressed by

$$R_c\,(t_{12-noon},\mathbf{X}) = R_o(t,\mathbf{X}) - \Delta R \tag{1}$$

where $R_o(t,\mathbf{X})$ represents the SNO-calibrated level-1c scene radiance at time *t* and geographic location **X**, $R_c\,(t_{12-noon},\mathbf{X})$ the adjusted radiance at the 12-noon local time, and $\Delta R = R_e(t,\mathbf{X}) - R_e(t_{12-noon},\mathbf{X})$ an estimated diurnal anomaly used for the adjustment. The diurnal anomaly is a function of time and geographic location and is difficult to estimate in many situations, and thus it contains large uncertainties. Different methodologies were created to estimate the diurnal anomaly for the MSU/ASMU observations: Christy et al. (2000) estimated it by accumulating local MSU or AMSU observations from different scan-positions at different local times, while Mears et al. (2003) at Remote Sensing Systems (RSS) adopted diurnal anomaly climatology generated from NCAR Community Climate Model (CCM) for the correction. Due to uncertainties in these estimations, the two methods resulted in large trend differences over land for the MSU lower-tropospheric temperature where diurnal drift effects are large (Mears and Wentz 2005).

In this study, we adopt the RSS diurnal anomalies for the correction. The RSS diurnal anomaly is a monthly mean hourly dataset downloaded from the RSS website. To minimize the uncertainties, we introduce a scaling factor, *f*, to multiply the anomaly dataset, where *f* is obtained by minimizing intersatellite differences over land. Specifically, we compute the standard deviation (σ) of the intersatellite difference time series averaged over land and adjust the scaling factor to minimize σ. Figure 2 shows how σ varies with different choices of the scaling factor. In the figure, f=0 represents the case without the diurnal drift correction and its corresponding trend was shown in Figure 1b. Relatively larger σ (0.065-0.07 K) is seen for f=0. The case f=1 corresponds to applications of the original RSS diurnal anomaly dataset. It is seen that σ is significantly reduced from f=0. The minimum σ occurred at f=0.875. Thus this point was selected as the final value for the diurnal correction.

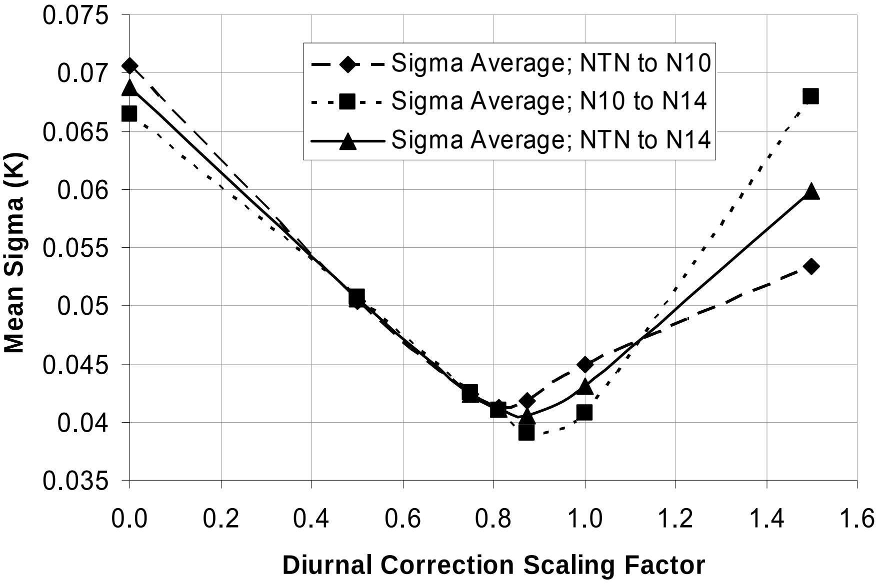
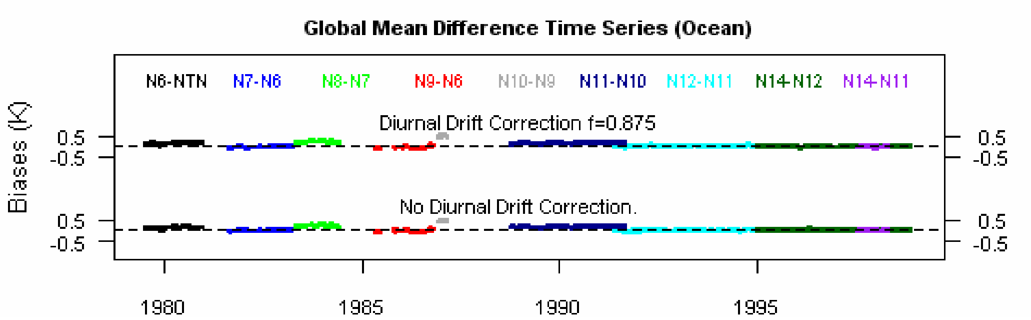
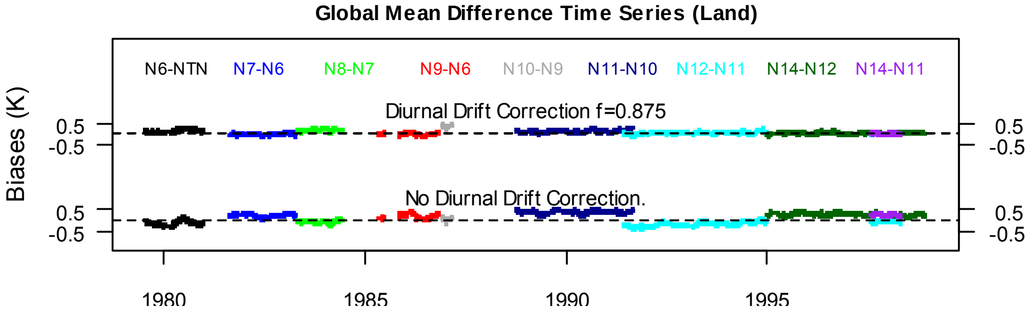


Figure 2 Mean standard deviation (σ) of the intersatellite difference time series for T_2 over land versus scaling factor (*f*) of the diurnal-drift correction. The caption 'Sigma Averages; NTN to N10' represents σ averages for satellite pairs TIROS-N to NOAA-10, and so on (see also Figure 3 for satellite pairs). The mean σ reaches minimum at *f*=0.875, thus this point is selected as the final scaling factor for diurnal drift correction.

Figure 3 shows how the diurnal-drift correction affects intersatellite difference time series between land and ocean. As mentioned earlier, the T_2 was generated based on SNO intercalibration where warm target errors have already been removed in the level-1c radiance dataset. This makes the T_2 difference time series over oceans to behave very well for all satellite pairs (small variability and stable biases with no drift). In addition, diurnal-drift correction has little effect on the difference time series over oceans, which is consistent with previous investigations. Over the global land, however, intersatellite differences without the diurnal-drift correction are still relatively large with larger variability. After the diurnal correction, the intersatellite bias and bias drift over land were significantly reduced. Specifically, the mean absolute intersatellite bias (standard deviation) for all the satellite pairs over land is 0.20 K (0.069 K) without the diurnal correction; however, it is reduced to 0.11 K (0.040 K) with the diurnal correction. This bias level is consistent with oceans, suggesting the diurnal drift correction is acceptable.



(a)



(b)

Figure 3 Intersatellite difference time series for MSU T_2 between different NOAA satellites. (a) Averages over the global oceanic atmosphere; (b) Averages over the global land atmosphere. The abbreviation “N11-N10” stands for NOAA-11 minus NOAA-10, and so on.

Figure 4a and 4b show the spatial pattern of intersatellite T_2 biases between NOAA-11 and NOAA-10 and the 28-year (1979-2006) T_2 trend pattern after the diurnal-drift correction. These are similar plots as shown in Figure 1a and 1b except with a diurnal drift correction. It is seen that the large intersatellite biases over land in Figure 1a are significantly reduced in Figure 4a by the diurnal correction. The trend pattern over land and oceans are now consistent with each other after the diurnal correction.

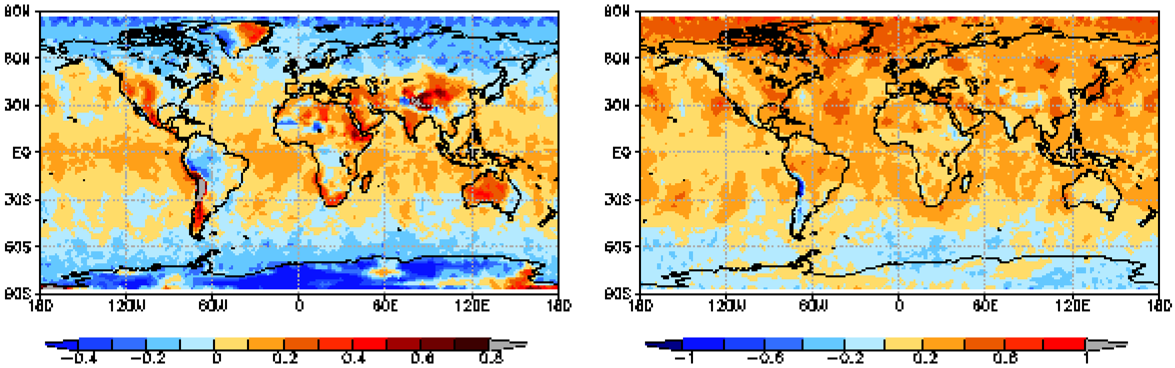


Figure 4 (a) Same as Figure 1a except with a diurnal-drift correction; (b) Same as Figure 1b except with a diurnal-drift correction.

Note that further correction is needed to remove the remaining biases after the diurnal drift adjustment to obtain the final trend as shown in Figure 4b. There are two options for this correction: (i) simply subtract constant biases for all overlaps so the difference time series have exact zero biases, and (ii) find a best fit empirical relationship between the brightness temperature correction term and the warm target temperature and then remove the best fit from the unadjusted time series. The second method was developed by Christy et al. (2000) and the idea was to remove the warm target contamination empirically from the residual biases. We have proved that the Christy correction complements the SNO calibration in removing the warm target effects so their combination yields invariant, stable trends in the SNO calibration framework (Zou 2009). Therefore, we have chosen the Christy correction to remove residual biases for a final merging. After all these adjustments, intersatellite differences are near zero for all overlaps with on obvious bias drift.

The final trend values for the 28-year (1979-2006) merged MSU T_2 time series are 0.193 K/Decade over the global land and 0.180 K/Decade over the global ocean. The global mean T_2 trend is 0.183 K/decade.

4. DIURNAL-DRIFT CORRECTION FOR THE AMSU TIME SERIES

Similar to the MSU observations, RSS diurnal anomalies for the AMSU observations were tested and implemented for diurnal drift corrections in the STAR MSU/AMSU atmospheric temperature CDR. Again, a scaling factor was first determined by minimizing intersatellite difference time series of the AMSU satellites. These include AMSU data onboard NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, European MetOp, and NASA AQUA. Figure 5 shows the σ variations versus the scaling factor for the AMSU channel 5 temperature for several NOAA satellite pairs. AMSU channel 5 is the companion channel for the MSU channel 2 and their merging will generate equivalent MSU/AMSU T_2 dataset. It is seen that when the scaling factor equals 0.917, minimum σ in a multi-satellites averaged sense was obtained. Thus, this point was chosen as the final scaling factor for correcting diurnal drift errors in the AMSU observations.

The impact of this correction on the intersatellite biases between NOAA-15 and NOAA-16 is shown in Figure 6. Before the diurnal correction, inconsistent bias patterns were found between land and ocean with large biases occurring over land (Fig. 6a). This is similar to the MSU situation (e.g., Fig. 1a). However, after the correction, consistent small biases were found over both land and oceans (Fig. 6b), although the correction appeared to be overdone over some areas such as the central South America.

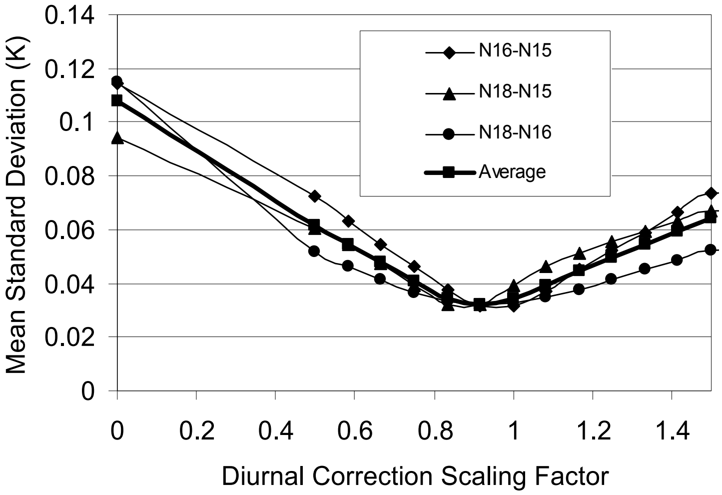
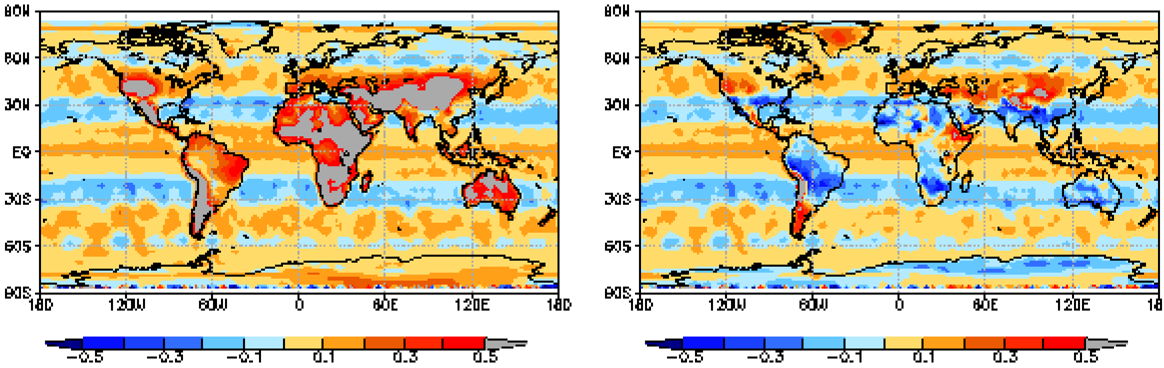


Figure 5 Same as Figure 2 except for AMSU channel 5 observations. The mean σ reaches minimum at f=0.917, thus this point is selected as the final scaling factor for the AMSU satellites.



(a) **(b)**

Figure 6 Mean intersatellite bias patterns between NOAA-15 and NOAA-16 (NOAA-16 minus NOAA-15) for 01/01/2001-05/04/2009 before (a), and after (b) the diurnal drift correction.

Note that before the diurnal dirft correction, an intersatellite calibration similar to the MSU observations were conducted for all the AMSU satellites using the SNO method. The intercalibration was mainly to remove an long-term bias drift between NOAA-15 and NOAA-16 and a detailed description on this intercalibration procedure and its results will be published elsewhere.

5. CONCLUSION

We used the RSS diurnal anomalies to correct the diurnal drift errors in the StAR MSU/AMSU T_2 time series over land. With an appropriate scaling factor determined from minimizing the intersatellite differences, the correction has significantly reduced intersatellite T_2 biases over land and yielded consistent trend patterns between oceans and land. Therefore, the RSS diurnal-drift correction scheme was implemented in the Version 1.1 and Version 1.2 of the NESDIS/STAR MSU/AMSU deep-layer atmospheric temperature time series.

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