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Recalibration of the AMSU-A Sensor for Climate Applications

The Advanced Microwave Sounding Unit-A (AMSU-A) onboard NOAA, MetOp-A, and NASA AQUA polar orbiting satellites provide critical global temperature profile measurements for both weather and climate applications. In weather applications, direct assimilation of the pre-launch calibrated radiance datasets in numerical weather prediction models have greatly improved model forecast skills. For climate applications, however, reprocessing and recalibration aiming at reducing calibration and satellite transition errors in satellite product retrievals and modelling reanalysis practice are required. In this working paper, we describe NOAA/NESDIS effort in AMSU-A sensor intercalibration onboard different NOAA and European MetOp-A satellites. We demonstrate how AMSU intersatellite biases were greatly reduced from using post-launch simultaneous nadir overpass method. We also describe merging of the AMSU observations with their precursor—the Microwave Sounding Unit (MSU)—to generate long-term atmospheric temperature climate data records. Finally, we provide the trend results of a 30-year well merged and inter-calibrated AMSU/MSU mid-tropospheric temperature time series.

Recalibration of the AMSU-A Sensor for Climate Applications

1 INTRODUCTION

The Advanced Microwave Sounding Unit (AMSU) on board the NOAA, MetOp-A, and NASA AQUA polar-orbiting satellites have provided critical global atmospheric temperature measurements for the past 10 years for weather and climate applications. In weather applications, direct assimilation of the pre-launch calibrated radiance datasets in numerical weather prediction models have greatly improved model forecast skills. For climate applications, however, reprocessing and recalibration aiming at reducing various calibration errors in satellite product retrievals and modelling reanalysis practice are required. Efforts are also needed to merge AMSU observations with their precursors—the Microwave Sounding Unit (MSU)—to generate consistent climate data record (CDR) and derive reliable climate trend. For these purposes, NOAA/NESDIS/Center for Satellite Applications and Research has been reprocessing and recalibrating the AMSU observations using simultaneous nadir overpass (SNO) method. In this working paper, we use companion AMSU channel 5 (53.71 and 53.48 GHz double sidebands) and MSU channel 2 (53.74 GHz single sideband) to demonstrate how global intersatellite biases existed in the pre-launch calibration are reduced by using post-launch SNO calibration method. In addition, merged temperature time series are derived from the AMSU channel 5 and MSU channel 2 intercalibration effort.

2 NESDIS/STAR MSU/AMSU intercalibration system

The MSU/AMSU satellite intercalibration and merging involve proper treatment of errors from many different sources. These include, but are not limited to, intersatellite biases due to independency of pre-launch calibration, orbital-drift related warm target contamination, nonlinear calibration, short overlaps between certain satellite pairs, earth-location dependency in biases, antenna pattern effect, diurnal drift errors, incident angle effect, and frequency differences between MSU and AMSU channels, etc. Some of these errors caused large uncertainties in the MSU/AMSU trend determination. For instance, the warm target temperature that was used to calibrate the raw observations suffered through a large variability and trend owing to orbital-drift related differences in sun heating on the instrument. These variability and trends were not completely removed from pre-launch calibration and thus manifested in the subsequent brightness temperature time series, a so-called warm target contamination effect. This effect, if not removed, will bring unwanted warm target temperature trend to the brightness temperature time series. The orbital-drift also resulted in a change of local observation time that, if not corrected, may introduce false climate trend by bringing diurnal trend in it. Its effect is particularly large on the lower- and mid-tropospheric channels where diurnal amplitude is large. Besides their effects on the climate trends, the warm target errors are also a source of uncertainties in the reanalysis bias correction practice. Therefore, these errors must be removed in the intercalibration activities.

An end-to-end approach was developed at NESDIS/STAR to obtain the best root-level (level-1c) calibration coefficients using simultaneous nadir overpasses to minimize warm target contamination. This process is accomplished by using observations over oceans, since diurnal drift errors are small there. In contrast, observations over land were used to remove diurnal drift errors so the errors in the warm target and diurnal drifts were decoupled and treated separately. The flowchart for such an approach is shown in Figure 1. In this approach, a sequential procedure was first developed to solve for the calibration coefficients for all NOAA satellites from simultaneous nadir overpass matchups. The sequential procedure requires the calibration coefficient of an arbitrarily selected reference satellite to be known first, and then coefficients of all other satellites were determined sequentially (one by one) from regressions of the SNO matchups between satellite pairs, starting from the satellite closest to the reference satellite. The selection of a reference satellite is necessary since one cannot solve the calibration coefficients of two satellites simultaneously from their SNO matchups owing to a colinearity problem in the SNOs. The sequential procedure reduced the calibration problem to the determination of the calibration coefficient of the reference satellite. In our approach, this reference satellite problem was tied to the removal of the warm target contamination.

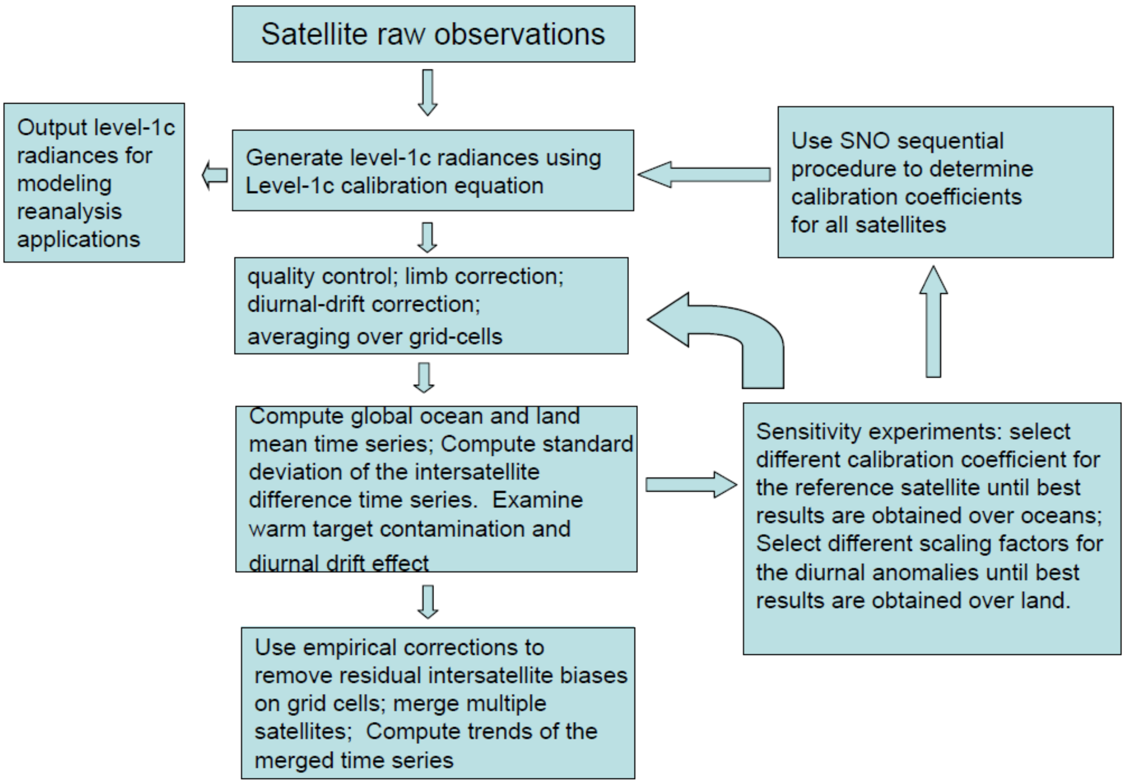


Figure 1 Flowchart showing the calibration, error correction, data merging, and trend computation processes for the MSU/AMSU instruments.

A best calibration coefficient for the reference satellite was obtained by minimizing the warm target contamination errors in the global ocean mean brightness temperature difference time series in a series sensitivity experiments. Then calibration coefficients for all other satellites were obtained sequentially from regressions of their SNO matchups. The calibration coefficients were then applied globally to every footprint observation to obtain a level-1c radiance dataset for each satellite using level-1c calibration equations. Next, a limb correction was applied to adjust different incident angles of the off-nadir footprints to the nadir direction. Diurnal-drift correction is also applied at this step for the MSU and AMSU lower and mid-tropospheric temperature channels over land.

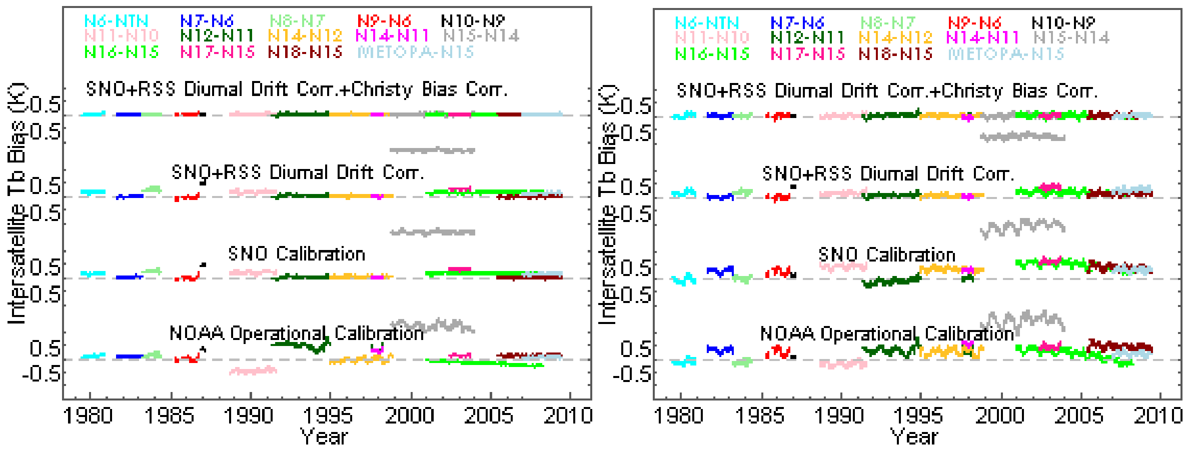
In the next step, the SNO derived, limb- and diurnal-drift-adjusted radiances were binned together to generate a pentad T_b dataset with grid resolution of 2.5^0 longitude by 2.5^0 latitude. Global ocean-mean temperature and their difference time series between satellites were further obtained from this gridded dataset. Mean biases and standard deviation of the global mean difference time series were further examined to understand how the calibration and error correction work. The process was repeated by fine-tuning the calibration coefficient of the reference satellite and scaling factor of diurnal anomalies applied in the diurnal correction until intersatellite biases minimized over both ocean and land.

In the next section, we show AMSU channel 5 and MSU channel 2 intersatellite differences to discuss the recalibration results. AMSU channel 5 and MSU channel 2 represent the deep-layer mid-tropospheric temperature and they are usually abbreviated in the literature as the T_2 product.

3 Inter-satellite bias analysis with SNO inter-calibration

Figure 2a and 2b show respectively the intersatellite difference time series for different calibration and bias correction procedures over ocean and land. From the bottom traces of Figure 2a one can see how warm target effect manifested in the pre-launch "NOAA operationally calibrated" MSU/AMSU brightness temperature difference time series. As mentioned earlier, level-1c radiances with time and geographic information at each footprint were converted from satellite raw observations using level-1c calibration equation and pre-scribed calibration coefficients, and then these radiances are binned together to derive global mean temperatures subject to quality control, limb-adjustment, and diurnal-drift corrections. In the NOAA operational calibration, the root-level calibration coefficients were derived from pre-launch laboratory chamber test data. It was known that diurnal-drift effect is small over oceans, thus errors in the ocean-mean intersatellite T_2 differences were attributed to the warm target contamination. For MSU satellites, the pre-launch calibration left a residual time-varying intersatellite biases on the order of 0.5 K with an averaged standard deviation about 0.1 K. These biases and variability are especially large for satellites NOAA-10 through NOAA-14, owing to the large warm target temperature drift in these long-lasting satellites and a larger calibration nonlinearity. Larger intersatellite biases and variability were found for all satellite pairs over land (Fig. 2b), but they are combined effects from both the warm target and diurnal drift errors.

The AMSU intersatellite biases are generally smaller than the MSUs, except there is a long-time bias drift between NOAA-15 and NOAA-16. In addition, AMSU intersatellite differences have much smaller warm target related variability. This is because the AMSU instruments in general have much smaller calibration nonlinearity than MSUs. The larger biases between NOAA-14 MSU channel 2 and NOAA-15 AMSU channel 5 are due to their frequency differences.



(a) (b)

Figure 2 Intersatellite difference time series for the MSU channel 2 and AMSU channel 5 T_2 product between different NOAA and MetOp-A satellites. (a) Averages over the global oceanic atmosphere; (b) Averages over the global land atmosphere. The abbreviation "N16-N15" stands for NOAA-16 minus NOAA-15, and so on. MSU channel 2 observations are from satellites on and before NOAA-14, while AMSU channel 5 are from satellites on and after NOAA-15 and on MetOp-A N15-N14 is a difference between AMSU channel 5 on NOAA-15 and MSU channel 2 on NOAA-14. See text for a description of the calibration and correction method for the different traces in the two panels.

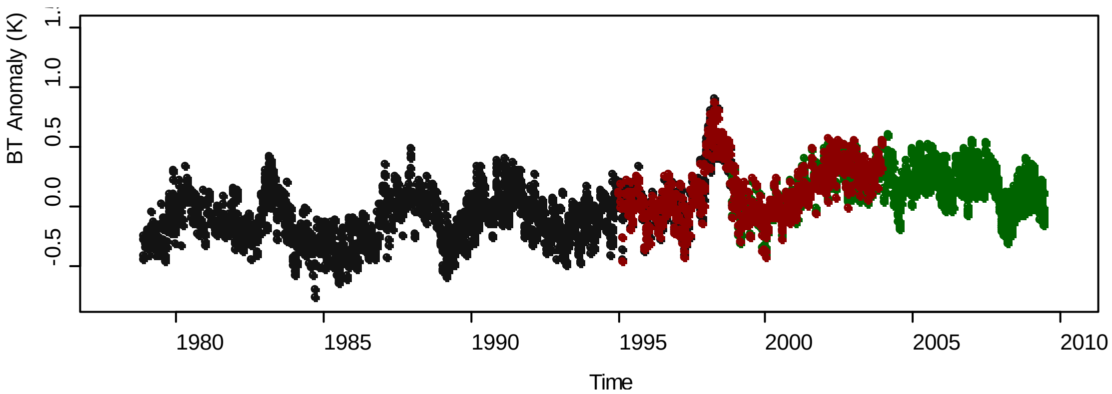
The SNO calibrated T_2 difference time series is shown in Figure 2 with a label 'SNO calibration' (the second traces from the bottom). By design (as described in the last section), the SNO-calibration procedure minimized the averaged warm target contamination and intersatellite biases over all satellite pairs. In addition, time-dependent calibration coefficient was introduced to the NOAA-16 AMSU observations to remove its bias drift relative to NOAA-15 and other AMSU satellites. Compared to the pre-launch calibration over oceans, the SNO calibration significantly reduced the global intersatellite biases and the warm target errors (all traces use the same quality-control, limb-adjustment, and diurnal correction procedure). Quantitatively, the averaged intersatellite biases and standard deviation of the oceanic atmosphere are 0.1K and 0.035 K, respectively, for the SNO calibration. This is significantly smaller than the pre-launch calibration. In addition, bias drift between NOAA-15 and NOAA-16 has been reduced to zero.

Over the global land, intersatellite differences are still relatively large compared to the ocean even after the SNO calibration, owing to the diurnal-drift effect. To correct this error, earth-scene footprint radiances at different observation times were adjusted to a fixed noon local time (12:00 pm) before they are binned together to generate gridded and global mean time series. The Community Climate Model (CCM)-based diurnal anomaly dataset generated by Remote Sensing Systems was used for the diurnal adjustment. However, a scaling factor measuring the diurnal magnitude was applied to account for the uncertainties in the dataset and the value of the scaling factor was determined by minimizing intersatellite differences over the global land. As seen in Fig. 2b (the third traces from the bottom), the intersatellite bias and bias drift over land were significantly reduced after this adjustment was made. Quantitatively, the mean absolute intersatellite bias (standard deviation) for all the MSU/AMSU satellite pairs (except for the NOAA-14 minus NOAA-15) 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. As mentioned earlier, nevertheless, the diurnal correction has no effect on the ocean mean difference time series as shown in Fig. 2a (comparison of the second and third traces).

4 Merged AMSU and MSU temperature time series and their climate trends

Further empirical correction is needed to remove the remaining biases after the SNO calibration and diurnal drift adjustment. 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 idea of the second method (referred to as Christy correction hereafter) was to remove the residual warm target contamination empirically from the residual biases. The results for this second method were shown in Figure 2 (the top traces). After all these calibration and corrections, intersatellite differences are nearly exact zero for all overlaps with on obvious bias drift. This demonstrates we have derived a well inter-calibrated multiple MSU/AMSU satellite time series.

The combined time series are an average of the available satellite observations after all adjustments were made and a linear regression trend was computed from the merged time series. Figure 3 shows the merged T_2 anomaly time series and trend over the globe separated into several different time periods. The time period separation is for both trend discussion and a consistency test of the correction procedures to increase our confidence on the trend. As seen in the Figure, the MSU-only (but without NOAA-14) 16-year trend from November 1978 to December 1994 is only 0.05±0.084 K/decade, which is quite small. In contrast, the 14-year MSU/AMSU trend from January 1995 to June 2009 is 0.11±0.11 K/decade, which is much larger than the earlier period. In addition, there was a 0.146 K jump between the linear regression trend lines of the two periods at the beginning of 1995, indicating the temperatures are in different regimes for the two periods. This gives an overall 30-year trend of 0.151±0.043 K/decade for the entire MSU/AMSU period. These results show that most of the atmospheric warming occurred in the later half of the 30-year period.



MSU/AMSU time series, demonstrating the robustness of the MSU/AMSU intercalibration and trend.

5 Summery and conclusions

The NESDIS/STAR MSU/AMSU intercalibration system as described above provides a consistent set of multi-satellite level-1c radiances and merged gridded level-3 deep-layer atmospheric temperatures. Instrument errors such as the warm target contamination have been minimized in the level-1c radiances; therefore, they will benefit modelling reanalyses when these radiances are assimilated into reanalysis systems. Incident angle and diurnal drift errors are further removed in the level-3 temperature products; thus, climate trend was determined with more confidence. Currently, a 28-year SNO calibrated MSU-only dataset is available online at STAR's website for applications of reanalysis data assimilation and climate trend monitoring. A SNO calibrated and merged MSU/AMSU dataset will also be put online once a quality control is completed. Finally, plans are being made at STAR to intercalibrate all AMSU-A channels including those not having companion MSU channels. Calibration results will be reported once they are available.