Connecting the Time Series of Microwave Sounding Observations from AMSU to ATMS for Long-Term Monitoring of Climate Change

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Abstract

The cross-calibrated measurements from Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit-A (AMSU-A) on board different NOAA polar-orbiting satellites have been extensively used for detecting atmospheric temperature trend during the last several decades. AMSU-A observations from NOAA satellites will soon be replaced by the Advanced Technology Microwave Sounder (ATMS) with the launch of Suomi National Polar-orbiting Partnership (SNPP) satellite. ATMS inherited most of the sounding channels from its predecessor AMSU. It is important to extend AMSU data records with ATMS observations. However, the ATMS field of view is different from that of AMSU. In this study, the Backus-Gilbert method is used for optimally remapping the ATMS FOVs to AMSU-A like FOVs. Differences in ATMS brightness temperatures introduced by remapping are firstly illustrated over the region of Hurricane Sandy which occurred in October 2012. Using the simultaneous nadir overpass (SNO) method, AMSU and ATMS remap observations are then collocated in space and time and the inter-sensor biases are derived for each pair of channels. It is shown that the brightness temperatures from SNPP ATMS are now well merged into the AMSU data family after remap and cross-calibration.

ATMS and AMSU-A Difference

ATMS is a total power cross-track radiometer and scans the earth within ±52.77° with respect to the nadir direction. It has a total of 22 channels. The first 16 channels are primarily for temperature soundings from the surface to about 1 kPa (~45 km) and are investigated in this study. The remaining channels 17-22 are for humidity soundings in the troposphere from the surface to about 200 kPa (~15 km) and are not included in this study.

Besides antenna patterns, the beam width of ATMS is also different from that of AMSU-A. All AMSU-A channels have a beam width of 3.3°. However, the ATMS channels 3-16 have a beam width of 2.2° and the beam width ATMS channels 1-2 is 5.2°. The differences in the beam width between ATMS and AMSU channels are the main reason for resulting in a significant difference in the sizes of field-of-view (FOV) between ATMS and AMSU (*Weng et al*., 2012).

Another major difference between ATMS and AMSU-A arises from the scanning mode. Since AMSU-A scans the Earth in a step and staring mode, there is no overlapping between neighboring FOVs in both cross-track and along track directions. However, ATMS FOVs are overlapping due to its continuously scanning mode, resulting an oversampling in both cross-track and along-track directions. A single FOV of either ATMS channel 1 or 2 overlaps partially with its neighboring four FOVs and four scanlines. A single FOV of any of ATMS channels 3-16 overlaps with its two neighboring FOVs and two nearby scanlines.

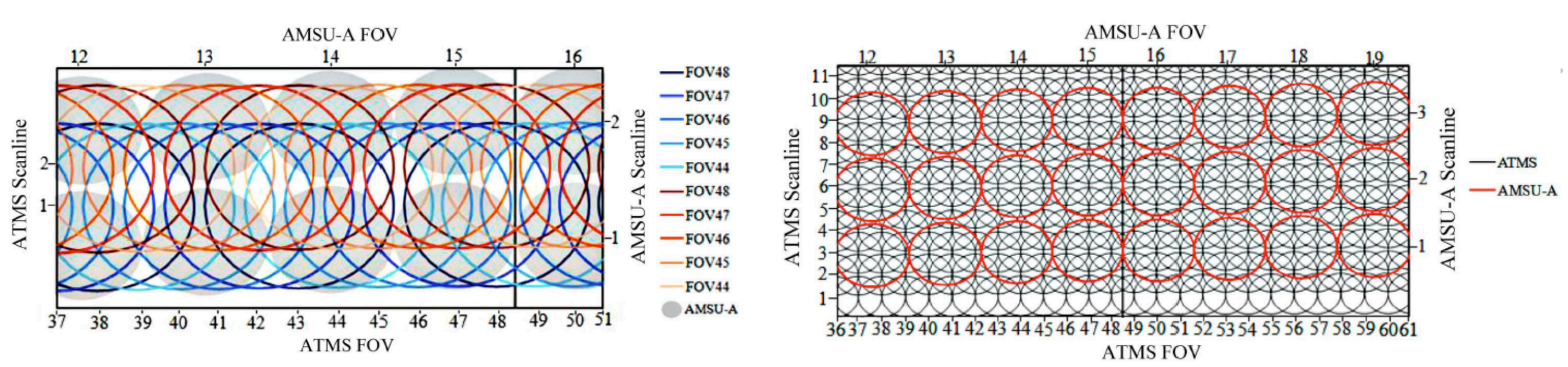


Fig. 1: FOVs for ATMS channels 1-2 (left) with ATMS beam width 5.2°, and channels 3-16 (right) with beam width 2.2°. The FOVs for AMSU-A onboard NOAA-18 are also shown. Figures From *Weng et al*., 2012.

Generation of AMSU-A Like ATMS Resample Data with Backus-Gilbert Algorithm

The Backus-Gilbert (B-G) inversion method is a process of finding a set of optimal weighting coefficients $w_{k_{i,j}}$ so that the k^{th} AMSU-A like ATMS data can be expressed as a linear combination of a total of $k_{i,j}$ adjacent ATMS brightness temperature

$$T_{a,k}^{resample} = \sum_{i,j=1}^{N_{ch}} w_{k_{i,j}} T_{a,k_{i,j}}^{ATMS}$$

The B-G algorithm seeks an optimal weighting coefficients $w_{k_{i,j}}$ by minimizing the following least-square problem

$$Q_0(w_{k_{i,j}}) = \int_{E_k} \left(\sum_{i,j=1}^{N_{ch}} w_{k_{i,j}} G_{k_{i,j},k}^{AMSU-A} - F(k_{i,j},k) \right)^2 dA$$

under the constraint (*Stogryn*, 1978)

$$\int_{E_k} \sum_{i,j=1}^{N_{ch}} w_{k_{i,j}} G_{k_{i,j},k}^{AMSU-A} \, dA = 1$$

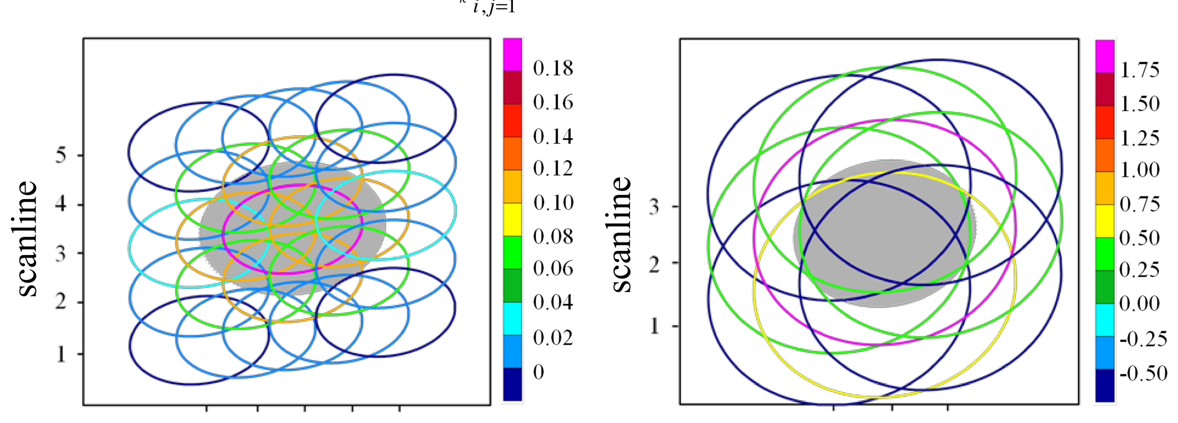


Fig. 2: The ATMS FOVs (circles) used for remapping into an AMSU-like FOV (shaded in light gray) for ATMS (a) channels 3-16 and (b) channels 1-2 FOVs. The magnitudes of B-G coefficients are indicated in colors. The integration time and satellite movement were taken into consideration.

LWP, IWP, and 10.8µm T^b within Hurricane Sandy

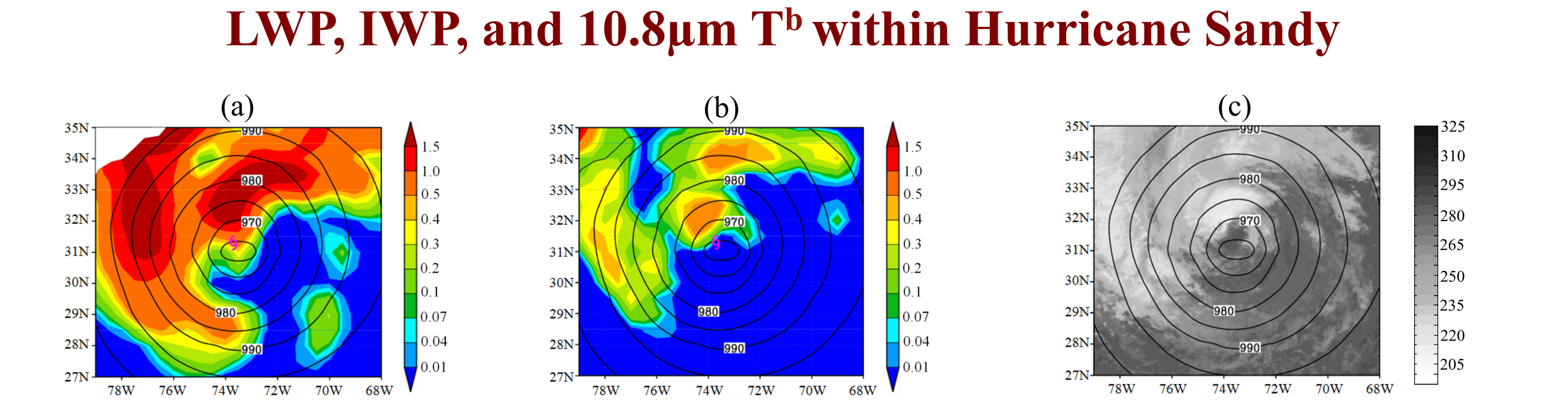


Fig. 3: (a) ATMS LWP from Suomi NPP and (b) MHS IWP retrievals and (c) brightness temperature observations of AVHRR channel 4 (10.8 µm) from NOAA-18 within Hurricane Sandy at 0600 UTC 28 October 2012. Hurricane Sandy is located at (31.3N, 73.7W). The SLP from NCEP GFS fields is plotted by contours at a 5-hPa interval.

Raw T^b and Remapped T^b of ATMS Data

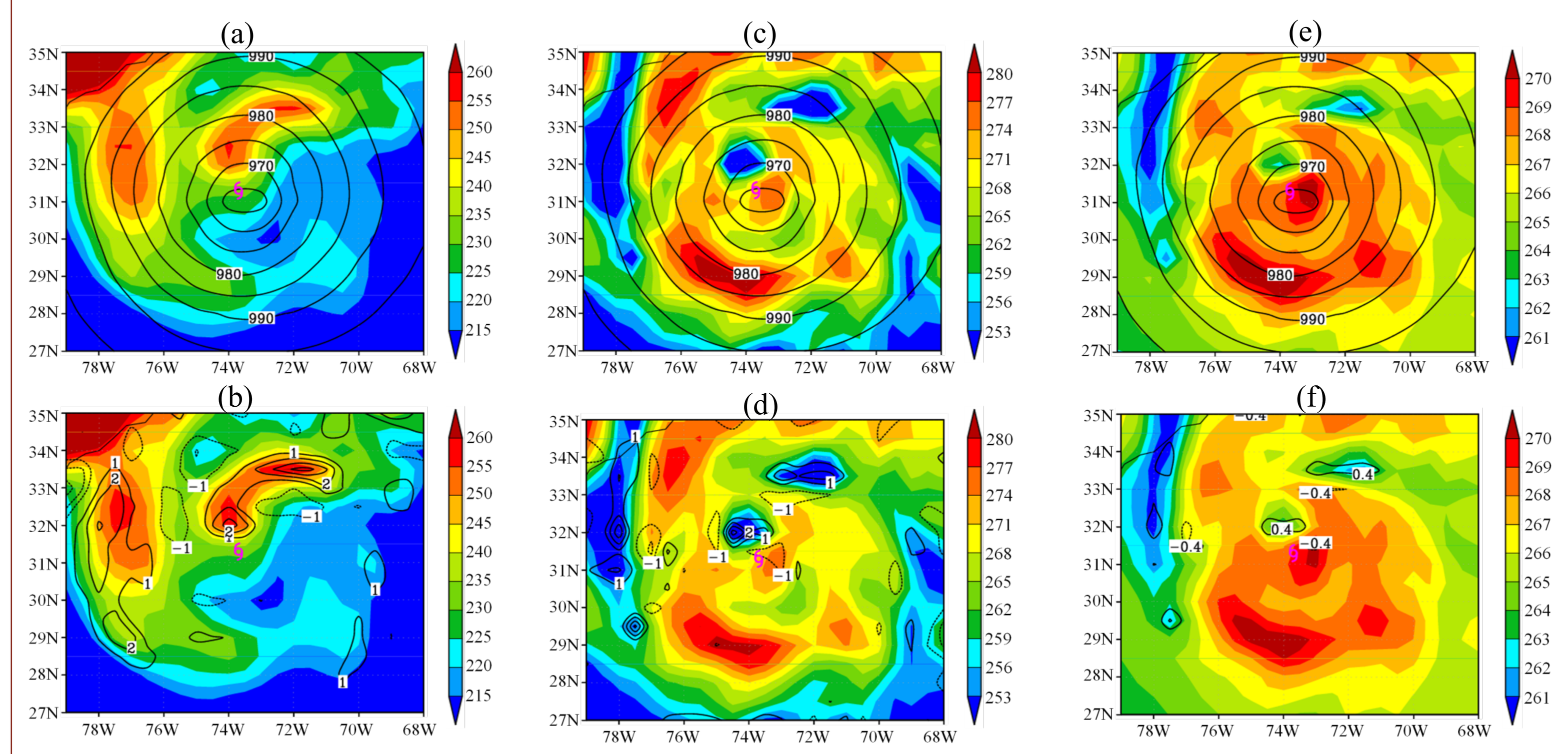
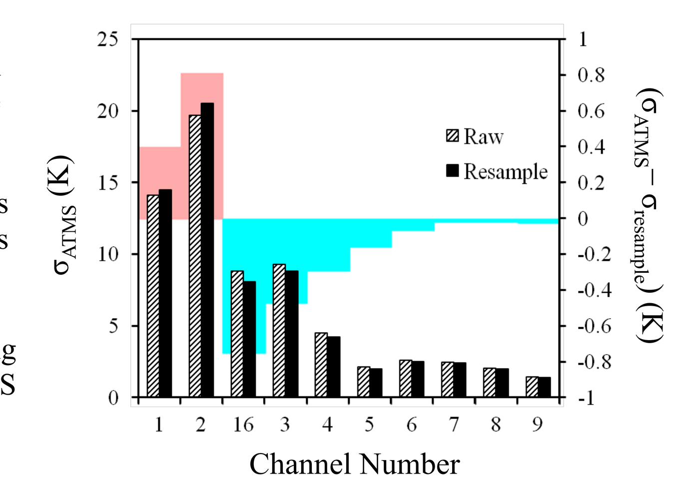


Fig. 4: ATMS brightness temperature observations for (a)-(b) channel 1, (c)-(d) channel 16 and channel 5 before (left panels) and after (right panels) resampling within Hurricane Sandy at 0600 UTC 28 October 2012. The SLP from NCEP GFS fields is plotted by contours (contour interval: 5 hPa). The differences introduced by resampling for channels 1 and 16

Standard Deviations of Remapped ATMS Data

- A resolution enhancement by remapping corresponds to an increase of the standard deviations of ATMS channels 1-2 on the order of 0.4-0.8 K
- A downscaling by remapping for ATMS channels 3-16 corresponds to a decrease of the standard deviations of measured brightness temperatures within Hurricane Sandy.
- Differences in standard deviations introduced by resampling decrease rapidly with the increase of channel number for ATMS temperature sounding channels.



Cross Calibration between Resample ATMS and AMUS-A

Coregistration of SNPP ATMS and NOAA-18 AMSU-A using the simultaneous nadir overpass (SNO) method ⇒ Remove outliers between $O^{ATMS\_resample}$ and $O^{ATMS\_resample} - O^{AMSU-A}$ ⇒ Derive the inter-satellite bias offset through linear regression

Coregistration of SNPP ATMS and NOAA-18 AMSU-A using the simultaneous nadir overpass (SNO) method

The SNO points between SNPP and NOAA-18 found during a 16 months period from January 1, 2012 to March 31, 2013 are used for the cross calibration between resample ATMS and AMSU-A data, as well as the cross calibration among AMSU-A data from NOAA-15, NOAA-18 and MetOp-A data.

The SNO points are found under the criteria

$$\begin{cases} \Delta s \le 15 \; km \\ \Delta t \le 60 \; seconds \end{cases}$$

Outliers Removal Between $O^{ATMS\_resample}$ and $O^{ATMS\_resample} - O^{AMSU-A}$

An SNO point is taken as an outlier if the brightness temperature difference of ATMS channel 5 is greater than 1 K or less than -2 K.

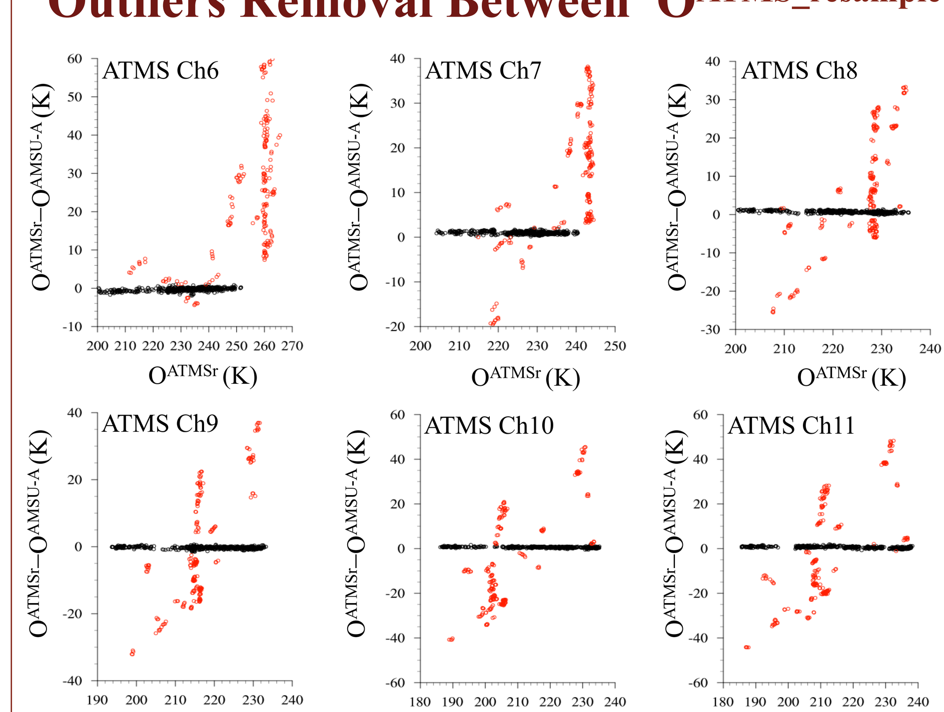


Fig. 5: Scatter plots of brightness temperature difference between resampled ATMS and AMSU-A data as a function of the resampled ATMS brightness temperature for ATMS channels 6-11. Outliers that are removed from cross calibration are indicated in each panel. The ATMS channel numbers are indicated in each panel.

Derivation of the Inter-satellite Bias Offset through linear Regression

Once outliers are removed, the remaining SNO points are used to derive an inter-satellite bias offset through a linear regression for each channel:

$$\mu_{ch} = \alpha_{ch} T_{b,ch} + \beta_{ch}$$

where the subscript "*ch*" indicates the ATMS channel number.

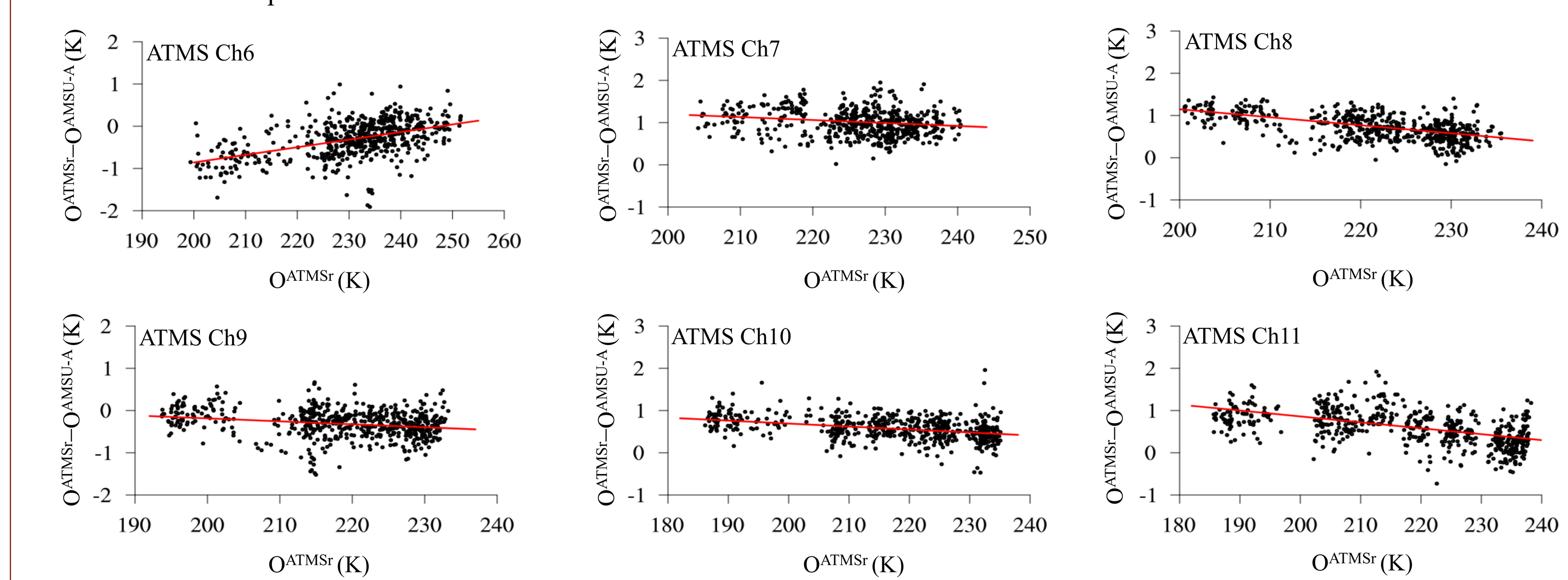


Fig. 6: Same as Fig. 5 except for removing outliers and adding the linear regression line in each panel (red line).

Time Series of T^b and Inter-satellite Difference

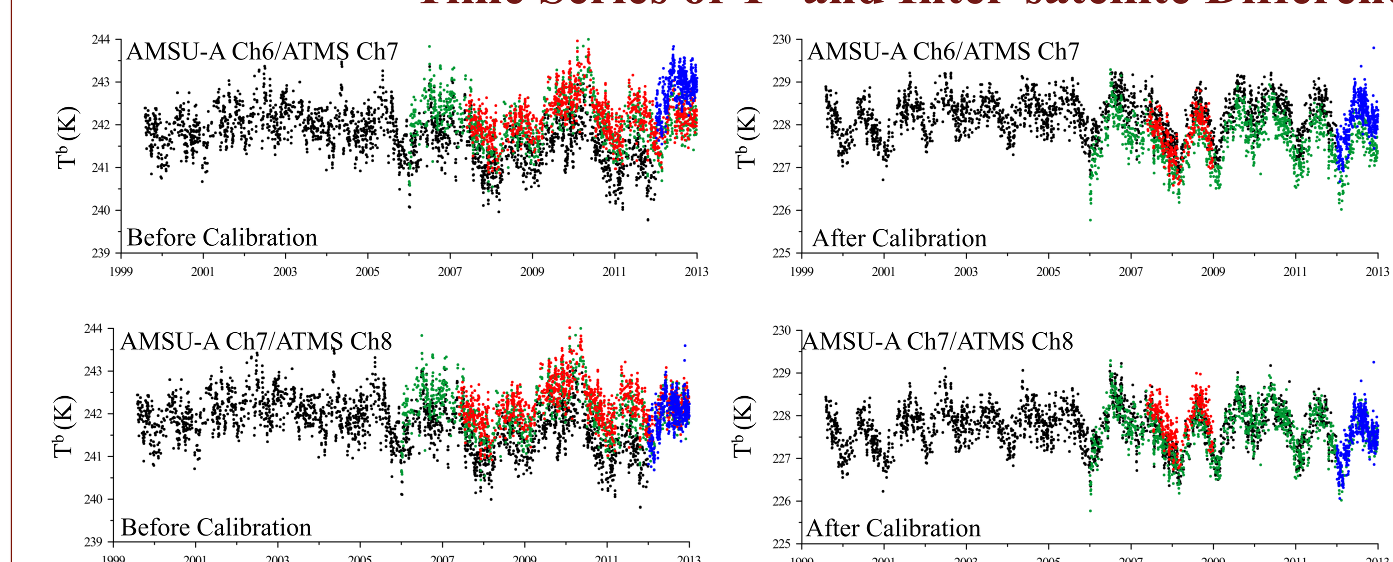


Fig. 7: Brightness temperatures at nadir within [2S-2N, 80W-100W] under clear-sky (e.g., LWP<0.01 kg m^{-2}) before (left panel) and after (right panel) SNO corrections for AMSU-A channel 6 from NOAA-15 (black), NOAA-18 (green), MetOp-A (red) and ATMS channel 7 (blue).

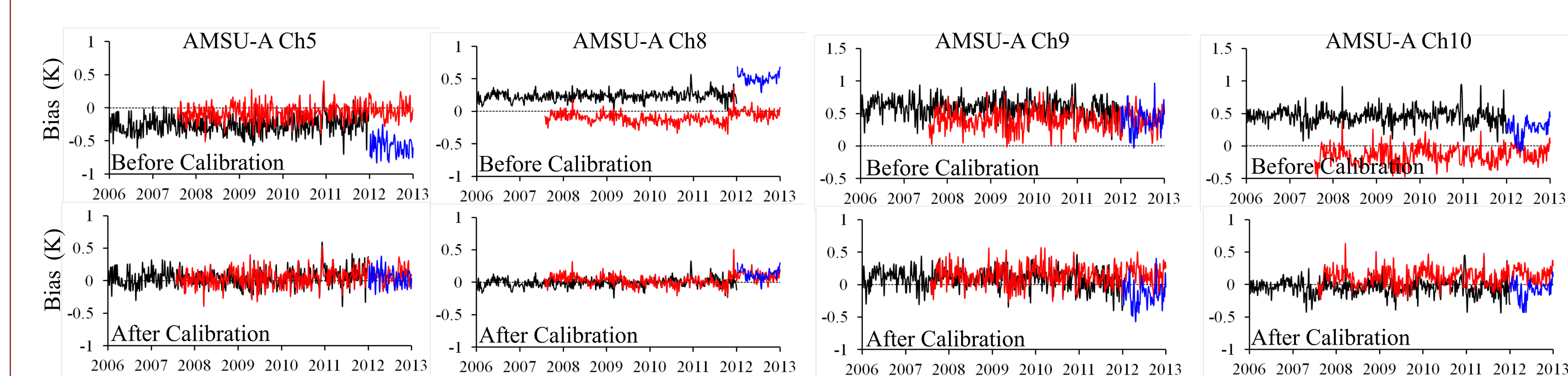


Fig. 8: Inter-satellite difference time series of the ocean mean clear-sky brightness temperature for the pentad data set within ±30°

Summary and Conclusions

The AMSU-A instrument have been on board NOAA and European meteorological satellites since the launch of NOAA-15 in 1998.The AMSU-A was replaced by the Advanced Technology Microwave Sounder (ATMS) when the NOAA SNPP satellite was launched on October 28, 2011. While allowing for improved applications to numerical weather prediction, some modifications in ATMS's channel frequency, data resolutions, beam width, and overlapping FOVs present new challenges for merging ATMS data to data from its predecessor heritage instruments AMSU-A and MHS combined.

This paper firstly applies the B-G method for converting the ATMS data to resample data in AMSU-A like FOVs, which is required for extending the time series of microwave temperature sounding observations for the purpose of monitoring climate change. A sub-pixel microwave antenna temperature simulation technique is employed for deriving a set of optimal weighting coefficients. An SNO matchup dataset for nadir pixels with criteria of simultaneity of less than 60 seconds and within a ground distance of 15 km is then generated for all overlaps of resample ATMS with AMSU-A onboard NOAA-18 from January 1 2012 to March 31 2013. The simultaneous and overlapping nature of these matchups eliminates the impact of orbital drifts and reduces weather-related impacts on the calibration. Finally, the performance of the B-G method and the SNO calibration method combined for merging microwave radiometers ATMS with AMSU-A data is analyzed.

It is found that availability of redundant information contained in different ATMS FOVs due to their overlapping features makes it possible to remap the AMTS observations into either a higher or a lower AMSU-A like spatial resolution of the same center frequency. Although the SNO matchups are confined within a latitudinal band centered around 81 degrees in both hemispheres due to orbital geometry, it is shown that brightness temperatures after SNO corrections are well merged to AMSU-A data from NOAA-15, NOAA-18 and MetOp-A satellites in two arbitrarily chosen tropical areas. The inter-satellite biases are very small among NOAA-15, NOAA-18, MetOp-A and SNPP.

Remapping of ATMS data into AMSU-A data resolution is a critical step for linking the ATMS data to NOAA MSU/AMSU time series and for creating a long-term fundamental climate data record in climate monitoring, re-analyses and forecasts. The present study will be substantiated as more ATMS data become available. We plan to continue the time series by merging the ATMS, AMSU and MSU observations using the SNO technique. In addition, a more refined inter-calibration work is ongoing. Once these merges are completed, the updated datasets will be put on the designated NOAA Web site for the scientific community to use.

Reference

Zou X., and H. Yang, 2013: Connecting the time series of microwave sounding observations from AMSU to ATMS for long-term monitoring of climate change, *J. Ocean Atmos. Tech. (submitted)*