Construction of a Consistent Microwave Sensor Temperature Record in the Lower Stratosphere Using Global Positioning System Radio Occultation Data and Microwave Sounding Measurements

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Abstract

In this study, we use FORMOSAT-3/Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) Global Positioning System (GPS) radio occultation (RO) data and CHAllenging Minisatellite Payload (CHAMP) data to simulate Advanced Microwave Sounding Unit (AMSU) brightness temperatures for the lower stratosphere (TLS) and compare them to AMSU TLS from different National Oceanic and Atmospheric Administration (NOAA) missions from 2001 to 2008. Our analysis shows that because RO data do not contain mission-dependent biases and orbit drift errors, and are not affected by on-orbit heating and cooling of the satellite component, they are very useful to identify the AMSU time/location dependent biases for different NOAA missions. Using RO simulated AMSU brightness temperatures, we calibrate AMSU TLS from different NOAA missions in the same month. A new microwave sensor temperature record in the lower stratosphere from 2001 to 2008 is constructed. The derived TLS record is compared with the newly available TLS datasets provided by Remote Sensing Systems (RSS) and University of Alabama in Huntsville (UAH). The causes of the TLS differences among these datasets are discussed.

Key word: GPS RO, AMSU, MSU, TLS

1. Introduction

The monitoring and detection of the vertical structure of atmospheric temperature trends are key elements in the climate change problem. Over the past decade, the roughly 30 years of Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) measurements have been extensively used for climate temperature trend detection (Christy et al. 2000, 2003; Mears et al. 2003; Grody et al. 2004; Zou et al. 2006). Because the MSU/AMSU operational calibration coefficients were obtained from pre-launch datasets (Mo et al. 2001), the orbital changes on MSU/AMSU measurements after launch may not be completely accommodated by these calibration coefficients. Different MSU/AMSU missions may contain different measurement biases, which actually vary with times and locations due to on-orbit heating or cooling of the satellite component (Ho et al., 2009a, b). Because the inter-calibration procedures used during periods of overlap are usually ill-determined and require subjective user judgment at some level and due to lack of an absolute reference, only relative biases are corrected. The temperature trends can still vary as much as 0.1K/decade when different satellite measurements are used as references (Christy et al., 2003), which leads to extra difficulties for the usage of MSU/AMSU temperature trends for the climate analysis (Christy et al. 2000, 2003; Mears et al. 2003; Grody et al. 2004; and Zou et al. 2006, Karl et al. 2006). See Karl et al., (2006) for a review.

The Global Positioning System (GPS) radio occultation (RO) is the first technique that can provide all-weather, high vertical resolution (from ~300 m near the surface to ~1.5 km at 40 km) refractivity profile. The basics of the GPS RO measurement is a timing measurement against reference clocks on the ground, which is timed and calibrated by the atomic clocks at the National Institutes for Standards and Technology (NIST). Compared to MSU/AMSU data, GPS RO data are not affected by weather, and don't have on-orbit calibration issue. Consequently, GPS RO data are ideally suited for use as a climate benchmark data type. Raw RO observations and precise positions and velocities of GPS and LEO satellites can be used to derive accurate atmospheric temperature and moisture profiles (Hajj et al., 2004; Kuo et al., 2004; Ho et al., 2009a,b). Significant advantages of SI-traceable GPS RO observations for climate monitoring include: (i) no satellite-to-satellite bias (Hajj et al., 2004; Ho et al., 2009a); (ii) great precision (Anthes et al., 2008; Foelsche et al., 2009; Ho et al., 2009a); and, (iii) no synoptic sampling bias (cloud / precipitation effects).

In this study, we use COSMIC data and CHAMP data to simulate AMSU brightness temperatures for the lower stratosphere (TLS) and compare them to AMSU TLS from different National Oceanic and Atmospheric Administration (NOAA) missions from June 2001 to

June 2008. Because RO data do not contain mission-dependent biases and orbit drift errors, and are not affected by on-orbit heating and cooling of the satellite component, they are very useful to identify the AMSU time/location dependent biases for different NOAA missions. RO TLS is used to calibrate NOAA AMSU TLS. Then the RO-consistent AMSU TLS from NOAA 15, 16, and 18 are used to construct a consistent microwave sensor temperature record in the lower stratosphere. A new microwave sensor temperature record in the lower stratosphere from 2001 to 2008 is constructed. The derived TLS record is compared with the newly available TLS datasets provided by Remote Sensing Systems (RSS) and University of Alabama in Huntsville (UAH). We describe datasets and analysis method used in the comparison procedure in Section 2. TLS differences from the newly constructed TLS with those from RSS and UAH are presented in Section 3. We conclude this study in Section 4.

2. Data and Methodology

The UAH MSU/AMSU Version 5.1 dataset (Christy et al. 2003) is used in this study. Both MSU/AMSU Tb on board NOA AM and PM satellites are included in this version. The monthly global temperature anomaly dataset contain 2.5 degree × 2.5 degree gridded mean values ranging from 82.5°S to 82.5°N. RSS MSU/AMSU Version 3.2 dataset is used in this study.

In this study, we apply all available RO temperature soundings from CHAMP and COSMIC from 2001 to 2008 to AMSU forward model to simulate AMSU TLS. A two-step strategy is implemented.

1) To perform the conversion of CHAMP temperature profiles into microwave Tb, an AMSU fast forward model from CIMSS (MWF_{CIMSS}) with 100 fixed pressure levels (Hal Woolf, CIMSS, personal communication, 2005), which was operationally employed in the International ATOVS Processing Package developed at SSEC, University of Wisconsin, was used here.

2) Then we match simulated GPS RO TLS to NOAA AMSU TLS within 30 minutes and 0.5 degree to find calibration coefficients for different NOAA satellites so that we can use GPS RO data to inter-calibrate other NOAA satellite. Then we use the NOAA satellite measurements calibrated by GPS RO data to calibrate multi-year AMSU/MSU data and generate consistent RO and MSU/AMSU TLS climate data records from 2001 to 2008.

Figure 1 depicts the scattering plot for the forward calculated COSMIC temperature in the lower stratosphere (TLS, e.g., AMSU Ch9) in September 2003 compared against the matched AMSU TLS from NOAA 18 (N18). Around 580 matched pairs for the whole month are used. The small but significant offset shown in Figure 1 indicates inadequate calibration for N18 AMSU measurements due to possible orbital decay since its launch time. The very high correlation coefficient (~0.998) between COSMIC and AMSU TLS with very small TLS differences (root mean square errors are all less than 1.2 K for these three cases) gives us confidence in our approach. Using this approach, the AMSU monthly on-orbit decay can then be quantified and corrected through these monthly RO-AMSU collocation pairs.

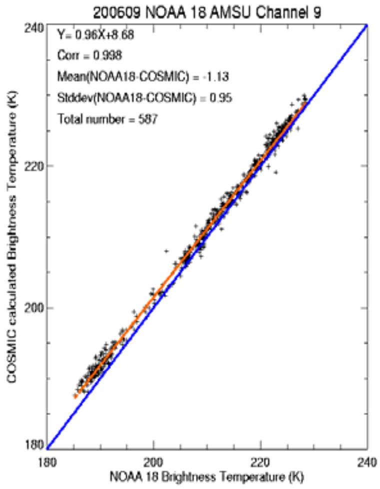

Figure 1. The scattering plot for the forward calculated COSMIC TLS in September 2003 compared against the matched AMSU TLS from NOAA18.

3. Results

With about 7 years (84 months) of data pairs, we can examine the TLS for RSS (RSS_{TLS}) and TLS for UAH (UAH_{TLS}) Tb anomalies against that of COSMIC and CHAMP data (RO_AMSU TLS). Figure 2 depicts RSS, UAH, and RO_AMSU TLS time series anomalies for (a) the global (82.5˚ N to 82.5˚ S region), (b) 60˚ N to 82.5˚ N zone, (c) 20˚ N to 60˚ N zone, (d) 20˚ N to 20˚ S zone, (e) 20˚ S to 60˚ S zone, and (f) 60˚ S to 82.5˚ S zone. The best-fit linear trend (the slope of the linear fit) of each processing center is also generated. In general, the de-seasonalized Tb anomalies from UAH_{TLS} and RSS_{TLS} are consistent with that from RO_AMSU TLS globally (Fig. 2a), the trends (in K/5year) found from RSS_{TLS}, UAH_{TLS} and RO_{TLS} Tb anomalies, however, vary at different latitudinal zones (Table 1).

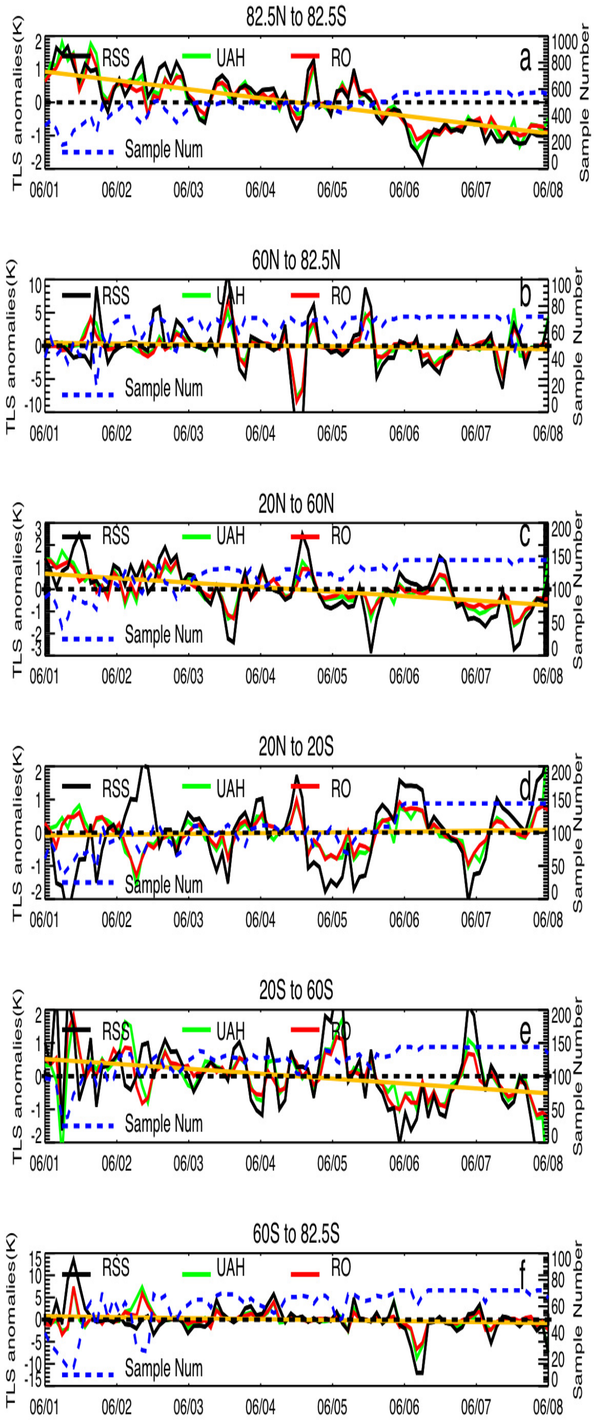

Figure 2. The de-seasonalized lower stratospheric Tb anomalies of RSS, UAH and CHAMP for (a) the global (82.5˚ N to 82.5˚ S region), (b) 60˚ N to 82.5˚ N zone, (c) 20˚ N to 60˚ N zone, (d) 20˚ N to 20˚ S zone, (e) 20˚ S to 60˚ S zone, and (f) 60˚ S to 82.5˚ S zone. The orange line indicates the mean trend for RSS. The corresponding numbers of matching pairs for each month in each latitudinal zone are in blue dash lines.

	RSS	UAH	RO_AMSU	RSS-RO_AMSU	UAH-RO_AMSU
82.5°N-82.5° S	**-0.52**	**-0.43**	**-0.37**	**-0.15**	**-0.06**
60°N - 82.5° N	**-1.21**	**-0.84**	**-0.76**	**-0.45**	**-0.08**
20° N - 60° N	**-0.62**	**-0.3**	**-0.22**	**-0.42**	**-0.08**
20° N - 20° S	**0.31**	**-0.09**	**-0.06**	**0.37**	**-0.03**
20° S - 60° S	**-0.19**	**-0.23**	**-0.14**	**-0.05**	**-0.09**
60°S - 82.5° S	**-2.58**	**-1.43**	**-1.39**	**1.19**	**-0.04**

Table 1. The 2001-2008 trends of de-seasonalized lower stratospheric Tb anomalies (in K/5yrs) for RSS, UAH, RO_AMSU, RSS-RO_AMSU and UAH-RO_AMSU for the global (82.5°N-82.5° S) and five latitudinal zones.

4. Conclusions

In this study, we use RO simulated AMSU brightness temperatures to calibrate AMSU TLS from different NOAA missions in the same month. A new microwave sensor temperature record in the lower stratosphere from 2001 to 2008 is constructed. The derived TLS record is compared with the newly available TLS datasets provided by RSS and UAH from 2001 to 2008. We reached the following conclusions.

1) he highly precise RO soundings are very useful to inter-calibrate AMSU/MSU data.
2) The long-term stability of GPS RO data is very useful for climate monitoring.
3) The de-seasonalized TLS anomalies from UAH and RSS are, in general, agree well with that from RO calibrated AMSU Tb in all latitudinal zones. Small trend differences are found between UAH and RO-calibrated AMSU TLS.

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