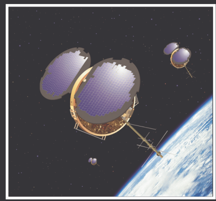

Validation of Microwave Lower Stratosphere Temperature using CHAMP GPS RO Data

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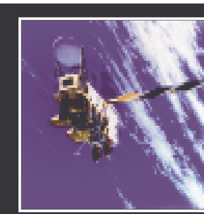
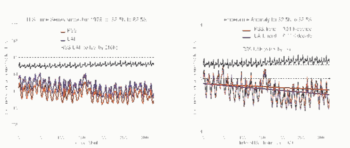


Introduction and Challenge

Introduction : The monitoring and detection of atmospheric temperature trends are key climate change problems.

Challenge :

- **NOAA AMSU/MSU satellite data**: On board the NOAA series of polar orbiting satellites, Microwave Sounding Unit (MSU) has provided data for climate studies since its inception in 1979. Beginning in 1998, the MSU has been replaced by the Advanced Microwave Sounding Unit (AMSU), which has similar channels with MSU. Because MSU/AMSU measurements, which are in the 50 to 70 GHz oxygen band, are directly proportional to the specific atmospheric layer temperatures corresponding to the weighting functions and are not affected by clouds, MSU/AMSU data are able to provide long-term temperature trend analysis of different atmospheric layers.
- **Difficulties** : due to changing platforms and instruments, different diurnal cycle sampling, and orbital decaying, it remains a significant challenge to use this dataset to construct homogeneous temperature records.
- **Current debate** : the trends derived from these measurements are under significant debate, with different groups [Mears et al. 2003 from Remote Sensing System (RSS) Inc, Christy et al. 2003 from University of Alabama in Huntsville (UAH)], yielding different trends.



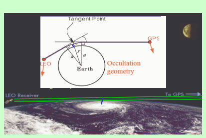
Objective

- **GPS RO data** :Because the basics of the GPS RO observation is a measurement of radio signal delay time against reference atomic clocks on the ground, GPS RO data, unlike MSU radiances, do not contain on-orbit drift errors and satellite-to-satellite bias. Therefore, it presents a unique opportunity to independently validate the analyzed brightness temperature from MSU/AMSU by RSS and UAH and to understand the possible causes of differences in temperature trends reported by these two teams.

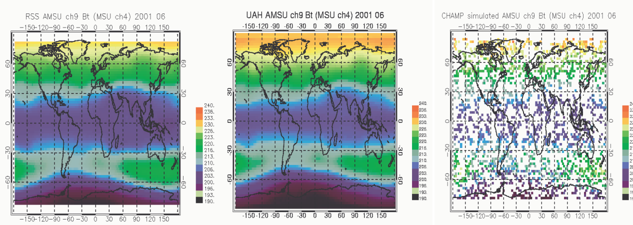
- **Objective : To validate the microwave brightness temperature for the Lower Stratosphere (TLS) datasets provided by RSS and UAH against the GPS radio occultation (RO) data from Challenging Mini-satellite Payload (CHAMP) over 51 months.**

Data

1. RSS monthly mean TLS brightness temperature (BT) in 2.5x2.5 grid: 51 months of RSS V02_1TLS BT download from RSS ftp site.
2. UAH monthly mean TLS BT in 2.5x2.5 grid: 51 months of UAH V5.1 BT download from UAH ftp site.
3. CHAMP dry temperature profiles: 51 months of CHMAP data downloaded from UCAR COSMIC CDACC

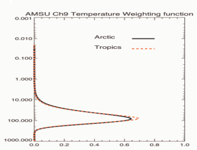


Approaches



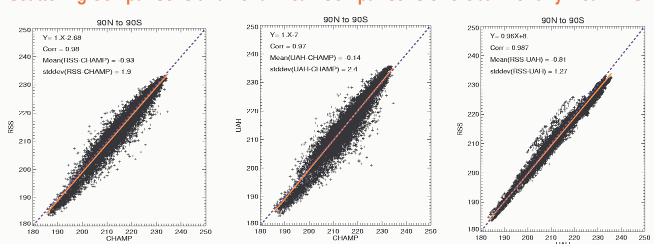
AMSU Channel 9 TLS in 2.5 degree x2.5 degree grid for RSS, UAH and CHAMP computed TLS

1. We first bin GPS RO soundings into each 2.5 degree x 2.5 degree grid to match the same spatial resolution of RSS and UAH data for the same month for each month.
2. Because temperature weighting function varies at different atmospheric temperature structures, we apply each 2.5 degree x2.5 degree gridded monthly mean CHAMP profile to Microwave forward model to simulate AMSU-9 BTs (TLS). Satellite viewing angle is set to nadir for our calculations to reduce the BT dependence on viewing geometry.
3. In order to reduce possible spatial and temporal representation errors at each grid box, we further bin each monthly mean MSU/AMSU and CHAMP 2.5 degree x2.5 degree matched pairs into 10 degree x10 degree grids.



AMSU Channel 9 Atmospheric weighting functions for a typical atmospheric profile in the Tropics and the Arctic, respectively. The weighting function is defined as d(transmittance)/dln(p).

Scattering Comparisons and Zonal Mean Comparisons of Global Monthly Mean TLS



The comparisons of global monthly mean TLS for each 10 degree x10 degree grid between RSS and CHAMP, UAH and CHAMP and RSS and UAH.

- The correlation coefficients of CHAMP-RSS pairs and CHAMP-UAH pairs are 0.98 and 0.97, respectively. Consistent differences (biases) between RSS_{TLS} and $CHAMP_{TLS}$ and between UAH_{TLS} and $CHAMP_{TLS}$ are found. Although the absolute difference between RSS_{TLS} and $CHAMP_{TLS}$ is larger (0.93K) than that between UAH_{TLS} and $CHAMP_{TLS}$ (0.14K), the standard deviation (Std) between RSS_{TLS} and $CHAMP_{TLS}$ (1.9 K) is smaller than that between UAH_{TLS} and $CHAMP_{TLS}$ (2.4K). RSS_{TLS} is systematically lower (0.81K) than UAH_{TLS}.

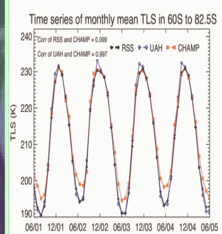
- Table 1 shows that RSS-CHAMP pairs are much closely correlated (smaller Stds and larger correlation coefficients) than that of UAH-CHAMP pairs in all latitudinal zones.

		RSS-CHAMP	UAH-CHAMP	RSS-UAH
60°N - 82.5°N	Correlation Coef. Mean Std	0.97 (0.97) -0.8 1.9 (0.68)	0.93 (0.97) 0.41 2.8 (0.69)	0.975 (0.97) -1.2 1.85 (0.25)
20° N - 60° N	Correlation Coef. Mean Std	0.97 (0.98) -1.45 1.4 (0.16)	0.96 (0.97) -0.33 1.6 (0.18)	0.989 (0.99) -1.11 0.88 (0.09)
20° N - 20° S	Correlation Coef. Mean Std	0.93 (0.95) -0.87 0.6 (0.17)	0.9 (0.95) -0.17 1. (0.2)	0.96 (0.99) -0.7 0.73 (0.08)
20° S - 60° S	Correlation Coef. Mean Std	0.94 (0.74) 0.08 1.8 (0.4)	0.9 (0.76) 0.69 2.47 (0.38)	0.98 (0.98) -0.62 1.02 (0.13)
60° S - 82.5° S	Correlation Coef. Mean Std	0.99 (0.98) -1.9 2.7 (0.56)	0.98 (0.96) -1.5 3.4 (0.67)	0.995 (0.99) -0.43 1.4 (0.33)

Table 1. The list of the correlation coefficients, mean biases (K) and standard deviations (K) to the mean TLS differences for RSS-CHAMP, UAH-CHAMP and RSS-UAH pairs for five latitudinal zones. The values in the parenthesis are corresponding correlation coefficients and standard deviations for the deseasonalized TLS anomalies.

The Time Series of Monthly Mean Comparisons

- The time series of RSS_{TLS}, UAH_{TLS} and $CHAMP_{TLS}$ demonstrate that all CHAMP, RSS and UAH TLS capture the prominent seasonal variations at different latitudinal zones.
- Although RSS_{TLS} and UAH_{TLS} are in general agreement with $CHAMP_{TLS}$ globally (Table 1), $CHAMP_{TLS}$ has 2-4 K systematic positive bias compared to both RSS_{TLS} and UAH_{TLS} at South Pole region (60˚S to 82.5˚S) during the South hemisphere winter.

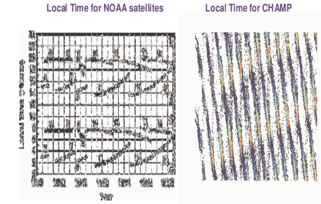


The time series of monthly mean values from June 2001 to August 2005 for RSS, UAH and CHAMP TLS for 60°S to 82.5°S.

The fact that this systematic difference cannot be explained either by the CHAMP dry temperature inversion procedure or by the temperature inversion procedure or by the procedures used to compare CHAMP soundings with microwave TLS may indicate unknown calibration anomaly for microwave sounders.

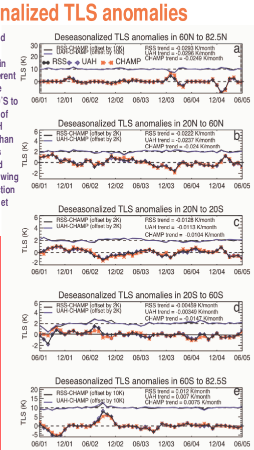
Possible Error Sources :

1. Spatial mismatch errors: In the procedure to produce $CHAMP_{TLS}$, we use the same RSS, UAH and CHAMP 2.5 degree x 2.5 degree pairs to minimize the spatial representation errors.
2. Temporal sampling differences : according to upper-air temperature estimates using radiosondes, the diurnal variation for TLS is generally less than 1 K [Seidel et al, 2005].
3. Uncertainty associated with ionospheric calibration lead to CHAMP dry temperature retrieval errors : We found a less than 1 K mean difference between CHAMP and SAC-C (CHAMP – SAC-C) at the height from 25 km to 30 km, which contributes to less than 0.1 K CHAMP simulated BT mean difference after applying the AMSU TLS weighting function.



Time series of deseasonalized TLS anomalies

- The deseasonalized TLS anomalies from UAH and RSS are consistent with that from CHAMP in all latitudinal zones. However, the computed trends (in K/month) from RSS, UAH and CHAMP vary at different latitudinal zones. The largest trend differences are found in the middle latitude south Hemisphere (20˚S to 60˚S) (Fig. d). In this 20˚S to 60˚S zone, the trends of TLS anomalies for RSS (-0.0046 k/month) and UAH (-0.0035 K/month) are three to four times smaller than that of CHAMP (-0.015 K/month). The cause of this trend of TLS anomalies difference among RSS and UAH especially in the south Hemisphere may be owing to the effect of different approaches for the correction of the on-orbit drift from these two groups [Mears et al. 2005].



The time series of deseasonalized anomalies for RSS, UAH and CHAMP TLS for (a) 60°N to 82.5°N, (b) 20°N to 60°N, (c) 20°N to 20°S, (d) 20°S to 60°S and (e) 60°S to 82.5°S.

Conclusions and Future Works

- The results in this paper generally demonstrate excellent agreement of monthly mean TLS between RSS and UAH to that of CHAMP data on the 10 degree x 10 degree grids. The subtle differences between RSS and UAH datasets caused by different calibration procedures were revealed using high precision CHAMP data. The $CHAMP_{TLS}$ matches better with that of RSS in terms of variations (higher correlation coefficient and smaller Stds) and matches better with that of UAH in terms of mean. RSS_{TLS} is systematically 0.93 K to 1.9 K lower than that of CHAMP at almost all latitudinal zones except for the 20°S to 60°S zone. The Stds between UAH_{TLS} and $CHAMP_{TLS}$ varies from 1 K (in 20°N to 20°S zone) to 3.4 K (in 60°S to 82.5°S zone), which is about 25% higher than that between RSS_{TLS} and $CHAMP_{TLS}$.

- A systematic cold bias at the latitudinal zone of 60°S to 82.5°S during the South Hemisphere winter was found for both RSS_{TLS} and UAH_{TLS} when comparing to $CHAMP_{TLS}$. This systematic bias cannot be explained either by the CHAMP dry temperature inversion procedure or by the procedures to convert CHAMP soundings to AMSU BTs and the procedure to bin the $CHAMP_{TLS}$ to the same spatial grids of the microwave data. In addition, although the deseasonalized TLS anomalies from UAH and RSS are, in general, agree with that from CHAMP in all latitudinal zones, large trend differences are found between RSS and UAH with that of CHAMP especially in the south Hemisphere. Further analysis on this topic and the cause of the systematic difference between CHAMP TLS and that for RSS and UAH in the South Pole region will be the subject of a future study.

- COSMIC was successfully launched on 15 April 2006. It will provide about 2,500 GPS RO profiles per day after it is fully deployed, which is about an order of magnitude more than the currently available GPS RO soundings from CHAMP and SAC-C. With COSMIC GPS RO soundings, we will be able to find finer regional patterns and atmospheric temperature trends with even smaller spatial and temporal mismatches with that from MSU and AMSU data.

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