# **GPS-RO as a Reference to Monitor Microwave/Infrared Sounder Observations**

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This document is in response to an action placed by Mitch Goldberg, GSICS Executive Director, on GRWG, which was subsequently passed onto the MW Subgroup - *[EP-18.02] GRWG to assess the utilization RO for microwave instrument monitoring purposes.*

The GPS-RO data are provided by receivers onboard low Earth orbiting (LEO) satellites. As an LEO satellite sets or rises behind the Earth’s limb relative to the GPS transmitter satellite, the onboard GPS receiver takes measurements of the phase and amplitude of the GPS signals. These phase measurements, together with the precise knowledge of the positions and velocities of the GPS and LEO satellites, can be collectively used to derive accurate information on the thermodynamic state of the atmosphere using the radio occultation (RO) technique (Kursinski et al. 1997). GPS-RO data are minimally affected by aerosols, clouds, or precipitation and are not expected to have instrument drift and satellite-to-satellite instrument bias. In contrast to the microwave sounders, the raw GPS-RO measurement is not based on a physical device that deteriorates with time---their performance is directly traceable to an absolute SI standard: International Atomic Time. Consequently, there is no need for calibration. This makes this limb-sounding technique extremely useful for calibration of other nadir sensors such as MSU/AMSU stratospheric channels (e.g., Ho et al. 2009).

Although many literature studies refer to GPS-RO temperature profile data as having an absolute accuracy of about 1K with a precision of 0.1K between ~5-25 km, our current view is that this too conservative. Indeed, GPS-RO data are treated as the ‘truth’ in the NWP data assimilation process, i.e., bending angles or refractivity are directly assimilated into NWP models and thus no bias correction is conducted before the data are assimilated into NWP models. This treatment actually improved the NWP forecasting skills (Kuo et al. 2000; Healy and Thepaut 2006, Poli et al. 2010).

Many studies (e.g., Zou and Wang 2012, He et al. 2014, Zou et al. 2014, Isoz et al. 2015, Moradi et al., 2015) have already used the GPS-RO data to characterize biases in microwave sounding observations. Figure 1 shows a comparison between GPS-RO temperature profiles and AMSU-A channel-9 observations. Statistics describing differences between GPS-RO retrievals the AMSU-A radiance measurements can be derived from such a comparison, such as mean and RMS difference as well as more in-depth information such as the dependence of such statistics on scene temperature.. Since GPS-RO retrievals are extremely stable, they can also be used to monitor bias jumps in other satellite observations due to calibration changes, instrument anomalies, and changes in local measurement time1, etc.

Based on these observations, we recommend the use of GPS-RO data as a reference source to monitor NOAA microwave and infrared temperature sounding data (i.e L1B) for upper tropospheric and lower stratospheric channels (i.e., AMSU-A channels 8-12) where moisture effects and instrument noise are negligible1. This could be established as part of the NOAA CAL/VAL plan with assistance from GSICS in the analysis of the monitoring results. The technology to perform this monitoring is already available at NOAA/STAR. This includes the capability of finding collocations between GPS-RO and NOAA satellites and converting the GPS-RO temperature profiles into channel-equivalent radiances for both microwave and infrared sounders using Community Radiative Transfer Model (CRTM) simulations. This allows direct comparisons between GPS-RO retrievals and sounder radiances.

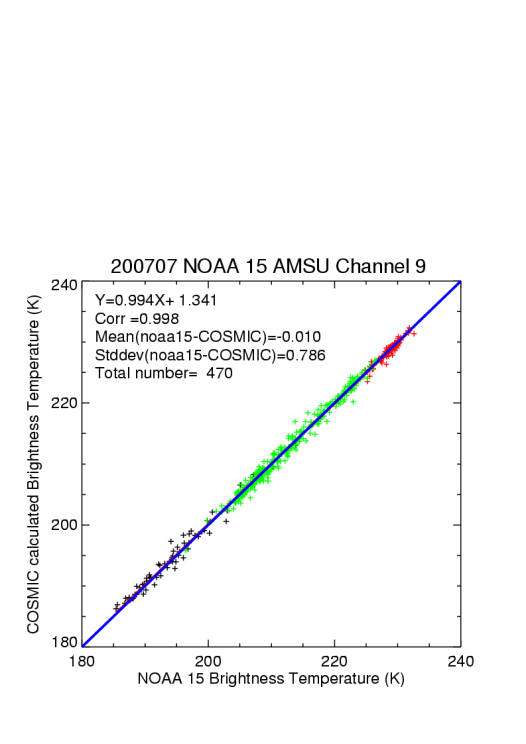


Figure 1 Scatter plot between the AMSU-A channel 9 brightness temperature at the 15th footprint onboard NOAA-15 and the collocated COSMIC retrievals during July 2007. The red dots represent the Arctic (60°N-90°N) data, the blue dots the Antarctic (60°S-90°S) data, and the green dots for the rest of the Earth (60°N-60°S). The AMSU-A data is from those recalibrated using IMICA approach (plot taken from Zou and Wang 2012).

**References:**

He, W.Y, C.-Z. Zou, and H. B Chen, 2014: Validation of AMSU-A measurements from two

different calibrations in the lower stratosphere using COSMIC radio occultation data, *CHINESE SCIENCE BULLETIN,* **59**, 1159-1166 *,* DOI: 10.1007/s11434-014-0125-9

Healy, S.B., and J.-N. Thepaut, 2006: Assimilation experiments with CHAMP GPS radio

occultation measurements, *Q. J. R. Meteorol. Soc.*, **132**, pp. 605–623 doi: 10.1256/qj.04.182

Ho, S. P., M. Goldberg, Y. H. Kuo, C.-Z. Zou, and W. Schreiner, 2009: Calibration of

temperature in the lower stratosphere from microwave measurements using COSMIC radio occultation data: Preliminary results. *Terr. Atmos. Ocean. Sci*., **20**, 87-100, doi: 10.3319/TAO.2007.12.06.01(F3C)

Isoz, O., S. A. Buehler, and P. Eriksson (2015), Inter-calibration of microwave temperature

sounders using radio occultation measurements, *J. Geophys. Res. Atmos.*, **120,** 3758–3773, doi:10.1002/2014JD022699.

Khaykin, S. M., et al. (2017), Post-millennium changes in stratospheric temperature consistently

resolved by GPS radio occultation and AMSU observations, *Geophys. Res. Lett.,*

**44**, 7510–7518, doi:10.1002/2017GL074353.

Kuo Y. H, Sokolovskiy S, Anthes R, Vandenberghe V. 2000: Assimilation of GPS radio

occultation data for numerical weather prediction. *Terr.* *Atmos. Oceanic Sci.* **11**: 157–186.

Kursinski ER, Hajj GA, Schofield JT, Linfield RP, Hardy KR. 1997. Observing Earth’s

atmosphere with radio occultation measurements using the Global Positioning System. *J. Geophys. Res.* **102**: D23429–23465.

Moradi, I., Ferraro, R. R., Eriksson, P., and Weng, F.: Intercalibration and validation of observations from ATMS and SAPHIR microwave sounders, *IEEE Trans. Geosci. Remote Sens.,* **53**, 5915-5925.

Poli P., Healy S.B., Dee D. P., 2010: Assimilation of Global Positioning System radio

occultation Data in the ECMWF ERA–Interim reanalysis. *Q. J. R. Meteorol. Soc.* **136**:

1972–1990. DOI:10.1002/qj.722

Zou, C.-Z., W. Wang, 2012, MSU/AMSU Radiance Fundamental Climate Data Record

Calibrated Using Simultaneous Nadir Overpasses Climate Algorithm Theoretical Basis Document (C-ATBD), NOAA/NESDIS

Zou, X., L. Lin, and F. Weng, 2014: Absolute Calibration of ATMS Upper Level Temperature

Sounding Channels Using GPS RO Observations, *IEEE Trans. Geosci. Remote Sens.,* **52**, 1397-1406.