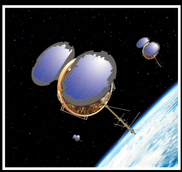


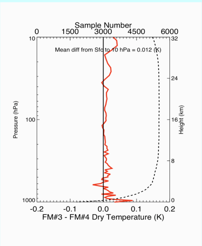
Assessment of Systematic Biases of Radiosonde Temperature and Moisture Measurements using Global Positioning System Radio Occultation from COSMIC

Shu-peng Ho, Ying-Hwa Kuo, Doug Hunt, Chris Rocken, William Schreiner, and Sergey Sokolovskiy
University Corporation for Atmospheric Research, Boulder, Colorado
Corresponding author address : Dr. Shu-Peng Ho, COSMIC, UCAR, PO BOX 3000 Boulder, Colorado, 80307-3000.
E-mail address: spho@ucar.edu, Tel: (303)497-2922

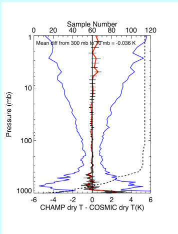
1. Introduction

Because the time delay of RO signal is traceable to international standards of time (SI traceability), GPS RO data, unlike radiosondes and satellite microwave sounders, are not affected by the changing of on-orbit extreme environments and are consistent with geographical locations (Kuo 2004, Ho et al., 2009a, b). In this study, we use COSMIC RO temperature and moisture profiles to identify the possible temperature and moisture biases from radiosonde, where sensor characteristics vary considerably in times and locations for different sensor types.

Characteristics of GPS RO Data:
- **Measure of time delay: no calibration is needed**
- **Requires no first guess sounding**
- **Uniform spatial/temporal coverage**
- **High precision**
- **No satellite-to-satellite bias**



Precision < 0.05 K



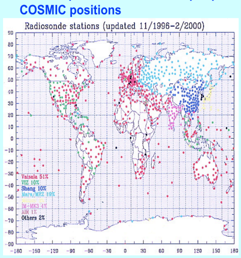
Satellite-satellite bias < 0.05 K

2. Data and Approach: Using COSMIC RO data to assess the quality of radiosonde data

RO temperature and water vapor profiles from the early phase of COSMIC mission from August 2006 to November 2006 are used in this study. In the neutral atmosphere, refractivity (N) is related to pressure (P), temperature (T) and partial pressure of water vapor (P_W) by the following equation

$$N = 77.6\frac{P}{T} + 3.73\times10^5\frac{P_W}{T^2}$$

Matching the following data :
COSMIC RO temperature and moisture profiles
Radiosonde temperature and water vapor measurements within 2 hours and 300 km of those from COSMIC soundings
ECMWF temperature and water vapor profiles interpolated into COSMIC positions



Region	Sonde Type	Matched Sample
Russia	AVK-MRZ	2000 (20%)
China	Shang	650 (6.1%)
USA	VIZ-B2	600 (5.9%)
Others	Vaisala	3140 (30%)

3. The Usefulness of COSMIC Data to Identify Temperature Biases of Different Types of Radiosonde Systems in the Upper Troposphere and Lower Stratosphere

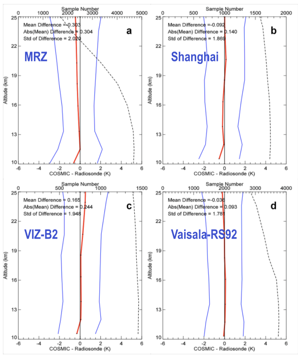
For each COSMIC and radiosonde match, we compute the difference between COSMIC dry temperature and radiosonde temperature at vertical level i

$\Delta T_{CR}(i)$ =COSMIC(i)-radiosonde(i)

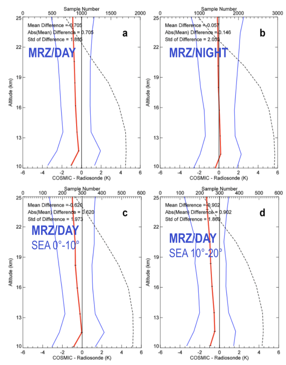
$SD_{\Delta T_{CR}}$ = the standard deviation of the temperature difference at vertical level i

Table 1. Mean and standard deviation of temperature differences from 10 km to 25 km between COSMIC and four types of radiosonde. [1]The percentage of the observation numbers of the radiosonde type to the global radiosonde observations available in the same time period.

Manufacturer	Radiosonde Type (WMO Buffer number)	Number of matches (percentage[1])	$\overline{\Delta T_{CR}}$ / ($SD_{\overline{\Delta T_{CR}}}$) (K)
Russia	MRZ (27)	4728 (17.8%)	-0.30/(2.02)
China	Shanghai (32)	1751 (6.6%)	-0.09/(1.87)
USA	VIZ-B2 (51)	1474 (5.6%)	0.17/(1.95)
Finland	Vaisala-RS92 (80)	3786 (14.3%)	-0.04/(1.78)



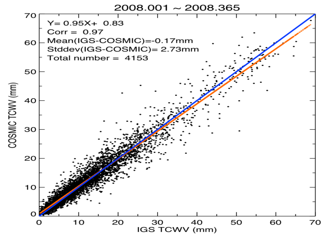
Comparisons of temperature between COSMIC and radiosonde for a) MRZ, b) Shanghai, c) VIZ-B2, and d) Vaisala-RS92 (the red line is the mean difference; the horizontal black lines superimposed on the mean are the standard error of the mean; the blue line is the standard deviation; the dotted line is the sample number. The top X axis shows the sample number. The same symbols are also used for the following plots).



Temperature difference between COSMIC and MRZ radiosonde in a) day, and b) night, and c) for solar elevation angle (SEA) 0°-10°, and d) for solar elevation angle 10°-20°.

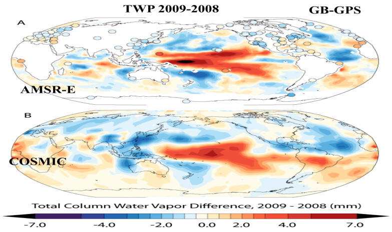
4. Global Validation of COSMIC 1D-Var Water Vapor Retrievals

Using refractivity data and reasonably independent temperature profiles, highly precise COSMIC water vapor profiles can be derived. Comparisons of total column water vapor (TCWV) from COSMIC with those derived from ground-based GPS (i.e., International Global Navigation Satellite Systems–IGS, *Wang et al., 2007*) show that the mean global difference between IGS and COSMIC TCWV is about -0.2 mm with a standard deviation of 2.7 mm (panel on the left). Panel on the right shows changes in TCWV from 2008 to 2009 measured by ground-based GPS, AMSR-E and COSMIC. Results show the dramatic moistening of the Tropical Pacific as the climate system shifted from strong La Niña conditions in 2008 to moderate El Niño conditions by the end of 2009 (panel on the right). The COSMIC measurements show this moistening extending across the Amazon basin, a region previously unobserved.



(Ho et al., 2010a BAMS)

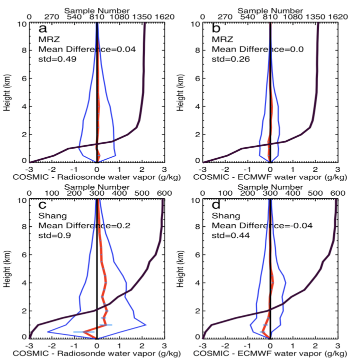
Global comparisons of total column water vapor (TCWV) between COSMIC and those derived from ground-based GPS (i.e., IGS) for 2008 .



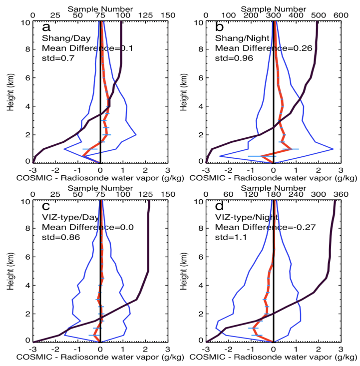
(Mears, Ho et al., 2010 BAMS)

Change in TCWV from 2008 to 2009. Panel A shows Measurements from AMSR-E and ground based GPS stations. Panel B shows measurements from COSMIC.

5. The Usefulness of COSMIC Data to Assess the Water Vapor Biases of Different Types of Radiosonde Systems



Comparison statistics (mean: red; standard error of the mean: horizontal light blue lines superimposed on the mean; standard deviation: blue; sample number of compared soundings: solid black line) of water vapor (g/kg) for (a) COSMIC-MRZ ensembles, (b) COSMIC-ECMWF ensembles near MRZ radiosondes, (c) COSMIC-Shang ensembles, and (d) COSMIC-ECMWF ensembles near Shang radiosondes. Radiosonde data that are collocated with COSMIC soundings within 200 km and 3 hours are used in these comparisons.



Comparison statistics (mean: red; standard error of the mean: horizontal light blue lines superimposed on the mean; standard deviation: blue; sample number of compared soundings: solid black line) of water vapor (g/kg) for (a) COSMIC-Shang ensembles during the day, (b) COSMIC-Shang ensembles during the night, (c) COSMIC-VIZ-type ensembles during the day, and (d) COSMIC-VIZ-type ensembles during the night. Radiosonde data that are collocated with COSMIC soundings within 200 km and 3 hours are used in these comparisons.

6. Conclusions and future work

- Systematic humidity errors for different types of radiosondes at five geographical regions during the day and night are quantified compared to COSMIC water vapor profiles.
- We identify that Shang radiosonde contain a 0.2 g/kg mean dry bias in the troposphere and VIZ-type and IM-MK3 contain a obvious 0.2 g/kg and 0.4 g/kg wet bias, respectively, relative to COSMIC water vapor data (Ho et al., 2010a).
- No obvious water vapor biases are found for MRZ and MEISEI radiosondes. A larger mean dry bias (~0.26 g/kg) for Shang radiosondes is found during the night than that during the day (~0.1 g/kg) (Ho et al., 2010b).
- Results found here are in general consistent with the comparison between ground-based GPS PW and radiosondes demonstrated by Wang and Zhang et al., (2008).
- Results show that temperature measurements from Vaisala-RS92 and Shanghai radiosonde systems agree well with those of COSMIC with a close-to-zero mean difference.
- Large temperature biases are shown for MRZ and VIZ-B2 radiosonde systems relative to COSMIC, which are possibly caused by diurnal radiative effects.
- With uniformly distributed data in time and space, multi-year COSMIC RO data will be very useful to quantify and correct the diurnal/geographical systematic humidity errors among different radiosonde types. This will be for a future study.

Summary of the mean difference, absolute mean difference, and standard deviation (std) of moisture (g/kg) of the COSMIC-radiosonde ensembles and COSMIC-ECMWF ensembles for MRZ, Shang, MEISEI, VIZ-type[a], and IM-MK3. [a] To increase the COSMIC-VIZ matches, we include VIZ-A, VIZ-B, VIZ-B2, VIZ transponder radiosonde, VIZ Mark I Microsonde in this comparison.

Sonde Type	MRZ	Shang	MEISEI	VIZ: VIZ-A, VIZ-B, VIZ-B2, VIZ transponder radiosonde, VIZ Mark I Microsonde	IM-MK3
Region	Russia	China	Japan	USA	India
Humidity Sensor	Goldbeater's Skin	Goldbeater's Skin	Capacitive Polymer	Carbon Hygristor	Carbon Hygristor
#of Matches for day and night	1350	600	150	450	60
Mean ΔW/abs (ΔW) (S.D.)	0.04/0.04 (0.49)	0.2/0.3 (0.9)	0.07/0.07 (0.9)	-0.18/0.19 (1.0)	-0.4/0.65 (1.94)
Mean ECMWF Δ W/abs (ΔW) (S.D.)	0.0/0.03 (0.26)	-0.04/0.07 (0.44)	0.0/0.04 (0.5)	-0.04/0.09 (0.52)	-0.12/0.27 (0.73)
#of Matches for Daytime	450	500	60	100	15
Mean Δ W/abs (ΔW) (S.D.) for Daytime	-0.06/0.06 (0.5)	0.1/0.26 (0.7)	0.0/0.1 (0.76)	0.0/0.07 (0.86)	-1.1/1.1 (1.8)
Mean ECMWF Δ W/abs (ΔW) (S.D.) for Daytime	0.0/0.04 (0.27)	0.0/0.09 (0.38)	0.0/0.07 (0.43)	-0.02/0.05 (0.45)	-0.24/0.3 (0.61)
#of Matches for Night time	900	100	90	350	45
Mean Δ W/abs (ΔW) (S.D.) for Nighttime	0.03/0.04 (0.47)	0.26/0.33 (0.96)	0.1/0.11 (0.9)	-0.27/0.28 (1.1)	-0.1/0.65 (1.76)
Mean ECMWF Δ W/abs (ΔW) (S.D.) for Nighttime	0.0/0.03 (0.25)	-0.04/0.07 (0.4)	0.01/0.05 (0.5)	-0.06/0.11 (0.55)	-0.04/0.28 (0.73)

References:

Kuo, Y.-H., T.-K. Wee, S. Sokolovskiy, C. Rocken, W. Schreiner, D. Hunt, and R. A. Anthes (2004), Inversion and error estimation of GPS radio occultation data. *J. Meteor. Soc. Japan, 82*, 507–531.

Ho, S.-P., M. Goldberg, Y.-H. Kuo, C.-Z Zou, W. Schreiner (2009a), Calibration of Temperature in the Lower Stratosphere from Microwave Measurements using COSMIC Radio Occultation Data: Preliminary Results, Terr. Atmos. Oceanic Sci., Vol. *20*, doi: 10.3319/TAO.2007.12.06.01(F3C).

Ho, S.-P., Wenying He, Y.-H. Kuo (2009b), Construction of Consistent Temperature Records in the Lower Stratosphere using Global Positioning System Radio Occultation Data and Microwave Sounding Measurements, A.K. Steiner et al. (Eds.), Springer Berlin Heidelberg, in press.

Wang, J. and L. Zhang, 2008: Systematic Errors in Global Radiosonde Precipitable Water Data from Comparisons with Ground-Based GPS Measurements, *J. Climate*, 21, DOI: 10.1175/2007JCLI1944.1

Ho, S.-P., Ying-Hwa Kuo ,William Schreiner, Xinjia Zhou, Using SI-traceable Global Positioning System Radio Occultation Measurements for Climate Monitoring [In "States of the Climate in 2009]. 2010a. *Bul. Amer. Meteor. Sci*.

Ho, S.-P., Zhou X., Kuo Y.-H., Hunt D., Wang J.-H. (2010b), Global Evaluation of Radiosonde Water Vapor Systematic Biases using GPS Radio Occultation from COSMIC and ECMWF Analysis. *Remote Sensing*. 2010; 2(5):1320-1330.

Mears C., J. Wang , **S.-P. Ho**, L. Zhang, and X. Zhou, Total Column Water Vapor, [In "States of the Climate in 2009]. 2010. *Bul. Amer. Meteor. Sci.*