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Comparison of COSMIC Radio Occultation Refractivity Profiles with Radiosonde Measurements

XU Xiaohua*[1,2] (徐晓华), LUO Jia[1] (罗 佳), and SHI Chuang[3] (施 闯)

[1] *School of Geodesy and Geomatics, Wuhan University, Wuhan,* 430079

[2] *School of Mathematical and Geospatial Sciences, RMIT University, Melbourne Victoria* 3001*, Australia*

[3] *GNSS Research Center, Wuhan University, Wuhan* 430079

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ABSTRACT

In recent years, radio occultation (RO) technology making use of global positioning system (GPS) signals has been exploited to obtain profiles of atmospheric parameters in the neutral atmosphere. In this paper, the RO refractivity profiles obtained from the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) mission are statistically compared with the observations of 38 radiosonde stations provided by the Australian Bureau of Meteorology during the period from 15 July 2006 through 15 July 2007. Different collocation criteria are compared at first, and COSMIC RO soundings that occur within 3 hours and 300 km of radiosonde measurements are used for the final statistical comparison. The overall results show that the agreements between the COSMIC refractivity profiles and the radiosonde soundings from the 38 stations are very good at 0–30 km altitude, with mean absolute relative refractivity deviations of less than 0.5%. Latitudinal comparisons indicate that there are negative refractivity deviations in the lower troposphere over the low latitude and middle latitude regions and large standard deviations exist in the lower troposphere of low latitude regions, which can reach up to ∼6%. The comparisons of COSMIC RO refractivity profiles and radiosonde observations for 3 polar stations in four different seasons indicate that the accuracy of GPS RO profiles is better in the Austral summer and autumn than in the Austral spring and winter during the year from September 2006 to August 2007.

Key words: GPS, radio occultation, radiosonde soundings, refractivity profiles, statistical comparison

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1. Introduction

The radio occultation (RO) sounding technique was initially developed for remote sensing of the planetary atmosphere (Fjeldbo et al., 1971). The idea of active profiling the terrestrial atmosphere making use of radio signals transmitted by the Global Positioning System (GPS) using RO technology was introduced by Yunck et al. (1988). A GPS receiver aboard a Low-Earth Orbit (LEO) satellite serves as the observation platform in this technology. When a rising or a setting GPS radio occultation event (ROE) occurs, phases and amplitudes of radio signals transmitted from the occulted GPS satellite are recorded with a high sampling rate of about 50 Hz. With the knowledge of the precise orbits and clock errors of GPS and LEO satellites, the excess phases induced by the neutral atmosphere and ionosphere are extracted from the original phase observations and, together with amplitude variations, are used to retrieve the bending angle profile. The refractivity profile of the neutral atmosphere is subsequently inverted from the bending angle profile with the Abel inversion method under the assumption of local spherical symmetry. Bending angle profiles and refractivity profiles can both be directly assimilated into numerical weather prediction (NWP) models (Wang and Wang, 2003; Zhang et al., 2004; Healy et al., 2005, 2006). Pressure, temperature, and water vapor profiles can

*Corresponding author: XU Xiaohua, xhxu@sgg.whu.edu.cn

also be inverted from the refractivity profile with variational retrieval methods by taking auxiliary information from NWP models or radiosonde observations as *a priori* atmospheric states (Palmer et al., 2000; von Engeln et al., 2003).

This concept of GPS RO technology was first successfully demonstrated by the U.S. in a proof-of-concept GPS/MET experiment launched in 1995 (Ware et al., 1996). A number of GPS RO missions, including the Danish Ørsted project, the German-U.S. Challenging Mini-satellite Payload (CHAMP) project, the Argentinian Satélite de Aplicaciones Cientificas-C (SAC-C) project, the European twin satellite Gravity Recovery and Climate Experiment (GRACE), the U.S.-Taiwan joint mission Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC), the European METeorological Operational satellite (MetOp-A), the U.S. Roadrunner program, and the German TerraSAR-X1 satellite have been launched during 1999–2007. The validation and assimilation studies of these missions have proved that with the ability to monitor the terrestrial atmosphere with long-term stability, high vertical resolution, global coverage and high accuracy, GPS RO measurements are of great significance for various applications in weather forecasting, atmospheric research, and climate monitoring (Hajj et al., 2004; Huang et al., 2005; Cucurull et al., 2007; Nedoluha et al., 2007).

The precision and accuracy of GPS RO data needs to be evaluated for its operational and research use. The precision of this new data source has been estimated with collocated RO soundings. Intercomparisons of collocated GPS RO soundings from CHAMP and SAC-C show that temperature profiles occurring within 30 min and 200 km of one another are consistent to within 0.05 K–0.1 K in the mean and 0.5 K in standard deviation, after removing the expected variability of the atmosphere (Hajj et al., 2004). Comparisons of closely collocated occultations from different COSMIC satellites shortly after launch indicate that the root mean square (RMS) difference of refractivity between 10 and 20 km altitude is less than 0.2% (Schreiner et al., 2007). The statistics of the differences in refractivities for over 2500 pairs of RO soundings from two COSMIC satellites with tangent points separated by less than 10 km and average time difference of 18 s show that GPS RO observations have the highest precision in the altitude range of 8–20 km (Anthes et al., 2008).

To compare the GPS RO data with data from other independent sources, including meteorological analyses, radiosondes, or other remote sensing satellites, is an efficient way to characterize the accuracy of this new type of observation. As the backbone of the global upper air observing system, radiosonde observations are the benchmark for calibration of satellite remote sensing and for validation of satellite-retrieved soundings. The comparisons between 280 matches of GPS/MET and radiosonde soundings show that GPS RO and radiosonde refractivities agree to within 1% from 2 to 25 km altitude, and the average difference of the dry temperatures agrees to better than 0.5°C from 2 to 28 km (Rocken et al., 1997). The validation of about 6 000 CHAMP RO profiles with observations from the global radiosonde network during 2001 and 2002 indicates that the RO refractivity accuracy is better than 0.5% between 10 and 35 km (Wickert et al., 2004). The comparison of more than 10 000 pairs of collocated CHAMP/SAC-C RO and radiosonde temperature profiles observed during the period from May 2001 to September 2004 indicates that GPS RO mean temperature is accurate to within better than 0.5 K between 200 and 20 hPa (Schmidt et al., 2005). The statistical comparisons of long-term CHAMP RO soundings with radiosonde observations over different geographical areas further reveal that GPS RO data is valuable for differentiating the performance of various types of radiosondes (Wickert et al., 2004; Kuo et al., 2005).

When validating the accuracy of GPS RO data with radiosonde observations, it is necessary to clarify the collocation criteria, which includes the maximum time difference and the maximum radial distance between collocated GPS RO and radiosonde measurements. Different collocation criteria, e.g., $\leqslant$3 h and $\leqslant$300 km, as used by Schmidt et al. (2005) and $\leqslant$2 h and $\leqslant$300 km, as used by Kuo et al. (2005), have been applied in previous studies, as mentioned above. Deeper investigation about the influence of different collocation criteria on the validation results is needed to get an assessment of which collocation criteria are most reasonable.

Among the six ongoing GPS RO missions including CHAMP, GRACE, COSMIC, MetOp-A, Roadrunner, and TSX-1, COSMIC is of special significance in that the LEO constellation is composed of six satellites, and can provide approximately 2 000 RO profiles per day in practice (Anthes et al., 2008). Compared with the $\sim$200 RO profiles provided by CHAMP, the unprecedentedly large daily number of ROEs provided by COSMIC makes it easier to validate the GPS RO profiles occurring over certain geographical areas. Although Wang and Lin (2007) have compared COSMIC data with collocated radiosonde soundings during the period from June to December 2006 and found that GPS soundings reveal a vertical domain of low temperature that is not clearly defined by radiosondes, only two radiosondes which are located over Antarctica are taken into consideration in the comparison and only the temperature profiles are compared. Comparisons between COSMIC RO data and radiosonde soundings from more stations over a longer period are needed to acquire detailed information about the accuracy of GPS RO data from COSMIC.

This paper presents and demonstrates the accuracy of COSMIC RO refractivity profiles over Australia and Antarctica through statistical comparisons between collocated RO and radiosonde soundings observed during 2006 to 2007. The radiosonde and COSMIC RO data used in the research are briefly introduced in section 2. Section 3 outlines the method for comparison. Section 4 gives the results and analyses. The influences of different collocation criteria on the validation results are studied in that section at first, and the most reasonable one is applied in the following work. The accuracy of COSMIC RO profiles over different latitudinal regions is compared accordingly. Seasonal variations of the accuracy of COSMIC RO profiles over Antarctica are also studied. Section 5 gives the conclusions.

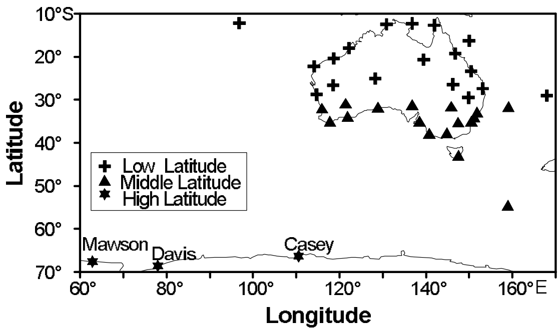

Fig. 1. Geographic distribution of the 38 radiosonde stations for the comparisons.

2. Radiosonde and COSMIC RO data

Radiosonde soundings are provided by the Australian Bureau of Meteorology (BoM). Within its national meteorological network, Australia currently has 38 radiosonde observation stations, which report atmospheric pressure, temperature, and relative humidity with an average observation interval of six hours every day. As shown in Fig. 1, 18 of these radiosonde stations are located in low latitude region (equatorward of 30°S), and three are located in the Antarctic region with latitudes poleward of 60°S, and the other 17 stations are located at middle latitudes (between 30°S and 60°S). Because additional assumptions and/or additional meteorological data are necessary to derive RO temperature and water vapor profiles, this comparison is focused on the refractivity, which is the independent observable derived from GPS RO measurements.

The COSMIC Data Analysis and Archival Centre (CDAAC) distributes COSMIC data products of different levels for free via the internet (http://cosmic-io.cosmic.ucar.edu/cdaac/). The data processing system is similar to that of its predecessors, including GPS/MET and CHAMP(Hajj et al., 2002; Kuo et al., 2004; Wickert et al., 2004). In this work, the observed refractivities with 100 m vertical resolution recorded in post-processing level2 wetPrf files are used for comparison. Being interpolated directly from the inverted RO refractivities, this data set is not influenced by background atmospheric states.

3. Method for comparison

The COSMIC RO refractivity profiles at certain mean sea level geometric heights with 100 m vertical resolution are readily available from CDAAC. Data of temperature, pressure, and dew point temperature at certain geopotential heights are recorded in the radiosonde sounding files provided by BoM. The geopotential heights in radiosonde data files can be converted to corresponding geometric heights according to Eq. (1):

$$H=\frac{h\cdot R_{\mathrm{e}}(\varphi)}{\dfrac{9.80616[1-0.002637\cos(2\varphi)+0.0000059\cos^2(2\varphi)]}{9.80665}R_{\mathrm{e}}(\varphi)-h}\,, \tag{1}$$

where h is the geopotential height in km, H is the geometric height in km, φ is the latitude of the radiosonde station in radians, $R_{\mathrm{e}}(\varphi)$ is the radius of the Earth at latitude φ in km, and

$$R_{\mathrm{e}}(\varphi)=\sqrt{1/\left(\frac{\cos^2\varphi}{6378.137^2}+\frac{\sin^2\varphi}{6356.752^2}\right)}\,. \tag{2}$$

The water vapor pressure can be calculated from the dew point temperature, which is given in the radiosonde data files, according to

$$P_{\mathrm{w}}=6.108\exp\left(\frac{17.27T_{\mathrm{d}}}{T_{\mathrm{d}}+237.3}\right)\,, \tag{3}$$

where T_{d} is the dew point temperature in °C and P_{w}

is the water vapor pressure in hPa.

For radiosonde soundings, refractivity is calculated from the observed temperature, pressure, and water vapor pressure as

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{P_{\mathrm{w}}}{T^2} , \quad (4)$$

where N denotes the refractivity, T the temperature in Kelvins, and P and P_{w} are the total air pressure and the partial pressure of water vapor in hPa, respectively.

The collocated observation pairs of COSMIC RO and radiosonde soundings are obtained under certain collocation criteria and the statistical comparisons are made accordingly. In the comparison, the COSMIC RO and radiosonde refractivities are both interpolated by cubic splines to standard altitude levels with 200 m intervals. Relative refractivity deviations are then calculated on this grid between 0 and 30 km. For each available pair:

$$\Delta N(l,m) = \frac{N_{\mathrm{COSMIC}}(l,m) - N_{\mathrm{RAOB}}(l,m)}{N_{\mathrm{RAOB}}(l,m)} , \quad (5)$$

where $\Delta N(l,m)$ is the relative refractivity deviation, $N_{\mathrm{COSMIC}}(l,m)$ and $N_{\mathrm{RAOB}}(l,m)$ are the COSMIC RO and radiosonde refractivities, respectively, l is the index for vertical height level, and m is the index for the observation pair. For each height level:

$$\overline{\Delta N(l)} = \frac{1}{M(l)} \sum_{m=1}^{M(l)} \Delta N(l,m) , \quad (6)$$

$$\sigma_{\Delta N(l)} = \left\{ \frac{1}{M(l)-1} \sum_{m=1}^{M(l)} [\Delta N(l,m) - \overline{\Delta N}(l)]^2 \right\}^{1/2} \quad (7)$$

where, $\overline{\Delta N(l)}$ and $\sigma_{\Delta N(l)}$ are the mean relative refractivity deviation and its standard deviation at the lth height level, respectively, and $M(l)$ denotes the number of observation pairs at that height level. Two statistical parameters can be calculated accordingly:

$$\overline{\Delta N} = \frac{\sum_{l=1}^{l=l_{\max}} \left|\overline{\Delta N(l)}\right|}{l_{\max}} \quad (8)$$

$$\overline{\sigma_{\Delta N}} = \frac{\sum_{l=1}^{l=l_{\max}} \sigma_{\Delta N(l)}}{l_{\max}} , \quad (9)$$

where $\overline{\Delta N}$ and $\overline{\sigma_{\Delta N}}$ are the total mean absolute relative refractivity deviation and the total mean standard deviation over all available levels respectively, and $l_{\max}$ is the index for the highest height level. Because some balloons do not reach 30 km and some COSMIC profiles do not reach the ground surface, $l_{\max}$ may be less than 151 in practice.

Although the quality of COSMIC data (version 3200) provided by CDAAC has been checked with ECMWF analyses as reference, quality checks for the collocated RO and radiosonde pairs are done before the statistical comparison is carried out, to eliminate the disadvantageous influence of outliers in the radiosonde data on the comparison results. Pairs which exhibit refractivity deviations greater than 20% at any height level are excluded from the data set.

4. Results

4.1 *Comparison under different collocation criteria*

With the radiosonde and COSMIC RO observations of one year from 15 July 2006 to 15 July 2007, the influences of different collocation criteria on the comparison results are investigated at first. The maximum time difference and the maximum radial distance between COSMIC and radiosonde measurements, Δt and d, vary between 1 and 3 h and between 100 and 300 km, respectively. The number of collocated observation pairs prior to and after the quality check, the total mean absolute relative refractivity deviation, and the total mean standard deviation corresponding to each combination of Δt and d are summarized in Table 1.

Table 1. Number of collocated observation pairs between COSMIC RO measurements and Australian BoM radio soundings (15 July 2006–15 July 2007), and the corresponding total mean absolute relative refractivity deviations and total mean standard deviations. P. Q. and A. Q. mean "prior to quality check" and "after quality check", respectively. Δt is the maximum time difference and d the maximum radial distance between the corresponding COSMIC and radiosonde profiles.

Δt (h)	d (km)	Data pairs (P. Q.)	Data pairs (A. Q.)	Data ratio (%)	$\overline{\Delta N}$ (%)	$\overline{\sigma_{\Delta N}}$ (%)
1	100	126	126	100.0	0.19	1.49
1	200	550	545	99.1	0.11	1.57
1	300	1212	1203	99.3	0.11	1.74
2	100	222	222	100.0	0.15	1.50
2	200	959	952	99.3	0.10	1.60
2	300	2102	2086	99.3	0.10	1.78
3	100	311	311	100.0	0.14	1.50
3	200	1338	1330	99.4	0.10	1.61
3	300	2949	2929	99.3	0.10	1.79

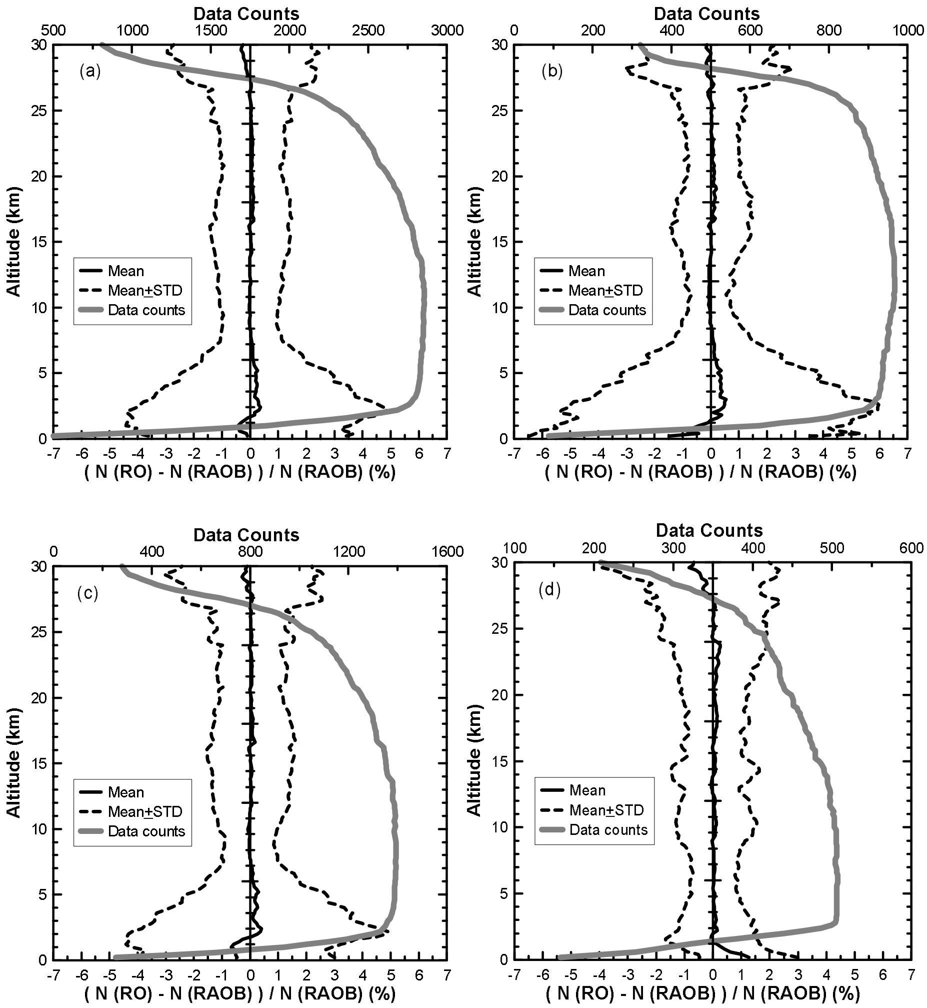

Fig. 2. (a) Statistical comparisons of refractivity profiles between collocated COSMIC RO and radiosonde soundings from all the 38 Australian BoM radiosonde stations, and (b–d) from radiosonde stations of low, middle, and high latitudinal bands, for 15 July 2006–15 July 2007. The black solid curves are mean relative refractivity deviations, the black dashed curves are mean relative refractivity deviations ± standard deviations, and the grey bold curves are the collocated data counts (axis labels at the top of figure).

4.2 *Comparison over different latitudinal regions*

The result of the statistical comparison between COSMIC RO refractivity profiles and radiosonde observations from all the 38 radiosonde stations during 15 July 2006 to 15 July 2007 is shown in Fig. 2a. In order to gain further insight on the performance of RO technology over different latitudinal regions, the statistical comparison results over low latitudes (equatorward of 30°S), middle latitudes (between 30°S and 60°S) and high latitudes (poleward of 60°S) are shown in Figs. 2b–d. It can be seen that the comparatively large number of data pairs in the middle latitude region makes the results for this region as shown in Fig. 2c resemble that for the whole region as shown in Fig. 2a.

As shown in Table 1, for all the 38 radiosonde stations, 2929 pairs of RO and radiosonde observations have passed the quality check under the collocation criteria of d = 300 km and Δt = 3 h. Among these collocated observations, 986 pairs are located in the low latitude region, 1427 pairs in the middle latitude region, and 516 pairs in the high latitude region. But the largest values shown in the grey bold curve indicate the data counts available for comparison at different height levels is 2858, 968, 1394, 507 in Figs. 2a, 2b, 2c, and 2d respectively. These values are all smaller than the corresponding number of the collocated observation pairs. It is also shown in Figs. 2a–d that the data counts drop significantly above 20 km and are decreasing with decreasing altitude in the lower troposphere (LT). This is because some of the radiosonde soundings terminate early before reaching 30 km altitude and some of the COSMIC profiles do not reach the lowest part of the troposphere. The multipath and super-refraction problems encountered by GPS RO technology can lead to a known negative refractivity bias in the LT (Wickert, 2004). The inverted LT refractivity data having large biases fail the quality check and are excluded from the final data product of CDAAC. As a result, the data counts at all the height levels between 0 and 30 km in the final statistical comparison may be less than the number of the collocated pairs.

It is shown in Table 1 that more than 99% of the RO and radiosonde collocated observation pairs have passed the quality check for each combination of d and Δt. When $d = 100$ km, all the collocated data pairs have passed the quality check no matter whether Δt is equal to 1, 2, or 3 hours. The number of collocated data pairs which have passed the quality check varies greatly under different collocation criteria and increases from 126 for the combination of $\Delta t = 1$ h and $d = 100$ km to 2929 for the combination of $\Delta t = 3$ h and $d = 300$ km.

The total mean absolute relative refractivity deviations vary from 0.1% to 0.2% no matter what kind of collocation criteria are applied. The total mean standard deviation reaches the smallest value of ∼1.5% for $d = 100$ km and increases to ∼1.75% for $d = 300$ km. The variation of d is more significant to the comparison results than the variation of Δt. Because the influence of the various combinations of d and Δt on the bias between COSMIC and radiosonde measurements is insignificant, a combination of $d = 300$ km and $\Delta t = 3$ h is chosen for the subsequent investigations to get more statistical confidence by using more extensive data.

It is shown in Fig. 2a that for the 38 radiosonde stations as a whole, the agreements between COSMIC and radiosonde refractivity profiles are very good at 0–30 km, with the mean absolute relative refractivity deviation less than 0.5%. Negative deviations exist below 1.6 km, which is attributed to the negative refractivity bias associated with RO soundings in the LT. The standard deviations vary greatly with a mean standard deviation of 1.79% through 0–30 km. The smallest standard deviation of 0.96% is found at 9.4 km and the largest standard deviations are found below 5 km, which reach up to 4.6% at ∼2.2 km. At altitudes above ∼25 km, there are negative deviations of refractivity and the standard deviation increases from 1.4% at 25 km to 2.5% at ∼30 km. The large standard deviations above 25 km are related to GPS RO observational noise, i.e., residual ionospheric effects, and the use of ancillary climate model data for noise reduction through an optimization procedure in the data processing system (Kuo et al., 2004).

From Figs. 2b–d, it can be seen that the negative refractivity deviations in the LT, which are distinct in the comparison results of the low and middle latitude regions, do not exist in the comparison results of the high latitude region. This is because water vapor content, the key factor leading to the negative refractivity deviations in the LT, is much less over the polar regions than over the low and middle latitude regions. The smallest standard deviations in each region are 0.73%, 0.88%, and 0.8%, occurring at altitudes of ∼12 km, ∼9.5 km, and ∼7 km (just below the tropopause in each case) for the low, middle, and high latitude regions, respectively. Moreover, the standard deviations in the LT are the largest in the low latitude region, reaching up to ∼6%, while the smallest LT standard deviations occur in the high latitude region, and are generally less than 2%.

4.3 *Comparison in different seasons over Antarctica*

The seasonal variations of the comparison results over Antarctica are studied through the statistical comparison of refractivity profiles from COSMIC RO and the radiosonde soundings for three Antarctic stations: Mawson, Davis, and Casey, during the four different seasons of one year from 1 September 2006 to 31 August 2007. The number of collocated pairs, the total mean absolute relative refractivity deviation, and the total mean standard deviation in each season are shown in Table 2. It can be seen that among the four seasons, the total mean standard deviation and the total mean absolute relative refractivity deviation both achieve the largest values in the Austral spring. The total mean standard deviation in Austral autumn is smaller than that of any other season, whereas the total mean absolute relative refractivity deviation in Austral summer is smaller than for any other season. There are more collocated pairs in Austral autumn than in any other season.

The statistical comparison results for the four seasons are shown in Figs. 3a–d, respectively. It can be seen that for the same reason as discussed in section 4.2, the largest values in the data count curves are a little smaller than the corresponding collocated data pairs for comparison. For example, the number of collocated pairs during the Austral spring shown in Table 2 is 117, but the largest data count in Fig. 3a is 114.

It can also be seen that the refractivity of COSMIC is nearly bias free in relation to the radiosonde data

Table 2. Number of data pairs after quality check, the total mean absolute relative refractivity deviation, and the total mean standard deviation of COSMIC RO vs. radiosondes over Antarctica from four different seasons during 1 September 2006 to 31 August 2007.

Austral season	Time period	Data pairs (A. Q.)	$\overline{\Delta N}$ (%)	$\overline{\sigma_{\Delta N}}$ (%)
Spring	1 Sep–30 Nov 2006	117	0.26	1.63
Summer	1 Dec 2006–28 Feb 2007	144	0.15	1.09
Autumn	1 Mar–31 May 2007	151	0.10	1.13
Winter	1 Jun–31 Aug 2007	126	0.14	1.46

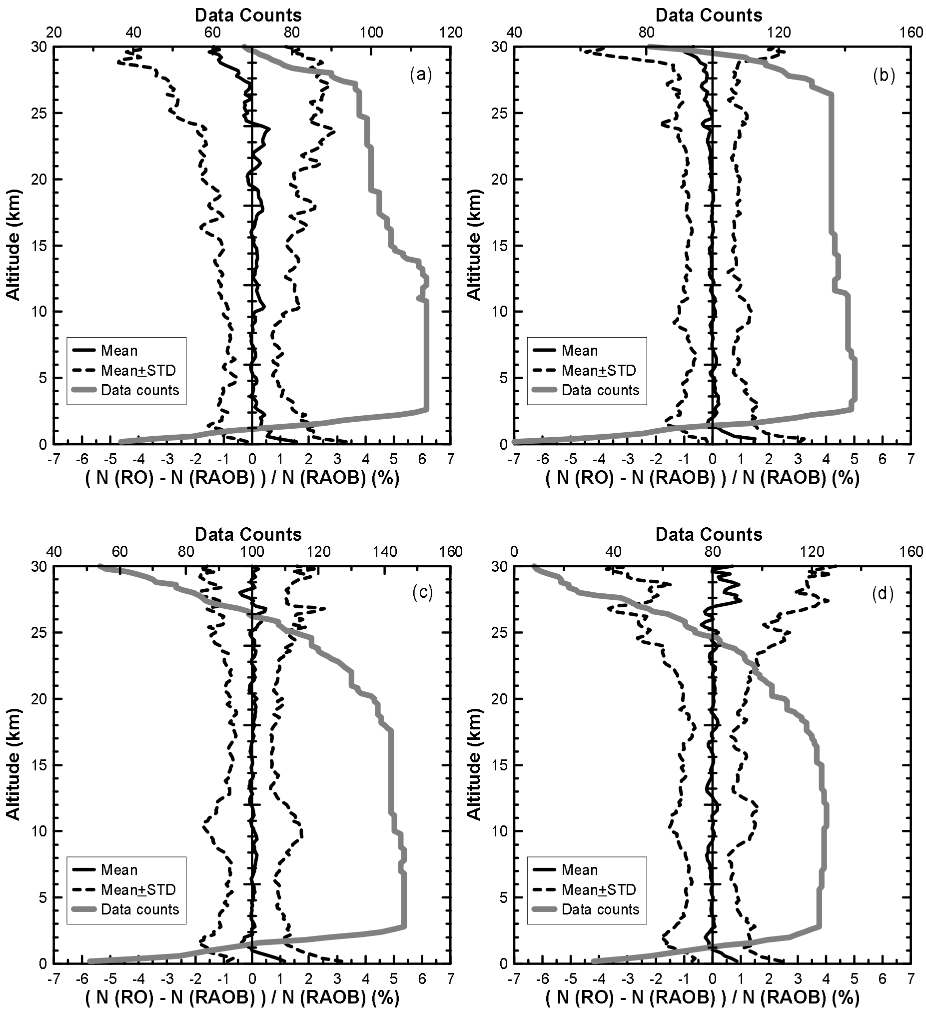

Fig. 3. Statistical comparisons of COSMIC RO refractivity profiles and radiosonde soundings from the three Antarctic radiosonde stations during four Austral seasons: (a) Spring: 1 September–30 November 2006; (b) Summer: 1 December 2006–28 February 2007; (c) Autumn: 1 March–31 May 2007; and (d) Winter: 1 June–31 August 2007. The black solid curves are mean relative refractivity deviations, the black dashed curves are mean relative refractivity deviations ± standard deviations, and the grey bold curves are the collocated data counts (axis labels at the top of figure).

between 1–25 km in each season. No negative refractivity deviations exist in the LT in any of the four seasons, which is because the collocation pairs used for comparison are all over the polar region, where moisture in the LT is small and has little influence on the RO refractivity inversion results. Relatively small standard deviations are found at around 6–7 km in each season.

The standard deviations shown in Figs. 3b and 3c are generally smaller than those in Figs. 3a and 3d at most of the height levels, which indicates that the accuracy of GPS RO refractivity profiles over Antarctica is better in Austral summer and autumn than in the winter and spring during the one year from September 2006 to August 2007. Figures 3a and 3d show that in Austral spring and winter, the standard deviations become larger than 1% above 18 km and 21 km, respectively, and reach ~2.5% at 30 km. The standard deviations shown in Figs. 3b and 3c are smaller than 1% between 3 km and 27 km except for a small hump at around 9–10 km, which probably corresponds to the sharp tropopause in the Austral summer and autumn.

5. Conclusions

In this paper, COSMIC RO refractivity profiles in the troposphere and lower stratosphere have been compared statistically with the observations from 38 radiosonde stations of the Australian BoM during the one year period from 15 July 2006 to 15 July 2007. The optimal criteria for obtaining the collocated GPS RO and radiosonde observation pairs was first investigated. The maximum time difference and maximum radial distance between COSMIC and radiosonde measurements, Δt and d, vary between 1 and 3 h and between 100 and 300 km, respectively. It is shown that although the variation of d is a little more significant to the total mean standard deviations than the variation of Δt, the resulting total mean absolute relative refractivity deviation is practically independent of the combination of Δt and d. To get more statistical confidence for the subsequent comparisons, the combination of $d = 300$ km and $\Delta t = 3$ h were chosen as the final optimal collocation criteria. Under these criteria, the accuracy of COSMIC RO refractivity profiles over the entire radiosonde network and over different latitudinal regions is studied.

The comparison results show that, in general, the agreements between the refractivity profiles of COSMIC and radiosonde soundings from the 38 stations are very good at 0–30 km, with mean absolute relative refractivity deviations of less than 0.5%. The respective statistical comparisons over three different latitudinal regions, low latitude (equatorward of 30°S), middle latitude (between 30°S and 60°S) and high latitude (poleward of 60°S), reveal that the negative refractivity deviations in the LT are distinct only over the low and middle latitude regions, the reason being that water vapor content is much lower over polar regions than over other regions. In the low latitude region, the standard deviation in the LT reaches up to ~6%, whereas in the high latitude region, the standard deviations in the LT are generally smaller than 2%.

To gain further insight on the accuracy of COSMIC RO refractivity profiles over the polar region during different seasons, refractivity profiles from COSMIC and those from three Antarctic radiosonde stations (Mawson, Davis, and Casey) are compared during the four different seasons of one year from September 2006 to August 2007. During this year, GPS RO performs better in the Austral summer and autumn than in winter and spring.

It can be concluded that the accuracy of GPS RO data from COSMIC is equivalent to that from radiosonde data in the upper troposphere and lower stratosphere. As it is able to complement the existing radiosonde network over the oceans and polar regions, the RO data are of great value for climate monitoring. This study is an initial investigation for the validation of COSMIC RO data. It is planned to extend this kind of study over the globe with more GPS RO and radiosonde measurements.

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