Issue 7: Profiling of the lower troposphere

Although temperature (and humidity) trends in the upper troposphere and stratosphere are important, a primary need for long-term monitoring lies in the lower troposphere. Deriving temperature and humidity trends separately from GPS-RO alone in the lower troposphere, however, is confounded by the contributions both make to RO soundings there (cf. issues 6 and 9). What role, therefore, should GPS-RO play in a baseline temperature (and/or humidity) monitoring network for the lower troposphere? To what extent will other sounding systems (e.g., a reference radiosonde network) still be required, and how should these other networks be optimally configured in conjunction with GPS-RO?

a. Background

Kuo et al (2004, link is provided in the suggested reading list) demonstrated that RO soundings (refractivity profiles) are of sufficiently high accuracy to differentiate performance of various types of radiosonde. In that paper, CHAMP RO refractivity profiles that occur within 2 hours and 300 km of radiosonde refractivity profiles are used during the period from June 2001 through March 2004. The comparison was made between the altitudes of 5–25 km, where RO soundings are most accurate. The main results for this paper are shown in **Figs. 1-2** and **Table 1**.

In slides 23, 25 and 26 in Ho et al. (AMS, 2008, re-plotted in **Figs. 3-5** here) demonstrated that

1) The fact that root mean square errors (RMS) between retrieved water vapor (WV) and true WV is much smaller than those between initial WV and true WV demonstrate that RO refractivity is very sensitivity to WV. RO refractivity is very useful to retrieve water vapor in the lower troposphere (see **Fig. 3**);
2) Total perceptible water (PW) integrated from 1D-var WV profile using NCEP moisture as initial condition (PW_{NCEP}) was compared to that using ECMWF as initial inputs (PW_{ECMWF}) (**Fig. 4**). **Fig. 4b** depicts that PW_{NCEP} is highly consistent to PW_{ECMWF} even NCEP total perceptible water is different than those of ECMWF (**Fig. 4a**). This indicates that 1D-var WV is relatively (may not be totally) independent on WV initial inputs.
3) Around 1% of N fractional bias will lead to about 2.2 K temperature (T) bias, and 1% of N fractional bias will lead to only 0.5 g/kg WV bias (**Fig. 5**). **Fig. 5** also gives us the magnitude of a possible WV bias caused by a temperature bias at a certain height.

b. Question to answer

The main question we want to answer is if GPS RO refractivity at lower troposphere is of sufficiently high accuracy to differentiate the performance of different types of radiosonde, and that the quality of RO soundings is independent of geographical location, are 1D-var temperature and WV at lower troposhere also useful to further differentiate the temperature and WV performance of different types of radiosonde?

To answer this question, COSMIC refractivity, derived temperature and humidity profiles that occur within 2 hours and 300 km of radiosonde profiles are used from July 2006 to Oct. 2006, where no COSMIC data were simulated into ECMWF analysis.

c. Comparison of COSMIC, Radiosonde, and ECMWF refractivity profiles at different regions

Mean difference, absolute mean difference, and standard deviation of fractional refractivity (%), temperature (K), and water vapor (g/kg) between COSMIC and those from the radiosonde over Russia, Japan, China, and regions that using Vaisala radiosonde (see **Fig. 1**) are summarized in **Table 2**. Statistics of similar comparisons between COSMIC and ECMWF over these regions are also listed in **Table 2**. With the open-loop tracking technique, COSMIC RO data penetrate much lower troposphere than those from CHAMP. Here the statistics are calculated from surface to 25 km for temperature and refractivity and from surface to 10 km for water vapor. The refractivity, temperature, and WV comparisons between COSMIC and radiosonde, and COSMIC and ECMWF are generated in **Figs. 6, 7 and 8**, respectively.

In general, we did not find significant variation of the quality of the RO soundings over different geographical areas. This is evidenced by the relatively small variations (in terms of absolute fractional difference) in the RO and ECMWF differences between geographical areas (as shown in **Table 2, Figs. 6-8**).

On the other hand, it can be seen in **Fig. 6** that obvious COSMIC-Radisonde fractional refractivity (%N) bias is over 10 km over Russia (in pink circle, **Fig. 6a**), where the obvious COSMIC-Radisonde refractivity bias over China is mainly below 8 km (in orange circle, **Fig. 6c**). No obvious fractional N biases are found over the same regions for COSMIC-ECMWF pairs (see **Fig. 6b and 6d**). Below 1 km, the -1.5 % negative bias for COSMIC may be due to super-refraction. Because there is only around 10 profiles are used, the cause is the negative N bias is uncertain in this point. More COSMIC-ECMWF, and COEMIC-radioosnde pairs over China are used. No obvious negative N biases below 1 km are found (no shown).

d. Comparison of COSMIC, Radiosonde, and ECMWF temperature and water vapor profiles at different regions

To further identify the source of the N bias, the COSMIC-Radiosnde and COSMIC-ECMWF T and WV are compared in **Figs. 7 and 8**, respectively.

Because GPS N is sensitive to T variation at higher troposphere, the COSMIC T shall be accurate at around 10 km. We identify that COSMIC-Radiosonde negative temperature bias is about -1K (in pink circle, **Fig. 7a**), which is consistent with 0.5 % N bias in the same height (**Fig. 6a**). This result is also consistent with COSMIC-ECMWF comparison in the similar height (**Fig. 7b**).

On the other hand, we don't find the COSMIC-Radiosnde T bias below 8 km over China (in orange circle, **Fig. 7c**), though the COSMIC-Radiosnde T is consistent with that of COSMIC-ECMWF pairs (**Fig. 7d**). Below 8 km, COSMIC N shall be very sensitive to WV variation. In COSMIC-Radisonde WV comparison, we found an obvious WV bias (~0.5 g/kg at 2.5 km, **Fig. 8c**) which is in the same magnitude of the N bias (~0.9 %, **Fig. 6c**). Again, in the same region between 1 to 8 km, COSMIC WV is very close to that from ECMWF (**Fig. 8d**). Both above evidences provide confidence to our 1D-var WV results. Results here demonstrate the potential usefulness of COSMIC 1D-var water vapor as a baseline humidity monitoring network for the lower troposphere.

e. Possible future studies

Studies have shown (not listed) that atmospheric perceptible water (PW) from ground-based GPS has accuracy of < 2 mm. However, there may exist PW bias between ground based GPS system when different types of antenna are used. In the future, we will use PW derived from ground-based GPS to further quantify the quality of COSMIC 1D-var water vapor.

More than one type of GPS ground based systems combined with COSMIC data shall be useful for sounding systems (e.g., a reference radiosonde network).