Issue 3: Reproducibility of refractivity results

The comparison of results from four different centers was based on large vertical layers, large latitudinal zones, and some time-smoothing of the data. Yet there remain small but non-zero differences in the four refractivity time series, and it seems important to note that these are not retrieved meteorological data, but raw refractivity. What are the sources of these differences and can they be eliminated? If not, why not?

a. Define the Question

This issue is based on slide 12 of Ho et al. (AMS COSMIC presentation, 2008), which is re-plotted in **Fig. 1**. Since an operational error was found in GPS RO data from Wegener Center of the University of Graz (WegC), Graz, Austria (it causes time constant systematic error and it will not be seen in a trend analysis), here only fractional refractivities derived from UCAR (the University Corporation for Atmospheric Research), JPL (Jet Propulsion Laboratory, Pasadena, CA, USA) and GFZ (GeoForschungsZentrum Potsdam (GFZ), Potsdam, Germany) are compared here.

The raw measurements of RO data are phase and amplitude of the GPS radio signals. Even beginning with the same phase and amplitude of the GPS radio signals, different inversion algorithms applied by different centers may contribute to these small but non-zero differences in **Fig. 1**. Refractivity uncertainty introduced by inversion procedures may be owing to different approaches for:

1) Initial Integral of Abel,
2) Inversion algorithm (from bending angle to refractivity),
3) Quality control of inverted RO signals,
4) Other assumption, simplification and approximations are used in the RO inversion procedures.

We leave details discussions of how 1), 2) and 4) will impact derived refractivity in responses to issue 5. Here the biggest uncertainty in **Fig. 1** seems due to sampling errors (e.g., item 3; see below).

b. The effect of sampling issue on time series of fractional refractivity differences

Fig. 2 shows the time series of fractional refractivity differences in the same latitudinal zones (in different panels) as those in **Fig. 1**. Because UCAR, JPL and GFZ used different quality control methods, different RO samples are used by different center in each month for each latitudinal zone. The sample number ratio between JPL and UCAR ({(JPL num – UCAR num)/ UCAR num}-0.5; in blue), and GFZ and UCAR ({(GFZ num – UCAR num)/ UCAR num}-0.5; in pink) are plotted in **Fig. 2**.

Here we circle (in pink) those months for some non-zero differences in **Fig. 1** and circle the same months in their corresponding time series of these differences in **Fig. 2**. It is depicted in **Fig. 1** and **Fig. 2** that relative larger fractional refractivity anomalies are usually related to larger fractional refractivity differences (**Fig. 2**), which result in larger sampling numbers differences. This is more obvious for 90°N-60°N region (**Fig. 2b**) and 90°S-60°S region (**Fig. 2f**) between UCAR and JPL. Because different quality control criteria is used over polar regions during summer and winter to eliminate the possible uncertainty caused by ionospheric calibration for JPL refractivity (personal communication with Dr. Chi Ao in JPL), the fractional refractivity differences and corresponding fractional refractivity anomalies among JPL and UCAR are more obvious at polar regions during winter/summer times. This is also true for GFZ refractivity in general. This can also be seen in time series of mean fractional anomalies for 8-12 km layer (**Fig. 3**), 12-20 km layer (**Fig. 5**), and 20-30 km layer (**Fig. 7**), and their corresponding time series of fractional refractivity differences in **Figs. 4, 6 and 8**, respectively.

The trend of fractional anomalies for each latitudinal zone for UCAR, JPL and GFZ are summarized in **Table 1**. Note that, because the seasonal variation of fractional refractivity differences among three centers over polar regions is more or less systematic (**Figs. 2, 4, 6 and 8**), the JPL, UCAR and GFZ trends are very close to each other (**Table 1**).

More evidences that current small but non-zero fractional refractivity differences are mainly due to sampling errors are shown in response of issue 4 where pixel level refractivity profiles are compared.

c. Future studies

Sampling error for RO data from each center will be quantified in a near future. Data from NCEP/NCAR reanalysis for CHAMP RO data have been generated (by Stephen Leroy from U. of Harvard) and will be used as references for our sampling error analysis.

RO community as a whole, including scientists from JPL, UCAR, GFZ and WegC U. of Harvard, U. of Arizona, is working together on this task. A paper entitled "Ho, S.-P., Gottfried Kirchengast, Stephen Leory, Chris Rocken, Ying-Hwa Kuo, Jens Wickert, Tony Mannucci, Sergey Sokolvskiy, William Schreiner, Doug Hunt, Andrea Steiner, Ulrich Foelsche, and Chi Ao, 2008: Estimates of the Uncertainty for using Global Positioning System Radio Occultation Data for Climate Monitoring: Inter-comparisons of Refractivity Derived from Different Data Centers" is in preparation for *J.* of Climate, and will be submitted in a near future.