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Atmospheric Measurement Techniques Discussions

Interactive comment on "Errors in GNSS radio occultation data: relevance of the measurement geometry and obliquity of profiles" *by* U. Foelsche et al.

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We would like to thank referee 2 for her/his favorable review and the constructive and useful comments. We have answered all comments below (for easier comparison the original comments are included in *italic*).

This well-written paper is an interesting contribution to the field of RO, I recommend publication in AMT with minor revisions. I have one general question and several minor comments / remarks described below:

If I understand correctly, the forward (ray-tracing) modeling uses the ECMWF refractivity field which, in general, deviates significantly from spherical symmetry in the lower troposphere. I wonder if the authors could comment on the magnitude of the error contributions originating from deviations from spherical symmetry and those stemming from profile obliquity which is the focus of the present study.

In our previous study on the influence of horizontal variability (Foelsche et al., 2004a; 2004b) we have addressed this point. In a similar setup (fewer occultation events, ECMWF fields in T511L60 resolution with slightly less horizontal variability) we have forward modeled two separate ensembles of 306 events: One with employing the analysis field with its 3D structure, the other with artificially enforcing spherical symmetry for all events. The latter case was obtained by applying the atmospheric profile at the mean tangent point of an occultation event over the entire domain probed.
After superposition of observation system errors and standard retrieval we analyzed the data as in the present study and obtained the results as shown in Fig. 1 (Top left: atmosphere with horizontal variability and vertical reference profiles at mean tangent point location; top right: atmosphere with spherical symmetry applied; bottom: horizontal variability with profiles along the true 3D tangent point trajectory as reference. Sub-panels: number of events versus height).
Dry Temperature standard deviations were found to be less than 1.5 K in the spherically symmetric atmosphere (top) while they reached values of about 5 K in the realistic atmosphere (top left). These results confirmed earlier ones by Kursinski et al. (1997) and underlined that horizontal variability is indeed the major error source in the troposphere – especially below 7 km altitude. A comparison of the left panels shows that the deviation form spherical symmetry (which can not be overcome) is the major contributor, but taking the profile obliquity into account (which can be easily implemented) reduces the errors considerably.

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Foelsche, U., and Kirchengast, G.: Sensitivity of GNSS radio occultation data to horizontal variability in the troposphere, Phys. Chem. Earth, 29, 225-240, doi:10.1016/j.pce.2004.01.007, 2004a.

Foelsche, U., and Kirchengast, G.: Sensitivity of GNSS occultation profiles to horizontal variability in the troposphere: a simulation study, in: Occultations for Probing Atmosphere and Climate, edited by: Kirchengast, G., Foelsche, U., and Steiner, A.K., Springer, Berlin- Heidelberg-New York, 127-136, 2004b.

Kursinski, E.R., Hajj, G.A., Schofield, J.T., Linfield, R.P., and Hardy, K.R.: Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System, J. Geophys. Res., 102, 23429–23465, 1997.

Minor comments / corrections:
Page 4265, line 25: Quote: "Overall, there is a uniform distribution in latitude [...]" On the basis of the data set considered here the meridional distribution appears to be flat; with better statistics, however, this turns out not to be strictly true. I suggest to rephrase this sentence to clarify that the apparent uniform distribution is an artefact of the limited data set (in terms of numbers of occultation events) generated for this study.

We did not want to imply that the distribution is strictly flat. The important point is that the distribution in the individual sectors is far from being uniform. By omitting the part about land and ocean (which is not so important in this context) this should become clearer: **Overall there is a quite uniform distribution in latitude but if we look at the distribution of RO events in individual sectors we can see some interesting and characteristic features.** "Quite uniform" seems to be appropriate for the overall distribution, and this also holds for larger ensembles of events.

Page 4265, section 3, line 21: Quote: "[...] and the TPT is obtained from (1) by repeating the calculations for each pair of satellite positions during the occultation event." I don't understand how Eqn. (1) is used to derive r_T (page 4269, line 21). I would expect that r_T is obtained from $a = n(r_T) \cdot r_T$ (Bouguer's law), where $n(r)$ denotes the refractive index at radius $r \cdot n(r)$ doesn't appear to be used in Eqn. 1, 2 or 3, though.

Thank you for this point. We have focused too much on describing how to get the latitude and longitude of the tangent point. The TP itself, i.e. including the height, is indeed obtained by multiplying the unit vector (Eq. 1) with r_T, which is found from $a = n(r_T) \cdot r_T$ as referee 2 points out. The paragraph will be adjusted accordingly.

Page 4270, section 4 "Results", line 22: Quote: "[...] the ray tracer stops when severe superrefractive or multipath structures are encountered." For clarity, I suggest to add a remark already in section 2.2 "Forward modelling" that the forward model excludes profiles (or segments of profiles) affected by multipath /critical refraction.

Right, we will add the sentence: **Since ray tracing, based on geometric optics, stops in case of superrefraction or multipath in the lower troposphere, when sharp vertical refractivity gradients are encountered, the simulations do not account for these effects (e.g., Sokolovskiy, 2003).**

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 4261, 2010.

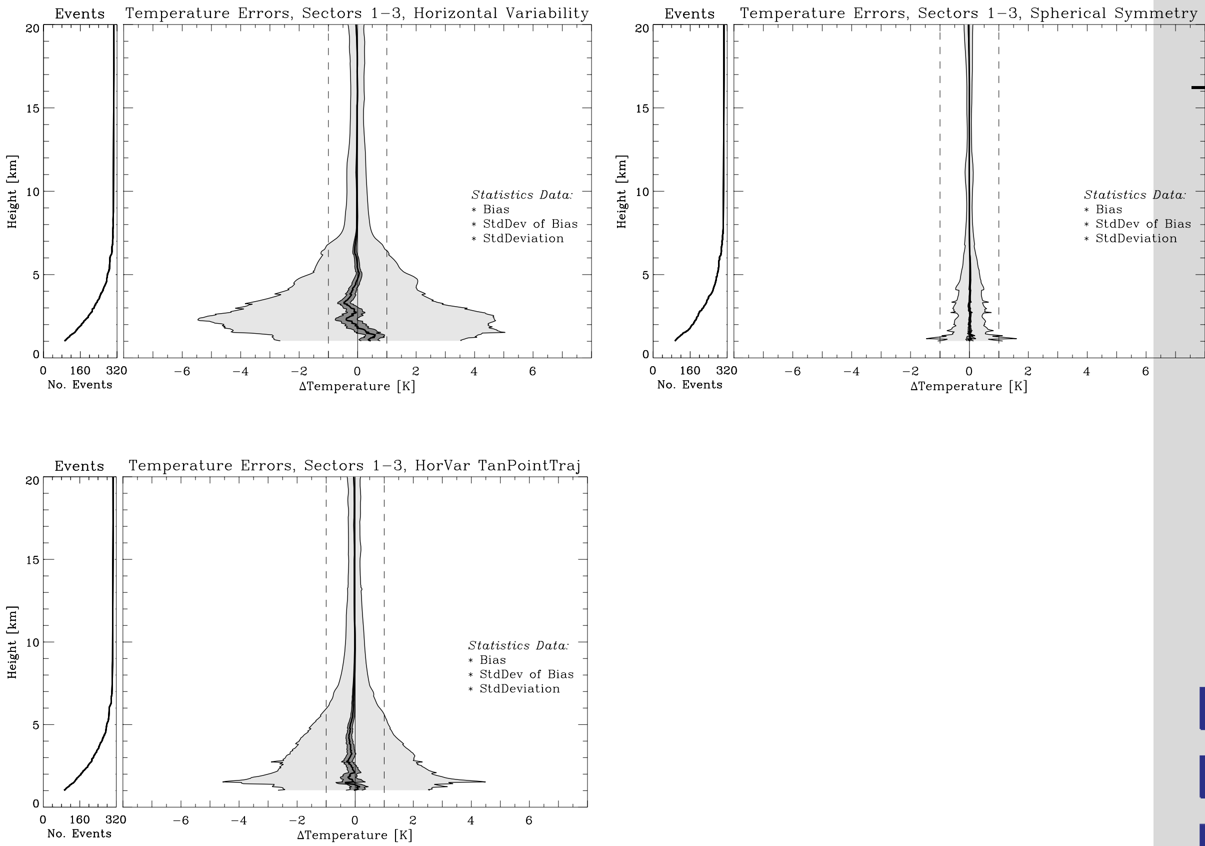

Fig. 1. Dry Temperature error statistics for an ensemble of 306 occultation events, with and without spherical symmetry (from Foelsche et al., 2004b, Fig. 3).