Interactive comment on “Validation of refractivity profiles derived from GRAS raw-sampling data” by F. Zus et al.

We thank the reviewer for her/his comments and suggestions. Below we answer the reviewer's questions and describe proposed changes in a revised version of the manuscript (italic).

Page 1830, Line 15: For the low-pass filtering of the L1/L2 excess phase paths and the simultaneous calculation of the L1/L2 excess phase path rates (derivative with respect to time) we apply a local polynomial regression of degree 3 using 71 samples (Savitzky-Golay smoothing filter).
Here it should be specified to what spatial scale this filter window corresponds. Around 2.5 km?

In the revised version of the manuscript the following sentence will be included on page 1830, line 18: “Assuming a tangent point vertical velocity of 2 km/s (the sampling rate is 50 Hz) a local polynomial regression of degree 3 using 71 samples corresponds to a spatial scale of around 2.2 km.“

Page 1831, Line 8: The observation error variance is taken to be 1.2 μrad.
The bending angle error estimate depends on the filter width. Does this estimate correspond to the filter width of 2.5 km?

The referee comment is correct. Typically, the observation error variance is estimated individually for each occultation event by using e.g. the bending angle differences between the observation and a background profile (a climatology or NWP analysis) in the altitude range 60-80km. von Engeln et al. 2009, GRL, estimate the GRAS bending angle noise in this way; the filter width of the Savitzky-Golay smoothing filter is not specified. Therefore, our estimate must be regarded as a crude estimate. Please note, that our statistical optimization scheme itself is not very sophisticated; we do not differentiate between different occultation events and we do not account for background error correlations and observation error correlations. We will emphasize this in the revised version of the manuscript, and provide a reference to a more sophisticated statistical optimization scheme, i.e. Lauritsen et al. 2011, AMT.

Page 1832, Line 7: Interpolation between grid points (0:5 0:5 horizontal resolution; 91 model levels in the vertical) and linear interpolation in time is performed 10 between 6 h analyses fields.Did you extract vertical profiles from ECMWF fields? How was the occultation point determined?

Yes, we extracted adjacent vertical profiles from ECMWF refractivity field. The occultation point, the point on Earth's surface to which the retrieved refractivity profile is assigned, is estimated under the tangent point where the GPS-LEO line-of-sight altitude equals 10km. We will include this (our) definition of the occultation point in the manuscript in section 2.2.3.

Page 1832, Section 2.4 It would be desirable to provide some more details on the QC. QC is a crucial point in all the processing.

As suggested we will provide more details on the QC. The section 2.4 (Quality Control) will be written as follows: “Quality Control (QC) is applied at different stages of the processing. The early stage QC is applied at Level 1 and Level 2 and identifies CL and RS data gaps, examines the CL/RS overlap, SNRs, and L1/L2 excess phase path ratios. Specifically, occultation events are rejected if there is a gap between the selected CL and RS record (see section 2.1), the ratio of L1/L2 excess phase path forward differences do not meet the criteria proposed by Beyerle et al. (2004) (excess *phase path forward differences are analyzed in our ionospheric calibration procedure) and the retrieved bending angle profile does not cover the altitude range 10-40 km. The final stage QC compares the retrieved refractivity profiles to the ECMWF refractivity profiles. Profiles where the fractional refractivity deviation exceeds ±10% at any altitude between 5 km and 30 km are rejected. No final stage QC is applied for altitudes <5 km.“*

Page 1833, Line 16: The source of this bias is yet not well understood.
Some ideas about the origin of the bias can be found in the following papers:

Sokolovskiy, S., C. Rocken, W. Schreiner, and D. Hunt (2010), On the uncertainty of radio occultation inversions in the lower troposphere, J. Geophys. Res., doi:10.1029/2010JD014058.
M. E. Gorbunov, K. B. Lauritsen, S. S. Leroy, Application of Wigner distribution function for analysis of radio occultations, Radio Science, 2010, V. 45, RS6011, doi:10.1029/2010RS004388.

On page 1833, line 16 (section 3.1) we focus on the standard deviation and mean deviation (bias) in the upper troposphere and lower stratosphere. The enhanced negative bias in the lower troposphere is discussed in section 3.2. There, the reference Sokolovskiy et al. 2010, JGR, is included in the manuscript. In the discussion of the enhanced negative bias in the lower troposphere we will include the reference Gorbunov et al. 2010, Radio Science. In particular, on page 1835, line 29, we will include the following sentence: "Another possible source of the negative bias in the lower troposphere are strong horizontal gradients as discussed by Gorbunov et al. (2010).“

Page 1834, Line 4: Therefore, it can not be excluded that this negative bias stems from the ECMWF analysis.
It is unlikely that the whole strong negative bias GRAS–ECMWF can be attributed to the positive bias of ECMWF data. However, some observations about the change of the COSMIC–ECMWF in years 2007–2009 can be found in the paper:

M. E. Gorbunov, A. V. Shmakov, S. S. Leroy, and K. B. Lauritsen, COSMIC radio occulta-tion processing: Cross-center comparison and validation, Journal of Atmospheric and Oceanic Technology, A-1489-HA, in press, 2011.
COSMIC bias is essntially the same as GRAS bias.

We agree, it is unlikely that the whole negative bias (present in the upper troposphere and lower stratosphere) can be attributed to the ECMWF analysis. In the meantime we experimented with different filter options (polynomial degree and window width) and realized that the bias is sensitive to the filter options (see e.g. Beyerle et al. 2011, ACP). Instead of the sentence: "Therefore, it can not be excluded that the negative bias stems from the ECMWF analysis.", we will formulate the sentence more carefully: "It can not be excluded that part of the negative bias is caused by the ECMWF analysis itself." The suggested reference Gorbunov et al. 2011, JAOT, will be included in the manuscript.

Page 1836, Line 24: Figures 11 and 12 show the fractional refractivity deviation versus altitude for rising and setting occultations for both options: the case when the RO signal is/is not truncated.
For a reader, it would be more convenient to see one figure for setting occultation with the refraction deviations for two case (signal is/is not truncated) and another similar figure for rising occultations.

We will change the figures accordingly.

References:

M. E. Gorbunov, K. B. Lauritsen, S. S. Leroy, Application of Wigner distribution function for analysis of radio occultations, Radio Science, 2010, V. 45, RS6011, doi:10.1029/2010RS004388.

M. E. Gorbunov, A. V. Shmakov, S. S. Leroy, and K. B. Lauritsen, COSMIC radio occultation processing: Cross-center comparison and validation, Journal of Atmospheric and Oceanic Technology, A-1489-HA, in press, 2011.

K. B. Lauritsen, S.Syndergaard, H.Gleisner, M.E.Gorbunov, F.Rubek, M.B.Sørensen, and H.Wilhelmsen, Processing and validation of refractivity from GRAS radio occultation data, Atmos. Meas. Tech. Discuss., 4, 2189-2205, 2011