Review of AMTD paper, Manuscript Number: amt-2011-28

Response to the comments of Reviewer #1

We thank the reviewer for the careful review and the helpful and constructive comments, which we fully took into account in the revision of the paper. Please see our detailed response below.

Specific points

- *Page 2751, Line 11: Steiner et al. (1999) reference. I do not think this is appropriate. A much better GPS/MET reference is the Kursinski et al. (1996) Science paper.*— We agree with the reviewer that the Kursinski et al. (1996) paper is an important reference, which we now included in the paper.

- *Page 2751, Line 22: "to investigate" should be "an investigation of"*—done.

- *Page 2752, first paragraph: The tracebility of the raw measurement is correct, but this is not the case for the retrieved quantities, such as bending angle, refractivity, and temperature, used in the climatologies. The paper should make this clear.*— Thanks for pointing to this important fact. We additionally note in the manuscript:

  We note that even though the measurements exhibit these beneficial characteristics, the data processing can induce a bias.

- *Page 2760, Line 8: "As stated by Lackner (2010), refractivity gradients reflect the mean bending angle for a layer." Can you quantify this statement? E.g., are they linearly proportional "mean_bending_angle = constant * refractivity gradient". What is the constant value?*

  A theoretical check of the Abel transform and an empirical investigation (see Figure 1) showed that the factor applicable to convert the refractivity gradient to bending angle is approximately −0.0005 rad/(N-Units/km). Using this conversion factor, differences between the retrieved bending angle and the refractivity gradient are smaller than 10 % almost everywhere in the lower stratosphere. Larger differences (>10 %) occur below approximately 15 km at all latitudes. They are attributable to the increasing curvature of the rays and associated larger differences between impact altitude and altitude.

  Since we focused on relative bending angle errors (in %) rather than absolute values, we did not use this conversion factor in our calculations because it basically cancels when calculating relative errors.

  We note in the manuscript:

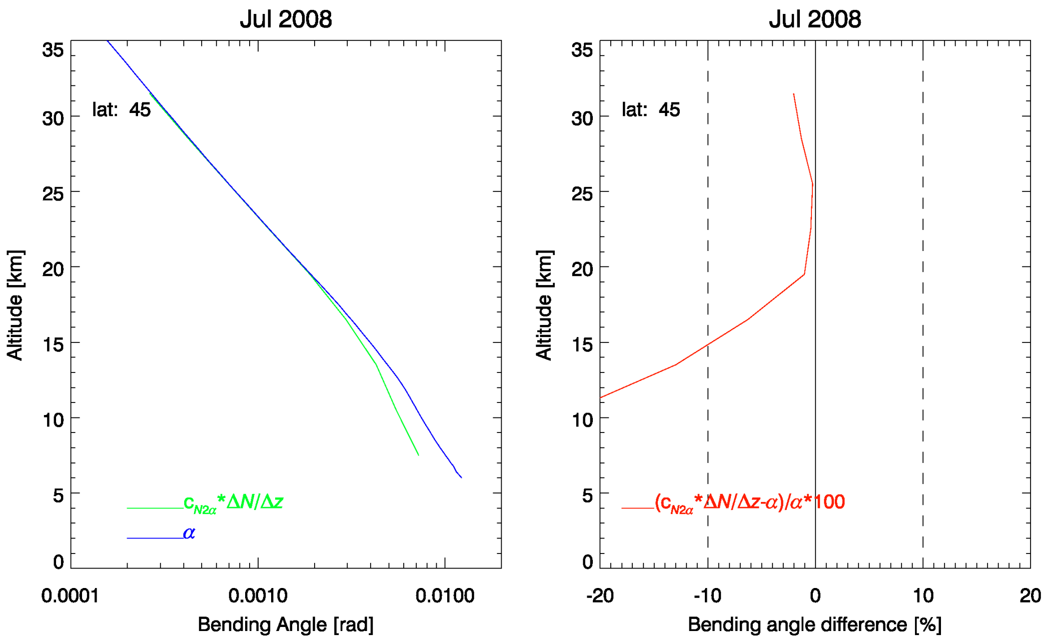

Figure 1: Example bending angle and refractivity gradient in July 2008 at 45°N (left panel) as well as their difference (right panel). Refractivity gradients are calculated for 3 km layers from 6 km to 33 km altitude (plotted between 7.5 km and 31.5 km altitude).

> A theoretical and empirical check showed that the factor converting refractivity gradients to bending angles is approximately −0.0005 rad/(N-Units/km) in the lower stratosphere, with the factor's magnitude gradually increasing into the troposphere along with the increasing curvature of rays. Since we focus on relative bending angle errors (in units %), the factor basically cancels, however, so its actual value can be disregarded.

And at the end of the following paragraph we added:

> . . . is a reasonable first approach, which we will refine in future when we have full bending angle fields directly available.

- *Page 2766, Line 15: Are the quoted temperature errors "(< 0.2 K) below 30 km" valid generally or at high latitudes? How does this number compare with recent RO trend results at high latitudes?*

  The quoted temperature error refers to the mean error in large-scale non-polar regions (such as zonal bands equatorwards of 60° with 30° or more latitudinal width) within 10 km and 30 km altitude. At high latitudes, the error is larger but it remains smaller than 0.5 K below 30 km (Gobiet et al. 2007). These results are confirmed by findings of an inter-comparison study on the structural uncertainty of RO data from different processing centers ("RO trend", manuscript in preparation).

  To clarify this statement we write:

"Due to worst quality of background climatologies, largest errors typically occur at high latitudes. However, the error decreases with altitude and is, in general, small (< 0.2 K in large-scale non-polar regions) below 30 km (Gobiet et al. 2007)."

- *Page 2766, horizontal gradient errors: The horizontal gradient error in bending angle can be written in terms of the horizontal refractivity gradients integrated along the ray path (Healy, JGR, 2001, Vol 106, 11875–11889). It should be possible to estimate these errors for the polar vortex etc.*

  We now cite Healy (2001) after "strong horizontal refractivity gradients" but decided for this current study not to give an explicit estimate for these errors for the polar vortex and other atmospheric phenomena affected by horizontal refractivity gradients. Future studies can refine this and look into different relevant phenomena more closely.

- *Page 2767, first paragraph: Horizontal gradients "challenging to signal tracking and processing". I agree that horizontal gradients will introduce inversion errors, but its not clear why they will make signal tracking above 4 km more difficult? Any references confirm this?*

  Investigating high-resolution radiosonde data, Sokolovskiy (2001) showed that the refractivity structure at low latitudes is smooth only above approximately 8 km. Below from about 6 km downwards these tropical profiles can be fairly complicated.

  Furthermore, the comparison of CHAMP and F3C signal tracking penetration depth reveals that open loop tracking results in a significantly deeper penetration and a reduction of the negative refractivity bias in the lower troposphere at low latitudes (30°S to 30°N) (Anthes et al. 2008).

  In the manuscript we add a statement that this error is more important in regions with high humidity. The sentence now reads:

  The main contributions increasing the error downwards into the troposphere are stronger horizontal gradients that are challenging to signal tracking and processing (most important in very moist regions, i.e., at low latitudes below approximately 8 km; Sokolovskiy 2001; Anthes et al. 2008) as well as generally degraded GPS L2 signal quality.

- *Page 2769, Line 10: Minor point, $k1 = 77,643$ (K/hPa) is not Rueger's (2002) recommended value. It is Rueger's value adjusted for use in a formula that includes non-ideal gas compressibility.*

  Thanks for pointing this out. We added:

  77.643 K hPa^{-1} (Rüeger 2002, adjusted for non-ideal gas effects)

References

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