Response to Reviewer #1

We thank Reviewer#1 for his/her positive overall evaluation and the helpful comments on our AMT discussion paper. We carefully addressed all four questions/comments of the reviewer and accounted for them in the paper as stated below. The original comments of the reviewer are cited in *italic font*, our response is put below each comment in standard font. The changes stated below are also highlighted in the Revised Manuscript (RM).

1) The method incorporates a background bias-calibration step. Could the general conclusions concerning the efficiency of this step be changed if you used a completely different reference data set (i.e. not ECMWF analyses, but some other comparable non-ECMWF model data)?

As long as the different reference dataset is of a character similar to the co-located ECWMF forecast profiles and analysis profiles (or background profiles combining analysis and mean-observed profiles, as in Eq. 5 of the Li et al. 2013 JGR paper) the efficiency of this step will not change. That is, the background bias calibration step (Eq. 11 in the Li et al. 2013 JGR paper) will be beneficial and mitigate the bias in this case. Such usefulness is typically to be expected as well if short-range forecast and analysis profiles from other centers like from NCEP or from re-analysis datasets would be used instead. Of course, if the different reference dataset would lead to a "doubtful" or "wrong" bias estimate, for example if one is just using some climatology dataset, it should not be used in a bias calibration step (i.e., Eq. 11 in the Li et al. 2013 JGR paper should in this case better be skipped).

2) The observed, raw bending-angle profile, α_o, *is almost exclusively the linear combination of the L1 and L2 bending angles. It is quite strongly affected by the preceding smoothing and filtering steps in the retrieval chain. Do you expect the same efficiency of the new method irrespective of the preceding filtering?*

As long as the type of smoothing and filtering in the bending angle retrieval is reasonable and therefore of a form as typically applied—such as for example the six leading RO processing centers EUMETSAT / ROM-SAF, GFZ, JPL, UCAR, WEGC apply it—we expect essentially the same efficiency of the new method. The new method would in each case just estimate the empirical error covariance matrix (according to the scheme in Fig 1 in the paper, right hand side) from the available bending angle data and it is not to be expected that the results would look very different, for typical filtering and smoothing. For example, the correlation lengths seen in the estimated observation error covariance matrices would naturally account for the (limited) differences in filter widths, etc.

3) The statistical optimization is primarily a method to reduce the impacts of random upper level bending-angle errors being propagated to refractivity and geophysical variables at lower altitudes. Could you say something about the ability to handle observational biases caused by remaining ionospheric errors.

Yes, we agree that the statistical optimization is primarily for reducing the propagation of random errors, and our new statistical optimization algorithm also reveals its best ability in reducing random errors. The ability to handle residual observational biases, such as residual ionospheric biases is only indirectly part of its capability, in the sense in that we increasingly apply a smaller observation-to-background uncertainty weighting ratio the higher the altitude is, so that background information dominates at high altitudes if the ECMWF analysis bias is estimated to be smaller than the estimated observational bias. We describe this in the manuscript. The next improvement step in this direction, which is also part of our on-going work in the Wegener Center, is that residual ionospheric biases are explicitly estimated for the retrieved bending angles so that they can be subtracted *before* the bending angle profiles enter the statistical optimization process. This is clearly the preferable option since the bias calibrations or subtractions, respectively, should make the input profiles to the optimization as unbiased as possible.
In order to point to this useful future improvement we now added in the 3rd-last paragraph of Section 2.2 (page 11) the following statement: "We currently did not include a bias calibration step similar to the background bias calibration (Eq. 5) at the observation side. Such a step may complement the $\mathbf{C}_{\mathrm{o}}^{k}$ estimation in future, however, for subtracting residual ionospheric biases in the observed bending angle profiles α_{o}^{k} before they enter the calculation of mean-observed bending angles (as part of estimating $\Delta\overline{\alpha}_{\mathrm{f\text{-}b}}^{k}$; Li et al., 2013) and the statistical optimization equation (Eq. 2).".

4) The method described adds quite a lot of complexity to the "optimization" of the observed, raw bending angles. If one was to speculate a bit: could further developments of ionospheric correction methods, e.g. by applying more physically realistic assumptions concerning the ionosphere, reduce the need for this type of very complex statistical-optimization step?

We think "complexity" is a matter of perspective here. In fact when we conceived the new method we felt as well it is quite more complex than the existing methods so we well understand this perspective. However, after the learning process we strongly see the benefits of the added "complexity", the advantages also summarized in the paper, and we now find it an elegant and powerful approach to fully implement the capabilities of the statistical optimization equation (Eq. 2 in the paper) by dynamic empirical formulation of the covariance matrices $\mathbf{C}_{\mathrm{b}}$ and $\mathbf{C}_{\mathrm{o}}$ plus by a bias calibration step that precedes the statistical optimization (Eq. 5 in the paper for background bias calibration; in future also a similar step can be done for residual ionospheric bias calibration of the observed bending angles, as mentioned in our answer to comment 3 above). Compared to existing methods this minimizes the leakage of both unnecessary biases (e.g., by climatological profiles with biases higher than co-located analysis or mean-observed profiles) and

unnecessary noise (e.g., by not properly accounting for the correlations in observations and background).
On the perspectives for future developments, especially regarding the correction of ionospheric residuals: yes, such developments will ease the statistical optimization job, as described above, since the observational bias problems are minimized. But the noise mitigation and filtering function—in the sense of providing a smooth and robust high altitude initialization of the bending angle profiles before they enter the Abel transform—will always keep its benefit. The new method with its general empirical error covariance matrices, which we in future also use as auxiliary information for retrieval-integrated uncertainty estimation, ensures that this benefit is harvested in a best possible manner.

Many thanks again to Reviewer #1 for his/her valuable comments that helped us to further improve our manuscript.