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Interactive comment on "Retrieval of temperature and water vapor profiles from radio occultation refractivity and bending angle measurements using an optimal estimation approach: a simulation study" *by* A. von Engeln and G. Nedoluha

A. von Engeln and G. Nedoluha

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Final Author Comments on:

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Title: Retrieval of temperature and water vapor profiles from radio occultation refractivity and bending angle measurements using an Optimal Estimation approach: A simulation study

Authors: A. von Engeln and G. Nedoluha

Authors Response:

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First of all thanks to both referees for their time and effort. Especially Referee #1 who very thoroughly went through our manuscript.

Most of the raised issues are answered in the updated manuscript, we will only briefly outline the change here. An updated manuscript can be found at:

http://www.sat.uni-bremen.de/members/ave/publications/papers/acpd-2004si05-010.pdf

and will also be submitted to ACP.

General Remarks:

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Referee #1 raised several questions about the validity of our error covariance matrix and suggested to instead propagate bending angle errors to refractivity errors to properly include correlations. He/She also questions the use of this setup for assessing the impact of an assimilation into a NWP model.

We fully agree with Referee #1 that the effects of including GPS data on a NWP model can only be fully understood when the data is assimilated and forecast models are run, etc.. We also fully agree that the choice of error covariance matrix will affect the retrieval, and certainly the optimal use of this data with a specific NWP model can only be accomplished by a very careful choice of the error covariance matrix. Nevertheless, we feel this study is useful because it does give a qualitative, non-NWP model specific estimate of the effect of including GPS data and, for two sets of reasonable error covariance matrices, shows that the results for bending angle and refractivity based forward models are similar. By comparing bending angle and refractivity results we also assure

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that the refractivity approximation is valid, since the definition of the bending angle error covariance matrix is not an approximation.

Specific Remarks Referee #1:

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- p 1586 l1-3: sentence has been clarified

- p 1588 l9-11: various choices avoided and more specific text included

- p 1588 l24-26: references to fast non-local operators included

- p 1591 l9-11: transform changed to inverse

- p 1591 l14-17: theoretical resolution modified to 50m, rephrased sentence

- p 1593 Sec3: in order to keep this publication short, we did not include the cost function. However we mention now explicitly that the Optimal Estimation is equivalent to a 1DVar setup.

- p 1594 Eq6: We start from the pure noise error in our setup but later on modify these errors to also include the representative error. We now more clearly mention that the initial setup uses only the pure noise part.

- p 1595 l15: contribution from limb sounding rephrased

- p 1595 l25-29: We did use different settings for the initial surface pressure uncertainty but also found out that the sensitivity to this uncertainty is very low, thus redoing all calculations will not alter the results. We did mention this in the manuscript. We did not use an ECMWF forecast as a priori because the actual differences between forecast and analysis are very small. Comparisons of radio occultation soundings with the real world show that ECMWF can be several Kelvins wrong, thus the use of a forecast would underestimate these errors.

- p 1596 l8-9: as mentioned above, we have included a few more cautious remarks on

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our simplified setup.

- p 1597 l3-5: vertical correlation statement clarified. Since different NWP centers have different vertical correlation schemes, we felt that not including any vertical correlation was the most generic choice.

- p 1597 l6-8: bias caused by a priori data rephrased

- p 1597 l14: further information on multipath included in the manuscript

- p 1597 l19-22: direct inversions (dry temperature) statement reworded

- p1597 l25-27: we did run simulations only down to 15km tangent altitude, these should then show whether integration issue improves the bending angles. These calculations did show slightly higher standard deviations than those that were run down to the lowest possible altitude. Ses also general remarks above

- p 1598 l1-4: Clarified that this is caused by our simplified setup. The correct propagation of bending angle to refractivity errors should remove this difference, although, as now mentioned in the paper, there are different ways to calculate correlations. Also, different NWP centers will use different correlations and possible parametrization of the refractivity correlations. The Abel integration to infinity is not a problematic issue in our setup since we do retrievals up to 100km.

- p 1598 l8-12: included a further statement that these results also hold for an optimized setup (a priori errors equals true errors) within an ideal retrieval. While it may be possible to optimize error covariances to improve the retrieval of water and temperature in the lower stratosphere, there remains the fundamental problem that we are trying to use one measurement to retrieve two quantities.

- p 1598 l18-19: dry temperature retrieval statement reworded

- p 1598 l25-26: Again, in order to keep this publication short we think this bias plot is not necessary. We however included some more comments with respect to the bias

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behavior throughout the manuscript. The bias is removed because we don't have to worry about the water vapor - temperature ambiguity at altitudes above about 10km, so the a priori becomes unimportant (until we get to altitudes limited by signal-to-noise).

- p 1599 l7-9: ray tracer statement modified

- p 1599 l27-29: see general remarks above

- p 1600 l3-4: see general remarks above

- p 1600 l9-13: all calculations are aligned, such that if an occultation with the ray tracer terminates at 4.5km, all other calculations also only go up to this altitude to make the comparisons meaningful. Thus multipath will likely be removed from all retrieval setups. We also validated our implementation of the Abel integral by comparing it to EGOPS ray tracer calculations with a symmetric atmosphere. EGOPS itself has been validated several times with actual radio occultation measurements and also by retrieving temperatures and water vapor from these measurements.

- p 1600 l13-14: included references to non-local operators

- p 1600 l15-17: included a further statement that these results also hold for an optimized setup (a priori errors equals true errors) within an ideal retrieval.

- p 1601 Sec5: we do find these results also for Fac 0.5 calculations. As mentioned above, we now state this also in the manuscript

- p 1603 l14-15: a priori weight sentence reworded according to suggestion

- p 1604 Sec7: see general remarks above

- p 1605 l4-5: rephrased this statement and included reference to non-local operators

- p 1605 l3-4: rephrased a priori above and below this altitude statement

- p 1607 l18: included that critical refraction for bending angles requires a special treatment

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- p 1612 Tab1: units included in table

- figure scaling: We leave the decision for the final size to the figures to ACP.

Specific Remarks Referee #2:

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- p 1586: reworded this statement

- p 1591: Jensen reference included, along with several other ones suggested by referee #1

- Table 1: units included

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 1585, 2005.