

## ***Interactive comment on “Stratospheric isotopic water profiles from a single submillimeter limb scan by TELIS” by A. de Lange et al.***

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### **1 Response**

First I would like to thank the referees for the time spent on reading and commenting the article. Below I will address all points made by the referees. All line and page numbers refer to the old text.

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#### 1.1 Referee 1 - Comment 1

*p866, line 11: The text states the importance of radiative transfer above the maximum tangent height of 37 km but this is not referred to again in the text.*

Author: The radiative transfer of the altitude range above 37 km has to be taken into account in order to conduct a proper retrieval in the altitude range covered by the tangent heights. Profile information in the range above 37 km is, however, scarce in the spectra. This is reflected by the steep increase in the retrieval error in conjunction with a strong broadening of the averaging kernels. In conclusion, the radiative transfer above 37 km has to be taken into account for the retrieval of the lower part of the stratosphere, but the actual retrieved values in this altitude range is of only limited value.

I propose to add the following lines on p870 after line 7:

"Above 37 km the retrieval error increases for both H<sub>2</sub><sup>18</sup>O and HDO in conjunction with a broadening of the averaging kernel as information in the spectra is limited for these altitudes. This is because no tangent heights are possible above the flight altitude of 37 km. Although the radiative transfer of this altitude range is of importance for the retrieval at lower altitudes, the actual retrieved values are of limited value only."

#### 1.2 Referee 1 - Comment 2

*p869, line 11: Error propagation for these unmeasured quantities is not taken into account. It would seem at least reasonable to assume an uncertainty in the temperature profile and carry out an error propagation for the sensitivity study.*

Author: I agree that this would make the paper stronger as it addresses another error source that can be anticipated upon. The proposed analysis has been performed and I propose to remove the line on <sup>16</sup>O<sup>18</sup>O on p869 and add in stead the following as section

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5.1:

"The assumed temperature profile has only limited accuracy and may therefore have an impact on the retrieval error. The temperature profile will be taken from the analysis data by the ECMWF (European Centre for Medium-Range Weather Forecasts). The accuracies for March 2009 in Northern Scandinavia is on the order of 1 K up to the maximum validated pressure level of 10 mbar which corresponds to an altitude of  $\approx 32$  km (private communication, Fielding, 2009). A slight increase can be discerned above  $\approx 27$  km. The accuracies are in the following analysis set to 1 K for altitudes up to 27 km and then a gradual increase to 2 K at 46 km. To assess the error propagation of this uncertainty onto the retrieved rare water isotopologue profiles the following formula is employed:

$$\mathbf{S}_{\bar{x}} = \mathbf{D}\mathbf{K}_T\mathbf{S}_T\mathbf{K}_T^T\mathbf{D}^T, \quad (1)$$

with  $\mathbf{S}_T$  the ECMWF temperature covariance matrix,  $\mathbf{D}$  the contribution matrix,  $\mathbf{K}_T$  the Jacobian of the temperature, and  $\mathbf{S}_{\bar{x}}$  the covariance matrix of the retrieved state vector (Rodgers, 2000). The result of this analysis is depicted in Fig. 1 (at the end of this document). As can be seen, the error is in the range of the tangent heights only  $\approx 0.2\%$ , which is less than the retrieval error (see Fig. 3) and is therefore of only minor consequence. Alternatively, the temperature profile may be determined from the measurements from the  $^{16}\text{O}^{18}\text{O}$  line at 508.996 GHz."

### 1.3 Referee 1 - Comment 3

*p872, line 30: It is noted in the text that "the averaging kernel narrows when pointing information is retrieved". How does the regularization parameter (gamma) change between the retrieval cases studied? The Tikhonov regularization can be set up so that a gamma value can be chosen set to provide an improved precision at the expense of a degraded (though still acceptable) vertical resolution. The L-curve (p867) determines the trade-off between retrieval precision and vertical resolution. Was this considered*

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*for the TELIS retrievals?*

Author: The bend in the L-curve is not a single point, but actually covers a small range of regularization parameters. The exact choice of this point depends on the specific algorithm (maximal curvature in the case of TELIS). The retrieval results, however, do not change much within this range of regularization parameters. To significantly improve the precision, the regularization parameter has to be increased to such an extent, that the modelled spectrum associated with the retrieved profile does not represent the measurement within noise limits anymore which is an undesirable situation.

I propose not to address this point in the article.

### 1.4 Referee 1 - Comment 4

*p872, line 18 and Fig 5: What is the explanation for the very large increase in retrieval error in going from a pointing offset of 5 arc min to 10 arc min?*

Author: In Fig 5 and 6 the retrieval results for a pointing offset are depicted for respectively HDO and  $\text{H}_2^{18}\text{O}$ . In Fig 6, the retrieval error increases gradually with increasing pointing offset. A similar trend is expected in Fig 5, but due to noise on the curves, this trend is obfuscated.

The explanation of why the increase in retrieval error occurs, is the following. The sensitivity of the intensity in the spectra to a pointing offset is in first order almost frequency independent, ie. a baseline offset. For large pointing offsets, however, the lineshape and linestrength change in addition to the baseline offset. These spectral features can also be attributed to a change in the profile of the species. Therefore, information on the pointing offset and the water isotopologue profile become entangled which is expressed by an increase in the retrieval error. This increase is first apparant at lower altitudes as the offset in kilometers at tangent point increases with decreasing altitude.

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I propose to replace the text after '... significantly larger.' (line 17, p872) by:

"This can be explained by the fact that a pointing offset corresponds to an increasing offset in kilometers at tangent point for decreasing altitude. The impact on the retrieval is therefore highest for the lowest tangent heights. For increasing pointing offsets, the affected range extends to higher altitudes. For an offset of 10 arc min, the retrieval error is deteriorated over the whole altitude range with respect to the retrieval without pointing offset."

#### 1.5 Referee 1 - Textual comments

*Minor corrections and typos.*

Author: All textual changes will be incorporated.

#### 1.6 Referee 2 - Textual changes

Author: Comments 2, 3, 4, 5, 7, and 10 pertain to textual changes and all are incorporated.

#### 1.7 Referee 2 - Comment 1

*Row 34: A reference to Ridal et al. might be appropriate*

Author: A reference to this work is indeed appropriate and is included.

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#### 1.8 Referee 2 - Comment 6

*Row 113: It should probably be noted here or elsewhere that these are the lines used by Odin*

Author: The lines are indeed also used by Odin and is now referred to in the text.

I propose to change the line into: "Notable exceptions are the H<sub>2</sub><sup>18</sup>O line at 489.054 GHz and the HDO line at 490.597 GHz which are also the lines probed by the Odin satellite (Urban et al., 2007). It is noted that the HDO line shows a small ozone feature in its wing."

#### 1.9 Referee 2 - Comment 8

*Row 175-180: should not equation 7 have r instead of y: y is never introduced as the measurement vector - A clean up of notation and its use is needed so as to not confuse the reader.*

Author: The measurement vector is  $\vec{r}$ , not  $\vec{y}$ , and is introduced above equation 6. In equation 6 the problem to be solved, is given, and is then linearized by means of a Taylor expansion. The result is equation 7 where  $\vec{y} = \vec{r} - \vec{F}(\vec{x}_{i-1}) + \mathbf{K}\vec{x}_{i-1}$  (see just below equation 7).  $\vec{y}$  is therefore related to the measurement vector  $\vec{r}$ , but is a slightly different quantity. I propose to leave the text as is.

#### 1.10 Referee 2 - Comment 11

*Row 255: Since HDO is depleted by 30%–80% in the stratosphere this approach is over estimating the amount. This should at least be noted but it would be preferable to check the calculations with a smaller amount HDO. It would also be nice to have the altitude of the tropopause noted for this atmosphere.*

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Author: I agree that HDO is indeed depleted in the stratosphere and this should be mentioned in the paper. The depletion is, however, a function of altitude and lessens with increasing altitude due to methane oxidation. The sensitivity of the measurement to changes in the HDO concentration is independent of the actual concentration. This leads therefore to a similar *absolute* retrieval error in both the depleted and undepleted case. A depletion of 30–50% would thus only imply an increase of 30–50% of the *relative* retrieval error; an error of 4% would become 5%–6%. It is noted that in the case of H<sub>2</sub><sup>18</sup>O the expected depletion is less than 10% (and was consequently not mentioned by the referee).

I propose therefore to add the following line on p869 after '... the principal isotopologues H<sub>2</sub><sup>16</sup>O': "It is noted that the profile of HDO may be depleted in the stratosphere by 30–50% which would lead to a lower signal strength. This depletion is a function of altitude and lessens with increasing altitude due to methane oxidation. The depletion of stratospheric H<sub>2</sub><sup>18</sup>O is less than 10%." The conclusion has been adapted as well.

The tropopause is  $\approx$  12 km and I would like to add the following line on p869 after '... AFGL US standard atmosphere (Anderson et al., 1985)': " with the tropopause of 217 K at  $\approx$  12 km."

#### 1.11 Referee 2 - Comment 12

*Rows: 265-280: It is unclear here how the retrievals were carried out. What initial profile was used? what other parameters were tuned.*

Author: In this study no other parameters are tuned or retrieved than the ones mentioned in the text. In the case described in lines 265–280 only instrument noise is taken into account. As H<sub>2</sub><sup>18</sup>O occurs in the wing of a strong water line and HDO features a small ozone emission line in its wing, H<sub>2</sub>O is retrieved in addition to H<sub>2</sub><sup>18</sup>O and O<sub>3</sub> to HDO. The initial profile is indeed not mentioned in the paper and will be added.

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I suggest to add some lines on the initial conditions of the retrieval after '... only receiver noise is considered' on p869: "As first guess, the true state vector is taken with a scaling factor. The scaling factor has no influence on the retrieval results in the range of 10% to the upper limit of 400%."

#### 1.12 Referee 2 - Comment 13

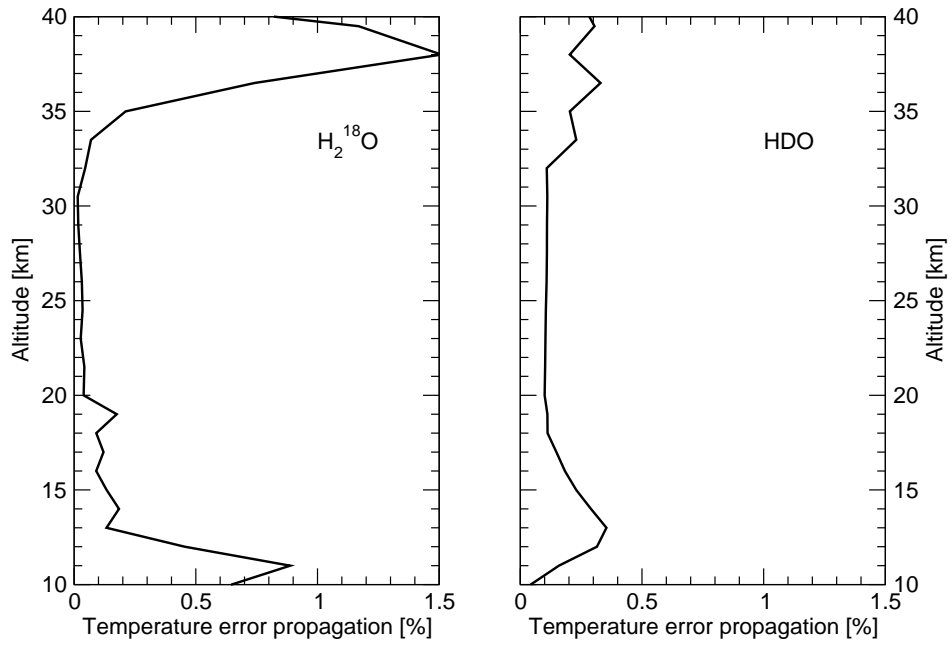
*Rows 320-350: It is unclear here what sort of pointing "offsets" are applied. In the text it is said that pointing is retrieved for each spectrum but the rest of the discussion sounds like a single pointing offset is applied to all views. In that case then it is unnecessary to retrieve for each spectrum. This needs to be clarified.*

Author: Both a single pointing offset and a different pointing offset for all views have been applied and both have been addressed in Sect. 6.1. It is true that it is not only unnecessary but even undesired to retrieve multiple pointing offsets when a single pointing offset has been applied to all viewing angles. However, it is anticipated that a pointing offset has to be retrieved for all line of sights in view of the rocking motion of the instrument with respect to the gondola as it is attached by springs, albeit very stiff ones. Although this is mentioned in the first paragraph of Sect. 6.1, I propose to mention it also where the random offsets are discussed. The line 'The rationale behind ... every spectrum separately.' on p873 will be replaced by: "The rationale behind this is that it is anticipated that the actual pointing angles of real measurements will show a general offset with a random component superimposed due to the springs by which TELIS is attached to the gondola, and hence, it must be retrieved for every spectrum separately."

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**Fig. 1.** The error propagation of the limited accuracy on the temperature on the retrieved HDO and H<sub>2</sub>-18O profiles is depicted. The error is given in % relative to the true state vector and can thus directly b