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Interactive comment on "Tomographic reconstruction of atmospheric gravity wave parameters from airglow observations" *by* Rui Song et al.

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Responses to reviewers' comments on
"Tomographic reconstruction of atmospheric gravity wave parameters from airglow observations" by Song et al.

The authors would like to thank the reviewers for their valuable comments, which helped us to improve the quality of this manuscript. We have addressed all the comments, and the reply to each comment is highlighted in blue as follows.

Reply to Anonymous Referee #1

The paper "Tomographic reconstruction..." by R. Song et al. describes a new variant of a tomographic retrieval which is custom tailored to a not-yet existing measurement system planned to be operated in a novel measurement mode. As a methodical preflight-study the scope of the paper fits well in AMT but a couple of details should be clarified prior to publication. In general, the paper is well written, well organized, scientifically sound, and as far as I can judge, all relevant literature has been referenced.

We thank the referee for carefully reviewing the manuscript and for the positive comments.

Scientific issues:

p2 l30: I am not quite sure if the term "oversampling" is adequate here, at least in the context of MIPAS (although MIPAS is not explicitly mentioned here, the Carlotti et al. reference hints at MIPAS). Von Clarmann et al., Atmos. Meas. Techn., Vol. 2(1), 47-54, 2009, "The horizontal resolution of MIPAS", find that the horizontal resolution of MIPAS in terms of along-track information smearing is better than the horizontal sampling in terms of the horizontal spacing of measurement geo-locations. Thus there is undersampling, not oversampling. Either reword, or define clearly in which sense you use the admittedly ambiguous term "oversampling". Does it refer to the retrieval space or the measurement space, etc?

Thanks for the suggestion. We agreed that the term "oversampling" is inadequate here. The original meaning of this sentence is to show that better horizontal resolution can be achieved for some limb sounders, such as MLS and MIPAS. As such instruments observe the atmosphere along the track of the orbit, the atmospheric variability along the LOS can be considered in the retrieval. In the paper "The

horizontal resolution of MIPAS" by Von Clarmann et al., the authors explained clearly that the along-track smearing is two times smaller than the horizontal sampling, which means the atmosphere is undersampled. Therefore, we have rewritten this sentence and added the reference of Von Clarmann et al. "...mitigate this general limitation by considering the horizontal variability of the atmosphere in the retrieval (Livesey and Read, 2000; Carlotti et al., 2001; von Clarmann et al.,2009)".

p5 l5 and p8 l15: On page 5 the atmosphere is assumed to be so opaque that any signal from the lower atmosphere and surface can be ignored. On page 8 the atmosphere is so optically thin that no self-absorption has to be considered. These two approximations seem to be in conflict with each other, except if the transmission jumps from 1 to 0 at the target air volume. I do not doubt that the approximations made can somehow be justified but I think that a little more discussion is needed to refute the apparent contradiction. Particularly in the sub-limb mode I expect that you either get considerable signal from altitudes below the target volume, or that the atmosphere in front/above the target volume is not really transparent.

In the infrared, this model assumes the atmosphere to be optically thick in the lower atmosphere and optically thin in the upper atmosphere. To avoid the conflict in the manuscript, we added a sentence to explain the assumption prior to use: "In the infrared the lower atmosphere is optically thick, whereas the upper atmosphere can be considered as optically thin. Since the O_2 A-Band is a transition to the O_2 ground state, the atmosphere becomes optically thick at stratopause altitudes. Therefore, any emission from the Earth's surface or tropospheric altitudes cannot reach the upper mesosphere at these wavelengths. At nightglow layer altitudes (upper mesosphere / lower thermosphere) the atmosphere is optically thin for the wavelengths considered. In our case,...".

p6, general comment: No statement is made how well the measurement geom-

etry is known, and in consequence, how well the pressures at the tangent points are known. The measured signal does not only depend on temperature but also on the number of molecules along the ray-path (or more precisely: the transparent and semi-transparent part of the ray-path). How is this multi-variable problem solved? Or is the tacit assumption made that the actual measurement geometry and pressure distribution are perfectly known? The manuscript should be a bit clearer with respect to this.

Thanks for the suggestion. In this simulation, the pressure is not needed and the actual measurement geometry is assumed perfectly known. The atmospheric temperature T is retrieved on the tangent altitudes in this study.

Wording and presentation issues and technical corrections:

Abstract: About a third of the abstract are like an introduction. I would prefer an abstract which includes less general introductory information but more methodical information and or results.

Thanks. We have revised the abstract according to your suggestion.

p1 l10: There is no "2-dimensional atmospheric state". Better say "allow for tomographic 2-dimensional reconstruction of the atmospheric state".

Agreed. This change has been made.

p1 l11: "As no real data are available" sounds too defensive to my ears. It is fully legitimate to present pre-flight studies and retrieval sensitivity studies in AMT. Why not simply "The feasibility of this tomographic retrieval approach is assessed using simulated measurements".

Thanks for the suggestion. This sentence has been rewritten.

p1 l12: "much smaller" than what?

The text has been revised to clarify this. "It shows that one major advantage of this observation strategy is that GWs can be observed on a much smaller scale than conventional observations."

p1 l20: comma after "(GWs)"

A comma has been added after "(GWs)".

p2 l14 "they include": not quite clear what "they" refers to. I suggest to reword.

This sentence has been reworded. "GWs can be also characterized by nadir viewing instruments, such as the Atmospheric Infrared Sounder (AIRS) (Alexander and Barnet, 2007; Hoffmann and Alexander, 2009; Ern et al., 2017) and the Advanced Microwave Sounding Unit (AMSU) (Wu, 2004)".

p3 l2 "limited-angle tomography". This sounds as if it was a technical term but I have never heard it before. Please either define this technical term, or avoid it and use generic terms instead.

This sentence has been rewritten to clarify this point. "This results in multi-angle observations of the target volume, such that a tailored retrieval scheme can be applied. This differs from classical limited-angle tomography, where only observations within a limited angular range are taken for the reconstruction."

p3 l3/4: The technical term "target mode" is used here twice but defined only in line 18. I suggest to write "In Section 2 we present the observation strategy which we call ‘target mode’ observations. Then it is clear that you give this name to something new and the reader will not wonder if he/she has missed anything.

Thanks for the suggestion. This sentence has been revised.

p3 l 16: Please define the term "sub-limb sounding".

The term "sub-limb" has been defined in text. "The sub-limb sounding has a similar geometry with limb sounding, whereas the tangent heights are near or below the surface."

p3 l 23: The description of the geometry is somewhat unclear. You talk about "limb sounding", not "limb imaging". This implies that during one limb scan the viewing geometry is changing all the time. It is thus not clear how multiple consecutive profiles can be obtained while a limb view is kept. The text would be much clearer if you distinguish between limb scanning (usually used as a synonym to limb sounding) or limb imaging (recording of multiple ray-paths at the same time) is used. The statement "The instrument will keep the limb view" currently has three possible different meanings: 1. A series of measurements is made using the SAME tangent altitude. 2. A profile of limb radiances is measured simultaneously with a 1D imaging device. 3. Tangent altitudes change while the limb is scanned, and the statement is just meant to tell me that it is not switched from the limb-scanning mode to the sub-limb mode. Please clarify. Perhaps use a weaker wording than "will keep this limb view"; perhaps say "The instrument will continue to measure under limb geometry for a period of time"; and finally clarify what type of "vertical profiles" are measured. I guess "vertical radiance profiles".

Thanks for finding and explaining this point that was not clear in the manuscript. We have revised this paragraph to avoid misleading the readers. First, the term "limb sounding" has been replaced by "limb imaging". Second, we accepted your suggestion for revising the sentence "The instrument will keep this limb view...". It has been rewritten as "The instrument will continue to measure under limb geometry for a period of time, and multiple consecutive vertical radiance profiles will be taken during this time".

p5 l18: Is A1 really a "transmission probability" or do you mean a "transition probability".

Corrected as "transition probability".

p6 l2: Is the A1 here the same as in Eq 3: Please use different symbols for different designates, and/or use the same technical terms for the same designates.

In Eq 3, the A-band transition probability is represented by A_1. In Eq 6, the wave amplitude is represented by A.

p8 Eq 13: Since $\mathbf{S}_a^{-1}$ is not the inverse of a covariance matrix but a freely defined regularization term, I find it inadequate to use the symbol Sa here, which is usually applied only for probabilistic a priori covariance matrices.

Thanks for the suggestion. Therefore, we use $\mathbf{R}$ instead of $\mathbf{S}_a^{-1}$ in Eq 13 and the following text.

p9 l2: Not clear what "It" refers to. The content suggests that it refers to the entire regularization procedure but grammatically it refers to the a priori data alone, which does NOT ensure that a unique solution can be obtained. I suggest: "The second term

in the cost function (Eq. 13) ensures that..."

Agreed. This sentence has been revised to : "The second term in the cost function (Eq. (13)) ensures that..."

p9 l5: references to Levenberg, Marquardt, and the implementation actually used would be appropriate.

Relevant references have been added. "(Levenberg, 1944; Marquardt, 1963; Ceccherini and Ridolfi, 2010)".

p9 l11: you may wish to add the term "unstable solution" here

Accepted. Sentence has been revised as "... while a small value will give an unstable solution".

p10 Eq 16: If you used the convention that $f' = \mathbf{K}$, then the equation would be easier to recognize (and, of course, define K prior to its use).

Agreed. f' has been replaced by $\mathbf{K}$ for easier recognition. A sentence has been added to define $\mathbf{K}$: "where $\mathbf{K}$ is the Jacobian of the forward model f at atmospheric state x".

p10 l20: For the non-specialist it would be helpful to clarify if you perturb the temperature field only or if you adjust pressure (and with this also absolute concentrations of species) hydrostatically.

A sentence has been added to clarify this: "The temperature, atmospheric density and concentrations of various constituents are perturbed by this simulated wave."

p14 l17: Has the acronym LOS already been defined? With respect to the "poor horizontal resolution", see my comment on p2 l30: At least for MIPAS it is the horizontal sampling and not the resolution of the measurement itself which is limiting the horizontal resolution of the data product.

The acronym LOS is defined in p3 l30 (discussion paper): "Figure. 2 shows how the line-of-sights (LOSs) of...". With respect of the "poor horizontal resolution", this point has been revised in the introduction according to the comment on p2 l30.