Atmos. Meas. Tech. Discuss., 3, C1661–C1670, 2010
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Atmospheric Measurement Techniques Discussions

Interactive comment on "Two-dimensional performance of MIPAS observation modes in the upper-troposphere/lower-stratosphere" *by* M. Carlotti et al.

M. Carlotti et al.

carlotti@fci.unibo.it

Received and published: 8 October 2010

Answers to reviewer #1

Introductory remarks.

In our opinion many of the objections raised by this reviewer require clarifications about the meaning of the Information Load (Ω defined in *Carlotti and Magnani* 2009). Therefore, before answering to specific questions, we specify some crucial points about this quantifier:

1. Ω is a scalar quantity, associated to each clove of the 2D discretization, defined by Eq. 4. In this equation the triple summation gives full details of a single summation (that could be used instead) extended to all the spectral signals that are affected by the value of the target quantity in the considered clove.

2. Eq. 4 originates from the necessity to combine the sensitivities (derivatives) of all the spectral signals that depend from the considered clove w.r.t. the target quantity; the adopted combination rule is the quadratic summation.

3. Eq. 5 is only meant to justify the choice of quadratic summation as combination rule. It shows that, in a retrieval analysis meant to determine the value of the target quantity q in clove h, **K** is a vector and the term in square brackets of Eq. 2 becomes identical (with some assumptions, see point 5) to the term in square brackets of Eq. 4. This means that the uncertainty on the retrieved value of q is given by $1/\Omega$ (see Eq. 3 of *Carlotti and Magnani* 2009). [In order to be more specific about this point Sect. 3.3 has been modified introducing corrections at lines 1 and 7 of page 2869 of the discussion paper].

4. The information load analysis is not a subset of the 2D retrieval analysis (see also point 6). As specified in *Carlotti and Magnani* 2009) it is a tool to identify the real atmospheric sampling of the observations; it can be used to arrange the retrieval grid where the information peaks (then avoiding to run into broad averaging kernels after the retrieval) or to compare the atmospheric sampling relative to different targets or different observation strategies (which is the matter of this study).

5. The main assumption made in Eq. (5) is that the variance-covariance matrix (VCM) of the observations $\mathbf{S}_n$ is the unity matrix ($\lambda = 0$ and $\mathbf{R} = \mathbf{0}$ can be

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imposed because no external constraints are considered). Actually we have also calculated maps of the *Weighted Information Load* ($W\Omega$) quantifier defined as $\mathbf{K}^T \mathbf{S}_n^{-1} \mathbf{K}$ where $\mathbf{S}_n$ is the VCM built for the set of observations that enter in $\mathbf{K}$. Unlike Ω the scalar quantifier $W\Omega$ also takes into account the noise level of the selected microwindows so that it becomes meaningful when the information load analysis is used to compare the performance of different sets of observations. For the present study the same MWs have been used for all the observation modes (see answer to general points below) and we have verified that the distributions of $W\Omega$ do not add insight w.r.t those of Ω. For this reason we preferred not to overload the paper by introducing the unpublished quantifier $W\Omega$.

6. The definition of $W\Omega$ made at point 5 could drive to a step forward with the calculation of the full solution formula (Eq. 1). This path would lead to a different 2D retrieval approach based on a composition of retrievals operated on the individual cloves. However with this approach correlations between the retrieval parameters would be completely neglected and this is why we state that the information load analysis is not a subset of the 2D retrieval (see point 4) so that 1/Ω cannot be compared with the estimated standard deviations of the *traditional* 2D retrieval.

In the discussion paper we quote four times the paper *Carlotti and Magnani* (2009) where Ω was introduced first; however we realize that the information load analysis is rather recent (the discussion paper reports its first application) and the reader can be barely familiar with the related topics. Therefore we have added at the end of Sect. 3.3 of the discussion paper some additional specifications about its meaning.

General points

The reviewer's comments are organized within four paragraphs. In our answers we refer to the paragraph order number.

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Paragraph 1.

The reviewer's considerations are correct in the case of real atmospheres where the sign of the horizontal gradients change with a frequency which is smaller than, or comparable to, the separation between the retrieval grid profiles. For our simulations the atmospheric fields are built using the climatological profiles taken from Remedios et al. (2007) that refer to six latitudinal bands (without day/night discrimination) whose amplitude ranges from 20 to 35 deg. The largest separation in our retrieval grids is less than 3.8 deg therefore the contribution of the systematic component (smoothing error) becomes negligible. We acknowledge that the above considerations are not straightforward in the discussion paper that, for the purpose, has been changed after line 20 of page 2871.

Paragraph 2.

As for the first question see the introductory remarks. Section 3.3 reports, for the convenience of the reader, a summary from the referenced paper *Carlotti and Magnani* (2009) that first introduced the information load analysis. In Sect. 3.2 of this paper (pg. 5352) is a paragraph describing the procedure adopted to calculate that we copy below:

The process of computing a map of Ω starts with the simulation of all the spectra of the considered orbit by means of a forward model. The cloves of the 2D discretization are then "switched on", one at a time, by giving an increment to the target quantity (see e.g. the clove considered in Fig. 2). The observation geometries that define the multiplicity of the considered clove are then calculated again and the spectra corresponding to the unperturbed atmosphere are subtracted to those corresponding to the perturbed atmosphere to build the incremental ratios that approximate the derivatives of Eq. (7). At this point the terms are all available for the calculation of the triple summation and

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of the Ω value as defined in Eq. (7).

Where Eq.(7) corresponds to Eq. (4) of the discussion paper.

We believe superfluous to report this description in our paper but we have added the specific reference to the above paragraph at line 10 of page 2869 of the discussion paper.

At line 8 of page 2872 of the discussion paper we state that “common MWs and auxiliary data (those adopted for the NOM operational analyses) have been used in the simulated retrievals reported in this and in the next sub-section".

At line 18 of page 2869 of the discussion paper we have included the information about the use of common MWs for the three observation modes, furthermore we have exchanged the position of this period with the previous one.

Paragraph 3.

To the considerations at points 3 and 6 of the introductory remarks we can add that in a retrieval analysis we expect better performance for parameters located in regions where Ω values are high. We have added a sentence in this direction at line 14 of page 2869 of the discussion paper.

Paragraph 4.

In our text we state that the uniformity of the Ω distribution “allows to select the retrieval grid without taking care to match the positions where the information accumulates" and that “the stability of the retrieval is determined by the trade-off between precision and spatial resolution". Retrieval instabilities occur when the spatial resolution requirements are too demanding w.r.t the information load of the observations even if its distribution is uniform (e.g. for UTLS2). We agree with the reviewer that *using the information load it is not possible to judge how well the problem is determined*. Indeed the Ω analysis is useful, and is used in our study, only for comparative analyses about the performance of different observation scenarios. The simulated retrievals answer the question about *how well the problem is determined* and we show that they confirm the indications provided by the information-load analysis.

About the reviewer's comments:

But it, especially for a uniform case, does not tell under which geometries observations are performed.

It is true that the information load does not tell which observation geometries contribute to it; this kind of analysis (multiplicity analysis) can be found in Sect. 3.2 of *Carlotti and Magnani* (2009). However what is meaningful is the value of Ω but not the observation geometries that contribute to generate this value.

But tomography requires that each observation is performed under its own unique geometry.

We do not understand this statement. Tomography requires that the analyzed atmospheric parcel is observed by more than one observation geometry (see *Carlotti et al.*, 2001).

The problem with small horizontal intervals between scans can be that the geometries are not completely unique, thus the problem becomes underdetermined.

An inversion problem that makes use of a given number of observations becomes underdetermined as the number of unknowns is increased beyond a threshold (see also answer to specific point 26).

Specific points

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Points from 1 to 5. Corrected as requested.

Point 6. A table has been added summarizing the main features of the observation modes in Sect. 2. Values of tangent altitudes cannot be collected in a table because of their waving behaviour: however they are visualized in Fig. 1.

Point 7. Among the manifold features of MIPAS we have chosen to report in Sect 2 only those related to this study; we refer to *Fisher et al.* (2008) for further details. However we admit that common spectral resolution and quality of the signals are meaningful details that we have added at line 23 of page 2864 of the discussion paper.

Points 8,9. Corrected as requested.

Point 10. As stated in *Ridolfi et al.* (2000) the MIPAS level 2 processor delivers geo-located profiles of the target quantity defined at the altitudes of the tangent points of the analyzed limb scan. Since it operates a 1D retrieval makes the assumption of horizontal homogeneity of the atmosphere. The horizontal resolution of the level 2 products depends on the altitude and changes from target to target, however it is of the order of the separation between the profiles (a few hundreds of km).

Point 11. We have corrected with "spectral radiance" however Eq. (4) is valid for any physical quantity representing the spectral signal.

Point 12. Corrected as requested

Point 13. See introductory remarks and answer at point 15.

Point 14. See the introductory remarks and the answers at paragraph 2 of general points and at point 7 of specific points.

Point 15. Since **K** is a vector (see point 3 of the introductory remarks) $\mathbf{K}^T\mathbf{K}$ is a scalar quantity that refers to clove h. Therefore we use $(\mathbf{K}^T\mathbf{K})_h$ in accordance with Eq. (8) of *Carlotti and Magnani* (2009).

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Point 16. See introductory remarks and answer at previous point.

Point 17. See answer at paragraph 2 of general points.

Point 18. In the layout of figure 4 we have chosen to attribute colors only to positive values of the difference after a number of trials including also negative values with different color scales. None of those trials provided a satisfactory visual discrimination between positive and negative areas. In Fig. 4 the negative values are represented by blank cloves and it is clear that, in the considered altitude ranges, their extension is surpassed by colored cloves. It is true that Fig. 4 does not allow to judge how large are the negative values. An additional evidence of what stated at page 2870 can be obtained looking the figures reporting only negative values that have similar intensities but smaller extension; such figures would have been redundant but we have added a sentence on this at line 3 page 2871 of the discussion paper.

Point 19. Corrected as requested.

Point 20. At an individual altitude a perturbation of 1% ($\sim$3K) is small but we apply the perturbations in the full altitude range with constant sign and this introduces large deviations in the spectral signals. Anyway we have verified that larger perturbations imposed to all the retrieval targets (up to about 8% for temperature) slow down the convergence (increase the number of iterations) but lead to the same results within the estimated standard deviations. A sentence with this consideration has been added at line 24 of page 2871 of the discussion paper.

Point 21. At line 12 of page 2872 we have added the requested details on λ and a-priori adding the corresponding reference (see also our reply to the short comment of Von Clarmann).

Point 22. Figure 5 is meant to provide only the qualitative appearance of the retrieval outcomes for one of the targets. Quantitative considerations can be found in Fig.s 6 and 9 and in the discussion related to them.

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Point 23. ($\sim$42 km) has been added at line 22 of page 2872.

Point 24. It can be seen in Eq.(4) that Ω is a summation of derivatives w.r.t. the atmospheric parameter q. The statement at line 24 implies that the value of the derivatives decreases as the number of spectroscopically active molecules decreases with altitude (as it is in the case of N_2O at high altitudes). This is not always the case, e.g. for NLTE conditions (that however are not considered in our simulations), but it is commonly accepted that (in the absence of scattering as for MIPAS observations) the maximum sensitivity (derivative) of the measurements is at tangent point. We do not consider appropriate to justify the statement at line 24 in our text.

Point 25. Corrected as requested.

Point 26. Here we are speaking of Fig. 7 where, in the left-hand panel it can be appreciated a colour alternation along the orbital coordinate at almost all altitudes. This alternation can be quantified (about 0.5 km) at the sample altitude of 18 km shown in the right-hand panel of Fig. 7. See introductory remarks and answer to paragraph 4 of general points. The information load is insufficient w.r.t. the resolution requirement of the natural retrieval grid. It is equivalent to say that the number of retrieval parameters corresponding to the natural retrieval grid is so high to trigger “underdeterminacy of the retrieval problem".

Point 27. The problem becomes less constrained. Trying to interpret the reviewer's comment we have added “with respect to the number of retrieval parameters" At line 22 of page 2874 of the discussion paper.

Point 28. As we have discussed above, variable horizontal (not vertical) resolution indicates retrieval instability that, of course, reflects into the retrieval error. We could have represented the behavior of retrieval errors but the conclusion would have been the same. By reporting the behavior of horizontal resolution we have adopted for the horizontal domain the commonly accepted criterion of profiles oscillation used (in the vertical domain) for 1D retrievals.

We have stated in our text that the leading criterion for setting an optimal retrieval strategy is the trade-off between retrieval error and spatial resolution.

Point 29. The numbers are different for the three considered quantities (precision, horizontal and vertical resolution) and for the seven retrieval target. On the other hand they can be evaluated looking at figure 6. We do not consider appropriate to provide such a long list in the conclusions section.

Point 30. See introductory remarks.

Point 31. Yes! Figures have been corrected. Thanks to the reviewer for tracking the error.

Technical corrections

Point 1. The signal has been denoted as Y in the revised text.

Points from 2 to 7. Corrected as requested.

Point 8. As they are, Figs. 6&9 are very crowded. We don't see how to add a legend box.

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 2861, 2010.

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