Atmos. Chem. Phys. Discuss., 5, S5270–S5277, 2005
www.atmos-chem-phys.org/acpd/5/S5270/
European Geosciences Union

Atmospheric Chemistry and Physics Discussions

ACPD

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Interactive Comment

Interactive comment on "Sensitivity analysis of methane emissions derived from SCIAMACHY observations through inverse modelling" *by* J. F. Meirink et al.

J. F. Meirink et al.

Received and published: 30 January 2006

We thank the referee for his/her comments, in response to which we have improved the manuscript. The comments are quoted (**C**) and addressed (**R**) below.

General comments

C One of the authors' primary conclusions is that the SCIAMACHY observations can contribute to considerable uncertainty reduction in methane source strengths. This conclusion is based on sensitivity experiments with synthetic data that test the sensitivity of an atmospheric inversion using SCIAMACHY observations to random errors, errors due to clouds, and the specification of a priori errors. However, there are a number of other sources of error in the SCIAMACHY observations that need to be addressed before one can reach this conclusion. The authors have briefly listed them (Page 9408, lines 19-24), but do not discuss their potential effect on the inversion, or why they chose specifically to investigate sensitivity to random errors, clouds, and priors.

R There are certainly many error sources in the SCIAMACHY observations. Those listed on page 9408 (lines 19-24) all give rise to systematic errors in the retrieved methane columns. In the revised version of the paper we have included a number of experiments in which systematic observation errors are taken into account. Rather than trying to predict the magnitude and spatiotemporal patterns of biases introduced by the various error sources, we have defined two types of errors. The first (experiments 5a-c) is an example of a regional bias, which could be introduced by, for example, errors in the albedo map. The second (experiments 6a-c) is a bias dependent on the solar zenith angle, which could be introduced by, for example, errors in the instrument calibration.

C It would also be interesting to see how the synthetic datasets generated for this paper compare to real SCIAMACHY observations.

R This paper focuses on experiments with synthetic data. Real data will be considered in future papers. The synthetic data sets include particular emission perturbations, with a magnitude that is in agreement with the expected uncertainty in bottom-up emission inventories. The random error in the synthetic data is set to 1% in the standard experiment. For comparison, the presently acieved precision of SCIAMACHY methane columns is estimated to be 1.8% on average (Frankenberg et al. 2006). Such precision is covered by the sensitivity experiments, in which the observation error is varied between 0.25 and 4%. Finally, we note that the cloud data *are* real data, retrieved with the FRESCO cloud algorithm. The estimated precision of these data appears to be realistic.

C This manuscript is dense with technical details and has limited explanations of some

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methods and terms that are specific to atmospheric tracer inversions and remote sensing. In particular, it would be difficult for anyone who is not a specialist these areas to understand the Methods section. Therefore, I recommend that the authors revise the text of the paper in order to make it more accessible for the general readership of Atmospheric Chemistry and Physics Discussions.

R In his specific and technical comments the referee has given many suggestions for improving the accessibility of the paper. By implementing these suggestions, we are confident that the paper is now much beter readable for a general audience.

Specific comments

C It would be interesting to see some discussion of how the uncertainty reductions from SCIAMACHY observations compare to similar inversions using flask samples alone.

R We have decided not to include surface observations because they give a completely different signature of surface flux uncertainty reductions. In particular, the uncertainty reduction obtained from the flask network depends strongly on the specific region that is looked at. For example, the northern-hemispheric midlatitudes are relatively well constrained since there are many stations. In contrast, the tropics are much less constrained. The particular emission perturbation that we investigate is located in the Amazon, and thus little additional value of the surface network can be expected.

The different impact of surface and satellite observations is explained in detail in, e.g., Houweling et al. (2004) for CO_2. Similar results are expected for CH_4, and since the paper is already quite lengthy we do not intend to study surface observations here.

C From my reading of the manuscript, it is still a little unclear how the inversion distinguishes between source categories in experiment 13 (Table 2 of the manuscript). The authors should also briefly discuss how well the satellite observations are able to distinguish between source processes with overlapping spatial patterns.

R 'Distinguishing between source categories' means that the assimilation control vec-

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tor is made up of all different categories, which are then assumed mutually independent. This is mentioned in the revised version. A real discrimination between different sources cannot be done on the basis of the satellite data by themselves, but only on the basis of prior information about the spatial distribution of the sources. Indeed, sources with overlapping patterns cannot be distinguished.

C The authors assume the error covariance matrix associated with the concentrations is equal to the difference between two simulations of the same model using first a 24-hour forecast and then a 48-hour forecast. This neglects the possibility of underlying errors in the model transport and chemistry. I don't think anyone has come up with a completely satisfying way of quantifying these errors, but the authors should discuss the issue.

R Two things should be separated here:

- The error covariance of the initial concentration field is derived from the difference between two tracer runs based on different underlying meteorological fields (namely 24-hour and 48-hour forecasts). This should reflect errors in transport reasonably well (but neglects chemistry errors).

- Within the assimilation window, also model errors develop, both due to uncertainties in transport and in chemistry. While these are assumed to be negligible in the assimilation framework, in reality they are of course not. We have added a short discussion of transport errors in the conclusions section, arguing that they may be less harmful in inversions of satellite data compared to surface measurements. Chemistry errors could be dealt with by including the OH field (in which chemistry errors finally boil down) in the control vector, with a realistic error estimate. As mentioned in the conclusions section, this is one of the topics for future work.

Technical Corrections

C P. 9406, l. 6, There should be a comma following “In this approach”

R Corrected.

C P. 9407, l. 5, “More than half of the methane emissions” is a plural subject; therefore, “is” should be changed to “are”.

R Corrected.

C P. 9407, paragraph 2, The authors could also mention here that the atmospheric growth rate of methane has large variability, and that there is considerable debate about the causes for this variability.

R This is mentioned in the revised version.

C P. 9407, l. 22, The authors state that “the observations contain statistically significant information on emissions only on continental scales.” This statement should be supported by a reference, since atmospheric methane inversions have been done on the grid scale level (e.g. Houweling et al., 1999).

R A reference to Houweling et al. (1999) has been added.

C P. 9407, l. 25 - 29, The use of the term “point measurements” in describing stations that observe strong signals from the sources may be somewhat misleading. As written, it could be interpreted to mean that stations that primarily observe background air are not point measurements.

R We skipped the word “point” to avoid confusion.

C P. 9408, l. 2, Please provide a brief description of what limb and nadir modes are.

R Done.

C P. 9408, l. 5, and other acronyms throughout, Please spell out the full name for acronyms at the first use.

R Done.

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C P. 9408, l. 24, A reference discussing the sources of error in the observations would be helpful

R References to Frankenberg et al. (2005) and Gloudemans et al. (2005) have been added.

C P. 9409, l. 4, A sentence or two describing how the 4-D var data assimilation technique works would be helpful.

R In our opinion the 4D-var technique is sufficiently explained in the Methods section. In the introduction we want to restrict mainly to giving references to earlier 4D-var studies (where the interested reader can find more information on the method).

C P. 9409, l. 24 - P. 9410, l. 2, The authors discuss how including initial concentrations in the control vector can minimize errors due to initial conditions in short term inversions, however it does not become clear what the control vector is and how introducing initial concentrations might be helpful until the following section. I recommend either moving this discussion to the Methods section or framing it in simple, physical terms.

R We have omitted the word "control vector", and rewritten the text to make it less technical.

C P. 9410, l. 4, The authors state here that they will "show, using SCIAMACHY measurements, that it is possible..." This wording is misleading because the authors rely exclusively on model simulations that approximate SCIAMACHY observations.

R We added "simulated" before "SCIAMACHY measurements".

C P. 9411, l. 17, It is not clear from this paragraph exactly how the chemical sinks modeled in TM4 are used in the inversion.

R We do not see what is unclear. As is described in the paper, we just save OH fields from a full-chemistry simulation, and prescribe these for the calculation of oxidation in the CH_4 tracer version.

C P. 9412, l. 11, A brief description of how the authors arrive at the observation operators would be helpful.

R There is presently a brief description in the paper, which is quite clear in our opinion.

C P. 9413, Please include a little discussion of the importance of the B and R matrices in the inversion and the relative weighting of the observations and priors.

R We have added a small discussion right after the error covariance matrices are introduced on page 9412.

C P. 9415, l. 26-27, Sentence fragment. Perhaps it should read, "In this study, all cloud fractions over desserts that were smaller than 0.35 were set to zero in our simulations."

R This is indeed what it should read. We have corrected it.

C P. 9420 - 9422, Much of this section reads as a catalog of figures, with too much emphasis on description of the figures rather than discussion of the results.

R It's unfortunate that the reviewer reads this section as a catalog of figures. We believe this section not only describes the figures but also distills the most important messages from the figures. The main 'messages' in this section are:

- In the reference inversion experiment 1, the SCIAMACHY measurements give a considerable improvement of the emission field estimate.
- The joint optimization of initial concentrations and emissions is shown to be both feasible and beneficial to the outcome of the inversion.

Reference: Frankenberg, C., J.F. Meirink, P. Bergamaschi, A.P.H. Goede, M. Heimann, S. Körner, M. van Weele, and T. Wagner, Satellite chartography of atmospheric methane from SCIAMACHY onboard ENVISAT: Analysis of the years 2003 and 2004, accepted for publication in J. Geophys. Res., 2006.

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 9405, 2005.

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