**Atmospheric
Chemistry
and Physics
Discussions**

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.

We thank the referee for his comments. In particular, the comment on systematic observation errors has lead to considerable improvements in the paper. The comments are quoted (**C**) and addressed (**R**) below.

General comments

C This paper describes Observing System Simulation Experiments (OSSEs) to show the effect of various error sources on the estimation of CH_4 surface fluxes from SCIA-MACHY observations. A 4D-Var set-up is used for the inverse problem. The paper concludes that SCIAMACHY observations at a precision of 1 - 2% will contribute con-

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Discussion Paper

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siderably to uncertainty reduction in methane source strengths. The study shows interesting results, but it would have been nice if inversions with real data were included or at least commented on. An OSSE is a good tool to get a feeling of the various error components, but real data contain (almost) always more error sources.

R We feel that the experiments with synthetic data described in our paper serve two goals. First, they give insight into the capabilities of the assimilation system. Second, the OSSEs allow to assess the degree in which SCIAMACHY methane observations can contribute to improving existing emission estimates, and to quantifying the impact of various error sources on the retrieved emissions. The experiments with synthetic data serve as a reference for studies with real data, which will be the subject of a future paper.

C Also, the effect of systematic errors is often the most critical component of using real data for flux inversions. Flux inversions obtain their information from the gradients in the measured tracer concentrations, which means that any regional bias will create artificial gradients and therefore incorrect surface fluxes. The authors are very brief in mentioning these systematic errors in their conclusions. I think it the paper could be much improved by also taking the effect of systematic errors into account.

R Systematic errors are indeed critical. Therefore, we have extended our discussion of such errors. We have performed some more experiments with biases added to the satellite observations, and added the results in Table 2. Two error types have been distinguished. The first is a regional bias, which might be caused by, for example, variations in surface albedo. The second is a bias dependent on the solar zenith angle, which often occurs in satellite measurements of reflected sun light. These biases are shown to have quite dramatic impacts on the retrieved emission distributions. This has been added to the main conclusions of the paper.

C Finally, how do these inversion simulations compare to the error reduction in flux inversions from surface observations.

R Such comparisons have been performed by Rayner et al. (2002) and Houweling et al. (2004) for CO_2. Their general conclusion was that satellite observations have the highest added value in regions that are poorly covered by the surface network. We believe there is no reason why this would be different for CH_4, and have therefore not specifically assessed this in the present paper. We did add a remark in the conclusions section that the SCIAMACHY measurements, by resolving relatively small spatial scales, are a very useful addition to the surface measurement network, which primarily constrains the (sub-)continental scales.

Specific comments

C Page 9412: The notation in Equation 1 should be consistent. Either use x instead of v in the background term or use v instead of x in the observation term. Keep this consistency in the notation below the equation as well. Also, the description is for a general 4D-Var system where only the initial state is perturbed in the minimization. Adding the (monthly mean???) flux to the state vector assumes a flux model equal to the identity matrix. Adding this disctinction between the model transport and the static flux model would help the presentation of the 4D-Var.

R We will make the following changes to the manuscript:

- Remove the separation between 'control' and 'state' vector, by changing v to x.

- Add a comment to equation (2) that $\mathbf{M}$ consists of the forward transport model *and* a trivial flux model. (The fluxes are indeed monthly mean.)

C Page 9412, line 6: A more technical point: the term background or a priori is generally used for the vector Vb, while the first-guess is the starting point for the minimzation. Most of the time the background is used for the first-guess.

R We have removed the term "first guess" to avoid confusion. (Indeed, we used the background for the first-guess.)

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C Page 9413: Did the authors consider adjusting the correlation lenght scales to reflect land-sea contrast in the surface fluxes? I realize this would complicate the set-up of the 4D-Var, but it seems quite important to me. Fluxes over ocean are definitely not correlated with fluxes over land.

R Theoretically, the referee is of course right. Fluxes over land and ocean should be un-correlated. However, practically this is not necessary since methane sources over the ocean are almost zero and prior errors are assumed relative to the actual source. This results in negligible source increments over the oceans. More generally, the sources of different categories are uncorrelated. This has been taken into account in experiments 10 and 13 (Table 2) by optimising all individual source categories, assuming them to be mutually uncorrelated.

C Page 9413, bottom: The NMC method used in this way only accounts for the errors in the model transport. It neglects errors and error correlations in the starting fields of methane used for the 24 hour and 48 hour forecasts.

R This is mentioned in the paper in lines 28/29 on page 9413 and line 1 on page 9414. For clarity, we have added to this sentence: ",while it neglects other sources of error."

C Page 9415, 1st paragraph: What is the effect of CO_2 variability on this normalization method?

R Variations in CO_2 will show up as biases in the retrieved CH_4 volume mixing ratio. Based on transport model results, it can be assumed that variations in CO_2 are much smaller than in CH_4, but they can still have a significant impact. One can try to min-imize errors due to CO_2 variations by using modelled CO_2 distributions to correct the retrieved CH_4/CO_2 ratio (Frankenberg et al., 2006).

C Page 9420, line 27: for clarity, please add the word 'incremental' to 'the result of the inversion'.

R Done.

C Page 9421, line 27: I think this is a bit overstated. There is still significant aliasing of the incorrect initial methane distribution into the estimated fluxes.

R There is indeed always some aliasing. We have added a remark that small-scale patterns in the initial concentration perturbation are not captured in the analysis. Therefore, the resulting emission field is somewhat worse than in experiment 1.

C Page 9423, section 3.2.1: Is only the observation error covariance matrix changed for these experiments or are the actual errors of the simulated observations changed as well (as they should)?

R The actual noise on the observations as well as the observation error covariance matrix are changed. This is mentioned in the revised version.

C Page 9425, bottom lines: This is always a trade-off when there is insufficient information from the observations. One can either increase the background constraint by (in this case) increasing the correlation lenght (to a value that is most likely incorrect), or leave more freedom to the inversion with the risk of creating spurious small scale variability

R The modelling of spatial correlations between surface fluxes is hampered by lack of knowledge. Therefore, in this study we decided to take a simple approach by assuming the correlation between grid point fluxes to be a Gaussian function of the distance between the grid cells only. We used the decorrelation length scale as a free parameter and checked a posteriori which length scale gave the best results.

C P9429: I didn't see any comment on the contribution of transport model errors to the estimated fluxes. These can be quite significant. Please, comment on that at least in your conclusions.

R This is indeed an important issue. We added a paragraph to the conclusions section, stating the importance of transport error. We also argue that transport errors may be less harmful in inversions of satellite data compared to surface data, for two reasons.

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First, satellite data have a far better spatial coverage, so that the signature of emissions at the observation location is less influenced by transport and errors therein. Second, errors in vertical transport, which is notoriously difficult to model, do in first order not affect the total column amount as observed by the satellite. It is a particular advantage of SCIAMACHY-type near-infrared measurements that they are sensitive to the whole vertical column.

C P9440: In Figure 4b, why are the column-averaged mixing ratios much lower over high terrain (Greenland and Himalaya)? Is this purely an effect of vertical gradients in methane?

R Yes. The methane mixing ratio is approximately constant in the troposphere and decreases in the stratosphere. Over high terrain the relative portion of stratospheric air is larger, resulting in lower column averaged CH_4 mixing ratios.

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

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