Answers to Interactive comment from anonymous referee #1 on ”Stable atmospheric methane in the 2000s: key-role of emissions from natural wetlands” by I. Pison et al.

The authors thank the Referee for his/her careful reading of the manuscript and for his/her constructive comments. We have tried and followed his/her suggestions to improve the content as recommended. A detailed point by point reply (in bold) is provided hereafter.

The paper describes the interpretation of observed variations in atmospheric methane concentrations during 1990-2009 using a process-based model and two atmospheric inverse model approaches, paying particular attention to the role of natural wetlands. This is certainly an important and relevant topic for ACP.

After reading the paper I found it difficult to pinpoint what I had learnt. The interpretation of the analysis was insufficient to tease out anything new and the message I am left with is that models and surface data have their own weaknesses that likely compromise in-depth analysis. Unless the authors substantial improve the analysis presented I find it hard to support the publication of this manuscript in ACP.
If the reviewer is left with the impression that nothing new appears in this paper, it means that we have to reformulate more clearly (which has been done in the revised version [see changes in Conclusion and Introduction]) what we think are important results and recommendations about the methane cycle :

- **we bring together top-down and bottom-up analyses which show a good agreement at the global and tropical scales concerning the IAV of methane emissions**
- **we address the very debated 2000-2006 stabilisation period and show that the previously inferred decrease of wetland emissions in some inversions (compensated by increasing anthropogenic emissions) is mostly due to South America**
- **this decrease is not consistent with process-based estimates which find increasing emissions over the same period under varying prior assumptions.**
- **both inversions and the process-based model agree that South America is a key region to explain trends in methane emissions, although the proposed trends are of opposite signs**
- **if wetland emissions are not decreasing between 2000 and 2006, this questions the increase of anthropogenic emissions found by inventories (e.g. EDGAR4) as concentrations are rather stable during this period, possibly meaning stable emissions (if sinks are not changing).**

We think that our paper brings an additional brick towards the understanding of the complex and uncertain period for the methane cycle which started after 2000.

All the following comments refer to section 3 of the manuscript. I have not commented on most typos.

Typo, line 17: “they are considered as good” as what? **This must be changed into “They are considered good.”**

Page 9028: The authors describe the broad-scale variations in methane in the last decade of the twentieth century. Here, it would be interesting to hear more about how ORCHIDEE is performing as well as INVANA and INVVAR. More broadly, I didn’t feel that the authors characterized the performance of ORCHIDEE in this manuscript, and given its importance in the analysis I strongly suggest this be addressed during the revision stage. It also wasn’t clear to this reader, given the sometimes large differences between the models, which one was more consistent with the data.

We agree with the reviewer that individual systems (ORCHIDEE, INVANA, INVVAR) are not evaluated against independent measurements in our work. The focus of our paper is the comparison of the different approaches and not their individual evaluation, which should be part of reference papers on each model. However, we propose here elements of evaluation for the reviewer.

First, the inversions, by design, fit the observations used to constrain them. Direct evaluation of the performance of the inverted fluxes is not straightforward as comparison with flux measurements are hardly meaningful because of the difference of representativity scales : 1 km x 1 km for a flux measurement and 200 km x 200 km for a model grid cell. Therefore, inversions are generally evaluated against the ability of inverted fluxes to better fit to independent (i.e. not used in the inversion) atmospheric observations after being transported in the atmosphere or by comparing the analyzed fluxes to independent fluxes. For instance, for INVVAR, we computed the bias and standard deviation between the simulated and measured concentrations at 38 fixed stations and 3 mobile platforms that are not used in the inversion, for the analyzed and the prior emissions. At all but 2 stations, the bias is decreased; the standard deviation is decreased at 34 locations. We hope these elements give confidence to the reviewer in the ability of inversions to improve prior estimates.

Second, ORCHIDEE, as most of the process-oriented models for global wetland CH4 emissions, has been previously evaluated by using two strategies:
1) a comparison of the simulated CH4 flux densities (flux per m^2 of wetland) against measures on sites (e.g. Ringeval et al., 2010, GBC).
2) a comparison of the simulated wetland extent against remote sensing products such as Papa et al., 2010 (which is a previous version of the dataset described in Prigent et al., 2012, and used in the current study) at the regional and global scales (Ringeval et al., 2012, GMD).
ORCHIDEE also participated in an inter-comparison of global wetland CH4 emission models: the WETCHIMP inter-comparison, detailed in Melton et al., 2013 and Wania et al., 2013. These papers in particular characterized the differences between the different models, regarding the wetland extent and the methane flux densities. Among the major conclusions which came out of this inter-comparison so far (Melton et al., 2013, Wania et al., 2013), three are of particular interest here:
- the models demonstrate extensive disagreement in their simulations of wetland extent and CH4 emissions, both in space and in time
- we presently do not have sufficient adequate wetland methane observation datasets to evaluate model fluxes at a spatial scale comparable to model grid cells
- the large range in predicted CH4 emission rates leads to the conclusion that there are substantial parameter and structural uncertainties in large-scale CH4 emission models, even after uncertainties in wetland areas are accounted for.
In the revised manuscript, consistently with the comments of reviewer2, we have developed the characterisation of the performances of the ORCHIDEE model, in relation with the WETCHIMP exercise: elements of this answer have been added to the revised text [see Section 2.1 l.135 seq].

Note that if one of the models were proven to be more consistent than the others with the data, it would be easy to use this one as a reference. The issue here is that the results are very different and yet, none is "truer" than the others, none can be actually disproved.

Page 9028: I wasn't clear of the scientific value of comparing INVANA and INVVAR given their different initial conditions and configuration. If the authors had reported that both methods resulted in the same fluxes that would've possibility said something to the information content of the measurements, but they didn't. How sensitive are both methods to assumed prior data and uncertainties or to measurement uncertainties?

The variational scheme used in the paper is an evolution of the analytical scheme. Both inversion schemes use the same transport model and chemical reactions and the same set of CH4 surface stations, although the variational inversion can assimilate individual observations whereas the analytical inversion assimilates monthly means. As the set of stations and the chemistry-transport model are two of the major causes of uncertainties in inversions, we think that the comparison is meaningful, notwithstanding the differences between the two (time and space resolutions of fluxes, error correlations, resolution of the different source categories or not, for instance). Indeed, INVANA and INVVAR give consistent flux changes at the global and tropical scales (see Fig.1). Going down to regional scales, differences may increase due to the differences in the set-ups such as large regions versus pixel estimates or different error correlations

The sensitivity of inversion methods to the prior and to error statistics is a well-known issue and widely studied. In principle, it would be possible to obtain the same fluxes from very different methods by tuning the prior emissions and error statistics, regardless of the assimilated data. In the present cases, the sensitivity to the prior assumptions can be seen in the 11 different inversions perform by INVANA, varying prior errors on observations and on fluxes, but also the prior distribution of wetlands or the time distribution of OH fields for instance. These 11 scenarios provide a range of results (see Fig. 1 & 3, or Fig. 3 & 5 in the revised version) which gives an insight into the uncertainties, even though they do not represent all the possible causes of errors. Note that such sensitivity tests are too costly to perform for a 20-year variational inversion. Another way of looking into the impact of the prior on the results is to look at the differences between the prior emissions and the inversion results. Here, prior emissions are assumed to be the same each year and in INVVAR, only biomass burning emissions are prescribed with IAV. Therefore, most IAV is inferred from the atmospheric data. As stated in previous answers and following remarks from reviewer 2, some comparisons to the prior emissions have been added in the revised text [see Figure 2, l.179 seq, l.209 seq, l.241-244].

Page 9029: I was left unconvinced whether the data available supported the level of geographical disaggregation that was reported. Methane fluxes from the Amazon basin appears to be a focus of the paper but it wasn't clear from the associated text that the data or the models sufficiently constrained the estimate, e.g., different magnitudes and phases of the seasonal fluxes over a large geographical domain should allow the authors to disprove one or all of them unless the data is not suitable for that purpose. Perhaps it would be useful if the authors showed a Figure that include the location of the data used in the study.

Regarding the capacity of the atmospheric observations to constrain the CH4 fluxes, it is not easy to disprove any of the visions of the models (ORCHIDEE and inversions) since each of them is self-consistent and consistent with the constraining data under its own assumptions. However, the comparison between ORCHIDEE and INVANA suggests that the current atmospheric observations are not sufficient to safely derive inversion trends in CH4 South American wetland fluxes. Please see also answer to the first comment. A map of the stations used by the inversions has been provided in the revised version [see Figure 1].

Page 9029: This reader believes it would be interesting to see spatial distributions of methane fluxes over South America to see if there are any similarities between the different bottom-up and top-down estimates.

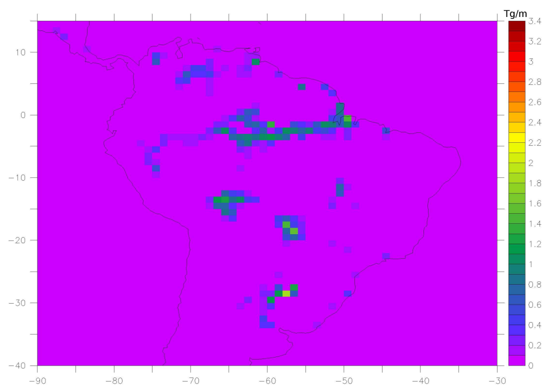
We agree with the reviewer that spatial distributions over a key region such as South America are very important to compare. We computed such maps (see the Figure below). They reveal consistent patterns of emissions (Amazon basin, North-South axis through Brazil and Argentina) although inversion patterns are more diffuse and coarse than ORCHIDEE. However, considering the uncertainties on the regional distribution at the pixel scale

(INVVAR), and possible aggregation errors (INVANA), we prefer not to show such "fine"-scale maps in the paper.

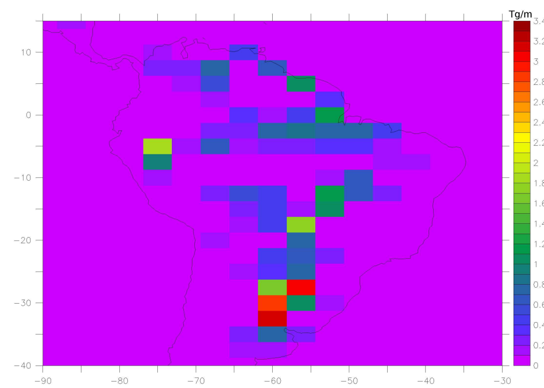
Figures: All need to be increased in size. Figures 1 and 3, in particular, contain lots of information that is difficult to read as they are presented.
The figure will be enlarged in collaboration with the editorial board.

References:

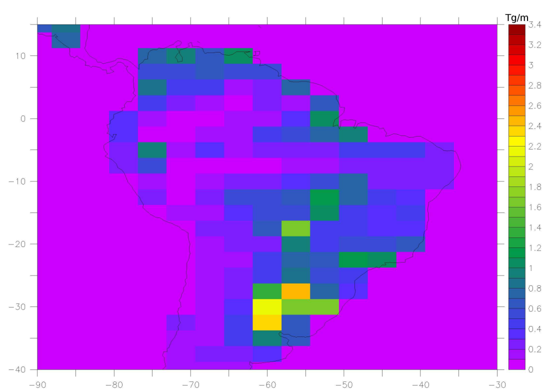
- Melton, J. R., Wania, R., Hodson, E., Poulter, B., Ringeval, B., Spahni, R., Bohn, T., Avis, C. A., Beerling, D. J., Chen, G., Eliseev, A. V., Denisov, S., Hopcroft, P. O., Lettenmaier, D. P., Riley, W. J., Singarayer, J. S., Subin, Z. M., Tian, H., Zürcher, S., Brovkin, V., van Bodegom, P. M., Kleinen, T., Yu, Z. C., and Kaplan, J.: Present state of global wetland extent and wetland methane modelling: Conclusions from a model intercomparison project (WETCHIMP), Biogeosciences, 10, 753–788, doi:10.5194/bg-10-753-2013, 2013.
- Papa, F., Prigent, C., Aires, F., Jimenz, C., Rossow, W., and Matthews, E.: Interannual variability of surface water extent at the global scale, 1993-2004, J. Geophys. Res, 115, doi:10.1029/2009JD012674, 2010.
- Ringeval, B., de Noblet-Ducoudré , N., Ciais, P., Bousquet, P., Prigent, C., Papa, F., and Rossow, W.: An attempt to quantify the impact of changes in wetland extention methane emissions at the seasonal and interannual time scales, Global Biogeochem. Cycles, 24, doi:10.1029/2008GB003354, 2010.
- Wania, R., Melton, J., Hodson, E., Poulter, B., Ringeval, B., Spahni, R., Bohn, T., Avis, C., Chen, G., Eliseev, A., Hopcroft, P., Riley, W., Subin, Z., Tian, H., Brovkin, V., van Bodegom, P. M., Kleinen, T., Yu, Z., Singarayer, J., S.Zürcher, Lettenmaier, D., Beerling, D., Denisov, S., Prigent, C., Papa, F., and Kaplan, J.: Present state of global wetland extent and wetland methane modelling: methodology of a model intercomparison project (WETCHIMP), Geosci. Model Dev., pp. 617–641, doi:10.5194/gmd-6-617-2013, 2013.



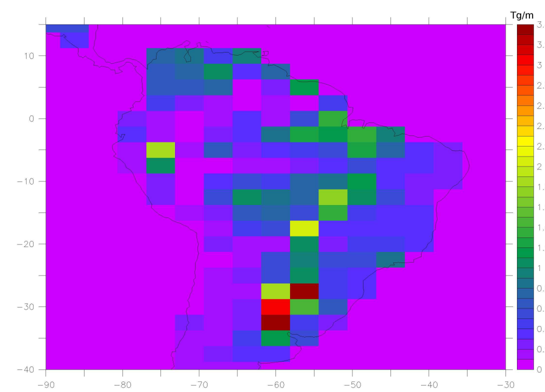
(a) ORCHIDEE



(b) INVANA wet



(c) INVVAR



(d) INVANA

Figure 1: *Methane emissions (in Tg/month) averaged over 1990-2009 (1990-2008 for INVVAR) and all scenarios (2 relevant scenarios in South America for ORCHIDEE,11 scenarios for INVANA, 1 for INVVAR): emissions due to wetlands by ORCHIDEE and INVANA and total net emissions by INVVAR and INVANA.*