

Answers to Interactive comment from anonymous referee #2 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.

This manuscript presents an evaluation of the methane trends between 1990 and 2009 with a focus on the years 2000-2006. The study presents a comparison between surface fluxes from inversions of surface data and from a process-orientated model for wetlands and they observe inconsistencies between both which they argue are due to problems in the inversion. Explaining and recent methane trend and the role of wetlands is certainly a key area of research of interest to the readers of ACP.

However, the presented study has a few issues. It is well known that the flux calculations from process-oriented models and from inversion of surface data have many issues and without addressing these issues in much more detail such a study is of questionable value. Indeed at least the problems of surface fluxes from inversion for the Tropics are mentioned at the end of the manuscript. Especially, for the S-America region which is the main focus of the presented study, the used surface network seems to provide little/no information so that a comparison of fluxes for these regions is not very useful. My suggestion is that the manuscript needs to provide much more information on the quality and performance of the process-oriented model and the inversions otherwise I do not think that such comparisons are useful.

We agree that both inversions and process-oriented models are complex tools, which rely on many different assumptions and should be used with possible caveats. Most of these issues are related and assessed in previous publications by the authors (and others) but it is possible to better summarize them in this paper and we have done so in the revised version [see changes in Section 2].

The focus on South America comes from the controversial trends in global emissions found by several published studies for the period 1999-2006 (Bousquet et al., 2006; Levin et al., 2012; Kai et al., 2011; Simpson et al., 2012 and others). In the inversions by Bousquet et al. (2006, 2011), it appears that South America contributes to most of the global trend. This is why we focus on this region in this paper and compare the regional inverted fluxes with process-based estimates. Although there are uncertainties in the process-based model on the magnitude of the sensitivity of methane fluxes to precipitations in the Tropics, it is rather admitted (e.g. Bloom et al., 2010) that this sensitivity is positive. In the ORCHIDEE simulations presented here, the positive sensitivity drives most of the flux increase, due to increasing re-analysed precipitations. Although wetland extents are uncertain, we apply two approaches (TOPMODEL and a sensitivity test with satellite-based retrieved extents) to derive wetland emissions and both find increasing emissions between 1999 and 2006, contrary to inversions. One can discuss the magnitude of the discrepancies between inversions and ORCHIDEE but we think that the positive trend in ORCHIDEE is a rather robust feature, thus questioning the negative one in inversions which are poorly constrained in the Tropics. We have clarified this message in the text and justified more clearly its interest [see 1.68-70 in Introduction and changes in Conclusion]: the CH₄ budget during the stabilization period is important to quantify precisely for a proper closure of the methane budget and the development of realistic future climate scenarios.

- The recent study of Melton et al., 2013 showed that there are very large uncertainties in CH₄ emission rate of process-oriented model for wetland regions even when accounting for uncertainties in wetland areas. Please provide a critical assessment of the uncertainties of the ORCHIDEE

calculation. Even better would be to use an ensemble of process-oriented model or provide some compelling arguments why ORCHIDEE should give a useful representation of wetland emission.

We agree with the reviewer about the large uncertainties in CH₄ emissions simulated by process-oriented models (Melton et al., 2013 (Biogeosciences) and Wania et al., 2013 (GMD)). These uncertainties are explained by differences between the models on the one hand and by the few constraints available at the global scale on the other hand. Differences between the models are due to differences in the models' structures (e.g. in order to approach the methanogenesis substrate, some models use the NPP, others use the soil carbon; see Figures 6 and 7 of Wania et al., 2013) and to differences in the sensitivity of processes to climate (e.g. difference in NPP sensitivity between two models). Our current knowledge does not allow us to estimate the contribution of each of these two sources of difference. Because of this, we do not think it is possible to say that a given model (.e.g ORCHIDEE) could be representative of all wetland emissions models participating into the WETCHIMP intercomparison. Nevertheless:

- ORCHIDEE is a state of the art global wetland CH₄ emissions model. Some of ORCHIDEE's limitations are also found in other models e.g. the lack of wetland PFTs, the lack of distinction in wetland types (bogs, fen, etc.), not accounting for nutrient limitation and no sub-grid treatment of the methanogenesis substrate (please, see the end of page 771 of Melton et al., 2013);**
- as compared to the other WETCHIMP models, the magnitude of global wetland emissions simulated by ORCHIDEE is at the up end of the range of the models (264 Tg/yr against mean of models: 190 Tg/yr).**

Because of the previously underlined differences between the models, we do not think that all wetland CH₄ emission models will converge in a near future. Thus, the evaluation of each model against independent approaches (as in the current study) or datasets is useful. In particular, ORCHIDEE is characterized by its prognostic computation of wetland extent through the use of a TOPMODEL approach. Within the global models participating to WETCHIMP, only ORCHIDEE and DLEM use such a “mechanistic” approach to diagnose wetland extent. Given the potential role played by wetland extent in the year-to-year variability of wetland emissions (Ringeval et al., GBC, 2010; Bloom et al., Science, 2010), it is particularly interesting to use ORCHIDEE in a comparison with inverse modelling results.

We summarized these elements in a new paragraph in the revised text [from l.135 in Section 2.1].

-Surface fluxes from inversions of atmospheric data will depend critically on the assumed a priori fluxes, transport model errors and representation errors and it is important to discuss these error components. Maybe most important is the influence of prior assumptions and you need to give some information on the impact of the prior on the results as well as of potential correlations between regions and source types.

We agree on the importance of prior assumptions in the inversions. We already detail the major assumptions, including prior errors and flux distributions (Section 2.2) but we have developed this part more in the revised version [see changes in Section 2.2, l.179 seq & 209 seq].

Regarding the impact of prior assumptions on the results, the 11 scenarios of the analytical scheme (INVANA) address this issue by changing prior errors on observations and on fluxes, but also the prior distribution of wetlands or the time distribution of OH fields for instance. Regarding wetland distribution, we added a new figure [Figure 2 in the revised version] which shows a comparison between the latitudinal distributions of the various priors. The 11 INVANA 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 it does not represent all the possible causes of errors. Such sensitivity tests are too costly to perform for a 20-year variational inversion like INVANA. This is one aspect in which we think that analytical and

variational inversions are complementary.

Regarding prior correlations on fluxes, the analytical inversion solves for large regions thus fixing the correlations to 1 within a region and to 0 between different regions. No correlation is prescribed between the different source types. For variational inversion, the flux is solved at the transport model space-resolution at a weekly time-resolution and spatio-temporal error correlations are prescribed as described in Section 2.2.

As an example of the impact of the prior on the results, it can be noted that most IAV is inferred from the atmospheric data since in INVANA, prior emissions are assumed to be the same each year and in INVVAR, only biomass burning emissions are prescribed with IAV.

-The manuscript presents two inversion methods, but the setup of both inversions is so fundamentally different (different surface data, different priori assumptions, different transport models, different correlations) that such a comparison is not very meaningful if not done in more detail. I also do not understand why the variational scheme does not estimate wetland emissions so that it could be used throughout the whole manuscript.

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).

The analytical scheme makes use of the information provided on spatio-temporal distributions of CH₄ fluxes in large regions to retrieve the emissions due to various processes at a monthly time resolution. In the variational scheme, CH₄ fluxes are solved at a high spatial resolution (the transport model grid's resolution) with a time resolution of one week; not enough information is available at these relatively fine scales to discriminate between processes and therefore only the total CH₄ flux is estimated in the variational inversion. We have clarified these points in the revised version [see Section 2.2 1.217 seq].

Minor:

- I would suggest capitalizing "El Nino" and "La Nina" throughout the whole manuscript
This has been done.

- p.2 153: (e.g. (Ringeval et al., 2010) and -> (e.g. (Ringeval et al., 2010)) and **This has been done.**

- p.4: Provide a discussion how well ORCHIDEE performs by validating/comparing it datasets or models (e.g. Melton et al., Biogeosciences, 2013)

As most of the process-oriented models for global wetland CH₄ emissions, ORCHIDEE has been evaluated by using two strategies:

1) a comparison of the simulated CH₄ flux densities (flux per m² of wetland) against measures on sites (e.g. Ringeval et al., 2010, GBC). This method for evaluating global models is prone to uncertainties, in particular because of:

→ a big difference in spatial scale between such measurements (usually made with flux chambers (~ 0.2 m²)) and global models (~ 1° lat x 1° lon)

→ high spatial variability in measured CH₄ flux density at the scale of flux chambers (e.g. hollows vs hummocks)

→ a potential good agreement in net fluxes between measures and models but based on non-realistic contributions of the different components of the flux: e.g. production, oxidation, transport. Please see Riley et al., 2011, for discussion about this limitation.

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). As discussed in Melton et al., 2013, such comparison is prone to uncertainty due to the large variability between the different global products of wetland extents.

A long part of the Melton et al., 2013 discussion focuses on the limitation of the current data to evaluate the global process-oriented models of wetland CH₄ emissions.

The comparison with inverse modelling results is also a way to reach a better understanding of the behaviour of the process-oriented models.

As compared to other WETCHIMP models, the magnitude of global wetland emissions simulated by ORCHIDEE is at the up end of the range of the models (264 Tg/yr against mean of models: 190 Tg/yr). This could be partly explained by some scaling to reduce global emissions in others process-based models (cf. LPJ in Wania et al., 2010, GMD). The latitudinal distribution of ORCHIDEE is in the spread of WETCHIMP models. ORCHIDEE shows the largest sensitivity to CO₂ fertilizing effect among the WETCHIMP models. But again, it is difficult to say whether this is realistic or not.

We have added these elements in the revised version [see Section 2.1, 1.135 seq].

– p4. L.108: water detection Papa et al. (2010); Prigent et al. (2012). -> water detection (Papa et al. (2010); Prigent et al. (2012)). **This has been done.**

– p. 4 1.113: fromWalter et al. (2001a);Ringeval et al. (2010) -> fromWalter et al. (2001a) and Ringeval et al. (2010) **This has been done.**

– p.5 1.131 Note that ORCHIDEE emissions are not used as prior emissions in INVANA nor INVVAR. -> INVANA and INVVAR are not yet introduced so that this needs some additional explanation. **This has been changed into “Note that ORCHIDEE emissions are not used as prior emissions in the inversions described hereafter.”**

– p. 5 1.145: Please specify which types for sources/sinks are estimated.

In the analytical inversion, 9 source types are optimized for large regions at a monthly time resolution : natural wetlands, termites, rice paddies, waste, animals, gas, oil and coal, ocean (including geological), biomass and biofuel burning. We have made this clearer in the revised version [see Section 2.2 1.169 seq].

- p. 5 1.146: Discuss the spatial distribution of the 68 surface sites.

We have added a Figure with the maps of CH₄ and MCF stations with a short discussion in the revised version [see Figure 1 and Section 2.2 1.229 seq]. The main point is that key areas for methane emissions such as South America or boreal Eurasia are almost devoid of surface stations.

– p.5 1.152: Elaborate on the a priori assumption for wetland emission. What is the assumed spatial and temporal distribution of emissions. How does this compare to the Orchidee emissions? Do you assume a spatial distribution within each of the 10 regions?

As described in Bousquet et al., 2006, the assumed prior spatial and temporal distribution of emissions is taken from Matthews and Fung, 1987, using their swamps, bogs and tundra distributions for ten of the 11 scenarios; it is based on Kaplan et al. (2002) for the eleventh scenario. A comparison of these distributions to the ORCHIDEE distribution has been plotted as Figure 2 in the revised version, with a short comment [see Section 2.2 1.181 seq]. Within each large region of the analytical inversion, the prior spatio-temporal distribution given by

the prior is kept.

– p. 6 l.161: Why do you only estimate net fluxes with INVAR? It should be possible to also estimate different types similar to INVANA (see eg. Bergamaschi et al., 2009).

An inversion makes use of a given quantity of information, contained in the observation data, in the prior and in their error statistics). This information is "redistributed" in a statistically optimal way in the inverted variables. Here we chose to use the variational scheme to work at the model grid's resolution with a time resolution of one week i.e. to make use of the information to inverse fluxes at high spatial and time resolutions; we think it leaves therefore no information to discriminate between processes. The analytical scheme makes use of the information to retrieve characteristics of various processes but it therefore has to work with large regions and a monthly time resolution. To be able to invert various processes at high spatial and time resolutions, it is necessary to introduce more information, for example using more observation data (as in Bergamaschi et al. (2009), where satellite data are used) or using other types of data such as isotopic measurements (Bousquet et al., 2006; Monteil et al., 2011).

– p.6, l . 162: Why is a different surface dataset used for INVVAR and INVANA. This will complicate the intercomparisons.

The interest of INVVAR is that it works at a finer spatial and time resolution than INVANA. Therefore, INVANA and INVVAR use the same dataset of stations but with different time resolutions. Whereas INVANA can only use monthly means concentrations (p.5 l.146), INVVAR is able to make use of observation data from flasks and continuous sites, using daily means (p.6 l.162-3). This has been made clearer in the revised text [see Section 2.2 l.194-196 & l.217 seq].

– p. 6, l. 173: How do a priori emissions, especially for wetland compare to those used for INVANA and to ORCHIDEE. What is the assumed spatio-temporal distribution of wetland emissions.

As stated above (answer to comment on p. 5 l.152), a short comparison of the prior emissions in INVANAs to ORCHIDEE has been added in the revised text. A short comparison of the prior emissions of INVANAs and INVVAR has also been added [see Figure 2 and Section 2.2 l.209 seq].

– p. 6, l.182: why is the reference period 1993-2007 and not 1990-2009?

We chose this period because satellite data used in Fig. 3 for example are available during this period only, so that it is the longest time-period covered by all our estimates. It enables us to make the same computation of anomalies throughout the paper.

– p.6, l. 182: why is 1993-2007 written in bold? **This has been changed.**

– p.7, l. 194 The total net emissions are . . . Is this now referring to the mean of the 1990-2009 time period? It might be better to summarize the values given in this paragraph in a table. **This has been done.**

– p.7, l. 204 are in good agreement, in the phasing through time. . . -> This is not true for the 2003-2005 time period

We computed the time correlations of anomalies in total net emissions by INVVAR and INVANA over the whole period (19 years) in this paragraph and we discuss the exclusion of the period 2000-2006 after, at l.238 seq., for the wetlands. Regarding the 2003-2005 period, the same computing for the three years only gives correlations between 73 and 86% even though the beginning and end of the decreases appear shifted by 6 months (Fig. 1 top panel).

– p.7 I would suggest to include the priori fluxes used for INVVAR and INVANA in figure 1. I would expect that this will be interesting to see how much variability has been built into the priori fluxes already.

We agree with the reviewer that the changes from the prior are interesting to estimate the impact of the inversion. For INVANA, prior emissions are assumed to be the same each year which means that all IAV is inferred from atmospheric observations. For INVVAR, only biomass burning emissions are prescribed with IAV. These points have been more clearly stated in the revised text [e.g. 1.211-212, 241-244] but overall, most IAV is inferred from atmospheric data.

– p. 7, l. 211, . . . which indicates that wetlands explain about 90% of the variability of total methane emissions.-> which indicates that wetlands explain about 90% of the variability of total methane emissions inferred with INVANA.

This has been done.

– p.9, l.278 The comparison between ORCHIDEE and INVANAN in figure 3 top panel looks pretty poor for the whole time period and the 2000-2006 does not appear very different in this figure except that the duration of the minimum in INVANA (and maximum in Orchidee) is longer

We agree with the reviewer that ORCHIDEE and INVANA are in poor agreement for South America over the whole period. However, the driver of our focus on the 2000-2006 period is twofold:

- at the global scale and in the Tropics, a good agreement between ORCHIDEE and inversions is found except for the 2000-2006 time period (Fig.1)

- differences in South America between ORCHIDEE and the inversions are driving this 2000-2006 discrepancy (Fig. 2).

This is why we focus on the 2000-2006 period over South America.

– p.9 l. 288 The time series between ORCHIDEE-all and ORCHIDEE-sat with the run with prescribed wetland areas from Prigent show little similarities so that it is difficult to have confidence that the somewhat better agreement for 2000-2006 has real significance.

Our aim in using Prigent et al. data for wetland extent in ORCHIDEE instead of the mechanistic model TOPMODEL is to find out whether the positive trend given by ORCHIDEE for 2000-2006 (and opposed to the trend found by the inversions) can become negative when using another wetland extent description. This is not the case, as both TOPMODEL and Prigent data lead to a positive trend in South America emissions between 2000 and 2006. Before 2000, year-to-year changes inferred with Prigent data are smaller than with TOPMODEL although the trend are not statistically different either.

This is explained in the current version of the paper p.9 l.283 seq.: “Whatever the choice of inter-annual variability (IAV) for wetland extent (i.e. computed or prescribed from remote sensing data), the IAV and the trend in the various ORCHIDEE scenarios are never close to INVANA’s (Fig. 3, upper panel)”. And p.9 l.288: “both descriptions lead to a consistent positive trend between 2000 and 2006” with “both descriptions” referring to ORCHIDEE-sat et ORCHIDEE-sat-Prigent. This has been made clearer in the revised text [see changes 1.337-339 & 344-345].

Differences between estimates when Prigent et al. datasets is used instead of TOPMODEL (i.e. difference between ORCHIDEE-sat and ORCHIDEE-sat-Prigent) is an argument to explain that accounting for floodplains is required in dynamic global vegetation models (DGVMs). This is already highlighted in the current draft.

References:

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