

Interactive comment on “Global atmospheric carbon budget: results from an ensemble of atmospheric CO₂ inversions” by P. Peylin et al.

P. Peylin et al.

peylin@lsce.ipsl.fr

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Dear Reviewer,

We thank the reviewer for his/her comments and positive feedback on the paper. We have addressed all his/her concerns and we provide below detailed responses.

As a general comment, we first need to mention that we decided to update the inversion results of five different groups for the final revision of the manuscript. We chose to do this for the following reasons:

* The initial submissions correspond to the beginning of 2011 and are thus relatively

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old, with several groups having significantly updated their system. For instance, JENA, NICAM, LSCEv, CarbonTracker US (CT2009), and CarbonTracker EU (CTE2008) have updated their set-up, changing the prior fluxes (i.e., the ocean fluxes for JENA), and/or changing the observation stations (i.e., NICAM), and/or correcting some optimization problems (i.e., CTracker). These changes led to changes in the estimated land and ocean surface fluxes.

* We need to provide the carbon cycle community a “state of the art” synthesis that compares up-to-date inversion results and that provides the current level of agreement and disagreement among the different surface fluxes. The reviewer has also mentioned this need.

* The changes with the new flux results for five inversions do not affect the main results of the paper and the main conclusions; they have just resulted in the removal of a few specific features resulting in an enhanced level of agreement between the different estimates, thereby providing a more coherent set of fluxes.

* We are aware that this paper will be part of a special issue and that the old inversion results were also used in other RECCAP papers of that issue. There is thus a need for “traceability” of the inverse results that were used in the other papers.

* In order to account for this (i.e., traceability), we propose to add in the revised manuscript i) a section that summarizes the differences between the new results and the old submissions used in the other RECCAP papers, and ii) a few sentences in the conclusion that reiterate these differences. We have also prepared two tar-files that gather the existing fluxes aggregated on the different regional domains discussed throughout the paper. These files will remain accessible under the “Transcom” web-site (<http://transcom.lsce.ipsl.fr/>).

We thus decided to update the inversion comparison with a more up to date set of inversion results for the final version of the paper. With this choice we thus claim to provide a state of the art synthesis of recent atmospheric inversions.

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We have verified with the Editor that such a change was acceptable within the context of the RECCAP Biogeoscience special issue. All figures have thus slightly changed and the major changes in the surface carbon fluxes are:

* The JENA system changed with a mean ocean sink that increased by 1 PgC/yr due to a different prior flux. The corresponding land sink decreased by the same amount bringing the JENA estimates closer to the other inversions. The inter-annual flux variations, the seasonality and the long-term trends remain similar.

* The NICAM inversion changes lead to smaller land uptake in North America compensated by a larger land uptake in the tropics. Similar interannual flux variations (IAV) are found with slightly smaller amplitude in the Tropics and the North, especially in North America and North Asia. The new results are more coherent with the other inversions for North America.

* The LSCE variational system (LSCEv) became the MACC-II product. It is the reference simulation for MACC-II European project. Compared to LSCEv, the prior fluxes and errors in MACC-II have slightly changed. The new estimated fluxes have a larger ocean uptake (mainly in the south) and a smaller tropical land uptake and show few small changes in the IAV. The flux long-term trends also slightly changed with increased tropical land carbon uptake in the 2000s in MACC-II.

* The CarbonTracker US system went through several changes in the inversion set-up, especially with a correction of the atmospheric transport model (TM5) and the realisation of several sensitivity tests (the reported fluxes correspond to the mean of four different prior land/fossil fluxes). The new product "CT2011_oi" thus replaces the previous product "CT2009" with similar long-term mean fluxes (only a slight increase of the northern land uptake) and with slightly larger amplitude of the flux IAV.

* The CarbonTracker EU system also went through substantial changes (version "CTE2013" versus "CTE2009") with a two-way nested transport from the 3x2 degrees grid to highest 1x1 degree resolution over Europe as well as over North America and

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changes in the observation stations. The covered period is extended to 2010 in the new release (CTE2013) with similar long-term mean fluxes and a slightly larger amplitude of the flux IAV.

In order to keep track of the inversion results submitted initially and used in the other RECCAP papers, we added a section at the end of the Supplementary Material that: i) summarises the changes for the five inversions and ii) displays the key figures of the paper with the old flux results.

GENERAL COMMENTS:

» In my opinion, as being a most up-to-date inversion comparison work as well as a part of RECCAP, this work has a good opportunity to make a suggestion for future inversion (and intercomparison) works (e.g. how this kind of intercomparison could be improved). To nail down an inversion intercomparison, one might need to think about using criteria which participating inversions should meet. One thing the authors (and the inversion community) might want to discuss is the given fossil fuel emissions. Although fossil fuel emissions are assumed to be known (and not optimized) in all inversions, the inversions are imposing different fossil fuel emissions and do not even agree on a global total (meaning, strictly speaking, the inversions are not solving the same CO2 budget problem - even ignoring some missing pieces in current inversions, which are pointed out by Prof Enting in his post). The comparison shown in this study frequently uses "fossil correction". Although it is "corrected", the interpretations for flux differences cannot be absolute. I don't think people must use the same fossil fuel emissions data for their own research. But I believe it would be nice to share the information given to inversions. The degree of complexity in the models (prior land and ocean and transport models) used in inversions has increased. Also, the wide spectrum of observational data to be inverted has become available. To work with those emerging tools and data, we might need to think about how to organize future intercomparisons (for instance, define a common setup) well in advance before each inversion work gets more unique. This is of course not mandatory (off from the purpose of the manuscript!), but it is a

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point I would personally like the authors to address.

The point raised by the reviewer is well taken by the inversion community. Several ideas were discussed and several directions envisaged:

* First, using the same fossil fuel (FF) emissions would indeed help the inter-comparison of the different inversion results. However, using a common FF emission also causes some problems, given that there are still significant uncertainties in these products. Not only do the basic numbers change (i.e., the annual country totals) depending on who is doing the compilation (EDGAR, CDIAC, or BP) or what version of the product one is using, but many other decisions need to be made about sub-annual and sub-country distribution of FF emissions. For example, figure 2 shows significant differences across the global FF totals used by the different inversions. A recent paper by Guan et al., 2012 ("The gigatonne gap in China's carbon dioxide inventories", Nature climate change) illustrates the current level of uncertainty in FF emissions over key regions of the globe. CarbonTracker US system has used different models for the emissions with significant impact on the estimated fluxes (see http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/documentation_ff.html#ct_doc for a quick summary).

* We can thus argue that the difference in FF products are beneficial to the inversion community, as the ensemble of inversions does include FF errors to some extent by using different FF products.

* However, we agreed that having one experiment with a common fossil fuel emission would be very useful to assess the contribution of FF emission choices to the overall spread of the estimated fluxes. We are thus planning to have such experiment in the near future.

* Finally, the inversion community sees the benefit of having regular inversion synthesis and this paper should be taken as the first of its kind effort. In order to facilitate the process we have discussed the possibility to make regular publication in the Earth

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System Science Data journal (ESSD) with a full description of each approach and regular update of the results. ESSD might indeed provide a "living update" process.

RESPONSES TO SPECIFIC COMMENTS

» P5304, L9: atmospheric CO2 efforts -> atmospheric CO2 inversion efforts Done

» P5304, L11: fossil emission -> fossil fuel emission (correct the rest of the manuscript accordingly)

We have corrected in the manuscript this expression.

» P5304, L21: 22 regions, better to mention 11 land and 11 ocean for the general audience of Biogeoscience. Done

» P5305, L9: Add a last access date to the URL if needed for Biogeoscience. Not Needed.

» P5305, L11: CO2 fluxes -> CO2 flux estimates Done

» P5305, L22: Section 3 -> Sect. 3 (keep the consistency) We changed to "section" everywhere.

» P5306, L6: "including natural and anthropogenic", this might be confusing for the general audience of Biogeoscience (anthropogenic is prescribed). Rephrase if appropriate.

We have rephrased to: ". . .the net carbon exchange at the earth surface, including the anthropogenic component that is prescribed to the system".

» P5306, L14: representativeness (of what? flux aggregation error?)

We defined the term with: "(i.e. scale differences between model and observed concentrations)"

» P5307, L11: parameters, can you be more specific (like ecological parameters). Rephrase if appropriate.

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We did not change as the concept is very general and the parameters can be “ecological” like the maximum photosynthetic capacity or “physical” like for the calculation of the aerodynamic resistance that controls the latent and sensible heat fluxes.

» P5307, L12: CCDAS, I thought this is a name for the model developed by Rayner et al. (2005).

No, CCDAS is an acronym that stands for “Carbon Cycle Data Assimilation System”. However it has indeed been first used by a system based on BETHY land surface model and described in Rayner et al. (2005).

» P5307, L17: above -> above-mentioned Done

» P5309, L4: Add a proper citation for GLOWBALVIEW-CO2.

We changed the reference to: “GLOBALVIEW-CO2: Cooperative Atmospheric Data Integration Project - Carbon Dioxide. NOAA ESRL, Boulder, Colorado [Available at <http://www.esrl.noaa.gov/gmd/ccgg/globalview/>]”

» P5309, L7: under-sampled, I do know what you want to say, but it might be unclear to the general audience. Please rephrase.

We completed the sentence to: “. . . Remain under-sampled, with only few scarce stations.”

» P5309, L8: air mass representative of . . . -> air mass representing ... Done

» P5309, L9: You might want to use parenthesis with e.g. Done

Given that there is also a “e.g.” at the end of the sentence, we kept the structure.

» P5309, L21: flux relationships -> flux covariations Done

» P5310, L7: The process included in models do not matter?

Yes the processes included in the terrestrial models do matter a lot and explain for a large part the differences in the simulated fluxes obtained by all models (for instance

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models including the nitrogen cycle produce different net carbon exchange compared to models that do not include the nitrogen limitation on carbon plant uptake). We have changed the sentence to include this notion.

» P5310, L12: Emissions from cement production are also often included in fossil fuel emissions.

Yes we have included cement production in the list.

» P5311, L3: inverse -> inversion Done

» P5311, L8: fossil-fuel -> fossil fuel (keep the consistency) Done

» P5311, L11: Define RECCAP.

The RECCAP acronym is already defined in the introduction.

» P5311, L12: It would be better to define each inversion here (even briefly), although we can find the definitions of inversions in the supplement.

We have considered this issue. However, with 11 inversions and with few sentences per inversion to describe even the basic features we would already obtain more than one page of description. We thus believe that Table 1 presents and defines the 11 inversions in a compact manner that provides the main features of each set up to the reader. We thus kept the text as it is.

» P5311, L18: chose to make this a single submission -> consider this as a single submission Done

» P5312, L5: Define IAV here rather than later. Done

» P5312, L13: positively quality controlled, what do you mean by this?

We wanted to specify that for these inversions, the modeling team has checked all site data to potentially remove outliers. We have completed the sentence to articulate this point.

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» P5312, L17: raw, do you mean they are not averaged?

Yes by raw data we mean the direct measurements from a given flask. The parenthesis in the text "(weekly flasks or continuous record; LSCEv, CT2009, CTE2008, JENA)" refers to that point. Given that more information is provided in the supplementary material we chose not to overload the text in this section.

» P5312, L24: the several groups, which groups?

After having checked, it turns out that all groups have made sensitivity tests on the number of station that is used. We thus changed "several groups" by "all groups".

» P5313, L2: representation uncertainty -> representation error (if stick to Kamiski paper) Done

» P5313, L9: A citation for TM5 is missing.

We agree. However, if we provide a citation for TM5, we need to provide also one for all model listed below: LMDz, CCAM, and MATCH. Given that these models are properly described in the supplementary material, we chose not to overload the main text, and only to add a reference to the supplement.

» P5313, L11: vertical mixing -> vertical mixing schemes Done

» P5313, L12: interannually varying -> interannually-varying Done

» P5313, L12: a single year of winds, do you mean a fixed wind field?

Yes we mean that one particular year of wind is repeated each year neglecting the inter-annual variations in transport fields. We believe the sentence "single year of winds, which is repeated to achieve multiyear results" is explicit enough.

» P5314, L21: varying, do you mean time-varying or a wide variety of prior fluxes?

We mean a wide variety of prior fluxes and not only time-varying aspects. We change "varying" by "diverse".

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» P5315, L13: From the supplement information, I imagine BP is used just for extrapolation.

The two Carbon-Tracker systems use annual global total fossil fuel CO₂ emissions from the Carbon Dioxide Information and Analysis Center (CDIAC) [Boden et al. 2011] which extend through 2008. In order to extrapolate these fluxes to 2009 and 2010, they extrapolate using the percentage increase or decrease for each fuel type (solid, liquid, and gas) in each country from the 2011 BP Statistical Review of World Energy for 2009 and 2010. The supplementary information now provides such information and a link to the web page that describes it in details.

» P5315, L16: I would suggest to describe if they included int'l bunker emissions in the supplement information.

This is indeed an important point. Most groups include international bunker emissions as they have used the CDIAC total emission, but some did not. We thus provide this information in the supplementary material, especially when a group did not use the international bunker emissions.

» P5316, L6: 4-D-var, this needs to be defined.

We did not define the four-dimensional variational scheme as it is complex and would require a too long description. We thus slightly changed the sentence and added one reference ("Courtier et al. 1994"), as such a scheme is relatively well know in the Data Assimilation community. The new sentence is: ". . .use a four-dimensional variational approach developed for numerical weather prediction (4-D-var; e.g., Courtier et al. (1994)) to iteratively search for the optimal fluxes."

» P5317, L15: care -> a care Done

» P5352, Fig. 1. I would suggest to include observation maps for all the inversions (in the supplement document) as it is a critical information to interpret each inversion result.

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We thought about that but this would lead to a very long supplementary document not easy to read. However, a table of all sites used is in the supplementary material (which was unintentionally omitted in the initial submission). We have, also, changed the caption of figure 1 to indicate the number of inversions that use a particular site. Moreover there are references in the supplement to the individual papers describing each inversion which may include observation maps.

RESPONSES TO SPECIFIC COMMENTS ABOUT THE SUPPLEMENTARY MATERIAL

» P1, L28: Piao et al., 2009 -> Piao et al. (2009) Done

» P3, L81: EDGAR v4, v4.x? We have added this information: EDGAR v4.0

» P6, L160: Patra et al., 2005 -> Patra et al. (2005) Done

» P6, L166: Define SPO. Would be helpful for the general audience of Biogeoscience Done

» P6, L167: interannually varying -> interannually-varying Done

» P6, L168: Define pre-subtracted fluxes.

We added a little explanation of what pre-subtracted fluxes represent: "(i.e., monthly biosphere fluxes with no net annual sink are imposed to the inversion system like fossil fuel emissions to account for the seasonal carbon fluxes from the vegetation)"

» P7, L176: Transcom -> TransCom Done

» P7, L176: real observation, I imagine you want to say the data is not averaged. Please rephrase.

We changed to "raw observation data"

» P7, L177: extended to which year?

We specified that it was extended to 2009.

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» P7, L178: What kind of modifications were done?

A vertical mixing problem in their transport model has been fixed. This has been specified.

» P7, L179: and monthly resolution -> on monthly basis Done

» P7, L184: Here you can use "SPO". Changed to SPO

» P7, L184: fossil fuel with. . . -> fossil fuel emissions Done

» P7, L189: Define CONTRAIL if not defined yet.

We have defined CONTRAIL measurement: "(observations from Airliners, <http://www.cger.nies.go.jp/contrail/contrail.html>)".

» P7, L189: this inversion -> the NICAM inversion shown in this study (or something like that)

We have changed accordingly to the reviewer's suggestion.

» P7, L190: limited aircraft measurements, what do you mean by that?

We indicated that this inversion is using a small number of aircraft measurements. We have changed the text and we now point to a table in the supplementary that was missing and that gather all station locations for each inversion.

» P7, L191: TRANSCOM -> TransCom Done

» P7, L194: The ocean flux partitioning -> The ocean flux region partitioning (or definition), please consider.

We changed according to reviewer's suggestion.

» P8, L200: A citation for further details of the aircraft data?

We have specified which aircraft data are used and added a reference: Niwa et al. (2012)

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