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Interactive Comment

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

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Dear Ian,

We thank Ian Enting for his comments and positive feedback on the paper. We address below his concerns providing 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

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

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:

» The year of this publication marks the 50th anniversary of the first attempt at CO2 inversion, by Bolin and Keeling (1963). On such an occasion, it is gratifying to see such an excellent compilation of work demonstrating the state-of-the art in CO2 inversions. (There is of course much on-going research activity, pushing the boundaries of the science, most notably in the area of improved statistical characterisation of model and observational error (e.g. Berchet et al., 2013; Kuppel et al., 2103)). It is however important to note the differences between a model intercomparison study (i.e. Transcom) and model applications aimed elucidating real world issues. As an intercomparison, Transcom embodied some simplifications that impinge minimally on model comparisons, but which are problematic for real-world studies. In particular:

» many of the inversions treat the fossil component as known exactly;

We agree that taking the fossil fuel emissions as a known component is a current weakness of all systems. However, given that no fossil fuel emissions were prescribed for this intercomparison, there are significant differences between the different emissions used by each group (see figure 2). As a result part of the uncertainty due to fossil fuel emissions is accounted for with the ensemble of 11 inversions. The inversion community is aware of this shortcoming. Some groups have started to include in their inversion framework the use of different fossil fuel emissions. For instance, CarbonTracker is using two different fossil fuel emissions for each release, in order to account partly for error in fossil fuel spatial and temporal distribution (see http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/documentation_ff.html#ct_doc for a quick summary).

» most if not all of the inversions ignore the atmospheric transport of reduced car- bon. This is discussed in more detail below.

We agree that all inversions have neglected the atmospheric transport of reduced carbon (see the response below to the more detailed comment). Since this paper is part of the special issue on RECCAP (REgional Carbon Cycle Assessment and Processes) (Canadell et al., 2011), there should be more emphasis on how this paper sits within the RECCAP structure. The following comments draw heavily on the RECCAP paper on uncertainties (Enting et al., 2012).

» RECCAP (see http://www.globalcarbonproject.org/reccap) proposes various 'synthesis of syntheses'. For this it is important to note that the flux estimates given in this paper represent a synthesis of top-down inversion with bottom-up estimates from priors. Thus the estimates will not be independent of the 'bottom-up' estimates produced in many of the other RECCAP contributions.

We agree with the reviewer. This point is rather crucial and we have reinforced it in section 5 (section on the "interpretation of regional fluxes"). We added that most atmospheric inversions use estimates from land and/or ocean model (bottom up approaches) as priors so that the inversions should not be considered as a fully independent piece of information when compared to bottom-up approaches in the different RECCAP synthesis.

» The neglect of atmospheric transport of reduced carbon represents a systematic bias in many (or all?) of the calculations reported here. It means that in general that the top-down fit is (approximately) a 'CO2 budget', while the bottom-up constraints are more generally those of a 'carbon budget'. (The approximation arises from treating all CO2 sources and sinks as being at the earth's surface âĂŤ this is not true for oxidation of

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reduced carbon compounds). Although the studies that introduced Bayesian synthesis inversion for CO2 (Enting et al., 1993, 1995) did include a crude representation of reduced carbon, this component was generally neglected in Transcom studies. For intercomparisons addressing transport error, the neglect of reduced carbon matters little, but such neglect causes biases estimates of regional carbon budgets. An initial study showing the latitudinal distribution of the bias was given by Enting and Mansbridge (1991). A more recent analysis, using 3-D modelling, is given by Suntharalingam et al. (2005). There is also a requirement for consistency between top-down vs bottom-up (priors) in the treatment of other lateral carbon transport through rivers and trade (Enting et al., 2012).

We agree with the reviewer that none of the inversions used in this study account for CO2 sources due to the oxidation of reduced carbon compounds. As discussed in Suntharalingam et al. (2005) and in the more recent paper of Nassar et al. (2010), the impact of 3-D atmospheric oxidation of reduced carbon compounds is not completely negligible and may lead to a flux bias of 0.2 PgC/yr in the northern continental land uptake (too large uptake). However, such bias remains two times smaller than the long-term mean flux differences obtained with the 11 inversions: standard deviation of 0.5 PgC/yr for the northern land (Figure 4). Thus, the neglect of this component of the carbon cycle does not change significantly the conclusions of the paper. It has a potential impact for the regional long-term mean fluxes that should be kept in mind. For the interannual flux variations and the long-term trend, we expect that the miss-allocation of this CO2 source (surface instead of the whole 3D atmosphere) remains constant over time and has thus a relatively small impact.

We have thus slightly revised the manuscript to mention the potential biases due to this missing 3D source of CO2 from oxidation of carbon compounds. We added in section 4.2 on the long-terms mean: "one should also notice that all inversions neglect the 3-D source of CO2 from the oxidation of reduced carbon compounds in the atmosphere (i.e., source treated as a surface flux) and that such simplification might bias

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the northern continental land uptake by 0.2 PgCy-1 (too large uptake) as discussed in Suntharalingam et al. (2005)".

Note finally that in the same line the inversions also need to inject the emissions of CO_2 from aviation at high altitude as well as fire emissions through pyrocumulus clouds and not at the surface as currently done.

» In passing, it is worth noting that the term 'carbon budget' has acquired a new meaning. There is the long-standing use in the carbon cycle community for a description of the partitioning of CO_2 (or carbon) fluxes to and from the atmosphere (as in this paper and in the various budget estimates from the global carbon project (e.g. Le Quéré et al., 2009)). A new meaning of carbon budget is the cumulative amount of CO_2 emissions consistent with stabilising concentrations. This concept (which is an approximation) comes from work such as Matthews and Caldeira (2008) and Allen et al. (2009). The concept achieved wider usage after being used in the Stern Report.

We thank the reviewer for raising the new meaning of "carbon budget". However, we kept throughout the paper the long-standing use in the carbon cycle community.

Interactive comment on Biogeosciences Discuss., 10, 5301, 2013.