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Comment

## ***Interactive comment on “CO<sub>2</sub> flux estimation errors associated with moist atmospheric processes” by N. C. Parazoo et al.***

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Anonymous Referee 1

The paper describes the impact of different sub-grid parameterizations of vertical transport (moist convection, turbulent diffusion) on inversion results when using column dry air mole fractions from satellite based remote sensing instruments. By using the same offline transport model, but meteorological fields from slightly different data assimilation systems, attribution of differences in retrieved fluxes can be attributed to specific dynamical differences in the met fields. I regard this manuscript as a very useful contribution to the field of CO<sub>2</sub> inverse modelling, and recommend publication after a few minor revisions.

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## General comments:

1) There should be a discussion on the significance of the flux errors derived as differences from different inversions, given that the uncertainties are mostly larger than the (statistical) errors for different regions. This is at least evident from the way it is presented in Figs. 5 a) and b). For example, the difference in “amplification” of the EU source due to only differences in vertical transport parameterizations (i.e. differences between Exp. 6 and Exp. 4) is about  $0.55 - 0.2$  GtC/year, while each has an uncertainty of about 0.25 GtC/year. For the N. America temperate region the situation is similar.

We thank the reviewer for this comment. The authors had not considered this point. When the significance of flux errors is put in the context of uncertainty between inversions, only the European flux error stands out ( $0.43 \pm 0.35$  PgC year<sup>-1</sup>), and even this error is only slightly significant relative to uncertainty. The reduced significance of total annual flux error over N. America is partly due to a strong cancellation of regional sources and sinks in Experiments 5 and 6. We have therefore relaxed the language throughout the paper stating the significance of the magnitude of transport related flux errors, but maintain the importance of the regionally coherent structure of flux errors created by systematic differences in transport.

Specifically, we address the reviewer comment with the following changes to text:

In the abstract on P9986, Lines 12-19 are replaced with

“Moist poleward transport is hidden from orbital sensors on satellites, causing a sampling bias, which leads directly to small but systematic source/sink estimation errors in northern mid-latitudes. Second, moist processes are represented differently in GEOS-4 and GEOS-5, leading to differences in vertical CO<sub>2</sub> gradients, moist poleward and dry equatorward CO<sub>2</sub> transport, and therefore the fraction of CO<sub>2</sub> variations hidden in moist air from satellites. As a result, sampling biases are amplified and continental scale flux errors enhanced, most notably in Europe ( $0.43 \pm 0.35$  PgC year<sup>-1</sup>).”

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In results on P9998, Lines 1-10 are replaced with

“In “biased” transport OSSE’s (Experiments 5 and 6), most regions experience an increase in total annual flux errors relative to baseline errors established in the equivalent “perfect” transport experiments (Experiments 2 and 4, respectively; see Fig. 5). For example in Experiment 5, Europe ( $0.57 \pm 0.25$  PgC year<sup>-1</sup>), Eurasian Temperate ( $0.32 \pm 0.23$  PgC year<sup>-1</sup>), and S. America Tropical ( $0.21 \pm 0.71$  PgC year<sup>-1</sup>) contribute most significantly to an enhanced global source ( $0.94 \pm 1.23$  PgC year<sup>-1</sup>), while N. America temperate and boreal regions contribute to an enhanced sink ( $0.42 \pm 0.45$  PgC year<sup>-1</sup>). Eastern N. America reverses from a weak source in Experiment 2 (Fig. 6B) to a strong sink in Experiment 5 (Fig. 8B). The global land source increases to  $1.4$  PgC year<sup>-1</sup> in Experiment 6 when slowly varying sinks are added (Fig. 5). The magnitude of flux errors in Experiment 6 is consistent with Chevallier et al. (2010).

The difference between flux errors in perfect transport (Experiment 2 and 4) and biased transport (Experiment 5 and 6) experiments primarily reflect differences in transport. Differences in the calculation of the dry air mole fraction of CO<sub>2</sub> due to differences in humidity fields between GEOS-4 and GEOS-5 are small ( $< 0.1$  ppm at grid scale in the annual mean) and therefore unlikely to contribute significantly to flux errors. With Experiment 6 as the reference and focusing on northern temperate and boreal regions, we therefore estimate that transport errors create a European source of  $0.43 \pm 0.35$  PgC year<sup>-1</sup>, Eurasian Temperate source of  $0.15 \pm 0.32$  PgC year<sup>-1</sup>, N. American Temperate sink of  $0.04 \pm 0.45$  PgC year<sup>-1</sup>, and N. American Boreal sink of  $0.15 \pm 0.20$  PgC year<sup>-1</sup>. The amplified European source is most significant relative to uncertainty between inversions.” In Conclusions, P9998 Lines 26-27 and P9999 Lines 1-7 are replaced with “First, CO<sub>2</sub> signals contained in moist air masses are hidden from orbital sensors on satellites. This causes small but systematic errors in regional and continental scale source/sink estimation in northern mid-latitudes. Second, moist processes are represented differently in GEOS-4 and GEOS-5, leading to differences in the vertical CO<sub>2</sub> gradient and hence the fraction of moist CO<sub>2</sub> air hidden from satellites.

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Thus, differences in vertical transport amplify sampling biases, which are then aliased in the inversion through increases in continental scale flux estimation errors throughout northern mid-latitudes. Specifically, the European source is amplified by  $0.43 \pm 0.35$  PgC year<sup>-1</sup> while a weak source in eastern N. America is replaced with a strong sink.

2) Although it is a commendable experiment in that only specific differences were allowed in the setup (same offline transport model, principally the same assimilation system to generate the met fields), there is also a downside: the differences retrieved fluxes from such an ensemble are likely to be smaller than those when allowing for other differences in the setups of the inversion system. Even then it cannot be assumed that the true error (difference between one of the inversion results and the true “real” fluxes) is bracketed by the ensemble spread. May be the authors can include a comment on this in the conclusions.

This is another important point that needs to be addressed in the conclusions to caution the reader that the paper describes only a subset of errors possible in our inversion framework. We therefore added a paragraph in the conclusions on P9999 L10:

“While these results are important for the interpretation of flux errors associated with satellite observations of CO<sub>2</sub>, we caution these errors in no way bracket the possible range of flux errors to be expected in an inversion of real data. We have eliminated factors such as transport model, assimilation system, and differences in specific humidity fields between GEOS-4 and GEOS-5, but have not addressed errors due to other differences in experimental setup, in particular the calculation of XCO<sub>2</sub>. For example, we have not considered aerosol effects, land surface type, or surface pressure. In the absence of condensation, aerosol effects may be important for frontal transport in urban areas in Europe and eastern N. America or in regions of biomass burning. High aerosol burden could have a similar impact on flux inversions as clouds, and should therefore be a focus of future studies.” 3) It should be clearly stated if for the inversions the synthetic data were used at their given temporal and spatial resolution, or whether there

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has been any temporal or special averaging applied such as aggregation to monthly averages. This of course has a major impact on the interpretation of sampling biases such as in the cloud screening experiment (experiment 3).

The authors thank the reviewer for pointing out that indeed, the Methods section describing the inversion setup does not clearly address data processing. This section has been augmented throughout. To specifically address the reviewer comment, the following text is added to P9993 L11:

“Soundings are sampled at the native resolution of the meteorological analysis in the nature run (see below) at 1:30 pm local time, and are assumed to represent the grid scale average. No temporal averaging of synthetic retrievals is applied.”

Specific comments:

P 9990 L 24: It is a bit unclear why GEOS-5 does not require time-averaging: for offline transport simulations to have transport consistent with the parent model, time integrated advective mass fluxes should be used (such that the mass balance is consistent).

We made this statement to show that on-line GEOS-5 transport does not require time-averaging. We do, however, use time averaged GEOS-5 fields for offline transport. To reduce confusion, we decided it is best to omit the statement “does not require time-averaging”.

P 9991 L 14: What is meant by “Wind vectors are also conserved”? This should be explained in a bit more detail. In order to have consistent advection between the two resolutions, dry-air mass fluxes (rather than winds) should be properly aggregated from fine to coarse resolution.

The authors made an incorrect statement by writing “Wind vectors are also conserved”. The reviewer is correct that it is the dry-air mass fluxes that are conserved. We have revised this statement with:

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“Vertical and horizontal advection is conserved, leading to smoothed spatial gradients.”

P9993 L 15: what is the impact of using glint retrievals beyond the  $\pm 20^\circ$  latitude band covered by GOSAT?

This is an important point for understanding the impact of our findings on inversions of real GOSAT data since glint mode is not used beyond  $\pm 20^\circ$  latitude from solar declination. We therefore performed an additional OSSE in the framework of Experiment 3 to understand the impact of these high latitude retrievals on flux estimation errors. After removing this data, we find that changes in flux estimation errors using the 2-week assimilation window are negligible. We address the reviewers point with several revisions of the text.

Text on P9993 L13-16 is replaced with:

“All possible glint retrievals are retained, including those beyond  $\pm 20^\circ$  of latitude from solar declination. In practice, however, glint mode is only used by GOSAT at latitudes within  $20^\circ$  of latitude from solar declination. We therefore run an additional OSSE in the signal detection experiment (Experiment 3, described below) to test for the impact of high latitude glint data on flux recovery.”

Text on P9997 L22-23 is replaced with:

“Perturbing the sinks with spatial noise and seasonality does not degrade recovery (Experiment 4, Fig. 5, yellow), nor does removing glint retrievals exceeding  $\pm 20^\circ$  latitude of solar declination (with the exception of slightly enhanced source in northern Europe and reduced source in temperate S. America, not shown).”

Note: The authors have chosen not to include a plot in the revised manuscript demonstrating the impact since it is not the primary focus of the study, but have a plot ready if the reviewers deem it necessary.

P 9998 L 4: Figure 8 does not show South America

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Thank you. This entire section has been strongly revised (see above).

P 9998 L 12: G4F05 does not exist; probably G5F05 is meant

Thank you for pointing this out.

Technical comments:

P 9986 L 9: I would suggest replacing “conveyors” with “conveyor belts”

Yes, “conveyors” is too vague.

P 9987 L 26: insert “in” between “differences” and “grid”

Thank you.

P 9993 L 1: remove the word “based”

Thank you.

P 9993 L 5: replace O2 by CO2?

Yes.

P9998 L3: replace “Figs. 3” by “Figs. 5”

Thank you. Please note there is heavy editing of lines 1-10, P9998.

P9998 L4: Figure 8 does not show South America

Thank you (see above, General Comments, Point 1).

P 10008 Fig 2: in a) the profiles from G5F05 and G5F10 extend much closer to the surface than those of G4F10 and G4F20, while in b) this is the opposite. Is this a plotting mistake?

This is not a plotting mistake. GEOS-4 products don't save vertical diffusion at the lowest model level, while GEOS-5 products don't save cumulus mass flux at the two lowest model levels.

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We have included the following statement at the end of the caption in Fig. 2 pointing out this discrepancy: “Note that vertical diffusion is zero in GEOS-4 at the lowest model level and cumulus mass flux is zero in GEOS-5 at the two lowest model levels.”

And we have included the following statement on P9995 L18 clarifying the effect on vertical transport: “Cumulus convection also starts higher in the PBL in GEOS-5 (Fig. 2B), reducing vertical transport from the surface”

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Interactive comment on Atmos. Chem. Phys. Discuss., 12, 9985, 2012.

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