Response to anonymous referee 1

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May 24, 2013

We thank the referee for the constructive feedback. Please find our responses below.

1 Temporal resolution and spatiotemporal correlation lengths

The main concern the referee has is with the inversion methodology, in particular (i) the monthly temporal resolution of the inverted fluxes, and (ii) spatiotemporal correlations for the prior fluxes. The two points are in fact related, therefore we would like to respond to them together. It is true that there is some degree of arbitrariness in the choice of the prior correlation structure, which can be problematic since the posterior fluxes depend heavily on the choice of prior correlations. However, the sensitivity to the prior correlations depends on what aspects of the posterior fluxes one wants to present. For example, if one only presents annual and seasonal aggregated fluxes over continental length scales – as we have done – then assuming shorter spatiotemporal correlations than we have done do not significantly alter those aggregates. There will certainly be differences, but as long as those differences are smaller than the error estimates on the posterior fluxes, those differences are not significant. To prove our case, we have performed the three inversions (surface only, GOSAT only and joint) with dramatically different correlation times and lengths, more in line with what the referee suggested. The two sets of correlation parameters are tabulated in table 1, while the flux aggregates are presented in figure 1.

TABLE 1: Covariance parameters for different categories, original (lc) and modified (sc)

Class	Category	L (km)	T (months)	ξ
lc	Biosphere flux	500	3	0.84
lc	Oceanic flux	3000	6	0.60
sc	Biosphere flux	200	1	2.213
sc	Oceanic flux	1000	3	1.569

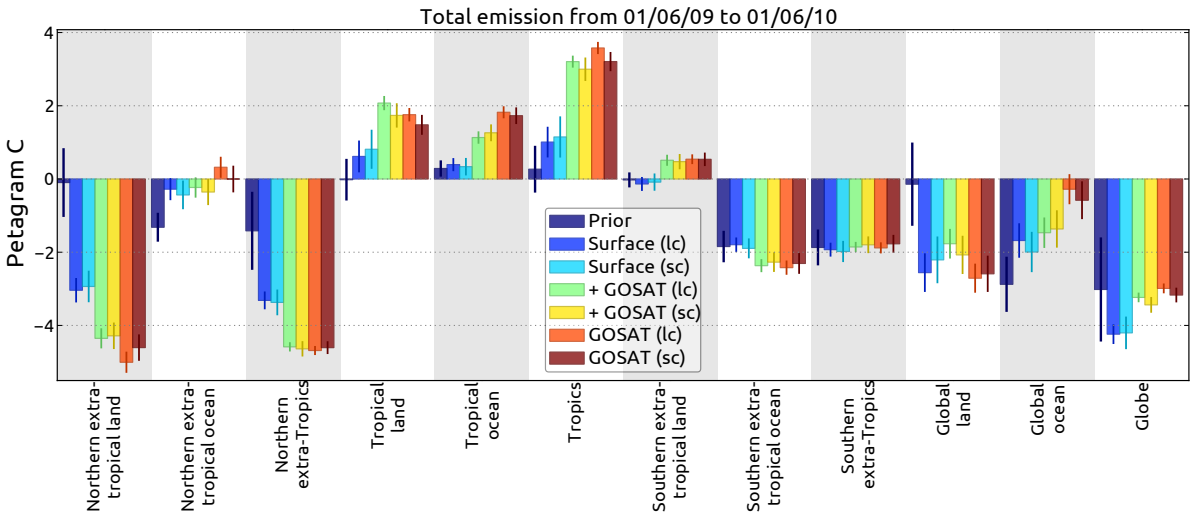

FIGURE 1: The impact of changing the prior spatiotemporal correlations on annual flux aggregates over continental length scales. The "lc" set – for "long correlation" – corresponds to the standard correlation parameters, whereas the "sc" set – for "short correlation" – corresponds to shorter spatiotemporal correlation lengths, as tabulated in table 1.

The ξ, i.e., the flux uncertainty per gridbox as a fraction of the absolute flux per category, was chosen for the modified correlation parameters to keep the global total prior flux uncertainty per category the same. Since shorter

correlations imply larger cancellations when aggregating, ξ had to be increased to keep the global total uncertainty constant. As can be seen from figure 1, although the aggregated fluxes can be different between the "sc" and the "lc" inversions, in all cases the two numbers are within $1-\sigma$ of each other. Therefore, we think that our estimates – as presented in the paper – are robust to reasonable changes in the correlation parameters. One minor difference between the sensitivity tests presented in § 4.4 and this one is that now our inversion system includes, by default, a land-sea bias correction as described in § 4.5. Therefore, the inversions "+ GOSAT" in figure 1 denote an inversion where a land-sea bias is optimized (equivalent to "+ GOSAT (BC)" of figure 15 in the manuscript). The "GOSAT" inversions in figure 1 assimilate GOSAT XCO_2 with this optimal land-sea bias applied. This of course does not change the conclusion of this sensitivity analysis, which is that changing the correlation parameters as described in table 1 does not change the conclusions in our manuscript.

An important point to note here is that the correlation parameters do not apply to the prior fluxes themselves, but to the *corrections* to the prior fluxes. What a high positive correlation between a grid cell i and another grid cell j means is that if the inversion decides to increase the flux from cell i by a certain amount relative to the prior in cell i, it should also increase the flux from cell j by a similar amount relative to its prior. These corrections can have really long correlation time and length scales, for example if the prior flux is different from the "true" flux because of an incorrect parameterization in the biosphere model (CASA GFED, in this case) which constructed the prior fluxes. Thus, if the productivity of Boreal coniferous forests were underestimated (say) by the biosphere model, then the corrections made to the flux from areas dominated by coniferous forrests should be highly correlated, all across Northern America and Eurasia. This is what happens, for example, in CarbonTracker, which effectively assumes perfect correlation between all regions having the same vegetation type, globally. Therefore, we think our assumed correlation parameters – the "long" correlation lengths and times – are not as unrealistic as they might look at first sight. And since our temporal correlations are at least one month, the inversion system cannot resolve weekly fluxes. Therefore, we have chosen one month as our temporal unit.

2 Error model R

We think calling R the "error model" is misleading. The error matrix R represents the model data mismatch, i.e., the confidence interval of $y^{\mathrm{mod}} - y^{\mathrm{obs}}$. Accordingly, it contains the observational error, i.e., how well we know y^{obs}, and the model representativeness error. This second component is a measure of how well the tracer transport model can represent sub-gridscale variability, i.e., how well it can reproduce y at a specific point in time and space, given a perfect representation of the total tracer mass within the gridbox and timestep containing y^{obs}. This component is a result of trying to represent a continuous tracer field with a spatiotemporally discretized model, and goes down as one increases model resolution. Our R matrix contains all the components mentioned above. However, R *cannot* contain errors due to wrong transport by the tracer transport model, since the inversion framework assumes "perfect" transport. This is not to say that there are no errors due to erroneous transport; there are, and it is the purpose of the sensitivity tests (changing the forcing meteo dataset, changing horizontal and vertical resolutions) to assess the impact of changing the transport. Those errors, however, cannot be bundled into R. Similarly, spatiotemporal aggregation errors cannot be put into R either. One of our sensitivity tests – changing the horizontal resolution – also quantifies to some extent the spatial aggregation error, since the fluxes are estimated at a different grid resolution and then aggregated. Currently, our inversion framework cannot estimate the temporal aggregation error. However, given our monthly (and longer) temporal correlations, we do not expect our temporal aggregation errors to be significant.

3 Other minor points

The fact that the analysis is based on the RemoTeC algorithm should be mentioned in the abstract, as the results only apply to that retrieval algorithm.

Good point. That information has been added to the abstract.

Clarify the distinction between the "older" missions/instruments (e.g. AIRS, TES, etc.) that were not designed for measuring CO_2 and missions that are specifically designed for this purpose (e.g. GOSAT, OCO-2). Otherwise, comparing them to one another is misleading.

Our point was to make clear that GOSAT was the not the first instrument to ever measure XCO_2. We did mention that they were not geared to study sources and sinks of CO_2, due to their lack of near-surface sensitivity. However, we realize that now it reads as if we are comparing (unfairly) TES, IASI, TOVS and AIRS to GOSAT, so we have changed the language to say that the earlier instruments were not designed to study sources and sinks of CO_2. Nonetheless, we do not think that the comparison is completely irrelevant, since inverse modelers such as Chevallier et al. [2005], Chevallier et al. [2009] and Nassar et al. [2011] did try to extract CO_2 source-sink signals from those instruments.

Make it clear that you are referring to correlations between errors, not the process values being observed.

Good point. The sentence has been changed from "the transport model can also generate correlations between observations" to "the transport model can also generate correlations between model-observation mismatches".

What constitutes a "definite demonstration"? Why do the other works cited by the authors using TES, AIRS, etc. data not qualify? I believe it is rather a matter of degree, not a matter of "definite" vs. not.

This is true. What we had meant was that whereas earlier work (e.g., [Chevallier et al., 2005] and [Chevallier et al., 2009]) did not show that assimilating satellite data resulted in stronger constraints on surface fluxes than surface data alone, or that there were features in the posterior flux estimates that were realistic and that were visible only when adding satellite data to the assimilation. In other words, we feel that those works did not conclusively demonstrate the added benefit of satellite-based CO_2 measurements to carbon cycle science. This was not because the methods themselves were faulty or limited, but because the satellites involved were not sensitive to near-surface changes in CO_2. What we have demonstrated is that we can extract CO_2 source-sink signals from GOSAT that we could not from only surface measurements. In accordance with the referee's suggestion, we have changed the sentence "We stress that this is the first definite demonstation that X_{CO_2} measurements from GOSAT and similar future satellite missions can quantify the carbon cycle, a result that bodes well for future remote sensing missions." to "We stress that we have demonstrated that X_{CO_2} measurements from GOSAT and similar future satellite missions can impose significant quantitative constraints on the carbon cycle, a result that bodes well for future remote sensing missions.".

At some point in the manuscript, it would be appropriate to at least briefly mention/describe the existence of the several other retrieval algorithms actively being developed and used for GOSAT XCO_2.

This is a good suggestion. While we do not want to dwell on the various retrieval algorithms in an inversion paper, we should nevertheless mention the existence of other retrieval algorithms for GOSAT XCO_2. Accordingly, we have added the sentence "The performance of RemoTeC in comparison with other algorithms for GOSAT X_{CO_2} retrieval can be found in [Oshchepkov et al., 2013]." to § 2.2.

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