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Interactive Comment

Interactive comment on "Error correlation between CO_2 and CO as constraint for CO_2 flux inversions using satellite data" *by* H. Wang et al.

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Interactive comment on "Error correlation between CO2 and CO as constraint for CO2 flux inversions using satellite data" by H. Wang et al.

Anonymous Referee #2: This study addresses the important question of how to improve inverse modeling techniques for the estimation of sources and sinks that suffer from transport model uncertainties. Transport model uncertainties are difficult to quantify and account for in inversions, and therefore methods to deal with this problem are of great interest. The authors take the novel approach of reducing the impact of transport errors by performing a joint inversion of two tracers, where the added mutual constraint comes only from the fact that the transport model errors can be considered similar for the two tracers. The idea is initially a bit counter intuitive and it also raises the suspi-

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cion that we are dealing here with a theoretical trick that could never work in practical applications. Regarding the latter, it should be mentioned that the study that first introduced this concept did target a practical application. However, as confirmed by the authors of the present study, there were some conceptual problems: 1) the confusion of concentration covari- ance and error covariance 2) the conclusion that reduced a posterior flux uncertainties necessarily imply improved a posterior fluxes. My main concern with this theoretical investigation is that it builds on the conclusions of previous work, while some fundamental questions regarding the approach itself have not yet been sufficiently addressed. This makes it difficult for the reader to judge how relevant the conducted experiments are in the first place. As will be explained in further detail below, to make this study suitable for publication in ACP it should either take a step backwards by addressing these more fundamental questions or it should acknowledge that there are still potentially important limitations of the approach.

We will acknolwdge potentially important limitations of the approach in Section 5.

GENERAL COMMENTS

Posterior fluxes versus posterior flux uncertainties My fundamental question about the CO-CO2 cross correlation approach is whether the gain in posterior flux uncertainty is accompanied by the expected improvement in the estimated CO2 fluxes. Inverse modelers are generally careful about interpreting posterior uncertainties. It is a useful indicator of the information-flow within the inversion, however, it is only a faithful measure of actual uncertainties if the statics of all the ingredients of the inversion are well represented. Usually the off-diagonal part of the covariance matrices is poorly defined. The CO-CO2 cross correlation approach relies entirely on the off-diagonals, which makes it potentially vulnerable to crude assumptions in the inversion set-up. The way I would explain the constraint from CO on CO2 in the joint inversion is by the fact that the CO inversion not only tightens the CO flux uncertainties, but also the CO posterior measurement uncertainties. Since the CO and CO2 uncertainties are correlated this also reduces the CO2 measurement uncertainty, etc. The problem is that the inversion

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has only degrees of freedom in the space of the fluxes, not in the space of uncertain transport model parameters. Therefore misfits between model and data can only be projected on the fluxes. The inversion set-up is in fact inappropriate to optimize tracer transport, and therefore the fit with the data is partially improved for the wrong reason. In that case, it is not clear that the posterior data are really an improvement over the prior data, even though the posterior data uncertainties suggest that it should.

The reviewer makes indisputable points about the effect of bias in model parameters (such as transport) and the reliability of the a posteriori error covariance matrix when errors have not been properly characterized. These are general problems in inverse modeling, not specific to our application. Under the admittedly idealized conditions of our simple OSSE, where errors are perfectly characterized (because imposed), reduction in the a posteriori error variance does diagnose an improvement. See below for change to be made to text.

In my view a much better way to test the benefit of the CO-CO2 cross correlation method would be to perform an inversion where pseudo data are generated using one version of the GEOS-CHEM model, and inverted using another model version. This way one could directly test if the skill of the inversion in reproducing the true CO2 fluxes improves when the CO-CO2 cross correlation method is applied. I realize that such a test involves quite some work, and would therefore be hard to require for the present study. However, not knowing the outcome of such a test puts the effort within this study in quite a different perspective. It should be made much clearer that this method is still in an experimental phase and needs further investigation before it can be applied to real-world applications.

on Page 11794, line 21, we will change the last sentence to "Our demonstration involves several simplifications such as neglecting instrument and representation errors, neglecting spatial and temporal correlations, neglecting a priori error correlations, and using the same model for both pseudo data and inversion. These simplifications may influence the benefits of the joint CO2-CO inversion [Chevallier, 2007]. A more exten-

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sive study will be needed to better understand their effects." On Page 11796, line8, we will replace "demonstrated" by "illustrated". Also we will add to the final paragraph of the conclusions, "We find that a posteriori CO_2 flux uncertainties are substantially reduced, implying significant improvement in the CO_2 flux inversion. Inversions using actual satellite observations are subject to measurement noise and model biases that complicate greatly the interpretation of results relative to our idealized example. Further work will be needed to demonstrate the value of CO2âĂŤCO error correlations as constraints on CO_2 fluxes in real-world applications."

Data covariance: The CO-CO2 cross-correlation is only one of several directions for which the covariances should formally be specified. It is unclear why the CO-CO2 cross correlation receives much attention here, whereas the spatial and temporal correlation of transport model error within the CO and CO_2 inversions seem to be ignored. This should be explained. It is not easy to think of how such correlations might influence the benefit of a joint CO-CO2 inversion, but there may well be an important effect.

We neglected spatial and temporal correlations in this study so that we could concentrate on the effect of CO2-CO model error correlation. See suggested change in response to previous comment, which acknowledges the need for including spatial and temporal correlations in future work.

The role of prior flux covariance: I find it hard to believe that the uncertainties of CO_2 and CO fluxes from biomass burning can be considered uncorrelated. The size of the emissions from individual burning events is very uncertain, which affects CO_2 and CO in the same manner and therefore contributes a positive correlation to their uncertainties. The question is if such correlations have any relevance for constraining CO_2 fluxes in a joint CO-CO2 inversion. I think it does, as I will try to explain below. The impact of accounting for data covariance in single tracer source/sink inversions has been investigated by a few authors in the past (see e.g. Chevallier et al, 2007). For spatial correlations decaying with distance, the posterior uncertainties of 'local' fluxes are reduced by the off-diagonals, whereas the posterior uncertainty at the large scale increases. The latter can be explained by the fact that the data covariance reduces the number of independent measurements. At the local scale, however, this effect is dominated by the number of measurements that address the local flux, which increases when the measurements become correlated. In a joint inversion I suppose 'local' and 'large-scale' in the example above can be replaced as 'independent tracer' and 'dependent tracer'. The implication is the following: if the CO and CO2 fluxes are correlated this extends their 'scale' (they become dependent tracers). In that case, the uncertainty gain by adding data covariance is expected to become less. If the prior fluxes are correlated strongly enough then adding data covariance will increase rather than decrease the posterior flux uncertainty. I'm not sure what Palmer et al. (2006) meant by stating that a priori error correlation was not useful in their inversion, but it could have reduced the benefit of adding CO2-CO data covariance.

The uselessness of a priori error correlations in the Palmer et al. work simply reflected the weakness of these correlations, not any reduction in the amount of information. See their section 2.2. The correlations are weak because the uncertainty in the CO emission factor is so large. The reviewer does have a point that the correlation would be stronger for biomass burning, and this is illustrated in Palmer et al. Table 1 and Figure 3 by the results for Southeast Asia (where emission is mainly from biomass burning). In their standard case, the correlation coefficient for SE Asia was only 0.17 (useless). However, as shown in their Figure 3, the correlation could become useful if uncertainty in fuel burned exceeded a factor of two (it would still be only marginally useful, cf. Figure 7 of Palmer et al.). We will add a sentence on line 11, p. 11,789: "A possible exception is biomass fires if uncertainty in fuel burned exceeds a factor of two".

In this study it should be made clear that the level of uncertainty reduction gained by the joint inversion approach may be different in real-world applications because of the choice of independent prior flux uncertainties.

We will metion this in Section 5 on Page 11794.

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SPECIFIC COMMENTS

Page 11791: It is not clear why the paired forecast method uses daily averaged biospheric fluxes and no biomass burning.

We took advantage of the existent ARCTAS forecasts which were not custom designed for this paper. This will be clarified in line 9 on Page 11791.

REFERENCES

Chevallier, F. (2007), Impact of correlated observation errors on inverted CO2 surface fluxes from OCO measurements, Geophys. Res. Lett., 34, L24804, doi:10.1029/2007GL030463.

This paper will be referenced in Section 5.

Palmer, P. I. et al. (2006), Using CO2 : CO correlations to improve inverse analysis of carbon fluxes, J. Geophys. Res., 111, doi:10.1029/2005JD006697. Interactive comment on Atmos. Chem. Phys. Discuss., 9, 11783, 2009. C1511

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