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Interactive Comment

Interactive comment on "The potential for regional-scale bias in top-down CO_2 flux estimates due to atmospheric transport errors" *by* S. M. Miller et al.

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We would like to thank the reviewer for suggestions and comments on the manuscript. The reviewer's detailed suggestions have been very helpful in improving the manuscript. Below, we have included the reviewers comments (in bold) along with our reply and the associated changes/updates to the manuscript.

- **General comment: Not all sources of transport model uncertainty are captured by an ensemble of forecasts with a single transport model. Somewhere in the paper it should clearly be listed which uncertainties are not**

included (e.g. spatial representation error/model resolution, uncertainty arising from imperfect parameterizations of turbulent processes and cloud transport, other structural model errors such as numerical diffusion).

The reviewer makes a good point here. We have added text accordingly in sections 2.2 to clarify this point.

- **P23684 L12: "correlated errors can bias" I suggest to replace this by "spatially correlated errors can bias"**

  We have changed this statement to "temporally and/or spatially correlated errors can bias ....".

- **P23694 L4-6: The case that the ensemble does not encapsulate the CO2 measurements might also be related to differences in the transport models used here and for CT (TM5). This should be mentioned.**

  We have added comments to this effect in sections 2.2 and 3.1 of the revised manuscript.

- **P23695 L17-18: "most existing top-down studies will underestimate the uncertainties in estimated CO2 fluxes" here references should be given as this is quite a strong statement. Some inverse modelling systems e.g. use error inflation to allow for covariance on timescales shorter than a week (e.g. Rödenbeck et al., 2003).**

  We have re-written this statement in the revised manuscript. In that statement, we wanted to communicate the importance of accounting for spatial and/or temporal correlations in the transport errors. For example, an inversion that includes these covariances would estimate larger uncertainties in the fluxes relative to one that uses a diagonal covariance matrix. We have revised that statement to clarify our intended meaning. Furthermore, we have expanded case study #1 in the revised

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manuscript to better indicate how these spatial and/or temporal error covariances can affect the estimated fluxes.

- **P23695 L25: I suggest dropping the comma after "top-down"**

  We have updated the manuscript accordingly.

- **P23696 L5-8: It might not a property of the tall towers to be more or less sensitive, but a property of the transport model. It should be mentioned that there is not really a difference expected, given the vertical resolution of the transport model. In that context, it would be appropriate to mention the number of vertical levels in the lowest km as this information seems hard to find for the reader.**

  We have clarified this point in the manuscript. In most regions there are 3 vertical levels within the lowest kilometer of CAM. (These three levels are centered at 929.6, 970.6, and 992.6 hPa over regions where the land/water surface is at sea level.). Hence, some CO_2 observation sites are associated with the lowest vertical level of the model while others are associated with the next vertical level. We have removed any comments from the manuscript on differences between short versus tall towers.

- **P23696 L8-9: I have difficulties averaging the bar plots for marine sites to 76%. There are three bars that are of scale, and the others average to something around 35% in February and 45% in July.**

  We have updated the analysis with more observation sites and have modified the associated figure.

- **P23698 L3-5: Figs. S16 and S17 do not really provide any information regarding the uncertainty represented in the meteorological ensemble, as they only show monthly mean values for each of the variables. A parameter that might be interesting in this regard is the coefficient of variation for**

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the boundary layer height (PBLH), as a small uncertainty in PBLH will lead to a large uncertainty in tracer in regions with low average PBLH.

We have added several additional plots to the supplement that visualize additional meteorological variables and their uncertainties (including the coefficient of variation for the boundary layer height).

- **Supplement S1, P1, first line of 3rd paragraph: suggest replacing "for each for the" by "for each of the"**

  We have changed this text in the supplement.

- **Supplement S2, P4, 4th paragraph: I don't quite understand why there is a need for manually setting inflation factors to 0.4 (the lowest values globally); in the text "unphysical temperature estimates near the tropopause" are mentioned. Are there no satellite data in this region available that are assimilated? Kalnay et al., (1996) mentions that TOVS sounder data are assimilated; also there should be a few radiosonde data in that region.**

  This issue is due to an enigmatic temperature instability in the meteorological model. In the forecast stage of the CAM model, the ensemble's temperature spread in this region can increase rapidly if the initial conditions (i.e., the posterior estimate from the previous time step) have a sufficiently large spread.

  Normally, one might expect the adaptive inflation to correct for this issue; the adaptive inflation adjusts the variance of the meteorology model ensemble to match the actual model-data residuals. In theory, this procedure should prevent the ensemble spread from exploding (given sufficient data). However, the inflation factor by design cannot change suddenly from one time step to another. The adaptive inflation procedure uses the previous time step as the prior inflation estimate, and that prior estimate has a finite uncertainty (in this case, a prior standard deviation of 0.03 – similar to the values used by Miyoshi (2011)). Because of this prior uncertainty, the adaptive inflation factor must evolve slowly over many days

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(if it changes at all). In most cases, this property is desirable because it prevents a single (or small number of) observation(s) from making dramatic changes to the evolution of the model-data system. However, in the case of this temperature instability, the instability in the model develops over 4-5 model time steps, much faster than the response time of the adaptive inflation factor.

The adaptive inflation procedure requires an initial inflation estimate for the first time step of the model run (i.e., an initial condition). The adaptive procedure then updates this estimate at the each model time step (e.g., Eq. S10). For this initial estimate or initial condition, we set a small value (0.4) for the equatorial western Pacific. During the one-month model spin-up period, the estimated inflation value evolves substantially from the initial estimate in most regions of the globe (e.g., Fig. S2). Over this region of the Pacific, however, the estimated inflation factor does not evolve or change very much; either this initial estimate is consistent with the actual model-data residuals or the meteorological data (and the adaptive inflation procedure) are not very informative over the region. In either case, this small initial condition prevents the ensemble spread from becoming unstable over the region.

We have added more explanation on these points within section S2 of the article supplement.

- **Supplement S3, P8, figures S7 and S8: The colour scale labelling seems to be wrong; I would expect a significantly smaller range for monthly averaged concentrations than for 6 hourly concentrations**

  Thank you for point out this mistake! The legend on these figures should be identical to Fig. 2c and 2d. We have corrected these figures in the revised manuscript.

- **Supplement S5, table S1: it should be mentioned (in the legend or in the text on page 16) that the locations for each of the sites can be seen in Figure 4, panel a).**

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This is a good suggestion. We have added many more observation sites to the analysis. As a result, we removed Fig. 4a and instead now list all of the site locations in table S1.

- **Supplement S6, Figure S15: SSR should have units (ppm^2), those should be added**

  We have revised case study #1 and no longer use sum of squared residuals (SSR). We have updated the supplemental figures accordingly.

References

Miyoshi, T.: The Gaussian Approach to Adaptive Covariance Inflation and Its Implementation with the Local Ensemble Transform Kalman Filter, Monthly Weather Review, 139, 1519–1535, doi:10.1175/2010MWR3570.1, 2011.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 23681, 2014.