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Geoscientific Model Development Discussions

Interactive comment on "Mass-conserving coupling of total column CO_2 (XCO_2) from global to mesoscale models: Case study with CMS-Flux inversion system and WRF-Chem (v3.6.1)" *by* Martha P. Butler et al.

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Response to Anonymous Referee # 1

"Mass-conserving coupling of total column CO2Âă(XCO2) from global to mesoscale models: Case study with CMS-Flux inversion system and WRF-Chem (v3.6.1)" [gmd-2018-342], Butler et al.

General Remarks:

We greatly appreciate the thoughtful and constructive suggestions from **Anonymous Referee # 1.** We have addressed all of the comments and made the revised manuscript clearer. Point-by-point responses follow. The original comments from the reviewer are in italics and the response in normal.

General Comments:

The authors have created a method for interpolating global model mixing ratios at coarse spatial scales to the grid for higher resolution models such as WRF-Chem, and then evaluate the differences between the resultant simulations with identical surface fluxes against TCCON and co-located GOSAT soundings near the TCCON site for the concentrations and rawinsonde data for the winds. This activity is useful and interesting for the community of regional tracer modelers, but the conclusions don't seem to demonstrate the utility of the boundary condition interpolation technique, and they certainly don't imply the added value of the regional modeling approach. While this negative result is in itself important, some further evaluation is required to understand why this is the case before I can recommend publication of these results. Specifically, evaluation against aircraft data to better understand the model-model differences in the tracer distribution in the vertical dimension, and evaluation against GOSAT data spatially. The tremendous amount of NOAA surface and tower data would also be extremely useful for differentiating between the PBL dynamics, as would meteorological analysis of the PBL differences between the two models. This represents an expanded scope for the manuscript, but the introduction of the boundary interpolation alone does not represent a significant scientific advance of sufficient scale to warrant publication.

Response: We thank the reviewer for the valuable recommendations. We have extended significantly our analysis to include i) a comparison with the original coupling scheme, which constitutes a commonly-used approach to couple global to regional models. This section highlights the importance of the boundary interpolation and mass-conservation techniques used here. We also included ii) a comparison to GOSAT data to evaluate the impact of transport on model-data residuals, iii) a comparison to NOAA aircraft profile data to identify differences in the vertical distribution of CO2 mole fractions, and iv) A comparison to tower measurements over the whole year to identify seasonal differences and the relationship between tower-based model-data residuals and column-integrated residuals. These significant additions have been inserted in the main text (Methods, Results, and Discussion sections) and our conclusions were modified accordingly. To support our text, five figures and one table were added to provide a full analysis of the model CO2 mole fractions using various types of measurements.

2.3.1 I wonder how sensitive your results are for different diurnal cycles. Particularly at higher spatiotemporal resolution, this could be important for matching observations. It does simplify the interpretation vs. the parent model, though.

Response: We agree with the reviewer that diurnal cycles can impact significantly the simulated column and in situ CO2 mole fractions. In this study, we focused on comparing transport models at two different spatial scales using identical surface fluxes. Because CMS is a well-established system, we avoided comparing different diurnal cycles but future studies should account for mis-representation of the short-term variability in surface fluxes. We have added a sentence in the Discussion section to highlight the importance of diurnal variations in simulating atmospheric CO2 mole fractions. "We also acknowledge here that diurnal variations in CMS surface fluxes are prescribed and might not exactly match the meteorological conditions in WRF. Comparison of fluxes

and PBL variations are shorter timescales is needed in future studies."

2.3.2 To call the method "mass conserving" would suggest that the XCO2 values at the boundaries should be much closer than 0.1ppm, right? I understand that the propagation into the domain might lead to these differences, but I would expect the overall differences at the time of interpolation to be tiny. Perhaps you could demonstrate that the actual mass is conserved, even if the column average mixing ratio is not (due to different surface pressures). Maybe some of the mass is lost in the upper 50hPa? Later on it says that you are using the CMS-Flux mixing ratios above 50mb, which makes this difference even more confusing.

Response: We show the differences at the boundaries in Fig. 2. The median for the western, eastern, and southern boundaries is about 0.03ppm. The northern boundary shows larger differences due to mountains (0.05ppm on average). Physically, the only approach to reduce further the mass differences is to avoid mountains at the boundaries of the simulation domain. Because the model surfaces are different, extrapolation (or removal) of CO2 is unavoidable. Because our scheme is intended to be used with in situ data, we minimized the modification of mixing ratios while conserving the column mass as best as possible.

For the air mass over 50hPa (not simulated in WRF), we used the CMS values in all our analysis. We clarified that point in the text. "Because the top of the atmosphere in WRF is at 50hPa, we used CMS mole fractions to complete the column values above 50hPa in our study."

Section 3 It seems that a lot of insight could be gained from comparisons to GOSAT in a spatial context, rather than just the model-model differences at simulated GOSAT sounding locations and times. Why is this not shown? Certainly the comparison in

3.2 at the Lamont TCCON is part of this, but the spatial information could shed light on the boundary condition effects, etc in other parts of the domain. This is reinforced by the very small bias of GOSAT at the Lamont TCCON site relative to the models. Remember that 0.5ppm difference in the column (particularly for a large scale average as shown in Figure 4) can amount to a significant difference that would be interpreted as a flux difference in an atmospheric inversion. Further insight into the vertical mixing differences could (and should) be gained by comparison to the NOAA light aircraft time series, for example at Lamont. Since the fluxes are the same in each model, the only difference would be the transport.

Response: This part has now been included with significant additions compared to the original study. We have added comparisons to GOSAT and aircraft profiles to our study. Tower data have also been used to understand seasonal differences.

Section 4 This would benefit from a comparison with the results recently made available in Schuh et al (2019), in which the authors examine the differences in GEOS-Chem (which drives CMS-Flux) and TM5 (which uses a different reanalysis). In particular, the authors look at the differences in vertical mixing and try attribute these differences to the way convection is handled in a rough way. They also draw conclusions about broad scale flux inference from these differences. It is a complementary study that deserves some mention here.

Response: Since Schuh et al. (2019) has been published after our study was submitted, we didn't refer to it. We can now cite Schuh et al. (2019) and discuss the potential role of deep convection. We have added in the Discussion section "A recent study showed the role of deep convection at Mid-latitudes by comparing two global models coupled to the same surface fluxes (Schuh et al., 2019). Their results suggest that the transport of continental surface fluxes by latitudinal atmospheric transport can greatly

impact the distribution of CO2 mole fractions across the northern hemisphere. Similar to our results, they conclude that additional evaluation of vertical mixing is needed to reduce transport errors above the PBL, esp. by deep convection and other detrainment processes.