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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Atmospheric carbon cycle dynamics over the ABoVEdomain: an integrated analysis using aircraft observations (Arctic-CAP) and model simulations (GEOS)" *by* Colm Sweeney et al.

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We thank reviewer 1 for his or her comments and suggestions. We believe an important point of our paper was missed by the reviewer, which we take as an indication that our present manuscript may not be clear on this point. Our understanding of natural emissions of CO2, CH4 and CO is rudimentary at best and is limited by data as well as mechanistic models that will allow us to predict change in the Arctic. A main focus of this paper is to describe an approach for evaluating and demonstrating the accuracy of the CO2 and CH4 surface fluxes in the NASA GEOS model for the Arctic. Our approach

takes advantage of the fact that the atmospheric profiles made during the ArcticCAP mission not only sampled most of the boundary layer but also included both residual layers and backgroud free troposphere. By integrating the enhancement of CO2, CH4 and CO with altitude from surface to 3000 masl from aircraft profiles to calculate a total enhancement in the atmospheric column for direct comparison with a forward model, we significantly reduce biases due to both model transport and background mole fraction that confound inverse estimate of surface fluxes. In fact, the majority of the papers that the reviewer refers to, have identified these types of biases as negatively impacting the accuracy of their estimates. But none of those studies aimed to quantify and diagnose such biases using information from multiple species of carbon, as is done in our paper.

One of the largest biases incurred during inverse estimates are the errors in the mixing layer height. By integrating a total enhancement from the surface to 3000 m (well above the boundary layer) we eliminate the bias that comes from inverting a point concentration measurement [mole fraction x molar density = mole/mˆ3] by using an integral [mole fraction x molar density x alt = mole/mˆ2]). This method is particularly useful for the Arctic and the high-latitudes, where forward model prediction is important for developing an understanding of how climate change will drive feedbacks in greenhouse gas fluxes as well as emissions of gases like CO. We have used this approach to show that indeed the selected forward model (GEOS) is quite good at replicating CO2 and CH4 fluxes, a first step toward assessing the capacity of the model to predict future concentrations. A second source of error in inverse estimation, especially for regional inversion models, comes from the boundary conditions that are specified. In this manuscript, we demonstrate the fidelity of a global model that can be used to supply the boundary conditions for three different species. This in itself is unique since such a dedicated study to evaluate the capability of a high-resolution global model over this domain does not currently exist in the literature, and is useful since it demonstrates that the GEOS model can supply the boundary conditions for regional inversion models to quantify the fluxes.

As the reviewer points out, there are many papers that have used aircraft data to infer fluxes using inverse methods or by comparing point measurements with forward model output, but few have leveraged the mole fraction x altitude integral method which avoids major biases in background and transport errors, thereby allowing us to evaluate seasonal and regional biases in fluxes and drive substantive future model improvements. The reviewer rightly points out that the next step is to focus on one tracer (e.g. CO2 or CH4) and compare the altitude integral of that species to the output from multiple bottom-up flux estimates as a way to rank/evaluate their accuracy. This paper focuses on the pros and cons of using this method on three different tracers. We demonstrate that in the Arctic the method might not work for CO due to the nature of the subgrid pyroconvection, and for CH4 we have identified areas where the seasonal and regional emissions need improvement. Because our altitude-integrated enhancement is dominated by local fluxes and is relatively agnostic to modelling errors, it is a quantity that can and should be optimized from a mechanistic perspective - thus improving future model predictability.

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