Response to Anonymous Referee #2 for Manuscript acp-2013-297

Comparison of ensemble Kalman Filter and variational approaches for CO_2 data assimilation

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We thank the reviewer for their critical comments. We certainly agree with the reviewer that the topic of inter-comparing data assimilation (DA) methods is "interesting, highly relevant and well scoped with respect to the Journal Subject Areas". We would like to add here that including a batch inverse modeling scheme in the inter-comparison framework, and isolating the degradation in the DA estimates relative to the batch is a rather novel topic. Such inter-comparison activities between the DA and the batch technique have not been pursued before, especially within the CO_2 inverse modeling community. Hence, this study has been intended to be generic and guide the selection of these methods for a real source-sink estimation problem.

We do acknowledge the reviewer's concern that the testing setup is highly simplified and there is no model of atmospheric process or dynamics. We do not think, however, that this undermines the value of this study or its ability to fit within the scope of ACP. As pointed out in the manuscript (p. 12829, lines 1-9), the motivation for using a simplified 1D problem is: (a) to allow flexibility in terms of setting up the inverse problem analogous to the CO_2 flux estimation problem, and (b) to allow implementation of a batch least squares method due to the computational efficiency of the 1D setup. This follows directly from the primary goal stated at the outset (p. 12826, lines 10-13; p. 12828, lines 21-27), which is to assess whether numerically approximate DA methods can *serve as a suitable long-term replacement of the batch technique under different inversion conditions*.

In order to fulfill this goal, it is clear that we need to run multiple inversion experiments as well as solve these multiple experiments using a batch inverse modeling scheme. If instead of using a computationally efficient 1D problem, we attempted to solve a real CO_2 flux estimation problem, obtaining multiple batch estimates for different experiments would not have been feasible. For each of the 9 experiments reported in the study, we would be required to run a full atmospheric transport model (p 12829, lines 19-21) either once per estimated flux region/period combination, or once per observation if an adjoint to the transport model was available. This additional computational expense may very well have deterred us from obtaining a batch solution multiple times, and we would have been left with a regular inter-comparison of DA methods for a highly specific/localized problem. Hence, we would argue that the ability to compare the two DA estimates with the batch estimates for different inversion scenarios is what makes this study unique. This has *general implications for the CO_2 (and other trace gases like CO, CH_4) inverse modeling community*, and indeed falls very much within the scope of ACP.

Additionally, we do not completely agree with the reviewer that the setup is not realistic and/or "limits the applicability of the results". It is true that we are not solving a real CO_2 flux estimation problem, and thus unable to address issues related to observation and model biases. But the methodological setup of the inversion problem (p. 12829, lines 10-26; p.12831-12832; p. 12833, lines 18-24) and the design of the experiments (Section 2.3) take into account many of the nuances of the flux estimation problem (for e.g., ill-posed and under-determined nature). In fact this allows us to ultimately 'scale-up' the conclusions from the experiments and discuss possible implications for a real CO_2 flux estimation problem (Section 4). We believe that the science questions targeted in this study (p.12828, lines 21-27) and addressed via these well-

defined realistic test cases do count as an 'atmospheric modeling' research activity, which happens to be one of the core research criteria for ACP. Simplified setups, which target broad science questions and are relevant to the general scientific community, are not uncommon in ACP. For example, *Banda et al*. [2013] used a 1D chemistry model representative for the global tropospheric column to simulate global methane changes while *Sessions et al*. [2011] and *Freitas et al*. [2010] discussed a simplified 1D entrainment plume model to investigate different vertical transport issues. Similar to our study, all of these studies have acknowledged that they have used a highly simplified setup but made an honest attempt to parameterize the model such that it is representative of a realistic implementation.

Finally, as pointed out in Section 4 (p. 12844, lines 12-17) and again in Section 5 (p. 12847, lines 8-13), work is ongoing to expand this study in order to compare the DA approaches for a real CO_2 flux estimation problem using satellite CO_2 observations. The new inter-comparison study does bring into play observations and model biases. Due to the computational expense, however, such an inter-comparison will not have a batch inverse modeling estimate as a benchmark. Not surprisingly, we are actually using the knowledge gained from this study to guide the parameter choices for the DA methods, so that we can minimize the degradation in the DA estimates relative to the estimates we would have obtained from the batch scheme.

In short, while we understand that the 1D setup presents some limitations on the aspects of a DA system that can be explored, and will describe these limitations more explicitly in the revision, we also maintain that the 1D setup presents unique advantages that could not be achieved within an inter-comparison based on a full-scale implementation of the problem. We thus strongly believe that there is a need for both types of studies in the atmospheric literature.

References:

- Bândă, N., Krol, M., van Weele, M., van Noije, T., and Röckmann, T.: Analysis of global methane changes after the 1991 Pinatubo volcanic eruption, Atmos. Chem. Phys., 13, 2267-2281, doi:10.5194/acp-13-2267-2013, 2013
- Sessions, W. R., Fuelberg, H. E., Kahn, R. A., and Winker, D. M.: An investigation of methods for injecting emissions from boreal wildfires using WRF-Chem during ARCTAS, Atmos. Chem. Phys., 11, 5719-5744, doi:10.5194/acp-11-5719-2011, 2011
- Freitas, S. R., Longo, K. M., Trentmann, J., and Latham, D.: Technical Note: Sensitivity of 1-D smoke plume rise models to the inclusion of environmental wind drag, Atmos. Chem. Phys., 10, 585-594, doi:10.5194/acp-10-585-2010, 2010