Responses to Reviewer Comments

Modeling inter-continental transport of ozone in North America with CAMx for the Air Quality Model Evaluation International Initiative (AQMEII) Phase 3

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The authors thank the reviewer for their helpful comments. Below we respond to each and note our changes to the manuscript.

Anonymous Referee #2 Received and published: 12 April 2017

The work presented in an interesting contribution to the scope of the ACP Special Issue and fits very well within the papers that I have seen published so far. In fact in its relative simplicity it addresses questions that are nicely linking the global and the regional scale in two relevant ways: the influence of long range transport on regional scale chemical budgets (read Ozone); but also the possible influences of global scale models on regional scale ones, which acquires from the first the mass budget at the boundaries. The paper is well written. If I have to find a criticism I would say that it is probably too well written or better to little written. What I mean by that is that in many places, basically all sections the explanations as well as the writing style are a bit too concise and to the essence. A contrast is present between the will to present facts and figures and the fact that most of the time qualitative definitions like, "large, bigger, better, acceptable" are use to characterize the results.

Response 1: We have checked to make sure that any qualitative characterization is always accompanied by numerical statement. For example, "CAMx has a large over prediction bias exceeding 15 ppb at the two sites when observations are low (~20 ppb)."

The figures are nice and give clear quantitative indication of the various aspects that the study tackles, which however is not reflected in the text at times. More elaboration and quantification is needed here and there to make the story more interesting and appealing and to elevate the valuable content of this paper from a report style. I am not asking to re-write the paper here, cause that would be unfair, just to indulge in a deeper explanation of the results by deepening only into those explanations that are worth exploring.

Response 2: We thank the reviewer for this suggestion. We have added more analyses and expanded our conclusion section to better capture essence of our story. Please see our modified conclusion as shown in bold text below.

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The overall MDA8 O_3 performance is within evaluation goals. We do not see evidence of systematic problems with the model setup, although performance at individual monitor does vary, and the potential for hidden biases and errors always exists. Future studies could benefit from refining model assumptions that may be important at specific sites. For example, overstated MBL O_3 at Trinidad Head is partly attributable to the lack of O_3 destruction by oceanic halogen chemistry. Other possible reasons include insufficient O_3 deposition to the ocean, too strong vertical mixing in the MBL, or a combination of factors. The model tendency to overestimate O_3 in spring may suggest overstated BC contributions as seen at Denver site. Perfecting model performance at individual sites across the US is not pursued in the current study. If accuracy in estimating BC contributions is critical, such as in demonstrating attainment of O_3 standards, model performance and BC contributions especially on high O_3 days cannot be overlooked.

Inert BC O_3 tracers consistently estimate higher BC contributions to seasonal average MDA8 O_3 across the US than reactive tracers, particularly in summer. The inherent bias in the inert tracer approach (i.e., omitting chemical destruction) can exceed 10 ppb in seasonally averaged MDA8 O_3 which is substantial in comparison to the 70 ppb level of the O_3 NAAQS. This information is critical for interpreting results obtained with inert tracers in AQMEII-3 and other studies.

Comparing inert tracers in two regional models that used substantially the same input data found differences in MDA8 O_3 that were **generally within 5 ppb**, smaller than the differences between inert and reactive tracers **run in a single model (CAMx),** but nevertheless **those inert model differences** were notable. Potential causes include differing numbers of model vertical layers (influencing movement of UTLS O_3 to ground level) and differences in model treatments of deposition. **This exercise emphasizes that source contribution analyses of BC O_3 (or other non-inert pollutants) using the inert tracer approach should only be interpreted qualitatively especially during the spring and summer period. Making tracers reactive is a simple improvement that is very important to this type of analysis. Future studies should consider adopting the reactive tracer approach.**

Contributions from O_3 BCs in three height ranges (LT, MT and UTLS) differ spatially and temporally. The LT BC tracers do not penetrate very far inland **with contributions to MDA8 O_3 up to 20 ppb in the coastal states**. The largest contributions to MDA8 O_3 are from the MT BCs with springtime maxima exceeding 40 ppb in the high terrain of the Western US. The high contribution of BC O_3 to ground level O_3 in portions of the Western US presents a significant challenge to air quality management approaches based solely on local emission reductions. Nonetheless, model comparison with observations suggest**s** that estimated high BC contributions in the Intermountain West could be overstated and that the bias inherent in O_3 BCs can affect model performance. **Replicating the highest end of observed O_3 distribution is particularly challenging. We encourage adopting multi-day metrics (such as Top 30) as an alternative to a single-day metric (e.g., H4MDA8) when examining contributions from international transport.**

Reducing emissions in East Asia (EAS scenario) revealed a near linear relationship between changes in BC O_3 and changes in surface O_3 in the Western US in all seasons and across the US in fall and winter with a near 1:1 slope. However, the surface O_3 decreases are small: below 1 ppb in spring and below 0.5 ppb in other seasons. These **O_3** reductions result mostly from reductions in MT and LT BC contributions. **Our 2010 EAS contribution results are slightly higher than the estimates of 0.35-0.45 ppb from multi-model experiment that also simulated the EAS scenario but for the year 2001 (Reidmiller et al.,2009). This is expected as East Asia emissions have increased over the last decade. Assuming a linear relationship, our study suggests an EAS total contribution of 2.5 ppb in certain seasons based on 0.5 ppb O_3 reduction with 20% emission decrease. It is difficult to quantify how the model biases affect the O_3 response to emission perturbations because the sources of biases are unknown.** In the GLO scenario US surface O_3 is more sensitive to domestic emission reductions than changes in the BCs.

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Cities are taken as locations for the comparison with data. It is important to characterize the monitoring sites and clarify whether those location are suitable to measure background levels of ozone.

Response 3: Our interest is high ozone and the selected locations have high ozone exposure. For this reason we look at the AQS rather than CASTNET monitors. The 22 major cities are selected based on their population size (~200K in Salt Lake to 8.5M in New York) and geographical location. If a city has multiple AQS monitors, then we select the one with highest H4MDA8. This is described at the end of Section 2.2 and in Figure S1. The selected AQS site ID is provided in Table S3.

The inert ozone tracer is a powerful tool that should be exploited more in the future, considering the relevance of the impact of BC bias on regional scale models.

Response 4: In our view, inert tracers are useful, but subject to a clear bias. Making tracers reactive is a simple improvement that is very important to this type of analysis and the community should adopt that approach.

A more detail break down in the vertical would be very instructive when studying for example boundary layer exchanges or transition from marine to land ABL. But this is probably for the future.

Response 5: We agree with this future-work recommendation.