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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Climatic effects of 1950–2050 changes in US anthropogenic aerosols – Part 2: Climate response" *by* E. M. Leibensperger et al.

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We thank the reviewer for their valuable comments and suggestions. Their input has improved the clarity and content of the manuscript.

Referee's comments are in plain text, our responses are **boldface**, and changes to the manuscript are ***italicized***.

The authors discuss the direct and indirect radiative effect of U.S. anthropogenic aerosols and the associated global and regional climate response. Main results include the regional nature of the response, and that most of that response has already happened. The topic and paper are interesting, and the manuscript is clear and well

written. I suggest publication after minor revisions, mainly to address some concerns about the impact of the experimental setup on results.

1 Main comments The authors use monthly-mean aerosol fields: this choice can impact the modelled aerosol forcing. They also use a q-flux ocean: this choice can impact the model response. Both impacts should be discussed in the paper along the following lines.

Using monthly aerosol fields instead of interactive fields modelled online causes two problems. First, the indirect effect is non-linear and monthly-mean aerosols will exert a different effect than interactive aerosols (see Appendix B of Jones et al., 2001). The authors state (page 24137, line 6) that their "indirect effect is comparable in magnitude to the direct effect". This is surprising: I would expect the indirect effect to be stronger, especially for aerosols of the chemical compositions found in the United States. The experimental setup may underestimate the indirect effect.

The details of our forcing calculations are presented in the companion paper and follow standard methods. We have added text discussing our modeling setup (using monthly mean aerosol distributions) as mentioned below.

Second, the climate response to aerosol radiative effects will in turn affect aerosol distributions: different clouds will lead to different wet deposition rates, for example. This effect cannot be captured using the experimental setup used in the study.

This is certainly true, but we believe the change in source amounts will dominate any change in aerosol abundances caused by the perturbed climate. We have added the following text to Sect. 2.2:

The use of archived monthly mean aerosol distributions as input to our climate simulations does not allow for feedbacks of changing climate on aerosol concentrations. These feedbacks are likely very small relative to the source driven aerosol perturbations implemented here, considering that both models

and observations indicate little direct sensitivity of aerosol air quality to climate change (Jacob and Winner, 2009; Tai et al., 2011). The use of monthly mean aerosol concentrations does not introduce significant bias in the calculation of the direct radiative effect (Koch et al., 1999), but it may affect the aerosol indirect due to the nonlinear relationship between aerosol amount and cloud droplet number (Jones et al., 2001) as seen in Eq. 1.

From experience, a q-flux ocean responds more quickly and more sharply to a perturbation than a dynamic ocean model. When the authors state (page 24138, line 19) that "some GCM studies find a strong spatial correlation between regional radiative forcing and climate response", I strongly suspect that the way the ocean is represented matters. A q-flux ocean model will not let the response move away from the forcing, and the regional response will therefore be stronger.

We agree that use of the Q-flux ocean represents a source of uncertainty. We have added the following text to the Conclusion discussing issues of experimental setup:

Relating aerosol radiative forcing to regional climate change is challenging. There are many model uncertainties involved in the mechanisms of aerosol-cloud interactions, the response of the hydrological cycle, the lateral transport of heat in the ocean (the Q-flux parameterization used here does not allow for change in that transport), and other aspects of the climate model. Multi-model analyses are needed to address the robustness of results (National Research Council, 2005). Our ability to reproduce observed 1950-2010 temperature trends lends some confidence to our conclusions.

2 Other comments - Page 24136, line 8: A radiative forcing of +0.4 Wm−2 is not that weak. How strong must a forcing be to exert a response that can be distinguished from the model internal variability?

+0.4 Wm^{-2} is not small on the global-scale, but is less impressive on a local scale. Looking at Figs. 2 and 8, it can be seen that the temperature signal is becoming close to statistically insignificant from 0C by 2040-2050 when the TOA radiative perturbation (Fig. 2) is between 1-1.5 Wm^{-2}. This has been added Sect. 2.2 of the text:

More generally, we find that a regional radiative forcing of about 1.0 W m^{-2} is necessary to produce a climate response greater than natural variability in the GISS GCM 3 with a 5-member ensemble.

Page 24138, line 7 and page 24145, line 5: A reason why the model underestimates surface radiation trends can simply be that the model underestimates aerosol radiative effects. Having reasonable aerosol fields does not guarantee radiative effects are correct, unfortunately.

In our view, the conclusion that aerosols alone cannot explain observed surface radiation trends is valid since other modeling groups have similarly failed to reproduce the trend. This is mentioned in the text of Sect. 3.1:

However, and as previously noted (Liepert and Tegen, 2002; Long et al., 2009; Wild, 2009a, b; Koch et al., 2011), we find that anthropogenic aerosols cannot explain the magnitude of the observed surface radiation trends.

We have added the following to Sect. 3.1 to make this more clear:

The discrepancy seems unlikely to arise from underestimated aerosol radiative effects since models consistently underestimate the observed trend (Liepert and Tegen, 2002; Long et al., 2009; Wild, 2009a, b, Koch et al., 2011).

- Page 24145, line 14: SST anomalies and aerosol radiative effects can very well be linked together.

We agree and have made this more clear in the text:

This hydrological contribution to the central US "warming hole" has been previously identified from observations by Robinson et al. (2002) and Pan et al. (2004) and attributed to sea surface temperature (SST) anomalies. We show that this mechanism is consistent with the expected effect of US anthropogenic aerosols on North Atlantic SSTs.

New References:
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