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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Adjoint sensitivity of global cloud droplet number to aerosol and dynamical parameters" *by* V. A. Karydis et al.

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General Comments

There are still uncertainties of aerosol indirect forcing for future climate prediction. Some of the uncertainties stem from uncertain parameters in cloud microphysics parameterizations in climate models. This study examines the sensitivity of cloud droplet number to some important parameters in a cloud droplet activation parameterization by using an adjoint approach implemented in two global Chemical Transport Models (CTMs). Sensitivity is compared for the two CTMs with different aerosol treatments and emissions. This is an interesting study. The manuscript is in general well written, although there are a number of places where the text needs to be clarified and improved. I recommend the publication of this manuscript after my general and specific *comments below are addressed.*

We thank the reviewer for the positive and thoughtful review. Below are our responses to the issues raised.

This study examines the sensitivity of cloud droplet number concentration (CNDC) at surface and compares modeled CDNC with observations. However, it is known that the cloud droplets in low-level warm clouds are above surface (e.g., 700-900 hPa). The CNDC in this study is diagnosed instead of predicted. All these tend to overestimate CDNC. The impact of these assumptions on model results needs to be discussed.

CDNC, and its sensitivities, are presented for the lowest cloud-forming level (at 960 mb) and not at the surface; we apologize if this was not stated clearly.

CDNC is indeed not computed with a two-moment scheme but is still physically-based, capturing the dependency of CDNC on aerosol and other parameters. A number of *in-situ* closure studies show that the CDNC computed this way reproduces observed concentrations quite well in non-drizzling marine stratocumulus (e.g., Meskhidze et al., 2005; Fountoukis et al., 2007; Morales et al., 2011), and, non-precipitating cumulus with appropriate treatment of entrainment (Morales et al., 2011). Comparing our predictions against observational data from around the world is consistent with this view, as our results are generally in good agreement over marine regions, though are biased somewhat high over the continents. This high bias can be attributed to the lack of droplet collision/coalescence processes in the model (which would be addressed with a two-moment scheme) and entrainment in the shallow cumuli; however, to account for this correctly requires the development of an adjoint for the two-moment scheme, which is left for a future study.

Specific Comments

P12083. L6, "climate sensitivity": Climate sensitivity usually is defined as the surface temperature change due to a doubling of CO2 concentration. Do you really mean this?

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Thank you for pointing this out. We refer to the sensitivity of climate to parameters other than CO_2 concentration, (for instance aerosol concentration). The sentence has been rephrased as: “The calculation of the susceptibility of climate to a variety of model parameters is at the heart of any climate impact assessment study.”

P12083. L13, “microphysical processes”: Do you mean aerosol or cloud microphysics or both?

We mean aerosol microphysical processes. We have also changed this sentence in the manuscript accordingly.

P12083. It is worthy mentioning the work of Liu and Wang (Environ. Res. Let, 2010, doi: 10.1088/1748-9326/5/4/044010) which examined the sensitivity of indirect forcing to hygroscopicity of organic aerosols.

This is a good point. A small discussion in the introduction section of the revised paper is now included.

P12084. L19, “...through discrete model evaluation,..” This is not clear.

We have removed this part of the sentence. It now reads: “. . . sensitivity is estimated by applying a finite difference on a function, with an additional model execution per parameter investigated.”

P12087. L9. please define “the critical supersaturation of the particle”.

The critical supersaturation of the particle is the level of supersaturation at which the particle activates into a cloud droplet. This is now clarified in the text.

P12088. L17. “adjoint forcing”. What do you mean “forcing”?

The adjoint forcing is an infinitesimal perturbation of the output variable (i.e. CDNC calculated during the forward execution of the parameterization) which drives the sensitivity calculations during the reverse execution of the parameterization. This term is clarified in the revised manuscript.

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P12093. L3. "the first model level". It is better to use "the lowest model level" since some models define the first level at model top (i.e., level increases from top to bottom).

Good point. We now say "lowest cloud-forming level (at 960 mb)"

P12093. L14. Can you compare the emissions of SO2, BC and POC used in the two CTMs, especially in East Asia?

The global emissions of SO_2, BC, and POC in GMI are 73.8 Tg-S yr^{-1}, 13.5 Tg yr^{-1}, 111.2 Tg yr^{-1}, respectively. Estimates from Leibensperger et al. (2011) for GEOS-Chem are representative of the annual global emissions in this study 105 Tg S yr^{-1}, 7.3 Tg C yr^{-1}, 33 Tg C yr^{-1}.

P12096. L19. Add "of" in between "change" and "the updraft velocity"

Done.

P12097. L14. Is it "CCN" or "CN"?

It is CCN. In particular, Sotiropoulou et al. (2007) presented the sensitivity of CDNC to CCN prediction error.

P12098. L16-17. ". . .to anthropogenic and biomass burning aerosol hygroscopicity". Do you mean "to hygroscopicity of specific species" or "to bulk (volume-mean) hygroscopicity of anthropogenic and biomass burning aerosols, since anthropogenic and biomass burning aerosols have several different species.

We refer to the bulk hygroscopicity. For the GEOS-Chem simulations, anthropogenic and biomass burning aerosols participate in the same internally mixed aerosol mode, and, therefore, we calculate the sensitivity of CDNC to the bulk hygroscopicity of this mode. In the revised manuscript, the sentence has been modified to: ". . .to the bulk hygroscopicity of anthropogenic and biomass burning aerosols."

P12099. L3. "~1". what is the unit of 1?

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The sensitivities presented in this work are fully normalized by the value of the input parameter and predicted CDNC and, therefore, are unitless ($\frac{dlnN_d}{dlnI}$, where I is the input parameter considered). For consistency we now use $\frac{dlnN_d}{dlnI}$ instead of $\frac{dN_d}{dI}$ throughout the text.

References

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