Simulating the Impact of Aerosols on Tropical Deep Convection

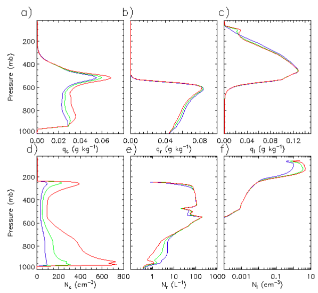
Research Highlight

Anthropogenic change of Earth's climate is one of the biggest challenges facing humankind in the 21st century. The last several decades have featured increasing awareness of the growing levels of atmospheric carbon dioxide and other greenhouse gases and their impact on climate. At the same time, other anthropogenic impacts on the climate system have been identified, including the effects of anthropogenic aerosols. A critical aspect of aerosol-cloud interaction is possible changes in cloud dynamics as the aerosols are modified, via impacts on atmospheric or surface radiative heating associated with direct and semi-direct effects or impacts on cloud microphysics through indirect effects. Coupling with the dynamics may be particularly important for deep convective clouds, where processes like latent heating and condensate loading, which are strongly influenced by cloud microphysics, determine buoyancy and therefore directly drive the convective motion field.

In this study, results from 240-member ensemble simulations of aerosol indirect effects on tropical deep convection and its thermodynamic environment were analyzed. Simulations using a two-dimensional cloud system-resolving model were run with pristine, polluted, or highly polluted aerosol conditions and large-scale forcing from a 6-day period of active monsoon conditions during the 2006 Tropical Warm Pool-International Cloud Experiment (TWP-ICE). Domain-mean surface precipitation was found to be insensitive to aerosols primarily because the large-scale forcing was prescribed and dominated the water and static energy budgets. The spread of the top-of-atmosphere (TOA) shortwave and longwave radiative fluxes among different ensemble members for the same aerosol loading was surprisingly large, exceeding 25 W m-2 even when averaged over the 6-day period. This variability was caused by random fluctuations in the strength and timing of individual deep convective events. These results illustrate the difficulty of generalizing and quantifying aerosol effects on deep convection based on single realizations in pristine or polluted conditions.

The ensemble approach demonstrated a small weakening of convection averaged over the 6-day period in the polluted simulations compared to pristine. Despite this weakening, the cloud-top heights and anvil ice mixing ratios were higher in polluted conditions. This occurred because of the larger concentrations of cloud droplets that froze, leading directly to higher ice particle concentrations, smaller ice particle sizes, and smaller fall velocities compared to simulations with pristine aerosols. Weaker convection in polluted conditions was a direct result of the changes in anvil ice characteristics and subsequent upper-tropospheric radiative heating and weaker tropospheric destabilization. Such a conclusion offers a different interpretation of recent satellite observations of tropical deep convection in pristine and polluted environments compared to the hypothesis of aerosol-induced convective invigoration. Sensitivity tests using the ensemble approach with modified microphysical parameters or domain configuration (horizontal grid length, domain size) produced results that were similar to baseline, although there were quantitative differences in estimates of aerosol impacts on TOA radiative fluxes.

Our results demonstrate the importance of feedbacks between convection and the thermodynamic environment; changes in convective dynamics or microphysics impact the environment, which in turn feeds back to the clouds and convection. Such feedbacks exert a strong constraint on quantities like surface precipitation and domain-mean updraft and downdraft mass fluxes. This systems-wide viewpoint contrasts process-level reasoning that is more applicable to an individual cloud or cloud system. We emphasize that feedbacks between the convective-scale and larger-scale dynamics were neglected in this study. This approach allowed us to simulate the impact of aerosols on clouds and convection in a framework that included realistic time-dependent forcing and feedback with the thermodynamic



Profiles of ensemble- and horizontally averaged a) cloud water mixing ratio, b) rain mixing ratio, c) ice mixing ratio, d) cloud droplet concentration, e) rain number concentration, and f) ice number concentration, Ni, for pristine (blue), polluted (green), and highly polluted. Aerosols have a large impact on the cloud water and ice mixing ratios and number concentrations, but much less impact on the cloud dynamics.

environment, but without complications arising from feedbacks with larger scale dynamics. Although we expect interactions between aerosols, microphysics, and convection to be strongly constrained by feedback with the environment as argued above, these interactions are expected to also be modulated by feedbacks with the larger scale dynamics. In future work we plan to investigate the impact of feedbacks between convection and larger scales in the context of indirect aerosol effects.

Reference(s)

Morrison H and WW Grabowski. 2011. "Cloud-system resolving model simulations of aerosol indirect effects on tropical deep convection and its thermodynamic environment." Atmospheric Chemistry and Physics, 11(20), doi:10.5194/acp-11-10503-201.

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Cloud Life Cycle, Cloud-Aerosol-Precipitation Interactions