Aerosol-mediated Changes in Deep Convective Cloud Radiative Forcing over the SGP

Research Highlight

Studies have shown that aerosols can fuel cloud vertical development and lift cloud-top heights. Cloud anvils can also expand under the influence of aerosols. Such aerosol-mediated changes in cloud parameters can alter the cloud radiative forcing (CRF), which is often referred to as aerosol indirect forcing or the aerosol indirect effect. Among the aerosol-induced changes in radiative energy described in the latest Intergovernmental Panel on Climate Change report, aerosol-mediated CRF has the largest uncertainty because of the poor understanding of the mechanisms behind it. Using observations to quantify the aerosol invigoration effect (AIV) and its impact on climate is important for climate modeling and climate prediction.

Motivated by a previous study that revealed the impact of aerosols on cloud vertical development and precipitation frequency using ground-based measurements, this study estimates the long-term AIV-induced changes in the CRF at the top of the atmosphere (TOA) and at the surface for deep convective clouds (DCC) using a combination of Geostationary Operational Environmental Satellite retrievals and ground-based observations made at the Southern Great Plains site from 2000-2011. Over this 10-year period, about 300 DCC systems were identified and further analyzed. Increases in aerosol loading were accompanied by the thickening of DCC cores and the expansion and thinning of anvils, due presumably to the AIV and the aerosol microphysical effect. Meteorological variables dictating these cloud processes were investigated. Consistent with previous findings, the AIV is most significant when the atmosphere is moist and unstable with weak wind shear. Such aerosol-mediated systematic changes in DCC core thickness and anvil size alter CRF at the TOA and at the surface.

Figure 1 summarizes DCC radiative forcing at the TOA and at the surface as a function of condensation nuclei (CN) concentration. The daily mean TOA longwave (LW) CRF increases monotonically from 113.1 Wm-2 to 127.8 Wm-2 as the mean CN concentration increases from 1000 cm-3 to 5000 cm-3. This is accompanied by a decrease in mean cloud-top temperature (CTT) from -46.0°C to -51.4°C. The slight enhancement of LW warming at the TOA is due to the reduction in CTT, leading to a decrease in outgoing thermal radiative fluxes. At the surface, the daily mean LW CRF changes from 66.7 Wm-2 to 72.7 Wm-2. The much smaller increase is consistent with the finding that cloud bases are much less sensitive to CN concentrations. The daily mean TOA shortwave (SW) CRF remains constant (~ -354 Wm-2) as the mean CN concentration increases from 1000 cm-3 to 3000 cm-3. It then sharply increases from -353.6 Wm-2 to -265.3 Wm-2 when the CN concentration increases from 3000 cm-3 to 5000 cm-3. At the surface, changes in SW CRF are similar to those at the TOA, but with smaller magnitudes. Note that the relationship between SW CRF and CN concentration is complicated because other factors are at play, such as cloud phase, cloud optical depth (COD), and cloud droplet size distribution. To further understand changes in CRF with changes in CN concentration, the frequency of cloud occurrence as a function of COD and cloud-top height (CTH) for different ranges of CN concentration is examined (Figure 2). As the CN concentration increases, clouds grow taller and spread out at the top with lower optical depths, intensifying the warming effect.

Overall, the long-term daily mean aerosol-mediated TOA and surface CRF over the SGP site due to the AIV is positive in sign, and 29.3 Wm-2 and 22.2 Wm-2 in magnitude, respectively. This net warming effect due to changes in DCC microphysics offsets the cooling resulting from the first aerosol indirect effect.

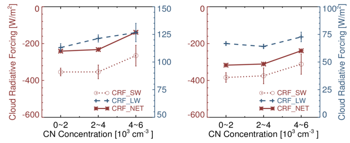

Figure 1. DCC radiative forcing at the TOA (left panel) and at the surface (right panel) as a function of CN concentration.

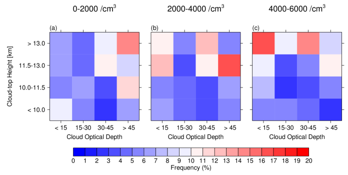

Figure 2. Cloud frequency of occurrence for three ranges of CN concentration: (a) 0-2000 cm-3, (b) 2000-4000 cm-3, and (c) 4000-6000 cm-3. Data are binned according to COD and CTH.

Reference(s)

Yan H, Z Li, J Huang, M Cribb, and J Liu. 2014. "Long-term aerosol-mediated changes in cloud radiative forcing of deep clouds at the top and bottom of the atmosphere over the Southern Great Plains." Atmospheric Chemistry and Physics, 14, doi:10.5194/acp-14-7113-2014.

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Cloud-Aerosol-Precipitation Interactions