Cloud Droplet Spectral Shape Sheds New Light on Aerosol-Cloud-Interaction Regimes

Research Highlight

Despite decades of research, aerosol indirect effects remain among the most uncertain climate forcings according to the latest Intergovernmental Panel on Climate Change report. Furthermore, climate models tend to overestimate the cooling of aerosol indirect effects and are more susceptible than observations to aerosols. Two microphysical factors have been proposed to be partially responsible for this tenacious problem. First, it is well known that for a given updraft velocity (w), the dependence of Nc on Na is nonlinear and regime dependent: Nc increases linearly with Na when Na is low in the aerosol-limited regime, but the Nc-Na relationship becomes sublinear and levels off when Na is high in the updraft-limited regime. The magnitude and importance of the aerosol indirect effect depend highly on the aerosol-cloud interaction regime.

Less understood is the second factor—dispersion effect—whereby changes in aerosol properties alter the spectral shape of the cloud droplet size distribution in addition to droplet number concentration (dispersion effect). Contrasting results have been reported in the literature. Some publications show that an increase of aerosol loading leads to an increase of relative dispersion: thus, dispersion effect is warming and negates the cooling from the aerosol-induced increase of droplet concentration (number effect). Others, however, show that an increase of aerosol loading leads to a decrease of relative dispersion: thus, dispersion effect is cooling and enhances the cooling from the number effect.

The two factors have been traditionally studied separately. By addressing the two plausible factors together, researchers at Brookhaven National Laboratory and Stony Brook University show that combined consideration of droplet concentration and relative dispersion better characterizes the regime dependence of aerosol-cloud interactions than considering droplet concentration alone. Given updraft velocity, relative dispersion first increases with increasing aerosol number concentration in the aerosol-limited regime, then peaks in the transitional regime, and finally decreases with further increasing aerosol concentration in the updraft-limited regime.

This new finding reconciles contrasting observations in literature, and highlights the compensating role of dispersion effect. Dispersion effect negates the number effect when the latter is strong in the aerosol-limited regime, but enhances the number effect when the latter is weak in the updraft-limited regime. Thus it is expected that consideration of dispersion effect will likely reduce the uncertainty in modeled aerosol indirect effects. The non-monotonic change of relative dispersion with aerosol concentration further allows the researchers to derive a relationship between the transitional aerosol concentration and updraft velocity that separates the aerosol- and updraft-limited regimes.

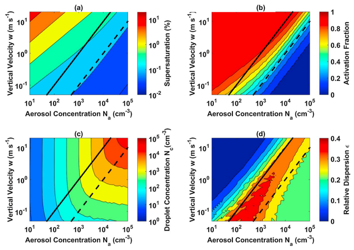

Figure 1. Joint dependence on aerosol number concentration (Na) and vertical velocity (w) of (a) maximum supersaturation, (b) activation fraction, (c) cloud droplet number concentration (Nc), and (d) cloud droplet relative dispersion #. The solid and dashed black lines denote the expressions obtained by Reutter et al. [2009] to distinguish between the different regimes: solid black line: w= 10 ^-3 Na; dashed black line: w = 10^-4 Na.

Reference(s)

Chen J, Y Liu, M Zhang, and Y Peng. 2016. "New understanding and quantification of the regime dependence of aerosol-cloud interaction for studying aerosol indirect effects." Geophysical Research Letters, 43(4), doi:10.1002/2016GL067683.

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Working Group(s)

Cloud-Aerosol-Precipitation Interactions