Mutual Information Analysis of Aerosol-cloud interactions by Meteorological State over Oklahoma, U.S.

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The aerosol indirect effect on cloud brightness has previously been measured over the Atmospheric Radiation Measurement (ARM) central continental U.S. Southern Great Plains (SGP) site in Lamont, Oklahoma for a handful of specially-selected cases. But an analysis of a 14-year dataset at the same location showed that the correlation between aerosol concentration and cloud radiative effect is negative as often as it is positive. Does co-variability with meteorological state sometimes mask the indirect effect of increasing aerosol concentration? Or instead, do feedbacks act to reduce or reverse an expected increase in cloud brightness due to increasing aerosol concentration?

To answer this question we use a scene albedo vs. cloud fraction framework to illustrate the co-variability between cloud brightness, cloud amount, diurnal variability, and variability due to meteorological state. We use a 14-year dataset as well as observations and Large Eddy Simulations (LES) from the current LES ARM Symbiotic Simulation and Observation (LASSO) campaign. We perform our own simulations with LASSO-processed initialization and ad-hoc perturbations of aerosol concentration, as well as adding measurements of natural aerosol concentration variability from SGP to perform high-resolution simulations of 18 different days with shallow cumulus of similar cloud fractions. A simulation keeping all else constant but doubling aerosol concentration shows the variability in the cloud fraction to albedo relationship illustrating the aerosol indirect effect (Figure 1). We have also performed and analyzed simulations based on days with similar doubling of aerosol concentration according to observations, but also including the observed difference in meteorological state between such days.

We calculate the information content, or Shannon entropy, of relevant variables, and then compare their mutual information. This is similar to an analysis of covariance, but has the advantage of not needing to assume a functional form (linear or otherwise) for any relationship. We then calculate the conditional mutual information to show which variables (and meteorological state) lead to a loss in mutual information between aerosol loading and cloud radiative effect. The conditional mutual information analysis allows us to quantify how much each variable leads to a loss of detectability of the aerosol indirect effect. Using multiple LES, a long-term observational dataset, and the mutual information analysis allows us to tease apart the interplay of convective dynamics, micro-physics, and meteorological state to quantify the detectability of cloud-aerosol interactions in shallow cumulus at SGP.

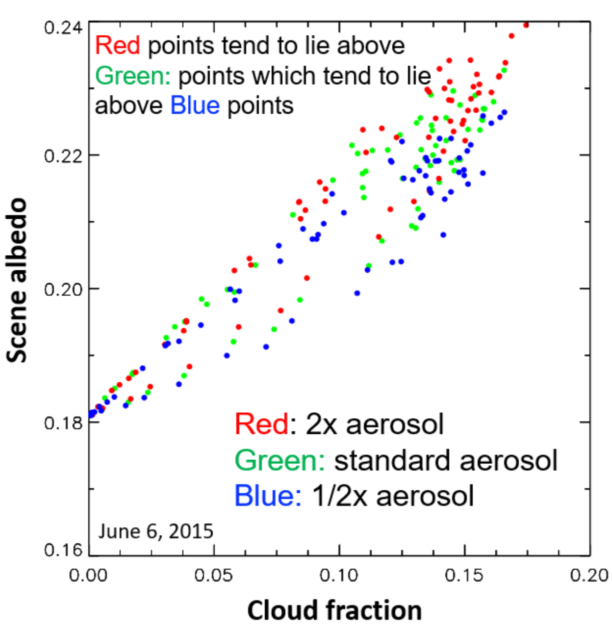

Figure 1. The scene albedo vs. cloud fraction for a simulation of the evolution of shallow cumulus over Lamont, Oklahoma on June 6th, 2015. Keeping all else constant, we perturb the aerosol concentration to illustrate the similar magnitude of brightening due to the aerosol indirect effect of a large aerosol concentration perturbation relative to the variablity of scene albedo vs. cloud fraction over the course of the diurnal cycle.