Assessing Marine Cloud Brightening as a Mechanism for Reducing Climate Risk

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Background/Objectives. Climate forcing by aerosol-cloud interactions is estimated to be between about 10% and 40% that of anthropogenic greenhouse gases (GHGs) and of opposite sign, providing an important but highly uncertain offset to GHG climate warming. While the magnitude of present-day climate forcing through aerosol-cloud interactions is highly uncertain, theoretical and observational studies indicate that aerosols can significantly increase albedo via aerosol-cloud interactions. This has led to the proposal that marine cloud brightening (MCB), i.e., the targeted addition of an optimized size and concentration of aerosols to specific low marine clouds, could be used to reduce climate warming and associated impacts. MCB would involve the injection of aerosol derived from seawater into the marine boundary layer in regions of susceptible clouds, increasing the number of droplets in the cloud; absent any other changes, this would increase cloud reflectivity. However, observations and high-resolution modeling studies have shown that clouds can respond to the increase in droplet concentrations in ways that can either reduce or increase cloud liquid water amount and cloud lifetime. Critical issues regarding the potential *efficacy* of MCB for cooling climate are a) quantifying the full range of responses of clouds to the addition of the injected sea salt under different meteorological and background aerosol conditions, and b) quantifying the frequency of occurrence of these different meteorological and aerosol regimes, and thus the potential for cloud brightening. This information is, in turn, critical to being able to quantify the potential *impacts* of different MCB implementation strategies under different climate scenarios.

Approach/Activities. Although climate modeling has demonstrated the potential for significant global cooling from MCB, doubts remain about the ability of large-scale models to accurately represent the subgrid processes and their interactions that are involved in producing an albedo response to aerosol injections. As such, satellite observations and process modeling (large eddy simulations and mixed layer models) are being used as the primary tool for quantifying cloud responses to aerosol perturbations. This presentation will, first, discuss what analyses to date of “ship tracks” (a proxy for MCB), process modeling studies and satellite-based observations in regions of low marine clouds indicate about the potential for intentionally brightening these clouds. Second, it will describe how joint analysis of aerosol-cloud perturbation field studies and well-coordinated modeling studies could be used to provide an essential test of the modeled cloud responses to aerosol injection. Finally, it will briefly present approaches to using global models to quantify the climate response to different MCB implementations, and therefore how MCB might alter climate risk, and how these studies can iteratively be made more realistic using the results of the high-resolution modeling and observational studies.

Results/Lessons Learned. Studies to date have revealed the critical role of cloud macrophysical responses to aerosol injection in determining whether and how much brightening might be achieved through MCB. A key process that determines cloud responses to aerosol is precipitation suppression, which is frequently observed in ship tracks. Although this can increase cloud lifetime by reducing surface moisture loss, the resulting cloud invigoration can drive increased entrainment drying. Entrainment drying also results from reduced cloud droplet sedimentation and more efficient evaporation of smaller droplets, although the relative contribution of each is currently unclear. Critically, adjustments to cloud liquid water can occur over relatively long timescales (~10-20 hours), and therefore both observing and modeling cloud responses over multiple days. Capturing this in large eddy simulations (LES) requires doing runs with prognostic aerosol and over large domains to allow realistic plume spreading, to effectively represent the effects of precipitation, and to capture the natural mesoscale organization present in most marine stratocumulus cloud systems. Given the costly nature of these runs, we present a strategy where principal component analysis (PCA) of reanalysis and satellite cloud observations is used to identify a few modes of coupled synoptic meteorological and cloud variability. This allows for using a smaller set of simulations and observational cases to span the true meteorological and aerosol phase space in a given region. This will permit a more faithful statistical comparison between satellite observations and LES, and provides guidance on how emulators might be used to generate improve parameterizations for global-scale models of the full range of cloud responses with different implementations of MCB.