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An emulator approach to adjustments and buffering in stratocumulus

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The radiative forcing due to aerosol-cloud interactions (ACI) remains the most uncertain anthropogenic forcing of the climate system. Its uncertainty is rooted in our insufficient understanding and representation of subgrid-scale processes, in particular convection, entrainment, and precipitation formation in shallow clouds. When the cloud system is perturbed by aerosol, the various processes internal to the system may adjust in a way that modifies the overall impact of the perturbation. These so-called adjustments have been hypothesized to weaken, or buffer, the response that would have occurred in the absence of adjustments.

We synthesize a simple picture of the radiative effect of ACI in stratocumulus (Sc) from the detailed process-representation of 159 large-eddy simulations (LES). These simulations of nocturnal Sc vary in their initial conditions for temperature, moisture, boundary layer height and aerosol concentration. Our synthesis is based on Gaussian process emulation, a technique related to machine learning. While emulators have so far been used to investigate the effect of model parameters, we apply emulation to evolving cloud field variables. We thus emulate process rates that govern the temporal evolution of liquid water path (LWP) and cloud droplet number concentration N. These process-rate emulators allow us to study Sc as a low-dimensional dynamical system in the spirit of Lilly's mixed-layer model. In contrast to the mixed-layer model, our dynamical system represents the full complexity of an LES model. It constitutes a simplified but not idealized representation of the LES, from which it emerges.

Our analysis highlights that ACI cannot be discussed without considering Sc cloud fields as systems that evolve in time. The systems evolve to two steady states: one a non-drizzling, high cloud cover and high N state, and the other a low cloud cover and low N, drizzling state. Both feature domain mean LWPs of about 60 g/m2. We distinguish between the natural evolution to these steady states, and adjustments that would occur if the system were to be perturbed. We show that adjustments are unlikely to be detectable when the natural evolution is fast. The detectability of adjustments increases as a system approaches its steady state. At the same time, adjustments in the steady state are small because steady-state LWPs are largely independent of the aerosol condition. Overall, our analysis points to a small contribution of adjustments in general and buffering mechanisms in particular to the radiative effect of ACI.