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Separating physical impacts from natural variability using piggybacking (master-slave) technique

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In a chaotic system, like moist convection, it is difficult to separate the impact of a physical process from effects of natural variability. This is because modifying even a small element of the system physics typically leads to a different system evolution. For natural clouds, a classical example is the inability to separate effects of convective cloud seeding from highly unpredictable convective cloud evolution. In a nutshell, it is impossible to tell how the seeded cloud would evolve without seeding, or how the unseeded cloud would change when seeded. One possibility is to study many clouds randomly either seeded or not seeded, and to apply statistical techniques to assess the impact of seeding. For the modeling, the ensemble approach, conceptually similar to observing many seeded and unseeded clouds, can be used. However, there is a simpler and less computationally demanding methodology referred to as the piggybacking or the master-slave approach. The idea is to use two sets of thermodynamic variables (the temperature, water vapor, and all aerosol, cloud, and precipitation variables) in a single cloud simulation. The two sets differ in a specific element of the physics, such as aerosol properties, microphysics parameterization, large-scale forcing, environmental profiles, etc. One thermodynamic set is coupled to the dynamics and drives the simulation, and the other set piggybacks the simulated flow, that is, thermodynamic variables are carried by the simulated flow but they do not affect it. By switching the sets (i.e. the set driving the simulation becomes the piggybacking one, and vice versa), the impact on the cloud dynamics can be evaluated. For the cloud seeding example, one thermodynamic variable set includes effects of seeding and the second one does not. This presentation will provide details of the method, and it will discuss results of its application to such problems as the postulated deep convection invigoration in polluted environments, the impact of changes in environmental profiles (e.g., due to climate change) on convective dynamics, and the role of cloud-layer heterogeneities on shallow convective cloud field development. Prospects for applying piggybacking technique to other areas of atmospheric simulation (e.g., weather prediction or geoengineering) will be presented.