Exploring Parametric and Structural Uncertainties of Bulk and Superdroplet Ice Microphysical Schemes in Large Eddy Simulations

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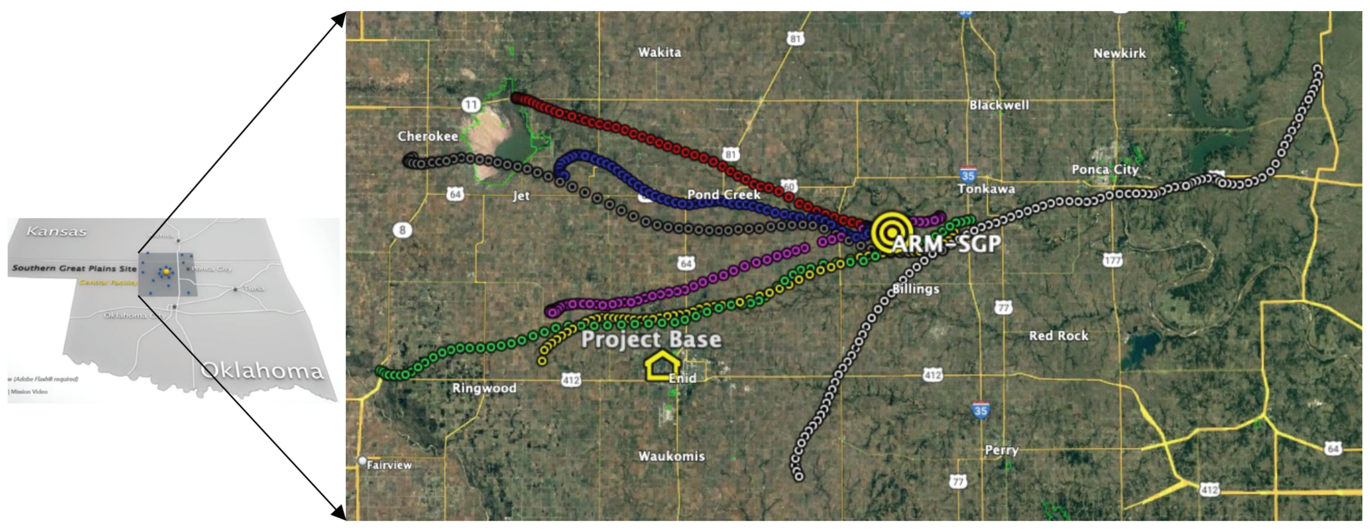
Background

Clouds are one of the largest sources of uncertainty in weather and climate models. Ice clouds (e.g., cirrus) are especially difficult to model because the underlying physics of ice processes are often represented in *ad hoc* fashion, and it is not always clear how to best choose parameters. Lagrangian superdroplet methods provide the most explicit representation of microphysics, however they are prohibitively expensive to run within climate models. One idea is to tune the parameters of cheaper, bulk microphysics using superdroplet simulations as proxies for ground truth. The original intent of this work was to tune parameters for the bulk vapor deposition scheme with equivalent superdroplet simulations. However, we found that even within the same dynamical framework (CM1), bulk and Lagrangian representations of ice microphysics result in vastly different simulated cirrus. This indicates significant structural differences between the two microphysics frameworks, highlighting the crucial need for observations to guide the improvements of both bulk and Lagrangian microphysics.

Example of typical cirrus clouds. Cirrus clouds are thin, high-altitude (>6km) ice clouds that often have a feathery, wispy appearance.

Simulation details

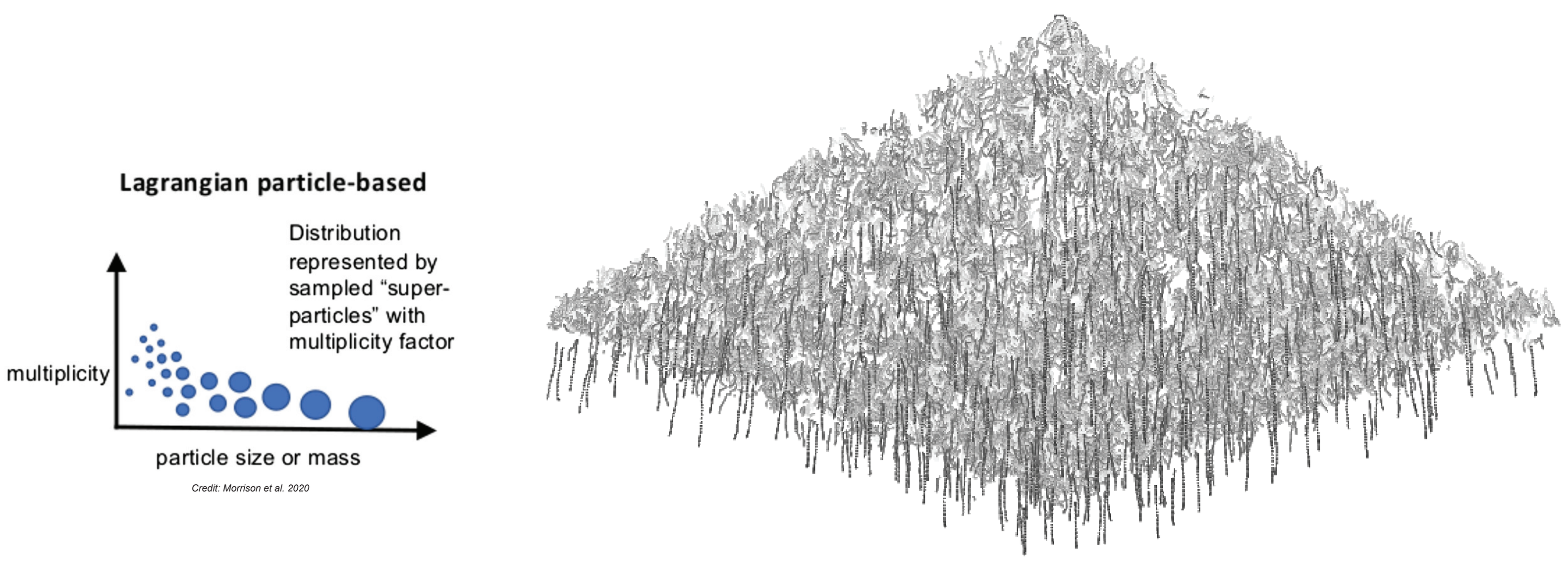


Cirrus LES simulations of the ICEBall field campaign were conducted using NCAR's Cloud Model 1 (CM1). The model was run at 50 m resolution, with a domain size of 12.8 km (W) x 12.8 km (L) x 14 km (H).

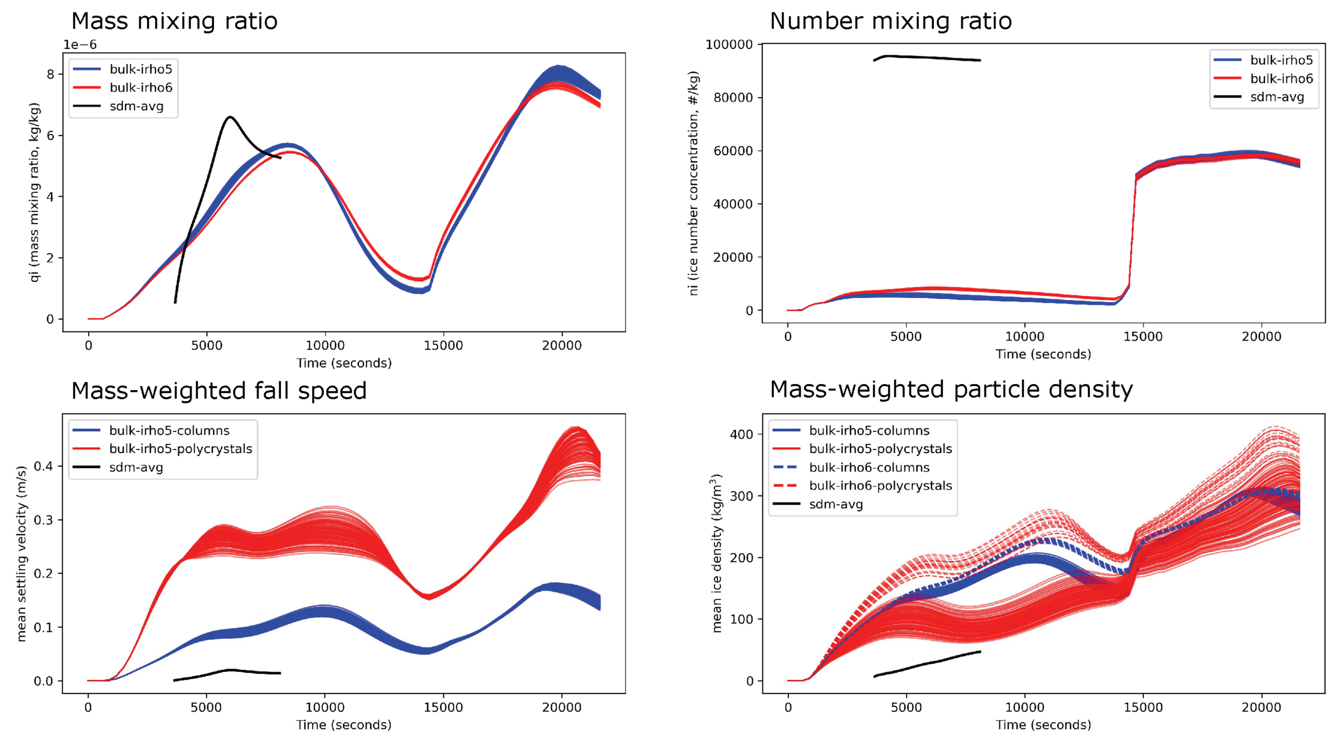
Left: Schematic and map of the ICEBall field campaign area located in Billings, Oklahoma. (Harrington & Magee)

Bottom left: Visualization from a bulk simulation. A 100-member ensemble of bulk LES simulations was conducted with two perturbed parameters for the vapor depositional growth scheme.

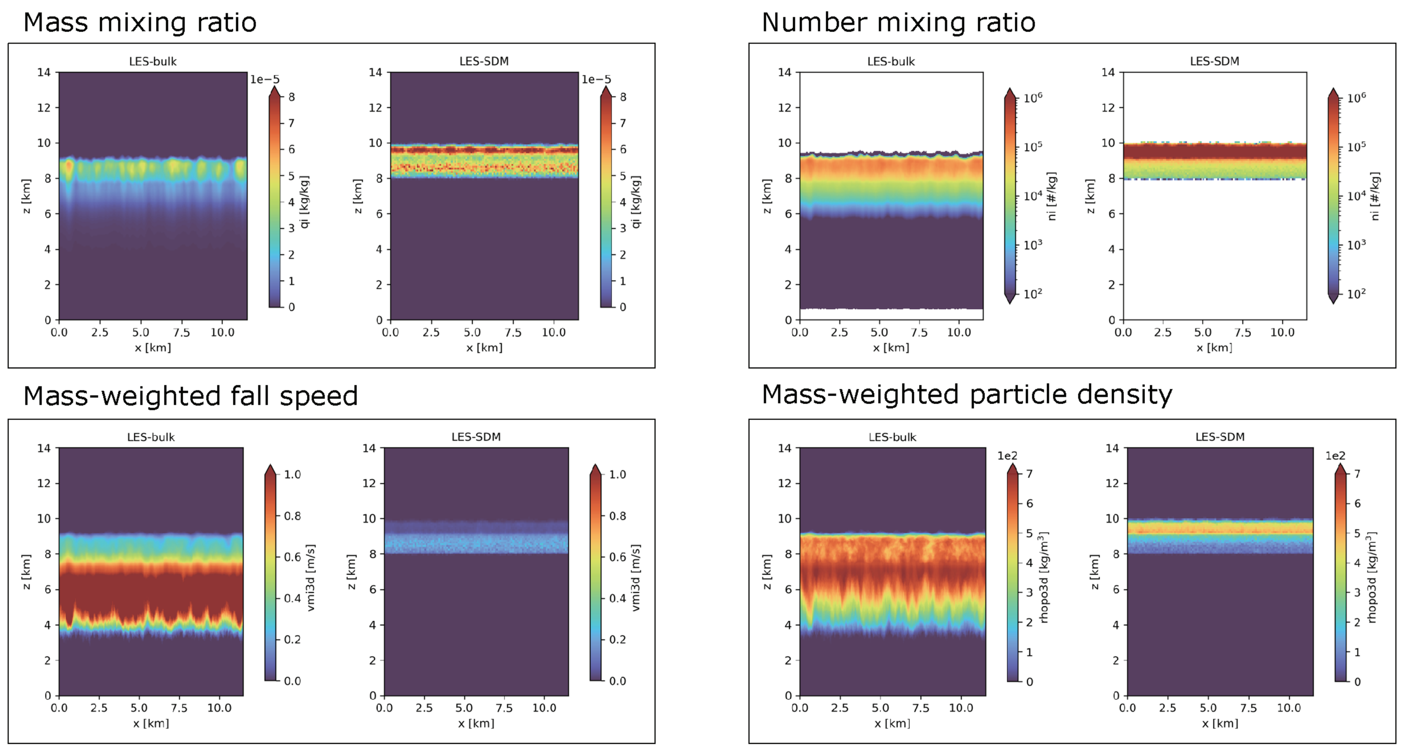
Bottom right: Visualization from an equivalent Lagrangian superdroplet simulation. A subset of 10,000 trajectories is shown for illustrative purposes. (Chandrakar et al. 2024)



Results: bulk vs. Lagrangian

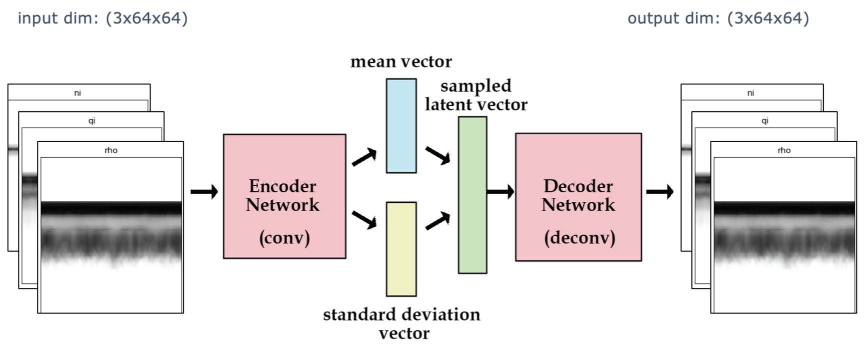


Comparison showing the time series of domain-averaged outputs of bulk (red & blue) and Lagrangian (black) runs.



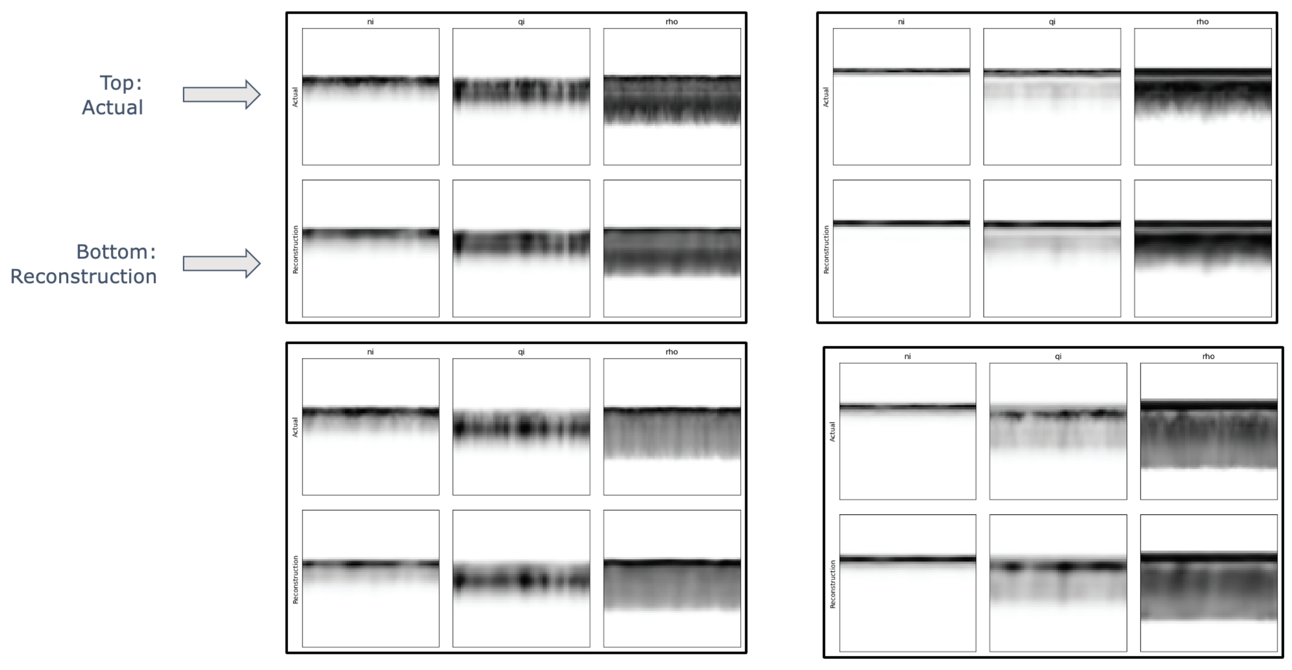
Comparison showing the vertical cross-sectional average for various outputs at a single timestep. In each panel, bulk is shown on the left and Lagrangian is on the right.

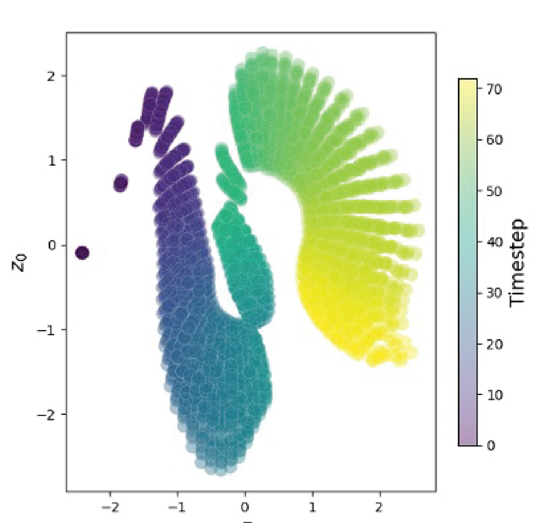
Can we utilize latent space representations?



Left: A variational auto-encoder (VAE) was used to find latent representations of the mass mixing ratio, number mixing ratio, and mass-weighted crystal density 2-D fields. Output from the 100 member bulk ensemble was used to train the VAE, resulting in a training sample size of N=7,300 (i.e., 73 timesteps x 100 members).

Right: Four examples showing the reconstructed 2-D fields (bottom) vs. the true 2-D fields (top) from the training dataset. Although the reconstructed fields are slightly blurred, they capture the most important features of the 2-D cross-section for all three channels.





Left: The 2-D fields represented in the latent space with only two latent variables (z1 and z2). Each point on the scatter plot represents a single, 3-channel cross-sectional snapshot of the bulk simulation. The point colors correpond to the timestep of the simulation. The point spread at each timestep is representative of the parametric uncertainty. This relatively smoothly varying manifold suggests that the most important spatial patterns of three microphysical state variables can be adequately represented with just two variables.

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