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Physical processes in present and future large-scale models

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Summary

The representation of cloud microphysics in numerical weather prediction models - Jason Milbrandt

Clouds and precipitation play a variety of roles in atmospheric models and their representation serves three main functions: to provide cloud optical properties to the radiative transfer scheme; to feed back to the model dynamics through latent heating/cooling during phase changes; and to provide rates and types of precipitation reaching the surface. Depending on the spatial and temporal resolution of the model (as well as the application), different degrees of complexity in the representation of clouds and cloud microphysical processes are appropriate. With continually increasing computational power, operational numerical weather prediction (NWP) models are quickly approaching the “cloud resolving” scale where the horizontal (and vertical) model resolution is considered to be sufficiently high that clouds of meteorological significance may be considered to be resolved. At this point, it is appropriate to parameterize clouds using a grid-scale condensation scheme, i.e. a bulk microphysics scheme (BMS).

Traditionally, BMSs partition hydrometeors into representative categories, where the bulk physical properties (e.g. density, terminal fall speed) are prescribed and are considered to be a type of average or representative value for the particles in that category (e.g. rain, hail, etc.). The particle size distribution for each category is described by an analytic function whose evolution is predicted through changes to one or more physical quantities (e.g. total mass) due to parameterized microphysical processes. Over the last few decades, the complexity of BMSs has increased considerably. More hydrometeor categories are used and more detail has been added to the calculation of the process rates, all in an attempt to increase to range of microphysical processes that are represented and the overall applicability of the schemes. Modern BMSs now include up to three prognostic “moments” per category, up to seven distinct hydrometeor categories, and several dozens of parameterized microphysical processes.

In the last 10 years or so there has been a paradigm shift in the modeling community in the way ice-phase hydrometeors are represented. While historically advances in bulk schemes typically involved the addition of more categories, researchers are now putting more attention on adding predictive information to the existing categories. As part of this shift, a fundamentally new approach has been recently proposed by Morrison and Milbrandt (2015) and a new microphysics scheme has been developed, referred to as the Predicted Particle Properties (P3) scheme. In P3, ice-phase hydrometeor properties are predicted and evolve locally in time and space by prognosing four independent mixing ratio quantities. From these variables, important physical properties that describe the ice hydrometeors at a given point in time and space can be derived. This allows the full range of ice particle types to be represented by a single “free” ice-phase category, which is both conceptually better and computationally cheaper than traditional, multi-category schemes.

As km-scale NWP modeling systems are becoming commonplace in weather centres around the world, and as global models are rapidly approaching near cloud-resolving scales, microphysics schemes in operational models are becoming a crucial component of the set of physical parameterizations. Despite the many advances, cloud microphysics remains a key uncertainty in models and improved observations, theory, and parameterizations will continue to be important for improved weather prediction.

References

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