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Toward unification of multiscale modeling of the atmosphere (Vilhelm Bjerknes Medal Lecture)

Akio Arakawa
Department of Atmospheric and Oceanic Sciences, University of California, Los Angels, California, USA

Vilhelm Bjerknes pointed out that a necessary condition for the rational solution of forecasting problems is a sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another. Numerical modeling of the atmosphere has been and still is a struggle for establishing such laws. This is especially true for modeling multiscale atmospheric processes. As far as representation of deep clouds is concerned, we have two types of model physics: one highly parameterizes cloud systems as in GCMs and the other explicitly simulates individual clouds as in cloud-resolving models (CRMs). Because a variety of processes mutually interact within a cloud system, parameterization of the net effect of a cloud-system is more than taking a statistical average of the local cloud effects. Ideally, these two types of model physics should be unified so that continuous transition of model physics from on type to the other takes place as the resolution changes. Unfortunately, such a unified formulation of model physics does not exist at present.

Unification of model physics in the above sense is an extremely challenging task. It requires a cloud-system model, which must be reasonably general but simple enough to be used as a framework for a parameterization. In addition, the closure assumption must be generalized far beyond those typically used in the current cumulus parameterization schemes. We will discuss some of these problems at the meeting.

For practical purposes of NWP and climate simulations, however, we should also consider another route: development of a numerical model that has cloud-resolving resolution, but not necessarily everywhere. Atmospheric modeling is not alone in facing this kind of problem. Heterogeneous Multiscale Modeling (HMM, E. et al. 2007), for example, which is a new approach in applied mathematics to solve multi-physics problems, has an objective similar to ours. In HMM, the ojective is achieved by applying the microscopic model only locally to gain efficiency, but only the gross features of its solutions is used in the macroscopic model.

"Super-parameterization" (Grabowski 2001, Khairoutdinov and Randall 2001), which is now called the "multi-scale modeling framework (MMF)", further takes advantage of the fact that 2D CRMs are reasonably successful in simulating the thermodynamic effects of deep clouds, replacing the cloud parameterization of a GCM by a 2D cloud-resolving model (CRM) embedded in each GCM grid box. While this prototype MMF can significantly improve climate simulations (e.g., Khairoutdinov and Randall 2005), it has important limitations arising from the two-dimensionality and periodic boundary conditions of the embedded CRMs. The Quasi-3D (Q3D) MMF being developed by Jung and Arakawa is an attempt to overcome these limitations without necessarily using a fully three-dimensional CRM. This is accomplished by using a "gappy" grid, which allows a partial representation of 3D processes. The Q3D MMF can be made to converge to a fully 3D global CRM as the GCM's resolution is refined. Consequently, the horizontal resolution of the GCM can be freely chosen depending on the objective. The Q3D MMF is the only known GCM-like system that has this property. An outline of the Q3D algorithm and highlights of preiminary results will be presented.