4.2.2 Session on cumulus parameterization

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Regarding the cumulus parameterization issues, ten major issues were raised that were suggested to be critical unknowns requiring immediate attention:

- Should convection be handled explicitly, implicitly, or both ways in models with grid meshes of 2-20 km? *It is essential to acquire a data base adequate for verification of cumulus parameterization assumptions and for development of new approaches.* This will require very high temporal resolution data over multiple scales to analyze complex interactions between clouds and the mass field. It will also require in-situ measurements of thermodynamic properties and hydrometeors.

- *What closure assumptions are valid when the model grid scale is 50 km or less?* Better means of comparing parameterizations and their component parts and assumptions need to be developed. Superficially, it would appear that cumulus parameterizations should just be black box subroutines that could be installed and tested against each other in any number of models. In practice, this doesn't work. Existing parameterizations tend to interface with many parts of their host models at several stages of the simulation. Some are greatly influenced by the initialization scheme, some are highly sensitive to vertical resolution or other physical packages in the model. Further, the schemes are complex, and it is extremely difficult to evaluate why one scheme behaves differently from another in a model run. One scheme might have a trigger function that is slightly better than another's in one particular situation, thereby producing a much better forecast, even though the losing scheme may contain a much more realistic closure or cloud model. Rather than direct tests between existing parameterizations, what is needed is to isolate the major assumptions used in each scheme and test these assumptions within carefully controlled experiments in which all other components of the scheme are similar.

- *There is a need for further research on the fundamental links between convection and the mesoscale circulations within which most deep convection occurs.* We need to find out how individual clouds interact and exchange mass and hydrometeors with their immediate surroundings. The sensitivity of simulations to different rates of net diabatic heat release and to its vertical distribution needs to be documented. Effects of the moisture field on convection and vice-versa need to be better understood. Further research is needed to develop cumulus parameterization approaches that predict convection in terms of the physical processes that directly cause clouds to form.

- Both shallow and deep convective clouds should be predicted with the same scheme, using similar physical assumptions.

- Efforts should be made to integrate implicit and explicit cloud parameterizations, as well as with radiation, turbulence and boundary layer schemes.

- *Momentum transport processes need to be accounted for.* Simple momentum mixing schemes (so-called cumulus friction) are not sufficient to account for the total momentum flux that occurs in an MCS. Development of momentum-exchange parameterization techniques is badly needed, particularly for climate models and other coarse-grid models.

- *The importance and effects of slantwise convection in MCS studies should be estimated.* Slantwise convection is important and often occurs in regimes where upright convection is less prevalent. In models with relatively fine grid meshes it may be possible to resolve these phenomena explicitly, though this would require high vertical resolution. Without sufficient resolution the model will tend to alias the slantwise convection to whatever shape it can resolve and may disassociate heat and momentum transports in a physically incorrect fashion. Further research is required in this area.

- *The most critical process that needs to be determined to improve cumulus parameterizations is the rapid interaction between the clouds and the mass field on meso-beta through synoptic scales.* Since the temperature perturbations associated with even the most intense deep convection are extremely small except at cloud top and in the boundary layer, the best way to infer these interactions is by observing the divergent component of the winds. While a dense large-scale rawinsonde network helps document the evolution of the wind field, temporal resolution is always insufficient to fully document rapid evolution of the divergent flow. It should be possible to use wind profilers to interpolate in time between rawinsonde sampling times to diagnose the interactions between convection and the mass field on large scales to a much greater degree than has been done previously. Specific modes of atmospheric response to convection can be documented, as well as changes in the large- scale divergence that precede changes in convection.

- *It is also important to document the detailed structure of the atmosphere on very small scales.* Despite a great deal of research on convection over the last several decades, there is still a considerable uncertainty about how convective updrafts interact with their immediate surroundings. Deep convection tends to be embedded within meso-beta-scale circulations that are often saturated and contain hydrometeors. *High temporal and spatial resolution measurements of the three- dimensional atmospheric winds on the scale of 2-20 km need to be obtained.* Doppler radar appears to be a logical system with which to make such measurements. These need to be augmented with in-situ measurements of hydrometeors and thermodynamic parameters from aircraft, coupled with a high-resolution surface network to determine boundary layer structure and rainfall patterns. Observations of convective draft structure need to be determined from a combination of in-situ and airborne Doppler radar observations.

In summary, convection is much more of a multi-scale phenomenon than is commonly realized; experiments that have focused only on the structure of individual clouds or MCSs have not been able to resolve the nature of the processes that cause convection or to document the complete effects of convection upon larger scales. There have been a number of valuable field experiments during the past few decades that have documented many features of deep convection and MCS structure. However, none of these experiments have had adequate time and space resolution of the surrounding regions, up to the synoptic scale, to allow accurate determination of the interactions between convective systems and the large-scale flow. Cumulus parameterization schemes currently assume various types of equilibrium between the convection and the grid- scale flow that are clearly ill-posed on the scales of mesoscale model grids. It is crucial that a better set of observations be obtained to design better parameterization approaches and to allow proper verification of parameterization assumptions.