at the mesoscale by convection, in particular the transport from the convective to the stratiform region is important during the early and mature phases of such systems.

Greg Tripoli reported on some of his modeling studies showing scale-interactive processes both within a convective weather system and between the system and larger scales. Tripoli then presented what he found to be the processes causing spiral rain bands in a tropical cyclone: these include the complex scale interactions between the cyclone circulation, deep gravity-inertia waves in the cirrus outflow, and density currents driven largely by ice microphysical processes. He then showed the processes modeled to form gravity-inertia waves within a strongly baroclinic weather system. The processes were depicted in part through three-dimensional animation using VIS5D.

3.5 Parameterization of sub-grid scale convection

William Frank: Overview of the cumulus parameterization problem

John Molinari:	*Interactions between explicit and implicit processes in mesoscale models*
Jack Kain:	*Effects of model grid size on the cumulus parameterization problem*
Mitch Moncrieff:	*Parameterizing convective effects on momentum fields in mesoscale models*
Mohan Karyampudi:	*Differences between slantwise and vertical cumulus parameterization*
Georg Grell:	*Experiments with different closure hypotheses*
William Frank:	*Coupling cumulus parameterizations to boundary layer, stable cloud, and radiation schemes*

Rather than give the details of each of the talks presented in this session, a summary of the issues will be given here. The discussion first briefly overviews the cumulus parameterization problem. More complete reviews of this topic already appear in the literature (e.g., Frank and Cohen 1987; Molinari and Dudek 1992). Current approaches are next discussed. Third, the strengths and weaknesses of existing parameterizations are presented. Recommendations appear in the workshop summaries.

1) Overview of the parameterization problem

Cumulus convection and mesoscale convective systems (MCSs) have major effects upon the mass, moisture and momentum fields. However, in most numerical models some or all of these phenomena are subgrid-scale. Hence, their effects on the resolvable-scale circulation must be parameterized. It is necessary to parameterize the combined effects of cumulus convection and MCSs in models with grid sizes $\Delta x > 100$ km, whereas in mesoscale models, which typically use grids of 10-50 km, the mesoscale circulations can be resolved explicitly, but the convection still must be parameterized. With very fine grid meshes ($\Delta x<2$ km), one can simulate convective drafts explicitly, and cumulus parameterization is usually not used (though there are still many subgrid-scale processes that need to be parameterized).

Ideally, a cumulus parameterization scheme would predict all significant convective processes with perfect accuracy in terms of the existing grid-scale variables. In practice it is not possible to represent all subgrid scales, so parameterizations must be designed to optimize predictions of the most important physical processes. *The relative importance of convective heat and moisture processes is scale-dependent.* For example, in climate models it is crucial that the parameterization predict the proper evolution of the moisture field due to the strong long-term effects of water vapor and clouds on the radiation budget. On smaller scales it becomes extremely important to predict the location and rate of convective latent heat release, as the evolution of mesoscale systems is highly dependent upon the diabatic heating.

Direct effects of convection on the momentum fields appear to be very important over a range of scales (Moncrieff 1992). These effects are more complex than simple estimates of momentum transport by cloud parcels (cumulus friction). Much of the momentum exchange occurs due to meso-beta-scale circulations. While these circulations may be explicitly resolved in higher resolution mesoscale models, their effects must be parameterized in climate models or other coarse resolution models.

Cumulus parameterizations can be thought of as performing three individual tasks: (1) they must diagnose the presence of convection and activate the scheme (the so-called trigger function); (2) they must determine the properties of the convection and its effects on the grid-scale fields (a cloud model of some type is usually, though not always, used); and (3) they must estimate the amount of convection that occurs during the current time step (the closure). Not all schemes separate these functions, and if they are difficult to isolate, it is not easy to evaluate the effects of individual assumptions on the performance of the scheme as a whole.

2) Current Approaches

Cumulus parameterization is preferred to explicit resolution of moist processes as a method of simulating the effects of convection at scales above ~20 km. However, in models with grid meshes small enough to resolve moist mesoscale circulations (roughly 20-50 km), it is desirable for a model to use both an explicit moisture scheme (to simulate the mesoscale circulations) and a cumulus parameterization scheme simultaneously, within the same grid column. The two schemes should interact realistically, including exchange of hydrometeors and air between clouds and the grid-scale circulation, an approach termed "hybrid parameterization" by Molinari and Dudek (1992). Most current cumulus parameterizations include assumptions of interactions between the cloud and the grid scale that become invalid when the convective clouds are not restricted to areas covering only a small fraction of the grid column. While there may be ways to reformulate the parameterizations (perhaps involving introduction of more parameters), *most current cumulus parameterizations do not appear to be valid when applied on grid meshes of less than about 20 km.* For grid meshes smaller than about 2 km, explicit moist processes appear to simulate the effects of convection better than do parameterizations. *However, when the grid mesh becomes greater than about 2 km, explicit moisture schemes tend to produce unrealistically large vertical drafts.* This raises the question of what to do when the optimum grid mesh for resolution of the phenomenon being studied lies between 2 - 20 km. Research is continuing to determine the best methods of simulating convection on this scale.

Most currently used cumulus parameterizations were designed for use in models with relatively coarse grids in which synoptic or larger scale circulations are simulated. In such models, there are sufficient temporal and spatial scale differences between the convection and the grid scale circulation that the convection can be assumed to respond to the evolving grid-scale circulation to maintain some sort of equilibrium. The grid-scale circulation is assumed to provide the forcing, and the convection responds either in a single time step or over a specified time interval to approach the hypothesized equilibrium state. Examples of convective equilibrium assumptions commonly used as closures in current schemes are:

- Moist convective adjustment assumes that convection forces the atmospheric lapse rates of temperature and moisture towards empirical profiles (Manabe et. al. 1969; Betts 1986).
- Rainfall is an empirical fraction of computed column-integrated moisture convergence (Kuo 1974).
- Clouds maintain the existing cloud-ensemble parcel instability, or quasi-equilibrium (Arakawa and Schubert 1974).
- Convective stabilization is sufficient to remove all or a fraction of the parcel instability within a specified advective time interval (Kain and Fritsch 1990).

Of these approaches, only the latter was designed for use on grid meshes as small as those typically used in mesoscale models (20-50 km), though all of the others have been tried on such scales.

3) Strengths and Weaknesses of Existing Parameterizations

There is a growing consensus within the parameterization community that moisture balance closures are too far removed from the physical processes that control convection to be used as the basis of a cumulus parameterization. Lapse rate adjustment schemes are simple, inexpensive and fairly stable and can be good choices for some modelling applications, but they are too empirical, and again too far removed from the processes that initiate and control convection, to be desirable for use in models with smaller grid meshes. The current trend is towards parameterizations in which the triggers and closures use concepts of parcel instability in some manner.

A major problem of parameterizing convection in models with grid spacings on the order of about 50 km or less is that the grid-scale circulation varies on approximately the same time scales as does the convection. Individual cumulus clouds typically have lifetimes of 15 - 60 minutes, sometimes longer. Since the individual grid columns are much smaller than the radius of deformation (L_R) in most instances, the heating released in the column causes a rapid adjustment of the mass field, dispersing the heating to very large scales (on the order of L_R). Unlike larger-scale models, which are usually predicting the evolution of large, relatively stable circulation features, the mesoscale model must often predict rapidly-varying, unbalanced circulations that are highly dependent upon the rate of local latent heat release.

The lack of temporal scale separation between convection and the grid-scale flow, as well as the small size of the grid column relative to L_R, have two major implications for cumulus parameterizations. First, to the extent that convection in heavily disturbed regions tends to approach a state of equilibrium with the large-scale fields, that equilibrium state is not predictable from the observed values within a local grid column. Rather the equilibrium requires knowledge of the fields and convection over a much larger area. Second, since convection varies on the same approximate time scale as the grid-scale circulation, it is not desirable to introduce a closure mechanism that estimates the amount of convection as that required to achieve equilibrium with the existing grid-scale conditions.

Despite the above inherent drawbacks in equilibrium-type closures, such closures may work reasonably well in models under the right circumstances (Grell et. al. 1991; Xu and Arakawa 1992). For example, if the convective scheme is activated at the right time in the right place, and if the rate of diabatic heating is equal to or slightly greater than the large-scale forcing (uplifting or other destabilization) in the column, then the heating will act to intensify the local circulation. If the parameterization scheme includes a realistic representation of downdrafts, these will eventually stabilize the column, shutting off the convection. Without downdrafts, the altitude of strongest diabatic heating will be so low as to cause erroneous positive feedbacks or "grid-point storms". It may not make too much difference whether the rate of heat release is accurate, so long as it is not less than the amount required to at least balance the grid-scale destabilization rate. Even if the heating rate is somewhat too large, it may tend to produce a similar amount of time-averaged heating in a column, over too short a time interval. On the other hand, if the scheme produces too little heating, the convection will not keep up with the grid-scale cooling, and the explicit moisture scheme will tend to produce explicit rainfall, which can greatly alter the characteristics of the solutions.

Another approach to closure in cumulus parameterization schemes is to predict the convection from processes that have strong controlling effects on the origins of the clouds, and then let the interactions between the cloud models and the grid-scale circulation determine their own equilibrium. Examples of this approach are Frank and Cohen (1987) and earlier schemes that use subcloud-layer mass convergence in some form for closure. These schemes do not assume any kind of equilibrium between the convection and the levels above cloud base. More recent approaches involve coupling cloud models to the turbulent fluxes in higher order turbulence models or to the mass flux predicted by boundary layer models. In each case, the amount and type of convection is predicted in terms of rapidly-varying local processes, and the evolution of the flow at higher levels reflects the interactions between the implicit convective fluxes and the grid-scale flow.

One problem with the rapid interactions between convective clouds and their organizing mesoscale circulations is that *there are no existing data sets with sufficient temporal and spatial resolution to verify closure hypotheses. Since the data cannot separate the convective response to grid-scale changes from the grid-scale response to convection, one can't tell whether equilibrium closures are working or not.* Verification of the schemes currently requires fully prognostic tests in which many other factors other than the cumulus parameterizations affect the outcome. It is highly desirable to obtain measurements that would be adequate to verify at least some of the major assumptions of cumulus parameterizations directly from observations.

On the subject of verification, one problem with direct comparisons between the performances of different schemes in models is that each parameterization tends to be a complex package with a large number of components and assumptions. Further, the method of interaction between the scheme and the host model may cause different schemes to work better in different models strictly for numerical or procedural reasons. When testing cumulus parameterization assumptions using numerical simulations, it is highly desirable to use a simple, common parameterization system that allows isolation and testing of one assumption at a time, as demonstrated in Grell et. al. (1991).

3.6 Coupled land surface/hydrologic/atmospheric models N94-24387

Roger Pielke

Lou Steyaert:	*Prototype land cover characteristics data base for the conterminous United States*
Ray Arritt:	*Surface evapotranspiration effects on cumulus convection and implications for mesoscale models*
Mercedes Lahtakia:	*The use of a complex treatment of surface hydrology and thermodynamics within a mesoscale model and some related issues*
Chris Smith:	*Initialization of soil-water content for regional-scale atmospheric prediction models*
Conrad Ziegler	*Impact of surface properties on dryline and MCS evolution*
Su Tzai Soong	*A numerical simulation of heavy precipitation over the complex topography of California by*
Roni Avissar:	*Representing mesoscale fluxes induced by landscape discontinuities in global climate models*
Peter Wetzel:	*Emphasizing the role of subgrid-scale heterogeneity in surface-air interaction*
Piers Sellers:	*Problems with modeling and measuring biosphere-atmosphere exchanges of energy, water, and carbon on large scales*

Each presenter was asked to submit an abstract summarizing their talks. These are reproduced in the following material with minor editing. Lou Steyaert discussed a prototype land cover characteristics data base developed by the US Geological Survey. The US Geological Survey EROS Data Center, with support from the University of Nebraska-Lincoln, has developed a prototype land cover characteristics data base for the conterminous United States. Biweekly composites of 1 km AVHRR data for 1990 have been analyzed to define seasonally distinct land cover regions. The essential input to the classification process was vegetation greenness profiles as depicted by seasonal variations in the Normalized Difference Vegetation Index (NDVI) derived from daily AVHRR data. The