3.7 SEQUENCES OF PRECIPITATION AND ORGANIZED CONVECTION: DYNAMICS AND PARAMETERIZATION

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1. Introduction

This is a systematic study of sequences of precipitation over the mid-continental US, with parameterization issues in mind. Sequences of precipitation directly involve the mesoscale organization of convection that, in turn, depends on dynamical aspects. Therefore, the dynamics of convective organization is a unifying theme in regard to collective effects and relationships to the large-scale variables. Several basic questions spring to mind, such as: is organized convection important in a large-scale context, how does it operate, and is it important in terms of parameterization?

The representation of organized convection is a relatively new issue in numerical weather prediction. The existence of organization is at odds with the scale-separation principle upon which parameterizations are based. The grid-increment of modern prediction models is comparable to the scale of organized convection, therefore the parameterization problem is ill posed. Organized convection touches on all steps of parameterization: triggering, transport and closure. Presently, dynamical aspects are poorly accounted for in parameterizations.

In about a decade, operational regional prediction models should have grid increments ~1 km. At this juncture, the resolution of global models, which already encounter problems with organized convection, will be comparable to that of today's regional models. Finally, mesoscale processes are conspicuous by their absence in climate models, apart from certain thermodynamic aspects (Donner 1993).

The Tropical Rainfall Measuring Mission (TRMM) quantified the ubiquity of coherent rainfall patterns in the tropics and sub-tropics. Laing and Fritsch (1997) pointed out a relationship among organized convection, mean flow and orography in a global context. Carbone et al. (2002) quantified the structure of sequences of warm-season precipitation over the continental US. Tripoli (1986) simulated idealized mesoscale convective systems originating over the Rockies, and identified various stages of its evolution.

Understanding the physical basis of convective precipitation over the US, a necessary step toward improve the skill of regional-scale and large-scale prediction models. Discussing and addressing this kind of problem is the centerpiece of this talk.

2. Basic Aspects

The large-scale role of mesoscale organization, evinced by coherent precipitation patterns of various kinds is not well understood. Fundamentally, canonical forms of complex processes are required for establishing a firm scientific basis and for parameterization purposes. We argue these goals are achievable for organized convection, for the following reasons.

Firstly, modern computers enable organized convection and its interaction with the environment to be treated explicitly and consistently in cloud-resolving numerical models. But it is impossible for any geophysical model to simulate convection from first principles: cloud-microphysics, cloud-radiation interaction and dissipative processes must be parameterized in all models. At least a 10-m grid-length is required to resolve the interaction between cloud-microphysics and dynamics (i.e., cloud-environment mixing, also known as entrainment). The diurnal cycle of convection implies that the interaction between convection and the convective boundary layer is important. It is not yet practicable to simulate the problem of boundary-layer/convection interaction explicitly.

The numerical models having 1-km grid-lengths models are capable of resolving the mesoscale organization of convection and its large-scale effects. In these *cloud-system – resolving models*, moist instabilities and interactions among processes and scales are treated with far more realism than large-scale models or even mesoscale models achieve.

Secondly, much is known about the organized convection *as a process* from observations and from numerical simulations. Furthermore, the underlying principles have been quantified using theoretical-dynamical models (Moncrieff 1981, 1992). Such canonical forms allow dynamics of organization to be reduced to first principles. In other words, stepping-stones are in place to reduce the complexity atmospheric observations to canonical forms. Figure 1 lays a pathway toward representing organized convection either explicitly by numerical models, or by theoretical-dynamical models that represent organized transport implicitly.

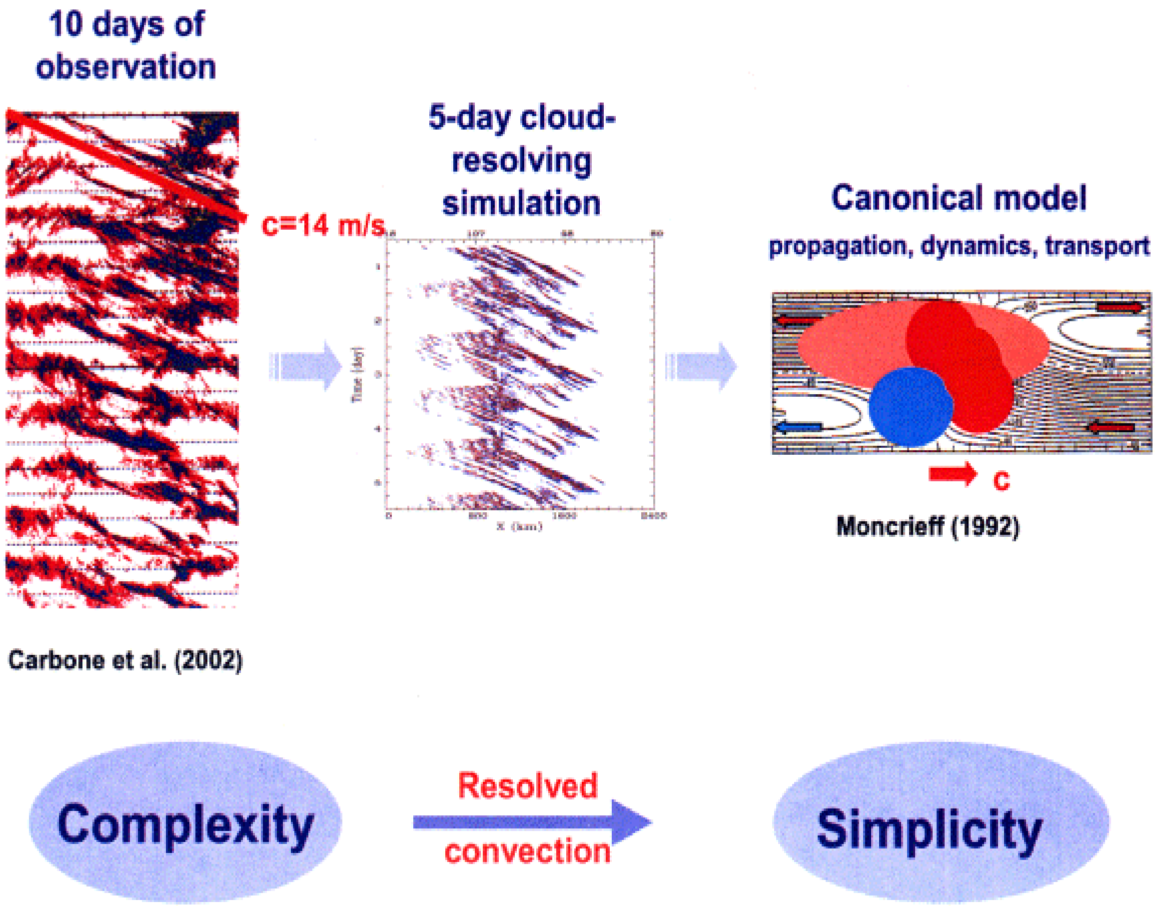

Figure 1. A strategy for quantifying the physics underlying coherent patterns of precipitation and a dynamics of organized convection based on the use of numerical and analytic models.

3. Parameterization Issues

Models operating convective parameterizations have great difficulty in realizing not only the correct diurnal cycle of precipitation but also sequences of convection during the warm season. In regard to the latter point, the problem is that even when a convective parameterization is operative, grid-scale circulations tend to develop but are under-resolved and therefore distorted. These surrogate circulations can even sometimes shut down the sub-grid-scale convective parameterization that should remain operative.

This kind of problem has long been recognized in regional prediction models (e.g., Zhang et al. 1988) but has only recently been quantified in the context of global weather prediction models (Moncrieff and Klinker 1997).

Figure 2 shows sequences of precipitation realized in MM5 that result from three distinct convective parameterization schemes. None of these sequences travels at the speed of the observed sequences (14 m/s). This kind of problem is not confined to MM5: it occurs in all regional models.

Basically, this problem is a product of under-resolved grid-scale convection (surrogate organization). This is a vexing problem in modern weather prediction models, and an important one. It is also pertinent to accurate deterministic precipitation of precipitation in operational global weather prediction models.

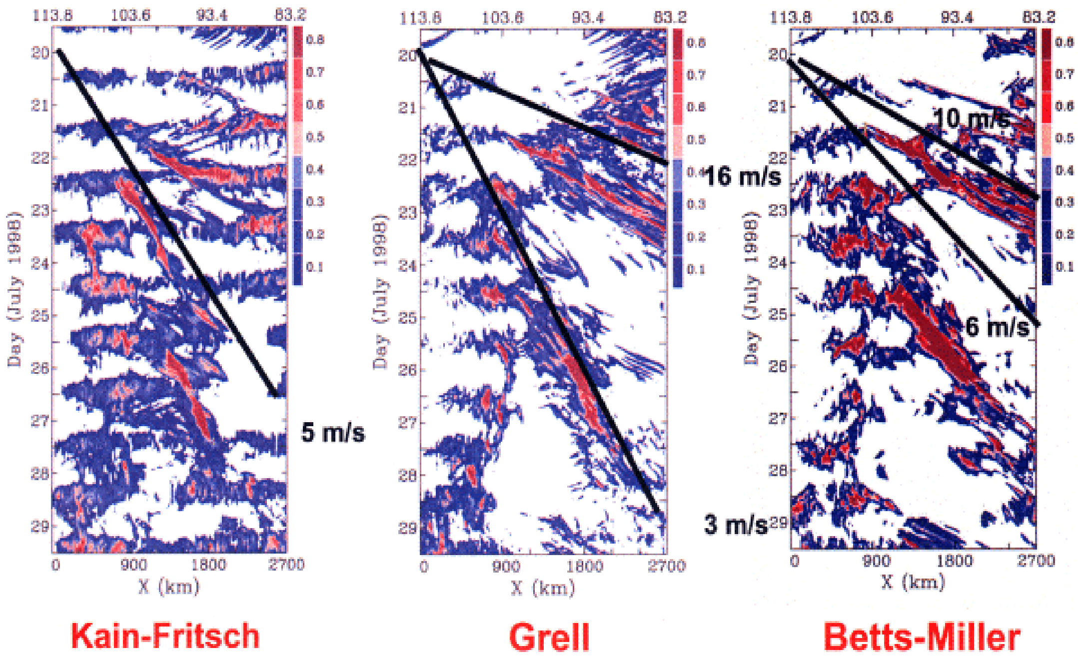

Figure 2. Sequences of precipitation realized using different convection parameterization schemes in MM5. None produces the correct propagation speed (14 m/s).

3. Approach

Our working hypothesis, stemming from process studies, is that sequences of precipitation are due primarily to vertical shear organizing mesoscale convective dynamics and its environmental interaction. This can be represented either explicitly using 1-km grid-increment numerical models or by canonical transport models of organized convection (Fig. 1). The latter is the counterpart of the entraining plume models used in traditional parameterization.

In order to simplify the problem, the generation of convective available potential energy (CAPE) by large-scale advective forcing of temperature and moisture and surface fluxes of these quantities is specified as an 'external forcing' for a cloud-resolving numerical model. Preferably, objective analysis of observations would be used but accurate estimates cannot be obtained except in field campaigns where 6-h or even 3-h soundings are available (e.g., Wu and Moncrieff 1996).

Intensive measurements are not available to specify the forcing over the large domain used here. Therefore, we made a compromise, the large-scale forcing and surface fluxes were provided by synthetic data from predictions using an interactively nested version of MM5 (Fig. 3) and NCEP global analysis defined the 'first guess'.

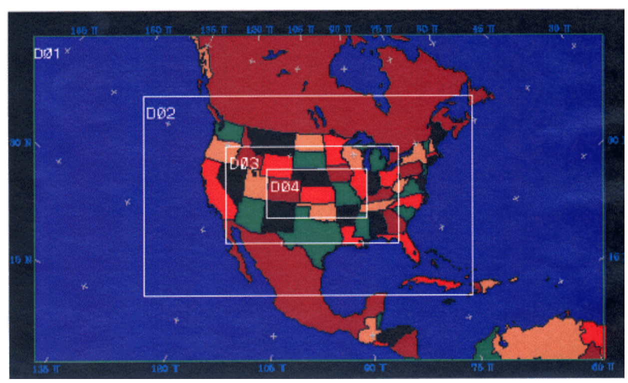

Figure 3. Nested domains of MM5 used to calculate the large-scale forcing and surface forcing. D04 is the cloud-resolving domain.

The initial states for the cloud-resolving simulations were the 10-day composite of the MM5 prediction, which provided the synthetic large-scale forcing and surface forcing for the Eulerian option of the Smolarkiewicz et al. (1999) cloud-resolving model.

A set of two-dimensional sensitivity experiments, run for 5 days, were performed over the inner-domain (D04) shown in Fig. 3. The orographic profile is a meriodinal average over the D04 sub-domain. The horizontal grid-increment is 1 km. Time-dependent open lateral boundary conditions were used. Because 10-day-averaged diurnally varying forcing was used, the 5-day simulation is a '5-member ensemble' realization of the sequences of precipitation.

4. Numerical Experiments

The following will be summarized:

- Control simulation.
- Orography removed.
- Large-scale forcing de-activated.
- Cloud-interactive radiation de-activated.

In the control simulation, the diurnally varying large-scale forcing and surface forcing, meriodinally averaged orography, and cloud-interactive radiation were all operative. The time-space diagram of the distribution of precipitation in the control simulation is shown in the center plate of Fig. 1.

In all cases, the propagation speed (14 m/s) observed by Carbone et al. (2002) was realized approximately. This is an important point in regard to the fidelity of cloud-resolving models. Another sensitivity experiment was performed in which the shear in the 1-10 km layer was modified. The distribution of the heaviest precipitation changed little, but with weaker shear the stratiform precipitation came mainly from forward-directed anvils, as anticipated.

Typically, convection developed over the Rockies in late morning, aggregated into horizontally extensive cloud clusters, which traveled off the Rockies onto the Plains in the evening and evolved into strong nocturnal

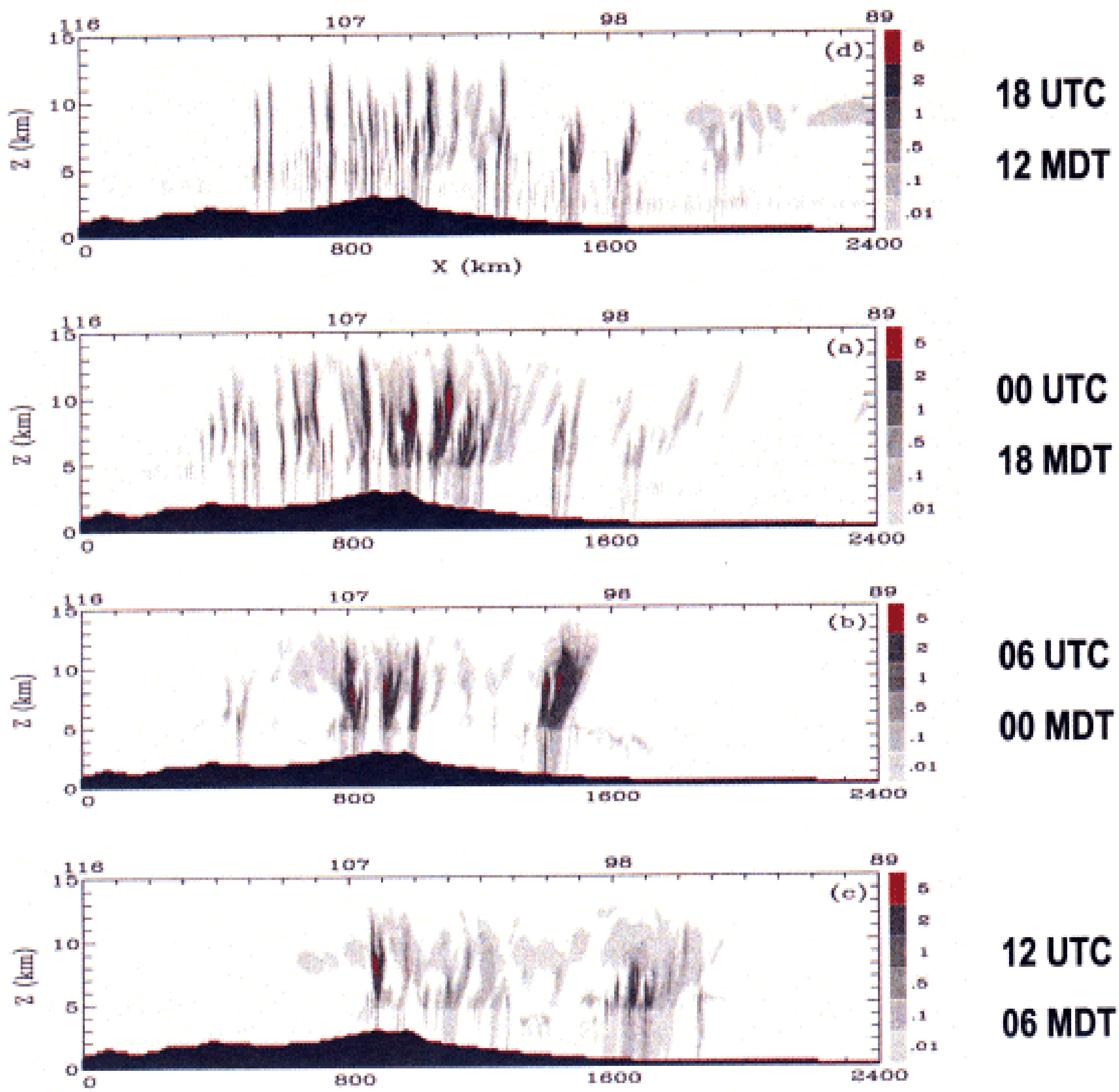

Figure 4. Snapshots of total condensate (rain + snow + cloud water) from the resolved-convection simulation. Convection starts over the Rockies, evolve into mesoscale convective systems that subsequently travel eastward at about 14 m/s.

systems hundreds of kilometers to the east (Fig. 5).

5. Future Work

The above preliminary experiments supported the working hypothesis that the sequences of convection were mainly a product of the environmental shear. Even though the extent of the sequences of precipitation depended strongly on the presence of orography and on the specified forcing (cloud-interactive radiation had little effect) the propagation of the precipitation systems, measured by the space-time distribution of the precipitation pattern, change little. However, the precipitation amounts were generally too small, and there are reasons why this is so. In future the following will be conducted:

- Numerical simulations in three-spatial dimensions, comparison with two-dimensional results, interactive surface fluxes.
- Canonical model of convective initiation to define dynamical trigger functions for organized convection.
- Canonical model of organized dynamics to represent transport by organized convection.

The following approaches will circumvent or at least mitigate the synthetic specification of large-scale forcing presently used in the cloud-system simulations:

i) Use a large cloud-resolving domain, which is limited by the technical issue of computer resources.

ii) Use cloud-resolving convection parameterization (Grabowski 2001).

iii) Use objectively analyzed observations from an intensive field experiment to specify the forcing.

In regard to the latter, the IHOP_2002 is the only new dataset available that can provide large-scale forcing and surface fluxes. The domain is smaller than the one used here, but three-dimensional domains need to be smaller anyhow. IHOP_2002 data will also be used to evaluate the numerical experiments.

This research will be conducted in collaboration with the NCAR Water Cycle Across Scales initiative (Fig. 5.), which has warm-season precipitation over the U.S. continent as its priority study.

6. Conclusions

A methodology was presented for reducing complex organized convection, responsible for coherent sequences of precipitation, to simple paradigms using cloud-resolving models. In this approach, convection and its environment evolve as a coupled system. This identifies the methodology from traditional process studies, and makes it useful for convective parameterization development.

Environmental shear is a key large-scale variable controlling the sequences of precipitation, which is a confirmation of the working hypothesis. This enables theoretical-dynamical concepts to be brought into play (Fig. 1).

The reported work addresses the basic questions posed in the first paragraph of the Introduction in regard to organized convection and its representation in regional-scale and large-scale prediction models. We identify two types of cloud-system representation:

Firstly, the explicit (*resolved convection*) representation produces precipitating convective systems moving at a realistic speed, which contrasts with the usually retarded speeds in the parameterized models. This is encouraging for eventual deployment of operational prediction models having continental-scale cloud-resolving domains (i.e., in Fig. 3 the inner domain D04 would span the entire US continent).

Secondly, the traditional approach of implicit representation (*convective parameterization*) should not be neglected in the interim. Important and basic problems have to be solved (e.g., surrogate organization, incorrect propagation). For the foreseeable future, global weather prediction models and, especially, climate models must rely on the implicit approach.

In summary, large-scale models do not correctly represent organized convection. In this respect, the canonical forms of convective organization shown in Fig. 1, which are based on dynamical considerations, provide a possible answer. The problem is how to build these canonical forms of organized transport into *cloud-system parameterizations*. In order to meet this challenge not only are transport modules required, but also new ways to represent convection initiation (as dynamically based trigger functions) in parameterizations. This procedure would enable the concept of dynamical coherence to be represented in convective parameterization, which is a fundamental role for mesoscale convective systems in the large scare context.

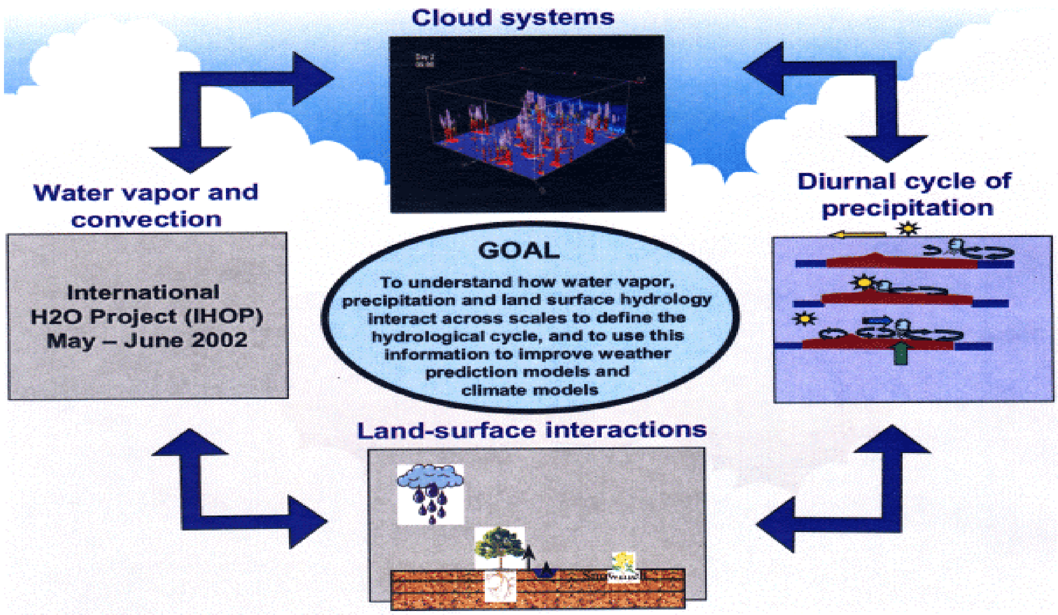

Figure 5. Phase I of the NCAR water Cycle Across Scales initiative.

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