Parameterization of Convective Clouds, Mesoscale Convective Systems, and Convective-Generated Clouds

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This presentation is a summary of research progress supported under the Atmospheric Radiation Measurement (ARM) project entitled "Parameterization of Convective Clouds, Mesoscale Convective Systems, and Convective-Generated Clouds." The approach used in this research is to perform explicit simulations of convective clouds and mesoscale convective systems for well-documented observed cases. The simulated data are used to help us in fabricating, calibrating, and testing parameterization schemes of these cloud systems. The approach is analogous to the large-eddy-simulation (LES) approach that has been quite successfully used in developing parameterizations of turbulent transport in the convective boundary layer. The work builds on research by Weissbluth (1991) who developed parameterizations of deep convective clouds updrafts and downdrafts.

The Channel Simulations

In the first phase of the research, we have been refining and independently testing the Weissbluth scheme by performing explicit simulations of Florida sea-breeze-forced convection. The Regional Atmospheric Modeling System (RAMS) developed at Colorado State University is set up in a nested-grid, channel configuration shown in Figure 1 in which the north/south boundaries are cyclic so that an idealized infinitely long Florida peninsula is simulated Three grids are used with the coarse grid having

$\Delta_x = \Delta_y = 4.5$ km, the middle grid having $\Delta_x = \Delta_y = 1.5$ km, and the fine grid having $\Delta_x = \Delta_y = 0.5$ km.

The fine grid, shown in Figure 1 is chosen to have sufficient resolution to explicitly simulate the large eddies in towering

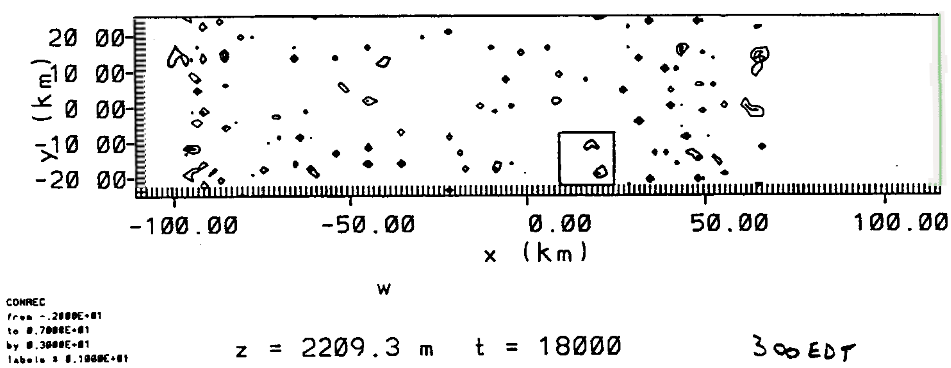

Figure 1. Vertical velocity (m/s) at z = 2.2 km over a domain with 1.5-km horizontal grid spacing. Land surface is located between -100 and +100 km, with water beyond those points. Insert indicates the location of a nested grid in which 0.5 -km grid spacing was used.

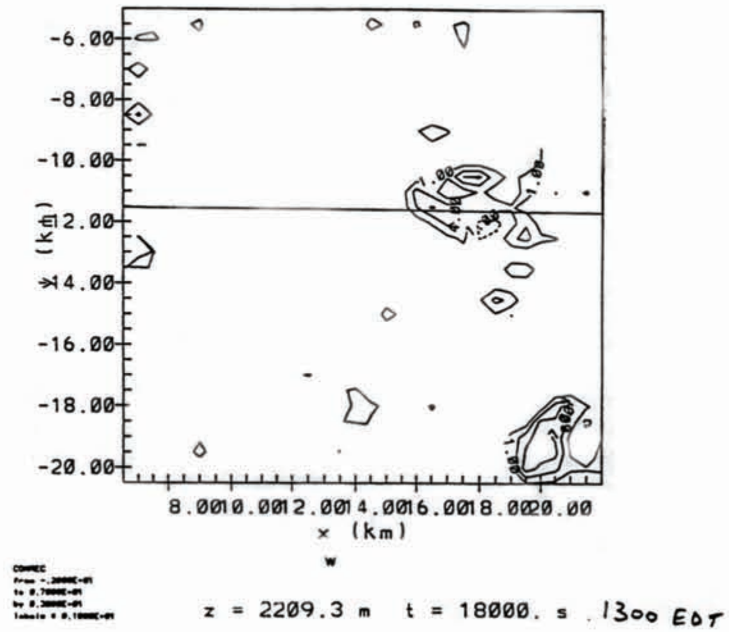

Figure 2. Vertical velocities (m/s) at z = 2.2 km on the fine-grid (0.5- km horizontal grid spacing) domain indicated in Figure 1 Contour interval is 3 m/s. Line at y = -11.5 km is the location of the cross section shown in Figure 3.

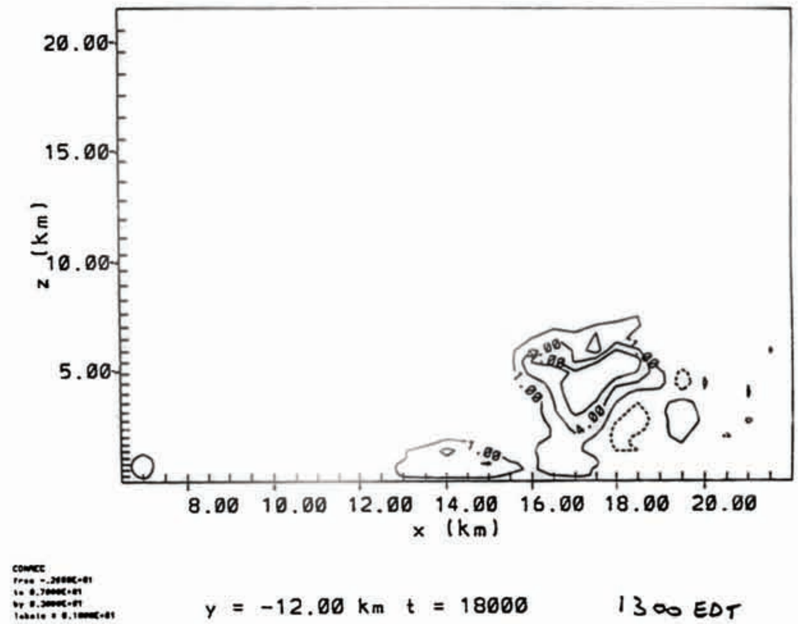

Figure 3. Vertical velocities (m/s) along the vertical cross section indicated in Figure 2. Horizontal grid spacing is 0.5 km. At this time strong convection is occurring; however, it has not yet deepened to upper levels. With the fine resolution, features such as the convective downdraft at x = 18 km can be explicitly resolved.

cumulus clouds and small, ordinary cumulonimbus clouds. Vertical and horizontal cross sections through the fine grid are shown in Figures 2 and 3. From those simulations we are deriving parameters such as convective condensate efficiencies which are needed to generalize the Weissbluth scheme. In addition, the Weissbluth scheme is independently run on a 5-km or 20-km grid version of RAMS to evaluate the ability of the scheme to reproduce the statistics derived from the run with explicit representation of cloud drafts.

Simulating Mesoscale Convective Systems

We are extending this philosophical approach to mesoscale convective systems (MCS), which are long-lived, heavy-raining systems that produce stratiform-anvil clouds that extend over dimensions in excess of 100,000 km^2. Our approach is simulate systems observed in mid-latitudes during the 1985 Oklahoma PRE-STORM and in the tropics during the Equatorial Mesoscale Experiment (EMEX).

Currently, we are selecting cases, assimilating data into RAMS, and performing test simulations of the cases with coarse resolution runs (grid spacing of 80 km) to determine the suitability of the cases for nesting down to high resolution explicit runs. We have selected the 3-4 June 1985 and the 10-11 June 1985 cases as two candidates. In the well-documented 3-4 June case (i.e., Fortune et al. 1992), a sequence of 4 mesoscale convective complexes (MCCs) formed and moved along the north side of a stationary front. The systems were spawned in the Texas panhandle region along the dry line and possibly associated with jet streaks aloft. Our first attempts at simulating this case using the modified Kuo cumulus parameterization scheme developed by Tremback (1990) were not very successful, with convection not organizing to MCS dimensions and residing to the south of the stationary front. Our first attempt to apply the new Weissbluth scheme to this case was much more successful, with convection forming to the north of the stationary front, and three of the four MCSs being simulated. Thus we plan to proceed further with this case.

The first attempt to simulate the 10-11 June case with the modified Kuo scheme was also quite successful, thus this case is also being considered as a case for high resolution simulation. We have also collected data and performed preliminary analysis of two MCSs observed in the tropical Australia region: the EMEX 9 cluster observed on 2 February 1987, and the squall line observed on 5 December 1989 during the Down Under Doppler and Electricity Experiment (DUNDEE). Test RAMS simulations of both cases show that both are promising candidates for high-resolution simulation.

Simulating CCN Impacts on Stratocumulus Albedo

Under a DOE NIGEC grant titled "Development of a Radiative and Cloud Parameterization Scheme of Stratocumulus Clouds which includes the Impact of CCN on Cloud Albedo," we are developing a large-eddy-simulation (LES) model of stratocumulus clouds coupled to a nested, detailed explicit microphysical model of cloud droplet size-distributions. Data from the simulated fields will be used to drive a detailed three-dimensional model of cloud radiances. These fields, in turn, will be used to develop a simple parameterization of the macroscopic, microscopic, and radiative properties of a horizontally-inhomogeneous field of stratocumuli or stratus. The parameterized model will have the unique ability to respond to changes in CCN as well as ambient thermodynamic and wind soundings.

We are currently installing the University of Tel-Aviv's detailed microphysics model into RAMS for performing those simulations.

The Dangers of Putting All ARM's Eggs in the Single-Column GCM Basket

Currently ARM measurement strategy is concentrated around the concept of development and testing of general circulation model (GCM) parameterization schemes over an area that roughly corresponds to a single GCM column. I would like to conclude with a few philosophical comments about this strategy. While I am sympathetic about the suitability of this approach for long-term monitoring, one should take a less myopic view of measurement strategy for intensive observational periods (IOPs). Fundamental to the one-dimensional (1-D) GCM measurement strategy is that a cloud parameterization scheme can be locally determined. That is, there is sufficient information over the 1-D GCM measurement volume to uniquely parameterize cumulus clouds, MCSs, stratus, and cirrus clouds. In other words, a local parameterization scheme will be suitable.

This philosophy may be appropriate for stratocumulus clouds and possibly even ordinary thunderstorms, because these clouds derive their energy from surface fluxes of heat and moisture, which can be locally contained within a 1-D GCM sample volume. However, there are other situations for which this local parameterization philosophy may be less appropriate. For example, MCSs can initiate through organized mesoscale circulations well removed from a 1-D GCM sample volume. They can then propagate into the sample volume as a mature, sub-grid-scale disturbance while producing a cloud shield, heating profiles, and precipitation which is only partially determined by the properties within the 1-D GCM sample volume. In other words, we suspect that a non-local parameterization scheme may be needed.

Piotr Flatau[a] proposed that parameterization of cirrus clouds may also require the formulation of a non-local parameterization scheme. This is because cirrus clouds can originate from the injection of moisture and water substance into the upper troposphere by deep convective clouds, orographic lifting, or jet streaks well upstream of a 1-D GCM sample volume. Ice crystals formed in the genesis region can advect laterally and survive long distances in the strong upper tropospheric winds and in regions of high relative humidity. Thus, a mature cirrus cloud can advect into a 1-D GCM sample volume and alter the radiative properties of the volume even though the moisture contents and vertical motion fields are not sufficient to initiate those clouds. It is hypothesized that a non-local parameterization scheme may again be required and that ARM, therefore, should make measurements that extend beyond the 1-D GCM sample volume to develop and test suitable parameterizations.

References

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(a) Personal communication with P. Flatau, Colorado State University, Ft. Collins, Colorado. 1991.