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AN APPROACH FOR PARAMETERIZING MESOSCALE PRECIPITATING SYSTEMS

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1 Introduction

Mesoscale precipitation systems are an important phenomena that only recently have been studied both observationally and numerically. While their importance is now generally recognized, their parameterization in large-scale models is nonexistent. The parameterization problem of these systems is complicated by the existence of both meso-γ-scale convective drafts and broader drafts organized on the meso-β and meso-α scales. The result is that existing cumulus parameterization schemes are not adequate for these systems since the mesoscale organization is not represented.

In order to represent these systems in numerical models having horizontal resolutions coarser than 50 km, we propose the use of a cumulus parameterization laboratory where the parameterization is conceived, designed, calibrated and finally verified against data obtained from some reference numerical model. The schematic in Fig. 1 shows the design of this laboratory. Of course, the fundamental link is the reference numerical model which must accurately describe the system of interest. In the following sections, the fabrication, calibration and verification stages of the cumulus parameterization laboratory are described as they have been implemented in two dimensions in Weissbluth (1991). The application of this method in designing a cumulus parameterization scheme in three dimensions is then extended to mesoscale precipitating systems.

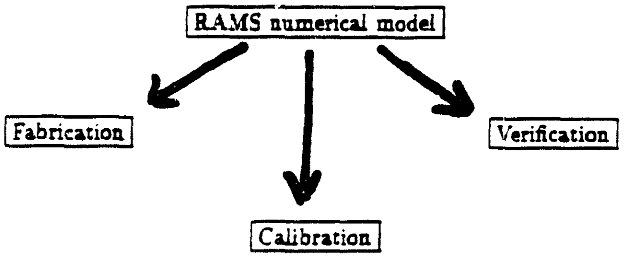

Fig. 1. The cumulus parameterization laboratory

2 Scheme fabrication

In Weissbluth (1991) and Weissbluth and Cotton (1988), a CCOPE supercell, Florida sea-breeze convection and a tropical squall line were explicitly simulated by the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University. Model output diagnostics were shown to be a powerful tool in interpreting the behavior of the storm since spatial and temporal resolution of the data is uniform and self-consistent, unlike real-world observations of these phenomena. By averaging over suitable areas of the explicit simulations, areal averages of the convective heat, momentum and moisture fluxes were obtained for each of the storms and intercompared. The vertical velocity variance seems to be a rather universal measure of convection regardless of the forcing of convection or its environment. Furthermore, vertical mass and moisture covariances appear strongly linked to $\overline{w'w'}$. For these reasons, we have based the present cumulus parameterization scheme on the prediction of $\overline{w'w'}$.

Weissbluth (1991) and Weissbluth and Cotton (1990) described the modifications made to the traditional Mellor and Yamada (1974) level 2.5 closure. Since the one prognostic variable is $\overline{w'w'}$, the scheme is termed a level 2.5w closure. Within this formulation, realizability conditions are imposed on the mixing coefficients as in Hassid and Galperin (1983) and the clipping approximation of Andre *et al.* (1976) is used. Furthermore, a generalized length scale is used as in Chen and Cotton (1987) to represent stable and unstable conditions where a buoyant heat flux may or may not be present.

The pressure and transport term are closed as in Zeman and Lumley (1976) who modeled these terms for a buoyancy-driven mixed layer. In their original formulation, the shear components were not included since they studied an environment without shear; in our formulation, contributions to $\overline{w'w'}$ from shear is included. The transport term is handled in a relatively sophisticated way in order to include counter-gradient transports in the mixed layer. Our formulation extends the original theory to include the virtual and rainwater effects on the buoyancy terms.

Thus far, only a higher order turbulence scheme has been described. In Weissbluth and Cotton (1991), the addition of a deep cumulus component is described which allows the scheme to be used as a cumulus parameterization scheme. The cumulus tendencies from deep convection are specified as

$$\left(\frac{\partial \overline{\mathcal{X}}}{\partial t}\right)_{\text{cumulus}} = \sigma_{u,d}\left[w^{**}\frac{\partial \overline{\mathcal{X}}}{\partial z} + \frac{1}{T}\left(\mathcal{X}_{u,d} - \overline{\mathcal{X}_e}\right)\right]. \quad (1)$$

The second term on the rhs of Eq. 1 is the convective adjustment term where T is the time scale over which convection modifies the environment, $\overline{\mathcal{X}}$ represents any scalar variable, u, d and e represent updraft, downdraft or environmental values of a variable and σ represents cloud core fractional coverage.

There are several interpretations of Eq. 1 which can be made. When cumulus forcing is diagnosed, the first term on the rhs combines with the resolvable advection. Bougeault (1985) then interprets the first term on the rhs as a subsidence term since the resolvable vertical motion in large-scale models is negligible compared to w^{**}. The second term is then interpreted as the detrainment term. In large scale models, then, the subsidence term prompts warming and drying while the detrainment term prompts warming and moistening.

In mesoscale models, the resolved vertical motion may be comparable to w^{**} and a different interpretation of the term is needed. In this case, the advection by the resolved motions and the first term on the rhs (now called the compensation term) combine to give near zero net advection which is desirable since the advection of the scalars is now being accomplished by the convective adjustment term. Double counting is then explicitly eliminated since the convective adjustment term wholly handles the updraft core warming and moistening.

3 Scheme calibration

Eq. 1 neccesitates the use of a cloud model. In the cumulus parameterization laboratory, the reference numerical model is used to calibrate the usual cloud model parameters such as entrainment for the updraft and the evaporative pressure scale for the downdraft, (Weissbluth, 1991 and Weissbluth and Cotton, 1990). Also described in these references is the unique incorporation into the parameterization scheme of hydrometeor source functions for the host model. Vertical profiles of various hydrometeors in the updraft and downdrafts are determined by conditionally sampling the drafts in the reference numerical model. The resultant parameterized profiles are then represented as parabolic curves whose shape is determined by general cloud parameters such as the lifting condensation level or the equilibrium temperature level. These curves are then normalized by the percent that each hydrometeor species contributes to the total conditionally sampled condensate in the reference numerical simulation.

4 Scheme verification

The results of the cumulus parameterization on a five and a twenty kilometer grid have been compared to a two dimensional explicit simulation on a 1.5 km grid of Florida sea breeze convection in Weissbluth (1991). The explicit simulation follows closely the experimental design of Nicholls *et al.* (1991) who examined the effect of varying initial wind and thermodynamic profiles on the evolution and structure of deep convection initiated by the propagating sea-breezes. They examined three wind profiles from which their Type I, discussed below, is chosen. The domain size is 600 km with land in the center third of the domain and water on either side and includes a stretched vertical grid having a resolution of 250 m near the surface and increasing to 1 km up to 21 km. There is a Rayleigh friction layer in the uppermost 7 km of the domain and Klemp-Wilhelmson (1978) radiative lateral boundary condition with a very large phase speed to effectively create a zero-gradient outflow condition. Full microphysics including rain, ice, graupel and aggregates are included. The simulation is run for 12 hours starting at 0800 local time in order to properly capture the development of the sea breeze. The Type I thermodynamic profile has a lifted index of about -4° while the wind profile indicates easterlies through the depth of the troposphere with a slight jet near the ground and near the troposphere.

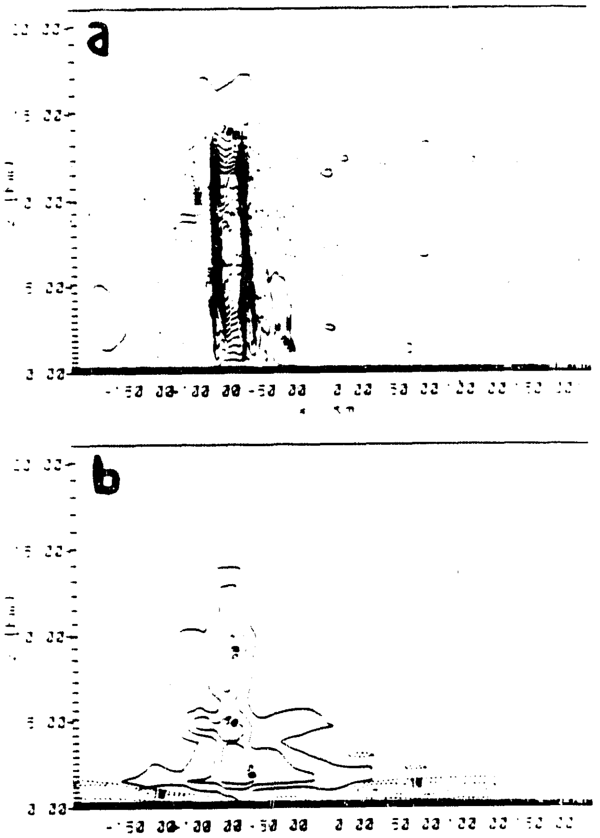

Fig. 2. 21 km running averages of the explicit two dimensional simulation for the inner 400 km of the domain at 1700 local time. The peninsula is between -100 km and 100 km. (a) vertical velocity (contours from -5.1 m/s to 2.7 m/s by 0.2 m/s) and (b) perturbation total water mixing ratio (contours from -21 g/kg to 19 g/kg by 2 g/kg; labels are multiplied by 10).

The sea breezes develop fairly early in the day as the solar radiation heats the ground more strongly than the water. A relative low pressure forms over the peninsula which draws in the relatively cooler and denser oceanic air over both coasts. The result is an eastward propagating sea-breeze front over the western coast and a westward propagating front on the east coast. As noted in Nicholls *et al.*, (1991) in their review of the Florida sea breeze phenomenon, this Type I situation is characterized by by development of deep convection along both coasts due to low level uplift at the sea breeze fronts. The east coast convection moves inland fairly rapidly, whereas the west coast convection moves more slowly due to the presence of an easterly component in the wind. The sea breeze fronts collide to the west of the center of the peninsula producing the strongest convection which diminishes in the early evening.

Figs. 2a,b indicate the vertical motion and perturbation total water mixing ratio from the explicit simulation analyzed with 20 km running averages while these fields from the parameterized simulation on a 20 km grid are shown in Figs. 3a,b. at 1700 local time. Fairly good agreement is evident between the two simulations, although their are some problems in the timing and location of the parameterized run.

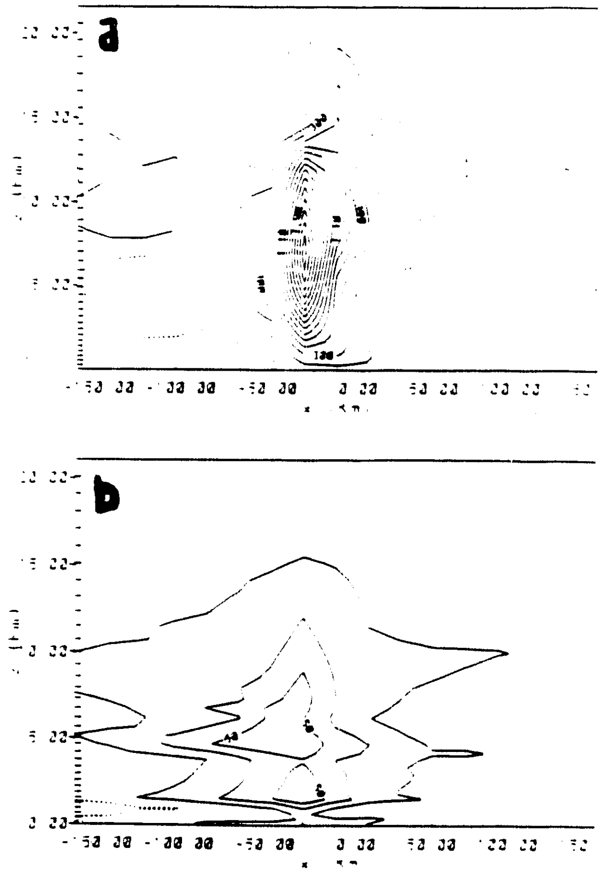

Fig. 3. As in Fig. 2 except for the 20 km parameterized simulation.

5 Extension to mesoscale precipitating systems

Thus far the cumulus parameterization laboratory has been used to develop a parameterization scheme suitable for use in a mesoscale model. The key features of this scheme are that convective drafts are parameterized, the scheme provides hydrometer source functions for the host model and the scheme is suitable for use in a wide range of grid resolutions. This scheme is being extended for use in parameterizing mesoscale precipitating systems on grids coarser than 50 km by moving the laboratory upscale; this involves the explicit simulation of a mesoscale convective system (MCS). Further calibration of the convective drafts can be made by using the previous conditional sampling criterea.

However, there is now information in these reference data to parameterize the mesoscale circulations. For example, mesoscale updraft properties and hydrometeor profiles can be determined by sampling those areas where vertical velocities are between 0.2 and 1.5 m/s (the convective drafts were sampled when vertical velocities were greater that 5 m/s). Eq. 1 would then be used with a similar equation which represents the parameterized mesoscale drafts.

6 Conclusions

A cumulus parameterization laboratory has been described which uses a reference numerical model to fabricate, calibrate and verify a cumulus parameterization scheme suitable for use in mesoscale models. Key features of this scheme include resolution independence and the ability to provide hydrometeor source functions to the host model. Thus far, only convective scale drafts have been parameterized, limiting the use of the scheme to those models which can resolve the mesoscale circulations. As it stands, the scheme could probably be incorporated into models having a grid resolution greater than 50 km with results comparable to the existing schemes for the large-scale models. We propose, however, to quantify the mesoscale circulations through the use of the cumulus parameterization laboratory. The inclusion of these mesoscale drafts in the existing scheme will hopefully allow the correct parameterization of the organized mesoscale precipitating sytems.

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