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VALIDATING CUMULUS PARAMETERIZATIONS USING CLOUD (SYSTEM)-RESOLVING MODELS

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1. INTRODUCTION

Convective systems consist of a complex mixture of dynamic and microphysical structures of various scales. Prominent among these features are updrafts and dowdrafts of cumulus scale, composed of elements whose entrainment and vertical-velocity characteristics vary widely, and mesoscale updrafts and downdrafts (*e.g.*, Leary and Houze, 1980). For coarse horizontal resolutions typical of those employed in general circulation models (GCMs), both mesoscale and cumulus-scale components of convective systems must be parameterized. To develop and validate such parameterizations, data from field experiments can be used, but these experiments are limited in number, and inferring details regarding many of the smaller-scale processes from field data is difficult. An additional method for evaluating and developing these parameterizations is to use high-resolution, limited-area nonhydrostatic models. These models represent explicitly the physical processes which are parameterized in GCMs. The high-resolution models themselves require further development, so it is important that they be examined against field data for robustness.

A three-dimensional, limited-area nonhydrostatic (LAN) model, developed at GFDL (Lipps and Hemler, 1986), has been used to examine tropical convection associated with large-scale moisture convergence. Domain-averaged properties of the convection, *e.g.*, phase changes and eddy fluxes of heat and moisture, are calculated explicitly using this model. Similar processes are parameterized in Donner (1993). A unique feature of Donner (1993) is its treatment of both cumulus-scale and anvil-scale processes. To explore the latter completely in the LAN model, a radiative-transfer formulation (*cf.*, Held *et al.*, 1993) has been included.

2. RESULTS

Some representative results from test runs of the LAN model are illustrated in Figures 1-3. The vertically averaged condensation rate is depicted in Figure 1. Other phase changes, involving evaporation, melting, freezing, deposition (from vapor to ice), and sublimation, are also calculated by the LAN model, as are conversion rates between cloud water (suspended particles) and snow and rain. Several distinct cumulus cells are evident. The domain-averaged condensation, as a function of height, is a crucial product of Donner (1993). When the condensation rate is added to other phase-change and eddy-flux-convergence rates, the large-scale (domain-averaged) forcing by the convective system is obtained. Figures 2 and 3 show the LAN model results for heat and moisture, respectively.

Figures 4 and 5 show large-scale thermal and moisture forcing diagnosed from tropical observations in the east Atlantic and from parameterizations for convective systems with various morphologies, discussed in Donner (1993). (The large-scale environment used to evaluate the parameterization in Figures 4 and 5 is not necessarily identical to that used with the LAN model.) On Figures 4 and 5, "Cells" refers to parameterized forcing by an ensemble of cumulus cells without a mesoscale anvil whose vertical velocities match observations. "Meso" refers to parameterized forcing by an ensemble of cumulus cells and a mesoscale anvil. "Diag" refers to forcing diagnosed from observations. "Strong" refers to parameterized forcing by an ensemble of cumulus cells whose vertical velocities are much stronger than observations. The LAN forcings exhibit some differences from both parameterized and diagnosed forcings, but it should be noted that the LAN integration shown covers only the early stages of the life cycle of a convective system, which is dominated by cumulus cells rather than mesoscale anvils. Note that the LAN forcings exhibit some of the features associated with parameterized cells, including a maximum in the heating profile at a lower height.

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3. CONCLUSION

A procedure by which high-resolution cloud-system-resolving models can be used to assess cumulus parameterizations for GCMs has been demonstrated. Individual physical processes can be isolated in the LAN integrations for comparison with their representation in parameterizations. The robustness of the LAN models themselves must be further assessed to establish the credibility of this procedure by using data from field programs.

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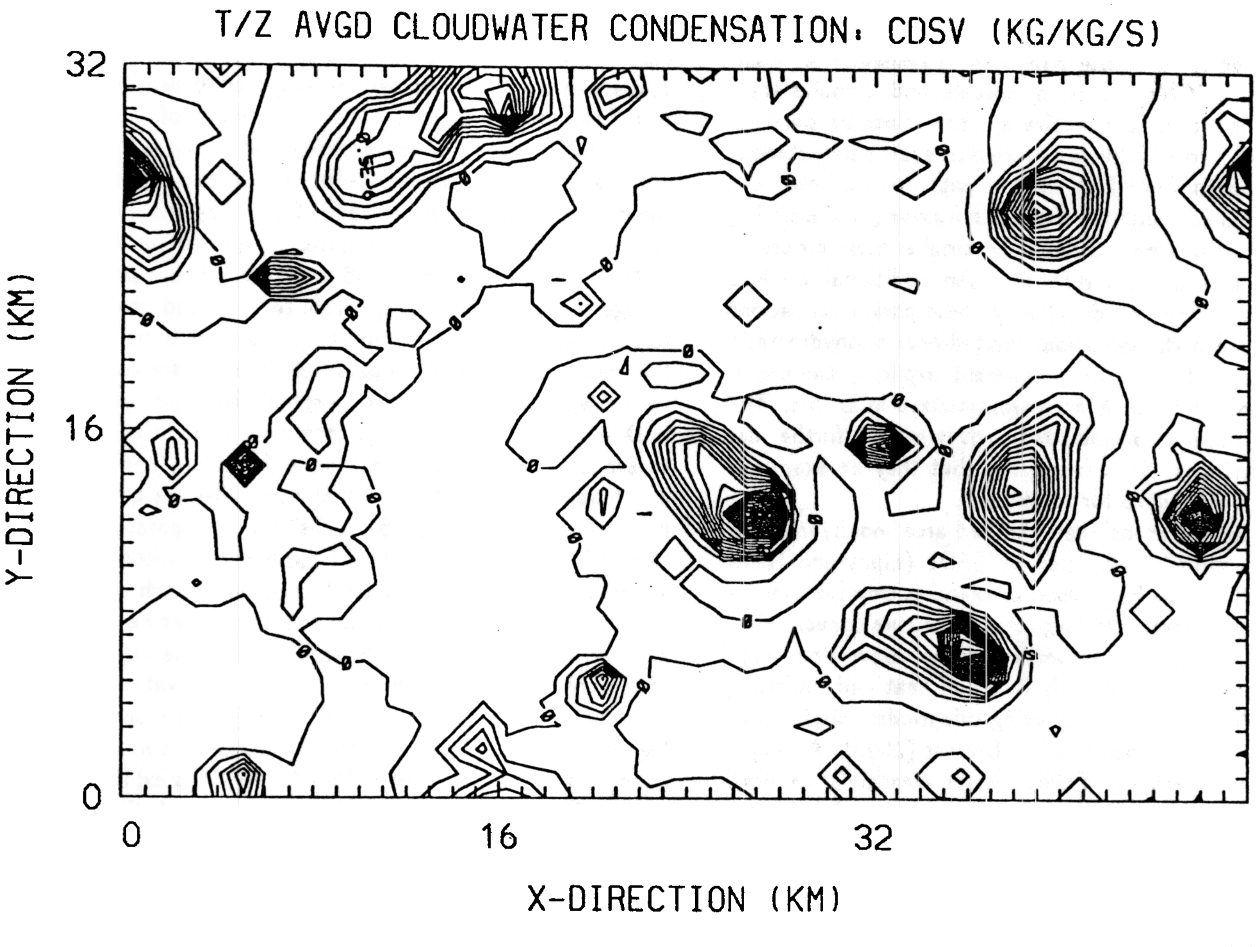

Figure 1. Vertically averaged (.125-15.125 km) rate of condensation for a 4-hour integration of the GFDL LAN model. Tropical conditions typical of deep convection in the east Atlantic. Horizontal resolution is 1 km and vertical resolution is 250 m. Contour interval is 10^{-7} kg kg^{-1} sec^{-1}.

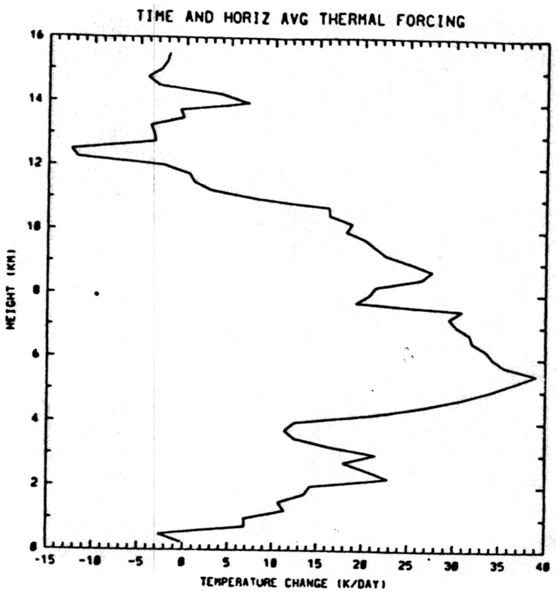

Figure 2. Large-scale thermal forcing by cumulus convection, calculated using the GFDL LAN model, for the integration shown in Figure 1.

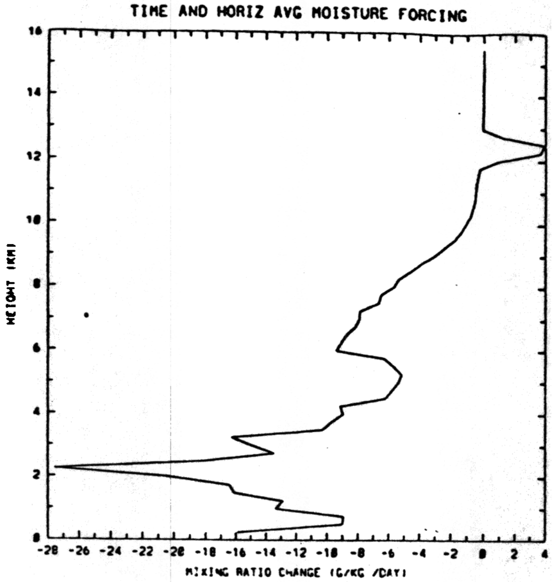

Figure 3. Same as Figure 2, except for moisture forcing.

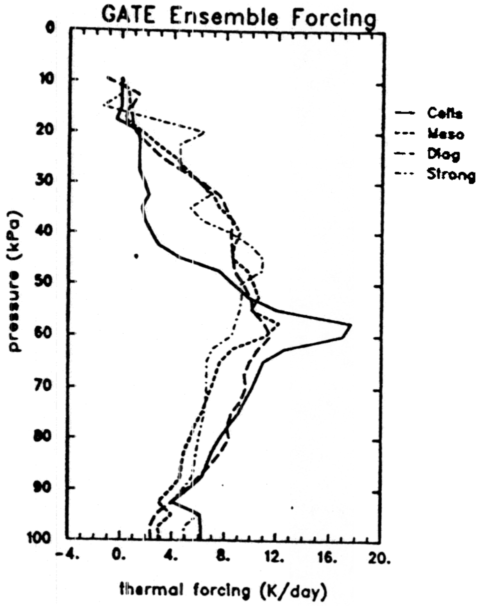

Figure 4. Large-scale thermal forcing by cumulus convection, calculated using Donner's (1993) parameterization and diagnosed from observations.

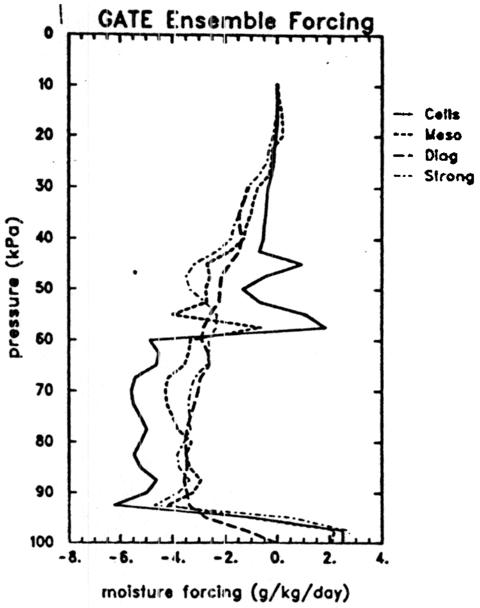

Figure 5. Same as Figure 4, except for moisture forcing.