Final Report

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Improvement in Moist Processes in Atmospheric General Circulation Models

Overview

The research supported by this grant consisted of two closely related studies. One of these involved further evolution and testing of a convective wake model designed to improve the parameterization of deep convection in climate models. The second area consisted of a statistical analysis of two tropical data sets designed to examine the predictability of the moisture field in the atmosphere with the goal of determining the limits of predictability and to develop better methods of preventing slow drift of the moisture field in climate models. The results of these studies are reviewed below.

Development and Refinement of the Convective Wake Model

It has long been known that the replacement of warm, moist boundary layer air with colder and usually drier air from convective downdrafts has major effects on the atmosphere. This is the primary mechanism by which the atmosphere is locally stabilized in the vertical, and the cold outflow boundaries of the convective wake help to organize convection on the mesoscale. Further, correlations between enhanced winds associated with these gust fronts and the anomalously cold, dry air of the convective wakes are thought to produce nonlinear enhancement of surface fluxes on scales well below the resolution of climate models.

Cumulus parameterization schemes that do not include simulated effects of convective downdrafts are physically unrealistic. However, simply including the estimated effects of downdrafts to the parameterizations effects on the average properties of the column often does more harm than good. Deep convection, particularly in the tropics, typically exists very close to a state of convective neutrality (Xu and Emanuel, 1989). Hence, a small amount of cool, dry air mixed in the boundary layer of a GCM grid column can stabilize the entire column, while in nature the convective wakes would occupy localized areas that would fill only a part of a model's grid column (McBride and Frank, 1998). Simplistic inclusion of downdrafts in parameterizations often causes the convection to flicker on and off at high frequency. Further, such methods offer no way of getting at either the mesoscale organizing effects of the wakes or the possible enhancement of surface fluxes.

The PI and his colleagues developed a simple but physically realistic wake model under support from a previous grant (Qian et al, 1997). This model confined the air detrained by downdrafts to a limited portion of the grid column and simulated the evolving dimensions and recovery of the wake. This allowed the cumulus convection to feed off undisturbed air from outside the wake and provided methodologies for estimating forced uplifting of air by gust fronts and enhanced surface fluxes of sensible heat and moisture.

In the current project the Qian et al. (1997) convective wake model was installed in a single

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column model version of the Community Climate Model Version 3 (CCM3) and tested with data sets from TOGA-COARE and GATE. The wake model was used with both the standard deep convective parameterization of CCM3 and a convective adjustment scheme that had been modified to include downdrafts (Betts and Miller, 1986). Further refinements and improvements to the wake model were developed and incorporated.

The wake model performed as expected, with the result that convection tended to occur in episodes of reasonable duration rather than in a flickering fashion. The TOGA-COARE tests were difficult to evaluate quantitatively due to apparently significant shortcomings of that data set. Forcing the model over 20-day periods with either parameterization scheme, with or without the wake model added, resulted in a major drift to unrealistically cold temperatures. Other researchers have found the same problem. Better results were achieved with the GATE Phase 3 data set. In these tests the lapse rate adjustment approach generally produced results that were judged more realistic than the results using the standard CCM3 parameterization. Inclusion of the wake altered the results and modified the time-averaged surface fluxes. We are currently performing diagnostics to assess how much of an improvement the wake caused, and this will be reported when we publish the results in the refereed literature. Our initial view is that the inclusion of the wake model is both physically logical and conducive to more realistic model simulations.

Statistical Analysis of Moisture Variations

Much of the research on cumulus parameterization techniques has focused on relationships between the convection and the vertical stability due to the obvious first-order effect of the latter on the former. However, climate models are used for long-term simulations wherein the effects of the parameterization on the slow evolution of the moisture field are often more important than the nature of the specified convective heating. This sensitivity results primarily due to the strong effects of the moisture, particularly in the upper troposphere, on the radiative heating. Cumulus parameterizations that apparently do a good job of getting approximately the right amount of heating in the right place are pleasing to persons interested in short-term weather forecasts, but if the moisture field drifts to an unrealistically dry or moist state, the equilibrium state of the atmosphere may go seriously awry when the scheme is applied in a climate model.

Our study examined the data sets from both GATE and to a lesser extent TOGA-COARE to analyze the time scales of atmospheric moisture variation and then to find statistical relationships between variations in both the amount and vertical distribution of water vapor in a column and a wide range of other variables and processes. The goal was to see whether empirically based predictors could be included in cumulus parameterization schemes to improve the model predictions of long-term evolution of the moisture field.

The sampling intervals of even these high-quality data sets (3 h for GATE, 6 h for COARE) are significantly longer than the time steps of numerical models, which limits resolution of moisture variability to periods of 12 h or longer. The data show some tendency for moisture to vary with the 12-18 h period typical of tropical mesoscale convective system lifetimes, but this signal is weak. Diurnal variations may be present but are difficult to analyze because of possible sampling errors introduced by solar radiation effects. The dominant variability in the moisture field during GATE occurs with a period of 3-4 days, which corresponds to the period of the African waves that were strong during GATE Phase 3.

Many potential predictors were tested, but only a few showed significant skill in predicting the slow evolution of either the precipitable water field or the relative humidity profile. In particular, the best skill was obtained from a procedure that used the change in total energy in the column (known from processes outside the cumulus parameterization in a model) as the primary predictor of changes in the moisture field. The results of this study suggest that it may be possible to improve the accuracy of the moisture field forecasts in climate models by incorporating empirical statistical procedures into the cumulus parameterization schemes. These procedures would adjust the parameterized convection to nudge the solutions towards more realistic temporal and spatial variations in the moisture field using predictors obtained from a variety of data sets. The adjustments to the parameterized convection would be small at individual time steps but would seek to constrain the solutions to avoid slow drifting of the humidity field during long simulations.

References

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