4B.5 EVALUATION AND IMPACT STUDY OF CONVECTIVE MOMENTUM PARAMETERIZATION USING 3D CLOUD-RESOLVING MODEL AND GENERAL CIRCULATION MODEL

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1. INTRODUCTION

Tropical cloud systems, through their release of latent heat and redistribution of heat, moisture and momentum, play an important role in the coupling of large-scale dynamic and thermodynamic processes. The effects of convection on the large-scale temperature and moisture fields (and indirectly on the large-scale momentum field) are represented by convection schemes in all GCMs, but the effects of convective momentum transport (CMT) on the large-scale field are usually neglected due to the complexity and inadequate understanding of the processes involved. Also, the development of convective momentum parameterization has been hindered by the lack of direct observation and accurate estimates of the "apparent momentum source" by cloud systems. Unlike heat and moisture, it is very difficult to get a reliable estimate of the apparent momentum source from observations. Cloud-resolving models (CRMs) are a comprehensive alternative.

2. CONVECTIVE MOMENTUM PARAMETERIZATION SCHEMES

Detailed descriptions of two CMT parameterization schemes can be found in Zhang and Cho (1991) and Wu and Yanai (1994). Physical processes through which convection affects the large-scale momentum field include: (1) the subsidence compensating cloud mass flux; (2) the detrainment of excess momentum from clouds; and (3) the convection-induced pressure gradient force. The Zhang and Cho scheme adopted a bulk cloud model for representing in-cloud temperature, moisture and momentum properties, while the Wu and Yanai scheme used a spectral cloud model. The cloud-scale pressure gradient force is related to the vertical wind shear, cloud mass flux and organization of convection.

3. CLOUD-RESOLVING MODEL AND 3D SIMULATION OF GATE CLOUD SYSTEMS

The NCAR CRM is based on the Clark-Hall finite-difference formulation of the anelastic, nonhydrostatic equations. A Kessler bulk warm rain parameterization and a Koenig and Murray bulk ice parameterization are used. The surface fluxes of sensible and latent heat are calculated using the observed sea surface temperature (SST) and a simple bulk scheme. The horizontal domain is 400 km×400 km with a 2-km resolution. There are 42 levels in the vertical with a stretched grid (100 m at the surface, increasing to 1200 m at the model top of 26 km). A time-step of 15 s is used. Periodic lateral boundary conditions ensure that there is no forcing inside the domain apart from large-scale forcing. Free-slip, rigid bottom and top boundary conditions are applied together with a gravity wave absorber in the uppermost 7-km of the domain.

The CRM is forced by the evolving large-scale

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advection of temperature and moisture. The observed radiative tendency is included in the large-scale forcing. Since the accurate calculation of the large-scale forcing for the horizontal wind field (especially the large-scale pressure gradient) is difficult to obtain from observations, a relaxation term is included in the momentum equations to ensure the domain-averaged horizontal velocities following the observed values. The 7-day (September 1-7, 1974) three-dimensional (3D) CRM simulation of GATE cloud systems, which is presented in Wu and Moncrieff (1996) and Grabowski et al. (1998), is used in this study. The 3D simulation produces remarkably realistic cloud field evolutions.

4. EVALUATION OF CMT SCHEMES

The performance of two CMT schemes are examined using the same large-scale conditions that force the 3D CRM. Figure 1 shows the 7-day evolution of apparent momentum sources from the 3D CRM and the Wu-Yanai scheme and the observed zonal wind component during GATE. The convective updrafts transport a significant amount of horizontal momentum vertically. There are larger apparent momentum sources (Figs. 1a and 1b) associated with a low-level easterly jet and stronger vertical wind shear (Fig. 1c) during days 3-5. The observed evolution of CMT is well reproduced by the Wu-Yanai scheme and also the Zhang-Cho scheme (not shown). The agreement between the CRM-produced and parameterized cloud mass flux contributes to this success.

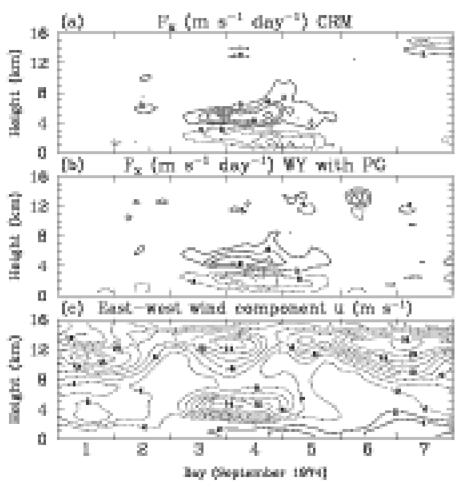

Figure 1: Evolution of (a) apparent momentum source (F_x) from 3D CRM, (b) F_x from the Wu and Yanai CMT scheme with the convective pressure gradient force, and (c) east-west wind component for the 7-day period (1-7 September 1974) during GATE.

Figures 2a and 2b show the 7-day mean vertical profiles of apparent momentum sources produced by the two schemes, respectively, and the 3D CRM-produced GATE result. Both the Wu and Yanai scheme and the Zhang and Cho scheme reproduce the apparent momentum source obtained from the 3D CRM. The inclusion of cloud-scale pressure gradient force in both schemes has a large impact on the in-cloud momentum and the parameterized apparent momentum source, especially in the upper troposphere.

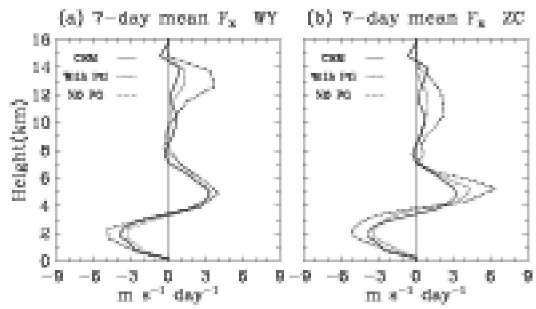

Figure 2: 7-day mean vertical profiles of apparent momentum source (F_x) from (a) the Wu and Yanai convective momentum scheme and (b) the Zhang and Cho scheme. Solid lines are from the 3D CRM, dotted lines are from two schemes, and dashed lines are from two schemes without the convective pressure gradient force.

5. GLOBAL IMPACT OF CMT

In order to assess global impact of CMT, two 20-year (1979-1998) CCM3 simulations (without and with the CMT scheme) have been conducted using the AMIP II monthly SST. Since the CCM3 uses the Zhang and McFarlane (1995) convection scheme, the implementation of the Zhang and Cho CMT scheme in CCM3 is straightforward. Upon the successful implementation of the Arakawa and Schubert convection scheme in CCM3, the Wu and Yanai CMT scheme will be tested.

The result shows strong impacts of CMT on the Inter-Tropical Convergence Zone (ITCZ). The global precipitation distribution is closer to the observed distribution than the standard CCM3 simulation. The December mean precipitation over the tropical western Pacific and the July mean precipitation over the tropical eastern Pacific are reduced in the runs with CMT, which are positive impacts for the coupled model as the standard CCM3 produced too much fresh water over these regions for the ocean model. Strong impact is also shown in the surface wind stress and surface heat flux fields. A detail analysis will be presented in the meeting.