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PURSUING REALISTIC INTRA-SEASONAL WAVE MODES USING A NOVEL APPROACH TO CONVECTIVE PARAMETERIZATION

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1. INTRODUCTION

Tropical intra-seasonal wave modes inevitably involve organization of convection at a variety of spatial scales leading to coherent and long-lived disturbances (Wheeler and Kiladis 1999). The absence of the representation of this organization within convection schemes may explain the poor performance of models in capturing such wave modes.

The parameterization of cumulus convection in low-resolution atmospheric models inevitably involves an assessment as to the type of air to be entrained. GCMs commonly need to retain low entrainment rates in order for convection to reach sufficient altitude. Such low entrainment allows the boundary layer to retain all moisture sensitivity, allowing little sensitivity to free tropospheric humidity. This profile of moisture sensitivity is incorrect (Mapes 2004). Low entrainment rates have also been shown to be detrimental to the timing of convection over land.

This study demonstrates a convection scheme which addresses low entrainment rate problems, and a representation of organization aiming to improve model variability.

2. SUCCESSIVE GENERATIONS

The approach taken in this study considers the *successive entrainment* of a number of convective plumes. In this approach, entraining plumes are assumed to always undergo strong mixing with their immediate environment, but that environment is allowed to deviate from the large-scale mean properties.

Specifically, plumes entrain exactly two types of air: saturated up to the level of previous cloud tops; environmental air above that. This representation appears to be a better description of convective potential than just referring to the energy (CAPE) of an undilute parcel ascent, which can be negatively correlated with convective activity.

Figure 1b shows the resulting buoyancy of plumes which entrain the properties of several previous generations of clouds existing in the environment of Fig 1a. In the absence of any organization the resulting convection is unlikely to be significant given the low likelihood of several generations randomly occurring in the same place. However, in the presence of pre-existing convective organization the chance of continued deep convection is much higher, as plumes have a tendency to be initiated in the same location. This example illustrates the merit of a successive generation scheme.

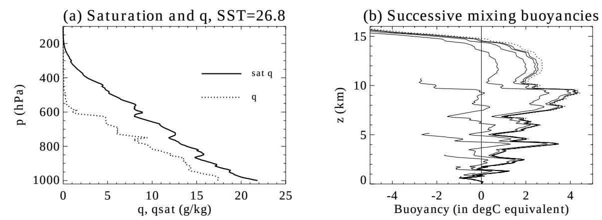

Figure 1. A successive-generation calculation (10 plumes) based on a single sounding, from a ship at 95W 0N on 15 Feb., 1995

3. MODEL FORMULATION

The current model solves the primitive equations in sigma coordinates with 4 vertical levels, based on code from Zhu et al. (2001). For simplicity radiative processes are idealized as a cooling of 1.25 K/day everywhere.

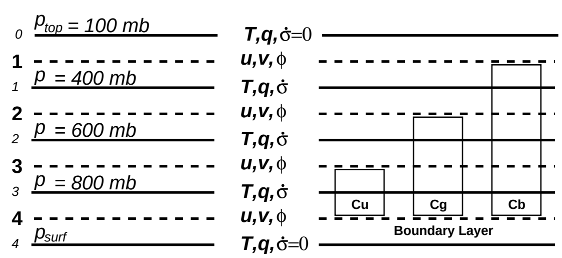

Figure 2. The model's vertical grid structure with approximate pressure value of levels and configuration of cloud types.

The vertical discretization is a useful test-bed for advanced cumulus parameterization (Fig. 2). This exploits the 'trimodal' spectrum of clouds as an appropriate complexity for the vertical structure of tropical convection (Johnson et al. 1999). The Charney grid is chosen to avoid spurious computational modes which may be significant in the Lorenz grid with such coarse vertical resolution.

Surface fluxes use a bulk aerodynamic formula with a single drag coefficient for heat, moisture and momentum. A low-wind speed correction uses an effective wind speed taken from consideration of the mean turbulent kinetic energy of the boundary layer (TKE), giving the effective value $u_f = (u^2 + 2TKE)^{0.5}$.

3.1 Convective Parameterization

Our consideration of surface based vertical convection allows three cloud types in the chosen vertical grid (Fig. 2). These are labeled cumulus (Cu), congestus (Cg), and cumulonimbus (Cb). The mass flux at the model's half

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(T,q,w) levels and for each cloud type is formed from $M=\rho w\sigma$: ρ being fixed density; w a prognostic vertical velocity; and σ a fractional area coverage.

The shape of the mass flux profile is controlled subject to a single value entrainment parameter. This still leaves sufficient model mechanisms to achieve a stable climate and variability. The operation of the scheme therefore lies in determining T and q convective tendencies individually from the different cloud types.

3.2 Prognostic Treatment Of Subgrid Organization

Horizontal variations in the PBL lie at the center of our methodology for convective organization. Observations clearly show the necessity of distinguishing between post- and pre-convective air. As a simple attempt to respect this fact we introduce a prognostic PBL temperature-range variable ΔT. We confine ourselves to variations only in PBL temperature as observations suggest rapid recovery of boundary layer humidity leaves q variations small.

We envisage ΔT to enhance convection in two ways. First, due to buoyant plumes arising from warmer than average PBL air ($T+\Delta T/2$). Second, by relating an 'organized' kinetic energy (OKE) to ΔT and thus reflecting some mean energetic lifting which occurs at gust fronts. The source term for ΔT is provided by the re-evaporation of rainfall leading to a downdraft eddy temperature flux. The sink of ΔT is a relaxation back to zero, based on bulk aerodynamic models of the temperature dependence of surface heat flux over water.

3.3 Closure

The scheme's closure is based around determining two target area fractions for each entrainment scenario; random, σ_{ran}; and organized, σ_{org}. Purely random convection has random overlap with the pre-existing stock of convective clouds (σ_{cu}, σ_{cg}, σ_{cb}). Organized new-updraft area probability is precipitation weighted, allowing for a higher probability for plumes to be initiated in proximity to existing convection.

The random fractional area formulation for each cloud type invokes Boltzmann's partition function from statistical mechanics. The probable area fraction of buoyant convection for an environment with RKE random kinetic energy and CIN convective inhibition in the PBL is thus, $\sigma_{ran} = \exp(-CIN/RFI)$. In a similar way σ_{org} for a particular plume scenario (e.g., pre-existing Cu) is also governed by this relationship, but the target area cannot exceed the area fraction of the entrained cloud type, such that $\sigma_{org}^{cu} = \exp(-CIN/OFI)\sigma_{cu.}$

4. RESULTS

Here we briefly describe results from two experiments. Detailed figures illustrating these results can be found at http://www.cdc.noaa.gov/~rneale/successive.html.

4.1 Tropical Wave Modes

In 3D experiments the model is able to reproduce a wide range of tropical wave activity on different time and space scales. Particularly encouraging is the significant power found at intra-seasonal time-scales and low zonal wavenumber. This localized (in time and space) wave power compares favorably with Wheeler and Kiladis (1999) and with the MJO-like disturbance captured by Grabowski (2003), who uses a more complex cloud-resolving convective parameterization method.

4.2 Diurnal Cycle Case Study

In addressing the problem of the premature daytime rainfall maximum over land, a simple 1D experiment using data from a GEWEX Cloud System Study (GCSS) diurnal cycle case study clearly shows the benefit of the organized aspect of the model's structure. With the inclusion of successive generation the model is able to simulate the gradual growth of convection, both in terms of area fraction and cloud depth, in response to the surface forcing. Furthermore the average timing of the rainfall maximum occurs in the afternoon, in response to the forcing provided by the integrated organization information of the ΔT and OFI parameters.

5. Conclusions

This work is still in its early stages and requires more refinement. Ultimately, the method will prove its worth by its inclusion in convection schemes of higher vertical resolution in reputable large-scale models.

References

Grabowski, W. W., 2003: MJO-like coherent structures: Sensitivity simulations using the cloud-resolving convection parameterization (CRCP). *J. Atmos. Sci.*, **60**, 847-864.

Johnson, R. H., T. M. Rickenbach, S. A. Rutledge, P. E. Ciesielski, and W. H. Schubert, 1999: Trimodal characteristics of tropical convection. *J. Climate*, **12**, 2397-2418.

Mapes, B. E., 2004: Sensitivities of cumulus ensemble rainfall in a cloud-resolving model with parameterized large-scale dynamics. *J. Atmos. Sci.*, in press, available at http://www.cdc.noaa.gov/~bem.

Wheeler, M. and G. N. Kiladis, 1999: Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain. *J. Atmos. Sci.*, **56**, 374-399.

Zhu, H., R. K. Smith, and W. Ulrich, 2001: A minimal three-dimensional tropical cyclone model. *J. Atmos. Sci.*, **58**, 1924-1944.