16B.6 CONVECTIVELY GENERATED INERTIAL-GRAVITY WAVES AND THE MULTI-SCALE ORGANIZATION OF CONVECTION

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1. Introduction

What determines the spatial distribution of precipitating convection? How does convective organization factor into the scale-selection problem?

Attempts at solving the scale-selection problem for precipitating convection has met with vexing and basic impediments. For example, in classical inviscid linear perturbation theory, where the Richardson number is the key dimensionless quantity: i) the most rapidly amplifying purely convective instabilities have too short a horizontal wavelength, infinitely short in unsheared mean flow; ii) systems tilt in the direction of travel (forward) never backward, yet a backward tilt is a prominent characteristic of squall lines; and iii) the Miles-Howard theorem means that linear perturbations always have a steering-level, so systems do not propagate.

The introduction of viscosity (Reynolds number) or planetary rotation (Rossby number) introduces finite scales of instability. There is a rich volume of literature on Rayleigh convection in the presence of shear and planetary rotation. Nevertheless, application of these dry theories to moist convection is less than satisfactory, suggestive of missing physics.

Bolton (1980) showed gravity-wave forcing alleviates difficulties: when out-of-phase with the vertical velocity, gravity-wave forcing permits amplifying and propagating linear disturbances as well as a backward tilt. Thus the interaction between convection and gravity waves partly addresses the above issues. Mapes (1993) shows that gravity waves affect convective clustering in the tropics.

Convectively-coupled gravity waves have been examined using ‘intermediate’ models, which are distinguished by a crude vertical resolution. These models incorporate simple parameterizations of convective downdrafts, radiative cooling, boundary-layer turbulence, and surface drag (e.g., Yano et al. 1995).

Majda and Shefter (2001) found two modes of maximum instability: at 200 km (mesoscale convective system, MCS) and at 1200 km (super-clusters). However, scale selection and propagation are alarmingly sensitive to parameters specified in the convective parameterization (e.g., cloud-fraction).

The multi-scale models of Majda and Klein (2003) are based on rigorous asymptotic theory. The scale selection properties have not yet been investigated.

In summary, on theoretical grounds, gravity waves, convective organization and scale selection are all interlinked. This paper seeks relationships among gravity waves and convective organization as revealed by 2-D numerical experiments.

Firstly, the dry dynamical response to the specified heating

$$Q(x,z) = Q_0 \cos\frac{\pi x}{H}\left[\sin\frac{\pi z}{H} - \gamma\sin\frac{2\pi z}{H}\right] \qquad |x| \le L;\ 0 \le z \le H$$

is examined. The parameter γ is a measure of the relative strengths of stratiform and convective heating. Secondly, the multi-scale organization and scale-selection of moist convection in a large-scale domain is examined using a cloud-resolving model.

2. Results

- The vertical heating profile affects the amplitude of the two gravest modes (‘fast’ and ‘slow’ waves). The fast wave is a response to deep heating. Temperature and moisture perturbations beyond the leading edge of the slow wave are insensitive to the heating profile.
- The slow wave is excited by stratiform heating. As amplitude increases, its effect on the near-environment is comparatively more important at all values of *f*, the Coriolis parameter. Enhanced low-level lifting implies that convective systems with stratiform regions are conducive to a strong slow-wave response affecting the initiation/maintenance of convection in the near environment.
- In a moist atmosphere, planetary rotation concentrates drying in the neighborhood of convective systems and reduces drying in the far field. This is detrimental to convection in the near field because it decreases CAPE and increases the convective inhibition.
- Enhancement of CAPE in the near-field by stratiform heating by the slow wave is consistent with the stratiform-heating response that enhances the CAPE and promotes convection in the near-field.
- Conversely, reduced warming and drying by planetary rotation favors convection in the far-field. Rotation modulated subsidence warming and drying indicates

that the low values of *f* the tropics favor convective clustering. This result is in agreement with Mapes (1993).

- Multi-day convection-resolving simulations in constant easterly flow reveals three scales of convective organization (Fig. 1). Convectively coupled gravity waves propagate eastward as large-scale envelopes of precipitating convection. Embedded within these envelopes are westward-traveling mesoscale convective systems that, in turn, contain westward-traveling deep convective cores. This is broadly similar to the scales of organization identified by Grabowski and Moncrieff (2001) in a larger domain.

- Triggering of the westward traveling convective cores is due to local forcing at the sharp fronts of density current outflow from convective downdrafts from antecedent cores (Liu and Moncrieff 1996).

- The effects of the *three* gravest wave modes on CAPE and convective inhibition was shown by Lane and Reeder (2001), for a single convective cell. Far-field CAPE was reduced by 15% and the near-field convective inhibition was reduced by 33%. Here the *two* gravest modes have the largest amplitude. Figure 2 shows a complex but nevertheless comprehensible relationship between CAPE and precipitation distribution by a population of convective systems.

- Lane and Reeder's second gravest wave mode produces *negative* displacements at low levels, herein there is a *positive* displacement. This difference has strong implications for convection initiation.

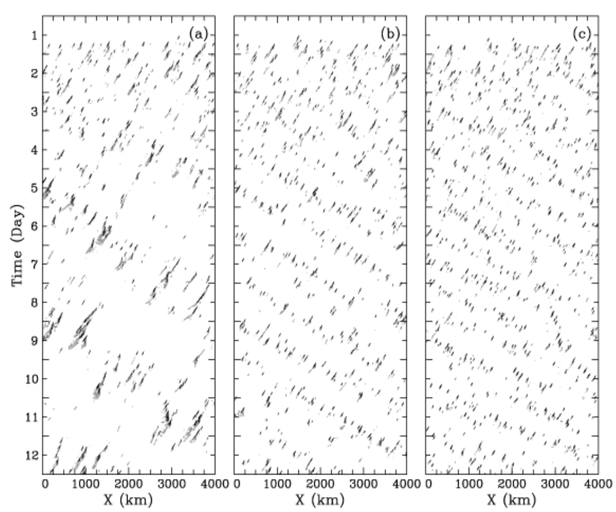

Figure 1 Space-time distributions of the surface precipitation rate for simulations having a constant easterly mean flow of 6 m/s maintained by Newtonian relaxation for a) f= 0; b) f= 0.5 x $10^{-4}s^{-1}$;and c) f= $10^{-4}s^{-1}$. The light and dark shading shows precipitation rates larger than 0.1 and 10 mm/h, respectively.

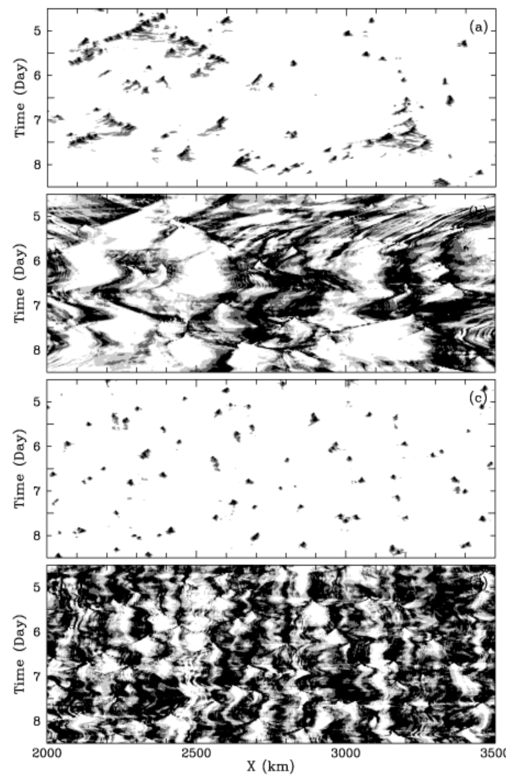

Figure 2. Space-time distribution of the precipitation rate and CAPE domain during a 4-day period over a sub-domain for simulations having a motionless initial state. Plates a) and b) are representative of the tropics, and c) and d) of mid-latitudes. Light gray, dark gray and black shading show values larger than 0.1, 1, and 10 mm/hr in a) and c) and 1, 1.5 and 2kJ/kg, in b) and d), respectively.

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