17B.2 EVOLUTION OF MIXED ROSSBY GRAVITY WAVES IN MJO TYPE ENVIRONMENTS

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1. Introduction

A linear shallow water model is used to examine the evolution of mixed Rossby-gravity (MRG) waves in an environment representative of the convective phase of the Madden Julian Oscillation (MJO). The impetus for this investigation is provided by past studies that have suggested a link between equatorial MRG waves and off-equatorial TD-type disturbances in the western Pacific (e.g., Liebmann and Hendon 1990; Takayabu and Nitta 1993). Sobel and Bretherton (1999) recognized that the development of TD-type disturbances from an MRG wave is a complex phenomenon that involves reduction of the wavelength of the MRG wave and the elimination of the antisymmetric structure of the MRG mode. In a recent study, Dickinson and Molinari (2002) documented the evolution of TD-type disturbances in association with an MRG wave within the convective envelope of the MJO in the western Pacific. Their observations are used to design the simulations presented here.

2. Method

The shallow water equations for a single layer of fluid, linearized about a basic state, are employed for the simulations. The steady state response of the tropical atmosphere to a mass sink in the presence of linear frictional damping is used to define the MJO type environment. The basic state is inhomogeneous in space, but invariant in time. The initial perturbation fields, i.e., the MRG waves, are analytically obtained following the method outlined by Zehnder (1991). All numerical experiments are conducted on an equatorial beta-plane with dimensions 40,000 km x 8000 km. The domain is continuous along the zonal direction and confined to a channel along the meridional direction.

3. RESULTS

The structure of the mass sink (Fig. 1a) is an idealization of the heating field associated with the MJO observed by Dickinson and Molinari (2002). Fig. 1b shows the basic state height, convergence and winds obtained after integrating the shallow water equations, starting from rest, until a steady state is reached in response to the mass sink and frictional damping. The basic state presented in Figure 1 is a variant of the solution described by Gill (1980). The steady state is interpreted as being a combination of a Rossby mode, west of the forcing, and a Kelvin mode, east of the forcing (Matsuno 1966; Gill 1980). Owing to the asymmetry in the mass sink, the Rossby gyre in the northern hemisphere is distinctly more prominent than its southern hemisphere counterpart. A broad trough along the equator comprises the response east of the mass sink. In the vicinity of the equator, the zonal flow reverses direction, from westerly to easterly, at about x=2000 km. This steady state response is taken to be the idealized MJO basic state within which the MRG waves are allowed to evolve in the linear shallow water model.

Fig. 2a depicts the initial vorticity field of the analytically derived MRG wave that has a wavelength of 5000 km. The basic state convergence associated with the MJO is shaded for reference in the background. In a quiescent environment, the MRG wave propagates westward, unmodified, with a phase speed of 9.2 m/s (not shown). The evolution in the presence of the MJO is significantly different, as seen in the vorticity fields after 120 h (Fig 2b) and 240 h (Fig 2c) of model simulation. The Hovmoller diagram for the meridional wind at the equator is presented in fig. 2d.

The salient features of the evolution are as follows: (1) At T=0 h, the vorticity centers are located at the equator, consistent with the unperturbed MRG wave mode; (2) By T=240 h, a series of small cyclonic and anticyclonic circulations, with a Northwest to Southeast orientation, has developed within the region of basic state convergence; (3) These circulations have length scales that are shorter than the initial MRG wavelength, and they propagate at a rate slower than the phase speed of the MRG wave; (4) Though off-equatorial parts of the MRG wave develop into these smaller scale features, the wave continues to propagate westward (fig 2d); (5) Portions of the wave experience contraction in the wavelength as seen around x=2000 km (fig. 2c); (6) The maximum vorticity at T=240 h is found at about 1000 km north of the equator (fig. 2c); (7) As evident in fig. 2d, the westward phase speed of the MRG wave is reduced as it encounters westerlies in the basic state; (8) As the simulation proceeds, a wave packet like structure develops with an identifiable eastward group propagation in the Hovmoller diagram (fig. 2d). In time, the group speed decreases in response to the opposing easterly flow and is accompanied by a decrease in wavelength, indicative of a process of wave accumulation (fig. 2d).

The small scale circulations that develop within the idealized MJO envelope in conjunction with the MRG wave may represent TD-type disturbances that have been observed in past studies (Liebmann and Hendon

1990; Takayabu and Nitta 1993; Dickinson and Molinari 2002). The results from the simulations show that in the presence of a basic state representative of the MJO, off-equatorial disturbances may develop out of a purely equatorial mode such as an MRG wave. Additionally, along the equator, an MRG wave packet seems to develop and grow through wave accumulation. These results appear to be consistent with the findings of Dickinson and Molinari (2002). This process may be particularly relevant to the cyclogenesis in the tropical western Pacific, a region that is influenced by the MJO, and where MRG waves are frequently observed.

Acknowledgments

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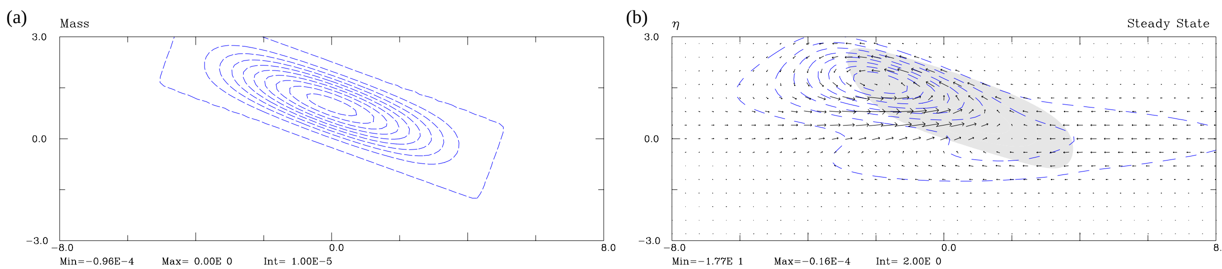

Fig. 1: (a) Mass sink representative of the idealized MJO; and (b) Steady state response to the mass sink used as the basic state - Height (dashed), convergence (shaded) and winds (vectors). Domain shown here is 16000 km x 6000 km.

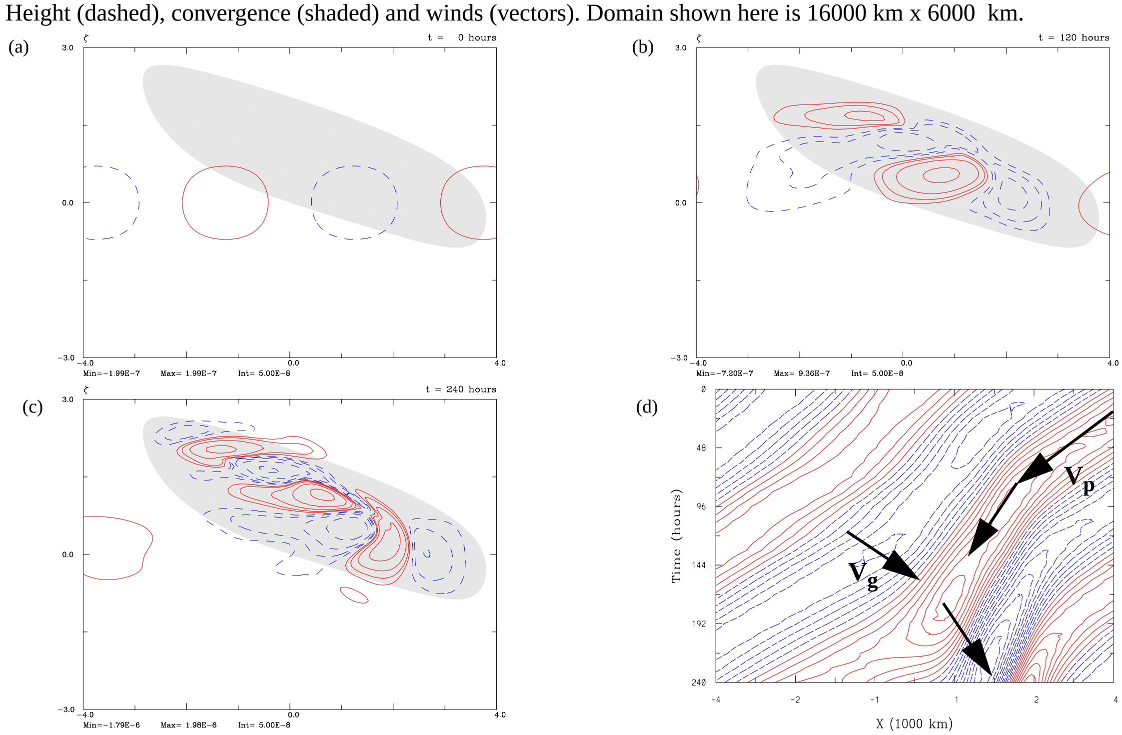

Fig. 2: Charts of relative vorticity associated with MRG waves in an idealized MJO environment at (a) T=0 h; (b) T=120h; and (c) T=240 h. Shaded area denotes convergence in the basic state; and (d) Hovmoller diagram of meridional wind speed at the equator. Domain shown here is 8000 km x 6000 km