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p4

ON THE ROLE OF SURFACE FRICTION IN TROPICAL INTRASEASONAL OSCILLATION

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1. INTRODUCTION

The Madden-Julian oscillation (MJO), or the tropical intraseasonal oscillation, has attracted much attention, ever since its discovery in the early seventies (Madden and Julian 1971, 1972, 1994) for reasons of both scientific understanding and practical forecasts (Ferranti et al. 1991). Among the theoretical interpretations of the MJO, the wave-CISK (conditional instability of the second kind) mechanism (Chao 1987, Lau and Peng 1987, Miyahara 1987, Hendon 1988, Chang and Lim 1988, Wang 1988, Kirtman and Vernekar 1993 and Blade and Hartmann 1993, among others) is the most popular. The basic idea of the wave-CISK interpretation is that the cooperation between the low-level convergence associated with the eastward moving Kelvin wave and the cumulus convection generates an eastward moving Kelvin-wave-like mode. Later it was recognized that the MJO has an important Rossby-wave-like component (Chao 1987, Nogues-Paegle et al. 1989). However linear analysis and numerical simulations based on it (even when conditional heating is used) have revealed two problems with the wave-CISK interpretation; i.e., excessive speed and the most preferred scale being zero or grid scale. Chao (1995) presented a discussion of these problems and attributed these problems to the particular type of expression for the cumulus heating used in the linear analyses and numerical studies (i.e., the convective heating is proportional to low-level convergence and a fixed vertical heating profile). It should be pointed out that in the relatively successful simulation of MJO with general circulation models the problem of grid scale being the most preferred scale does not appear and the problem of excessive speed is not as severe as in the linear analysis.

Various attempts have been mounted to salvage the wave-CISK interpretation. Among them are the phase-lagged wave CISK and the frictional wave-CISK (hereafter, FWC). Phase-lagged wave-CISK (Davies 1979) managed to avoid the zero preferred scale problem, but the excessive speed problem remained. Also it created a new problem of not maintaining the close balance between convective heating and adiabatic cooling due to vertical motion (Davies 1979), not to mention the unresolved problem of how to determine theoretically the magnitude of the phase lag. Because of these problems the phase-lagged wave-CISK interpretation is not considered as a strong contender. Chao and Deng (1997) gave further discussion on this matter. FWC (e.g., Wang 1988) also managed to avoid the zero preferred scale problem. But the excessive speed problem is not completely resolved at least in the linear analysis, though it is possible that when a different convective scheme is used this problem may disappear. The FWC interpretation has gained some notice in recent years (Salby et al. 1994, Sperber et al. 1997), especially after researchers encountered difficulties with another important interpretation--the surface wind induced surface heat exchange (WISHE) mechanism (Emanuel 1987, Neelin et al. 1987). WISHE requires that the surface heat fluxes to be larger to the east of the convective region (so as to induce the convection region to move eastward) than to the west. Recent observational studies have shown that this is not the case (e.g., Chen et al. 1996, Lin and Johnson 1996). The FWC interpretation stresses the critical role of surface friction in avoiding the most preferred growth of short waves.

The increasing attention that the FWC interpretation of the MJO has received has prompted us to investigate the role of the surface friction in the MJO by comparing two integrations of a GCM, one with and the other without surface friction. The first integration is demonstrated to exhibit realistic MJO; thus the model is considered suitable for the present purpose. Then, the second integration is demonstrated to exhibit realistic MJO also, thus indicating that surface friction is not necessary to the existence of the MJO. Nevertheless surface friction does play a modifying role in MJO. This modifying role will be discussed based on this comparison. The implication of these findings for the FWC interpretation of the MJO will be assessed.

2. THE MODEL

The latest version of the Goddard Earth Observing System general circulation model version 2 (GEOS-2) is used. A 4x5 grid size and 20 levels are used. The relaxed Arakawa-Schubert scheme (RAS, Moorthi and Suarez, 1992) is a part of the model. This scheme gives almost identical time-mean results as the original Arakawa-Schubert scheme at much reduced computational cost. RAS is used in conjunction with a rain-reevaporation scheme (Sud and Molod, 1988). The large-scale moist and dry convection remain the same as documented in Kalnay et al. (1983). The boundary layer and turbulence parameterization, a level 2.5 second-order closure model, is that of Helfand and Labraga (1988). Long wave radiation package is that of Chou and Suarez (1994). Short wave radiation package is that of Chou (1992) and Chou and Lee (1996). The prognostic cloud water parameterization of Del Genio et al. (1996) is used. Land surface process parameterization is that of Koster and Suarez (1996). Sea surface temperature is specified at observed values.

3. PRELIMINARY RESULTS AND DISCUSSIONS

Both integrations (with and without surface friction) started on January 1, 1987 and ran for four years. The preliminary results are summerized as follows:

Zonal mean fields

In the four-year average of both the December-January-February (DJF) and the June-July-August (JJA) zonal mean wind fields the low and high level easterlies in the tropics remain in the w/o surface friction case. The results show a stronger easterly near the surface, and stronger westerly in the tropical upper troposphere in the without surface friction case. The most conspicuous difference is in the middle and high latitude in the southern hemisphere. The lack of surface friction results in large zonal wind there year around (as high as 85 m/s at 500mb and 60S). The vertical wind shear is not enhanced. In the northern hemisphere middle and high latitude the lack of surface friction has not produced the similar large zonal wind. Presumably mountain torque, which is more dominant in the northern hemisphere, keeps the zonal wind from sharp increase. The location of the westerly maximum is moved to higher latitude in the without surface friction case. The time-zonal meridional wind fields indicate that the Hadley circulation is somewhat weaker in the without surface friction case. Overall, the zonal mean circulation in the tropics shows relatively (to middle and high latitudes) little changes when the surface friction is removed.

200 mb velocity potential

200 mb velocity potential is equivalent to divergence, which is closely related to precipitation, divided by the total wavenumber squared. Thus the low zonal wave numbers and low meridional modes are heavily weighted. Therefore this field is particularly suitable for detecting the intraseasonal signal, which has a planetary scale. The variance of the field in the 20-80 day band is concentrated in the Indian Ocean and western Pacific in both integrations. Fig. 1a shows 200 mb velocity potential as a function of time along the equator. It shows that the model exhibits eastward propagation of the circulation field in the intraseasonal time scale. The signal is clearer in the second half of the year in Indian Ocean and western Pacific. The model results do not show good seasonal dependence of the intraseasonal signal. Fig. 1b shows the same plot for the without surface friction case. It demonstrates that without surface friction intraseasonal oscillation signal can still exist with equal intensity.

Power spectral analysis

Fig. 2a shows the wave-frequency spectral of the 200 mb velocity potential at 2^{o}N. A clear peak at wave number 1 and eastward at 30 day period exists for the case with surface friction. In addition a weaker peak exists at wave number 1 and 50 day period. Fig. 2b shows the same plot for the without surface friction case. A peak at eastward wave number 1 is found at 23 day period and a weaker peak at 37 day period.

Composites

The composites are done along the eastward moving precipitation centers in Indian Ocean and western Pacific as revealed in the bandpass filtered precipitation field. Figs. 3a and b show the latitude-longitude composite of divergence. The shaded region is the center of precipitation. The precipitation pattern shows protrusions in WNW and WSW directions in the case with surface friction, as observed, but not in the case without surface friction. In the case of with surface friction the divergence in the lower troposphere is somewhat smaller than the case of without surface friction. Also note that the maximum 1000mb convergence is to the east of the precipitation center in the case with surface friction (as discussed in Salby et al.) and slightly to the west in the case without surface friction.

In summary, our preliminary results show that surface friction is not necessary for the existence of the MJO, but it plays an important modifying role. This calls for a reassessment of the FWC interpretation of the MJO. MJO is a phenomenon involving the scale interaction of many scales, from wave number 1 down to the cloud scale. Therefore linear analysis, which considers one wave component at a time (even when conditional heating is used), is not a suitable approach. The particular difficulty of studying one wave component is that the effect of all other wave components on this particular wave component is not known to the degree that it can be easily expressed mathematically. The concept of FWC has been built on the linear analysis and thus should be revised to include nonlinear effects. One way of making this revision is the wave-packet view suggested by Chao and Lin (1994) and Chao and Deng (1998). The emphasis that FWC places on the surface friction is found in this study to be not crucial, but surface friction does play an important modifying role.

Finally, our simulations are far from perfection. The weak strength of the MJO in the model, lack of correct seasonal variation of the modeled MJO intensity, and the too high frequency are the principal deficiencies of the model. Continued effort in model improvement is patently necessary.

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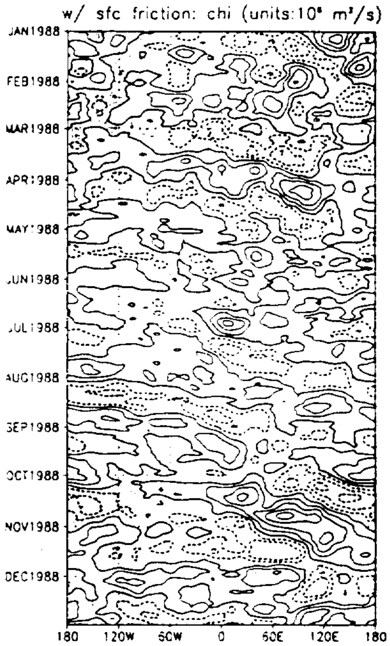

w/ sfc friction: chi (units: 10^6 m^2/s)

Fig. 1a

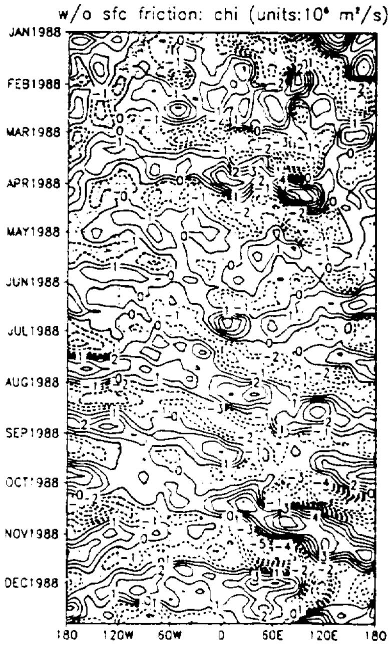

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Fig. 1b

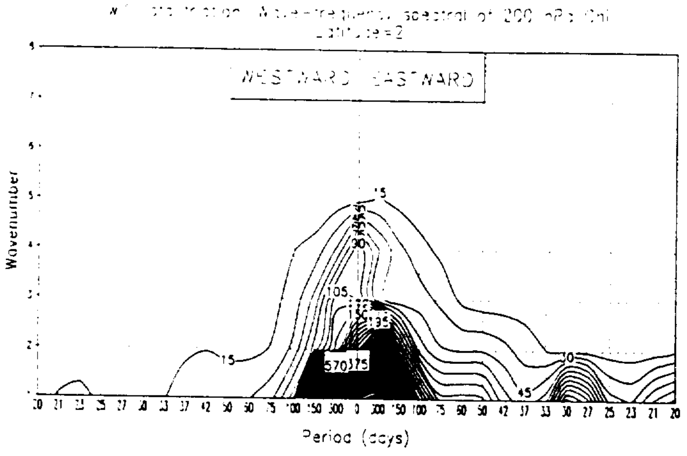

Fig. 2a

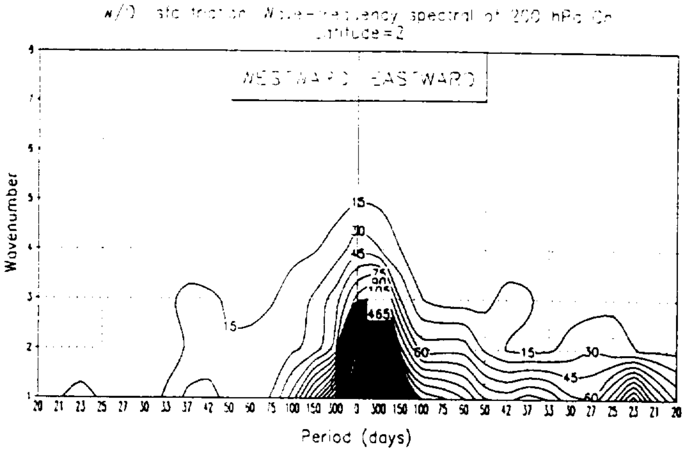

Fig. 2b

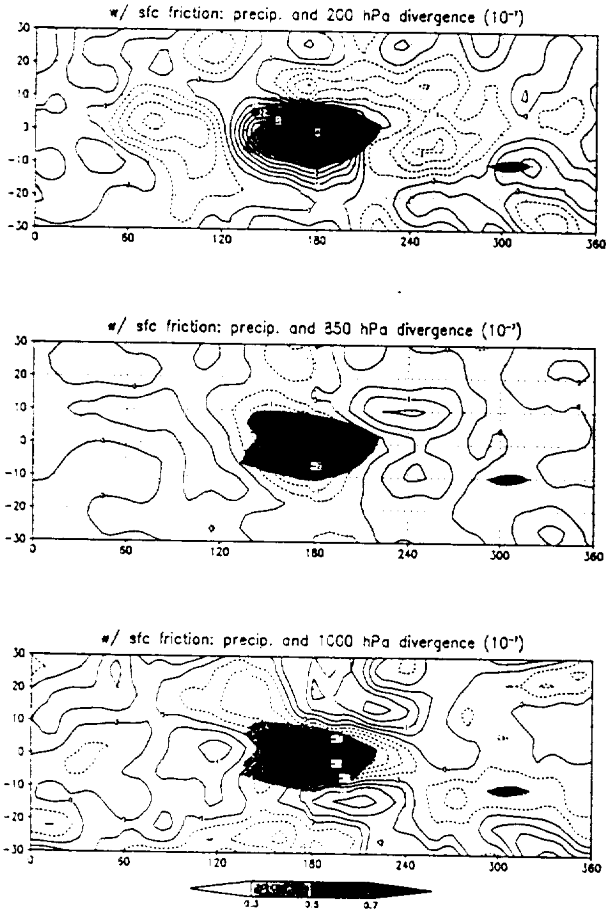

Fig. 3a

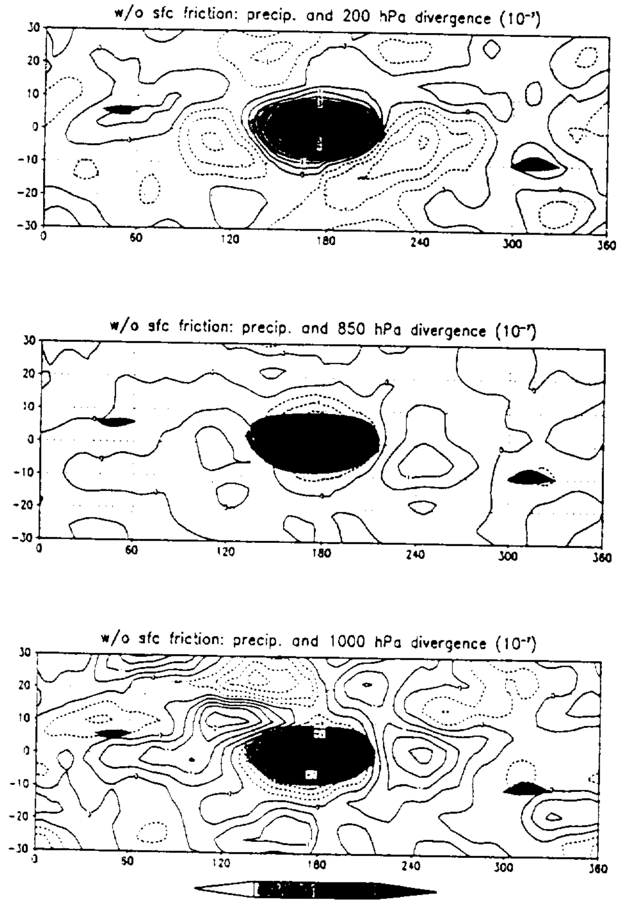

Fig. 3b