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# MECHANISMS OF SOME TROPICAL INTRASEASONAL OSCILLATIONS

B.N. Goswami and P. Goswami
Indian Institute of Science

Abstract. A underlying mechanism for two westward propagating tropical intraseasonal oscillations is discovered. Destabilization of equatorial normal modes by moist feedbacks, in particular, by evaporation-wind feedback, is responsible for both of them. The westward propagating 4-5 day oscillation and the quasi-biweekly oscillation result from destabilization of the mixed Rossby gravity (MRG) wave by the evaporation-wind feedback. The frequency and scale-selection of the the unstable MRG wave depend critically on the background mean wind. In mean easterlies (as in the Pacific and the Atlantic), it results in the 4-5 day oscillation while in mean westerlies (as in the Indian Ocean during northern summer) it results in the quasi-biweekly mode.

## Introduction

Three intraseasonal oscillations in the tropics with well separated time scales are well known. The most extensively studied amongst them is the Madden and Julian or the 30-50 day oscillation (Madden and Julian, 1971, 1972, Krishnamurti et al, 1985, and many others). The most important feature of this oscillation is its eastward propagation around the globe over all three oceans throughout the year. Somewhat less well known are the westward propagating quasi-biweekly (10-20 days) (Yasunari 1979, Krishnamurti and Bhalme, 1976, Krishnamurti, 1985) and the 4-5 day oscillations (Liebmann and Hendon, 1990; Takayabu and Murakami, 1991). The quasi-biweekly oscillation is observed only during northern hemisphere (NH) summer over the south Asian monsoon region while the 4-5 day oscillation is observed over the Pacific and the Atlantic but not over the Indian Ocean during NH summer. In the recent years many studies have attempted to explain the Madden and Julian oscillation, all of which involve equatorial Kelvin wave modified by moist processes (wave-CISK and evaporation-wind feedback). Similarly, Itoh and Ghil (1988) using a numerical model indicate that moist processes are essential for generating the 4-5 day westward propagating oscillation in the troposphere. Recent work by the authors have shown (Goswami and Goswami, 1991, hereafter referred to as GG91) that the westward propagating 4-5 day oscillation results from mixed Rossby gravity (MRG) wave driven unstable by the moist processes. However, no quantitative theory was available so far to explain the frequency selection for the quasi-biweekly oscillation. For the first time, we provide a mechanism for frequency selection for the quasi-biweekly mode and show that both the westward propagating oscillations arise due to the same physical process namely, modification of a tropical normal mode by the moist processes.

The convergence feedback (or wave-CISK) and the evaporation-wind feedback (hereafter referred to as E-W feedback) are the important moist processes. Emanuel (1987) and Neelin et al. (1987) showed that E-W feedback drives the equatorial Kelvin wave unstable. However, it does not provide a scale selection mechanism. In general, the effect of E-W feedback depends on whether the background mean winds are easterlies or westerlies. The studies cited above (Emanuel, 1987, Neelin et al, 1987) assume that the background winds are mean easteries. The Madden and Julian oscillation is strongest during NH summer over the Indian Ocean where the mean winds are westerlies. We show that under the influence of the E-W feedback the Kelvin wave decays in westerly mean background. Thus, the E-W feedback, by itself, is unlikely to explain the Madden and Julian oscillations. However, we show that the MRG wave is also driven unstable by E-W feedback. This mechanism in association with convergence feedback also provides a natural scale selection for the unstable MRG wave as it has a low frequency maximum in the growth rate. This low frequency maximum, however, depends sensitively on the nature of the background winds. In easterly background (as in the central Pacific and Atlantic throughout the year), this corresponds to the 4-5 day oscillation. In mean westerlies (as over Indian Ocean during NH summer) it corresponds to the monsoonal 10-20 day oscillation. This may be why the 4-5 oscillation is not seen over the NH Indian Ocean if continuous data is taken (e.g. Liebmann and Hendon, 1990).



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## The model and results

To study the modification of the equatorial waves by the moist processes, we use a linear equatorial beta-plane model with a first baroclinic mode vertical structure. The model, the method of nondimensionalization, the parameterization of the moist processes and the parameters used are discussed in detail in GG91. The nondimensional equations may be written as

$$\frac{\partial u}{\partial t} - yv/2 + Au = \frac{\partial \theta}{\partial x},$$

$$\frac{\partial v}{\partial t} + yu/2 + Av = \frac{\partial \theta}{\partial y}, \quad (1)$$

$$\frac{\partial \theta}{\partial t} - \Gamma\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + \Lambda u + B\theta = 0,$$

where u and v represent the zonal and meridional wind perturbations, $\theta$, potential temperature prturbation in the middle level and A and B represent Raleigh friction and Newtonian cooling coefficients respectively. The time and length scales used for nondimensionalization in Eq.(1) are approximately 0.22 days and 1100 km respectively. The nondimensional parameter $\Gamma$ represents the reduced static stability due to convergence feedback. $\Gamma = 1$ and $\Gamma = 0$ represent the no convergence feedback and the moist neutral states respectively. The parameter $\Lambda$ represents the strength of the E-W feedback and is positive in mean easterlies and negative in mean westerlies. A nondimensional value of $\Lambda = 1$ roughly gives an evaporation rate of about 1 mm $day^{-1}$ of water vapour from the surface for a wind speed of 5m $s^{-1}$. Seeking wave solution of the form

$$(u, v, \theta)(x, y, t) = (u, v, \theta)(y) \exp\{i(kx-\omega t)\},$$

the dispersion relation for the Kelvin wave (for which the meridional velocity v = 0) can be written as

$$(\omega+iA)(\omega+iB) - (\Gamma k + i\Lambda)k = 0 \quad (2)$$

Assuming that there is no Raleigh friction (A=0) and no Newtonian cooling (B=0) and introducing $\omega = \omega_r + i\omega_i$, the Eq. (2) can be easily solved to give

$$\omega_r = \pm\left[\frac{k^2\Gamma + (k^4\Gamma^2 + k^2\Lambda^2)^{1/2}}{2}\right]^{1/2} \quad (3)$$

and
$$\omega_i = \frac{k\Lambda}{2\omega_r} \quad (4)$$

For the Kelvin waves, $C_r = \omega_r/k \geq 0$. When k is positive, we have to accept $\omega_r > 0$ solution for Eq (3) while if k is negative we have to accept the $\omega_r < 0$ solution of Eq. (3). In either case it is easy to see that the growth rates are directly proportional to $\Lambda$. Hence, for

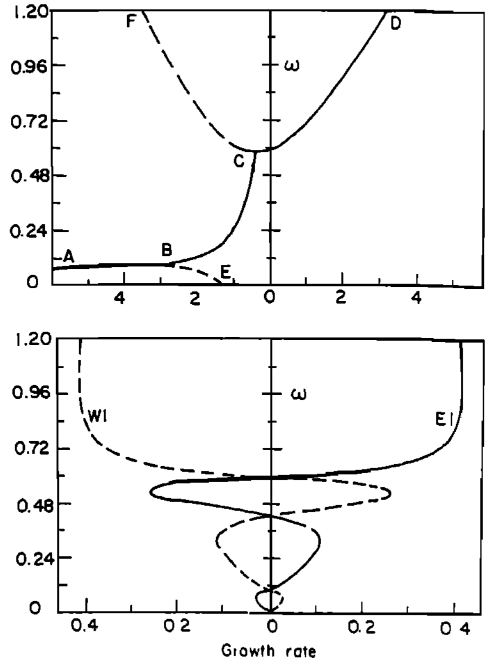


Fig. 1: Non dimensional dispersion relation for the MRG wave with A=B=0, $\Gamma$ = 0.1 and for $\Lambda$ = 0.25 and $\Lambda$ = -0.25. (a) Dependence of real wavenumber $k_r$ on frequency $\omega$. The real part of the solution for both $\Lambda$'s are identical. (b) Dependence of growth rates on $\omega$.

westerly mean background flow the Kelvin waves decay and for easterly background winds the Kelvin mode is unstable.

Eq. (1) contains all the dry tropical normal modes (Matsuno, 1966), modified by the moist processes. The moist processes also introduce some new modes. GG91 discusses in detail the dispersion relation for the lowest meridional mode (n = 0) in the presence of mean easterlies. In this study, we compare the n = 0 equatorial modes modified by E-W feedback in the presence of mean easterlies ($\Lambda > 0$) with those in the presence of mean westerlies ($\Lambda < 0$). In the dry atmosphere, the n = 0 case contains only the MRG wave. The presence of E-W feedback introduces an additional westward propagating mode. Assuming that the frequency, $\omega$, is positive definite and allowing the wave-number, k, to be positive or negative, the dispersion relation for $\Gamma$ = 0.1 and for two values of $\Lambda$ namely, $\Lambda = \pm 0.25$ are shown in figure 1 for the n = 0, nondissipative case (A = B = 0). The dependence of the real wave number ($k_r$) on frequency (figure 1a) shows that apart from the modified MRG wave (ABCD), a new westward propagating mode (EBCF) is introduced. It can be easily shown that this mode (not allowed in the dry case as its eigen functions are unbounded) has bounded eigen functions in the presence of the moist feedbacks. As long as the strength of the E-W feedback remains the same ($|\Lambda|$

= const.), the dependence of $k_r$ on $\omega$ is not affected by whether the background wind is easterly ($\Lambda > 0$) or westerly ($\Lambda < 0$). E1 and W1 in figure 1(b) represent the growth rates for the MRG wave when $\Lambda = +0.25$ and $\Lambda = -0.25$ respectively. In the presence of mean westerlies, the growth rate curve for the MRG wave is a mirror image of the corresponding growth rate curve in the mean easterlies. In mean easterlies the new wave is always damped (not shown). The MRG wave in this case is unstable in the low frequency domain with a low frequency maximum in the growth rate (around nondimensional $\omega = 0.3$). This corresponds to a westward propagating wave with a period of about 4.5 days and wavelength of about nine thousand kilometers. In mean westerlies, on the other hand, the MRG (W1) wave is unstable with two maxima, one in the low frequency (around nondimensional $\omega \approx 0.1$) and the other in the high frequency (around nondimensional $\omega \approx 0.5$) regime. The low frequency maximum corresponds to a westward propagating wave with a period of about 14 days and wavelength of about three thousand kilometers. In mean westerlies, the new branch in the nondissipative case (not shown) is also unstable but with no maximum in the growth rates. The presence of a small amount of dissipation ($A=B\neq0$), makes this branch neutral but does not change the low frequency maximum in the other branch appreciably. The characteristics of the maximally growing wave in the easterlies agree extremely well with the observed westward propagating 4-5 day wave in the Pacific and Atlantic (Liebmann and Hendon, 1990). The maximally growing low frequency wave in mean westerlies also agree well with the quasi-biweekly mode observed over south Asian summer monsoon region (Krishnamurti and Bhalme, 1976, Krishnamurti and Ardunay, 1980). The wavelength is somewhat shorter than observed. Our model being very simple, we believe that inclusion of other physical processes may provide better agreement of the wavelength with observations. Thus, the destabilization of the MRG wave by the E-W feedback provides the long sought mechanism for the frequency selection in the 4-5 days as well as in the 10-20 days.

Another characteristic feature of the intraseasonal oscillations that needs to be explained is their quasi-periodicity. Most of these oscillations occur over a band of frequencies rather than a single frequency. While the 4-5 day oscillation show relatively lower variation, it is quite large for the quasi-biweekly oscillation (10-20 day). Our theory offers a natural explanation of this quasi-periodicity when we consider the dependence of the strength of these feedbacks on the prevailing mean conditions, such as the strength of the mean winds, static stability, sea surface temperature etc. Thus, the strengths of these processes may vary from one equatorial region to another and from one season to another. We envisage that the observed quasi-periodicity of the tropical intraseasonal oscillations may be due to the variations of the strength of the moist feedbacks. In figure 2 and figure 3, we show how the period and wavelength of the maximally growing low frequency wave vary with strengths of

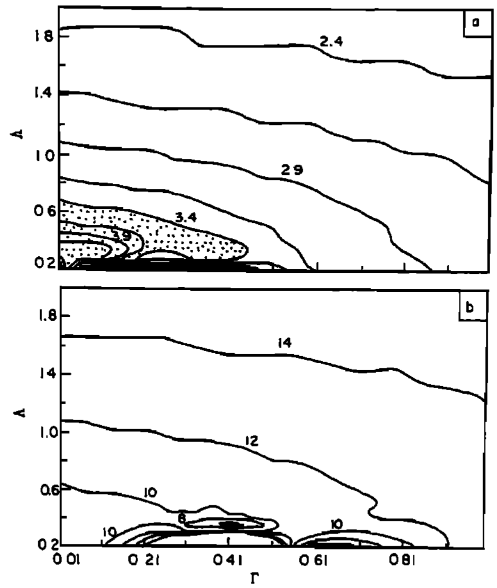


Fig. 2:Dependence of the period (a) and wavelength (b) of the maximally growing low frequency wave in mean easterlies. Periods are in days with contour interval 0.25. Wavelengths are in thousand km with contour interval 2.

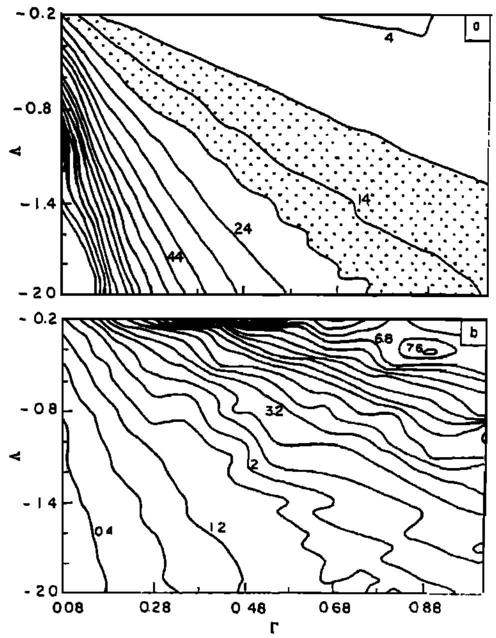


Fig. 3: Same as in Figure 2 but for the maximally growing low frequency wave in mean westerlies. Contour interval for periods is 5 and that for wavelength is 0.4

convergence feedback (Γ) and E-W feedback (Λ) in mean easterlies and in mean westerlies respectively. Hatchings in figure 2a and figure 3a show the approximate range of the strengths of the feedbacks that provide the observed periods. We also note that the period and wavelength of the low frequency maximum in westerlies is rather sensitive to the variation of the feedback strengths but those for the low frequency maximum in mean easterlies vary little over a wide range of variations of Λ and Γ. This also agrees well with the observation that the spectrum around the 4-5 day is rather sharp while the period for the quasi-biweekly mode varies from 10 to 20 days. The moist feedbacks also modify the eigen functions of the MRG wave and introduce a meridional propagation which also agrees with observations. Further details on the modification of the n = 0 waves by E-W feedback in mean westerlies will be published elsewhere.

## Conclusions

It is shown here that two equatorial westward propagating oscillations namely, the 10-20 day oscillation and the 4-5 oscillation both result from destabilization equatorial normal modes (MRG) by E-W feedback. The moist processes introduce the required frequency selection in case of both these oscillations. In addition, they give rise to latitudinal phase propagation as observed. The observed quasi-periodicity of these waves is a reflection of the spatial and temporal variations of the strengths of the moist feedbacks. The mechanism for the 4-5 day lower tropospheric wave discussed here also provides a long sought explanation for the forcing required for the observed 4-5 day lower stratospheric wave. We believe that the discovery of this commonality in the mechanisms for these two classes of westward propagating intraseasonal oscillations is an advance in our understanding of intraseasonal variability in the tropics. We also predict that if data for only winter is examined over the equatorial Indian Ocean (when the mean winds are easterlies), the 4-5 day oscillation should be seen even over the Indian Ocean.

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B.N. Goswami and Prashanth Goswami*
Centre for Atmospheric Sciences
Indian Institute of Science
Bangalore 560 012, India.

*Present affiliation:
Department of Physics
Indian Institute of Technology
Kanpur 208 016, India.

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