2D.5 THE ROLE OF EQUATORIAL ROSSBY WAVES IN WESTERLY WIND BURSTS

Paul E. Roundy* and George N. Kiladis
NOAA/CIRES Earth Science Research Laboratory
Physical Sciences Division

1. Introduction

Atmospheric equatorial Rossby (ER) waves modulate winds and rainfall throughout the tropics (Wheeler and Kiladis, 1999; Roundy and Frank 2004a). They influence tropical cyclogenesis (Frank and Roundy 2006; Molinari et al. 2006), and interact with the tropical intraseasonal or Madden-Julian Oscillation (MJO, Roundy and Frank 2004b). We suggest here that these waves may also influence changes in the El Niño/Southern Oscillation (ENSO).

In a recent study, Roundy and Kiladis (2006, hereafter RK) showed that the MJO occasionally couples to Kelvin waves in the equatorial Pacific Ocean, causing it to slow down and amplify the waves more than it otherwise would without the coupling effects. Along with other factors, the coupling probably contributes to a transient reduction in the phase speeds of both the MJO and Kelvin waves over time during a trend toward El Niño.

The MJO is probably not the only mode that contributes to the intraseasonal zonal wind anomalies that initially trigger oceanic Kelvin waves. Among other modes, westward-moving ER waves that are symmetric across the equator also generate alternating anomalous zonal wind on the equator. Since these waves often occur at the same times and regions as the MJO (e.g., Roundy and Frank 2004b), they help to determine the locations of the strongest winds within the MJO envelope. If the MJO and ER waves are present at the same location, then the total wind anomaly might be greater or less than that contributed by the MJO alone.

* Corresponding Author address:
NOAA Earth System Research Laboratory R/PSD1, 325 Broadway, Boulder, CO 80305-3328, paul.roundy@noaa.gov

After a wind burst initially develops during a trend toward El Niño, the developing oceanic Kelvin wave can advect warm surface water eastward, with the atmosphere responding by inducing more forcing west of the wave crest (RK). This air-sea coupling generally occurs where zonal sea surface temperature (SST) gradients are strong. The relative phases of ER waves to the MJO in a region of strong SST gradients may determine whether such air-sea coupling can develop and thus influence the propagation of the MJO. For example, if an ER wave is phased such that it also induces westerly anomalies in the sensitive region, it may support initiation of the coupling effects. ER waves may also modulate a wind burst after it has developed, causing its intensity to fluctuate.

The purpose of this study is to diagnose how the MJO changes when the phase of ER waves relative to the MJO changes over the West Pacific. The method we apply may implicitly include some of the effects of air-sea coupling, although describing the coupling is not an objective of the analysis. We first discuss relevant data and a statistical model, followed by its potential implications to ENSO.

2. Data and Methods

Interpolated outgoing longwave radiation (OLR) data were provided by the NOAA Earth System Research Laboratory (ESRL) Physical Sciences Division (PSD, formerly the Climate Diagnostics Center (CDC)). Two filters were applied—one for the MJO, eastward wavenumbers 0-10 and periods of 30-100 days, and the other for the ER waves, 10-100 days and westward wavenumbers 1-14.

Regression models were applied relating unfiltered OLR anomalies at each grid point in the global tropical band to time series of these filtered datasets at the equator and 150°E. MJO and ER wave activity are both strong at 150°E, and eastward-moving anomalies of MJO convection tend to slow down there when atmospheric forcing begins coupling to developing oceanic Kelvin waves (RK).

The regression models are of the form

$$\begin{aligned} y = a_0 + a_1 x_{MJO} + a_2 x_{ER} + a_3 \dot{x}_{ER} + \\ a_4 x_{MJO} x_{ER} + a_5 x_{MJO} \dot{x}_{ER} + \\ a_6 x_{MJO}^2 + a_7 x_{MJO}^3 + a_8 x_{MJO}^2 x_{ER} + \\ a_9 x_{MJO}^2 \dot{x}_{ER} + a_8 x_{MJO}^3 x_{ER} + a_9 x_{MJO}^3 \dot{x}_{ER} \end{aligned} \quad , (1)$$

The dependent variable y is the unfiltered OLR anomaly at some grid point and time lag. x_{MJO} is the time series of base point OLR filtered for the MJO band and x_{ER} is the time series of base point OLR filtered for the ER band. Power terms allow the model to diagnose how the shape of the MJO anomalies changes in time and space. These terms model asymmetric patterns in time and space. For example, these terms combined can show whether the active convective phase of the MJO has a structure different from that of the suppressed phase (Roundy and Frank 2004). Cross product terms diagnose modulation—that is, the portion of the OLR anomaly that develops due to the simultaneous action of both modes that would not be present if both modes did not occur at the same place at the same time. The regression coefficients are calculated at each grid point and time lag by matrix inversion, then values are substituted for the independent variables to make composites.

The model allows us to construct composites based on maintaining the MJO phase fixed at the base point and the zero time lag, while adjusting the phase of the composite ER wave train. This is done by substituting a single value for x_{MJO} and a range of values for x_{ER} and $\dot{x}_{ER}$. Thus changes in the MJO associated with different ER wave phases can be diagnosed. The regression model framework allows for diagnostic analysis that cannot be easily done with a composite average.

3. Results

We include here two snapshots of the regressed OLR and zonal wind anomalies, based on nearly opposite phases of ER waves at 150°E. Figures 1 and 2 show regressed OLR including terms with subscripts 1 and 4-9 in equation 1. Contours of the regressed ER wave (including term 2 only) are included for reference. The shading in Fig. 1 shows the MJO when the active convective phase of the ER wave intersects with it near 150°E. This composite MJO follows the pattern generally associated with a typical MJO. In contrast, during the opposite phase of the ER wave (Fig. 2), convection is far more intense over the West Pacific than over the Indian Ocean, and the Indian Ocean structure is disorganized. Other ER wave phases range between these two extremes (not shown). For example, as phase differences increase from that shown in Fig. 1, the MJO shows reduced amplitude and organization over the Indian Ocean and higher amplitude and lower phase speed across the West Pacific. Figures 3 and 4 show regressed zonal wind for the same ER wave phases shown in Figs. 1 and 2 (respectively). The regressed wind patterns are negatively correlated with the corresponding regressed OLR patterns.

3. Conclusions

Figures 1 through 4 suggest that the behavior of the MJO differs with the phase of ER waves. The active convective phase of the MJO is most continuous across both the Indian and West Pacific Oceans when the active convective phase of the ER wave intersects with the active convective phase of the MJO near 150°E. This relationship is similar to the mean relationship between the MJO and ER waves suggested by Roundy and Frank (2004b). In contrast, during the opposite phase of the ER wave near 150°E, the MJO does not tend to organize and propagate continuously across the Indian Ocean, but convection does become active across the West Pacific.

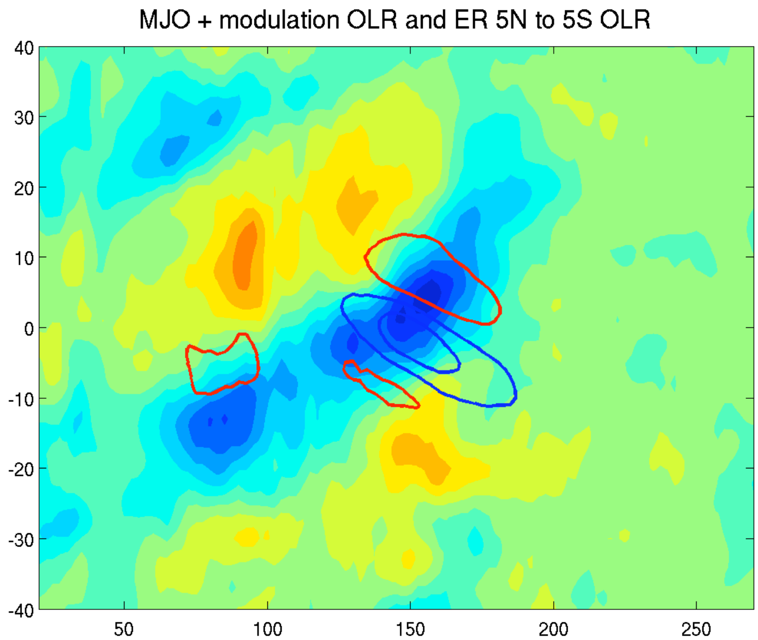

Figure 1: Regressed MJO and modulation OLR (shading), and ER band OLR (contours), averaged from 5°N to 5°S. Time lag in days is given on the left, and longitude in degrees east is on the bottom. The contour interval for MJO OLR is 5 Wm^{-2} and the interval for the ER band is 10Wm^{-2}, with minimum contours at +/- 5 Wm^{-2}.

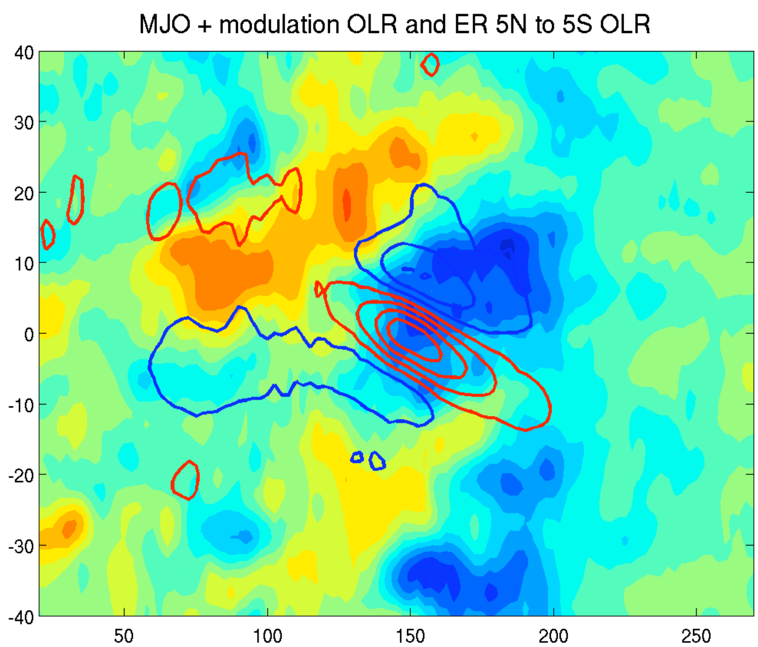

Figure 2: Same as Figure 1, except the phase of the equatorial Rossby wave is reversed.

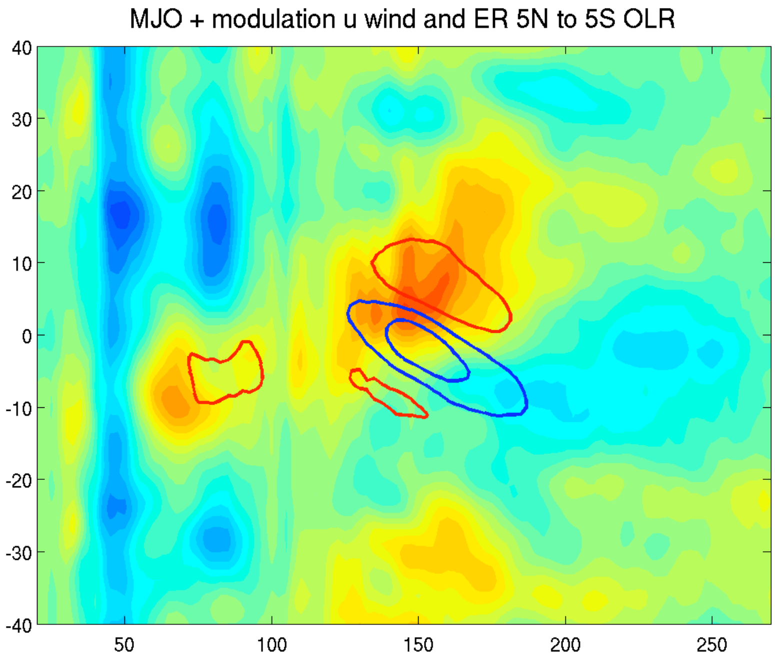

Figure 3, Regressed equatorial zonal wind (shading) and ER OLR, comparable to Fig. 1. Maximum winds are +/- 4 ms^{-1}.

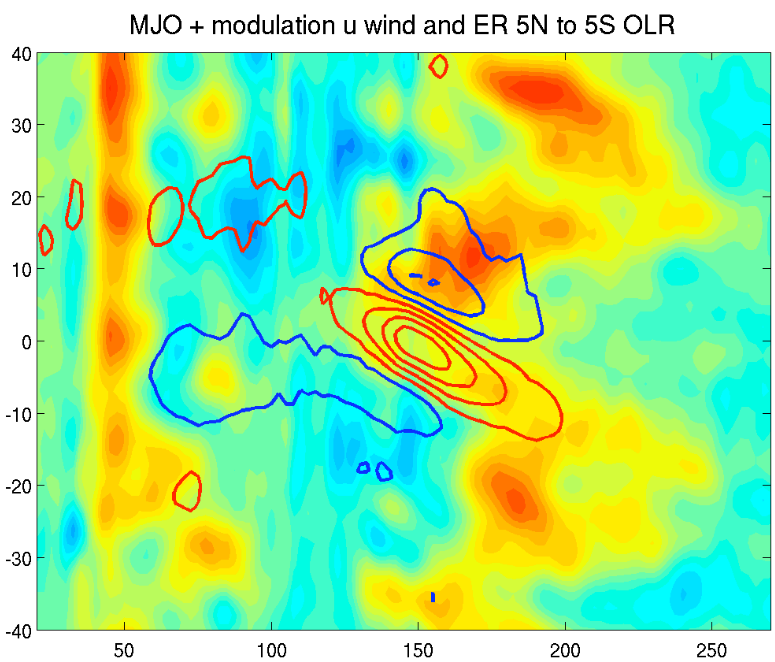

Figure 4, Same as Figure 3, except comparable to Figure 2.

Composite zonal wind shown in Figs. 3-4 suggests that the zonal wind also responds differently to these two ER wave pattern extremes. When the ER wave phase is as shown in Fig. 3, easterly anomalies occasionally develop across the Pacific, blowing toward the convectively active phase of the MJO over the Indian Ocean (regressed MJO OLR is shown in Fig. 1). These easterly anomalies tend to have amplitudes similar to the westerly anomalies seen during the previous and subsequent active phase of convection over the West Pacific. In contrast, when the waves intersect as shown in Figs. 2 and 4, westerly anomalies develop in the active convective regions over the West Pacific, but these are not replaced by easterly anomalies of similar intensities.

These two patterns might influence ENSO in different ways. We compared these results with composites of OLR and wind stress based on an index of oceanic Kelvin waves at the dateline (e.g., those shown in RK). Such composites show that the wind stress pattern associated with the development of oceanic Kelvin waves is asymmetric in time and space. During a trend toward El Niño conditions, moist deep convection and westerly winds associated with the active phase of the MJO slow down as they encounter developing oceanic Kelvin waves. The amplitude of convective and wind anomalies is also greater over the West Pacific than over the Indian Ocean, and enhanced trade winds do not usually influence the Kelvin waves along their trajectories. This pattern is similar to that seen in Fig. 2 and 4. However, during a trend away from El Niño conditions, westerly wind bursts associated with the MJO are replaced by basin-wide surges in the trade winds along the trajectories of the Kelvin waves. The Kelvin waves attenuate to the east and do not subsequently influence East Pacific SST.

These results suggest that ER waves play important roles in the development of the MJO and that these waves might influence the forcing of oceanic Kelvin waves. If ER waves influence oceanic Kelvin waves, then they may also affect changes in the state of ENSO. However, another possibility is that the ER waves might just be responding to changes in the basic state and that their influence on the state of ENSO is negligible. Further analysis is under way to distinguish the extent of their influence.

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