14D.4 INTERACTIONS BETWEEN THE MADDEN-JULLIAN OSCILLATION AND EQUATORIAL ROSSBY WAVES THROUGH HIGH-FREQUENCY TRANSIENT EDDIES

Naoko Sakaeda
Department of Atmospheric and Environmental Sciences
University at Albany, State University of New York, New York 12222, U.S.A

1. INTRODUCTION

A family of equatorially trapped waves derived from shallow water equation and the Madden-Julian Oscillations (MJO) are recognized as dominant modes of intraseasonal variability in the tropics. The dynamical understanding of these wave modes and their associations with one another is considered important for a further improvement of realistic atmospheric simulation and long-range forecasts. Past studies have demonstrated their association of these signals with midlatitude weather and climate because the tropical variability can modulate the extratropical circulation, which can in turn modulate or generate oscillations in the tropics.

Extratropical waves that propagate into the east Pacific basin modulate convection in the ITCZ during boreal winter when upper-level westerly winds are present (Kiladis 1998). The MJO can influence this equatorward extratropical wave activity by modulating the background state convection and upper level winds of both the extratropics and the tropics through which the high-frequency waves propagate. The extratropical waves can enhance the ITCZ convection and trigger atmospheric equatorial Rossby (ER) waves that interact with and feed back onto the convective signals on the timescale of the MJO (Matthews and Kiladis 1999a). It has previously been recognized that the ER activity tends to be enhanced within or on the east of convectively active envelope of the MJO. However the dynamical mechanism of this relationship is yet to be understood. This study investigates the role of the modulation of extratropical waves by the MJO in the association between the MJO and ER waves.

2. DATA AND METHODS

NCEP/NCAR Reanalysis data and interpolated Outgoing Long Radiation (OLR) from 1980 to 2010 are used in this study. The study focuses on the boreal winter (December, January, and February). 200hPa meridional wind data filtered to retain only equatorward propagation are used to represent the extratropical equatorward propagating Rossby waves. This study focuses on the effect of those waves propagating from the Northern Hemisphere.

In order to enable linear analysis between the activity levels of phenomena at different frequencies, two-dimensional wavelet analysis using complex Morlet wavelet is applied to the data filtered. At each time step and grid point, a complex Morlet wavelet at targeted time frequency and zonal wavenumber is multiplied by consecutive windows of the OLR data to obtain wavelet coefficients corresponding to the temporal and spatial scales of ER waves. Power is then obtained by multiplying the result by its complex conjugate. The rectangular box including wavenumber 1 to 14 eastward and periods of 10 to 100-days is chosen as ER band for this study. The same wavelet analysis but in time frequency only is applied to the filtered equatorward propagating 200hPa meridional wind to obtain its power in 6-25 days band.

Both the extratropical waves and ER waves have large seasonal as well as interannual variability associated with ENSO state (Matthews and Kiladis 1999b; Huang and Huang 2011). In order to remove any variability with lower frequency oscillations, a 100-day high pass filter is then applied to the obtained time series of power. The filtered power is referred as anomalous power throughout the remainder of this study.

The MJO index used in this study is the index used in MacRitchie and Roundy (2011). This index is defined in the same way as Wheeler and Hendon (2004) except that it is calculated from MJO-filtered OLR and winds.

3. RESULTS AND DISCUSSION

This section examines the association between the MJO and ER wave activity. Then it assesses the

*Corresponding author address: Naoko Sakaeda, Univ. at Albany, Dept. of Atmospheric and Environmental Sciences, Albany, NY 12205; email: nsakaeda@albany.edu

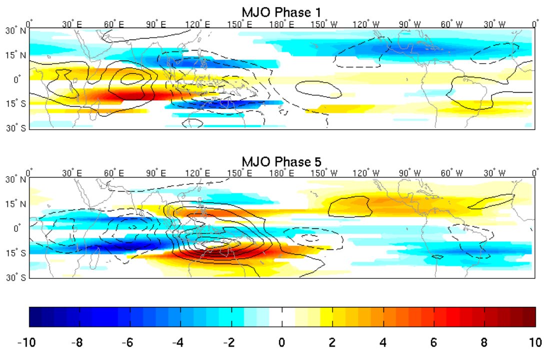

FIG.1: Composite maps of anomalous ER power (shaded) in MJO Phase 1 (a) and Phase 5 (b). Black contours are MJO-filtered OLR (solid line suggests enhanced convection and dashed line suggests suppressed convection). Only regions with above 90% statistical significance are shaded.

association between the MJO and extratropical wave activity. Finally, it assesses how the two might be related.

3.1 *ER variability on MJO timescale*

The variability of convective activity in the ER band shows both meridionally symmetric and asymmetric patterns during different portions of the MJO life cycle. In general, ER activity is enhanced (suppressed) within the convectively active (suppressed) envelope of the MJO (Figure 1). The result is consistent with the past findings of Kiladis and Wheeler (1994) and Masunaga (2007).

However Fig.1 shows that the ER wave variability associated with the MJO is more complicated. Its response is not always symmetric across the equator and is also not geographically constrained within the MJO convective signal. This result suggests that the ER wave is not only modulated by the background stability influenced by the local phase of the MJO but it may also be modulated by the global circulation signal associated with the MJO.

3.2 *High-frequency extratropical wave variability with the MJO*

Wheeler and Kiladis (1999a) showed that 200hPa extratropical wave signals in the 6-25 day band evolve differently through the MJO life cycle. When the convectively active MJO is over the Maritime Continent to the west Pacific, the enhanced westerly wind duct over the east Pacific allows extratropical waves to propagate farther into the tropics. Consistent with the results of the previous studies, the anomalous power of southward propagating 6-26 days upper-level meridional wind signal shows more enhanced and equatorward extended activity at east of the dateline in phase 5

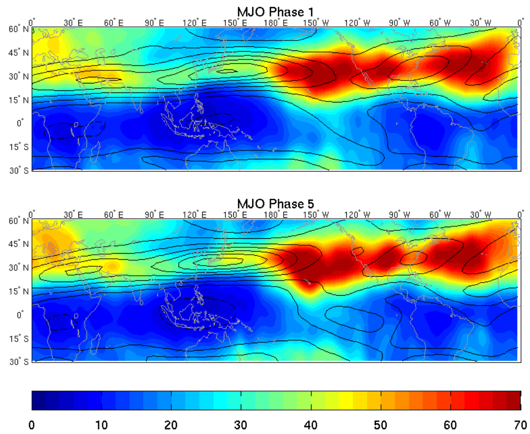

FIG.2: Composite maps of power in 200-hPa southward propagating 6-25days meridional wind (shaded) in MJO Phase 1 (a) and Phase 5 (b). Black contours are 200hPa zonal wind (solid indicates westerly and dashed indicates negative).

than phase 1 (Figure 2).

During phase 5, the subtropical jet is less zonally uniform and shifted northward and eastward. The westerly winds over the equatorial east Pacific are stronger during phase 5 which would allow more equatorward propagation of the extratropical Rossby waves.

This equatorward propagation of 6-25 days extratropical waves seems to have a strong association with anticyclonic wave breaking events. The composite map of 200hPa potential vorticity at the time of strong equatorward extratropical wave propagation clearly shows a pattern of anticyclonic wave breaking (Figure 3). The equatorward propagation of the wave frequently occurs when the subtropical jet is shifted northward and retracted westward due to the meridional PV advection by the MJO upper-level divergent winds. The anticyclonic wave breaking events are also observed frequently when the jet is shifted northward. This consistency in the background condition for the occurrence of 6-25 day equatorward extratropical Rossby wave and anticyclonic wave breaking events suggest a strong association between them.

3.3 *The role of extratropical wave activity on ER*

The above sections showed significant variation of the subtropical jet, extratropical wave propagation characteristics, and ER convective activity with the MJO. Several studies have suggested that the extratropical waves propagating toward the equator over the east Pacific can act as a source for ER waves (Kiladis 1998; Hoskins and Yang 2000). Then a question that arises is how much of the MJO modulation of extratropical wave activity explains the association between variability in ER waves and the MJO.

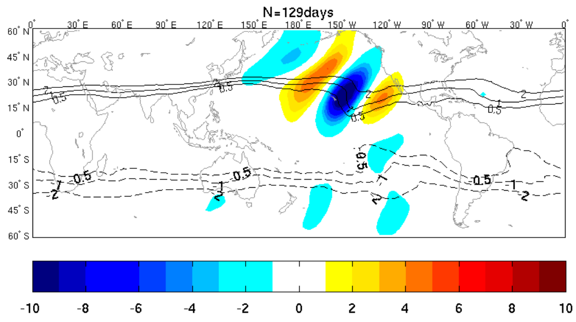

FIG. 3: Composite maps of 200hPa 6-25 days meridional winds (shaded) when its northerly wind maximized at 20N and 150E. 200hPa PV is contoured in black at positive and negative 0.5, 1, and 2 PVU.

Figure 4 shows composites of ER power during phase 5 of the MJO when the equatorward propagation of the extratropical waves is strong and weak at 20ºN and 150ºW. The strong (weak) period is defined as the time when its power was greater than 0.5 standard deviation (less than -0.5 standard deviation). 0.5 standard deviation is chosen to include more days in the composites since the distribution was a highly centered and concentrated distribution. Fig.4 clearly shows that the both the anomalous ER activity and the MJO patterns look different between the times when the extratropical waves are more or less active propagating into the equator.

The ER convective activity is more enhanced over the Southern Hemisphere when the extratropical waves are more actively propagating into the equator (Fig.4a). This signal may result from the seasonally varying background state. When anticyclonic wave breaking is observed over the Northeastern Pacific, coupled anticyclonic wave breaking tends to occur from the south in phase with the one in north (shown in Fig.3). When the upper-level cold air from the extratropics is brought into the equator from both hemispheres, the seasonal state of sea surface temperature (SST) and background convergence zone favors more convection over the southern hemisphere.

Whereas when the waves are less frequent, contradictory to the expectation, the ER wave activity is more enhanced over the Northern Hemisphere (Fig.4b). If one assumes that the extratropical waves are the sources for ER waves, enhanced ER wave activity is expected during the times when the extratropical waves are more actively propagating into the equator. It is unclear why the result shows the opposite case. Since the chosen band for ER has a broad period from 10 to 100days, if the effect of the extratropical waves is only concentrated on higher portion of the ER frequency, it may not be expressed in the total ER activity including all frequencies. Figure 5 also shows stronger upper-level westerly

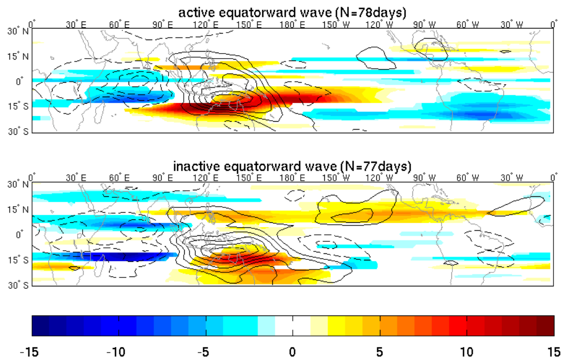

FIG.4: Composite maps of anomalous ER power (shaded) in MJO Phase 5 when the southward extratropical wave at 20ºN and 150ºE is active (a) and inactive (b). Black contours are MJO-filtered OLR (same as Fig.1). Only regions with above 90% statistical significance is shaded

over the east Pacific when the extratropical waves are less active. Zhang and Webster (1989) showed theoretical effects of background zonal wind on the equatorial waves. They showed that ER waves are less equatorially trapped in westerly wind background states. The enhanced ER activity during inactive extratropical wave propagation over northern east Pacific may be a result of extension of ER waves across a broader meridional width. The lower amplitude signals to the south could be due to the cold SST off the east coast of South America during the season when such events are most prevalent.

However, it is still unclear why the upper-level westerly winds over the east Pacific are more enhanced during the less active extratropical wave propagation times. It may be a result of the less frequent equatorward propagation of the waves as they act to bring the westerly momentum poleward. Another possible scenario is that when the waves are less active at the selected location, it may be active at another favored location leading to the resultant circulation pattern and generation of ER waves elsewhere.

3.4 *Feedbacks onto the MJO*

Figure 6 shows hovmollers of MJO-filtered OLR averaged over 5N to 5S during the active and inactive extratropical wave propagation at 20N and 150E during MJO phase 5. The MJO tends to propagate at a constant speed with consistent amplitude across the Maritime Continent during the time when the equatorward waves are active. Whereas it tends to speed up over the Maritime Continent then slows down again over the Pacific when the equatorward waves are infrequent. Fig.4 shows the amplitude of the horizontal structure of the MJO become smaller when the waves are inactive.

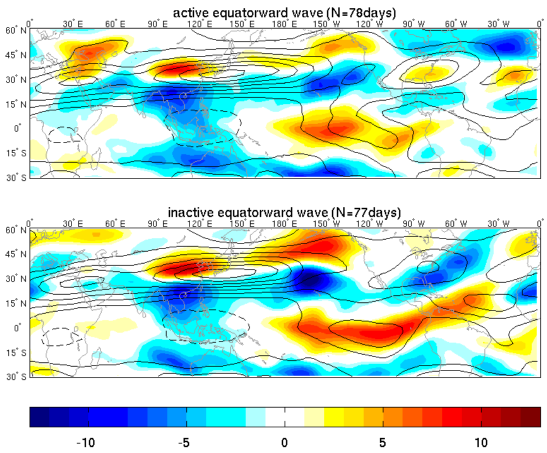

FIG.5: Same as FIG.4 except the shaded is the anomalous 200hPa zonal wind from its seasonal cycle and black contours is the total zonal wind.

At the same time, ER waves are also less enhanced ahead of the MJO. Since the speeding up of the MJO has previously been associated with weakening of the moist convection, it suggests that the enhanced ER convection ahead of the MJO may play a role to precondition the atmosphere to enhance the MJO convection. The ER convective signal ahead of the convectively active envelope of the MJO could destabilize the atmosphere through its diabatic heating, which might later enhance the MJO convection.

This result suggests that the ER activity modulated by the extratropical wave might be important for organizing the MJO convection itself, which then modulates the subtropical jet and feeds back onto the extratropical wave propagation characteristics.

4. SUMMARY

This study demonstrated the circular association between the MJO, ER, and the high-frequency extratropical waves. The associated extratropical and tropical background state combines with the MJO to determine the propagation characteristics of the extratropical wave propagation into the equator. Those extratropical waves influence the activity of ER waves, which might feed back onto the organization of the MJO convection. The structure and strength of the MJO convection then in turn influences the extratropical waves as well.

This circular association is further modulated by seasonal and interannual variability such as El Nino Southern Oscillation. Further study will reveal how the circulation modulates the observed seasonal variability of the MJO and ER waves.

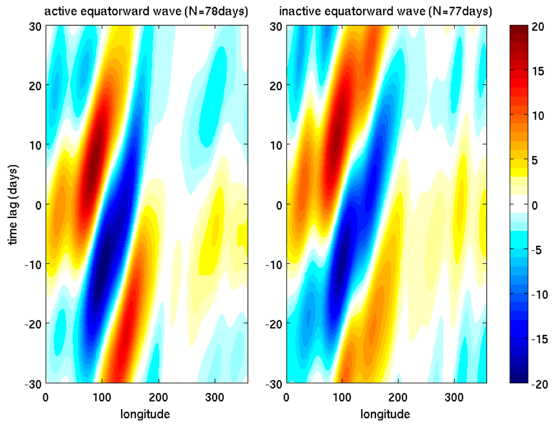

FIG.6: Longitude-time hovmollers of the MJO-filtered OLR averaged from 5N to 5S when the southward propagating extratropical wave at 20N and 150E was active (a) and inactive (b) at time lag zero.

5. REFERENCES

Hoskings, B. J. and G.-Y. Yang, 2000: The equatorial response to higher-latitude forcing. J. Atmos. Sci., 57, 1197-1213.

Huang, P. and R. Huang, 2011: Climatology and interannual variability of convectively coupled equatorial waves activity. J. Climate, 24, 4451-4465.

Kiladis, G. N. and M. Wheeler, 1995: Horizonal and vertical structure of observed tropical equatorial waves. J. Geophys. Res., 100, 22981-22997.

Kiladis, G. N., 1998: Observations of rossby waves linked to convection over the eastern tropical pacific. J. Atmos. Sci., 55, 321-339.

MacRitchie, K. and P. E. Roundy, 2012: Potential vorticity accumulation following atmospheric Kelvin waves in the active convective region of the MJO, J. Atmos. Sci., 69, 908-914.

Masunaga, H., 2007: Seasonality and regionality of the Madden-Julian Oscillation, Kelvin wave, and equatorial Rossby wave. J. Atmos. Sci., 64, 4400-4416.

Matthews, A. J., and G. N. Kiladis, 1999a: The tropical-extratropical interaction between high-frequency transients and the Madden-Julian Oscillation. Mon. Wea. Rev., 127, 661-677.

Matthews, A. J., and G. N. Kiladis, 1999b: Interactions between ENSO, transient circulation, and tropical convection over the pacific. J. Climate, 12, 3062-3086.

Wheeler, M. C. and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: development of an index for monitoring and prediction. Mon. Wea. Rev., 132, 1917-1932.

Zhang, C. and P. J. Webster, 1989: Effects of zonal flows on equatorially trapped waves. J. Atmos. Sci., 46, 3632-3652.