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Influences of the Madden Julian Oscillations on Temperature and Precipitation in North America during ENSO-Neutral and Weak ENSO Winters

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1. Introduction

A number of studies have shown that the Madden-Julian Oscillation (MJO) have a strong influence on the atmospheric circulation and precipitation patterns in the tropical and extratropics (Madden and Julian 1971; Lau and Chan 1985; Knutson and Weickmann 1987; Kayano and Kousky 1999). Recent studies also suggest that the MJO-related tropical forcing is linked to precipitation events along the west coast of the United State during the winter season (Mo and Higgins 1998; Higgins et al. 2000).

Dynamical models generally simulate the MJO quite poorly, partly because of inherent difficulties in parameterizing tropical convection. Statistical prediction models have shown a modest skill relating subseasonal variations in tropical convection to week-2 prediction of wintertime rainfall in western North America (Whitaker and Weickmann 2001). Operational week two ensemble predictions show levels of skill that are comparable to the statistical forecasts. However, neither statistical or dynamical prediction models have demonstrated useful levels of skill in forecasting MJO-related impacts beyond week 2.

We believe that improved monitoring and assessment of the MJO and its impacts on the atmospheric circulation and precipitation patterns will lead to better prediction. In this work we focus on ENSO-neutral and weak ENSO winters since the MJO is known to be quite active during those times. Velocity potential at 200-hPa has been used to construct a composite index for life cycles of the MJO (Knutson and Weickmann 1987). A similar approach is taken here. An extended Empirical Orthogonal Function (EEOF) analysis is applied to the bandpass filtered (25-87 days) pentad velocity potential at 200-hPa for ENSO-neutral and weak ENSO winters (November-April) during 1979-2000. The first EEOF is composed of ten time-lagged patterns. We construct ten MJO indices by regressing the filtered pentad data onto the ten patterns of the first EEOF. Keyed on the ten MJO indices, ten composites for the major MJO events are derived for various fields, including surface air temperature and precipitation. Our composites are constructed with unfiltered pentad data in which the winter season mean is removed.

Significant MJO-related influences on surface air temperature and precipitation in North America are found. The potential predictability for those fields derived from the tropical MJO-related forcing is discussed.

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2. Data

The data set used in this study consists of nonoverlapping five-day (pentad) means for 200-hPa velocity potential, 200-hPa zonal wind and 500-hPa geopotential height derived from the NCEP/NCAR CDAS/Reanalysis data (Kalnay et al. 1996). As a proxy for deep tropical convection we use pentad OLR data derived from measurements made by the NOAA operational polar-orbiting satellites for the 1979-2000 period. We also use the GPCP pentad precipitation analysis for its global coverage (Xie et al. 2002). The pentad global surface air temperature is based on GTS data (Ping-Ping Xie, personal communication).

3. MJO indices

The ENSO-neutral and weak ENSO winters during 1979-2000 are selected according to the CPC ENSO classification (http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/8/ensoyrs.txt). Based on this, 15 winters are selected and used to calculate the EEOF of velocity potential at 200-hPa (referred to as CHI200 hereafter). The first EEOF, composed of ten time-lagged patterns, describes an eastward propagation of the MJO with a timescale of about 45 days (Fig. 1). We construct ten MJO indices by regressing the filtered pentad CHI200 onto each of the ten patterns. So positive indices correspond to the convectively active phase of the MJO at different longitudes. Those MJO indices have been implemented for the real time monitoring of the MJO at CPC: http://www.cpc.ncep.noaa.gov/

products/precip/Cwlink/daily_mjo_index/mjo_index.html.

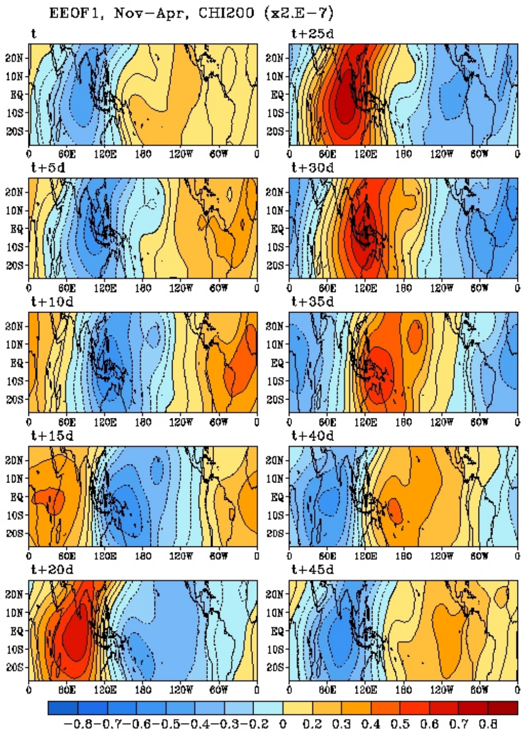

Fig. 1. The first EEOF of the pentad velocity potential at 200-hPa for the ENSO-neutral and weak ENSO winters (November-April) during 1979-2000.

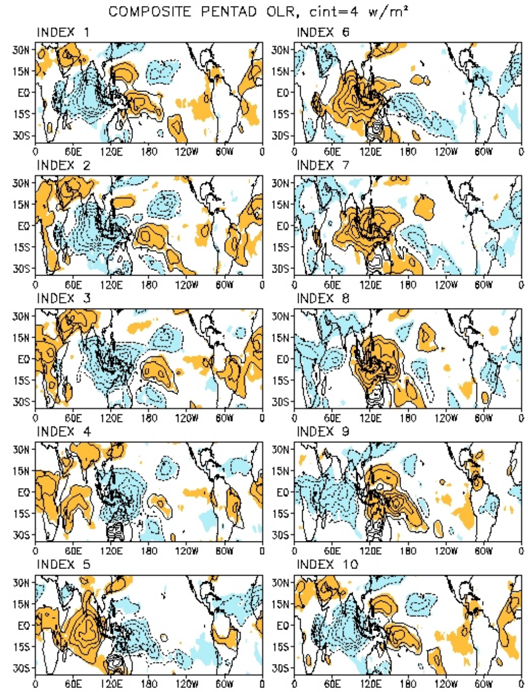

Fig. 2. OLR composites keyed on the ten MJO indices. The contour interval is 4 w/m2, and the zero contour is omitted. The blue (yellow) shading denotes negative (positive) anomalies significant at the 95% level.

4. MJO composites

We identify MJO events when the maxima of the standardized MJO indices exceed 0.8 standard deviations. To increase the sample size, one to four pentads centered on the maxima are used in composites, depending on the amplitudes of the indices. So the stronger events are weighted more in composites than the weaker ones are. We restrict our cases to the extended cold season (December to April). Based on this, about 25 to 29 MJO events are selected for each of the ten MJO indices. The number of pentads included in each composite varies from 67 to 83 since more than one pentads are used for each MJO event. The statistical significance of the composites at each grid point is evaluated by comparing selected MJO pentads to the remaining non-MJO pentads in the ENSO-neutral and weak ENSO winters via a two-tailed student's t test.

The life cycle of the MJO and its influences on the upper-tropospheric circulation are described by the composites of OLR and 200-hPa zonal wind (Fig. 2 and 3). The initial phase of the cycle is characterized by enhanced convection in far eastern Africa and the Indian Ocean, and suppressed convection in the western Pacific and the South Atlantic Convergence Zone (SACZ) (index 1 and 2). There are twin anticyclones located to the west and twin cyclones to the east of the tropical forcing, which in turn retracts the East Asian Jet (Fig. 3). When the enhanced convection shifts eastward towards Indonesia, westerly wind anomalies prevail in the upper troposphere over the gulf of Alaska and the Pacific North West (PNW), which brings wet condition there (Fig. 4). As the enhanced convection moves out of Indonesia and suppressed convection sets up over the Indian Ocean, the East Asian Jet extends eastward (index 5). This circulation pattern remains quisi-stationary for about three pentads (index 6-8 in Fig. 3). When the enhanced convection moves to northern South America and Africa, a new cycle begins (index 9-10 in Fig. 2).

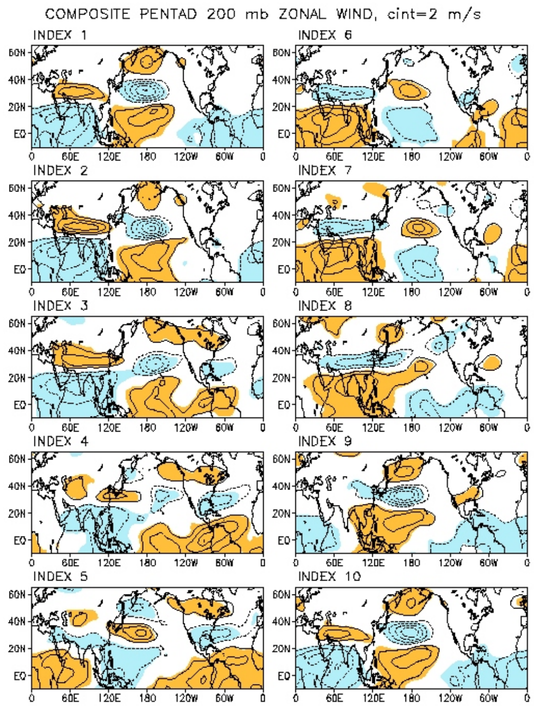

Fig. 3. Same as Fig. 2 except for the 200-hPa zonal wind. The contour interval is 2 m/s.

Concurrent with the tropical MJO-related forcing, significant precipitation signals are found in the U.S. (Fig. 4). The MJO-related precipitation signal is most pronounced along the west coast, which is consistent with previous studies (Mo and Higgins 1998; Higgins et al. 2000). During index 3 and 4, the PNW is wet and California is dry. However, the wet signal in the PNW is negligible compared to the local climatology because most MJO events happen during later winter and early spring, while the PNW receives its peak precipitation in Dec-Jan. The California precipitation begins as the enhanced convection moves to the date line (index 7) and persists for two to three pentads. This is probably associated with the upper-tropospheric westerly wind anomalies that act to steer weather systems into this region (Whitaker and Weickmann 2001, hereafter WW). We noticed that the OLR pattern of index 8 agrees very well with the canonical predictor OLR pattern (at a 2-week lag) for the week-2 prediction of the western north American rainfall of WW. It appears that the precursor OLR signal for the week-2 prediction of California precipitation in WW is that around index 5.

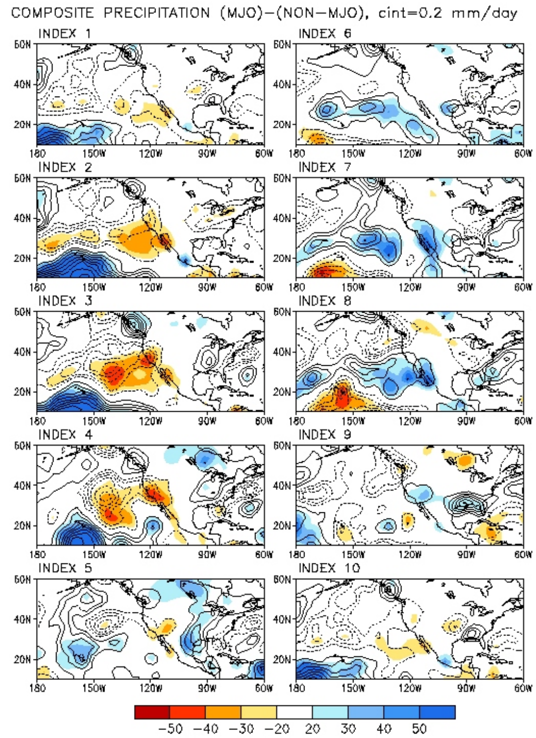

Fig. 4. Differences of composites of MJO pentads and non-MJO pentads. The contour interval is 0.2 mm/day, and the zero contour is omitted. The shading denotes the percentage departure relative to the climatological pentad precipitation based on te Dec-Apr period.

Significant MJO-related influences on surface air temperature in North America are found (Fig. 6), that are consistent with the MJO-related influences on 500-hPa geopotential height (Fig. 5). When the enhanced convection is in the Indian Ocean (index 1 and 2), strong blocking activity occurs in the northwestern Pacific and a deep trough is located over the gulf of Alaska. As the enhanced convection moves eastward toward Indonesia (index 3 and 4), the composite 500-hPa geopotential height resembles a negative PNA pattern, that is characterized by a ridge in the northeastern Pacific, a trough in the northwestern U.S. and a ridge in the southeastern U.S.. This quisi-negative PNA pattern lasts 2-3 pentads, producing warm anomalies in the eastern U.S. and cold anomalies in the western Canada (Fig. 6). As the enhanced convection moves toward dateline, a weak positive PNA pattern forms, causing warm anomalies in the western Canada (index 8 in Fig. 5 and 6). As the enhanced convection returns to Africa and the

Indian Ocean, anomalous trough covers the western U.S., producing cold anomalies in the west (index 9). Averaged over the cycle, the U.S. tends to be warm-than-normal in the east and cold-than-normal in the west. These long lasting warm anomalies (2-3 pentads) in the east will undoubtably contribute significantly to monthly forecasts issued regularly at the CPC when the MJO is active ("forecasts of opportunity").

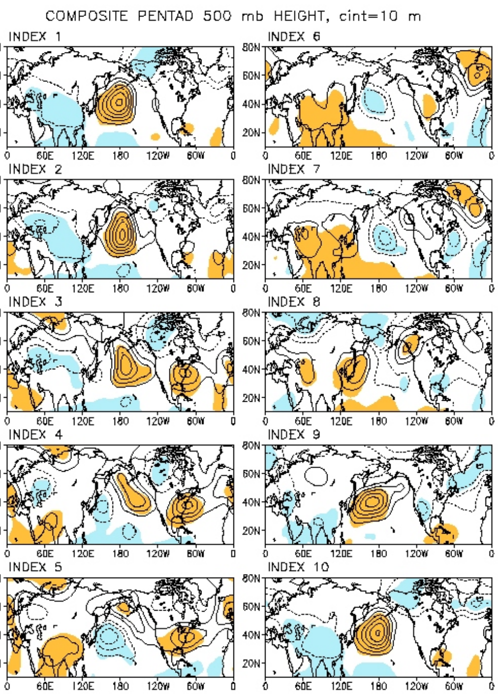

Fig. 5. Same as Fig. 2 except for the 500-hPa geopotential height. The contour interval is 10m.

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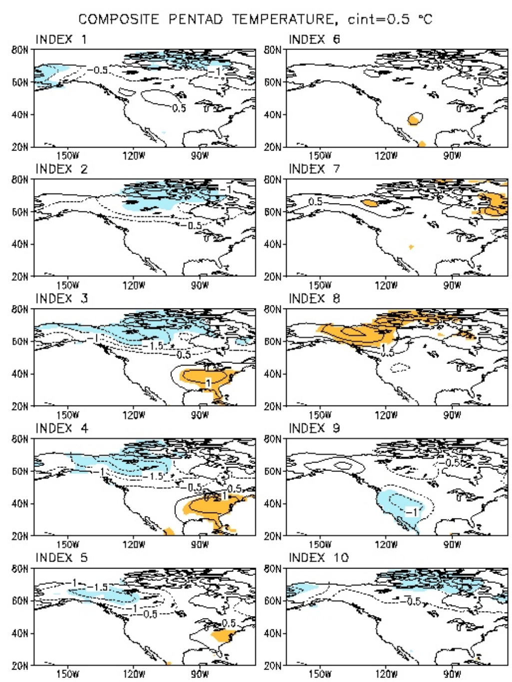

Fig. 6. Same as Fig. 2 except for surface air temperature. The contour interval is 0.5 degree.