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The Multivariate PNA Index: A New Index for Identifying MJO Impacts over North America

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1. Introduction

The Madden–Julian Oscillation (MJO; Zhang 2005) influences weather patterns around the globe with its 30–60 day period. Recent studies have shown that it can influence temperature and precipitation patterns over North America (Becker *et al.* 2011; Zhou *et al.* 2012). These impacts are frequently diagnosed using the Wheeler–Hendon (2004) Real-time Multivariate MJO (RMM) index. The eastern United States tends to be warm when the MJO's enhanced convection is over the western Pacific (phases 5/6) and cold when that convection is over the Western Hemisphere and Africa (phase 8/1).

These impacts are driven by interactions between the MJO's tropical convection and extratropical weather patterns like the Arctic Oscillation, the North Atlantic Oscillation, and the Pacific/North American (PNA) teleconnection (Riddle *et al.* 2012 and references therein). Naturally not every MJO event produces the same extratropical response. This project develops a new index, the Multivariate PNA (MVP), to discern which MJO events will affect North American temperatures and which will not.

2. Data

Outgoing longwave radiation (OLR) from the NOAA polar-orbiting satellites will be used here as a proxy for the tropical convection associated with the MJO. The extratropical responses will be identified using streamfunction, geopotential heights, and temperatures from the NCEP–DOE Reanalysis 2. Both datasets were obtained from NOAA/ESRL/PSD. Only dates from December–February 1979/80–2010/11 are used.

3. Constructing the MVP

When the MJO affects North American temperatures, the tropical convective heating forces a Rossby wave train. For that reason, we use a combined empirical orthogonal function (EOF) of outgoing longwave radiation (OLR) and streamfunction at 850 hPa and 200 hPa. This combined EOF is calculated using data that have been filtered for 20–100 days to focus on the MJO time scale. Such data is difficult to produce in near-real time, so we project the filtered EOF onto unfiltered data to produce the principal component time series.

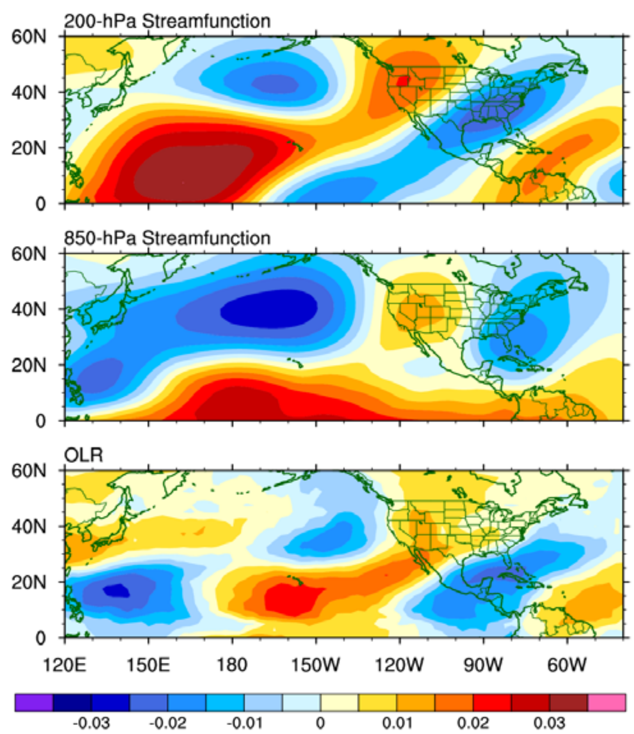

Fig. 1 EOF loading pattern for 200-hPa streamfunction (top), 850-hPa streamfunction (middle), and OLR (bottom).

Figure 1 illustrates the resulting EOF loading pattern. The 200-hPa streamfunction (top panel) shows

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a wave train pattern originating in the tropical Pacific, crossing North America, and then descending back to the tropical Atlantic. This pattern is reminiscent of the conventional PNA pattern, although the waveguide in the new index is shifted 5°–10° latitude farther south. The new index has a 0.57 correlation with the PNA from NOAA's Climate Prediction Center (NOAA/CPC). To reflect this connection, the new index is dubbed the "Multivariate PNA" (MVP) index.

At 850-hPa (middle panel), the streamfunction shows the low-level reflection of the wave train, along with anomalous zonal flow near Hawaii. The OLR pattern identifies anomalous convection near Hawaii that extends to the southwestern United States, like the familiar "pineapple express." Three opposite-signed OLR anomalies are also found to the north, east, and west.

4. North American impacts

As noted before, we expect to see warmth over the eastern United States when the RMM is in phase 5 and cold in phase 8. Figure 2 illustrates how we can use the MVP to discern which MJO events will produce these impacts. It shows composite anomalies of 850-hPa temperatures (shading) and 500-hPa geopotential height for phases 5 (top) and 8 (bottom). The composites are subdivided by the MVP. Days where the MVP ≤ -0.75 are on the left, $-0.75 <$ MVP $< +0.75$ are in the middle, and MVP $\geq +0.75$ are on the right. In each case, the anomalies are averaged for the pentad centered 8 days after the composite date to show the predictive potential.

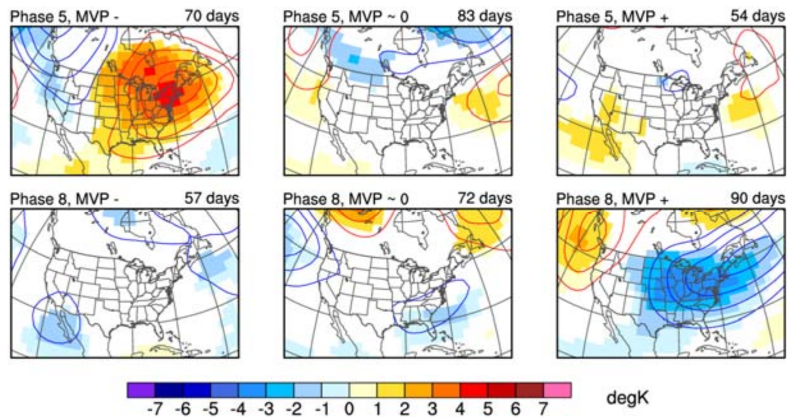

Fig. 2 Composite anomalies of 850-hPa temperature (shading) and 500-hPa geopotential height (contours) averaged 6–10 days after the RMM is > 1.0 and in phase 5 (top) or phase 8 (bottom). The composite dates are further subdivided by days when MVP ≤ -0.75 (left), $-0.75 <$ MVP $< +0.75$ (middle), and MVP $\geq +0.75$ (right). Only temperature anomalies that are 95% significant are shaded. Geopotential height anomalies are contoured every 20 m.

As discussed before, warm anomalies are generally associated with phase 5, but the top row of Fig. 2 shows that these anomalies are only observed for MVP ≤ -0.75. When the MVP is neutral or positive, that warm signal disappears. Conversely, the bottom row shows that the cold in Phase 8 only occurs for MVP $\geq +0.75$. The signal is absent for the neutral and negative phases. The number of dates used for each composite is shown in the upper right. Note that for both RMM phases, the MVP is relatively equally distributed among positive, negative, and neutral.

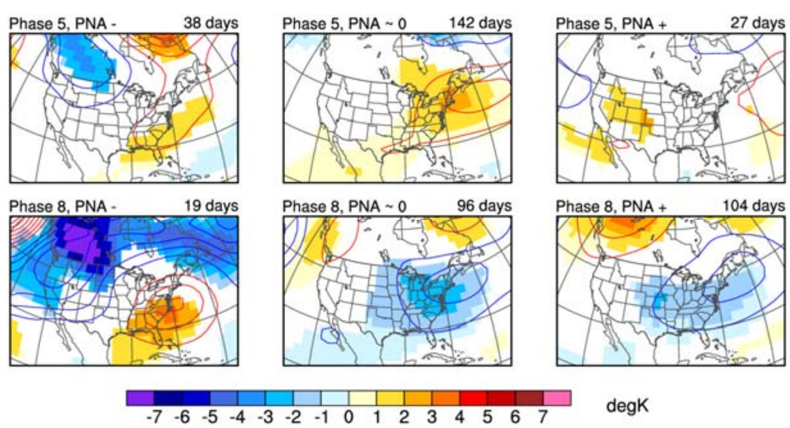

Fig. 3 As in Fig. 2, but subdivided by PNA ≤ -0.75 (left), $-0.75 <$ PNA $< +0.75$ (middle), and PNA $\geq +0.75$ (right).

Figure 3 repeats the composite analysis using NOAA/CPC's PNA index, which does not show the same sensitivity. For phase 5, the largest warm signal occurs when the PNA is neutral, which accounts for 69% of the days. A weaker signal is found when the PNA is negative, and none when it is positive. For phase 8, cold signals are observed for both the positive and neutral PNA composites. The negative PNA is actually associated with a warm signal over the southeastern United States and a cold signal over northwestern North America. However, this composite accounts for only 9% of the total days in phase 8.

Since the MVP is focused on the North Pacific basin, it could be influenced by the El Niño–Southern Oscillation (ENSO). To investigate this possibility, Fig. 4 shows the number of days per year where the RMM is in phase 5 (top) or phase 8 (bottom) and the MVP is ≥ +0.75 (red) or ≤ −0.75 (blue). Some degree of interannual variability is apparent, most notably the large number of negative MVP events in phase 8 during 1991/92. However, if ENSO were a driving factor, then significant ENSO years like 1982, 1997, and 1998 would stand out.

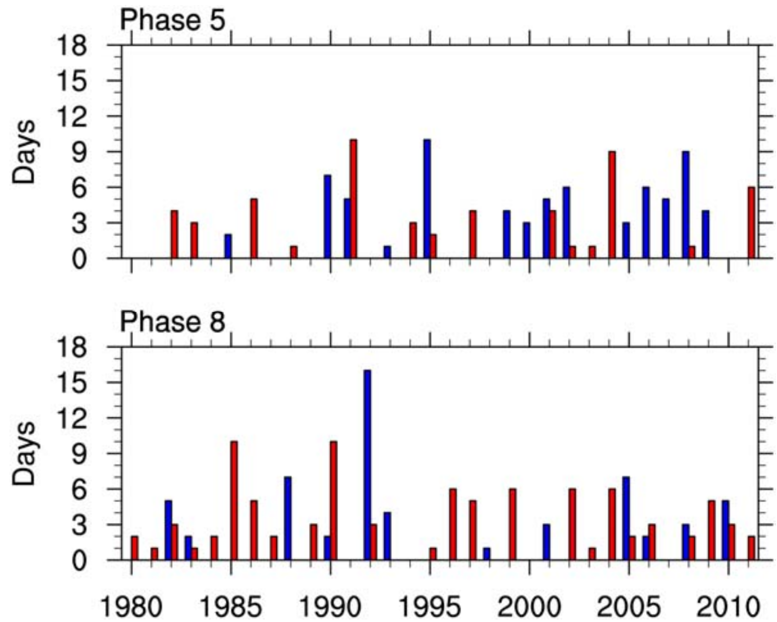

Fig. 4 Number of days per December–February when the MVP ≤ −0.75 (blue) or MVP ≥ +0.75 (red) and the RMM is in phase 5 (top) or phase 8 (bottom).

5. Summary and future plans

This study proposes a new index, the MVP, for identifying which MJO events will influence North American temperatures and which will not. This index is based on a combined EOF of 20–100 day filtered OLR and streamfunction at 850 hPa and 200 hPa. Composites indicate that the warm anomalies in phase 5 are strongly associated with the MVP being negative, while the cold anomalies in phase 8 occur with a positive MVP.

The MVP is related to the conventional PNA, but the PNA is unable to replicate these signals. There are several possible explanations:

1) The MVP more explicitly incorporates the MJO's diabatic heating by including OLR.
2) The wave train in the MVP is shifted 5°–10° southward, which might be associated with more persistent temperature patterns.
3) The phase of the PNA is too closely related to that of the MJO to provide enough null cases that lack the expected temperature signals.

For these reason, the MVP seems to be more useful for identifying the MJO's impacts over North America.

A logical next step will be to determine why some MJO events produce a response over North America while others do not. Preliminary results suggest that the convective anomaly near Hawaii in the bottom panel of Fig. 1 might play an important role. This convection may be associated with anti-cyclonic wave breaking from the extratropics. Therefore, further research is required to determine whether the convection is driving the circulation or vice versa.

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