The Madden Julian Oscillation: Can it Play a Significant Role in Improving Forecasts of Hydrologically Significant Rainfall for Week Two?

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1. INTRODUCTION

It has been noted (Mo and Higgins, 1998, Jones, 2000) that tropical influences can have a significant impact on California precipitation. Specifically, hydrologically significant events can occur along the West Coast during the cool season when tropical seasonal oscillations (Madden Julian Oscillation or MJO is one type of intraseasonal phenomena, with a 30 to 45 day oscillation) occur. El Nino and La Nina (ENSO) are inter-seasonal in nature meaning they last on the order of a year. The manifestation of El Nino and La Nina is the location and extent of tropical convection and the impact it has in modifying the mid latitude circulation.

It has been observed that during ENSO neutral years there is a higher frequency of occurrence of the MJO. During cool season 2003-04, a well-defined 30 to 60 day cycle of the MJO was observed beginning in December and continuing throughout the year. In years in which the MJO is well behaved and cycles through on a regular 30 to 45 day period, the MJO provides an opportunity to forecast, with up to two weeks lead-time, potential flooding along the West Coast. As with anything to do with atmospheric predictability, there are large uncertainties associated with any 7 to 14 day forecast. It will be necessary to quantify this uncertainty such that reservoir operators can make critical decisions, i.e. reservoir releases in anticipation of capturing the floodwaters, with reduced risk of not refilling the reservoirs if the event fails to materialize or its magnitude is less than expected.

2. MJO Identification

As stated, during 2003-2004 cool season, the occurrence of the negative phase (convective phase) of the MJO was closely monitored. This *using NOAA's Climate Prediction Centers (CPC) MJO index page.

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_mjo_index/mjo_index.html

These five-day running mean charts shown on what is called a Hovmoller diagram, allows the forecaster to track the eastward progression of the convective disturbances moving out from the Indian Ocean. Figure 1 shows the diagram from May of 2004.

The occurrence of the negative phase of the MJO is not sufficient by itself to cause flooding along the West Coast. As CPC has noted, there appears to be a favored large-scale synoptic pattern, Pacific North American or PNA, that,

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when MJO is in the positive phase, provides a favored flow pattern for the MJO to increase the mid-latitude westerly flow or jet stream into the West Coast. In effect the Southeast Asian Jet extends well east and south of its normal position similar to what can occur during El Nino years but on a shorter time scale. This is shown conceptually in Figure 2 from CPC's web site.

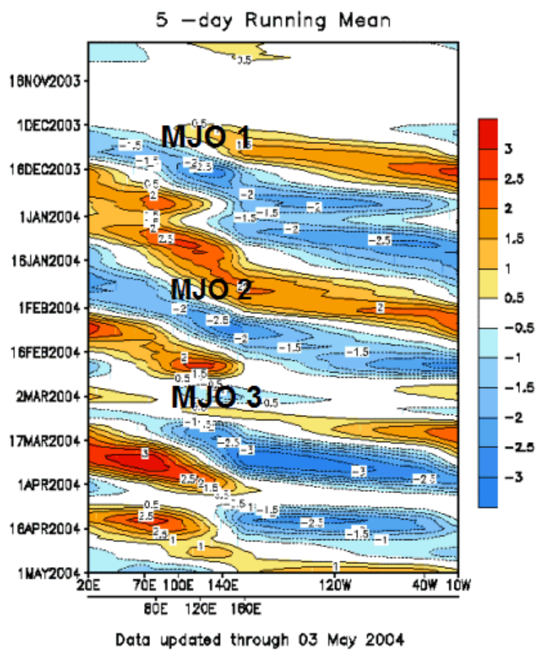

Figure 1 5-day running mean of the MJO Index from CPC. Blue shading denotes negative (enhanced convection) of the MJO cycle. The three major cycles during the cool season are noted. The date is along the Y-axis and the longitude is along the X-axis.

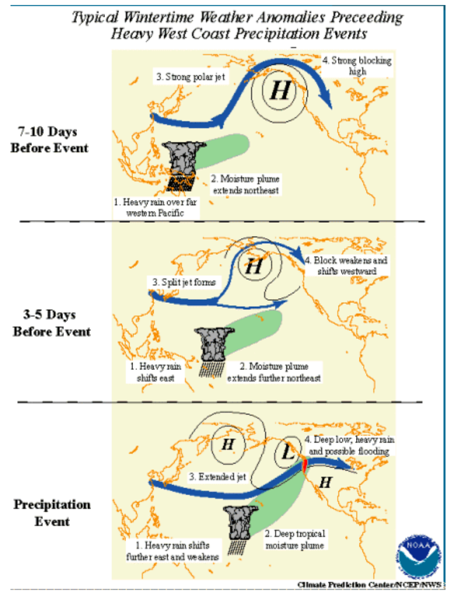

Figure 2 Conceptual patterns of large scale flow field and a scenario that would allow the MJO to enhance rainfall to potentially extreme amounts along the West Coast. Taken from CPC MJO Tutorial.

3.0 Application of the MJO to Week Two Forecasts

For the 2003-2004 cool season, the MJO index was monitored closely along with the

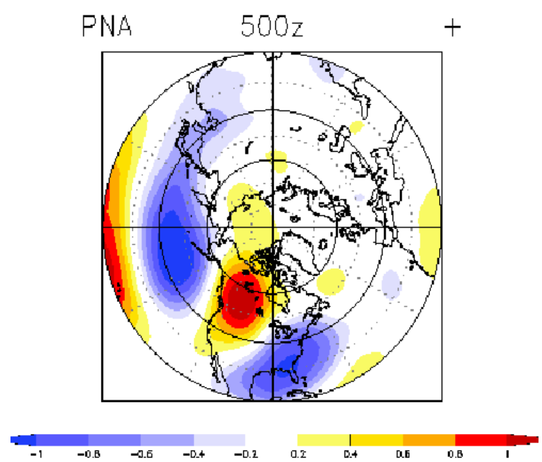

Figure 3 Positive Phase of the PNA pattern as depicted at 500 mb. Red areas denote positive height anomalies and blue areas denote negative height anomalies.

output from the Global Forecast Model or GFS and its ensembles. Since the GFS and its ensembles are now run out to 15 days it is possible to analyze the model output with respect to the pattern identified in Figure 3 to determine that when the MJO negative phase approaches 120E longitude there could be potential heavy rain 7 to 14 days later (MJO propagation speeds of 5-10 m/s) in California. Note in Figure 3 that the below normal height anomalies in the northern Pacific and the above normal height anomalies in the tropical and sub-tropical Pacific infers a strong zonal jet stream over the central Pacific. It is the enhancement of this jet by the tropical convection associated with the MJO out near the dateline that allows the jet to undercut the ridge over western North America slamming the jet into California. Since the jet is coming into California from lower latitudes, the jet can entrain tropical to sub-tropical moisture producing what Ralph et al (2004) call an Atmospheric River (see Fig. 7).

It was possible by analyzing all these features to begin an open discussion among the West Coast forecasters some ten days ahead that a major pattern change was possible and could lead to flooding. The 120E longitude line was used as a threshold to begin these discussions. Since the MJO moves on average of about 7 degrees longitude per day a rather specific date could be given as to the pattern change. Additionally, the numerical models do not usually handle the breakdown of the large West Coast ridge patterns very well. One reason for this is the models do poorly in simulating the MJO and its impacts. Thus in situations when the models are continuing what would be a dry pattern in 7 to 10 days, the forecaster, by his/her awareness of the MJO and the PNA pattern, can add significant value to the forecast process by forecasting a breakdown of the ridge and a turn to much wetter conditions.

Twice during the past cool season this scenario was followed. The first event came in December of 2003. The second event occurred in February of 2004. Referring back to Figure 1, this would be what was called MJO #1 and MJO #2. Figure 4 shows a hydrograph for the Napa River at St Helena for a period running from December 1, 2003 through 19 February 2004. The red line denotes the flood stage for the Napa River. Annotated on the chart are the dates when the negative phase of the MJO was noted at 120E longitude.

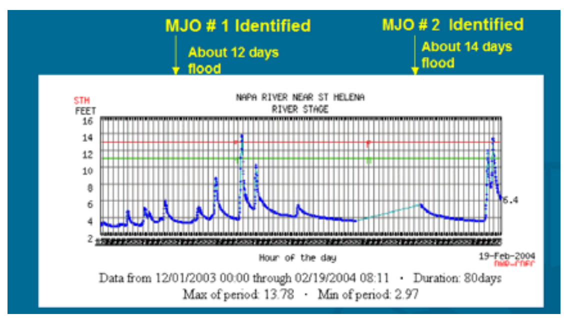

Figure 4 Hydrograph for the Napa River at St Helena in the north San Francisco Bay Area showing two periods of flooding believed to be correlated with the MJO's identified some 12 to 14 days earlier.

Figure 5 shows the 500 mb height field for 10 February, 2004. This is indicative of a positive PNA pattern. The atmosphere appears to be more conditioned to respond to the convective forcing when the PNA pattern is present.

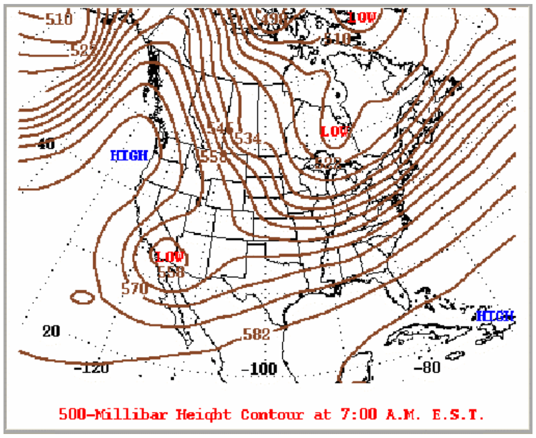

Figure 5 500 mb height field for 10 February, 2004. This pattern is indicative of a positive PNA pattern.

Figure 6 shows the hydrograph for the Russian river at Guerneville. This is the largest river in the San Francisco hydrologic service area. Note that for the February MJO, flood stage was obtained on the 17th.

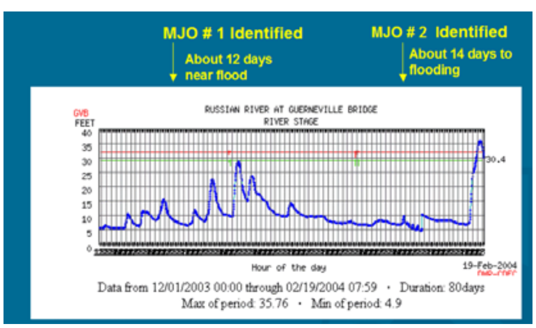

Figure 6 Hydrograph for the Russian river at Guerneville for the period December 1 through February 19, 2004. The red line indicates flood stage.

Figure 7 shows and image of the total precipitable water from the SSMI data from the NOAA polar orbiter satellite. It shows a narrow plume of high PWs extending back to the tropical pacific near Hawaii. It has been noted in the past that the very heavy rains in California have what has been coined a pineapple connection, the name relating to the extension of clouds back to near the Hawaiian Islands.

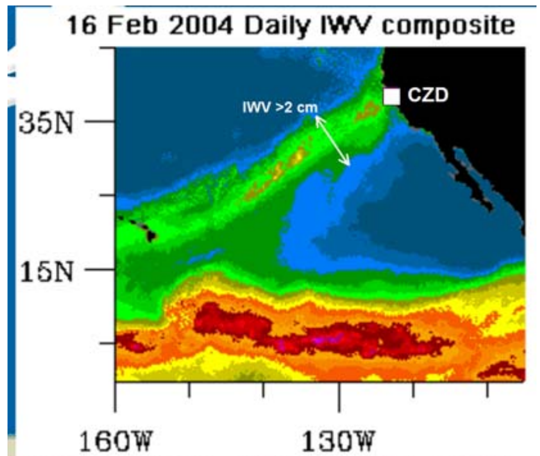

Figure 7 SSMI total precipitable water image for 16 February, 2004. The location called CZD is located in the Russian river watershed. IWV here stands for Integrated Water Vapor.

The December and February cases stand out as excellent cases where identifying the MJO out near 120E and identifying that the synoptic regime might be more conducive to the influence of the MJO provides a week two heads up to water managers.

As you can see from Figure 1 there was a third MJO in March. However there was no impact on California rainfall from this MJO. One possible reason for this is that the large-scale flow regime was not representative of the positive PNA pattern. Figure 8 is the 500 mb chart for March 12, 2004. It indicates that the westerlies have receded north in Canada and that there is no full latitude

West Coast ridge representative of the positive PNA pattern.

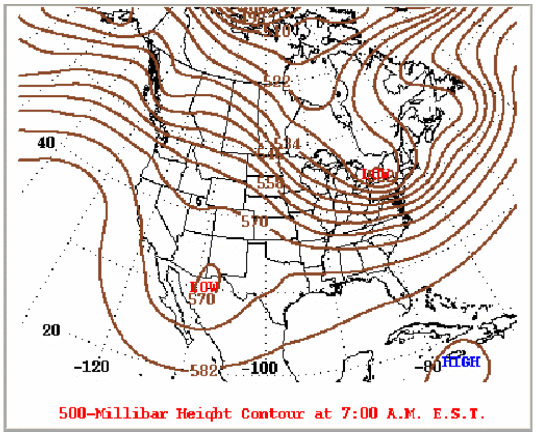

Figure 8 500 mb chart for March 12, 2004. This pattern is not representative of the positive phase of the PNA pattern.

4.0 **SUMMARY**

NOAA's Climate Prediction Center has outlined a set of circumstances whereby the negative phase of the MJO can enhance the East Asian Jet to produce heavy to extreme rainfall in Central and Northern California. The more extreme of these events have been coined the pineapple connection in reference to a tap to the deep tropical moisture near and south of Hawaii. As part of the National Weather Service's new Climate Services Program (NWS, 2003), this study is an attempt to develop a climate-weather connection that can be used in a weather forecast office to provide up to two weeks notice of a potential significant hydrologic event. One can think of this as similar to the identification of a strong EL Nino such as those of 1982-83 and 1997-98 that had profound influences on California's precipitation. The MJO however provides a more specific time frame then do the seasonal El Nino forecasts such that if confidence is sufficient, water managers may be able to utilize this information to more efficiently manage reservoir operations to both benefit flood control, hydro power generation, and water supply needs. However it is anticipated that a much better understanding of the interactions of the MJO with the mid-latitudes is needed before confidence can be raised to a level that reservoirs can be more efficiently managed. The hope in this paper is to stimulate further studies by the research and climate communities to help the operational forecaster have more confidence in issuing week two flood outlooks that in turn can be used by water managers to take action.

It is important to understand that it is the location, extent and magnitude of the tropical convection that is the major forcing function during the cool season impacting the large scale flow and thus precipitation on the West Coast. Fig 9 from Nitta, 1987 and Wallace and Horell, 1981, is a classic example of how the diabatic processes of convection excite the Southeast Asian Jet allowing anomalous Rossby waves to propagate to higher latitudes forcing downstream amplification near the west coast. In fact the PNA pattern is most likely a result of these types of processes and maybe why it correlates with stronger MJO impacts. We saw in the cool season of 2004 and 2005 that southern California was significantly impacted by what was a persistent trough just off the coast. The persistent and semi-stationary of convection in the tropics reinforced this persistent pattern leading to extreme rainfall and flooding several times from January into February. The MJO contributed to this. It is believed that Rossby wave dispersion induced by tropical convection is a significant contributor of wave amplification off of California. It should be noted that recurving typhoons in the Western Pacific can also produce downstream amplification such as occurred in mid-May 2006 from Typhoon Chanchu. The location and persistence of this trough can have a significant impact on whether the rainfall is a typical winter storm system or becomes a February 1986, January and March 1995, or New Years 1997.

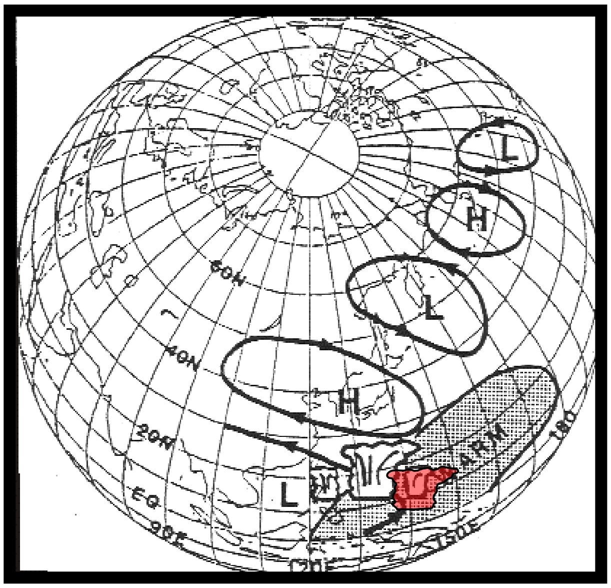

Fig. 9 Classic Rossby wave dispersion generated by tropical western Pacific convection leading to long wave trough off west coast. (Nitta, 1987)

5.0 **REFERENCES**

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