

## INTRASEASONAL MODULATION OF PRECIPITATION OVER THE NORTH AMERICAN MONSOON REGION

George N. Kiladis<sup>1</sup> and Eileen A. Hall-McKim<sup>2</sup>

<sup>1</sup>NOAA Aeronomy Laboratory, Boulder, CO

<sup>2</sup>University of Colorado, Boulder, CO

### 1. Introduction

This study investigates summer precipitation variability over the North American Monsoon System (NAMS) on a variety of timescales for the period 1948-present. Our study area extends from tropical Mexico northward to the desert southwest and Colorado Plateau/southern Rockies region of the United States. The main focus concerns the time and space scales of variability of precipitation over the NAMS, and their relationship to large scale atmospheric circulation. While we are primarily emphasizing intraseasonal time scales, interannual variability is also of interest, especially as it contrasts to the patterns isolated on the intraseasonal time scale, and also as it relates to the modulation of

higher frequency disturbances from year-to-year and within monsoon rainy seasons. Ultimately we plan to compare results from historical data to events observed during the field phase of the North American Monsoon Experiment (NAME), planned for the summer of 2004.

### 2. Data and Methodology

The precipitation data used for this study is based on an updated daily one degree resolution version of the Higgins et al. (1996) gridded dataset for the United States and Mexico. Other data sources include radiosonde, satellite-derived Outgoing Longwave Radiation (OLR) and the NCEP/NCAR and ECMWF reanalysis data sets.

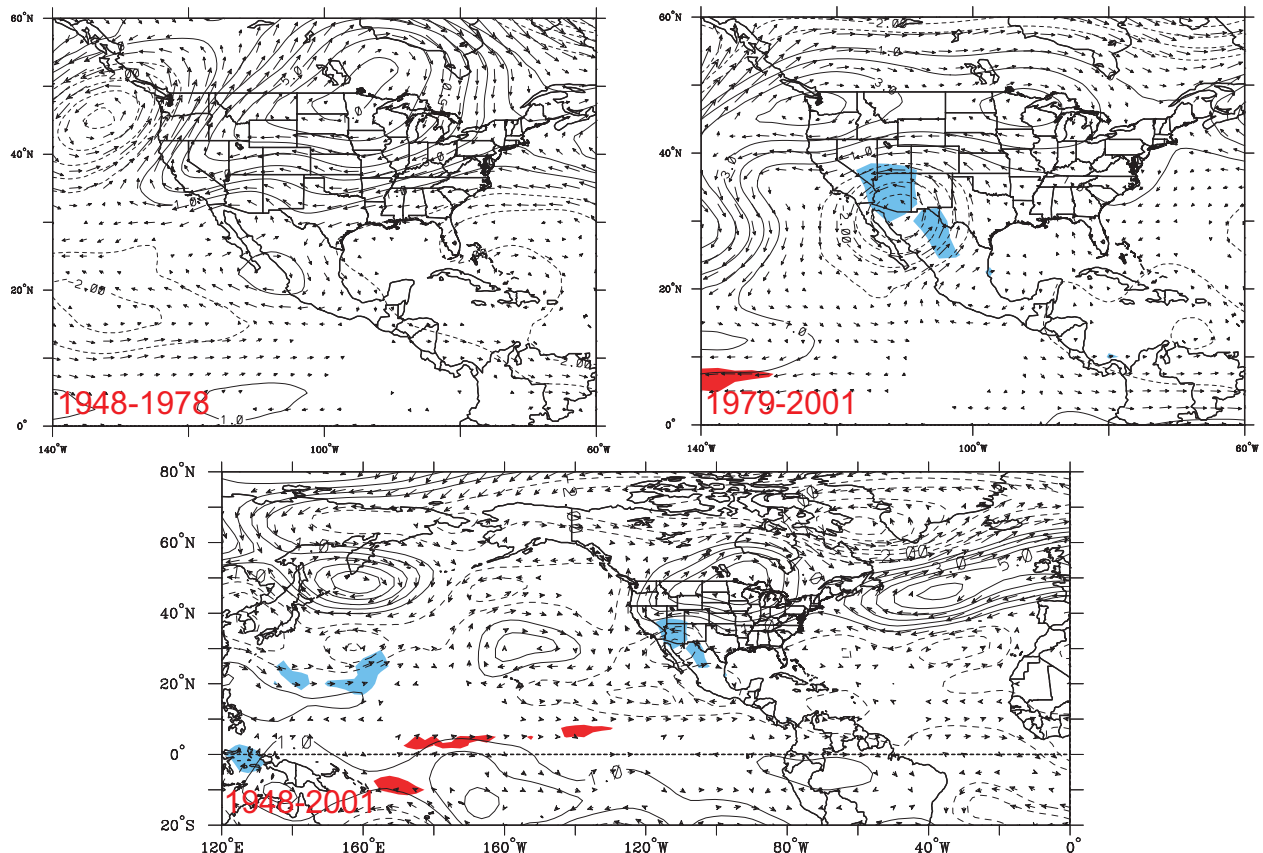


Figure 1. Anomalous 500 hPa streamfunction (contours) and wind regressed against a +1 standard deviation in AZNM precipitation (around 25 mm) for July-August 1948-78 (top left) and 1979-2001 (top right). On the bottom is the pattern for the entire 1948-2001 period. OLR perturbations are shown as blue (negative) and red (positive).

Corresponding author address: George N. Kiladis,  
Aeronomy Laboratory, NOAA, R/AL3, 325 Broadway,  
Boulder, CO 80305-3328; email: gkiladis@al.noaa.gov

Composite fields have been constructed corresponding to signals of precipitation over the southwestern U.S. for both interannual and intraseasonal time scales. Interannual fluctuations correspond to year-to-year July-August total precipitation averaged over specific areas. The area examined in this report is the Arizona-New Mexico (AZNM) region as was defined by Higgins et al. (1997). The AZNM precipitation time series are derived from area averages of precipitation over the region  $32^{\circ}\text{N}$ - $36^{\circ}\text{N}$ ,  $113^{\circ}\text{W}$ - $107^{\circ}\text{W}$ , centered on the active summer monsoon regions of Arizona and New Mexico.

Composites were constructed both by picking out precipitation events above a given threshold, and by utilizing a regression approach whereby dynamical fields were correlated and regressed against an entire time series of precipitation. Results are very similar using either technique, so we adopt here the regression approach which is more objective, and yields less noisy results overall. Interannual variability was examined using July-August precipitation anomalies for each year as the independent variable. This analysis extends back to 1948 using NCEP/NCAR reanalysis data.

Intraseasonal variability is isolated to submonthly time scales by high-pass filtering the precipitation data with a 30 day cutoff. This removes signals associated with the Madden-Julian Oscillation (MJO), which will be examined in a separate study. All regression results are plotted for an arbitrary +1 standard deviation in the independent variable. We emphasize that while the results shown here statistically represent the most "preferred" patterns for precipitation events, variability between individual events is large, and is a topic of current investigation.

### 3. Interannual Variability

Figure 1 shows the 500 hPa wind and streamfunction regressed onto the July-August AZNM anomalous precipitation, as defined by the seasonal total minus the 1948-2001 climatology at each grid point. The upper left panel shows the result for the period 1948-78. The upper right panel shows the same for 1979-2001, and includes OLR. Features common to these plots include a cyclonic perturbation over northwest Mexico, and an anticyclone to the north, giving anomalous easterly flow over AZNM. However there are marked differences in the overall patterns, perhaps not surprisingly given the relatively small sample sizes.

The lower panel of Figure 1 shows the 500 hPa wind and streamfunction regressed onto July-August AZNM precipitation as above, except including the entire 1948-2001 period over the entire Pacific/North America sector. OLR is from 1979-2001. Overall, the results are similar to Higgins et al. (1999), with wet monsoon seasons over AZNM corresponding to southeasterly

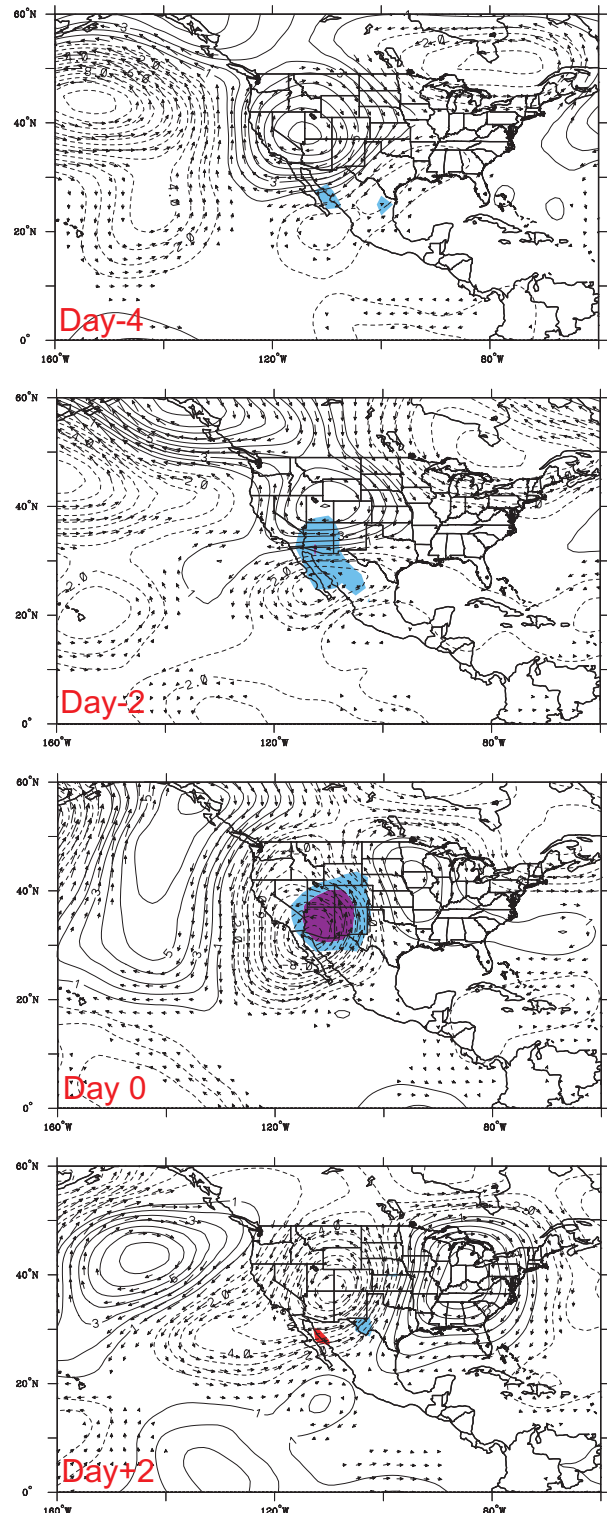


Figure 2. Anomalous 500 hPa streamfunction (contours), wind and OLR (blue negative) regressed against a +1 standard deviation in < 30 day filtered AZNM precipitation (around 2 mm) for July-August 1979-2001. Lags from Day-4 (top) to Day+2 (bottom).

flow anomalies aloft induced by anticyclonic flow centered over the upper Midwest and a cyclone over Baja California. Based on the OLR signal, when precipitation is enhanced over AZNM it is also above normal over northern Chihuahua and Sonora. There is a weak indication of suppressed convection over the central Pacific, consistent with results from other studies. Nevertheless the lack of robustness between the plots displayed above does indicate that multiple potential forcings are likely responsible for interannual variability of AZNM summer precipitation.

#### 4. Intraseasonal Variability

Figure 2 shows the OLR (color, blues are negative) and 500 hPa wind and streamfunction (contours) regressed onto the < 30 day filtered daily July-August AZNM precipitation from 1979-93 for four different lags, from Day-4 to Day+2. These dynamical fields are obtained from ECMWF reanalysis (ERA 15). Results from NCEP/NCAR reanalysis are nearly identical down to fine detail. The plots are scaled to a +1 standard deviation in filtered precipitation, and so while the amplitudes and

signs are arbitrary, they are consistent relative to each other. By design using this technique the precipitation will peak at simultaneous lag (Day 0), and as expected the OLR signal is at a minimum over AZNM on this day.

Submonthly precipitation events over AZNM are associated with a cyclonic perturbation over Baja California and anomalous ridging to the north in the upper troposphere. The ridge propagates eastward along 40°N over time while the cyclone moves slowly northward along the west coast of Mexico. The combination gives anomalous easterly flow over AZNM, not unlike the interannual patterns shown in Figure 1, resulting in moisture advection into the region as will be described below in Figure 5. Anomalously low OLR over the Gulf of California and northeastern Mexico precedes the AZNM precipitation on Day-4, and by Day+2 the cyclone has moved northward over the Colorado plateau and a negative OLR signal lies over westernmost Texas. In earlier lags (not shown) the OLR and moisture signal appears to originate within the tropical easterlies lying over the Gulf of Mexico. These results complement those obtained by Mo (2000) for AZNM. From the full set of

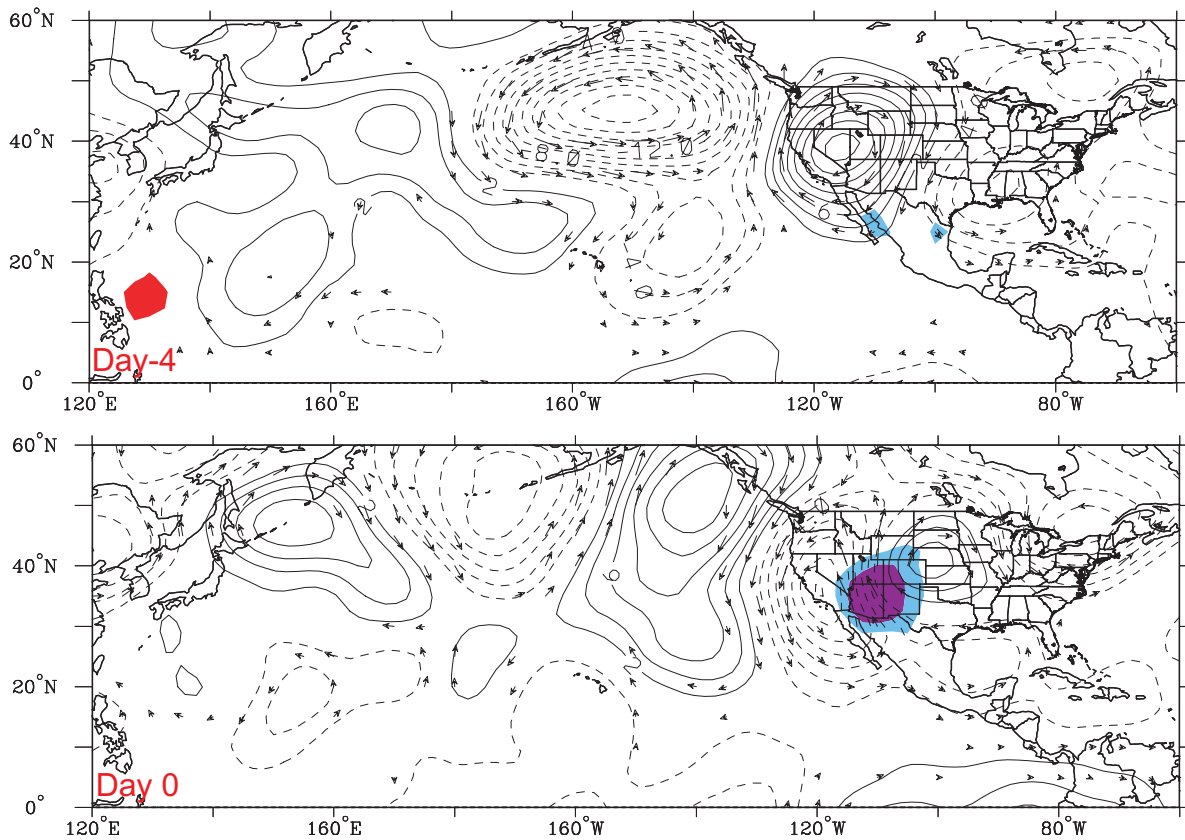


Figure 3. Same as Figure 2 except showing the entire Pacific/North American sector. Day-4 (top) and Day 0 (bottom).

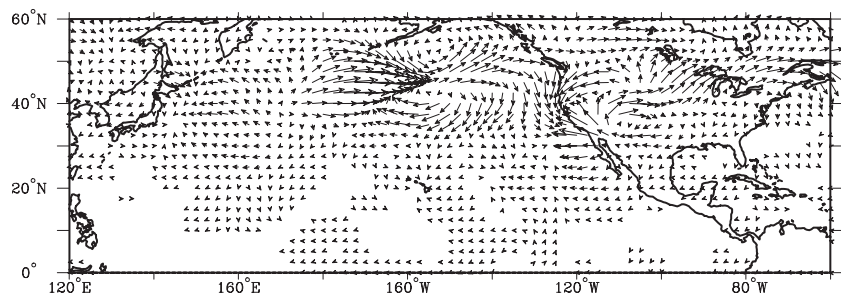


Figure 4. E Vectors at 200 hPa calculated from the regressed  $u'$  and  $v'$  fields from Day-12 to Day+12 using the < 30 day filtered AZNM example represented in Figures 2 and 3.

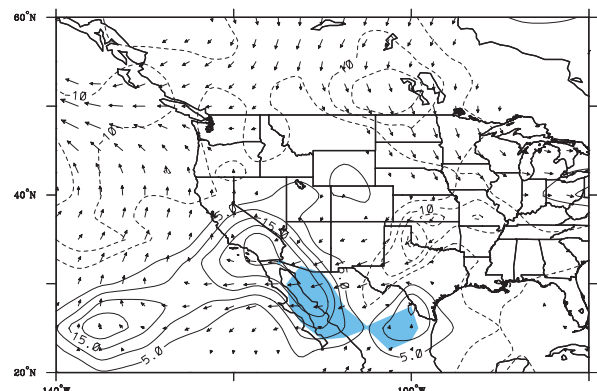


Figure 5. As in Figure 2 except for anomalous specific humidity at 700 hPa (contours), 700 hPa wind and OLR (blue negative) for Day-3.

lagged OLR it can be seen that the dominant period for precipitation events over AZNM is around 18 days, in agreement with spectral results of Mullen et al. (1998).

Pacific and North America for the preferred circulation which leads to precipitation over AZNM during the monsoon season.

Figure 3 is identical to those in Figure 2 except for OLR and 200 hPa wind and streamfunction, extending over the Pacific. These plots show that an anomalously strong cyclonic circulation in the Gulf of Alaska tends to precede intraseasonal precipitation episodes over AZNM, which retrogrades westward in the days leading up to the event itself. Apparent dispersion of wave energy organizes a wavetrain tied to the amplification of the west coast cyclone and subsequent northeastward displacement of the mean subtropical ridge to northeastward towards the upper Midwest of the U.S.

Figure 4 shows clearly that submonthly July-August precipitation events over the AZNM are associated with the dispersion of Rossby waves from the North Pacific into North America. The wavetrain signal for AZNM is somewhat further south and east than it is for regions further north (not shown). Evidently wave energy originating over the North Pacific is most commonly responsible for the perturbation circulation shown in Figures 2 and 3, which cause circulation changes and moisture advection leading to precipitation events over the desert southwest.

### 5. E Vectors

### 6. Moisture

The E vector (Hoskins et al., 1985) is a statistical measure of the mean dispersion characteristics of Rossby wave activity. The E Vector is a pseudo-vector constructed by calculating time mean covariances between the perturbation zonal and meridional wind components:

$$E = (\overline{v'^2 - u'^2}, -\overline{u'v'})$$

Together the two components approximate the preferred direction of the group velocity of the waves. Kiladis (1998) shows that the E vector can be utilized to give a picture of the dispersion characteristics of a mean wavetrain evolution such as that shown in Figures 2 and 3. For Figure 4 E vectors are calculated from the regressed <30 day  $u'$  and  $v'$  from Day-12 through Day+12 for AZNM submonthly precipitation. These signals can be considered as perturbations from the mean energy propagation characteristics of Rossby waves over the

Figure 5 shows the perturbation 700 hPa specific humidity (contours) and wind along with OLR preceding AZNM precipitation on Day-3. At previous lags (not shown) it can be seen that moisture for AZNM preferentially originates in the tropical easterlies, where it is then advected poleward around the anomalous mid-tropospheric anticyclone shown in the previous panels. For AZNM the moisture perturbations appear to peak over the Gulf of California three days prior to the precipitation event. At this time there are anomalous easterlies at 700 hPa, but at 1000 hPa an anomalous southerly flow along the Gulf appears evident (not shown), although this is likely not resolved well by the ECMWF reanalysis. At previous lags there is an "easterly wave" type signature in the easterly flow, as was seen by Fuller and Stensrud (2000) to precede "Gulf surges" of moisture. For a variety of examples further north, moisture perturbations maximize at 500 to



700 hPa, and are advected northward over the high terrain in mid-tropospheric southerlies.

## 7. Conclusions

As is well known to operational forecasters and synopticians studying the NAMS region, a common synoptic situation producing intraseasonal precipitation events over AZNM during the summer monsoon season is associated with cyclonic circulation over western Mexico, and ridging over the midwestern U.S. This pattern produces anomalous southerly flow and moisture advection over the region. We have shown that such a pattern is tied to a pattern of Rossby wave dispersion originating over the North Pacific. This dispersion is accompanied by a strong cyclonic development in the Gulf of Alaska.

Mid-tropospheric moisture associated with submonthly precipitation over AZNM originates in the subtropical easterlies over Mexico, and is first advected westward and then northward around the anomalous subtropical ridge as it migrates eastward over the southwestern U.S. into the Midwest. Moisture also feeds into the desert southwest at low levels on anomalous southerly flow up the Gulf of California. This view is consistent with that found by Schmitz and Mullen (1996), at least for the Sonoran desert region of the southwest U.S. The precise relationship between these varying sources of moisture and precipitation over different regions of the western U.S. still needs to be investigated in detail.

Circulation associated with the preferred pattern of submonthly precipitation over AZNM bears some broad resemblance to the interannual patterns. Wet July-August seasons on interannual time scales are generally associated with anomalous cyclonic circulation over northwestern Mexico, as on intraseasonal time scales, although the flow is somewhat more easterly over AZNM with a broad anticyclone to the north. In this case anomalous moisture advects into the region from more of a southeasterly direction. However the interannual circulation signals for AZNM precipitation are not particularly robust, with large event-to-event variability.

Submonthly precipitation over AZNM is associated with the propagation of Rossby wave energy into North America several days in advance of the event. It would appear to be crucial for operational forecast models to handle the development of this circulation evolution over the Pacific in order to skillfully be able to forecast wet and dry periods over the southwestern U.S. on the medium range time scale. The precise sequence leading up to this dispersion will be examined in detail for this study.

We emphasize that while the submonthly results shown here depict the most "preferred" patterns associated

with precipitation variability, event-to-event variability is certainly substantial and needs to be documented and quantified. As one approach the type of analysis utilized here can be extended through the use of a multiple regression, by taking out the variance due to the first isolated mode, and this can be repeated until the bulk of the variance has been accounted for. Other methodologies will also be investigated, such as EOF and cluster analysis.

As a necessary first step to developing meaningful spatial averaging for this study, ongoing work is examining the spatial scales interannual and intraseasonal variability of precipitation and circulation over the NAMS, along with case studies. Ultimately, we plan to analyze NAME data in some detail as a basis for comparison.

## 8. References

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