# Progress in American Monsoon Research: Climatological Forecasting of the North American Monsoon System


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## 1. Introduction and Motivation

The relationship between global sea surface temperatures and warm season precipitation activity over the United States are explored. Analyses of PRISM precipitation fields for a 60-year record (1950-2010) and National Climate Data Center (NCDC) sea surface temperatures (SSTs) provides credence for potentially skillful forecasts for the North American Monsoon (NAM). In this summary, the use of a combination of oceanic indices, such as the Pacific Decadal Variability (PDV), the El Niño Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO) via the use of rotated empirical orthogonal functions (REOFs) will be evaluated for correlation and precipitation forecasting capability over the southwestern United States (primarily southern Arizona). This study was heavily motivated by ongoing drought conditions over the core monsoon region prior to the 2011 monsoon season (Figure 1).

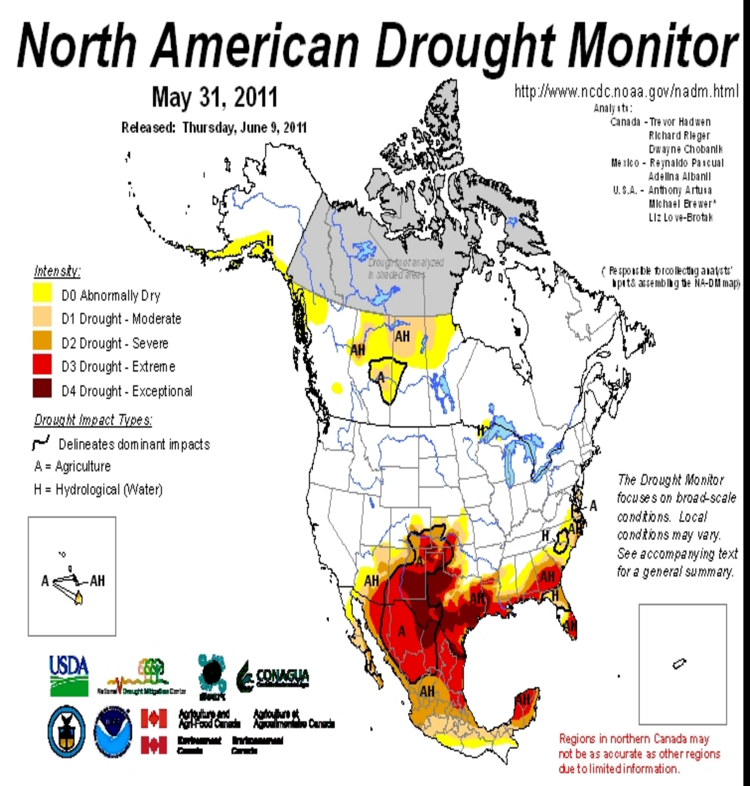


**Figure 1**: North American Drought Monitor, May 31, 2011.

## 2. Global SST Patterns and Relationship to NAM

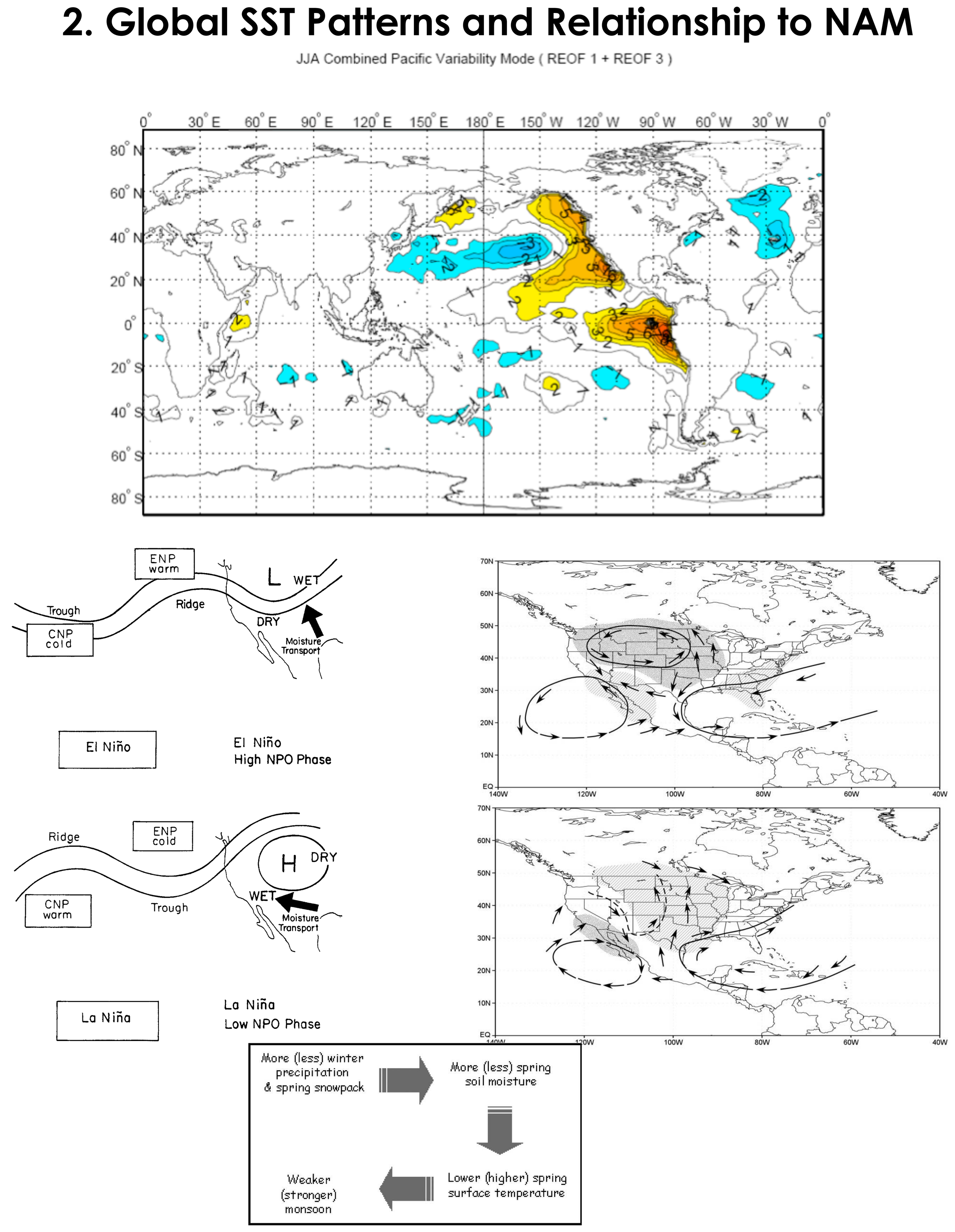


**Figure 2 (Top):** JJA REOF Analysis of NCEP SST data, after methods of Castro et al. (2007)
**(Center Left)**: PDV and ENSO atmospheric teleconnection to the NAM (Castro et al. 2001)
**(Center Right)**: AMO lower tropospheric teleconnection to AMO warm (top) and cold (bottom) phases (Hu et al. 2011, *accepted*)
**(Bottom)**: Proposed winter-summer land surface-atmosphere feed hypothesis for NAM (Zhu et al. 2005)

Many studies have documented that sea surface temperatures from the Pacific Ocean and, most recently, the Atlantic Ocean greatly influence large scale weather patterns. This is no different when investigating interannual climate variability, such as those completed by Castro et al. 2007 and Hu et al. 2011 (*accepted*) in the *Journal of Climate*. As a summary background, the dominant patterns of summer global SST and their associated time series were determined using a rotated principal component analysis. SST modes 1 and 3 are centered in the Pacific and Northern Atlantic, and strongly govern North American summer climate. When taken together, Castro et al. (2007) proposed that this comprised the Combined Pacific Variability Mode (CPVM). However, as Hu et al. (2011) argued, the influence of the signal over the Northern Atlantic cannot be ignored and should be utilized. Other studies, such as that conducted by Zhu et al. (2005), proposed that antecedent winter/spring snowpack conditions could potentially play as much a role in modulating the NAM, though it could be argued that antecedent SST states may influence the amount of snow that falls in the western United States.

## 3. Interannual Precipitation Variability

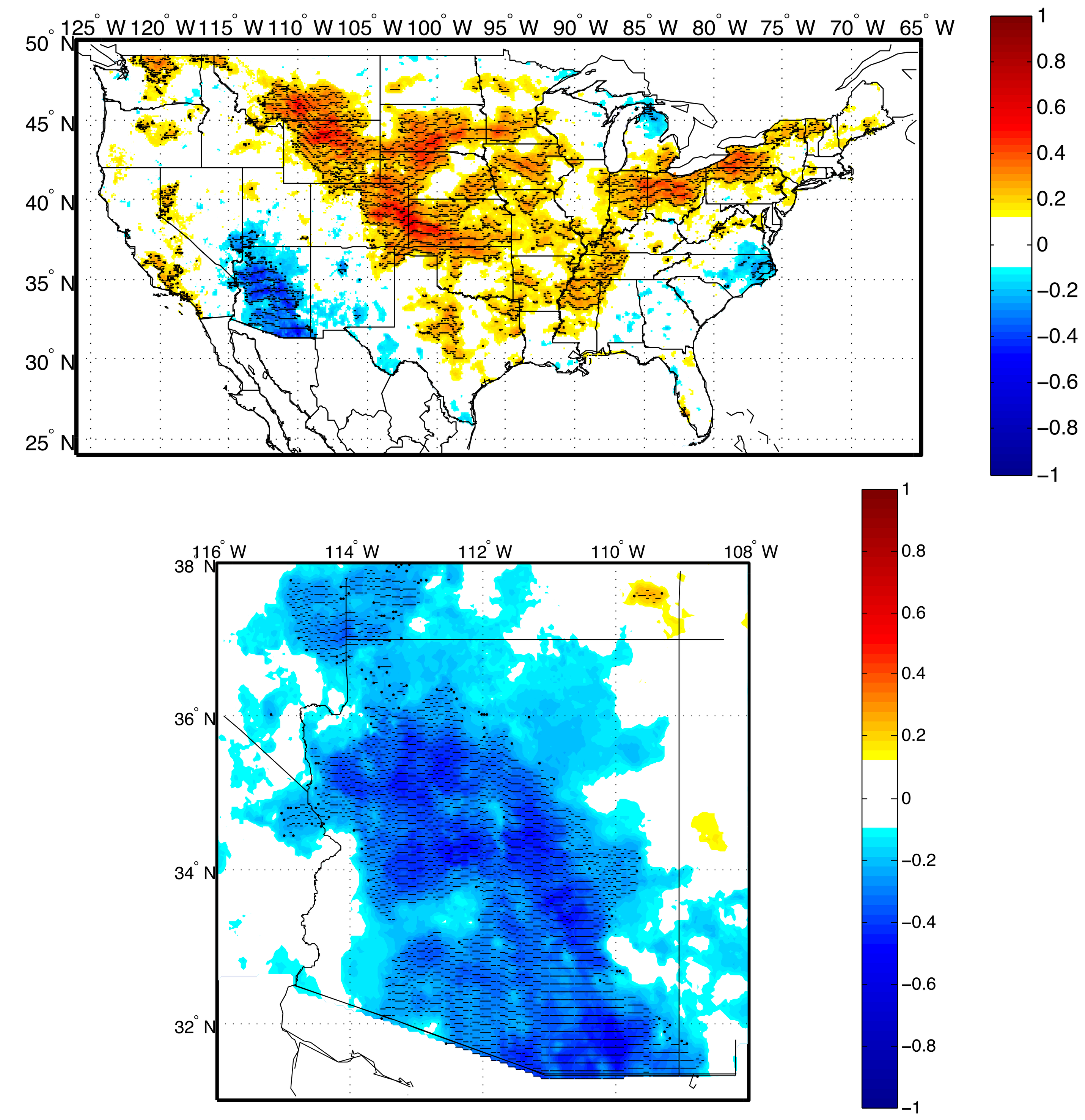

**Figure 3 (Top)**: PRISM precipitation data correlation with REOF 1 and 3 of the NCDC SST time series for the conterminous United States. Stippling indicates 95% local significance.
**(Bottom):** Same as the top figure, except focus on the state of Arizona.

The PRISM dataset was selected due to the high spatial resolution that it provided, which is critically important over the complex terrain of the affected NAM region. Though it is clearly understood that the interpolation scheme involved may introduce a degree of error in certain spots where data is lacking (e.g. southwest Arizona), the research group was willing to accept this degree of error.

These early results point towards the importance of the SST relationship to boreal summer precipitation anomalies. A clear and distinct out of phase relationship exists, supporting the conclusions of Castro et al. (2007), over the central United States and the southwestern United States. This out of phase relationship would suggest that the atmospheric teleconnection with the monsoon ridge would play a role in suppressing convection over the central plains, while increasing the moisture flux into Arizona during the NAM and introduce more destabilizing inverted troughs into Arizona (Bieda et al. 2009).

As a result of what these figures suggest, a first cut attempt at forecasting the 2011 NAM season for southern Arizona utilized SSTs in the highlighted regions of Figure 2 (Top) based upon understanding from what present literature has hypothesized or found (rest of Figure 2).

## 4. Antecedent Conditions for the 2011 NAM Seasonal Forecast

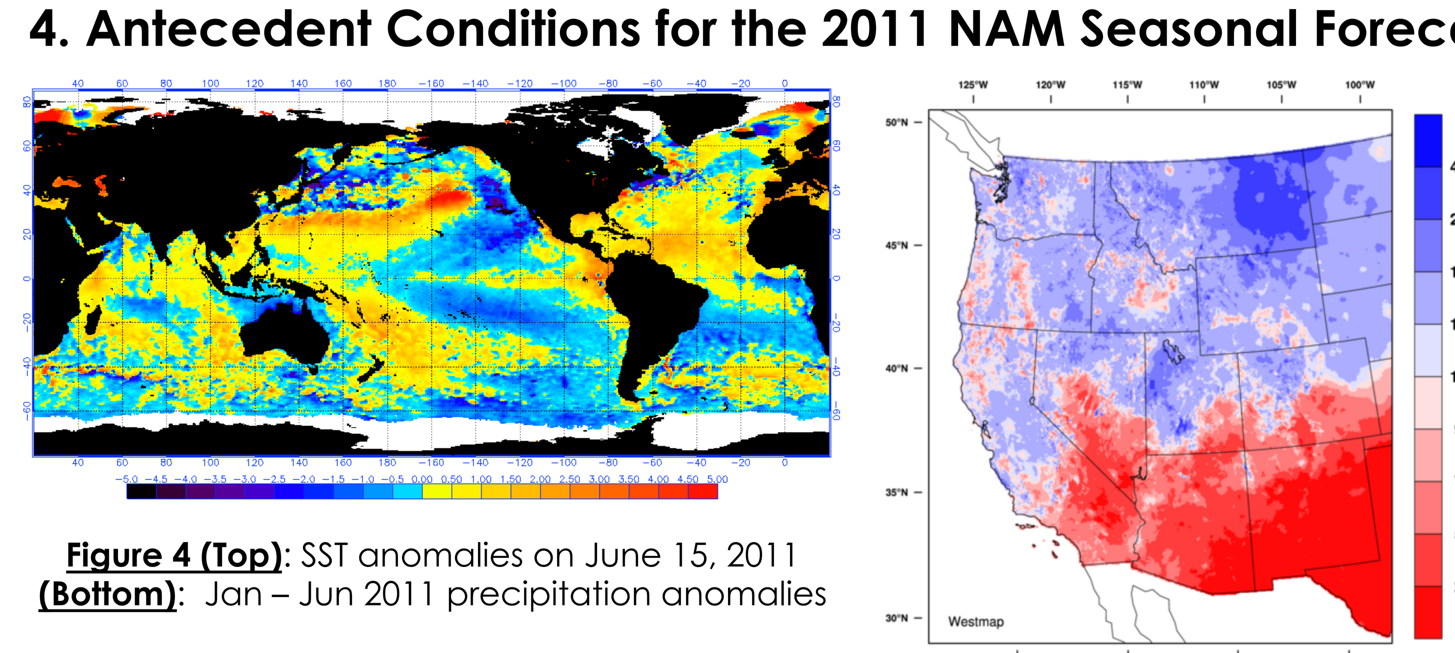

**Figure 4 (Top)**: SST anomalies on June 15, 2011
**(Bottom)**: Jan – Jun 2011 precipitation anomalies

Prior to the start of the 2011 NAM Season, the eastern north Pacific Ocean was cold, the central North Pacific Ocean was warm, the North Atlantic was in a warm phase, and the ENSO phase was trending towards neutral. In addition, the northern tier states of the western United States had received above normal precipitation (mostly snow) while the southern tier states was in the grips of a significant drought, one of the worst for the states of New Mexico and west Texas. These antecedent conditions presented contradictory information for stakeholders to make a forecast, based upon the present understanding of the literature, but a forecast was attempted to present stakeholders with what the 2011 NAM Season may look like.

## 5. The 2011 North American Monsoon Seasonal Forecast

| 1 La Niña conditions (MEI-based) | 2 Persistence trend toward neutralizing La Niña conditions (MEI-based) | 3 Negative PDO* | 4 Persistent trend of Negative PDO* | 5 Positive AMO* | 6 Persistent trend of Positive AMO* | 7 June 1-15 STR latitudinal position and pattern score* | 8 Analog years selected |
|---|---|---|---|---|---|---|---|
| 1950 | | 1950 | 1950 | | | | |
| 1951 | 1951 | 1951 | 1951 | 1951 | 1951 | 3 | **1951** |
| 1955 | | 1955 | 1955 | 1955 | 1955 | 0 | |
| 1956 | | 1956 | 1956 | 1956 | | | |
| 1962 | | 1962 | 1962 | 1962 | 1962 | 1 | **1962** |
| 1963 | 1963 | 1963 | 1963 | 1963 | | 4 | **1963** |
| 1967 | 1967 | 1967 | 1967 | 1967 | | 3 | **1967** |
| 1968 | | 1968 | 1968 | | | | |
| 1971 | | 1971 | 1971 | | | | |
| 1974 | 1974 | 1974 | 1974 | | | | |
| 1975 | | 1975 | 1975 | | | | |
| 1976 | 1976 | 1976 | 1976 | | | | |
| 1985 | | | | | | | |
| 1989 | 1989 | 1989 | | | | | |
| 1999 | 1999 | 1999 | 1999 | 1999 | 1999 | 5 | **1999** |
| 2000 | 2000 | | | | | | |
| 2006 | 2006 | | | 2006 | | 2 | **2008** |
| 2008 | 2008 | 2008 | 2008 | 2008 | 2008 | | |

**Table 1**: An analog approach was undertaken to attempt to match SST indices and their persistence with subtropical ridge (STR) position to form a list of years as guidance for the 2011 NAM Seasonal forecast.

| YEAR | Onset Date* (date, timing) | JJAS* Precipitation (total, % of average*) | | June* | | July | | August | | September | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | July 11 (late) | 4.49 in | 74% | 0.00 | 0% | 1.49 | 66% | 2.66 | 111% | 0.34 | 26% |
| 1962 | June 27 (early) | 4.97 in | 82% | 0.24 | 160% | 1.38 | 61% | 0.48 | 20% | 2.86 | 222% |
| 1963 | July 3 (on time) | 5.97 in | 98% | 0.00 | 0% | 1.66 | 74% | 2.86 | 120% | 1.45 | 112% |
| 1967 | June 18 (early) | 6.63 in | 109% | 0.36 | 240% | 1.21 | 118% | 2.00 | 84% | 1.35 | 105% |
| 1999 | June 26 (early) | 8.33 in | 137% | 0.16 | 107% | 4.15 | 184% | 3.05 | 128% | 0.97 | 75% |
| 2008 | July 5 (on time) | 5.52 in | 91% | 0.16 | 107% | 3.42 | 152% | 1.70 | 71% | 0.24 | 19% |
| Average | June 30 (on time) | 5.94 in | 98% | 0.15 | 100% | 2.47 | 110% | 2.13 | 89% | 1.20 | 93% |

**Table 2 (top)**: The resultant selected years and average for Tucson, AZ

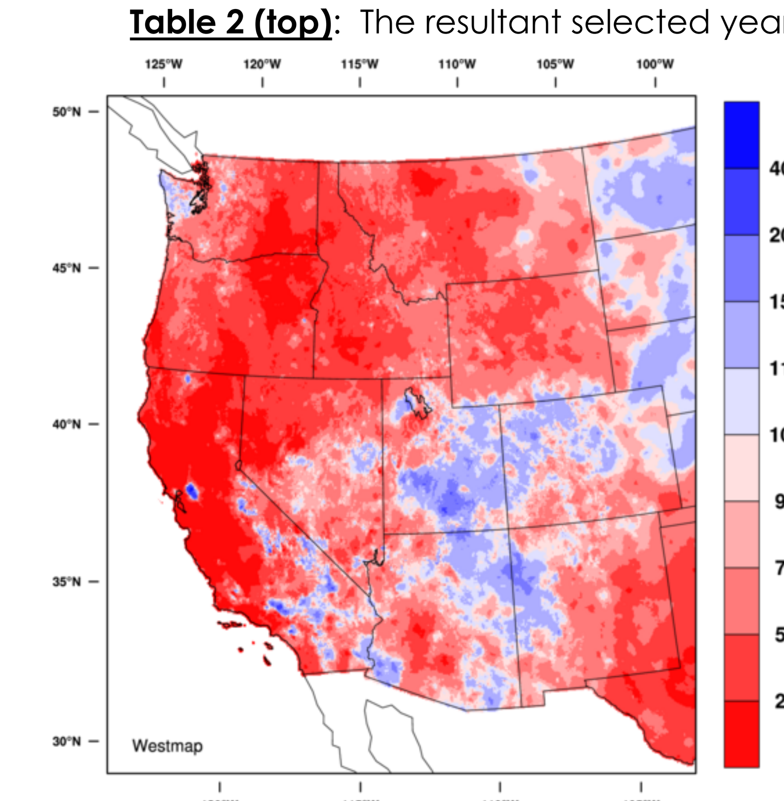


**Figure 5**: Final seasonal totals for JJAS 2011, where most of the NAM region in the SW CONUS was below normal, with a few exceptions

An analog approach was undertaken to identify years that closely matched the criteria of what the literature presented suggested for SST and positioning of the STR. The resulting forecast for the NAM region of southern Arizona was for near normal conditions, with a start (based on old 54 degree dew point criteria) of June 30 – July 5. Though the forecasters got the start date correct, the factors of positive AMO and a potential El Niño, despite favorable negative PDO conditions, presented a below normal monsoon for most of southern Arizona.

As this project was attempted on an operational basis, future work will now involve a statistical vs. dynamical forecasting approach future forecast accuracy improvements.

## 6. References


Bieda, S. W., III et al. 2009. The Relationship of Transient Upper-Level Troughs to Variability of the North American Monsoon System. *Journal of Climate* 22:4213–4227.

Castro, C. L., T. B. McKee, and R. A. Pielke Sr. 2001. The Relationship of the North American Monsoon to Tropical and North Pacific Sea Surface Temperatures as Revealed by Observational Analyses. *Journal of Climate* 14:4449–4473.

Castro, C. L. et al. 2007. Investigation of the Summer Climate of the Contiguous United States and Mexico Using the Regional Atmospheric Modeling System (RAMS). Part II: Model Climate Variability. *Journal of Climate* 20:3866–3887.

Hu, Q., S. Feng, and R. J. Oglesby, 2011. Variations in North American Summer Precipitation Driven by the Atlantic Multidecadal Oscillation. *Journal of Climate, Accepted*.

Zhu, C., D. P. Lettenmaier, and T. Cavazos. 2005. Role of Antecedent Land Surface Conditions on North American Monsoon Rainfall Variability*. *Journal of Climate* 18:3104–3121.