North American Monsoon Variability: Implications to Water Resources Management in the Southwestern US

By Balaji Rajagopalan, WWA and Katrina Grantz[1] , USBR Upper Colorado Region

The North American Monsoon (NAM) is responsible for 50-70% of annual precipitation in the arid southwestern U.S., particularly Arizona and New Mexico. Water managers in this region are dependent on the NAM seasonal precipitation and resulting streamflows, which typically occur between July and September. However, water managers and scientists alike have observed a shift towards later NAM precipitation and streamflows in the last 30 years. Engineers at WWA and University of Colorado have analyzed this shift and its causes, and they have developed a forecasting tool that water managers in the southwest can use to save both water and money. This article summarizes our research on the spatial and temporal variability of NAM precipitation and streamflow in Arizona and New Mexico. We also give an example of the utility of the research in water management for the Pecos River basin (in New Mexico).

NAM Background

The NAM is a large-scale atmospheric circulation system that drives the dramatic increase in rainfall experienced in the desert southwestern U.S. and northwestern Mexico during the summer. Summer thunderstorms typically begin in early July and last until mid-September, accounting for as much as 50-70% of the annual precipitation in the arid region (Carleton et al. 1990; Douglas et al. 1993; Higgins et al. 1997; Mitchell et al. 2002; Sheppard et al. 2002). The typical daily NAM precipitation pattern generally peaks in the afternoon and early evening (Dai et al. 1999; Berbery 2001; Trenberth et al. 2003; Anderson and Kanamaru 2004). The timing of the onset of NAM each year depends on both atmospheric and land surface conditions. The NAM begins when the winds shift from westerly in winter to southerly in summer. This brings moist air from the Gulf of California, the eastern Pacific Ocean and the Gulf of Mexico northward to the land during

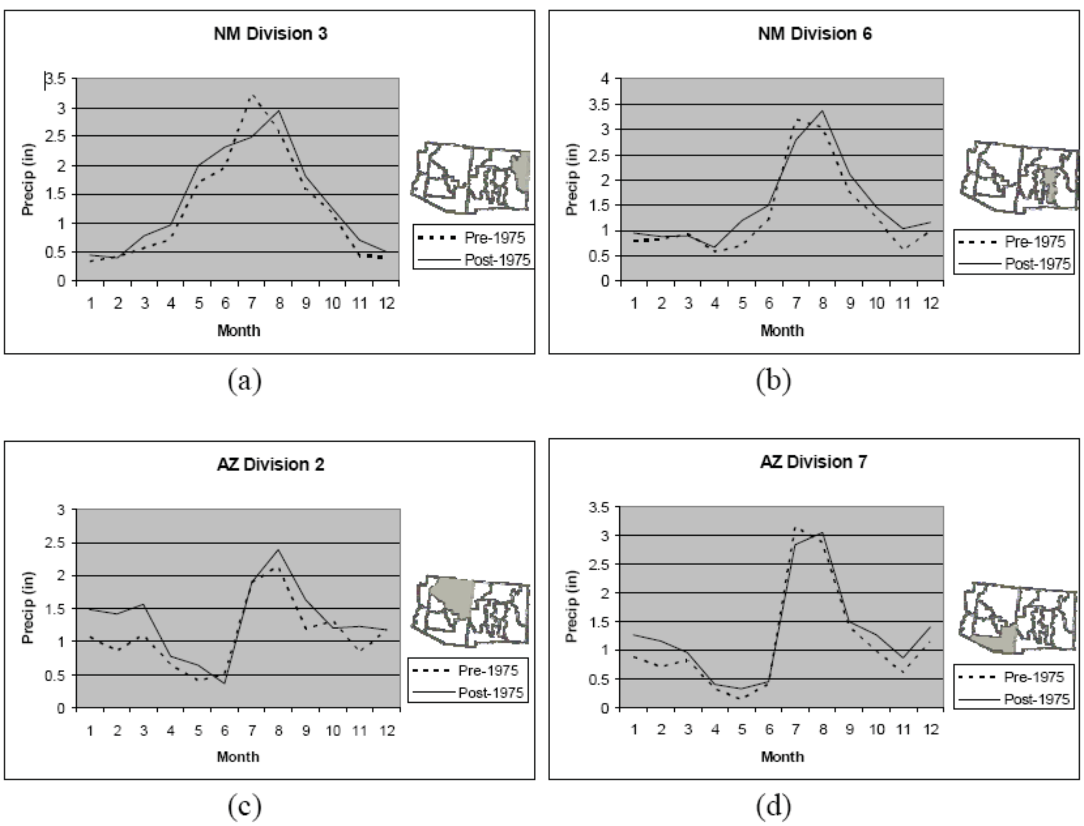

Figure 1a: Shows the shift in the annual cycle at couple of locations in the South Western US. Annual cycle of precipitation during 1948-1975 (dashed line) and 1976-2004 (solid line) at two climate divisions in New Mexico (a, b) and two climate divisions in Arizona (c, d)

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the summer months (Adams and Comrie 1997). As the moist air interacts with the rising air over the hot desert , there is an increase of convective instability, which causes frequent summer precipitation events (Adams and Comrie 1997; Barlow et al. 1998).

Shift in NAM precipitation and streamflows

After analyzing the precipitation and streamflow trends in the southwestern U.S. (Arizona and New Mexico) between 1948 and 1999, we attributed the shift toward a later onset of the NAM to a chain of large and small-scale atmospheric patterns.

We observed a trend toward NAM precipitation beginning late and extending beyond the typical end time. Through an analysis of daily precipitation for the summer season (Jul – Sep), they found a significant delay (approximately 10-20 days) in the entire summer rainfall cycle. The delay resulted in a decrease in rainfall during the early monsoon (July) and an increase in rainfall during the late monsoon (August and September; Figure 1d).

During this same period, the authors observed a trend of increased antecedent (winter/spring) rainfall and resulting soil moisture. We observed nterestingly, this antecedent rainfall affects climate conditions that help bring on the start of the monsoon. Several recent studies have demonstrated an inverse relationship between winter precipitation, particularly snowfall, and subsequent summer monsoon precipitation (Higgins et al. 1998; Gutzler 2000; Higgins and Shi 2000; Lo and Clark 2002; Zhu et al. 2005). Researchers theorize that above average winter precipitation results in above average spring and summer soil moisture, which continues to evaporate well into the summer months. Greater amounts of snowfall in winter require more energy to melt and evaporate the moisture by summer. This delays the land surface warming and the formation of the land-ocean temperature contrast necessary for monsoonal circulation patterns, thus delaying the onset of the NAM.

We attribute the increased antecedent rainfall, resulting soil moisture, and delayed onset of NAM precipitation with large-scale ocean-atmosphere conditions, in particular the El Niño Southern Oscillation (ENSO). The El Niño phase is associated with above average precipitation in the southwestern U.S. during winter months, and this phase has been more active in recent decades. Combining these observations completes the delayed NAM onset causal chain of events (Grantz et al. 2007):

* A more active ENSO cycle leads to more frequent El Niño phases, which causes increased winter precipitation in the southwestern U.S., resulting in increased spring and summer soil moisture.
* This moisture takes longer to evaporate and as a result, the land surface takes longer to heat up. This delays the onset of convection and NAM precipitation.
* The delayed onset of NAM shifts the timing of precipitation, causing below average precipitation in July and above average precipitation in September and October (Figure 1b).

Consequently, a delayed NAM onset affects streamflow timing, as well. During the study period, the authors observed an increase in winter and spring streamflows and a trend toward a later seasonal peak in summer streamflows. This change was especially pronounced in southern areas of Arizona and New Mexico, where up to 80% of annual precipitation occurs during the monsoon season (Grantz 2006).

Potential use for water resources management: Pecos River Basin, NM

The links between antecedent rainfall, NAM precipitation, and land/ocean interactions offer hope for long-lead forecasts of the summer monsoon. In addition, the relationship between winter precipitation and summer NAM precipitation is very important for streamflow prediction. Our understanding of the variability of summer monsoon precipitation and related was used streamflows to generate ensemble streamflow forecasts in the Pecos River basin.

Like most river basins in the western U.S., the Pecos River basin in central New Mexico (Figure 1c), has multiple competing demands for its limited water resources. The reservoirs of the Pecos River system are operated primarily to optimize water delivery to farmers of the Carlsbad Irrigation District (CID) and to protect the habitat of the endangered Pecos Bluntnose Shiner fish. In addition, Pecos River water is managed for inter-state flow deliveries to Texas (Boroughs and Stockton 2005).

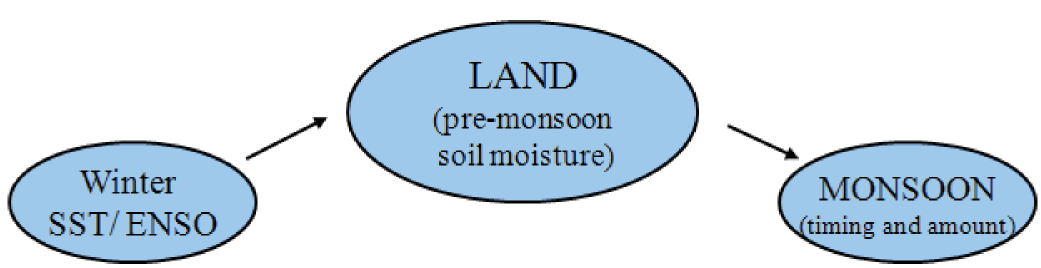

Figure 1b: Schematic of land-ocean-atmospheric processes that interact to cause the onset of the NAM.

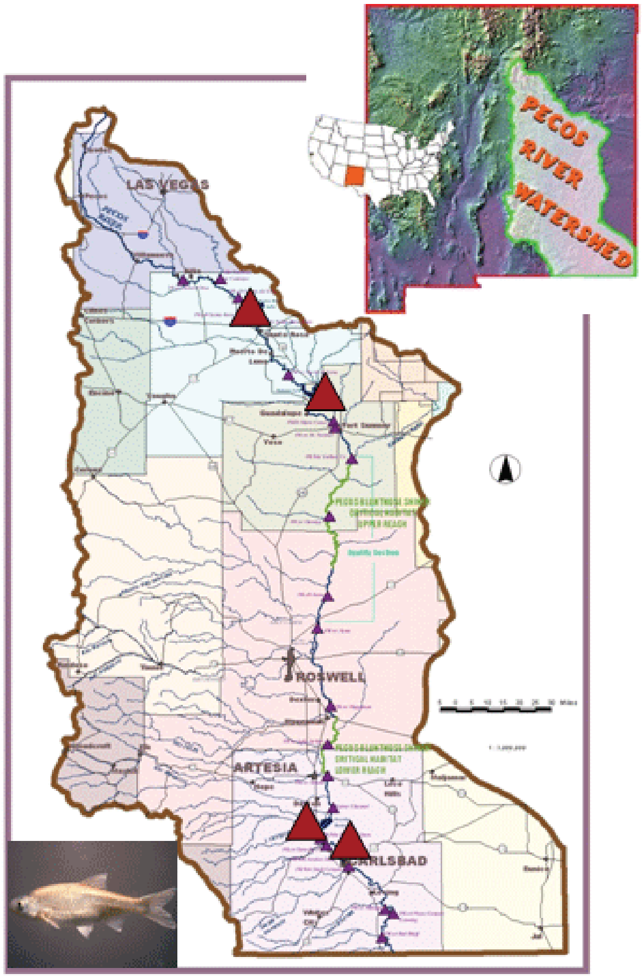

Figure 1c: Pecos River study area. Triangles represent reservoirs, which are primarily managed for irrigation by the Carlsbad Irrigation District. Streamflows are also managed for the protection of the endangered Pecos Bluntnose Shiner (lower left). (Source: Craig Boroughs and New Mexico Interstate Stream Commission (NMISC).

We used a suite of large-scale land-ocean-atmosphere predictors in a statistical forecasting method to generate ensemble streamflows. The forecast of the seasonal streamflows are very skillful, especially when forecasting wet years (Figure 1d). Pecos River Basin water management operates under the conservative assumption that each year will be a dry year (below average NAM precipitation), so the high forecast skill in wet years has important implications for capitalizing on this “extra” water. For example, under the dry year assumption, extra water not allotted to irrigation spills out of reservoirs, but it does not count toward the inter-state compact with Texas. Water managers could take advantage of the wet year forecast by alloting more water to irrigation and not overfilling their reservoirs.

We compared hypothetical operations decisions based on forecasts with operations using existing criteria (e.g. assuming a dry year) in order to evaluate potential benefits to Pecos River water managers. Two scenarios were tested: (i) the inclusion of streamflow forecasts in the calculation of irrigation allotments to provide a better estimate of the season’s available water, and (ii) the reduction of block releases in forecasted wet years to better capture monsoon runoff in the lower Pecos basin and reduce spill to Texas. The results of scenario (i) show that water managers could allot 14% more water to irrigators using the forecasts (Figure 1e). The results for scenario (ii) show insignificant improvements due to the relative size of block releases in comparison with large monsoon events. The coupling of streamflow forecasts with a decision tool in the Pecos River Basin demonstrates that using large-scale climate information to predict NAM streamflow can have significant positive impacts on water management in the region.

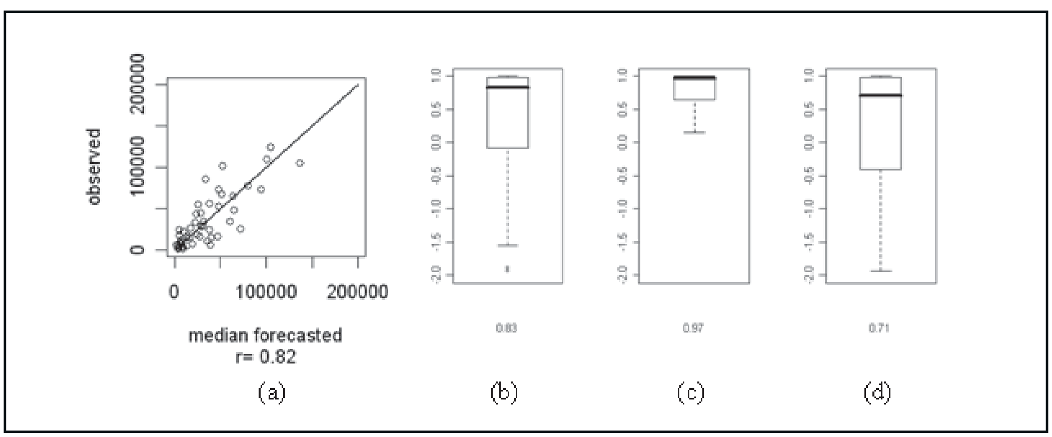

Figure 1d. Skill scores for the May 1st forecast of May - June upper Pecos River streamflow. The median of the ensemble forecast versus the observed streamflow is shown in (a). The RPSS (a categorical skill score) is shown broken into three categories: all years (b), wet years (c) and dry years (d). Median RPSS values are listed below the boxplots, and forecasts for wet years have the highest skill.

Conclusion

The North American Monsoon is responsible for a large portion of annual precipitation and resulting streamflows in the arid southwestern U.S. Scientists have observed changes in the monsoonal pattern, specifically a shift towards a later onset of the monsoon. By attributing these changes to large-scale atmospheric circulation patterns, we were able to develop a streamflow forecasting tool that could potentially help water managers increase the efficiency of annual water supply operations.

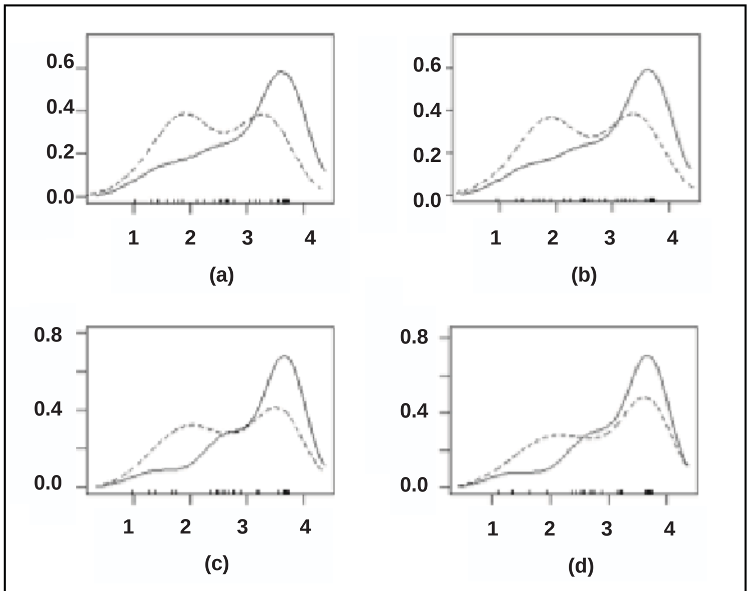

Figure 1e. Probability density functions (PDFs) of allotments (acre-ft/acre) for March 1st (a), May 1st (b), June 1st (c) and July 15th (d). The solid lines represent allotments based on the forecasts and the dashed lines represent baseline scenarios. Management decision based on forecasts would allow higher allotments at all time periods.

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