The North American Monsoon (NAM) system controls the warm season climate over much of southwestern North America. Characterized as a semi-arid environment, understanding the regional behavior of the hydroclimatology and its associated modes of variability is critically important to effectively predicting and managing poorly-stressed regional water resources. This work explores the hydroclimatology of southwestern Mexico, i.e., the core region of the NAM, by developing a detailed hydroclimatic record from 15 unregulated headwater basins along the Sierra Madre Occidental mountains in western Mexico. The present work is distinct from previous studies as it focuses on the intra-seasonal evolution of rainfall-runoff relationships and contrasts the sub-regional behavior of the rainfall response. It is found that there is substantial sub-regional coherence in the hydroclimatic response to monsoon precipitation. Three physically-plausible regions emerge from a related Principal Components Analysis of streamflow and basin-averaged precipitation. Month-to-month streamflow persistence, rainfall-runoff correlation scores and runoff coefficient values demonstrate regional coherence and are generally consistent with what is currently known about sub-regional aspects of NAM precipitation character.

Fig. 2: The streamflow regime in NW Mexico is dominated by a strong summertime signal concomitant with summer monsoon (Fig. 2a). All basins show a distinct summer-maximum in monthly flow volume. Interannual monthly streamflow variability (quantified as the coefficient of variation of monthly flow volume, Fig. 2b) is lowest during the summer months indicating that the higher flows are a regular feature. There is marked flow variability in the low flow season in the spring and also in the fall. The increased variability in the late fall and early winter is likely due to land-falling tropical storms. In nearly all basins, the months with maximum flow volume are summer months.

Table 1: EOFs for the Principal Components Analysis of streamflow and basin-averaged precipitation, month-to-month streamflow persistence, rainfall-runoff correlation scores and runoff coefficient values for all 15 basins. Statistically significant correlations are present in 9 out of 15 basins. It is noticed that all of the southern basins and those that drain to the sea are significantly correlated while only 2 basins from the northwestern part of the domain are. Also shown in Table 4 are correlation coefficients for each of the individual months of the warm season. As with Qr, P-Q correlation values increase from July-October, further illustrating the process of hydrologically-conditioning. Essentially, as the summer evolves in-basin storage reservoirs such as soil moisture, rock fissures and surface depressions become filled. Subsequent rains are then more likely to runoff.

Fig. 3: Lag 1 autocorrelations for monthly streamflow volumes. The clear signal in the annual cycle of streamflow does not necessarily imply increased predictability in summer-time streamflow. Figure 3 shows the 1 month lag autocorrelation values for the 15 test basins. While low flow months tend to have a strong serial correlation the transitional months of May and Jun and the summer months of June, July, August, and Sept each possess comparatively low correlation values with the respective preceding month's streamflow.

Fig. 4: The North American Monsoon Region: Selected Test Basins

Table 2: Mean monthly precipitation and runoff coefficients for the selected test basins. As can be seen from Table 2, mean values of the seasonal (JAS) runoff coefficient varied from 9-43%. Smaller values of the runoff coefficient towards higher values as the summer progresses. This evolution indicates that the basins are becoming "hydrologically-conditioned" by the summer rains.

Fig. 5: EOFs for the Principal Components Analysis of streamflow and basin-averaged precipitation, month-to-month streamflow persistence, rainfall-runoff correlation scores and runoff coefficient values for all 15 basins. Statistically significant correlations are present in 9 out of 15 basins. It is noticed that all of the southern basins and those that drain to the sea are significantly correlated while only 2 basins from the northwestern part of the domain are. Also shown in Table 4 are correlation coefficients for each of the individual months of the warm season. As with Qr, P-Q correlation values increase from July-October, further illustrating the process of hydrologically-conditioning. Essentially, as the summer evolves in-basin storage reservoirs such as soil moisture, rock fissures and surface depressions become filled. Subsequent rains are then more likely to runoff.

Rainfall Runoff Correlation Structure

Interannual Variability of NAM Streamflow

The time series of regionally averaged JAS streamflow reveal a regime possessing substantially increased variability relative to that of the pre-decadal period (Fig. 6). Climatological aspects of this interannual variability have been discussed in Brito-Castillo and Gochis, 2004 and Gochis and Brito-Castillo, 2004. As with the precipitation record, however, there appears to be a marked reduction in the interannual variability as the summer drought period is prolonged (Fig. 6). Enhanced stratified periods (not-shading/low-shading) are periods when there are significant differences in precipitation between north, south and central region streamflow. It is hypothesized that during periods when there is a regional coherence (shading) certain large scale inter-oceanic mechanisms may be exerting significant influence such as the El Niño-Southern Oscillation (ENSO) and its coarse resolution (2.5 deg) annual PDSI reconstruction may be only marginally useful for diagnosing NAM streamflow variability.

Conclusions

As an exercise we have also plotted the time series of reconstructed annual Palmer Drought Severity Index (PDSI) for all 15 basins. The PDSI appears to show a strong multi-year persistence than does JAS streamflow. It is notable that the PDSI reconstruction is based on tree-ring data and therefore is an integrated drought measure across warm and cool seasons. Combined with the noted lack of inter-basin spread in PDSI and its coarse resolution (2.5 deg) this annual PDSI reconstruction may be only marginally useful for diagnosing NAM streamflow variability.

References and Publications


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Fig. 6: PJ-Aug-Sep