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Hydroclimatology of the North American Monsoon region in northwest Mexico

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Abstract

The North American Monsoon (NAM) system controls the warm season climate over much of southwestern North America. In this semi-arid environment, understanding the regional behavior of the hydroclimatology and its associated modes of variability is critically important to effectively predicting and managing perpetually stressed regional water resources. Equally as important is understanding the relationships through which warm season precipitation is converted into streamflow. This work explores the hydroclimatology of northwestern Mexico, i.e. the core region of the NAM, by (a) presenting a thorough review of recent hydroclimatic investigations from the region and (b) developing a detailed hydroclimatology of 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-runoff response. It is found that there is substantial sub-regional coherence in the hydrological response to monsoon precipitation. Three physically plausible regions emerge from a rotated 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.

Keywords: North American Monsoon; Hydroclimate; Runoff; Regionalization; Intra-seasonal variability; Mexico

1. Introduction

An increasing body of literature is documenting salient features of the North American warm-season circulation and precipitation regime over the region of northwestern Mexico that is the core of the North American Monsoon System (NAMS). The region is generally semi-arid, with an annual precipitation regime dominated by warm-season convection that strongly interacts with the regional topography and surrounding bodies of seawater (For a complete discussion of the NAMS, please refer to the North American Monsoon Experiment (NAME) Science

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Plan (NAME Science Working Group, 2004) or Higgins et al., 2003). The circulation features responsible for this warm-season precipitation regime have been well documented (Higgins et al., 1997; 1998; 1999; Higgins and Shi, 2000; Carleton et al., 1990; Douglas et al., 1993; Schmitz and Mullen, 1996; Castro et al., 2001; Hu and Feng, 2002). Such studies consistently document a transition in the regional climate from an arid subtropical regime dominated by westerly flow at middle and upper levels, to a regime with substantially higher relative humidity, easterly flow at mid and upper levels, and strong diurnal convection. This transition occurs during June and early July and is designated as the 'onset' of the summer monsoon. The monsoon circulation, its onset, precipitation character, and the hydrological response to it, exhibit considerable spatial and temporal variability. This variability complicates diagnostic and predictive efforts and limits responsive management of regional water resources. This work explores the complex relationship between precipitation and streamflow in the NAM region by: (a) reviewing recent works that have examined precipitation and streamflow variability and (b) constructing a regional hydroclimatology from selected headwater catchments in northwest Mexico.

2. Background

2.1. Overview of the North American Monsoon precipitation regime

The internal structure of NAM precipitation is complex and subject to considerable spatial and temporal variability. The centroid of NAM precipitation, which is often defined as the total rainfall in July, August, and September (JAS), is located along the western slope of the Sierra Madre Occidental (SMO) in northwestern Mexico (Douglas et al., 1993; Higgins et al., 1999; Gochis et al., 2004). In this region, the coefficient of variation of precipitation is high in the global context (Dettinger and Diaz, 2000), but comparatively low relative to surrounding regions (Higgins et al., 1997; Mosino and Garcia, 1974). The region was identified as the leading pattern in a regionalization analysis of the warm-season precipitation regime for southwestern North America (Comrie and Glenn, 1998). Strong diurnal pulsing of low-level moisture flux helps drive the diurnal precipitation regime. Berbery (2001), Anderson et al. (2000), Stensrud et al. (1995), Gochis et al. (2003a; 2004) and Fawcett et al. (2002) have each documented distinct diurnal cycles in precipitation and low-level moisture fluxes over the Gulf of California and SMO. Here, precipitation is typically generated by deep convection that is initiated over the high terrain of the SMO and then propagates away, both eastward and westward, from the cordillera during the evening hours (e.g. Negri et al., 1994; Vazquez, 1999; Fawcett et al., 2002; Gochis et al., 2004). Precipitation in areas peripheral to this 'core' monsoon region exhibit high spatial and temporal variability, and precipitation appears to be closely dependent on transient features such as the passage of mid-latitude waves, tropical easterly waves (Fuller and Stensrud, 2000), and, very importantly, tropical storms (Douglas, 2000).

The NAM precipitation regime exhibits substantial variability on interannual to interdecadal timescales that is potentially linked via teleconnections to remote forcing. Variability on these timescales can be critically important for the effective management of water resources (e.g. Brito-Castillo et al., 2002). Sea surface temperatures (SSTs) in the North Pacific (e.g. Higgins and Shi, 2000; Englehart and Douglas, 2002; Brito-Castillo et al., 2002) and in the Gulf of California (Mo and Juang, 2003) each are somewhat correlated with NAM rainfall. Correlation structures display sub-regional spatial coherence such that particular SST anomalies are related to rainfall variability over specific regions within the core NAM region. For instance, using teleconnective correlation analyses, Englehart and Douglas (2002) showed that the region west of the SMO is modestly correlated with El Niño/Southern Oscillation (ENSO), but only during positive phases of the Pacific Decadal Oscillation (PDO). Conversely, during positive PDO phases, the altiplano or plateau region of central Mexico are not correlated with ENSO. Significant correlation between ENSO and precipitation during the negative phase of the PDO are not found in either region.

Englehart and Douglas also show that rainfall in both of these regions appears to be related to the positioning of the subtropical anticyclone. In particular, rainfall in the western SMO is weakly positively