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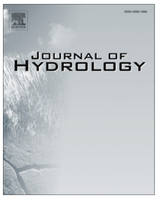

Research papers

Relationships between sea surface temperature anomalies in the Pacific and Atlantic Oceans and South Texas precipitation and streamflow variability

Dorina Murgulet [a,b,*], Murgulet Valeriu [a,b], Richard R. Hay [b], Philippe Tissot [a,c], Alberto M. Mestas-Nuñez [d]

[a] Department of Physical and Environmental Sciences, Texas A&M University-Corpus Christi, United States
[b] Center for Water Supplies Studies, Texas A&M University-Corpus Christi, United States
[c] Conrad Blucher Institute, Texas A&M University-Corpus Christi, United States
[d] Department of Geological Sciences, University of Texas at San Antonio, United States

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ABSTRACT

While many studies have described linkages between large-scale climate phenomena and precipitation and streamflow, fewer studies explicitly address the climatic modulations at sub-regional scales. This study quantifies statistically the temporal variability in precipitation and streamflow at a regional scale in the semi-arid area of South Texas associated with three climate indices: El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multidecadal Oscillation (AMO). Results show that ENSO and PDO strongly modulate rainfall during the cold season and, to various extents, streamflow during the cold and warm seasons. In addition, this study shows that in South Texas streamflow is consistently below normal (i.e. means) while precipitation slightly increases during AMO-warm. To different extents, the Pacific and Atlantic sea surface temperature (SST) anomalies show stronger influences on the climate of South Texas when coupled. Droughts are more correlated with La Niña events but these events play a secondary role during PDO-cold. Although the PDO-cold phase is the dominant driver of droughts in this area, our analyses also show that the coupled effect of the PDO-cold/AMO-warm phases significantly increases the intensity of drought conditions to a degree similar to the PDO-cold/La Niña coupled effect. Given its stronger response to climate anomalies, streamflow offers a more effective tool for predicting climate variability impacts on South Texas water resources when compared to precipitation.

1. Introduction

While the societal impacts of water resource depletion are well documented (Backlund et al., 2008; Karl, 2009; Pachauri et al., 2014; Taylor et al., 2013), it is not yet clear how the effects of climate change will combine with non-climatic factors such as increased water use, land use/land cover changes, and management practices to impact available freshwater resources. Ecological effects along our ocean coastlines as related to changes in riverine inflows are expected to vary (Dai and Trenberth, 2003). While an increase in discharge from the Mississippi River will intensify the frequency of hypoxia in the Gulf of Mexico, the opposite would happen due to higher discharges in Hudson Bay (Parry, 2007).

An emerging body of research shows that precipitation patterns and streamflow across much of the United States are associated with interannual to multidecadal periods of warming and cooling of the surrounding Pacific and Atlantic surface waters. Clark et al. (2014) and Fu et al. (2010) studied the El Niño Southern Oscillation (ENSO) linkages on precipitation and streamflow in the southeastern U.S. region. Hidalgo and Dracup (2001, 2003) acknowledged a possible ENSO – Pacific Decadal Oscillation (PDO) modulation of spring-summer streamflow and rainfall in the upper Colorado River basin and a strong influence of the Atlantic Multidecadal Oscillation (AMO) on cold season precipitation in the northern Rocky Mountains and the upper Colorado River. Enfield et al. (2001) determined that during the AMO warm phase less than normal rainfall occurs in most of the U.S. territory. Additionally, the streamflow response to the AMO's shift in phase was shown to be significant in the upper Mississippi River basin, the northern Rocky Mountain region, and upper Colorado River basin (Rogers and Coleman, 2003). McCabe et al. (2004) estimated that more

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* Corresponding author at: Department of Physical and Environmental Sciences, Texas A&M University-Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412, United States.
E-mail address: dorina.murgulet@tamucc.edu (D. Murgulet).

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than 50% of the spatial and temporal variance in multidecadal drought frequency in the U.S. could be attributed to PDO and AMO effects. Research in the Yellowstone basin based on tree ring reconstructions shows that the major drought in the past 250 years in this basin occurred during a warm AMO-PDO cycle (Hidalgo, 2004). In contrast with streamflow studies based on climate indices, a study conducted by McCabe and Wolock (2014) found that the temporal variability of streamflow in several U.S. regions of coherent spatial variability were only weakly associated with climate indices.

Assessment of water resources at the large-regional scale with applications to small-regional scales can be problematic mainly because water uses and climate gradients can be significant at the sub-regional or local scale and are typically not accurately represented (Faurès, 1997). Predictions derived from general circulation models (GCMs) related to the effects of climate change on two of the most important drivers of freshwater inflow to estuaries, precipitation and temperature, are not consistent. The Canadian CGCM1 and the Hadley HADCM2 models for instance, predict future extreme rainfall and runoff events for the Mississippi River but they disagree on both the magnitude and direction of the change (Day et al., 2005; Wolock and McCabe, 1999). Inaccuracies in these predictions for such large-scale river basins are expected to amplify for sub-regional and small-scale areas.

While these types of analyses provide valuable insight, significant gaps still remain (Kuss and Gurdak, 2014; Meixner et al., 2016). Results derived from regional-scale studies lack the level of detail necessary for informed decision-making (Döll and Fiedler, 2007; Taylor et al., 2013), while those from local scales are almost non-existent. We hypothesize that the comprehensive investigation of sub- or small-scale regions is important and that the large-scale ocean atmosphere phenomena (i.e. ENSO, PDO, and AMO) may be significantly modulated by local forcing, such as topography, surface heterogeneity, and coastal and regional water bodies. Therefore, in order to provide the best tools to assess current water resources and proactively mitigate future supply issues, it is important to quantify the potential relationships between large-scale climate indices and river basins at the sub-regional and/or local scale. These objectives have typically not been addressed in previous studies especially using a long historical record (almost a century) of streamflow or precipitation.

This study investigates the intricate problem of linking the response of rainfall and runoff over semiarid catchments in the South Texas region due to large-scale Atlantic and Pacific ocean-atmosphere phenomena from interannual to multidecadal time scales. The specific objectives are to analyze the statistical relationship of ENSO, PDO, and AMO indices (independently and coupled) with precipitation and streamflow. The derived relations are used to ascertain those climate indicators having the most impact on the water resources to improve predictions as part of an integrated water resources management.

Time-series of climate indices based on monthly sea surface temperature (SST), streamflow (raw monthly mean data for 16 stations from 1922 to 2012), and precipitation (raw daily rainfall amount values for 200 stations over a 110-year period) for extended periods were used to investigate interannual, interdecadal and multidecadal oscillations and the subsequent effects on the hydrology of South Texas. Precipitation and streamflow responses to the individual ENSO, PDO, and AMO and combined PDO-AMO and PDO-ENSO influences were analyzed using non-parametric testing. The correlations are quantified for both (cold and warm) seasons and similar temporal phases of the climate indices in this regional watershed. Through these investigations, the individual and coupled effect of climate phenomena on streamflow and precipitation variability, for almost a century, are identified and analyzed from a water resource perspective.

2. Data and methods

2.1. Study area

The area was selected for its geographic location within North America (i.e. on the semi-arid Gulf Coast) and the interaction with seasonal air masses, which affect its unique climate variability (TWDB, 2012). The study area encompasses approximately 23,500 km^2 in South Texas and is delineated by the Nueces and Guadalupe river sub-basins to the North and South, respectively (Fig. 1).

With a large zonal precipitation gradient (<500 mm to the west to >1000 mm to the east, see Fig. 1), the climate is predominantly subtropical (Kim et al., 2013) humid with a regional climate dominated by hot summers and mild winters with occasional severe freezes (mean annual temperatures 23.5 °C). The prevailing southeasterly trade winds bring large quantities of moisture from the Gulf of Mexico, causing South Texas to experience some of the highest atmospheric moisture contents in the U.S. (Norwine et al., 1995).

Commonly, rainfall and evaporation are the main drivers of the flow of rivers and streams in South Texas. There is very information regarding the groundwater discharge to rivers in this area. For the Gulf Coast aquifer outcrop (which includes the study area), there is a general trend of decreasing baseflow from northeast to southwest. The overall lowest baseflow in the state of Texas are estimated for the study area, except for the upper reaches where some of the largest increasing rends are calculated (BEG, 2005). Compared to eastern Texas where mean annual rainfall is nearly 1500 mm and annual evaporation is less than about 1780 mm, western Texas annual evaporation rates can be as high as 2670 mm; whereas, mean annual rainfall is significantly lower, ranging from 200 to 500 mm. Consequently, streams in eastern Texas flow year round while most western Texas streams flow intermittently (TWDB, 1996). For instance, the springs that feed the Comal and San Marcos Rivers, in the north side of the San Antonio river basin, have an average monthly discharge of 8.7 and 4.6 cubic meter per second ($m^3 \cdot s^{-1}$), respectively. During the severe drought of the 1950s the Comal Springs, which are more prone to drought conditions, ceased to flow, while San Marcos River continued to flow, but dropped to 1.3 $m^3 \cdot s^{-1}$ (SAR BBEST et al., 2011). While mostly driven by precipitation patterns that influence the spring flow supporting the river, stream flow can be amplified by treated municipal effluent that originates primarily as groundwater from the Edwards Aquifer (SAR BBEST et al., 2011). Furthermore, the hydrology in the lower part of San Antonio River varies seasonally. In the investigated area, the rainy season is often defined as the months of April-June and September-October with summer/warm (April to September) and winter/cold (October to March) mean monthly rainfall of 72.7 (number of records in months (n) = 620) and 44.9 mm (n = 492), respectively. The highest streamflow months typically extend from July through October. The mean monthly basin-normalized streamflow for the warm and cold months are $1.13 \cdot 10^{-3}$ (n = 444) and $1.12 \cdot 10^{-3}$ $m^3 \cdot s^{-1} \cdot km^{-2}$ (n = 356), respectively.

2.2. Data

The major data sets used to develop the relationships between South Texas streamflow, precipitation, and SST variability were surface flow discharge from streams unimpaired by dams and barriers, daily precipitation data in the study area, and SST data for the Pacific (ENSO 3.4 and PDO) and Atlantic Oceans (AMO).