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Origins and variability of extreme precipitation in the Santa Ynez River Basin of Southern California

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A R T I C L E I N F O

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A B S T R A C T

Study region: Santa Ynez River Basin, Santa Barbara County, California.
Study focus: Lake Cachuma, a reservoir on the Santa Ynez River, provides water for over 280,000 residents and agricultural lands of Santa Barbara County, California. This area experiences high inter-annual precipitation variability, which we hypothesize is driven by the presence or absence of a few large precipitation events each year. We use daily precipitation observations from 1965 to 2017 to identify extreme precipitation events, defined as those exceeding the 90th percentile. We examine the role of these events, their associated synoptic patterns, and the El Niño Southern Oscillation (ENSO) in driving inter-annual precipitation variability in this basin.
New hydrological insights for the region: On average, a wet year features three or more extreme events, a normal year 1–2 events, and a dry year 0–1 events. We identify four distinct synoptic-scale weather patterns associated with extreme events and find that 74% of events are associated with atmospheric rivers. El Niño years tend to have a greater number of extreme events, though this relationship is not dependable. The reliance on just a few extreme precipitation events and diversity among these events highlights the challenges of seasonal prediction and resource management in this area. This novel approach to defining variability on a watershed scale can support ecological, geological, and hydrological studies as well as regional water resource management.

1. Introduction

Lake Cachuma, a reservoir on the Santa Ynez River in Santa Barbara County, California, gained local and national attention in early 2017 (e.g., Serna, 2017). Following a multi-year drought, in early January 2017 Cachuma storage stood at 8% of capacity and 12% of historical average (California Department of Water Resources, 2017), nearly shutting off agricultural deliveries and prompting water agencies to utilize other resources in their portfolios (e.g., purchasing water from other agencies). Two atmospheric river storms, featuring narrow corridors of high water vapor transport from the tropics (AMS, 2017a), in late January and mid-February 2017 provided some relief for the area. These events raised the lake level to nearly 50% of capacity by late February. Without these two large storms, those who depend on Cachuma for water resources would have been facing dire circumstances.

Individuals with water resource and hydrologic interests in the area often note that the difference between a wet, dry, or "average" year is often just a few storms (e.g. Burns, 2017), as was the case in 2017. However, the magnitude of this dependence has

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not been quantified at a local scale. We analyze station data from within the Santa Ynez River Basin to document precipitation variability due to large storms and investigate the associated synoptic meteorological conditions.

The Santa Ynez River drains a 2322 km^2 area nestled in the Transverse Ranges of southern California (Fig. 1). The river basin is bounded to the south by the Santa Ynez Mountains (~300–1400 m in elevation) and to the north by the San Rafael Mountains (~600-2000 m in elevation). From westto east, the basin increases in elevation from sea level at its terminus near Lompoc, CA, to over 1200 m at its headwaters. Cachuma is the largest of three reservoirs on the river and was built in 1953 to meet growing water demands of the surrounding communities (Latousek, 1995; Loáiciga, 2001). Cachuma currently provides up to 85% of the water supply depending on district for over 280,000 Santa Barbara County residents and is used to irrigate over 15,000 acres of agricultural land (e.g., Goleta Water District, 2017; Carpinteria Valley Water District, 2017; Montecito Water District, 2017).

Santa Barbara County is a semi-arid region characterized by high precipitation variability (Fig. 2) and has a long history of impactful multi-year droughts (Upson and Thomas, 1951; Latousek, 1995; Loáiciga, 2001). Nearly all (> 95%) of Santa Barbara County's precipitation falls between October and May (WRCC, 2017) in association with synoptic scale disturbances. Roughly half of this rainfall can be associated with atmospheric rivers (Dettinger et al., 2011; Rutz et al., 2014). Moist, onshore flow associated with these features creates conditions favorable for orographically forced precipitation in the Santa Ynez Mountains (Conil and Hall, 2006). Climatologically, precipitation tends to increase with elevation on the southern side of this range (Hughes et al.,2009). This region also commonly experiences short-duration, high intensity convective precipitation events within the larger scale disturbances (Oakley et al., 2018).

Several studies have addressed precipitation variability in California. The southern portion of the state observes larger differences between wet and dry years than anywhere else in the United States (Dettinger 2011). Some of the most extreme three-day precipitation events in the country occur in the Transverse Ranges (Ralph and Dettinger, 2012). Additionally, the seven wettest days of each year account for more than 80% of the variations in total precipitation in southern California (Dettinger, 2016). Total precipitation tends to be higher in southern California during the El Niño phase of the El Niño Southern Oscillation (ENSO; e.g., Wise, 2010; Harris and Carvalho, 2018). While we are not aware of an analysis specific to our study area, Cayan et al (1999) demonstrate that > 90th percentile precipitation days at San Diego are more likely during El Niño than La Niña. Additionally, they show that over the period 1931–1995, 12 of 21 El Niño winters produced above normal (> 5 days) of > 90th percentile precipitation while only three of nine La Niña winters did the same.

We investigate precipitation variability in the Santa Ynez River Basin using a unique approach of parsing daily precipitation observations into extreme precipitation events rather than using wet days alone. This definition is more representative of colloquially-defined "storms", which relate more directly to local hazard and water management preparations and also agree well with a hydrologic approach of looking at the impact of wet periods rather than individual days (e.g., SBCPWD, 2017). With the storm events generated, we answer these questions for the Santa Ynez River Basin:

1) What is a meaningful way to define normal, above normal, and below normal wet season precipitation totals?
2) What frequency and magnitude of precipitation events best represents inter-annual precipitation variability?
3) What synoptic patterns are favorable for large storm events, and what is the role of atmospheric rivers?
4) Does ENSO modify the frequency of extreme precipitation events in a way that offers predictive capabilities?

The results of this analysis provide quantitative knowledge that can be used by local agencies to communicate regional precipitation variability and impacts to their stakeholders. These materials provide a broad understanding of regional drought mechanisms and risk, give insight to the challenges of seasonal prediction, and augment water managers' abilities to understand and plan for impactful events. Additionally, the novel investigation of regional precipitation variability may inspire new insights in ecological, geological, and hydrologic studies in Santa Barbara County, and serve as a baseline for evaluating change in the future.

2. Methods

2.1. Precipitation data

We focus on precipitation during the wet season, which we define as October through May. Period-of-record daily precipitation data were acquired from long-record (> 50 years) stations in Santa Barbara County Public Works Department's (SBCPWD) Automated Local Evaluation in Real Time (ALERT) network of automated tipping bucket gauges[1]. These data have been quality controlled by SBCPWD and observation time is stated as 0800 Local Standard Time (LST) throughout the period of record. For precipitation days or periods where a particular gauge is not reporting, SBCPWD fills the station's record with data from another station of the network of similar elevation and situation within the terrain; these stations are not displayed in Figure 1[1]. SBCPWD data only reports dates on which precipitation occurred, thus it cannot be determined if missing dates are present. We make the assumption that the record is complete.

We also acquired period-of-record daily precipitation data for long record (> 50 years) stations in the Global Historical Climatology Network-Daily (GHCN-D; Menne et al., 2012) through SC-ACIS (http://scacis.rcc-acis.org/; Fig. 1). These data have been quality controlled by the National Centers for Environmental Information. Observation time ranges across the period of record for

[1] Can be accessed online at: http://www.countyofsb.org/pwd/dailyrainfall.sbc