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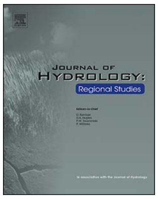

Assessing and quantifying changes in precipitation patterns using event-driven analysis

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ABSTRACT

Study region: The Little Washita River Experimental Watershed (LWREW) is located between Chickasha and Lawton in southwestern Oklahoma, US.

Study focus: In this study, frequency analyses were conducted on sub-hourly precipitation event descriptors to quantify the changes in precipitation patterns commonly masked in annual analysis. Precipitation events were derived from 5-min data collected by USDA-ARS from 1961 to 2015.

New hydrological insights for the region: During the 1962–2015 period, this region experienced successive regional long-term wet (1962–1995) and dry (1996–2015) dominated periods of more than 20 years each. During the wet period, precipitation intensity ranging from 1 to 12 mm were 20% less likely to occur while event daily average precipitation and number of events increased by 10% and 11%, respectively. Also, the average daily precipitation occurred more often at lower intensities. In contrast, during the dry period, instantaneous intensity ranging from 1 to 12 mm became more likely to occur (64% increase; 1996–2015) while event daily average precipitation and number of events decreased by 16% and 18%, respectively. Overall, comparisons with the baseline data (1962–2015) indicated that in the last 20 years, sub-hourly precipitation intensities have increased while daily event duration and extreme 5-min precipitation intensities larger than 24 mm (precipitation intensification below extremes) have remained unchanged.

1. Introduction

The annual mean precipitation at the global scale is expected to increase by the end of this century with extreme precipitation events becoming more intense and more frequent in some regions (IPCC Fifth Assessment Report, IPCC, 2013). The effects of these changes at the local scales are not clearly understood although the evaluation of projected impacts on ecosystems are typically assessed from trends derived from climate observations (e.g. Chu et al., 2014) and global circulation models (GCMs) scenarios (e.g., Jones et al., 2005; Perry et al., 2005; Menzel et al., 2006; Parmesan, 2006; McKenney et al., 2007). However, Westra et al. (2014) concluded that intensity variability on sub-daily extreme precipitation is more sensitive to change, especially at hourly and sub-hourly scales when compared to daily precipitation. Studies indicated that precipitation extremes at hourly and sub-hourly temporal scale increase non-linearly up to twice as fast with rising temperature as it was originally predicted by GCMs (Lenderink and van Meijgaard, 2008, 2010; Mishra et al., 2012). However, there is also evidence that this rate of increase peaks and decreases beyond the

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approximated daily average surface temperatures of 24 °C most likely driven by moisture availability (Westra et al., 2014) and perhaps changing aerosols linked to vegetation changes – cloudiness (Portmann et al., 2009).

Downscaled high spatio-temporal precipitation from GCMs are in the early stages of development and may be insufficient to represent sub-daily precipitation variability required to quantify critical sub-kilometer hydrological responses. On the other hand, long-term continuous ground-based sub-daily precipitation datasets at watershed scale are scarce, especially those that encompasses the boundary of the analog and digital era data collection and also includes periods of records of more than 20 years before and after the anomaly departure in global-mean temperatures around 1980 (GISTEMP Team, 2017). Nevertheless, analysis of long-term, high temporal resolution precipitation data is needed to reduce the risk of masking climate signals when assessing future scenarios. Nonetheless, the presence of data inconsistencies (e.g., site relocation, change in instrumentation) must be identified and accounted for before further data analysis is conducted.

In this study, a dataset of 55 years, 5-min watershed average precipitation from the Little Washita River Experimental Watershed (LWREW) located in Oklahoma, part of the Southern Great Plains, were used to assess changes in sub-daily precipitation patterns. The occurrence of drought conditions in this region is mainly tied to precipitation driving soil moisture depletion (Livneh and Hoerling, 2016) and associated to sea temperatures anomalies and teleconnections to the Southern Oscillation (ENSO), the Pacific Decadal Oscillation, and the Atlantic Multi-Decadal Oscillation (Meinke et al., 2005; Basara et al., 2013; Cook et al., 2015). In 2012 the great plains experienced the most severe seasonal drought in the past 117 years that was mostly linked to natural variations in weather (Hoerling et al., 2014). However, projections in the 21st century from both moderate (RCP 4.5) and high (RCP 8.5) future emission scenarios indicated that drought intensification will likely exceed the most severe megadrought periods of the Medieval climate (1100–1300 CE) (Cook et al., 2015). Moreover, it remains unclear how the storms characteristics are changing along the oscillations between the long-term regional wet (i.e., periods of 10 or more years with an average precipitation surplus over the historic mean) or dry (i.e., periods of 10 or more years with an average precipitation deficit over the historic mean) dominated periods.

The overall goal of this study was to identify and quantify the changes in precipitation patterns during long-term wet or dry dominated periods by comparing the changes in the frequency distribution derived from event metrics (total precipitation, intensity, and duration of events) at the watershed scale. Long-term (1962–2015) high spatio-temporal resolution precipitation data from more than 20 sites in the LWREW were used to derive the frequency distribution analysis on event metrics at the watershed scale. This study was aimed to specifically address three important hypotheses: (1) Storm characteristics most likely result in different precipitation patterns during long-term regional dry and wet oscillations periods, (2) Characteristics of storm frequency, intensity, and duration have changed in the LWREW in the last 55 years, and (3) The changes in precipitation during the period of record were due to physical changes in its patterns rather than data inconsistences in the observations. Since climate change is projected to impact the spatio-temporal precipitation characteristics at local scales, an analysis of locally collected high spatio-temporal resolution precipitation can elucidate the implications of climate variability and change that may not be detectable from analysis of individual sites, or multiple sites reporting only daily, monthly, or total annual precipitation.

2. Materials and methods

2.1. Study area

The LWREW, located in central Oklahoma (Fig. 1a), is part of a conservation and research effort initiated in 1961 to mitigate soil erosion. In 1961, the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS) set up 36 stations as part of the Southern Great Plains Research Watershed (SGPRW) program to monitor climate (precipitation, air temperature, relative humidity, etc.) and hydrological variables (e.g., groundwater levels). This research program focused on evaluating basin scale impacts of flood mitigation strategies, specifically headwaters flood retarding structures (Garbrecht et al., 2007), and details of the data collection was a primary focus (Starks et al., 2014). Considerable efforts were made to characterize precipitation over the watershed as the main driver of frequent floods and soil erosion occurring during extreme precipitation events (Starks et al., 2014). At the end of the SGPRW program in 1994, climatological observational networks transitioned to digital technology and consequentially there were changes in data collection protocols. In 1978, the LWREW was selected by the USDA and the U.S. Environmental Protection Agency (USEPA) as one of seven national benchmark watersheds to study the effects of land conservation in water quality (Garbrecht et al., 2007).

The LWREW drains an area of approximately 620 km^2 with predominantly rangeland and pastureland use. The elevation of the watershed ranges from 300 m to 500 m above mean sea level. The soil textures range from fine sand to silty loam, while the exposed bedrock is sandstone. Average annual temperature in the watershed is 16 °C.

2.2. Precipitation data

Instrumenting the LWREW started in 1961 with the establishment of 12 gauging stations using the analog Belfort 5–780 dual-traverse weighing bucket rain-gauges (Belfort Instrument, Baltimore, MD; Fig. 1b). Charts from selected stations where later digitized by the USDA-ARS Grazinglands Research Laboratory to produce breakpoint storm event data. In 1994, a transition from the analog rain-gauges to Met One Model 280C digital tipping bucket rain-gauges (MetOne Instruments Inc., Grants Pass, OR) begun. Also, the number of stations deployed increased to a total of 35. These stations were also equipped with instruments to measure air temperature, relative humidity, incoming solar radiation, and soil temperature. The measurement network is known today as the Micronet (http://ars.mesonet.org/) (Fig. 1c). Additionally, a state-run network of meteorological stations, the Mesonet, (Fig. 1d) also operated four stations in and around the LWREW (McPherson et al., 2007). By 1995, all the analog instruments were replaced by