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A multi-scale analysis of Namibian rainfall over the recent decade – comparing TMPA satellite estimates and ground observations

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ABSTRACT

Study region: Namibia.
Study focus: The lack of ground observations has long been a major obstacle in studying rainfall patterns in many dryland regions, particularly in the data scarce African continent. In this study, a continuous 6-year (2008–2013) daily record of ground observations collected from Weltevrede Farm at the edge of the Namib Desert was used to evaluate TRMM Multi-satellite Precipitation Analysis (TMPA, 0.25° resolution) daily rainfall estimates of this area. A Mann-Kendall trend analysis was conducted using all the available annual TMPA satellite data (1998–2015) to examine long-term trends in rainfall amount, intensity, frequency and seasonal variations over four locations across a rainfall gradient.
New hydrological insights for the region: The agreement between ground and satellite rainfall data was generally good at annual/monthly scales but large variations were observed at the daily scale. Results showed a spatial variability of rainfall trends across the rainfall gradient. We observed significant changes in frequency along with insignificant changes in intensity and no changes in total amount for the driest location, but no changes in any of the rainfall parameters were observed for the three wetter locations. The results also showed increased rainfall variability for the driest location. This study provided a useful approach of using TMPA data associated with trend analysis to extend the data record for ecohydrological studies for similar data scarce conditions. The results of this study will also help constrain IPCC predictions in this region.

1. Introduction

Rainfall is one of the main components of hydrologic cycle and the major source of water for natural vegetation as well as agriculture and livestock production in dryland regions (Wang and D'Odorico, 2008). About 90% of the world's dryland population is in developing countries (Wang et al., 2012), where the vast majority of drylands consist of rangelands (Millennium Ecosystem Assessment, 2005) (i.e., 69%). Dryland rangelands support approximately 50% of the world's livestock and its production is particularly vulnerable to climate variability, of which rainfall is the most important component (Millennium Ecosystem Assessment, 2005). African rangelands are of critical importance since they cover 43% of Africa's inhabited surface

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and are home to 40% of the continent's population (AU-IBAR, 2012). Though the proportion of rainfed cropland is not as significant as rangeland, rainfed agriculture is most prominent in some regions of Africa such as Sub-Saharan Africa where more than 95% of the cropland is rainfed (Rockström et al., 2010). Changes in rainfall amount, intensity and rain patterns could significantly affect dryland agriculture leading to decreased resource productivity and production (Daryanto et al., 2016). Erratic rainfall patterns in Nigeria, for example, made it difficult for farmers to plan their operations and resulted in low germination in cropping season, reduced yield and crop failure (Oriola, 2009). Study of maize production in Zimbabwe also indicated that more accurate climate predictions would be valuable in crop management decisions in that it reduced risk in agricultural production associated with rainfall variability at the site level (Phillips et al., 1998).

However, most areas of Africa lack sufficient observational data to study long-term rainfall trend and variability. Apart from the scarcity of data, an additional complication is that, in many regions of Africa, discrepancies exist between different observed rainfall data sets (Barros, 2014). Intergovernmental Panel on Climate Change (IPCC) has predicted a likely decrease in annual rainfall over parts of the western and eastern Sahel region in northern Africa as well as a likely increase over parts of eastern and southern Africa during the period of 1951–2010 (Barros, 2014). Particularly, a reduction in late austral summer rainfall has been observed and projected over western parts of southern Africa extending from Namibia, through Angola, and towards Congo during the second half of the 20th century (Barros, 2014). As shown in the IPCC AR5, signal of future change in precipitation is not obvious (less agreement) until the middle of the 21st century over southern Africa. IPCC prediction using General Circulation Models (GCMs) is run at a coarse spatial resolution of 150–300 km while the rainfall process has a much higher spatial variability, and thus high-resolution data is needed for better prediction. IPCC prediction has great uncertainty and ground data is therefore very important to constrain the model prediction for the future.

Rain gauges have historically been considered the most accurate form of local rainfall measurement (Villarini et al., 2009). However, they can only capture the variability of small areas and therefore in many cases, precipitation estimates from rain gauges are subject to uncertainty when representing the entire observation site. Errors and omissions or power outages from the recording devices, human operators, and data transmission could also cause valuable data to be lost, damaged, or altered and result in poor data quality (Kneis et al., 2014). In many regions of the world, rain gauge data is difficult to access due to technical or administrative reasons (Kneis et al., 2014). Particularly in many remote parts of developing countries, ground-based rainfall measurements are rare or nonexistent. Radar and satellite-based rainfall estimates have been shown to provide a potential solution to the limitations of rain gauge data (Ward and Trimble, 2003). But satellites do not measure rainfall directly, so combining of ground observations with radar and satellite remote sensing of rainfall estimates (e.g., using ground observations to correct satellite data bias) could be a viable approach to produce a consistent, long sequence of climate data records (Villarini et al., 2009).

Although previous studies have documented some characteristics of Namibia rainfall (Eckardt et al., 2013), rarely have they looked at how well satellite-based rainfall data is correlated with ground-based observations. More importantly, no attempt has been made to comprehensively analyze the long-term changes in rainfall in Namibia, where the rainfall is highly variable both spatially and temporally with the greatest rainfall variation coefficient over Southern Africa (Eckardt et al., 2013). A normal rainy season spans from October to April (Foissner et al., 2002), and October, as the transition month from dry season to wet season, is characterized by very high inter-annual rainfall variability (Eckardt et al., 2013). There hasn't been a rainfall observation site from the Namibia Meteorological Services at the edge of the Namib Desert, so the ground rainfall measurements from this region are very valuable. Moreover rainfall in this region could be highly localized with large inter- and intra- annual variation as the area is located right on the steep rainfall gradient from the desert interior to the Namibian highland (Eckardt et al., 2013; Kaseke et al., 2016). As a result of strong the NE-SW rainfall gradient across, Southern Africa rainfall events mainly occur in the north-eastern, northern and central parts, and the southern parts of Namibia are largely hot and dry having only isolated rainfall occurrences, and ultimately the west Namib coast is hyper-arid (Eckardt et al., 2013). Therefore, another focus of this study is to evaluate the rainfall pattern changes at different locations along the rainfall gradient; and for each location, the detailed rainfall trend analyses will be conducted (e.g., total rainfall trend, rainy season rainfall trend, the average rainfall depth per storm, and the average storm frequency).

In this study, we compared the TRMM Multi-satellite Precipitation Analysis (TMPA) satellite data with available ground observations from the local rain gauges. The TMPA satellite estimates were then used to resolve the spatial and temporal distributions of rainfall over the study area. TMPA satellite is a US-Japan join mission launched in November 1997 (Simpson et al., 1988), and its primary goal is to measure precipitation in the Tropics where surface observations are scarce (Bowman, 2005). It operates in a low-inclination (35°), low-altitude orbit (Bowman, 2005), and the primary merged microwave-infrared product is computed at finer scale with the 3-h, 0.25° x 0.25° latitude–longitude resolution (Huffman et al., 2007). In this study, we aim to address the following questions: 1) are satellite based rainfall data useful to study the rainfall characteristics at regions with the lack of ground observations traditionally? 2) if so, what are the temporal scales at which the satellite rainfall data are comparable with ground observations? and 3) are there any significant long-term changes in rainfall characteristics over multiple locations in Namibia across a rainfall gradient?

2. Methods

To examine the spatial variations and assess the long-term rainfall trends as well as long-term rainfall variability, we analyzed TMPA rainfall estimates from four locations across a rainfall gradient (Fig. 1). The four locations are Farm 1 and Farm 2 within the Weltevrede Guest farm, the Gobabeb Research and Training Center (GRTC, TMPA pixel centered at 23.625°S,