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Assessment of the consistency among global precipitation products over the United Arab Emirates

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ABSTRACT

Study region: United Arab Emirates.

Study focus: Numerous global precipitation products have been developed and calibrated. However, their performance over arid regions such as the United Arab Emirates (UAE) has been revealing notable differences triggered by a combination of climatic and terrestrial attributes. The objective of this study is to cross-validate and analyze the consistency of four global precipitation products from the GPCC, TRMM, WM, and CMORPH datasets over the UAE using a network of 53 rain gauges from 2000 to 2010. The spatial analysis of their consistency versus topography and land cover is expected to reveal the factors affecting the country's rainfall regime. The study also identifies and calibrates the best statistically performing precipitation product as an essential climatic input for monitoring, forecasting, and modeling hydrologic applications over the UAE.

New hydrological insights for the region: The UAE, similar to other dryland environments lacking adequate hydrologic monitoring networks, presents a unique area to evaluate satellite remote sensing products and the erratic spatiotemporal nature of precipitation in diverse environments. Statistical analyses indicate that the TMPA V7 precipitation products record the highest overall agreement with the observational network. Within the UAE, areas that receive high rainfall and fall within the vegetated highlands (e.g., > 250 m), provide the most promise for incorporating satellite precipitation into hydrologic monitoring, modeling, or water resource management.

1. Introduction

In the last few decades, the Middle East has undergone substantial development that led to the establishment of large cities such as Dubai and Abu Dhabi in the United Arab Emirates (UAE), among others, with a considerable increase in water demand. The lack of renewable water resources in arid regions such as the UAE requires accurate monitoring of the scarce rainfall events. The challenge exists in the sporadic nature of rainfall events across the UAE with significant variability in space and time. Increased understanding of precipitation variability over arid regions should lead to a better understanding of recharge regimes, mitigation of the risk of flash floods, and more optimized management of available resources. This has become particularly important where rain gauges or ground-

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based radar are generally sparse, mainly because such regions are remote and stretch over large domains with low population densities, diminishing the need to deploy a network of rain gauges and automated weather stations. Therefore, estimates of precipitation have relied on other alternatives including satellite measurement, numerical models, or hybrid approaches that integrate both.

Global precipitation products from remote sensing observations and/or numerical models offer an operational and systematic monitoring of rainfall events in arid regions. Currently, remote sensing precipitation products are widely available covering the entire globe with high spatial (e.g., 0.1 arc-degree) and temporal resolutions (e.g., 30 min) (Awange et al., 2016). However, remotely sensed products are very susceptible to a wide range of errors. Other factors such as cloud top reflectance, thermal radiance, orbital drift and retrieval algorithms are amongst the main sources (Kummerow et al., 2004). Moreover, short life span and sensor degradation cause data inhomogeneity (Kummerow et al., 2004). Infrared sensors do not directly measure the precipitation. Instead, they capture the cloud top brightness as a proxy for rainfall and may not be accurate (Kalinga and Gan, 2010), whereas microwave sensors estimate relatively accurate rainfall but with a lower temporal resolution (Dinku et al., 2007; Joyce et al., 2004; Pan et al., 2010). Compounding the problem further, previous studies have shown that there is significant inconsistency among the products over the globe which makes their assessment over arid regions particularly important where the error can be larger than the observation. In situ observations are not without their own limitations in certain environments (e.g., arid, complex terrain). Errors are found in these environments given the uneven distribution of observational networks (Jeffery, 2006; Hughes, 2006; Beesley et al., 2009; Nicholson, 2013). The topography of the region also affects the representativeness of the rain gauge. For instance, rain gauges on mountainous regions are not representative of the region's precipitation due to the terrain complexity (Peng et al., 2014). Such deficiencies of rain gauges observations lead to a rise in the popularity of remote sensing-based products (Sawunyama and Hughes, 2008; Li et al., 2009). A common way to improve the estimation is by integrating both technologies in a comprehensive system that minimizes the effect of their drawbacks (Boushaki et al., 2009).

One of the most commonly used precipitation products, the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA), provides near global products at a spatial resolution of 0.25° and a temporal scale of three hours (Huffman et al., 2007). However, several studies demonstrated that TRMM products exhibit significant systematic bias. For example, the TRMM 3B42 product overestimated precipitation over the Zambezi River Basin (Cohen Liechti et al., 2012) and the Tibetan Plateau in China (Yin et al., 2008), but underestimated it in Nepal (Islam, 2009). Moreover, TRMM 3B43 monthly product failed to show significant linear correlation with the rain gauges in eastern Kyrgyzstan (Karaseva et al., 2012). TRMM products were found to be well in line with the rain gauge observations in west Africa according to Jobard et al. (2011). Recently, Milewski et al. (2015) assessed the four TMPA products: 3B42: V6, V7temp, V7, RTV7 using a rain gauge network in Northern Morocco. They found the latest product, 3B42 V7, to be the most consistent with the gauge observations based on spatially interpolated Pearson correlation coefficient results, while recording overestimations across all four products in arid environments. Building upon the success of TRMM, the Global Precipitation Measurement mission, launched in February 2014, is providing higher temporal (30 min) and spatial (0.1 arc-degree) resolution precipitation estimates through the IMERG product (Integrated Multi-satellitE Retrievals for GPM). The GPM IMERG product intercalibrates, merges, and interpolates GPM constellation satellite microwave precipitation estimates with microwave-calibrated infrared estimates, and rain gauge analyses to produce a higher resolution and more accurate product (Huffman et al., 2014) The GPM core satellite estimates precipitation from two instruments, the GPM Microwave Imager (GMI) and the Dual-Frequency Precipitation Radar (DPR). More importantly for this study, the GPM radar has been upgraded to two frequencies, adding sensitivity to light precipitation. These sensors are upgrades over the TRMM sensors and promise the ability of increased accuracy in the aforementioned terrains.

The Climate Prediction Center MORPHing technique (CMORPH) produces global precipitation analysis at high spatial and temporal resolutions with exclusive reliance on low orbiter satellite microwave observations. The daily CMORPH product overestimated precipitation when evaluated against the rain gauge observations in the Zambezi River Basin (Cohen Liechti et al., 2012), in West Africa (Jobard et al., 2011), and in Indonesia (Vernimmen et al., 2012). It also showed significant underestimation when examined over the Ethiopian river basins (Bitew and Gebremichael, 2011; Romilly and Gebremichael, 2011). CMORPH was found to perform well over the US, Australia, and Northwestern Europe according to Ebert et al. (2007).

Satellite-based products have shown uncertainty throughout the world. They seem to be time and space sensitive as their reliability varied over different regions and during different seasons. This creates a potential bias in water resource assessments and investigations when integrating such products in hydrological models or studies. Significant disagreement with the rain gauges was noticed in arid regions compared to mid-latitude regions in the world (Fekete et al., 2004). Assessment of these precipitation products was rarely performed over arid and semi-arid regions despite their abundance (arid areas cover almost a quarter of the world). Fekete et al. (2004) stated that precipitation estimates over arid and semi-arid areas require significant improvements. The uncertainty in estimating precipitation is causing significant fluctuations in the hydrologic processes, such as runoff, due to the nonlinear relationship. The PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) product developed by Sorooshian et al. (2014) and the CMORPH product were found to overestimate the precipitation over the arid regions of northwest China, while the TRMM daily product 3B42 performed relatively better with acceptable precision, but a correction factor was suggested before application (Yang and Luo, 2014). Recently, Liu (2015) compared TRMM, GPCC (Global Precipitation Climate Center), and WM (Willmott et al., 2001) rainfall products overland on the global scale. The products showed climatology agreement in terms of spatial, distribution, zonal means as well as seasonal variations, but large discrepancies were found in light rain.

Precipitation retrieval over arid regions has been challenging because of uncertainties in estimating land surface properties, mainly land surface emissivity. Yan and Weng (2011) demonstrated lower accuracy in the Global Forecast System (GFS) system over arid regions. Also, Zheng et al. (2012) showed that over the desert, there is a cold and significant bias during daytime in estimating