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Research papers

Assessment of global precipitation measurement satellite products over Saudi Arabia

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ABSTRACT

Most hydrological analysis and modeling studies require reliable and accurate precipitation data for successful simulations. However, precipitation measurements should be more representative of the true precipitation distribution. Many approaches and techniques are used to collect precipitation data. Recently, hydrometeorological and climatological applications of satellite precipitation products have experienced a significant improvement with the emergence of the latest satellite products, namely, the Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (GPM) mission (IMERG) products, which can be utilized to estimate and analyze precipitation data. This study focuses on the validation of the IMERG early, late and final run rainfall products using ground-based rain gauge observations throughout Saudi Arabia for the period from October 2015 to April 2016. The accuracy of each IMERG product is assessed using six statistical performance measures to conduct three main evaluations, namely, regional, event-based and station-based evaluations. The results indicate that the early run product performed well in the middle and eastern parts as well as some of the western parts of the country; meanwhile, the satellite estimates for the other parts fluctuated between an overestimation and an underestimation. The late run product showed an improved accuracy over the southern and western parts; however, over the northern and middle parts, it showed relatively high errors. The final run product revealed significantly improved precipitation estimations and successfully obtained higher accuracies over most parts of the country. This study provides an early assessment of the performance of the GPM satellite products over the Middle East. The study findings can be used as a beneficial reference for the future development of the IMERG algorithms.

1. Introduction

Precipitation, which is a major component of the hydrological cycle, falls in many different forms according to the meteorological conditions. Moreover, precipitation is one of the most important components of the global energy cycle (Kidd and Huffman, 2011; Ebert et al., 2007). Measurements of precipitation provide one of the primary inputs for hydrological, meteorological and climate models, which are used to predict different natural hazards such as landslides, floods, and droughts (Li et al., 2013; Wu et al., 2012). The responses of the hydrological and energy cycles depend upon not only the precipitation amount but also other characteristics, including the spatial pattern, intensity, and duration of precipitation (Heistermann and Kneis, 2011; Sorooshian et al., 2011). Therefore, precipitation estimates with a high spatiotemporal resolution are always needed for various applications. The acquisition of precipitation measurements and the quality control of precipitation products are the most important steps prior to performing any analysis or constructing any hydrologic model (Li and Shao, 2010). The most widely used techniques to estimate precipitation are point measurements (i.e., rain-gauges), commercial microwave links, satellite-based sensors, and ground-based weather radar (Li et al., 2013; Raich et al., 2017).

Rain gauges can provide direct measurements of precipitation, and they are considered to provide ground truth for precipitation observations due to their accuracy when compared with other sensors. There are many types of recording rain gauges. However, only three types, namely, the tipping bucket, the universal weighing-type gauge, and the float-type gauge, are commonly used by hydrometeorological agencies to measure precipitation. All three

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types of gauges have numerous measurement problems that can be summarized as follows: (1) the underestimation of heavy precipitation due to splashing; (2) instrumental problems; (3) external factors such as wind and evaporation of precipitation; and (4) observer errors (Tapiador et al., 2012). In addition, gauge measurements represent point values and not aerial measurements, and thus, they cannot describe spatial variations in precipitation.

Radar instruments measure precipitation indirectly by making use of the backscattering of electromagnetic waves via hydrometeors (i.e., water drops). The main benefit of radar is its ability to monitor large areas with a high, real-time resolution (Germann et al., 2006). However, radar measurements also have many error characteristics, such as range-dependent systematic errors, mean-field systematic errors, random errors, and obstruction by topography. In addition, radar networks do not cover all parts of the world (Tang et al., 2016).

During the past thirty years, the utilization of multiple satellite sensors to measure the global precipitation has increased significantly (Ebert et al., 2007; Tang et al., 2016). The first devoted satellite that was used to measure precipitation was the Tropical Rainfall Measuring Mission (TRMM), which became operational in 1997 (Li and Shao, 2010; Tian et al., 2007; Prakash et al., 2016; Ning et al., 2016). The TRMM satellite was intended to measure moderate to heavy rainfall to provide a better understanding of the precipitation distribution around the globe and generate near-real-time precipitation products (Li and Shao, 2010; Tian et al., 2007; Prakash et al., 2016; Zhou et al., 2008).

Several free-access satellite precipitation products have been extensively studied, and they have been verified both globally and regionally and subsequently released for public use (Tang et al., 2016). Examples of these products include the Precipitation Estimation from Remote Sensed Information using Artificial Neural Networks (PERSIANN) technique (Sorooshian et al., 2000), the Climate Prediction Center (CPC) MORPHing technique (CMORPH) (Joyce et al., 2004), the PERSIANN-Cloud Classification System (PERSIANN-CCS) (Hong et al., 2004), the TRMM Multi-satellite Precipitation Analysis (TMPA) (Huffman et al., 2007), and the Global Satellite Mapping of Precipitation (GSMaP) project (Kubota et al., 2007). Using these products, many studies demonstrated that Earth-observing satellites can reasonably estimate precipitation rates and that they are also able to represent the spatiotemporal variations in the precipitation over most parts of the world with a high resolution (Wang et al., 2017; Tang et al., 2016; Tian et al., 2007; Dixon and Wilby, 2015).

The newly introduced Global Precipitation Measurement (GPM) mission is an international constellation of satellites grouped to provide next-generation measurements of global rain and snow at high spatial ($0.1^\circ \times 0.1^\circ$) and temporal (half-hourly) resolutions. The constellation consists of one main observatory satellite surrounded by ten partner satellites (NASA, 2016a). The GPM Core Observatory satellite was launched through the cooperation between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA) on February 27, 2014. The GPM adopts modern technology and instruments, thereby raising the standard of precipitation measurements. The GPM mission aims to improve the existing knowledge about the global water and energy cycles, enhance the ability to predict extreme events, and provide precipitation products that can be applied directly to all scientific fields (NASA, 2016b).

The GPM has many products, which are classified into four categories according to NASA. The GPM categories (i.e., levels) are Level 0, Level 1, Level 2 and Level 3 as shown in Table 1. The recommended product for use by researchers is Level 3. This product is provided by the Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm, which is designed to incorporate, merge, and inter-calibrate all precipitation microwave (MW) estimates along with infrared (IR) satellite estimates, ground precipitation gauges, and all other precipitation estimators involved in the era of Tropical Rainfall Measuring Mission (TRMM) satellites (Huffman et al., 2015; NASA, 2016c). NASA provides three main IMERG products: "Early" near-real-time run products, "Late" run products, and "Final" run products.

Some studies investigated the accuracy of the GPM IMERG products using earlier satellite products, such as the Tropical Rainfall Measurement Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) 3B42-V7 product, and demonstrated their potential for hydrological applications. Recent studies reported a significant improvement in the detection and measurement of rainfall intensities using the GPM satellites compared with earlier satellites (e.g., Khodadoust Siuki et al., 2017; Wang et al., 2017). Other studies evaluated the GPM products against ground measurements and reported a good agreement between the satellite estimates and the ground observations (e.g., Asong et al., 2017; Sungmin et al., 2017).

The TRMM rainfall products for Saudi Arabia were evaluated by (Almazroui, 2011) for the period from 1998 to 2009. As the results showed varying degrees of accuracy for the TRMM across different events and regions, the study recommended using TRMM rainfall products only for ungauged regions and for those regions with extremely sparse rain gauge networks to supplement the rainfall data in the country. Another recent study (Tekeli and Fouli, 2016) recommended using TRMM rainfall products for flood warning purposes in urban areas and concluded that TRMM rainfall products could provide limited input information for flood warning systems, and thus, they cautioned against relying solely upon those product during large rainfall events.

Both a comparison and an evaluation of the GPM IMERG products against ground observation gauges are highly important for different regions across the world because those products are being continuously refined; moreover, feedback on the perfor-

Table 1
Definition of GPM data product levels.

Product	Input Data	Distributed to Users	Description
Level 0	–	No	Depacketized data by an Application Process Identifier (APID).
Level 1A	Level 0	No	These data are managed as the master data in the mission operation system. *Main parameters:* sensor output value, satellite altitude and location information, sensor conditions, conversion parameters.
Level 1B and 1C	Level 1A	No	Products created via geometric collection and processing. *Main parameters:* received power, brightness temperature.
Level 2	Level 1A, 1B, and 1C	Yes	Products containing various physical quantities related to precipitation. *Main parameters:* radar cross section of the Earth's surface, precipitation type, bright band altitude, attenuation-compensated radar reflectivity factor and precipitation intensity, spectral latent heating.
Level 3	Level 1 or Level 2	Yes	Products created via spatiotemporal statistical processing. *Main parameter:* Precipitation rate.