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Comparison of GPM IMERG, TMPA 3B42 and PERSIANN-CDR satellite precipitation products over Malaysia

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ABSTRACT

The launch of the Global Precipitation Measurement (GPM) mission has prompted the assessment of the newly released satellite precipitation products (SPPs) in different parts of the world. This study performed an initial comparison of three GPM IMERG products (IMERG_E, IMERG_L and IMERG_F) with its predecessor, the TMPA 3B42 and 3B42RT products, and a long-term PERSIANN-CDR product over Malaysia. The performance of six SPPs was evaluated using 501 precipitation gauges from 12 March 2014 to 29 February 2016. The annual, seasonal, monthly and daily precipitation measurements were validated using three widely used statistical metrics (CC, RMSE and RB). The precipitation detection capability (POD, FAR and CSI), probability density function (PDF) and the 2014–2015 flood event analysis were also considered in this assessment. The results show that all the SPPs perform well in annual and monthly precipitation measurements. The spatial variability of the total annual precipitation in 2015 is well captured by all six SPPs, with high precipitation amount in southern East Malaysia, and low precipitation amount in the middle part of Peninsular Malaysia. In contrast, all the SPPs show moderate correlation at daily precipitation estimations, with better performance during the northeast monsoon season. The performance of all the SPPs is better in eastern Peninsular Malaysia, but poorer in northern Peninsular Malaysia. All the SPPs have good precipitation detection ability, except the PERSIANN-CDR. All the SPPs underestimate the light (0–1 mm/day) and violent (> 50 mm/day) precipitation classes, but overestimate moderate and heavy (1–50 mm/day) precipitation classes. The IMERG is shown to have a better capability in detecting light precipitation (0–1 mm/day) compared to the other SPPs. The PERSIANN-CDR has the worst performance in capturing all the precipitation classes, with significant underestimation of light precipitation (0–1 mm/day) class and overestimation of moderate and heavy precipitation classes. The IMERG near-real time products with finer temporal and spatial resolutions can be regarded as a reliable precipitation source in studying the 2014–2015 flood event in Malaysia.

1. Introduction

Satellite precipitation products (SPPs) have emerged as a main precipitation measurement approach in recent decades (Tan et al., 2015; Xu et al., 2017). Compared to ground-based measurements such as gauges and radars, SPPs are able to cover the precipitation system at a nearly global-scale, irrespective of the less accessible mountainous and oceanic regions. Generally, precipitation gauges are frequently prone to large missing values, wind effects, insufficient number of stations and sparse network problems (Maggioni et al., 2016). Meanwhile, ground-based radar measurements are affected by signal attenuation, surface backscattering and reflectivity-rain-rate (*Z-R*) relationship uncertainty issues (Einfalt et al., 2004). Therefore, SPPs are widely utilized in many environmental applications such as precipitation characteristics analysis (Petersen et al., 2002; Song and Sohn, 2015), hydrological modelling (Zhu et al., 2016; Tan et al., 2017a) and drought monitoring (Tao et al., 2016; Tan et al., 2017c).

Numerous satellite missions have recently become operational and their products are made freely available to public, including the Global Precipitation Measurement (GPM) (Hou et al., 2014), Tropical Rainfall Measuring Mission (TRMM) (Huffman et al., 2007) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (Hsu et al., 1997). The launch of the GPM satellite on 27 February 2014 was intended to replace the TRMM satellite, which officially ended its 17 years of service on 8 April 2015. Generally, the newly released Integrated Multi-satellite Retrievals for GPM (IMERG) products have improvements in term of the coverage (60°N-60°S), spatial (0.1°) and temporal (30 min) resolutions. Moreover, the

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GPM Microwave Imager (GMI) and the Dual-frequency Precipitation Radar (DPR) onboard GPM are much more advanced than the five instruments onboard TRMM. For instance, the frequency range of the GMI (13 channels) is higher than the TRMM Microwave Imager (TMI, 9 channels). The TRMM Multi-satellite Precipitation Analysis (TMPA) products, which are available from 1998 until mid of 2018 (Huffman, 2015), have a lower spatial (0.25°) and temporal (three hourly) resolutions and a smaller regional coverage from 50°N to 50°S. In 2015, the PERSIANN - Climate Data Record (PERSIANN-CDR), with > 30 years (1983 to date) of daily precipitation data coverage, was developed and released by Ashouri et al. (2015) for long term hydro-climatic changes studies. The PERSIANN-CDR covers the latitude band of 60°N-60°S at a spatial resolution of 0.25°.

A preliminary validation of SPPs for a specific region is essential to foster improvement in the SPPs' algorithms and satellite sensors development. The International Precipitation Working Group (IPWG) was established in 2001 to promote the standards in SPPs' operational analysis and validation procedures (Turk and Bauer, 2006). Since then, SPPs validation efforts have been carried out in various parts of the world, i.e. Africa (Dinku et al., 2007), Asia (Zhou et al., 2008), Australia (Pena-Arancibia et al., 2013), Europe (Lockhoff et al., 2014), North America (Tian et al., 2010) and South America (Fensterseifer et al., 2016). Many current SPPs validation studies are focused on the IMERG (Gaona et al., 2016; Guo et al., 2016a; Sahlu et al., 2016) and the PERSIANN-CDR (Ashouri et al., 2015; Miao et al., 2015; Katiraie-Boroujerdy et al., 2017) products as they are recently made available to public. These studies showed that the performance of the SPPs varies from place to place. For instance, the IMERG has a very high correlation with ground-based measurements at daily precipitation estimations in China (Tang et al., 2016b), but only a moderate correlation in Iran (Sharifi et al., 2016) and Blue Nile Basin (Sahlu et al., 2016). Therefore, a preliminary assessment of SPPs is important to understand their capability in a specific region before applying them into any applications.

Malaysia is a tropical country that consists of two non-contiguous regions of Peninsular Malaysia and East Malaysia (Fig. 1). Numerous studies have been conducted to evaluate the reliability of the TMPA and PERSIANN-CDR in climatology and hydrology applications over Malaysia (Varikoden et al., 2010; Semire et al., 2012; Tan et al., 2015; Semire and Mohd-Mokhtar, 2016; Tan et al., 2017c). These studies found that in general the monthly and annual precipitation measurements of SPPs are more reliable than the daily precipitation measurement. In addition, the performance of the SPPs is generally better in the eastern and southern parts of Peninsular Malaysia. To date, Tan et al. (2015) is the only study that compared the TMPA and PERSIANN-CDR products over Malaysia. They concluded that the TMPA products outperformed the PERSIANN-CDR product in this country, particularly in estimating precipitation during the 2006–2007 flood event. However, the SPPs' capability in recent years remains unclear because the assessment period of this study is only from 2003 to 2007. As the IMERG product is only recently available, the application of the IMERG product in Malaysia is still rather limited. This work is thus one of the first studies that provide an early assessment of the IMERG product across the whole Malaysia.

This study attempts to address three main research questions: (1) what is the overall performance of the IMERG, TMPA and PERSIANN-CDR products in recent years; (2) are there any improvements in the IMERG products compared to the TMPA products; and (3) what is the accuracy of the SPPs in the estimation of flood precipitation. The main objective of this study is to evaluate the reliability of the SPPs at daily, monthly, seasonal and annual precipitation measurements over Malaysia from 12 March 2014 to 29 February 2016. Other validation measures such as spatial variability assessment, precipitation detection capability, Probability Density Function (PDF) and the 2014–2015 flood event analysis were also taken into account in this study. Three IMERG Early Run (IMERG_E), Late Run (IMERG_L) and Final Run (IMERG_F) products version 4 were considered in this study. The IMERG_E and IMERG_L are useful for disaster-based (i.e. flood and typhoon) monitoring as they are near real-time products. On the other hand, the IMERG_F is a calibrated product and hence recommended for research purpose. This study serves as a useful reference for those who like to apply the latest SPPs in hydro-climatic applications in Malaysia. As a tropical country, Malaysia is indeed a very good test site for the SPPs' sensor and algorithm developers to assess better the capability of SPPs in high precipitation variability regions. The results could be useful for them to improve their products in the future.

2. Study area and datasets

2.1. Study area

Malaysia is one of the South-east Asia countries that are located near the equatorial region (Fig. 1). The continental area of Malaysia is about 330,000 km^2, bounded by 0° N - 8° N latitudes and 99° E - 120° E longitudes. Both Peninsular Malaysia and East Malaysia are separated by South China Sea, with a distance about 530 km apart. The topography map of Malaysia is shown in Fig. 1b, with high mountainous regions mainly found in the middle part of Peninsular Malaysia and East Malaysia. Mount Kinabalu located in the northern part of East Malaysia is the tallest mountain in Malaysia.

Malaysia is exposed to high amount of precipitation (~2500 mm/year) annually, with temperature ranges from 23 to 32 °C (Tan et al., 2015). The northeast monsoon season (NEM) starts from December to early March, and is divided into wet and dry phases. The wet phase (early NEM) brings moderate to heavy precipitation to the eastern Peninsular Malaysia and northern East Malaysia, and the dry phase (late NEM) is characterized with drier climate condition from late January to early March. Meanwhile, the southwest monsoon season (SWM) starts from June to September, bringing moderate precipitation to the western part of Peninsular Malaysia. Generally, SWM brings lesser precipitation to Malaysia than NEM because the precipitation is attenuated by the Indonesian mainland. There are two inter-monsoon seasons which occur between the NEM and SWM seasons and bring precipitation that normally caused by the sea breeze circulation and strong surface heating.

2.2. Precipitation gauges

For validation of the SPPs, a total of 501 precipitation gauges that distributed across Malaysia were collected from the Department of Irrigation and Drainage Malaysia (Fig. 1a). These gauges were chosen as they contain no missing values from 12 March 2014 to 29 February 2016. Fig. 1a indicates that no gauges can be found in the middle part of East Malaysia because this region is dominated by tropical rainforest. The daily precipitation was taken as accumulated precipitation over 24 h from 0800 a.m. Malaysia local time, which is equivalent to 0000 Coordinated Universal Time (UTC). Hence, the daily precipitation values of gauges are directly compatible with the SPPs because the SPPs also measure daily precipitation at 0000 UTC.

In general, many SPPs integrate the Global Precipitation Climatology Centre (GPCC) precipitation gauge data to calibrate their products. Hence, the reference precipitation dataset for any SPPs' validation studies should be independent from the GPCC product, in order to avoid any misleading results. However, the exact location and time period information of the precipitation gauges used for the GPCC product development is not made available to public. To clarify the independent status of the reference dataset used in this study, we analyzed a number of precipitation gauges supplied by the Malaysia government to the GPCC's developer. It is worth noting that the supplied gauges could differ over time, so we only evaluated the GPCC product during our validated period. Fig. 2 shows that, in January 2015, only about 24 precipitation gauges over Malaysia were used in