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A preliminary assessment of GPM-based multi-satellite precipitation estimates over a monsoon dominated region

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SUMMARY

Following the launch of the Global Precipitation Measurement (GPM) Core Observatory, two advanced high resolution multi-satellite precipitation products namely, Integrated Multi-satellitE Retrievals for GPM (IMERG) and Global Satellite Mapping of Precipitation (GSMaP) version 6 are released. A critical evaluation of these newly released precipitation data sets is very important for both the end users and data developers. This study provides a comprehensive assessment of IMERG research product and GSMaP estimates over India at a daily scale for the southwest monsoon season (June to September 2014). The GPM-based precipitation products are inter-compared with widely used TRMM Multi-satellite Precipitation Analysis (TMPA), and gauge-based observations over India. Results show that the IMERG estimates represent the mean monsoon rainfall and its variability more realistically than the gauge-adjusted TMPA and GSMaP data. However, GSMaP has relatively smaller root-mean-square error than IMERG and TMPA, especially over the low mean rainfall regimes and along the west coast of India. An entropy-based approach is employed to evaluate the distributions of the selected precipitation products. The results indicate that the distribution of precipitation in IMERG and GSMaP has been improved markedly, especially for low precipitation rates. IMERG shows a clear improvement in missed and false precipitation bias over India. However, all the three satellite-based rainfall estimates show exceptionally smaller correlation coefficient, larger RMSE, larger negative total bias and hit bias over the northeast India where precipitation is dominated by orographic effects. Similarly, the three satellite-based estimates show larger false precipitation over the southeast peninsular India which is a rain-shadow region. The categorical verification confirms that these satellite-based rainfall estimates have difficulties in detection of rain over the southeast peninsula and northeast India. These preliminary results need to be confirmed in other monsoon seasons in future studies when the fully GPM-based IMERG retrospectively processed data prior to 2014 are available.

1. Introduction

Accurate estimates of precipitation are crucial for a wide range of applications from hydrology to climate studies. In the last three decades, satellite measurements of precipitation are proven to be cost-effective, uninterrupted, and reliable sources over large data-void regions (Yilmaz et al., 2005; Hossain and Katiyar, 2008; Collins et al., 2013; Tapiador et al., 2012). The first dedicated meteorological precipitation satellite – the Tropical Rainfall Measuring Mission (TRMM), launched in late 1997, was capable to measure moderate and heavy tropical precipitation with reasonable accuracy from last 17 years and enhanced our understanding of weather systems and real-time monitoring of monsoons and extreme weather events (Liu et al., 2012; Mitra et al., 2013; Hamada et al., 2015; Prakash et al., 2015c). With the splendid success of TRMM, the Global Precipitation Measurement (GPM) Core Observatory was launched in February 2014 to provide next-generation global rain as well as snow observations in near-real-time (Hou et al., 2014; Yong et al., 2015). It carries an advanced 13-channel passive microwave radiometer namely, GPM Microwave Imager (GMI), paired with a Ka/Ku-band dual-frequency

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precipitation radar (DPR) which serve as a benchmark to unify and advance precipitation estimates made by a constellation of research and operational microwave sensors (Draper et al., 2015). The Ka-band in DPR is more sensitive than TRMM – precipitation radar (PR) in light rainfall (sensitivity of Ka-band is 0.2 mm h^{-1} and that of PR is 0.5 mm h^{-1}) and high-latitude snowfall measurements. In addition, the DPR is able to detect and estimate extreme precipitation more precisely, which would be crucial to study their impacts in the global climate models in order to better understand the global water cycle (Liu and Zipser, 2015).

Multi-satellite rainfall estimates are very useful for several applications as they integrate relative advantages of various available satellite-based sensors to estimate more accurate gridded rainfall. The TRMM Multi-satellite Precipitation Analysis (TMPA) is one of the most suitable TRMM-era multi-satellite rainfall products for research as well as near real-time applications (Liu et al., 2012; Mitra et al., 2009, 2013; Prakash et al., 2014; Zhou et al., 2015; Yong et al., 2014). TMPA products were gone through major revisions several times and version 7 (V7) was released in late 2012 (Huffman et al., 2007; Huffman and Bolvin, 2014). However, a comprehensive evaluation of these products is essential for their integration in several applications, improvement in retrieval algorithms and numerical model output verification. Recently, several advanced methods were proposed to specify the error components in any satellite-based rainfall product (e.g., Ebert et al., 2007; Turk et al., 2008; Hossain and Huffman, 2008; Tian et al., 2009; Anagnostou et al., 2010; Gebremichael, 2010; Tian and Peters-Lidard, 2010; AghaKouchak et al., 2012; AghaKouchak and Mehran, 2013; Mehran and AghaKouchak, 2014; Li et al., 2015; Tang et al., 2015). The differences between real-time and research versions of TMPA-V7 data sets and between TMPA-V7 and V6 data sets at global scale were comprehensively evaluated by Liu (2015a, 2015b). Additionally, TMPA-V7 showed an overall improvement over its predecessor V6 data sets over India and surrounding oceanic regions with some exceptions (Prakash et al., 2013, 2014, 2015a, 2015d; Prakash and Gairola, 2014). This rainfall data set is superior to other contemporary multi-satellite data sets over India for the southwest monsoon season (Prakash et al., 2014, 2015b, 2015d, 2015e).

The Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation products were released in early 2015 (Huffman et al., 2014). This very high resolution precipitation product is now available at 0.1° latitude/longitude spatial and half-hourly temporal resolutions in three modes namely, early, late, and final runs based on latency and accuracy. This product is considered as the next generation of multi-sensor precipitation data that includes features from three already existing satellite precipitation products: (1) TMPA (Huffman et al., 2007), (2) CMORPH (Climate Prediction Center Morphing; Joyce et al., 2004), and (3) Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN; Hsu et al., 1997; Sorooshian et al., 2000). The final run of IMERG is analogous to TMPA research product which combines multi-satellite and gauge analyses for research applications and model verification. However, a recent preliminary evaluation of both IMERG and TMPA rainfall products over India indicate a notable improvement in IMERG over TMPA in heavy monsoon rainfall detection (Prakash et al., 2016). Additionally, the Global Satellite Mapping of Precipitation (GSMaP) version 6 product was released in late 2014, which uses a new algorithm for the GPM mission to retrieve rain rate and uses rain gauge analysis for bias correction (Ushio et al., 2013). A critical evaluation of these newly released precipitation data is very important for both the end users and data developers.

The Indian summer monsoon (June to September, JJAS) is a key component of the South Asian monsoon which has paramount social, environmental, and economic impacts. Therefore, accurate estimation and prediction of the Indian summer monsoon rainfall at sub-daily to seasonal scales are crucial for various applications such as for agricultural practices, hydrology, water resource management, and energy sectors. Furthermore, characteristic geographic and multifaceted topography (Fig. 1), and huge spatial as well as temporal variability in the monsoon rainfall make India a good test-bed to assess the accuracy of any satellite-based rainfall estimates (Gadgil, 2003; Prakash et al., 2014, 2015a, 2015c, 2015d). India has an appreciably good network of rain gauges (about 7000 gauges) well-spread across the country except over the northern Jammu & Kashmir (J&K) state (Pai et al., 2014).

The objective of this study is to evaluate the GPM-based IMERG research version and Global Satellite Mapping of Precipitation (GSMaP) version 6 rainfall products over India for the southwest or summer monsoon season of 2014 using gridded gauge-based rainfall data developed by the India Meteorological Department (IMD). The IMERG and GSMaP data sets are also compared with widely used gauge-adjusted TMPA data over India for the same period. Section 2 describes about the different data sets used in this study. The methodologies used for the evaluation are presented in Section 3. Results are presented and discussed in Section 4, and finally Section 5 contains the concluding remarks. Since most of the "precipitation" during the monsoon over India occurs as "rainfall", we interchangeably used both terms in this paper.

2. Rainfall data sets

Three gauge-calibrated multi-satellite and one gauge-only gridded rainfall data sets for the southwest monsoon season of 2014 (JJAS-2014) are used in this study primarily due to the reason that the IMERG is currently available from March 2014 onwards and the retrospective processing of data prior to 2014 have not been completed. A brief description of each data set is given here.

2.1. IMERG data

IMERG is the Day-1 U.S. multi-satellite precipitation estimation algorithm for GPM which is based on components from three existing multi-satellite algorithms such as TMPA, CMORPH and PERSIANN (Huffman et al., 2014). This Day-1 algorithm was used at launch of the GPM Core Observatory and continued to use for precipitation estimation. IMERG is a suite of very high spatial (0.1° latitude/longitude) and temporal (half-hourly) resolution multi-satellite precipitation products. It is available in three distinct modes – early, late, and final runs, depending upon latency and requirements. The post-real-time research product (version 03D) in the IMERG suite of products, released in January 2015 and available since mid-March 2014, is used in this study. The input precipitation estimates for IMERG are computed from various passive microwave and infrared satellite sensors. The microwave precipitation estimates are calibrated against the GPM Combined Instrument product and after morphing, integrated with microwave precipitation-calibrated infrared fields. Finally, monthly rain gauge analyses from the Global Precipitation Climatology Center (GPCC) are used for bias adjustments in the research version product.

2.2. GSMaP data

The GSMaP data sets are multi-satellite rainfall products which synergistically use available microwave imagers/sounders and infrared satellite observations at high temporal and spatial resolution for meteorological and climate studies (Ushio et al., 2009). Similar to IMERG and TMPA rainfall, GSMaP estimates are also available in near real-time and delayed mode. Recently, a new algorithm for the GPM mission has been used to retrieve rain rate

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