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Early assessment of Integrated Multi-satellite Retrievals for Global Precipitation Measurement over China

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ABSTRACT

Two post-real time precipitation products from the Integrated Multi-satellite Retrievals for Global Precipitation Measurement Mission (IMERG) are systematically evaluated over China with China daily Precipitation Analysis Product (CPAP) as reference. The IMERG products include the gauge-corrected IMERG product (IMERG_Cal) and the version of IMERG without direct gauge correction (IMERG_Uncal). The post-research TRMM Multisatellite Precipitation Analysis version 7 (TMPA-3B42V7) is also evaluated concurrently with IMERG for better perspective. In order to be consistent with CPAP, the evaluation and comparison of selected products are performed at 0.25° and daily resolutions from 12 March 2014 through 28 February 2015.
The results show that: Both IMERG and 3B42V7 show similar performances. Compared to IMERG_Uncal, IMERG_Cal shows significant improvement in overall and conditional bias and in the correlation coefficient. Both IMERG_Cal and IMERG_Uncal perform relatively poor in winter and over-detect slight precipitation events in northwestern China. As an early validation of the GPM-era IMERG products that inherit the TRMM-era global satellite precipitation products, these findings will provide useful feedbacks and insights for algorithm developers and data users over China and beyond.

1. Introduction

Precipitation measurements provide essential information for various applications such as numerical weather prediction, climate modelling, global energy and circulation pattern analysis, and climate diagnostic studies (Arkin & Xie, 1994; Kidd et al., 2012). Such data are critical sources of the main inputs to hydrologic, climatologic, and agricultural studies (Chen et al., 2013b; Habib et al., 2012; Seyyedi et al., 2015; Tang et al., 2015). Despite their great importance for different applications, reliable and accurate measurements of precipitation at global or regional scales with high resolution remain a scientific challenge because of the great heterogeneity across different spatiotemporal applications (Chen et al., 2013a; Li et al., 2013; Lo Conti et al., 2014; Mei et al., 2014). Common approaches for quantifying precipitation include ground rain gauge observations, weather radars, and estimates from satellite observations. Conventional rain gauge networks provide a direct physical measurement of surface precipitation amount with high temporal frequency (Xie & Arkin, 1995, 1996). However, the inhomogeneous distribution of rain gauges, limited spatial representativeness, and data latency hamper the use of these data for some applications (Ebert et al., 2007; Kidd et al., 2012; Porcù et al., 2014). Ground-based weather radars can provide precipitation estimates with relatively high spatial and temporal resolutions, but with limited coverage, variable accuracy, and limited utility in cold weather and mountainous terrain (Anagnostou, 2004; Ciach et al., 2007; Germann et al., 2006; Mei et al., 2014; Piccolo & Chirico, 2005; Schneebeli et al., 2013; Sharif et al., 2002). Precipitation estimates from satellite-based sensors may have great potential for various applications due to their extensive spatial coverage, consistent measurements over land and oceanic regions, as well as free access to near real-time data through the Internet (Bajracharya et al., 2015; Barrera et al., 2007; Karaseva et al., 2012; Stisen & Sandholt, 2010). Some of them have fine spatial and temporal resolutions and can provide information on precipitation occurrence,

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amount and distribution with smaller errors in area averaged estimation over sub-basins, even when precipitation at a single pixel may be not precise (Barrera et al., 2007).

Since the launch of the Tropical Rainfall Measuring Mission (TRMM) in 1997, extensive efforts have been made in developing satellite-based quantitative precipitation estimates (QPE) algorithms and operational satellite-based QPE products with high resolution. A series of TRMM-era satellite-based precipitation retrieval algorithms have been generated through the combined use of infrared (IR) and passive microwave (PMW) observations from multiple satellite sensors, such as TRMM Multi-satellite Precipitation Analysis (TMPA) (Huffman et al., 2007), Climate Prediction Center morphing technique (CMORPH) (Joyce et al., 2004), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (Hong et al., 2004; Hsu et al., 1997; Sorooshian et al., 2000), and Global Satellite Mapping of Precipitation (GSMaP) (Kubota et al., 2007; Okamoto et al., 2005). The ongoing efforts to improve retrieval algorithms and estimation techniques from the scientific community have resulted in the start of the GPM era.

The Global Precipitation Measurement (GPM) mission is composed of an international network of satellites that provide the next-generation global observations of rain and snow. As a global successor to TRMM, GPM focuses on the deployment of a "Core" satellite carrying an advanced radar/radiometer system to measure precipitation from space and serve as a reference standard to unify precipitation measurements from a constellation of research and operational satellites. The post-real time product Integrated Multi-satellite Retrievals for GPM (IMERG) is now available online at https://stormpps.gsfc.nasa.gov/storm. Much effort has been made to investigate the error and uncertainty characteristics of satellite-based precipitation products, such as TRMM, GSMaP, CMORPH, and PERSIANN over China (Chen et al., 2013b; Chen et al., 2014; Chen et al., 2016; Gao & Liu, 2013; Guo et al., 2015a; Liu et al., 2014; Qin et al., 2014; Shen et al., 2010b; Yin et al., 2008; Zhou et al., 2008). However, there have been very few reports associated with verification of IMERG products. Here we evaluate the performance of IMERG (latest released version) over China. This is one early study to assess the performance of the post-research product of IMERG with and without calibration over China, spanning the time from 12 March 2014 through 28 February 2015. Specifically, the error structures analyzed are characterized in terms of spatial distribution, temporal variation, and frequency of precipitation with different intensities. To obtain a better perspective of the error characteristics associated with the IMERG products, the version 7 post research product of TRMM Multisatellite Precipitation Analysis (TMPA) (hereafter, 3B42V7) is also included in this evaluation. 3B42V7 has been extensively evaluated in previous studies (Casse et al., 2015; Chen et al., 2013b; Chen et al., 2013c; Gao & Liu, 2013; Ghajarnia et al., 2015; Guo et al., 2015b; Huang et al., 2013; Liu, 2015; Shen et al., 2010b) and the strengths and weaknesses of the product are well understood. Building upon extensive existing studies on satellite-based precipitation products in the TRMM era, the goal of this study is to yield more insight into IMERG's error characteristics, thus providing useful information for users of the IMERG products and developers of IMERG algorithms.

The rest of this paper is organized as follows. Section 2 introduces the study region, the IMERG products, ground reference dataset, and evaluation metrics. Section 3 focuses on the analysis of spatial characteristics and the error quantification for IMERG. A brief summary and conclusions are given in Section 4.

2. Study region and datasets

2.1. Study region

The geography of China is variable, with regional differences in topography. A map showing the topographic variability from a digital elevation model (DEM) is given in Fig. 1a. Similar to the divisions presented in Chen et al. (2013b), China is separated into seven subregions in terms of elevation, mountain ranges (Tang et al., 2006) and the annual mean precipitation distribution (Qian & Lin, 2005). These subregions are shown in Fig. 1a and are referred to as: I) the Xinjiang (XJ) region, which has arid and semi-arid climate characteristics; II) Qinghai–Tibet Plateau (TP) which has an average elevation about 4500 m; III) Northwestern China (NW) bounded by the 400 mm annual precipitation isohyet; IV) Northeastern China (NE) located in the north of Yan mountain; V) Northern China (NC) located in the north of Qinling Mountains–Huai River line; VI) Yunnan–Guizhou Plateau in southwestern China (SW) which is bounded by the Ta-pa Mountains and Wulingshan mountains to the north and east; and VII) Southern China (SC) south of the Nanling mountains and southeast of the Wuyi Mountains. These subregion abbreviations are labeled in Fig. 1a, and will be used herein.

The climate in XJ is characterized by semi-arid climates, and its precipitation is primarily influenced by the mid-latitude westerlies with moisture contributions from the North Atlantic Ocean (Bothe et al., 2012). Coupled with the effects of complex terrain, the East Asia subtropical monsoon brings a large amount of precipitation over eastern China. The rainy season in most of China generally begins with the onset of the summer monsoon and ends with its withdrawal (Zhou et al., 2009). The monsoon rain belt moves from low latitudes to mid-high latitudes as the summer monsoon advances northward (Liu & Wang, 2011). The shift of the monsoon (Shen et al., 2010b; Zhou et al., 2008) and the landfall of typhoons (Carr & Elsberry, 1995) result in the Mei-yu, a persistent front of convective rainfall, from June and July in along the Yangtze–Huai river valley. Southwestern China is dominated by the monsoon between the Qinghai–Tibet Plateau (TP) and the Indian Ocean.

2.2. Ground reference dataset

The China daily Precipitation Analysis Product (CPAP) is produced and routinely calibrated by the National Meteorological Information Center (NMIC) and China Meteorological Administration (CMA). The CPAP product with a 0.25°/daily spatiotemporal resolution is used as a reference to evaluate the IMERG precipitation products. About 2400 heated rain gauge observations were interpolated with the climatology-based Optimal Interpolation (OI) technique to yield the gridded analysis product. Snowfall can be measured accurately by these heated rain gauges through manual heating method (Yan Shen, personal communication, January, 2016). An objective technique was used to define CPAP (Chen et al., 2008; Xie & Xiong, 2011; Xie et al., 2007), and the Parameter-Elevation Regression on Independent Slopes Model (PRISM) is used to correct orographic errors (Chen et al., 2016). All the gauge data used in CPAP have undergone strict quality control in three levels including the extreme values' check, internal consistency check, and spatial consistency check (Shen et al., 2010b). CPAP has been systematically validated by Shen (Shen & Xiong, 2015), and found that the daily analysis has very good agreements with the observations over different regions of China (Shen & Xiong, 2015). CPAP exhibits a relative bias of 3.21% at the 0.5° scale when compared to independent gauge observations in the validation (Shen et al., 2010a). And the gauge-based dataset has been successfully adopted to validate high resolution satellite-based precipitation estimates by some studies (Chen et al., 2013b; Chen et al., 2016; Guo et al., 2015a; Qin et al., 2014; Shen et al., 2010b).

The spatial distribution of rain gauge locations in Fig. 1b used in this study for a typical day represents the median gauge number for the whole study period. The Chinese rain gauge network is distributed unevenly over China. Gauge stations are densely spaced in eastern China where it is climatically wet and the population is dense, whereas relatively sparse gauge stations are found in western China. Gauges are especially infrequent in the areas of NW, XJ and TP, all of which are dominated by semiarid and arid climates. The limited number could