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Statistical assessment and hydrological utility of the latest multi-satellite precipitation analysis IMERG in Ganjiang River basin

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ABSTRACT

This study aims to statistically and hydrologically assess the hydrological utility of the latest Integrated Multi-satellitE Retrievals from Global Precipitation Measurement (IMERG) multi-satellite constellation over the mid-latitude Ganjiang River basin in China. The investigations are conducted at hourly and 0.1° resolutions throughout the rainy season from March 12 to September 30, 2014. Two high-quality quantitative precipitation estimation (QPE) datasets, i.e., a gauge-corrected radar mosaic QPE product (RQPE) and a highly dense network of 1200 rain gauges, are used as the reference. For the implementation of the study, first, we compare IMERG product and RQPE with rain gauge-interpolated data, respectively. The results indicate that both remote sensing products can estimate precipitation fairly well over the basin, while RQPE significantly outperforms IMERG product in almost all the studied cases. The correlation coefficients of RQPE (CC = 0.98 and CC = 0.67) are much higher than those of IMERG product (CC = 0.80 and CC = 0.33) at basin and grid scales, respectively. Then, the hydrological assessment is conducted with the Coupled Routing and Excess Storage (CREST) model under multiple parameterization scenarios, in which the model is calibrated using the rain gauge-interpolated data, RQPE, and IMERG products respectively. During the calibration period (from March 12 to May 31), the simulated streamflow based on rain gauge-interpolated data shows the highest Nash–Sutcliffe coefficient efficiency (NSCE) value (0.92), closely followed by the RQPE (NSCE = 0.84), while IMERG product performs barely acceptable (NSCE = 0.56). During the validation period (from June 1 to September 30), the three rainfall datasets are used to force the CREST model based on all the three calibrated parameter sets (i.e., nine combinations in total). RQPE outperforms rain gauge-interpolated data and IMERG product in all validation scenarios, possibly due to its advantageous capability in capturing high space-time variability of precipitation systems in the humid climate during the validation period. Overall, RQPE and rain gauge-interpolated data exhibit better performance compared with the newly available IMERG product, and RQPE is better than rain gauge-interpolated data to some extent due to the combination of both radar and rain gauge observations. IMERG-forced hourly CREST hydrologic model based on the Gauge- and RQPE-calibrated parameters performs well over Ganjiang River basin. Future studies should promote the hydrological application of RQPE datasets at global and local scales, and continuously improve IMERG algorithms.

1. Introduction

Severe storms cause disastrous floods and landslides, posing a great threat to personal security and national security as well as to the economy (Pfeifroth et al., 2015). Hydrologic models provide critical information for studying the water cycle and are irreplaceable for streamflow simulation, water resources management, and disaster prediction (e.g., floods and landslides) around the world (Kidd and Huffman, 2011). However, the availability of high-quality rainfall forcing data is a prerequisite for conducting meaningful hydrologic studies (Ali et al., 2005).

At present, surface precipitation is generally measured using three approaches: (1) rain gauges, (2) ground-based weather radars, and (3) satellite sensors. Rain gauges provide point-based surface rainfall data (Brommundt and Bárdossy, 2007; Dubois et al., 1998; Nystuen et al., 1996), which are usually interpolated to provide spatially

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continuous precipitation fields for hydrological studies (Ahrens, 2006; Bloschl and Grayson, 2001; Creutin and Obled, 1982; Garcia et al., 2008; Gebregiorgis and Hossain, 2015; Haberlandt, 2007; Tang et al., 2016a, 2016b).

China's new generation weather radars (CINRADs) are manufactured according to the Weather Surveillance Radar-1988 Doppler (WSR-88D) specifications. CINRADs provide precipitation observations not only with continuous representation of spatial and temporal variability but also with well captures of the 3-D distribution of precipitation as an important supplement to conventional rain gauges over a large area (Fulton et al., 1998; Gourley et al., 2011; Jameson, 2008; Méndez-Antonio et al., 2013; Teague et al., 2013). This makes radar quantitative precipitation estimation (QPE) data valuable for hydrological studies at the basin scale (Borga et al., 2006; Corral et al., 2000; Gourley et al., 2010; He et al., 2011; Kitzmiller et al., 2013; Neary et al., 2004). However, the inherent uncertainty in radar systems due to beam blockage and calibration etc. reduces the effectiveness of radar QPE data in hydrologic applications (Chokngamwong and Chiu, 2008; Hossain et al., 2004). As a result, both radars and rain gauges have their advantages and disadvantages, respectively. In this study, before converting the radar reflectivity factor (Z) to rain rate (R), a storm identification algorithm is first used to derive a new grouping scheme that classifies different dynamic Z-R relationships within storm events (Gou et al., 2015). Subsequently, the radar QPE data derived from the dynamic Z-R relationships are bias-corrected by the dense rain gauge network (described in details in Section 2.2.1). According to previous studies, gauge-corrected radar QPE product, referred to as "RQPE" in this study, can provide effective forcing data for hydrology (Goudenhoofdt and Delobbe, 2009; McKee, 2015). Gourley et al. (2010) determined that the radar precipitation product adjusted by rain gauge observations has the best hydrologic skill. He et al. (2013) generated reliable streamflow and water balance simulations by forcing a hydrologic model using four years' radar QPE data at the daily scale. In this study, we retrieve a seven-month hourly RQPE for hydrologic modeling.

Satellite sensing provides valuable global and regional precipitation estimates for hydrology, especially over sparsely monitored areas (Conti et al., 2014; Gourley et al., 2009; Hong et al., 2007; Li et al., 2015; Nijssen and Lettenmaier, 2004; Seyyedi et al., 2015; Schubert et al., 1993; Wu et al., 2012). The validation studies over well-instrumented areas around the world are very important for error characterization of satellite-based precipitation products (Li et al., 2015; Liu, 2015; Tang et al., 2015, 2016a). The Global Precipitation Measurement (GPM) mission comprises an international satellite network and can provide the next generation of global precipitation products. The GPM Core Observatory was launched on February 28, 2014, as a successor to the TRMM satellite, carrying both active and passive microwave sensors. The GPM sensors can detect light and solid precipitation more accurately than TRMM sensors (Guo et al., 2016; Hou et al., 2014). The GPM Core Observatory carries a conical-scanning multichannel GPM Microwave Imager (GMI), which has the frequency channels ranging between 10 and 183 GHz, and a Dual-frequency Precipitation Radar (DPR) with the Ku-band at 13.6 GHz and Ka-band at 35.5 GHz. Here, we use the hourly multi-satellite QPE product provided by the Integrated Multi-satellite Retrievals for the Global Precipitation Measurement (IMERG) algorithm. The algorithm intercalibrates, merges, and interpolates microwave QPE, microwave-calibrated infrared QPE, rain gauge observations, and other potential QPE into $0.1° \times 0.1°$ spatial scales and half-hour resolutions (Hou et al., 2008, 2014). IMERG products are calibrated by the Global Precipitation Climatology Centre (GPCC) monitoring product (version 4) whose data source is from the Global Telecommunications System (GTS) with about 7000 stations. The IMERG precipitation product is superior to standard TRMM precipitation products at a daily temporal resolution over the Ganjiang River basin (Tang et al., 2016a). However, so far, few studies have evaluated the applicability of the newly available IMERG estimates for hydrologic modeling at the hourly scale. Thus, conducting a detailed statistical and hydrological assessment of IMERG product to examine its utility at the hourly time scale is meaningful for hydrological research.

This study aims to statistically assess IMERG product and to evaluate its hydrological performance against RQPE and rain gauge-interpolated data under multiple parameterization scenarios at hourly and $0.1° \times 0.1°$ resolution over the Ganjiang River basin. Results could provide perspective to the error characteristics and the hydrological applicability of IMERG product over regions with similar terrain and climates. The rest of the paper is organized as follows: Section 2 introduces the study area and datasets used in the study as well as the CREST hydrologic model, Section 3 statistically evaluates IMERG product and RQPE, Section 4 analyzes the applicability of IMERG product and RQPE for the CREST hydrologic model, and Section 5 summarizes the main conclusions.

2. Material and methods

2.1. Study area

The Ganjiang River basin is the seventh largest branch of the Yangtze River in the Jiangxi province, located within 113°30′–116°40′E and 24°29′–29°21′N (Fig. 1(b)) in the southeast of China. It has a total drainage area of 81,158 km^2 above the Waizhou hydrologic station and is a historically flood-prone region. The elevation of this catchment ranges from 11 to 1997 m. The northwestern boundary of the Ganjiang River basin is the Jiuling mountain, which has an elevation of approximately 1794 m. The eastern Ganjiang River basin is bordered by the Wuyi Mountain.

With moderate climate and sufficient rainfall, the Ganjiang River basin belongs to the subtropical moist monsoon climate zone and is one of the typical rainstorm regions in China. Because of the combined effect of the complex terrain and the East Asian Monsoon climate, flood disasters frequently occur in this region. It receives an average annual rainfall between 1400 and 1600 mm, and the rainfall distribution is heterogeneous throughout the seasons. Over 70% of the total rainfall is concentrated in the period from April to June, which is the plum rain season, because of the convergence of cool and warm air masses and the existence of surface quasi-stationary front over the basin. Furthermore, due to local topography and monsoon climate, maximum precipitation usually occurs in the northwest and east of the Ganjiang River basin during the rainy season. Hu et al. (2014) evaluated the performance of six high-resolution satellite QPE products with monthly resolution over this basin and concluded that TRMM 3B43V6 product performs best. Tang et al. (2016a, 2016b) revealed that the IMERG product performs better than TRMM Multi-satellite Precipitation Analysis (TMPA) 3B42V7 and 3B42RT products at a daily and sub-daily resolution. However, the statistical and hydrological performances of hourly IMERG product are still unknown over the Ganjiang River basin.

2.2. Dataset description

This study uses multi-source precipitation data as forcing data of the CREST hydrologic model to evaluate the applicability and quality of the IMERG product relative to RQPE and rain gauge-interpolated data over the Ganjiang River basin at the hourly resolution.

2.2.1. RQPE

We obtained the base data from seven S-band China CINRADs located in Nanchang, Yichun, Jian, Ganzhou, Shaoguan, Meizhou, and Sanming with 6-min and 1-km resolutions from March 12 to September 31, 2014. The locations of the seven radar stations and their spatial coverage of the Ganjiang River basin are shown in Fig. 1(a). Since the Ganjiang River basin is surrounded by mountains, non-precipitation echoes including ground objects and super refraction can influence the quality of radar QPE data. Therefore, radar QPE data must be