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Research papers

Evaluation of the TRMM multisatellite precipitation analysis and its applicability in supporting reservoir operation and water resources management in Hanjiang basin, China

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ABSTRACT

In this study, we first evaluated a satellite-based precipitation product (3B42V7) using gauge observations and then investigated its utility in supporting reservoir operation and water resources management in Hanjiang basin from January 1998 to December 2013. Direct comparison of 3B42V7 with gauge observations shows that it can well capture the spatial and temporal characteristics of precipitation over the study basin. However, the 3B42V7 estimates generally show slight underestimation of precipitation, especially for extreme precipitation events, which need be considered in the future algorithm development. Next, we conducted the long-term (2008–2013) hydrologic evaluation of the 3B42V7 product using a calibrated monthly hydrologic model. The results show that the performance of the monthly hydrologic model driven by 3B42V7 is compatible to the results driven by gauge-based simulations according to high values of Nash-Sutcliffe coefficients (0.83 and 0.66 for observation-driven and 3B47V7 driven simulations, respectively) and small values of biases (−8.16% and −3.98%). We further evaluated the applicability of 3B42V7 in reservoir operation through a set of operation experiments, in which modeled inflow series were used to make decisions. The results indicate that reservoir operations based on modeled streamflow using the 3B42V7 estimates perform well in water allocation decision-making and strongly agree with actual inflow based operations. Despite that 3B42V7 tends to slightly underestimate precipitation, the resultant operations do not impact the functions and benefits of reservoir operation much. This suggests that the 3B42V7 precipitation estimates are valuable and useful for monthly streamflow simulation and long-term reservoir operation in Hanjiang basin. This study provides a new insight on the evaluation and utility of the remote sensing based precipitation estimates.

1. Introduction

Accurate and timely observations and estimates of regional and global precipitation are crucial for various researches and applications. Recently, we have witnessed significant developments in the field of satellite rainfall estimation. A variety of satellite-based precipitation products with continuous temporal availability and global coverage have been produced, such as the Precipitation Estimation from Remotely Sensed Information using artificial neural networks (PERSIANN) (Sorooshian et al., 2000) and PERSIANN-cloud classification system (PERSIANN-CCS) (Hong et al., 2004), the Climate Prediction Center (CPC) morphing algorithm (CMORPH) (Joyce et al., 2004), Tropic Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) (Huffman et al., 2007), and Global Precipitation Measurement (GPM) (Huffman et al., 2015). These satellite products provide valuable rainfall sources to the research community at different spatial scales, especially over regions that lack adequate rain gauges or radars (Anagnoston et al., 2001). Most of these satellite precipitation products have been widely used for hydrological studies and applications (Guetter et al., 1996; Grimes and Diop, 2003; Hughes, 2006; Wilk et al., 2006; Li et al., 2009; Islam et al., 2012; Gupta et al., 2013;

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Chen et al., 2015). However, the errors and uncertainties of satellite-based precipitation products always impose limitations on the full utilization of these products in hydrologic and water resources applications (Su et al., 2008; Srivastava et al., 2014; Zhang et al., 2015). Yilmaz et al. (2005) used the PERSIANN satellite precipitation algorithm to forecast streamflow using a lumped hydrologic model over several medium-size basins in the southeastern United States; they found that it showed poorer performance in the smaller basins than in the larger basins compared to the streamflow gauge observations. Hong et al. (2006) quantified uncertainty in streamflow prediction of a conceptual hydrologic model forced by satellite rainfall estimates using the PERSIANN-CCS algorithm and provided improved uncertainty assessment of the error propagation into hydrologic simulation. Artan et al. (2007) evaluated a satellite rainfall product for streamflow modeling with a spatially-distributed hydrologic model over four subbasins of the Nile and Mekong Rivers, which demonstrated a better performance when the hydrologic model was recalibrated with the satellite data than when calibrated with the gauge observations. Yong et al. (2010) evaluated two standard TMPA products (3B42RT and 3B42V6) at a small-size basin in northeast China and found that the 3B42RT showed unrealistic overestimation year-round and the 3B42V6 had greater potential for hydrologic modeling. All of these studies demonstrated both the advantages and disadvantages of satellite-based precipitation estimates, which shows needs to further improve these satellite products.

Since the launch of the TRMM satellite on November 27th, 1997, a series of high-resolution, near real-time and quasi-global TRMM-based precipitation estimates have been developed and improved. As a recently released product, the TMPA 3B42V7 shows largely improved accuracy than its predecessors and gains many hydrological applications. Yong et al. (2014) compared the V6 and V7 TMPA and found that both the real-time and research products of V7 TMPA show improvements over their V6 counterparts. Xue et al. (2013) explored the improvements and error propagation of the latest 3B42V7 algorithm relative to its predecessor 3B42V6 using the Coupled Routing and Excess Storage (CREST) hydrologic model in the mountainous Wangchu Basin of Bhutan. This study found that 3B42V7 generally improved upon 3B42V6's underestimation with lower bias and improved its occurrence frequency across the rain intensity spectrum. Other studies also demonstrated a better performance of the 3B42V7 precipitation products in terms of rainfall estimation improvement and hydrological application than its previous version (Zhang et al., 2013; Chen et al., 2013; Liu et al., 2016). However, most of these studies are mainly focused on evaluating the performance of the TMPA precipitation estimate and its applicability as forcing in streamflow modeling. To the best of our knowledge, the practical applications of the 3B42V7 products in reservoir operation and water resources management are still very few. In this study, a critical basin located in central China is chosen as the study area to evaluate the data quality of 3B42V7 and its applicability in reservoir operation and water resources management from January 1998 to December 2013 using a set of statistical analysis methods, a conceptual hydrologic model, and reservoir operation rules. The paper is organized as follows: Section 2 introduces the data and methodology; Section 3 presents the evaluation results and discussion; the summary and conclusions are summarized in Section 4.

2. Study area, data and methodology

2.1. Study area

The Hanjiang River, with a total drainage area of 151,000 km^2, is the biggest tributary of the Yangtze River. It originates in the south of Qinling Mountain in the southwest of Shanxi Province and runs through Shanxi, Hubei and Henan Provinces (Fig. 1). The basin lies within 30°–34.5°N and 107°–114.5°E in the middle of China with a humid, monsoon climate. The average annual precipitation, temperature and runoff during the period of 1960–2013 were 920 mm, 14 °C and 350 mm, respectively. Due to the monsoon climate, precipitation in flood season (May to October) accounts for 75% of the annual total. The runoff has a similar seasonality. Since 1960s, many reservoirs have been built to fully exploit the rich water resources of this basin. The most noteworthy one is the Danjiangkou reservoir, which is located in the center of Hanjiang basin and divides the basin into the upstream and downstream parts. Since it functions as the source of the middle route of the South-to-North Water Transfer project in China, its crest elevation was heightened from 162 m to 176.6 m in 2012. Its storage capacity was correspondingly expanded to 1.66 times of its original value. In December 2014, Danjiangkou reservoir started to supply water to the north for Henan, Hebei, Tianjing and Beijing via the water diversion channel, aimed at alleviating water shortage in these northern provinces. Meanwhile, Danjiangkou reservoir plays an important role in flood control, irrigation, water supply and power generation. In the recent years, the Hanjiang River basin has been experiencing population increase, increased frequencies of floods and droughts, and changes in hydrologic flow regime, which boost the pressure of local water management in water supply, flood control and river ecological protection. It is necessary to further study the flow regime in Hanjiang basin to provide scientific opinions for water resources allocation as well as South-to-North water transfer project.

2.2. Data

In this study, we obtained 16 years daily precipitation data of TRMM (3B42V7) at a spatial resolution of 0.25° × 0.25° resolution. We also used observed daily precipitation data from 1998 to 2013 in 29 rain gauges roughly spread evenly throughout the basin. The daily rainfall product in mm/day is supplied by NASA and derived from the original 3-hourly TRMM 3B42 product (see http://trmm.gsfc.nasa.gov/). Daily gauge data are collected from National Meteorological Information Center of China, including daily precipitation and daily pan evaporation (see http://data.cma.cn/). Some nearby rain gauges are also chosen as the data sources to improve the basin-wide precipitation estimates, though they are outside the basin. The monthly inflow of the Danjiangkou reservoir and the monthly discharge at the Xiantao Hydrological station—a downstream gauge station—from 1998 to 2013 are obtained from the 'Hydrological Year Book' published by the Hydrological Bureau of the Ministry of Water Resources. Monthly water demand for human needs and navigation in the downstream region of Hanjiang basin and water diversion plan for the middle route of South-to-North Water Transfer project are collected from Changjiang Water Resources Commission of the Ministry of Water Resources.

2.3. Hydrologic model

A two-parameter monthly water balance model developed by Xiong and Guo (1999) is used to evaluate the application of TRMM (3B42V6) as forcing to hydrologic simulations in this study. The concept of the model is that most of the rainfall can be converted into runoff in the rivers and water vapor in the air within a month, if no obvious effects of intakes in a catchment. Therefore, it is possible to use a simpler monthly water balance model with fewer parameters than the daily hydrological model. Different from other physical models (Li and Zhang, 2008; Yao et al., 2014; Huang et al., 2016), this model has only two parameters and requires only the