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Hydrologic evaluation of satellite precipitation products over a mid-size basin

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SUMMARY

Since the past three decades a great deal of effort is devoted to development of satellite-based precipitation retrieval algorithms. More recently, several satellite-based precipitation products have emerged that provide uninterrupted precipitation time series with quasi-global coverage. These satellite-based precipitation products provide an unprecedented opportunity for hydrometeorological applications and climate studies. Although growing, the application of satellite data for hydrological applications is still very limited. In this study, the effectiveness of using satellite-based precipitation products for streamflow simulation at catchment scale is evaluated. Five satellite-based precipitation products (TMPA-RT, TMPA-V6, CMORPH, PERSIANN, and PERSIANN-adj) are used as forcing data for streamflow simulations at 6-h and monthly time scales during the period of 2003–2008. SACramento Soil Moisture Accounting (SAC-SMA) model is used for streamflow simulation over the mid-size Illinois River basin.

The results show that by employing the satellite-based precipitation forcing the general streamflow pattern is well captured at both 6-h and monthly time scales. However, satellites products, with no bias-adjustment being employed, significantly overestimate both precipitation inputs and simulated streamflows over warm months (spring and summer months). For cold season, on the other hand, the unadjusted precipitation products result in under-estimation of streamflow forecast. It was found that bias-adjustment of precipitation is critical and can yield to substantial improvement in capturing both streamflow pattern and magnitude. The results suggest that along with efforts to improve satellite-based precipitation estimation techniques, it is important to develop more effective near real-time precipitation bias adjustment techniques for hydrologic applications.

1. Introduction

Precipitation is the key input for hydrometeorological modeling and applications. For accurate flood predictions, reliable quantification of precipitation data is crucial. However, in many populated regions of the world including developing countries, ground-based measurement networks (whether from radar or rain gauge) are either sparse in both time and space or nonexistent. This situation restricts these regions to manage water resources and hampers early flood warning systems resulting in massive socioeconomic damages.

With suites of sensors flying on a variety of satellites over the last three decades, many satellite-based precipitation estimation algorithms have been developed to make the precipitation data available to the community in quasi-global scale. Several high resolution precipitation products are now operational in high resolution at quasi-global scale. Among those are the TRMM Multi-satellite Precipitation Analysis (TMPA; Huffman et al., 2007), the Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN; Hsu et al., 1997; Sorooshian et al., 2000), Climate Prediction Center (CPC) morphing algorithm (CMORPH; Joyce et al., 2004), and the Naval Research Laboratory Global Blended-Statistical Precipitation Analysis (NRLgeo; Turk et al., 2000). Although different in the precipitation estimation procedure, in all of the listed products a combination of information from infrared and microwave sensors on geostationary and low earth orbiting satellites are used in attempt to improve the consistency, accuracy, coverage, and timeliness of high resolution precipitation data.

Given different estimation techniques and the existing uncertainties in retrieving precipitation characteristics from satellite information (Krajewski et al., 2000; Adler et al., 2001; Ebert et al., 2007; Gottschalck et al., 2005; AghaKouchak et al., 2009; McCollum et al., 2002; Tian et al., 2007), studies on reliability of hydrologic predictions based on the satellite-derived precipitation

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data need to be continued. One useful feedback of such studies is to assess the applicability of satellite-based streamflow prediction for data sparse regions. These types of studies are also motivated by global decline of in situ networks for hydrologic measurements (Stokstad, 1999; Shiklomanov et al., 2002) as opposed to the growing trend in the availability of satellite sensors providing more frequent and more accurate precipitation-relevant information and also near future mission such as the Global Precipitation Measurement (GPM) missions among others. In concert with such developments, great deals of research are being conducted to improve quality and resolution of precipitation products from individual or combination of sensors (e.g., Behrangi et al., 2010b among others).

Several previous studies estimated streamflow by using hydrologic models with inputs obtained from remotely sensed data (Hong et al., 2006; Hossain and Anagnostou, 2004; Yilmaz et al., 2005). Schultz (1996) proposed a model to reconstruct monthly runoff estimates based on the geostationary satellite data, and applied a hydrologic model to obtain flood hydrographs. Tsintikidis et al. (1999) evaluated the feasibility of satellite-derived mean areal precipitation estimates for hydrologic application across northern Africa. Using Meteosat inferred precipitation data Grimes and Diop (2003) predicted streamflow estimates and concluded that inclusion of numerical weather model outputs might improve the estimated flood hydrographs. Nijssen and Lettenmaier (2004) investigated the effect of satellite-based precipitation sampling error on estimated hydrological fluxes. Using TMPA data, Su et al., 2008 investigated the feasibility of satellite-based precipitation data for hydrologic predictions. They concluded that satellite estimates have potential for hydrologic forecasting particularly with respect to simulation of seasonal and inter-annual stream-flow variability.

This study aims to assess the use of available near real-time operational precipitation estimation products in streamflow forecasting. The objective of present study is threefold. First, how does precipitation estimation from satellite data using different algorithms and ground multi-sensor product compare at a mid-range size basin. Second, assuming that the hydrologic model generates reliable streamflow estimations, how differences in input precipitation characteristics among different products are reflected in resulting streamflow hydrographs at the time scale (usually 6 h) used by the NWS. The results provide insights on needed accuracy for precipitation input. Finally, evaluation of precipitation inputs with respect to ground-based streamflow observations at watershed outlet can provide a secondary check, particularly for hydrologic applications.

The paper consists of 5 sections. In Section 2, case study specifications including period and area of study, description of hydrologic model, and datasets are provided. Method and model calibration are described in Section 3. Section 4 outlines the results and discussion of findings. Finally, concluding remarks are presented in Section 5.

2. Case study specifications

2.1. Period and area of study

The experiment is performed using 6 years of data (2003–2008) over the Illinois River basin located upstream of USGS gauging station (07195430) south of Siloam Springs, Arkansas (Fig. 1). The watershed (hereafter referred to as the Siloam basin) has been utilized as a test basin for the Distributed Modeling Inter-comparison Project (DMIP). The size of the Siloam basin is typical of the size used as an operational forecasting unit by NWS (Smith et al., 2004) and occupies 1489 km^2. Elevation ranges from 285 m at the outlet to 590 m at the highest and the basin's land cover can be described as uniform with approximately 90% of the basin area being covered by deciduous broadleaf forest with the remainder being mostly woody. The dominant soil types in the basin are silty clay (SIC), silty clay loam (SICL), and silty loam (SIL).The average annual rainfall and runoff of the basin are about 1200 and 300 mm/year, respectively (Smith et al., 2004). Siloam basin is free of major complications such as orographic influences, significant snow accumulation, and stream regulations (Smith et al., 2004).

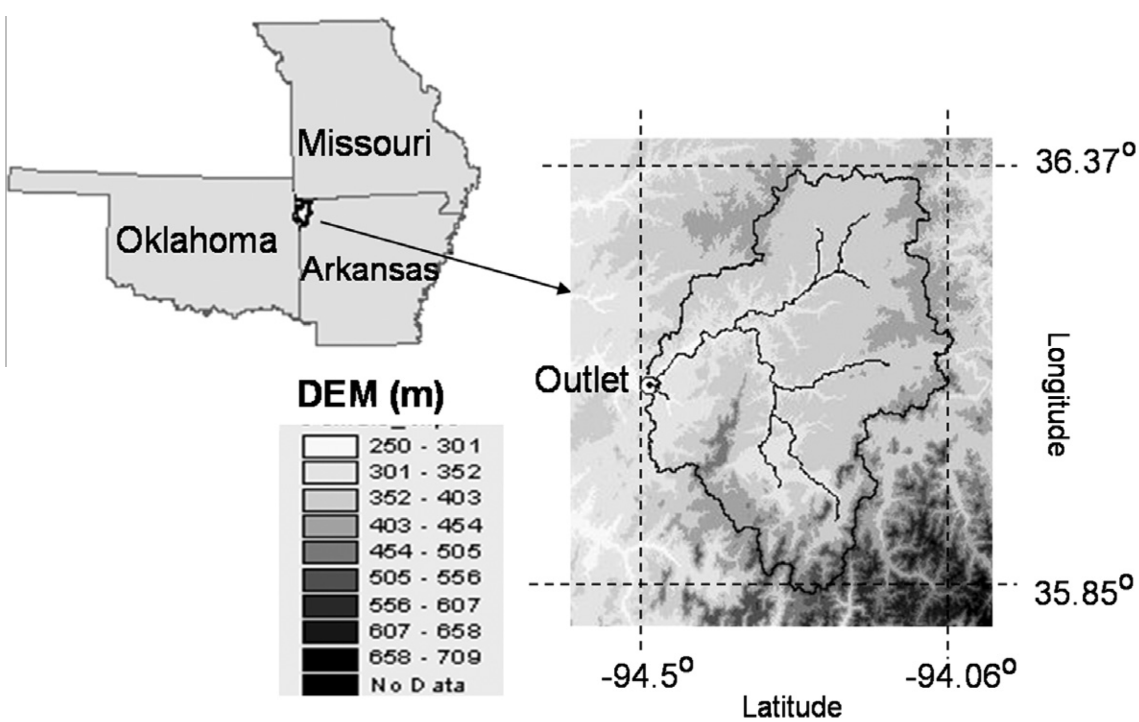

Fig. 1. The study basin with overlain elevation map and streams.