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ScienceDirect

Advances in Space Research 54 (2014) 670–684

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Evaluation of three high-resolution satellite precipitation estimates: Potential for monsoon monitoring over Pakistan

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Received 21 September 2012; received in revised form 14 December 2013; accepted 24 April 2014
Available online 9 May 2014

Abstract

Multi-sensor precipitation datasets including two products from the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) and estimates from Climate Prediction Center Morphing Technique (CMORPH) product were quantitatively evaluated to study the monsoon variability over Pakistan. Several statistical and graphical techniques are applied to illustrate the nonconformity of the three satellite products from the gauge observations. During the monsoon season (JAS), the three satellite precipitation products captures the intense precipitation well, all showing high correlation for high rain rates (>30 mm/day). The spatial and temporal satellite rainfall error variability shows a significant geo-topography dependent distribution, as all the three products overestimate over mountain ranges in the north and coastal region in the south parts of Indus basin. The TMPA-RT product tends to overestimate light rain rates (approximately 100%) and the bias is low for high rain rates (about ±20%). In general, daily comparisons from 2005 to 2010 show the best agreement between the TMPA-V7 research product and gauge observations with correlation coefficient values ranging from moderate (0.4) to high (0.8) over the spatial domain of Pakistan. The seasonal variation of rainfall frequency has large biases (100–140%) over high latitudes (36N) with complex terrain for daily, monsoon, and pre-monsoon comparisons. Relatively low uncertainties and errors (Bias ±25% and MAE 1–10 mm) were associated with the TMPA-RT product during the monsoon-dominated region (32–35N), thus demonstrating their potential use for developing an operational hydrological application of the satellite-based near real-time products in Pakistan for flood monitoring.

Keywords: Satellite precipitation; TRMM; CMORPH; Pakistan monsoon

1. Introduction

In Pakistan major floods are caused by the summer monsoon, which have a long track stretching from the ocean to the convection near the Himalayan foothills. The 2010 floods were the worst natural disasters in the history of Pakistan killing and injuring nearly 5000 people directly, displacing as many as 20 million and inundating 20% of the country. In the scientific community, these events generated an interesting debate on monitoring the extreme amount of monsoon precipitation that led to the flooding (Houze et al., 2011; Wang et al., 2011; Webster et al., 2011). It has been discussed that satellite precipitation and weather forecast

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http://dx.doi.org/10.1016/j.asr.2014.04.017
0273-1177/

models can be used to monitor and predict the development and movement of such convective precipitation systems (Houze et al., 2011; Webster et al., 2011). However, the argument that the 2010 floods could have been predicted is contingent on the accuracy of the precipitation estimates as well as the appropriate use of physically based distributed hydrologic models. An in-depth analysis has not been performed on the accuracy and uncertainties of near real time satellite precipitation estimates to predict and monitor the monsoon flooding in Pakistan. In this context, we attempt to investigate the error characteristics of three widely-used high resolution satellite precipitation products over Pakistan.

The monsoon system in Pakistan occurs mainly due to land-sea temperature differences inciting moisture-laden fluxes from the Bay of Bengal and the Arabian Sea resulting in low pressure and convection. The moist air moves northward, passing through the lower Indus plain and encounters the relief of the Hindu Kush-Himalayas resulting in enhanced orographic effects and high rainfall rates. Pakistan receives precipitation during two seasons: (i) heavy summer rains in the northeastern part from monsoon currents; and (ii) late winter and early spring rains due to disturbances in the mid-latitude westerlies (Khan, 1993; Wang et al., 2011). Accurate precipitation estimates during monsoon season (JAS) is crucial in rainfall runoff modeling for flood monitoring and prediction. Traditional dense rain gauge networks have been used for flood monitoring and other hydrologic studies but their distributions are often sparse in developing countries and data availability over mountainous terrain is inadequate (Astin, 1997; Griffith et al., 1978; Huffman et al., 2001; Maddox et al., 2002; Margulis, 2001; Simpson et al., 1996; Steiner et al., 2003; Vicente et al., 1998). Contrary to ground based measurements, precipitation estimates from space with high-spatiotemporal resolution and large areal coverage can supplement the existing precipitation estimates for hydrological models in regions where conventional in situ precipitation measurements are not readily available (Semire et al., 2012; Su et al., 2008; Yong et al., 2012). Thus, satellite-based precipitation estimates provide a good representation of spatial rainfall patterns and have been complementary to the ground-based rain gauge and radar measurements.

The leap forward in precipitation estimation from space radar began in 1997 with the introduction of the Tropical Rainfall Measuring Mission (TRMM). The Ku-band TRMM Precipitation Radar (PR) is the first operational space borne radar that is exclusively used for precipitation estimation (Kawanishi et al., 2000; Kummerow et al., 1998; Simpson et al., 1996). The TRMM PR has enabled the global mapping of rainfall in the tropics and has contributed to the increased physical understanding of storm cloud characteristics accompanying various forms and levels of rainfall rates. Since then, numerous high resolution, quasi-global and near real-time satellite precipitation algorithms have been developed and satellite precipitation products are readily available for use over the internet (Hong et al., 2007; Huffman et al., 2007; Joyce et al., 2004; Kubota et al., 2007; Sorooshian et al., 2000; Turk and Miller, 2005). Among the fine resolution satellite precipitation data products comprises the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) products (Huffman et al., 2007), the Naval Research Laboratory (NRL) Global statistical precipitation product (Turk and Miller, 2005), the Climate Prediction Center (CPC) morphing algorithm (CMORPH) (Joyce et al., 2004), the Passive Microwave Calibrated Infrared (PMIR) algorithm (Kidd et al., 2003), the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (Sorooshian et al., 2000), and the PERSIANN Cloud Classification System (Hong et al., 2004). The advancement of these estimation methods throughout the last decade is the cornerstone for the future Global Precipitation Measurement (GPM) mission (Smith et al., 2007), that will be launched in June 2014.

The instantaneous availability and wide-ranging coverage of satellites data offers invaluable precipitation estimates especially over complex terrain and ungauged regions that lack adequate surface-based observations. However, these datasets with their global availability and spatiotemporal advantages might come with limitations on the accuracy of quantitative precipitation estimates. Moreover, the use of space and ground based multi-sensor rainfall estimates for flood monitoring and prediction cannot be achieved without understanding the errors characteristics of these estimates. Previous studies assessed the accuracy of various satellite rainfall products by comparing gauge data around the world. At present, the most extensive error studies focus on the continental United States (Ebert et al., 2007; Habib et al., 2009; Hossain and Huffman, 2008). Studies in other continental regions include comparisons over several basins in South Africa by Su et al. (2008), over the La Plata basin in South America, and (Dinku et al., 2011; Li et al., 2009) conducted a comprehensive evaluation of ten different satellite estimates using gauge observations over East Africa. Another detailed comparison of several operational precipitation estimates has been performed by Andermann et al. (2011), Bookhagen and Burbank (2010) and Islam et al. (2010) while (Yin et al., 2008; Yong et al., 2010) looked at complex terrains in Himalaya region in South Asia and Tibetan Plateau in China. More recently, Tian and Peters-Lidard (2010) evaluated an ensemble of six satellite precipitation products including TRMM-V7, TRMM-RT and CMORPH and provided a global view of the error characteristics of these estimates.

Realistic depiction of temporal and spatial rainfall estimates associated with intense rainfall is central for improvement of operational flood monitoring techniques and early warning strategies. Therefore, it is critical to evaluate the performance of satellite precipitation products for any flood modeling for monsoon systems. Several studies performed