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Evaluation of satellite-based precipitation estimation over Iran

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ABSTRACT

Precipitation in semi-arid countries such as Iran is one of the most important elements for all aspects of human life. In areas with sparse ground-based precipitation observation networks, the reliable high spatial and temporal resolution of satellite-based precipitation estimation might be the best source for meteorological and hydrological studies. In the present study, four different satellite rainfall estimates (CMORPH, PERSIANN, adjusted PERSIANN, and TRMM-3B42 V6) are evaluated using a relatively dense Islamic Republic of Iran's Meteorological Organization (IRIMO) rain-gauge network as reference. These evaluations were done at daily and monthly time scales with a spatial resolution of $0.25° \times 0.25°$ latitude/longitude. The topography of Iran is complicated and includes different, very diverse climates. For example, there is an extremely wet (low-elevation) Caspian Sea coastal region in the north, an arid desert in the center, and high mountainous areas in the west and north. Different rainfall regimes vary between these extremes. In order to conduct an objective intercomparison of the various satellite products, the study was designed to minimize the level of uncertainties in the evaluation process. To reduce gauge uncertainties, only the 32 pixels, which include at least five rain gauges, are considered. Evaluation results vary by different areas. The satellite products had a Probability of Detection (POD) greater than 40% in the southern part of the country and the regions of the Zagros Mountains. However, all satellite products exhibited poor performance over the Caspian Sea coastal region, where they underestimated precipitation in this relatively wet and moderate climate region. Seasonal analysis shows that spring precipitations are detected more accurately than winter precipitation, especially for the mountainous areas all over the country. Comparisons of different satellite products show that adj-PERSIANN and TRMM-3B42 V6 have better performance, and CMORPH has poor estimation, especially over the Zagros Mountains. The comparison between PERSIANN and adj-PERSIANN shows that the bias adjustment improved the POD, which is a daily scale statistic.

1. Introduction

In arid and semi-arid regions of the world, estimation of precipitation is not only of particular interest to the decision makers (i.e., water managers, agriculturalists, industrialists, climatologists, etc.), but is also important for human life and activities. Accurate precipitation measurements provide essential detailed information of spatial and temporal variability in precipitation, which is needed for hydrologic and climate models. In areas with complicated topography, precipitation estimation is very difficult to obtain. Rainfall data are usually available from gauges that show point-scale measurements. These instruments have the advantage of being direct in-situ measurements, but their poor areal coverage over many regions, such as oceans, deserts, and less-developed land areas, is a major problem. Weather radar can provide rainfall information at higher spatial and temporal resolutions, but also has a number of shortcomings. Among the limitations, not all regions of the world have radar coverage because it can be expensive and, hence, not many nations have weather radar. In addition, as discussed by Aghakouchak et al. (2011), radar coverage is limited, especially over high terrain and mountainous areas.

In recent years, a number of satellite-based precipitation estimation products with high spatial (quarter latitude/longitude degree) and temporal (hourly) resolution and near-global coverage have been developed. Satellite-based precipitation data are especially useful in semi-arid regions, where ground measurements are very sparse and/or nonexistent. Furthermore, some of the satellite products use ground-based measurements such as gauge data to reduce the bias. Although these products are similar in that most of them combine data from passive microwave and thermal infrared

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sensors, each of them has its unique approaches in cross-calibrating, weighting, and blending the various data sources. Because the satellites measure processes in the atmosphere remotely, their main problem is bias. Biases may be due to a diurnal sampling bias, tuning of the instrument or the precipitation algorithm, or unusual surface or atmospheric properties that the algorithm does not correctly interpret. Therefore, the quality of different satellite products must be evaluated over different climatic and geographic regions of the world. This will be useful to users in selecting a product for their special applications under different circumstances and provides some information about the impact of errors on these applications.

Many studies have been devoted to verification and validation of satellite-based precipitation data with respect to ground-based data in variety of temporal and spatial scales. Some of these studies have been done on a global scale (e.g., Smith et al., 2006; Xie and Arkin, 1996), and some other studies have used monthly Global Precipitation Climatology Project (GPCP) gauge data (Rudolf et al., 1994; Huffman et al., 1997). Some of the studies done in daily scale are carried out for extended areas, such as the continental United States (e.g., Tian et al., 2009; Boushaki et al., 2009), Europe (e.g., Kidd et al., 2012), and Australia (e.g., Ebert et al., 2007). Finally, some studies are done for other limited regions of the world, such as Korea and Colombia (e.g., Dinku et al., 2010; Sohn et al., 2010). Based on our literature review, only a few evaluations of satellite products and rain-gauge data have been reported for the Middle East area. Javanmard et al. (2010) compared the spatial distribution of mean annual rainfall for a 0.25°-gridded synoptic gauge data set (includes 188 gauges) with the Tropical Rainfall Measuring Mission (TRMM) 3B42 V6 over Iran for the period 1998–2006. They concluded that TRMM 3B42 V6 underestimates mean annual rainfall over Iran, especially over the Caspian Sea region. Baranizadeh et al. (2012) evaluated the mean annual and seasonal PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) precipitation product over Iran at 0.25° spatial scale. They found that, compared to the observational gauge network APHRO_ME_V1003R1 (Yatagai et al., 2008), PERSIANN recognizes the precipitation pattern, but underestimates the mean amount of rainfall. It should be mentioned that both of the above studies over Iran were performed for mean amounts (annual and monthly). Therefore, the temporal variability of observations cannot be detected. In this region, the satellite products are most needed because of the sparse rain-gauge network over most parts of the area.

The purpose of the present study is to examine the validity of four satellite products at a relatively higher temporal (daily) resolution. This is done by comparing the products with rain-gauge data collected over a network deployed over Iran. The evaluation time period was 2003–2007. The products evaluated include CMORPH (CPC MORPHing technique, Joyce et al., 2004), PERSIANN (Sorooshian et al., 2000), adj-PERSIANN (bias-adjusted PERSIANN, Behrangi et al., 2011), and TRMM 3B42 V6 (Huffman et al., 2007). It must be mentioned that the adj-PERSIANN and TRMM 3B42 V6 are bias-corrected using the monthly-gauge data set provided by the Global Precipitation Climatology Project (GPCP). The study region and data sets employed are presented in Section 2. The dichotomous analyses applied to evaluate the daily precipitation of satellite estimates are described in Section 3. Section 4 presents the results of precipitation evaluations in different climate regions. Finally, the conclusions are given in Section 5.

2. Study area and data sets

2.1. Study area

Iran is located between 20N–40N latitudes and 44E–63E longitudes and has an area of about 1,640,000 km^2. Although the area is a plateau, it has different elevations. For example, the elevation of the coast of the Caspian Sea is about 16 m below the Mean Sea Surface Level, and the surrounding mountains are more than 5000 m above the Mean Sea Surface Level. Despite the fact that Iran is located in the subtropical high-pressure belt of the Earth, it includes different climates.

Based on the De Martonne (1948) climate classification index, Iran is categorized as generally being arid and semi-arid. About 65% of the country has an arid climate, and about 20% has semi-arid climate, of which half is suitable for farming. Only 10% of the country has a humid climate (Khalili et al., 1991). Two major mountain ranges—the Alborz along the north and the Zagros in the west—play fundamental roles in determining the amount and distribution of precipitation over Iran. The most humid part of the country, where annual rainfall usually exceeds 1500 mm, is located in the northern slopes of the Alborz Mountains to the coastal areas of the Caspian Sea. The central, southern, and eastern parts of Iran are generally arid to extremely arid and include two great deserts: the Lut Desert and the Kavir Desert (Fig. 1). This complex topography presents challenges in measuring and estimating the amount and spatial distribution of precipitation.

Precipitation in Iran originates mostly from migrating Mediterranean lows from the west and Sudan lows from the southwest. The interactions between these synoptic systems and the main topographic features result in precipitation that is highly variable in space and time. Thus, in this region, a significant part of precipitation variability occurs in small scales, and spatial coherence is small.

In most parts of Iran (except the coastal area of the Caspian Sea), the main precipitation occurs during winter (December–February) and spring (March–May), when the area is affected by polar fronts and synoptic systems.

2.2. Data sets

2.2.1. Satellite data

Four high-resolution satellite-based precipitation data sets are used in this study. These data sets are denoted as CMORPH (Janowiak et al., 2005; Joyce et al., 2004), PERSIANN (Hsu et al., 1997; Sorooshian et al., 2000), adj-PERSIANN, and TRMM 3B42 V6 (Huffman et al., 2007, 2010).

CMORPH (Joyce et al., 2004) uses IR imagery to follow the motion of precipitation patterns and interpolates between microwave scans. PERSIANN (Sorooshian et al., 2000) uses an Artificial Neural Network (ANN) system and IR imagery geostationary satellites to estimate precipitation. Its parameters are adjusted by Passive MicroWave (PMW)-based estimates, including measurements from the Defense Meteorological Satellite Program Special Sensor Microwave Imager/Sounder, the Polar Orbiting Environmental Satellite Microwave Humidity Sounder, and the Aqua Advanced Scanning Microwave Radiometer E (AMSR-E) (CPC, 2008).

The 3B42 version 6 of TRMM is the multi-satellite precipitation analysis product, which is provided by the National Aeronautics and Space Administration (NASA). This product uses the most PMW scans from low-orbiting satellites, including the TRMM Microwave Imager (TMI), the Special Sensor Microwave Imager (SSM/I), the advanced Microwave Sounding Unit-B, and the most recent Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) of the National Oceanic and Atmospheric Administration (NOAA) satellite series.

CMORPH and PERSIANN are near real-time products, but the adj-PERSIANN and 3B42 V6 also use GPCP products for bias correction (Adler et al., 2003; Huffman et al., 2007; Huffman et al., 1997). The GPCP data are at 2.5° monthly scale. At first the 3-h and 0.25° PERSIANN data aggregate to 2.5° monthly scale. The ratio of GPCP and PERSIANN data is calculated. Then this ratio is used to