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Evaluation of high-resolution satellite precipitation estimates over southern South America using a dense rain gauge network

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ABSTRACT

Six different satellite rainfall estimates are evaluated for a 24-hour accumulation period at 12 UTC with a 0.25 degree resolution. The rain gauge data are obtained from a dense inter-institutional station network for December 1, 2008 to November 30, 2010 over South America. The evaluated satellite rainfall products are the Tropical Rainfall Measuring Mission 3B42 V6, V7 and RT, the NOAA/Climate Prediction Center Morphing technique (CMORPH), Hydroestimator (HYDRO) and the Combined Scheme algorithm (CoSch). The validation and inter-comparison of these products are focused on southern South America. The performance improves in the "blended" estimates by including microwave observations and surface observations in the adjustments, i.e., 3B42 V6, V7 and CoSch; however, large overestimations are detectable in CMORPH, principally for extreme values over plains areas. The estimates based on parameters associated with infrared images only (HYDRO) underestimate precipitation south of 20° S and tend to overestimate the warm precipitation to the north. The inclusion of observed precipitation data is convenient from monthly (3B42 V7 and V6) to daily scales (CoSch) and improves the estimates. The estimates that include microwave observations show a strong tendency to overestimate extreme values of precipitation over 70 mm. This effect is strongly evident in northern and central Argentina and southern Brazil. A deeper assessment is necessary, particularly over the Central Andes, where effects of topography principally associated with solid precipitation correspond to the persistence of majorly overestimated precipitation.

1. Introduction

Precipitation plays a fundamental role in regulating the climate system. The knowledge of the areas where precipitation occurs enables management of water resources, the prevention of natural disasters and, consequently, better developed human activities. For this reason, accurate precipitation measurements provide important information for decision making by multiple users (Kucera et al., 2013).

Precipitation measurement is a major challenge due to the high spatial and temporal variability. The knowledge of the structure of precipitation requires observing networks with very high spatial and temporal resolutions, which are difficult to implement in areas covered by deserts, mountains, and oceans and in large areas with low population densities. This issue also presents a challenge for developing countries in South America where the maintenance of these networks is extremely expensive.

Rain gauges are the principal source of direct precipitation measurements in South America and are necessary for calibrating and validating precipitation estimates obtained from indirect measurements – radar or satellite – and numerical models. However, observations over South America are insufficient and unevenly distributed. Their temporal resolution is low, i.e., the accumulation periods are 24 hours or, occasionally, 6 hours.

The introduction of meteorological satellites in the 1970s made it possible to perform hemispheric observations of cloudiness. This encouraged scientific research on multiple satellite-based remote sensing technique of meteorological variables. However, estimates of precipitation based on radiometric observations are an ongoing challenge. The first techniques used visible (VI) and infrared (IR) wavelength data to infer precipitation based on cloud reflectivity and cloud top temperature, respectively (Arkin and Meisner, 1987; Scofield and Kuligowski, 2003 and all of the papers cited therein). Non-precipitating clouds with cold tops can be easily misinterpreted as highly precipitating systems if IR data are used. However,

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precipitation is not necessarily associated with cold clouds; in some cases, precipitation develops from warm and relatively low clouds as observed in the development stage of deep convection and in tropical areas (Houze, 1994).

Introducing passive microwave (PM) measurements on satellite platforms made it possible to develop algorithms that explain the internal structure of cloudiness based on the analysis of the attenuation of the PM field generated by cloudiness. These algorithms generally provide more accurate estimates of instantaneous precipitation than the algorithms based on VI or IR data on the global scale (Ebert et al., 1996; Smith et al., 1998; Ebert et al., 2007). However, the advantage of using IR equipment onboard geostationary satellites to generate precipitation estimates is the finer spatial and temporal resolutions and nearly global coverage compared to the PM observations of polar-orbiting satellites where only one image is retrieved every three hours from a large range of orbits of different satellites.

Precipitation products derived from combining IR observations (higher spatial and temporal resolution) with PM observations (high quality), known as "blended techniques," perform better in the global context (Ebert et al., 2007). A large number of IR-PM algorithms was developed using different strategies to optimally include both estimates (Huffman et al., 2001; Xu et al., 1999; Miller et al., 2001; Kidd et al., 2003; Sorooshian et al., 2000; Kuligowski, 2002; Joyce et al., 2004) and to consider surface information in the calibration procedure (Huffman et al., 2007; Vila et al., 2009; Kidd and Levizzani, 2011). An updated list of the available estimations is presented in Table 2 in Tapiador et al. (2012).

The performances of products over South America have recently been assessed and present several challenges. South America, a region that experiences some of the most intense mesoscale convective systems (MCSs) on Earth (Zipser et al., 2006), has areas of complex topography (i.e., the Andes cordillera), snow-covered surfaces, and heavy precipitation from warm clouds in areas such as northeastern Brazil and the Amazon (Liu and Zipser, 2009). Su et al. (2008) validated the daily TRMM Multi-satellite Precipitation Analysis (3B42; Huffman et al., 2007) version 6 for La Plata Basin and found that it performed well on the monthly scale and that performance decreased on the daily scale, mainly at the highest precipitation thresholds. In addition, results of inputting 3B42 V6 data into hydrological models show the ability of the method to capture flood-related events and the seasonal and interannual variability of river streamflow; thus, it is a potential tool for hydrological forecasting in the region. When verifying this method on the daily scale, Ruiz (2009) found that although the CPC MORPHing Technique (CMORPH; Joyce et al., 2004) captures precipitation events adequately and despite the good relationship in the relative intensity of each of those events, the technique tends to overestimate mean precipitation over eastern Argentina, Uruguay and in the area close to the border of Paraguay in Brazil. Vila et al. (2009) and Rozante et al. (2010) assessed the performance of the Combined Scheme (CoSch; Vila et al., 2009) for summer and winter estimates over South America; De Vera and Terra (2012) applied a similar methodology for Central Uruguay. The results showed that over areas with a high density of rain gauge observations, this technique is equivalent to averaging rain gauge data over the available grid points, while in areas where the observation network is coarser, the results are better and indicate the potential of this product. Dinku et al. (2010a, 2010b) validated seven satellite precipitation estimates on daily and 10-day time scales in an area of complex topography in Colombia. The best results were obtained for the plains area in eastern Colombia, and the product performance was markedly worse on the Pacific Coast. In this case, CMORPH performed well compared with the other analyzed products.

The previously described examples show that progress is needed to determine the quality of these products for South America and to provide an adequate evaluation for different users. The studies mentioned explore individual estimates for an area of interest, but a thorough study assessing the performance of multiple estimates using high spatial density rain gauge networks is lacking over these areas. This study focuses on assessing the performance of satellite rainfall estimates available over the area, particularly southern South America, by validating the data using available 24-hour information over a dense rain gauge network. The data and methodology are described in Section 2. The results of the product intercomparison are presented in Section 3. Lastly, the discussion and conclusions are provided in Section 4.

2. Data and methodology

2.1. Rain gauge information

The present study was conducted over a period of 2 years, from December 1, 2008 to November 30, 2010. The period was selected based on the availability of rain gauge information. An extensive rain gauge network that covers Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay was used in this study. Fig. 1 shows the number of rain gauges available in 0.25° latitude by 0.25° longitude boxes. A total of 5414 stations are available during the selected period. Data were interpolated to a 0.25° resolution grid by averaging the available data over each 0.25° × 0.25° area and assigning the mean value to the center of the grid. This methodology had been applied by Liebmann and Allured (2005). The methods used to grid the observations for matching rain gauge and satellite data have several problems, and many studies show that there is no single algorithm outperformance in all conditions (Ebert et al., 2007; Porcu et al., 2014). In areas with not equally distributed and sparse rain gauges, the different rain gauge analysis will provide similar results. In this case, data were interpolated to a 0.25° resolution grid by averaging the available data over each 0.25° × 0.25° area and assigning the mean value to the center of the grid. This methodology had been applied by Liebmann and Allured (2005), who obtained good results for the region. In the same way, DeMaria et al. (2011) indicated that the impact of the interpolation method does not have an effect on the results of a similar study over southeastern South America. The available network is unevenly distributed over 3881 grid points. To achieve the most representative and consistent data for verification, only grid points that have information for at least 70% of the days were taken into account.

It is important to emphasize that the observation network used in this study is composed of numerous networks that are not available in real time to any of the institutions in charge of adjusting precipitation estimates; thus, this database is the subject of a major assessment. In turn, for a correct validation, data retrieved from the Global Telecommunication System were excluded from the data set. This study considers 24-hour accumulated precipitation at 12 UTC.

Data were provided by the following institutions: Dirección General de Aguas — Chile, Servicio Meteorológico Nacional — Argentina; Administración Provincial del Agua — Chaco, Argentina; Subsecretaría de Recursos Hídricos de la Nación — Argentina; Universidad de La Punta — San Luis, Argentina; Autoridad Interjurisdiccional del Agua — Neuquén, Argentina; Instituto Nacional de Tecnología Agropecuaria — Argentina; Bolsa de Cereales — Argentina; Dirección Nacional de Meteorología — Uruguay; Dirección de Meteorología e Hidrología — Dirección Nacional de Aeronáutica Civil — Paraguay; Comisión Técnica Mixta Salto Grande; Centro de Previsão de Tempo e Estudos Climáticos — Brazil; National Oceanic and Atmospheric Administration — USA.

At the database development stage, a thorough quality control was performed on the observations; it mainly consisted of analyses of extremes, contiguous values and days without precipitation.