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Assessment of satellite precipitation estimates over the slopes of the subtropical Andes

María Paula Hobouchian [a,*], Paola Salio [b,c,d], Yanina García Skabar [a,e,d], Daniel Vila [f], Rene Garreaud [g]

[a] Departamento de Investigación y Desarrollo, Servicio Meteorológico Nacional, Argentina
[b] Centro de Investigaciones del Mar y la Atmósfera, CONICET UBA, Argentina
[c] Departamento de Ciencias de la Atmósfera y los Océanos, FCEyN, Universidad de Buenos Aires, Argentina
[d] UMI-Instituto Franco Argentino sobre Estudios del Clima y sus Impactos, Argentina
[e] CONICET, Argentina
[f] División de Satélites y Sistemas Ambientales, CPTEC, Brazil
[g] Departamento de Geofísica, Universidad de Chile, Chile

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ABSTRACT

A validation of four satellite daily precipitation estimates at a spatial resolution of 0.25° is performed over the subtropical Andes, an area of highly complex topography: The Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA, 3B42 V7 and RT), the Climate Prediction Center Morphing technique (CMORPH) and the Hydro-Estimator (HYDRO). Remote mountainous regions represent a major challenge for these satellite data products and for studies examining their quality with surface data.

For the assessment of the satellite products, a period of seven years from January 1st 2004 to December 31st 2010 was considered. Different statistics were analyzed considering their variability in the study area and identifying their main differences between the warm and cold seasons. The results indicate a decrease in winter errors which coincides with the wet season over the windward side of the Andes. Also, a significant underestimation of precipitation is observed for all estimates throughout the period analyzed.

The analysis with respect to terrain height shows a greater dependence of errors with topography for all the algorithms that combine infrared and passive microwave data, HYDRO providing the most stable result. The main limitations of the estimates associated with the type of precipitating event and their location relative to the orography are assessed.

Finally, the analysis of two intense precipitation events is presented and allows the assessment of the latest advances in satellite derived estimates with the launch of the Global Precipitation Measurement.

1. Introduction

Precipitation has a fundamental role in regulating the hydrological cycle, as well as different socio-economic activities. For this reason, accurate precipitation measurements provide important information for decision-making (Kucera et al., 2013). In South America, the available rainfall network has significant limitations in its infrastructure, maintenance, density and frequency of observations.

Satellite Precipitation estimates continue to be an ongoing challenge today. Passive microwave (PM) measurements are capable of inferring the internal structure of clouds generally providing higher quality precipitation estimates than the algorithms based on visible (VI) or infrared (IR) data on the global scale (Ebert et al., 2007). However, the advantage of using IR precipitation estimates from geostationary satellites is that they have a higher temporal resolution, and a nearly global coverage. Precipitation products derived from combining IR observations with PM observations, known as "blended techniques," perform better in the global context (Ebert et al., 2007). Some algorithms further consider active microwave data and surface information in the calibration procedure (Huffman et al., 2007; Vila et al., 2009; Kidd and Levizzani, 2011). An updated list of the available precipitation estimations is presented in Table 2 in Tapiador et al. (2012).

The most recognized precipitation estimates include: the Climate Prediction Center Morphing Method (CMORPH; Joyce et al., 2004); the Multi-satellite TRMM Precipitation Analysis (TMPA, known as 3B42; Huffman et al., 2007); the Global Satellite Mapping of Precipitation (GSMaP; Okamoto et al., 2005); the Hydro-Estimator (HYDRO, Scofield and Kuligowski, 2003); the Remotely Sensed Precipitation Estimation from Information using Artificial Neural Networks (PERSIANN; Sorooshian et al., 2000); local developments in South America such as the Combined Scheme (CoSch; Vila et al., 2009); and the recent developments exploiting the new Global Precipitation Measurement (GPM)

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[*] Corresponding author at: Departamento de Investigación y Desarrollo, Servicio Meteorológico Nacional, Av. Cnel. M. Dorrego 4019, C1425GBE Buenos Aires, Argentina.
E-mail address: phobouchian@smn.gov.ar (M.P. Hobouchian).

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mission, namely the Integrated Multi-Satellite Retrievals for the Global Precipitation Measurement mission (IMERG, Huffman et al., 2015).

Globally, the performance of retrieval algorithms is highly dependent on surface conditions, latitude and season. 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 range), snow-covered surfaces, and heavy precipitation from warm clouds in areas such as northeastern Brazil and the Amazon (Liu and Zipser, 2009).

Salio et al. (2015) advanced on determining the quality of satellite rainfall estimates over South America by evaluating them over a dense rain gauge network providing 24-hour accumulation information. Precipitation estimates that included microwave data showed a remarkable performance, which was shown to improve further by including surface observations. In the south of South America, CoSch departed favorably from the rest of the estimates, and 3B42 V7 improved over 3B42 V6, 3B42 RT and CMORPH showed a greater degree of overestimation for the most intense precipitation events, and HYDRO showed an underestimation in all seasons and in most of the thresholds. The errors were minimal in the northeastern region of Argentina and in southeastern Brazil, mainly affected by convective precipitation. The greatest difficulties were shown to arise in mountainous areas and in non-convective precipitation events. Particularly, over the subtropical Andes, the persistence of underestimated precipitation estimates was observed.

Complex topography presents additional challenges for satellite rainfall retrievals. The main problem is the lack of rain gauge observations over mountainous regions. In recent years, scientific research has focused on evaluating the performance of satellite precipitation estimates in different mountainous regions (Dinku et al., 2008, 2010, 2011, Hirpa et al., 2010; Habib et al., 2012, Gao and Liu, 2012, Blacutt et al., 2015, Salio et al., 2015).

Dinku et al. (2010) validated seven satellite precipitation estimates on a daily time scale for an area of complex topography in Colombia. The products showed overestimations in both rainfall amount and occurrence over the relatively dry northern region and significant underestimations over the mountainous regions and the Pacific coast. The best performance was achieved over the eastern plains of Colombia, and the performance of the products was relatively poor over the Pacific coast. The overestimation over the northern region has been associated to possible subcloud evaporation, and the underestimations observed over the mountainous and coastal regions may be associated with warm-rain processes. Similar results were found over the highlands of Ethiopia in a study that focused on the mountainous and arid regions of east Africa (Dinku et al., 2011; Dinku et al., 2008). The daily validation over complex terrain in Africa (Dinku et al., 2008) showed that CMORPH and 3B42 RT perform reasonably well in detecting the occurrence of rainfall. However, their performance is poor in estimating the amount of rainfall in each pixel. In this line, Hirpa et al. (2010) made an Evaluation of High-Resolution Satellite Precipitation Products over Very Complex Terrain in Ethiopia. 3B42 RT and CMORPH showed similar rainfall results but showed an elevation-dependent trend. IR based rainfall algorithms have also shown major limitations in reproducing rainfall fields in mountainous regions of East Africa, considerably underestimating rainfall in high-elevation areas.

Gao and Liu (2012) carried out a daily evaluation of the performance of CMORPH and 3B42 V6 on the Tibetan Plateau, and showed the 3B42 V6 outperformed CMORPH due to its monthly surface data adjustment. Products were shown to overestimate weak precipitation and underestimate moderate to strong rainfall over the threshold of 10 mm per day. Gao and Liu (2012) further noted that products that depend heavily on microwave data produce better precipitation estimates in complex terrain regions than PERSIANN that relies primarily on IR data. The results were further analyzed by differentiating between dry and wet regions by taking into account land elevation. PERSIANN showed a marked difference in the underestimation of precipitation events at lower altitudes and the overestimation of precipitation events at higher elevations. The products derived from the added combination of PM data do not show such dependence in terrain elevation, which also show better results in the statistical data of the wetlands of the Tibetan plateau compared to the more arid regions.

A comparison for the 3B42 V7 and CoSch datasets was performed by Blacutt et al. (2015) for the rainy and dry seasons over Bolivia. These products exhibit underestimated heavy rainfall (>50 mm day^{-1}) on both rainy and dry seasons and overall, the outcome of combining 3B42 V7 with the surface observations is shown to be positive over this complex terrain region.

The main limitations of satellite precipitation estimation in mountainous regions arise from the underestimation of precipitation from warm clouds, the underestimation of very heavy rainfall without an internal structure of ice crystals, the overestimation on snow-covered surfaces, and the overestimation generated by evaporation of rainfall below the cloud base before reaching the surface, the latter difficulty increasing in the more arid regions. Warm clouds lack sufficient vertical growth to reach low cloud top temperatures that are used as thresholds in IR retrieval algorithms. Heavy rainfall lacking a vertical structure of densely populated frozen hydrometeors fails to produce the scattering signals used in microwave retrieval algorithms while snow-covered regions can be mistaken for precipitation in microwave retrieval algorithms.

The Subtropical Andes (30–40°S) divide the areas of central Chile and west-central Argentina. It is of great interest to advance in the understanding of precipitation events that develop in this remote region characterized by a lack of observations. Satellite derived precipitation data is thus a crucial tool for hydrological applications, water management and decision-making in the region.

The present study extends the comprehensive evaluation of the performance of satellite precipitation estimates over southern South America conducted by Salio et al. (2015) over a longer period of time (to cover 7 years) in order to focus on mountainous regions, specifically over the subtropical Andes. This study proposes a systematic evaluation of 24 h precipitation accumulation periods in relation to terrain complexity and the differences between the warm and cold seasons.

This paper is organized as follows: Section 2 presents the validation region and the rain gauge data used. Section 3 presents the satellite precipitation estimates used. The methodology is detailed in Section 4, and results of the product intercomparison are presented in Sections 5 and 6. Finally, the discussion and conclusions are presented in Section 7.

2. Study region and rain gauge data

The present study was conducted over a common period of 7 years, from January 1st, 2004 to December 31st, 2010. Fig. 1 shows the region analyzed denoted by a box which covers the subtropical Andes range in Argentina and Chile, and the complex terrain at the spatial resolution of the satellite estimates. Fig. 2 shows the percentage of the days with data and the number of rain gauges available in each 0.25° latitude by 0.25° longitude area. 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 for the selected period. The available network is unevenly distributed over 230 grid points.

This study considers 24-hour accumulated precipitation at 12 UTC. Precipitation measurements on the Argentinean side of the Andes are determined from heated rain gauges during the winter to measure snowfall inside mountain valleys and regular rain gauges at low elevation areas. On the Chilean side of the Andes, standard rain gauges (mostly Hellmann type or similar) with no heating are available. Although the non-heated instrument may have some problems during snow storms, nearly all stations in Chile are located below 2000 m above sea level and they hardly receive solid precipitation.

The methods used to grid the observations to match rain gauge and satellite data have several problems, and many studies show that there is no single algorithm that outperforms in all conditions. In areas with