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# Evaluation of the TMPA-3B42 precipitation product using a high-density rain gauge network over complex terrain in northeastern Iberia

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The performance of the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA)-3B42 version 7 product is assessed over north-eastern Iberia, a region with considerable topographical gradients and complexity. Precipitation characteristics from a dense network of 656 rain gauges, spanning the period from 1998 to 2009, are used to evaluate TMPA-3B42 estimates on a daily scale. A set of accuracy estimators, including the relative bias, mean absolute error (MAE), root mean square error (RMSE) and Spearman coefficient was used to evaluate the results. The assessment indicates that TMPA-3B42 product is capable of describing the seasonal characteristics of the observed precipitation over most of the study domain. In particular, TMPA-3B42 precipitation agrees well with in situ measurements, with MAE less than 2.5 mm.day$^{-1}$, RMSE of 6.4 mm.day$^{-1}$ and Spearman correlation coefficients generally above 0.6. TMPA-3B42 provides improved accuracies in winter and summer, whereas it performs much worse in spring and autumn. Spatially, the retrieval errors show a consistent trend, with a general overestimation in regions of low altitude and underestimation in regions of heterogeneous terrain. TMPA-3B42 generally performs well over inland areas, while showing less skill in the coastal regions. A set of skill metrics, including a false alarm ratio [FAR], frequency bias index [FBI], the probability of detection [POD] and threat score [TS], is also used to evaluate TMPA performance under different precipitation thresholds (1, 5, 10, 25 and 50 mm.day$^{-1}$). The results suggest that TMPA-3B42 retrievals perform well in specifying moderate rain events (5–25 mm.day$^{-1}$), but show noticeably less skill in producing both light (<1 mm.day$^{-1}$) and heavy rainfall thresholds (more than 50 mm.day$^{-1}$). Given the complexity of the terrain and the associated high spatial variability of precipitation in north-eastern Iberia, the results reveal that TMPA-3B42 data provide an informative addition to the spatial and temporal coverage of rain gauges in the domain, offering insights into characteristics of average precipitation and their spatial patterns. However, the satellite-based precipitation data should be used cautiously for monitoring extreme precipitation events, particularly over complex terrain. An improvement in precipitation algorithms is still needed to more accurately reproduce high precipitation events in areas of heterogeneous topography over this region.



## 1. Introduction

Accurate measurement of precipitation over both space and time is crucial to better characterize and understand water and energy cycles (Lorenz and Kunstmann, 2012), to enhance understanding of climate regimes and their associated dynamics (Scarsoglio et al., 2013) and to improve hydro-meteorological forecasting (e.g., drought and flood) (Su et al., 2008). Though providing the principal source to describe precipitation characteristics, the performance of ground-based precipitation estimates is very sensitive to the spatial density of rain gauges, terrain complexity, the quality of data and the completeness and length of meteorological records (Groisman and Legates, 1994). Apart from providing basic meteorological forcing for diverse hydrological applications, assessing the potential impacts of global warming on the regional scale requires accurate data at fine spatial and temporal resolutions. However, this kind of assessment is challenging in areas of heterogeneous terrain, not only due to the high spatial and temporal variability of precipitation in these regions, but also as a consequence of the lack of a spatially dense network of rain gauges that can reliably capture the impacts of topographical gradients on local and regional climate (López-Moreno et al., 2008; Evans and McCabe, 2013).

Over the last three decades, many attempts have been made to improve precipitation retrievals from satellites through merging various data sources, such as radar, microwave and thermal infrared remote sensing, allowing for a significant improvement in the accuracy,

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consistency and coverage of the retrievals (Behrangi et al., 2011). Currently, many sources of conventional remotely sensed precipitation estimates are available at high spatial (0.25° or finer) and temporal (3 hourly or shorter) resolutions, including (among others): the Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) (Sorooshian et al., 2000), the Climate Prediction Center (CPC) Morphing algorithm (CMORPH) (Joyce et al., 2004), the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) (Huffman et al., 2007), Multisensor Precipitation Estimation (MPE) (Seo et al., 1999) and NASA Global Precipitation Measurement (GPM) (Battaglia et al., 2015). However, given that satellite-based estimates rely primarily on the interpretation of emitted or scattered radiation received by the satellite instruments, these estimates are accompanied by a host of uncertainties. Such uncertainties can originate from different sources, including sampling frequency, attenuation correction, attenuation–reflectivity relationships, partial beam filling and surface clutter rejection (Ebert et al., 2007). Levizzani et al. (2007) provide a detailed review of the errors associated with satellite precipitation retrievals.

Few studies have tested the performance of space-based precipitation products over regions with complex topography, especially in mid-latitude mountain systems (e.g., Shrestha et al., 2012). Presumably, this shortcoming is associated with the paucity of rain gauges over space and time, the poor siting of the instrumentation and the high cost of equipment installation and maintenance, especially with the vast unpopulated areas across these regions. In mountainous areas, the complex orography induces rapid changes in climatic parameters, particularly temperature and precipitation, over very short distances (Gobieta et al., 2014). These changes are also associated with strong variations in other environmental processes (e.g., soil types, land cover and land use). The interactions between the mountains and the general circulation of the atmosphere add more complexity to climate conditions in the mountainous regions, particularly with the competing interactions of different synoptic regimes (e.g., maritime and continental configurations). In addition, mountainous regions are often subjected to climate extremes (e.g., floods, drought, windstorms, … etc.), which are associated with profound social and economic impacts on local communities.

The Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) products, which are available since early 1998, are one of the major sources of satellite retrieved precipitation, providing spatially homogeneous observations with good spatial coverage and few missing values (Huffman et al., 2007). Moreover, although TMPA radar data, which is one of the important sources of the data for the multi-satellite algorithm, is unavailable at the extra-tropical regions, TMPA retrievals incorporate multiple-sensor and multi-satellite data, in addition to in-situ based observations, allowing for accurate and reliable precipitation estimates (Huffman and Bolvin, 2012). In this work, we focus on assessing the performance of the recent version of the TMPA research monitoring product (3B42 V7) in a complex terrain region over northeastern Iberia. From many perspectives, this domain constitutes an ambitious setting to assess the capabilities of TMPA at high spatial detail. First, the network of precipitation observatories in the region is one of the densest regional precipitation networks in the Iberian Peninsula, providing a representative areal means and allowing for a detailed and conventional assessment of precipitation products. Second, the region is characterized by complex terrain that exerts strong precipitation gradients, associated with different underlying microphysical and dynamical processes of climate. In this regard, numerous studies have already identified a wide range of large-scale drivers and rainfall phenomena associated with the high spatial–temporal variations of precipitation in the region, including orographic rain, convective processes and thunderstorm activities (e.g., Ramis et al., 1997; Beguería et al., 2009; López-Moreno et al., 2010). Finally, the study domain shows strong topographic gradients and large topographic diversity, containing mountains of more than 3400 m, four different mountain chains, semiarid depressions as a consequence of topographic barriers and the influence of two seas: the Atlantic Ocean and the Mediterranean Sea (El Kenawy et al., 2013). In areas of complex topography like northeast Iberia, strong scattering signals are likely to occur, whose effects can differ markedly depending on exposure and altitude, especially over cold land surfaces and snow-covered areas. However, while a number of studies have already assessed the uncertainty associated with TMPA product across varying regions worldwide (e.g., Adeyewa and Nakamura, 2003; Feidas et al., 2009; Vila et al., 2009; Prakash and Gairola, 2014), relatively little work has been done to assess the accuracy of TMPA products or to use these data for meteorological studies over the Iberian Peninsula. In their assessment of the accuracy of satellite precipitation products over the Unites States, Europe and Australia, Ebert et al. (2007) found that the performance of a single product can significantly differ from one region to another. Therefore, evaluating the skill of TMPA products on a regional basis over the Iberian Peninsula is required to ensure confidence in the product estimates.

The major objective of this work is to assess the ability of TMPA-3B42 (V7) precipitation product to accurately replicate precipitation variability and extremes using a dense and high-quality rain gauge network in northeastern Iberia. Considering the high spatial and temporal variability of precipitation in the region, such a comparison is useful not only for providing a better indication on the accuracy of TMPA-3B42, but also for improving their retrievals on this regional scale, offering a basis for better assessment of precipitation and related hydrological impacts across the region. Furthermore, given that assessing the performance of satellite-based precipitation products is required over diverse regions and seasons to define and improve the quality of measurements and to accurately reveal climatological features, this study could contribute to developing a consistent and robust global product.

## 2. Data and methods

### 2.1. Study area

The study domain is located in northeast Iberia between latitudes 39°43′N and 43°29′N and longitudes 05°01′W and 03°17′E. It covers an area of approximately 186,000 km$^2$, which accounts for roughly 32% of the total area of the Iberian Peninsula (Fig. 1). The topography varies from mountains with a maximum elevation of 3400 m above mean sea level (the Pyrenees), to the alluvial plains in the lower reaches of the Ebro basin, which is the largest hydrological division in the peninsula. The study domain encompasses a large variety of climate zones, including semi-arid, Mediterranean, oceanic, continental and mountainous. These climate zone variations were derived mostly from weather system interactions associated with atmospheric circulation, latitude, altitude, topography, vegetation cover and land–sea interactions. From a global perspective, the region encompasses a climatic gradient between mid-latitude and subtropical regimes. It is also situated in a transitional zone where the Mediterranean configurations and the Atlantic influences interact with each other. The mean annual rainfall in the region typically exceeds 650 mm (Capel-Molina, 2000), with maximum precipitation recorded during the period from October to May, which provides about 60%–80% of the annual precipitation, with two main peaks in October and April. Seasonally, summer and winter contribute to nearly 16.9% and 23.1% of the annually averaged accumulated precipitation, respectively, compared with 27.9% in spring and 32.1% in autumn. The Pyrenees and the most elevated sites in other mountainous regions are covered with snow during winter and early spring. A detailed summary of the climate of the study domain can be found in Font-Tullot (1983) and Capel-Molina (2000).

### 2.2. Data sets

#### 2.2.1. TMPA data set

The TRMM was launched in 1997 as a collaborative project between the National Aeronautics and Space Administration (NASA) and the