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Conference Proceedings Paper

Evaluating extreme precipitation events on the Iberian Peninsula using TRMM data

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Published: 10/11/2017
Academic Editor: Ricardo Trigo

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Abstract: An assessment of extreme precipitation events (EPEs) is performed using the high-resolution (0.2°) gridded daily precipitation database available for the IP, the accumulated precipitation from ERA-Interim reanalysis by EMCWF at 6-hour intervals, and the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) dataset, based on multisatellite estimates of precipitation and gauges measurements, for the common period since 1998. This study presents an analysis and validation of the extreme precipitation characteristics over IP, using both satellite and ground observations. Results show that there is a good general agreement between total precipitation analysis from observational gridded and TRMM datasets, both temporal and spatially, although TRMM TMPA results are underestimated when compared to observations and ERA Interim data.

Keywords: extreme precipitation; extreme events; TRMM TMPA products; natural hazards; Iberian Peninsula

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1. Introduction

Heavy precipitation events have recently gained great importance to the general public and policy makers, partly as a consequence of high impact events that affected western Europe being responsible for human fatalities and extensive socioeconomic costs. Recently several studies have analysed the occurrence and mechanisms responsible for EPEs over the Iberian Peninsula (IP; e.g. [1-3]) and, based on gridded precipitation datasets, ranked EPEs over the IP according to different time scales [4,5]. Regional quantitative precipitation estimations are thus vital for understanding hydrometeorological cycles, EPEs frequency and intensity, as well as effectively detecting and managing associated natural disasters. However, obtaining accurate quantitative precipitation estimations is still a challenge and advances in remote sensing may represent an important tool for spatial and temporal variability evaluation and mapping of EPEs.

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission of National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), launched in 1997. TRMM is a research satellite designed to improve understanding of the distribution and variability of precipitation within the tropics. It fills a gap in observations and it is revolutionary in its ability to observe storms within the tropics. Following the success of the TRMM, the Global

Precipitation Measurement (GPM) mission comprises a consortium of international space agencies, including the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). It is an international network of satellites that provide the next-generation of global observations of rain and snow. It is worth noting that the GPM mission expands the observational capabilities beyond the tropics, namely for the study of extratropical storms.

As the most recent TRMM products available should evolve into products for the GPM mission, the objectives of this paper are to assess the ability and accuracy of TRMM TMPA products for studying EPEs on an extratropical area such as the IP; and therefore contribute to further improve future precipitation retrieval algorithms. Relative to TRMM, it is expected that the enhanced measurement and sampling capabilities of GPM may offer many advanced science contributions and societal benefits, namely improved knowledge of the Earth's water cycle, its link to climate change and extended abilities in monitoring and predicting extreme weather events (https://pmm.nasa.gov/GPM/).

The following sections describe the various datasets and methods applied (Section 2) and results are presented for four EPEs occurring on the study area in Section 3, followed by discussion of obtained results (Section 4) and conclusions (Section 5).

2. Data and Methods

Extreme precipitation events (EPEs) identified from the ranking of high-resolution daily precipitation extreme events for the Iberian Peninsula (IP) [4] and three precipitation datasets are used in this paper as described below. This analysis is restricted to the period of overlap among all datasets (1 January 1998 through 31 December 2008).

2.1. Extreme precipitation events (EPEs) dataset

EPEs are selected from the ranking of twenty daily precipitation events in the IP described in [4] for the common period of all precipitation datasets (1998-2008). In this ranking the magnitude of an event is characterized not only by the area affected but also by its average intensity. For the IP domain, from the top twenty most extreme precipitation days, only four of them occurred between 1998 and 2008 (Table 1).

Table 1. Anomalous daily precipitation events between 1998 and 2008 for the Iberian Peninsula. [1]

Year	Month	Day	A [%]	M [mm]	R = AM [%(mm)]	Ranking No.
2001	Feb	6	29.77	4.34	129.33	5
2006	Oct	22	32.52	3.76	122.16	7
2001	Mar	1	37.18	3.17	117.81	9
2000	Dec	6	23.79	4.04	96.20	13

[1] The first three columns correspond to the date of the event. Column A corresponds to the area (in %) of the domain that has precipitation anomalies above two standard deviation. Column M corresponds to mean value of these anomalies over area A that is above two standard deviation. Column R corresponds to the final rank index used for ranking the days. The final column corresponds to the ranking of the event. See details in [4].

2.2. Precipitation Datasets

2.2.1. High-resolution daily precipitation dataset for the Iberian Peninsula (IP)

The most comprehensive database of daily precipitation sum available for continental IP (IB02) is used as the ground truth. It results from the combination of two national datasets, "PT02" for mainland Portugal [6] and "Spain02" for peninsular Spain and Balearic islands [7]. The database covers the period from 1950 to 2008, with a spatial resolution of 0.2° latitude/longitude grid. These databases are based on a dense network of rain gauges, combining a total of more than 800 stations over Portugal and 2000 stations over Spain, all quality controlled and homogenized. This large number of stations is crucial to allow meaningful regional assessments of extreme precipitation over medium-size river basins.

It is worth mentioning that there are differences in the daily accumulation periods considered for the Portuguese and Spanish datasets. Thus, daily precipitation records obtained in Portugal for any given day *n* correspond to the precipitation registered between 0900UTC of day *n−1* and 0900 UTC of day *n*. On the other hand precipitation records obtained in Spain for the same day *n* correspond to the precipitation registered between 0700UTC of day *n* and 0700UTC of day *n+1* (notice the difference in both the hours and the days). Therefore in order to derive the most consistent common dataset, the Portuguese daily precipitation was shifted by 1 day [4]. The high number of quality controlled and homogenized stations as well as the various studies performed with this dataset justify its use as the ground truth for this study.

2.2.2. TRMM Multisatellite Precipitation Analysis datasets

The TRMM Multisatellite Precipitation Analysis (TMPA) dataset developed by the NASA Goddard Space Flight Center (GSFC) [8] is used in this research. The TMPA provides a calibration-based sequential scheme for combining precipitation estimates from multiple satellites, as well as gauge analyses where feasible, at fine spatial and temporal scales (0.25° and 3 hourly). The gauge-adjusted version product (3B42) covers the global latitudinal band 50°N–50°S for the period from 1998 to present.

In this work, we consider the rain rate data from TMPA-3B42 product (Version 7, hereafter, 3B42V7), which was officially released in December 2012 to improve the algorithms of earlier versions (V4 to V6) [9]. In addition to the enhanced spatial coverage, the TRMM Microwave Image (TMI) land rainfall algorithm in the V7 products has several improvements over previous versions [10]. One of the key improvements is that the algorithm combines precipitation estimates from land surface rain gauge analyses, in addition to multiple satellite sensors and systems (*e.g.*, microwave-adjusted merged geo-infrared (IR)) [10]. In the 3B42V7, integrating MW and IR measurements makes this product more beneficial for diagnosing precipitation characteristics, relative to previous versions that relied on a single sensor. A detailed description of other improvements in 3B42V7 is given in [10].

2.2.3. Reanalysis dataset

Total precipitation (*mm*) from Interim Reanalyses (ERA-Interim) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), global atmospheric reanalysis available since 1979 up to the present [11,12] is used. Precipitation data were extracted at 6-hourly resolution (00, 06, 12 and 18 UTC) over the Northern Hemisphere for the common period 1998 to 2008 and then projected onto a 1-degree latitude/longitude grid.

2.3. Methods for temporal-spatial and intensity assessment

To evaluate the accuracy of 3B42V7 product on the assessment of daily EPEs in the IP, all precipitation datasets are maniputaled and daily accumulated precipitation datasets are built. Precipitation data from the original (3-hourly or 6-hourly) products are aggregated on a daily (in $mm.day^{-1}$) version and sampled at 0.25-degree and 1-degree spatial resolutions.

Nevertheless there are still differences in the daily accumulation period to be considered. Daily precipitation records in IB02 refer to 07(09)UTC of day *n* and 07(09)UTC of day *n+1*. The 6-hourly precipitation from ERA-Interim dataset is then accumulated using 4 timesteps: from 09UTC (timestep 12UTC) of day *n* to 09UTC (timestep 06UTC) of day *n+1* (Figure 1). The 3-hourly precipitation product fromTRMM may then be accumulated either on the so-called backward period – from 7.30UTC (09UTC timestep) of day *n* to 7.30UTC (06UTC timestep) of day *n+1* – or on the so-called forward accumulation period – from 10.30UTC (12UTC timestep) of day *n* to 10.30 UTC (09UTC timestep) of day *n+1* (Figure 1).

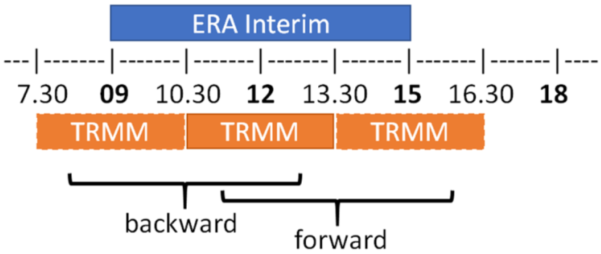

Figure 1. Scheme for 6-hourly ERA Interim data (centered at 12 UTC timestep) and 3-hourly TRMM data (centered at 9, 12 and 15 UTC timesteps). A TRMM 6-hour period may be considered either choosing the backward period (7.30 to 13.30 UTC) or the forward period (10.30 to 16.30 UTC).

In this work we compare results from the daily accumulated precipitation datasets obtained through the forward method (Table 2).

Table 2. Example of accumulation periods for the EPE of 6 February 2001.

Dataset	Month	Day	Hour (UTC)	Month	Day	Hour (UTC)
IB02	Feb	6	07(09)	Feb	7	07(09)
ERA-Interim	Feb	6	09	Feb	7	09
TRMM	Feb	6	10.30	Feb	7	10.30

In order to assess the accuracy of intensity over continental IP, a mask has been created and the high resolution TRMM (0.25°) data have been interpolated onto the same IB02 (0.2°) grid prior to perform a regression analysis. Since the purpose of this research is the analysis of EPEs, only precipitation values higher than 2 *mm* have been considered.

The performance of the 3B42V7 product against the ground reference IB02 values is accomplished by direct comparison. To estimate the accuracy of the product, the evaluation statistics include the Pearson linear correlation coefficient (r), the coefficient of determination (r^2), the root-mean-square error (*RMSE*) and the relative bias (*RB*), defined as follows [13]:

$$r = \frac{cov(\mathrm{TRMM},\mathrm{IB02})}{\sigma_{\mathrm{TRMM}}\sigma_{\mathrm{IB02}}} \quad (1)$$

$$RMSE = \sqrt{1/N\sum(\mathrm{TRMM} - \mathrm{IB02})^2} \quad (2)$$

$$RB = \sum(\mathrm{TRMM} - \mathrm{IB02})/\sum \mathrm{IB02} \quad (3)$$

where *RMSE* is in $mm.day^{-1}$ and *r*, r^2 and *RB* are dimensionless. In equation (1) "cov ( )" refers to the covariance and σ indicates the standard deviation of TRMM or IB02 data, respectively. The coefficient of determination measures the fraction of variability explained by the regression model while the *RMSE* measures the standard deviation of the residuals, *i.e.*, the spread of the points about the fitted line. The *RB* denotes the degree of underestimation or overestimation, in percentage if it is multiplied by 100.

3. Results

The four EPEs (Figures 2-5) that occurred between 1998 and 2008 (Table 1) in the IP are presented and compared on two key aspects: i) the evaluation of the performance of the spatial and temporal rainfall distribution; and ii) the accuracy of the precipitation estimates.

3.1. Spatial-temporal analysis of daily precipitation

Figures 2-5 show the spatial distribution of accumulated daily precipitation over the IP and adjacent oceans. The observational spatial distribution (Figures (a)) show that most precipitation is affecting western continental IP on all the four events. This spatial pattern is also identified when we consider the spatial distribution of accumulated daily precipitation over the IP derived by ERA-Interim data (Figures (b)), even though the latter values are underestimated. When comparing these panels with the corresponding figures derived from TRMM 3B42V7, on high resolution (Figures (c); 0.25°) or on 1-degree resolution (Figures (d)), a similar pattern is found on three of the four events (Figures 2, 3 and 5) although values are even more underestimated. In fact, all except the event of 1 March 2001 show accumulated daily precipitation over a considerable area of the western continental IP, with some maximum values similar to those on ERA-Interim (*cf.* Figures (b) and (c)). In addition the comparison of the panels derived from TRMM 3B42V7 at both resolutions (*cf.* Figures (c) and (d)) shows that both patterns and intensities are much affected by a relative decrease when coarser resolution is considered. Moreover it is worth mentioning that most maxima are coincident with mountaneous regions on continental IP.

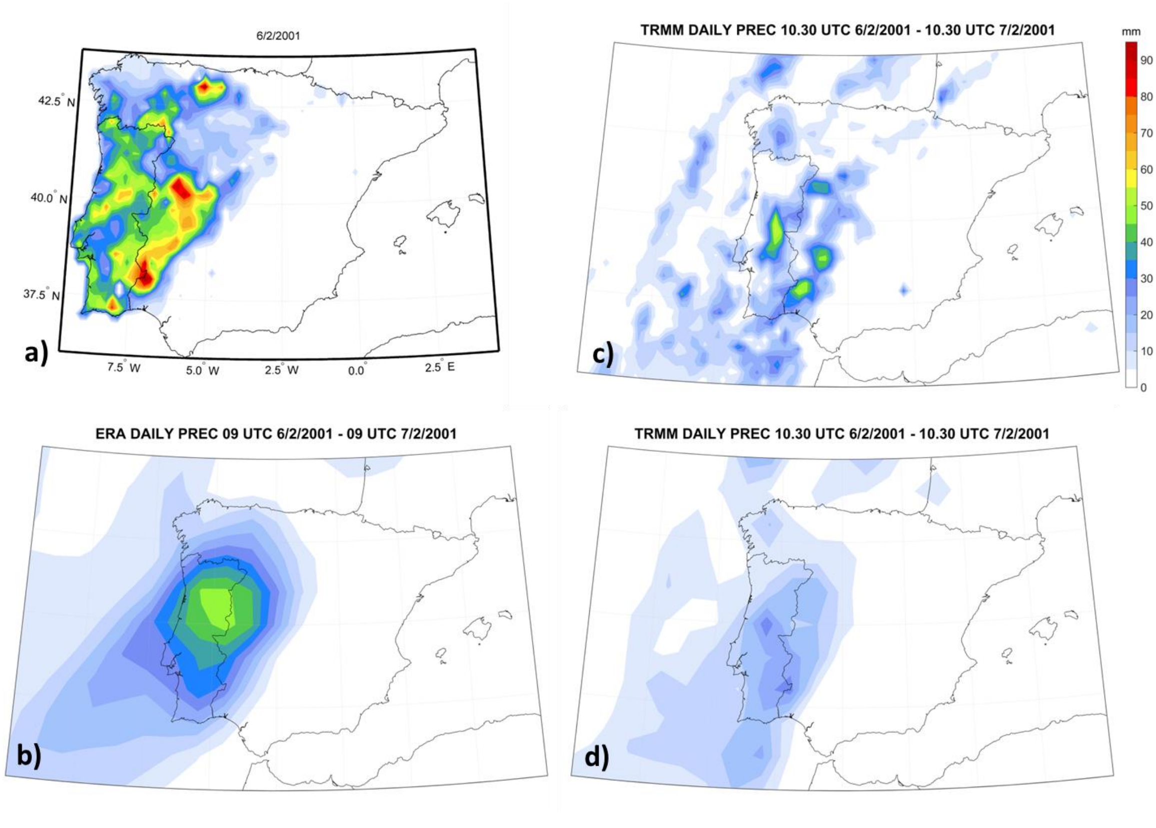

Figure 2. Extreme precipitation (*mm.day*$^{-1}$) event on 6 February 2001. (a) IB02 on 0.2° gridded data; (b) ERA Interim 1° gridded data; (c) TRMM on 0.25° resolution; (d) TRMM on 1° resolution.

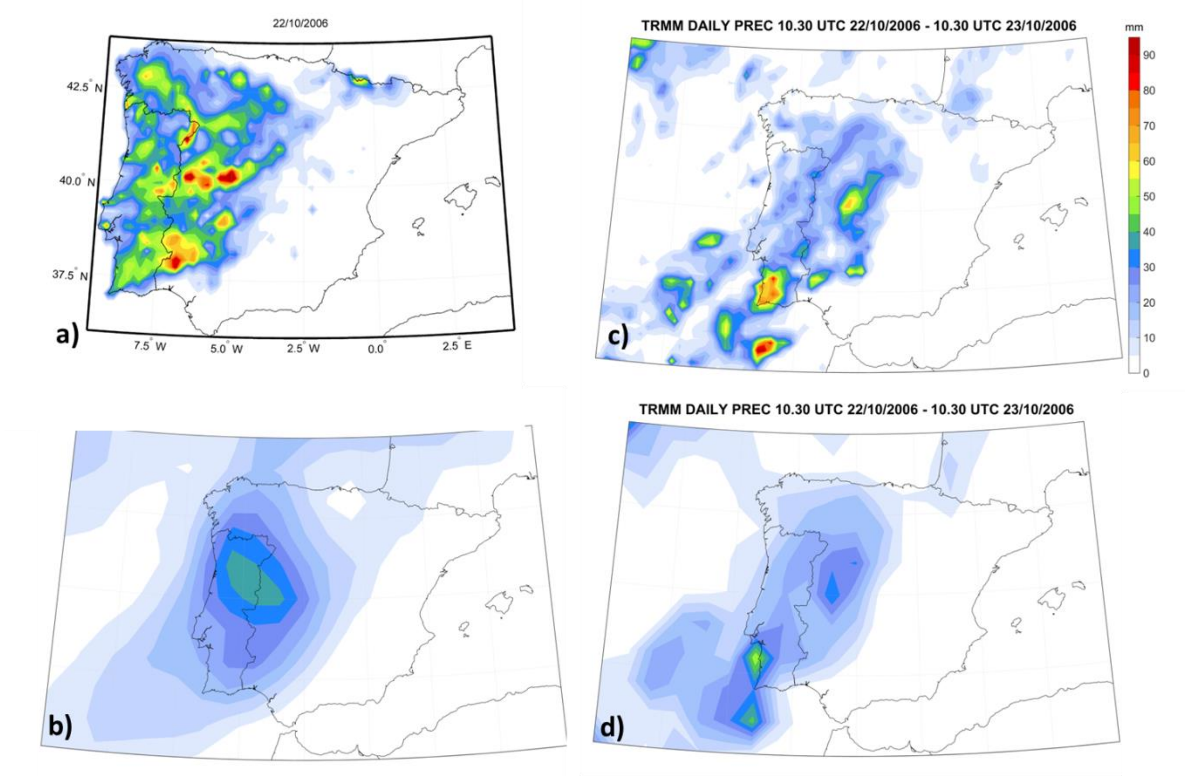

Figure 3. As Figure 2 for extreme precipitation (*mm.day*$^{-1}$) event on 22 October 2006.

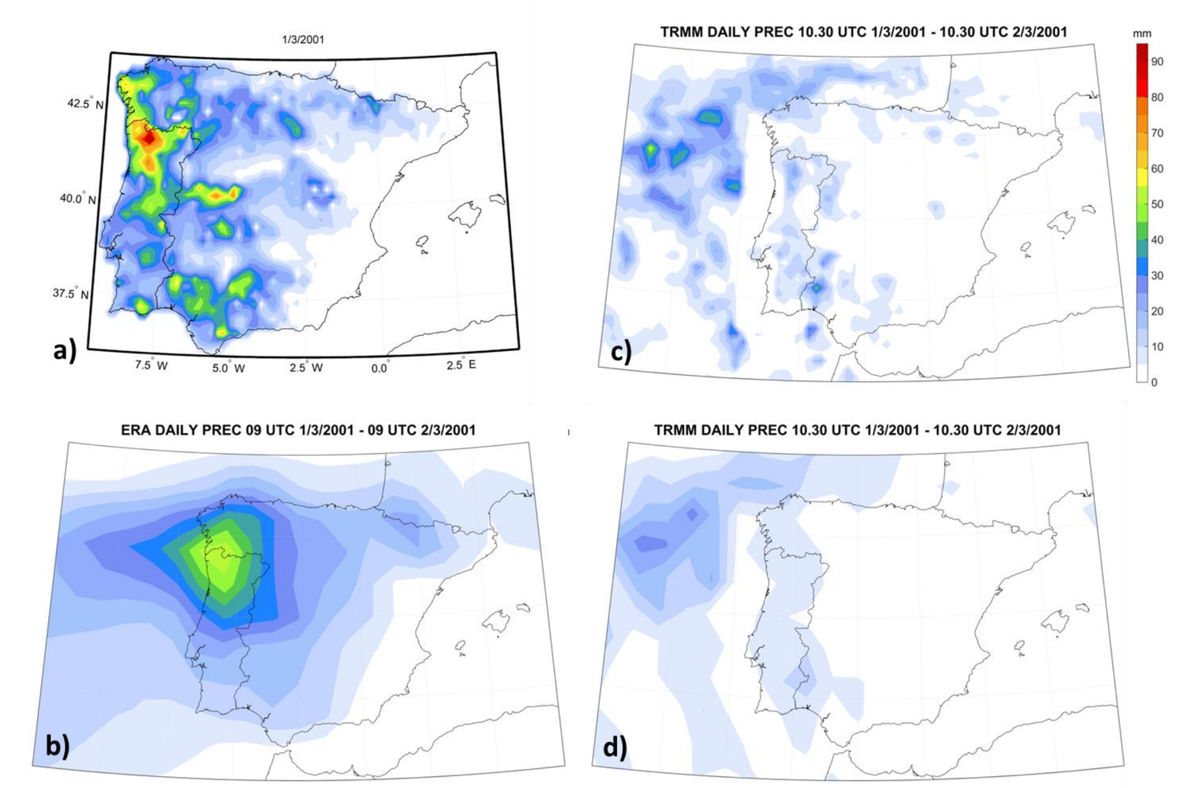

Figure 4. As Figure 2 for extreme precipitation (*mm.day*$^{-1}$) event on 1 March 2001.

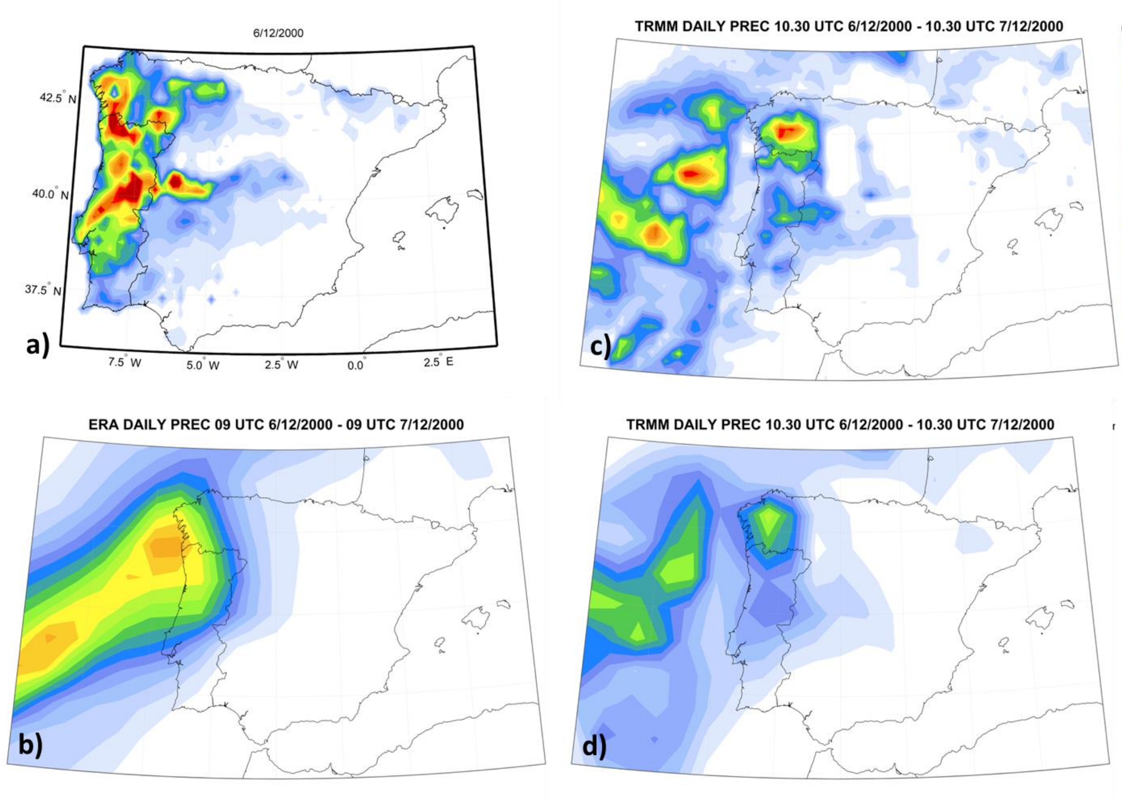

Figure 5. As Figure 2 for extreme precipitation (*mm.day*$^{-1}$) event on 6 December 2000.

Notably, with the exception of the event of 1 March 2001 (T#9, number 9 in the ranking; Table 1), these results put also into evidence the temporal simultaneity of the EPEs occurrence on all datasets (Figures 2, 3 and 5). As shown on the paper by Ramos and colleagues [14] all these events are associated with the presence of an atmospheric river (AR) and this feature is clearly identified over the Atlantic Ocean either using reanalysis (Figures (b)) and using the TRMM 3B42V7 products (*cf.* Figures (c) and (d)).

3.2. EPEs intensity

Figure 6 presents the scatterplots of accumulated daily precipitation (*mm.day*$^{-1}$) of TRMM 3B42V7 at higher resolution versus IB02 and at 1-degree resolution versus ERA-Interim, for all the four EPEs considered. Accuracy of precipitation values and patterns over continental IP, on TMPA products, is here estimated through correlation coefficient (r), coefficient of determination (r^2), root-mean-square error (*RMSE*) and relative bias (*RB*) of the satellite product interpolated to the IB02 grid.

Results pointed out on last section are now confirmed by Figure 6 and statistics. TRMM 3B42V7 underestimates the accumulated daily precipitation by more than 40% (*RB* < - 44%) for all EPEs. For the event of 1 March 2001 (T#9) this value is *RB* = - 82.5%, which is in accordance with its low performance of the spatial distribution of accumulated daily precipitation shown in Figure 4(a,c-d). The data pairs between TRMM and IB02 observations are clustered more closely towards IB02. In contrast, on the other EPEs, TRMM data demonstrate significant underestimation of the precipitation (*RB*: - 44.8% to - 63.6%) but show greater consistency with the observed IB02, with moderate correlation coeficients of r = 0.58 to r = 0.67 and root-mean-square error around 10 *mm.day*$^{-1}$ at the daily scale.

Likewise the assessment for TRMM 3B42V7 and ERA-Interim returns similar results even though with better adjustment: underestimation by more than 22% (RB < - 22%) for all EPEs, higher correlation coeficients on three of the four events (r = 0.73 to r = 0.82) and lower root-mean-square errors around (4.2 to 6.9 *mm.day*$^{-1}$).

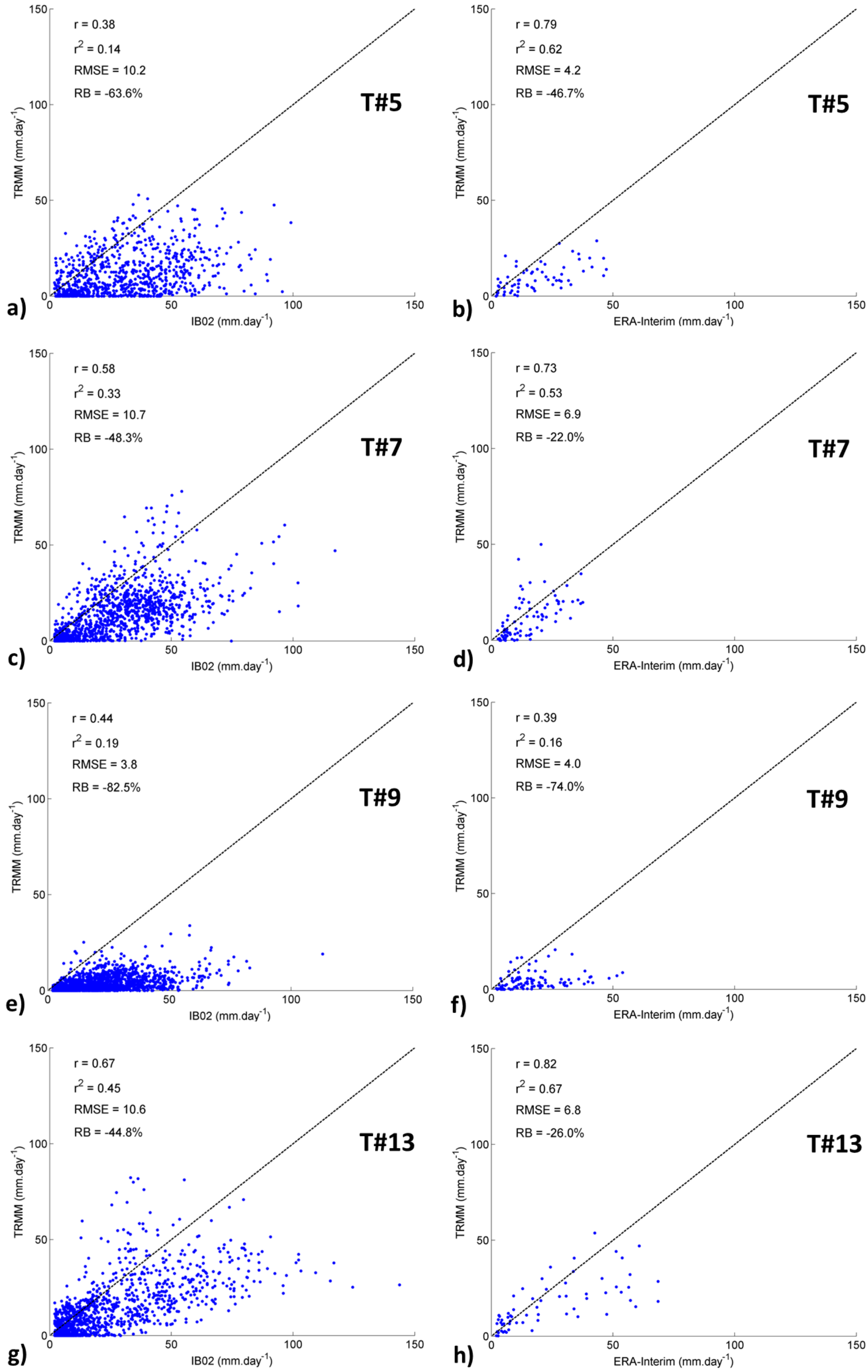

Figure 6. Scatterplots of accumulated daily precipitation (*mm.day*$^{-1}$) for: (a-d) TRMM 3B42V7 versus IB02; for: (e-h) TRMM 3B42V7 versus ERA-Interim. Events: (a-b) T#5 on 6 February 2001; (c-d) T#7 on 22 October 2006; (e-f) T#9 on 1 march 2001; (g-h) T#13 on 6 December 2000. Correlation coefficient (r), coefficient of determination (r^2), root-mean-square error (*RMSE*) and relative bias (RB) of the satellite products are displayed.

This statistical analysis is in accordance with the fact that intensity maxima on the 3B42V7 products have some correspondence to maxima on the IB02 and ERA-Interim maps, in spite of being underestimated. On the other hand, some existing maxima on IB02 (gound truth) are not identified on TRMM maps.

4. Discussion

Although TMPA products were mainly developed to monitor rainfall characteristics in the tropics, the accuracy of TMPA daily accumulated precipitation products (including the 3B42V7) have recently been evaluated by several research teams, at different temporal and spatial scales, over various regions of the globe [*e.g.* 15-19]. Over the northeastern IP [17] showed that TMPA 3B42 provides improved accuracies in winter and summer, whereas it performs much worse in spring and autumn at daily scale for the 12-year period (1998–2009). According to these authors, spatially, the retrieval errors show a consistent trend, with a general overestimation in regions of low altitude and underestimation in regions of heterogeneous terrain.

However extreme precipitations have also been assessed on some of these studies [*e.g.* 15,17,18] with contradictory results. While for example [15] refer that the occurrence of strong precipitation events is well assessed on Peru, but the intensities are underestimated, [18] indicate that the TRMM 3B42V7 product can be well used in the estimation of extreme precipitation and extreme streamflow in the Ganjiang River basin, a region where the extreme precipitation varied greatly. For northeastern IP, [17] refer that TMPA-3B42 underestimated rainfall rates during high precipitation events, whereas it overestimated rainfall during light precipitation events.

This work provides, under a different perspective, an assessment of the 3B42V7 product over the extratropics, by analysing specific EPEs on a particular continental region. Southern Europe and the IP in particular have long been identified as one of the most vulnerable regions to climate change [20-22]. According to the Intergovernmental Panel on Climate Change (IPCC), an increase in the average global temperature is very likely to lead to changes in precipitation, including shifts towards more frequent events and more extreme precipitation during storms [23]. Since the GPM mission expands observational capabilities beyond the tropics, the GPM may contribute to monitoring EPEs and to improving weather forecasting also on the mid-latitudes, by advancing predictions of high-impact natural hazard events and providing accurate high-resolution precipitation data.

Therefore these results put in evidence the need for the implementation of algorithms improvements and/or the inclusion of information from new sensors, namely in continental areas over the mid-latitudes, so as to better represent intense precipitation events, in view of enhanced extreme weather systems understanting, flash-flood forecasting and impacts assessment using the GPM over these regions.

5. Conclusions

An evaluation of the accuracy of the TMPA 3B42V7 daily accumulated precipitation in reproducing the spatial and temporal characteristics of extreme precipitation events (EPEs) in continental Iberian Peninsula (IP) is undertaken. For this assessment daily accumulated precipitation from a high resolution (0.2°) gridded dataset IB02 and from ERA-Interim reanalysis are considered. Four EPEs from the top twenty on IP [4] are analysed for the available data overlapping period from 1998 to 2008.

Results for accuracy assessment indicate that the performance of TMPA 3B42V7 in identifying the spatial and temporal EPEs patterns is reasonable for three of the four events, comparing well both with ERA-Interim and IB02 data, although the intensity estimates are underestimated with respect to the gridded IB02 data, with an overall bias (*RB*) between -44.8% and -63.6% and a *RMSE* of around 10$mm.day^{-1}$ at this daily scale. These results are in agreement with other previous studies for the northeastern IP [17], and suggest the need for improving the algorithms of the TMPA precipitation estimation in order to better represent extreme precipitation events (EPEs) over continental areas at mid-latitudes.

Acknowledgments: The authors acknowledge the National Aeronautics and Space Administration (NASA) for providing the TMPA 3B42V7 dataset; the Portuguese and Spanish Meteorology Institutes for gridded precipitation datasets (PT02 and SPAIN02, respectively); the European Centre for Medium-Range Weather Forecasts (ECMWF:) for ERA-Interim Reanalysis used in this research. This work is partly supported by FCT - project UID/GEO/50019/2013 - Instituto Dom Luiz. R. Hénin is supported through a doctoral grant (PD/BD/114479/2016) and A.M. Ramos is supported by a postdoctoral grant (FCT/DFRH/SFRH/BPD/ 84328/2012) both funded by Fundação para a Ciência e a Tecnologia, Portugal (FCT)

Author Contributions: M.L.R. Liberato and A.M. Ramos conceived, designed and conducted the research; R. Hénin, A.M. Ramos and M.L.R. Liberato performed the experiments; M.L.R. Liberato, R. Hénin, A.M. Ramos and C. Gouveia analysed the data and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:
3B42V7: TMPA gauge-adjusted, post-real-time research version 7 product
AR: atmospheric river
ECMWF: European Centre for Medium-Range Weather Forecasts
EPEs: Extreme precipitation events
ERA-Interim: ECMWF Interim Reanalyses
EUMETSAT: European Organization for the Exploitation of Meteorological Satellites
FCT: Fundação para a Ciência e a Tecnologia, Portugal
GPM: Global Precipitation Measurement
IB02: high resolution (0.2°) daily precipitation sum for continental Iberian Peninsula
IP: Iberian Peninsula
IPCC: Intergovernmental Panel on Climate Change
IR: infrared
JAXA: Japan Aerospace Exploration Agency
MW: microwave
NASA: National Aeronautics and Space Administration
GSFC: Goddard Space Flight Center
TMI: TRMM Microwave Image
TMPA: TRMM Multisatellite Precipitation Analysis
TRMM: Tropical Rainfall Measuring Mission
UTC: Universal Time Coordinated

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