Evaluation of the Version 7 TRMM Multi-Satellite Precipitation Analysis (TMPA) 3B42 product over Greece

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Abstract. In this research work, the latest version 7 (V7) of the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) 3B42 product is evaluated over Greece, at five different temporal scales; 3, 6, 12, 24 and 48 hrs. Evaluation is conducted using data from 34 rain gauge stations, for the 2009-2014 period. It has been found that, although there is a notable improvement in the accuracy of the estimates at coarser time scales, the product reliability still remains low (the value of the efficiency coefficient is about 0.22 and about -0.23 in the 48 hr and 3 hr scales respectively). Furthermore, the product systematically underestimates precipitation and the correlation between the satellite and ground data is poor – lower than 0.6 in all cases. The examination of the spatial distribution of bias shows that the error at high resolution temporal scales (3 hr and 6 hr scales) is negative in the greatest part of the country, in contrast to the lower scales, at which the product turns to slightly overestimate precipitation over the regions that are generally characterized by lower total precipitation amounts.

Keywords: TRMM, 3B42 V7, evaluation, precipitation, Greece

1. Introduction

Reliable precipitation estimates play a critical role in various applications, such as water resources management, flood and drought monitoring and forecasting. At present, there are several precipitation measurement systems, including point measurements at gauge and spatial measurements from radar and satellite.

While gauges are considered to be the only source of physical measurement, the lack of temporal and spatial sampling hinders the relevance of such measurement (Boushaki *et al.*, 2009). On the other hand, ground-based weather radars provide fairly continuous coverage in space and time, but the quantitative range of their measurements is generally limited to 150 km or less. Most importantly, both rain gauges and radars provide incomplete coverage over remote and undeveloped land areas and particularly over the sea, where such instruments are virtually not available (Feidas, 2010). Because of this fact, satellite-based quantitative precipitation estimates (QPE) products have become widely used due to their global coverage and spatial continuity. However, the inherent error sources in satellite-based measurements (e.g., the spatiotemporal variation of the precipitation fields) have not yet been well understood (Chen *et al.*, 2013).

In this frame, there are many studies which aim to evaluate different satellite-based precipitation products. Many of these have focused on the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA) TMPA products (e.g. Liu, 2015; Chen *et al.*, 2013; Junzhi *et al.*, 2012; Villarini and Krajewski, 2007 and others) over different regions of the world. In Greece, similar efforts have also taken place (e.g. Katsanos *et al.*, 2004; Feidas, 2010; Nastos *et al.*, 2015). None of these, however, concern the latest Version 7 of the TMPA 3B42 product.

The objective of this study is to evaluate the reliability of the Version 7 TRMM Multi-Satellite Precipitation Analysis (TMPA) 3B42 over the very complex Greek terrain. This product has been developed by the Mesoscale Atmospheric Processes Laboratory at NASA Goddard Space Flight Center and provides precipitation estimates at 3-hourly temporal resolutions on a 0.25-degree × 0.25-degree grid available from January 1998 to present (Liu, 2015). The 3-hourly TMPA consists of two products: near-real-time (3B42RT, spatial coverage: 60°N–60°S) and research-grade (3B42, spatial coverage: 50°N–50°S). The latter, available approximately two months after observation, is calibrated with gauge data, different sensor calibration and additional post-processing in the algorithm and is considered more suitable for research (Huffman *et al.*, 2010).

2. Data and methodology

2.1 Data used

In this study, the TMPA 3B42 V7 product is evaluated at five different high resolution temporal scales; 3, 6, 12, 24 and 48 hrs. The 6, 12, 24 and 48 hr precipitation estimates were calculated by aggregating the 3 hr source data. Furthermore, data from 34 rain gauge stations over the study area were acquired for the evaluation procedure from three different sources; the Hellenic National Meteorological Service (HNMS), the Hydrological Observatory of Athens (HOA), as well as, the National Observatory of Athens (NOA). Their spatial distribution is illustrated in Figure 1. The verification period spans the 2009 to 2014 6-year period.

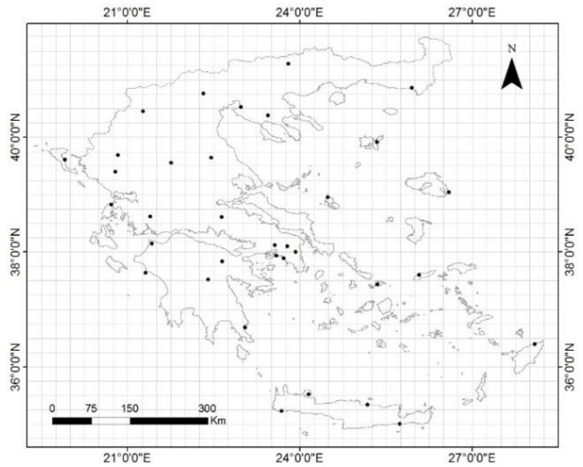

Figure 1. Rain gauge stations used for verification and product grid over Greece

2.2 Validation methodology

The first step of the analysis was to calculate modelled timeseries at the location of the rain gauges used. For this purpose, a technique for making inferences at small regional scales from coarser model scales based on grid points, was adopted. The timeseries of the four closest 0.25-degree grid points of each one of the 34 rain gauges examined were averaged, weighted by the inverse of their square distance from the rain gauge. This way the satellite and observed data were compared directly. This methodology was followed mainly due to the limited number of stations available for the study.

Using the modelled satellite timeseries, some quantitative and qualitative error statistics for the whole 6-year period were calculated. The quantitative measures applied were an efficiency coefficient (Eff) (Nash and Sutcliffe, 1970), the linear correlation coefficient (R), the bias (Bias), the mean absolute error (MAE) and the root mean square error (RMSE). Bias, MAE and RMSE were calculated as percentages of the mean 6-year precipitation recorded at gauges, as well as, in mm of precipitation amount. The former was performed so as the results, among the different analysis temporal scales, to be directly compared. Based on the values of these measures, surfaces showing their spatial distribution over Greece were also constructed, using an ordinary Kriging procedure.

In addition, three qualitative measures were also calculated (Katsanos *et al*., 2004). These were the Probability of Detection (POD), False Alarms Ratio (FAR) and Critical Success Index (CSI) scores, the values of which are based on a 2x2 contingency table (a: satellite yes, observation yes, b: satellite yes, observation no, c: satellite no, observation yes and d: satellite no, observation no). Using this notation for a, b, and c, the qualitative measures are written as:

$$POD = \frac{a}{a+c} \quad (1)$$

$$FAR = \frac{b}{b+a} \quad (2)$$

$$CSI = \frac{a}{a+b+c} \quad (3)$$

These scores were estimated for different precipitation thresholds, in order to evaluate the skill of the product in light and heavy rainfall events. The thresholds are different for each analysis temporal scale, since they were determined from the 1st, 10th, 25th, 50th, 75th, 90th and 99th percentiles of the total 6-year precipitation recorded at the stations.

3. Results and discussion

Figure 2 presents the verification results concerning the values of the quantitative error statistics Eff, R, Bias, MAE and RMSE for Greece. It is evident that there is a notable improvement in the accuracy of the estimates at coarser temporal scales. Eff takes negative values at the 3 and 6 hr analysis timescales and becomes positive at the 12 hr scale. Its maximum value, which corresponds to the 48 hr interval, is close to 0.25. The linear correlation coefficient ranges from 0.29 (at the 3 hr interval) to 0.59 (at the 48 hr interval). Furthermore, the percentage increase of the index is notably higher at the fine temporal scales compared with the coarse ones. Namely, the value of R increases approximately by 40% between the 3 hr and 6 hr scales, 20% between the 6 hr and12 hr scales, 12% between the 12 hr and 24 hr scales and by 8% between the 24 hr and 48 hr scales. A similar trend can also be noted in the rest of the error statistics calculated, as shown in Figures 2c, 2d and 2e.

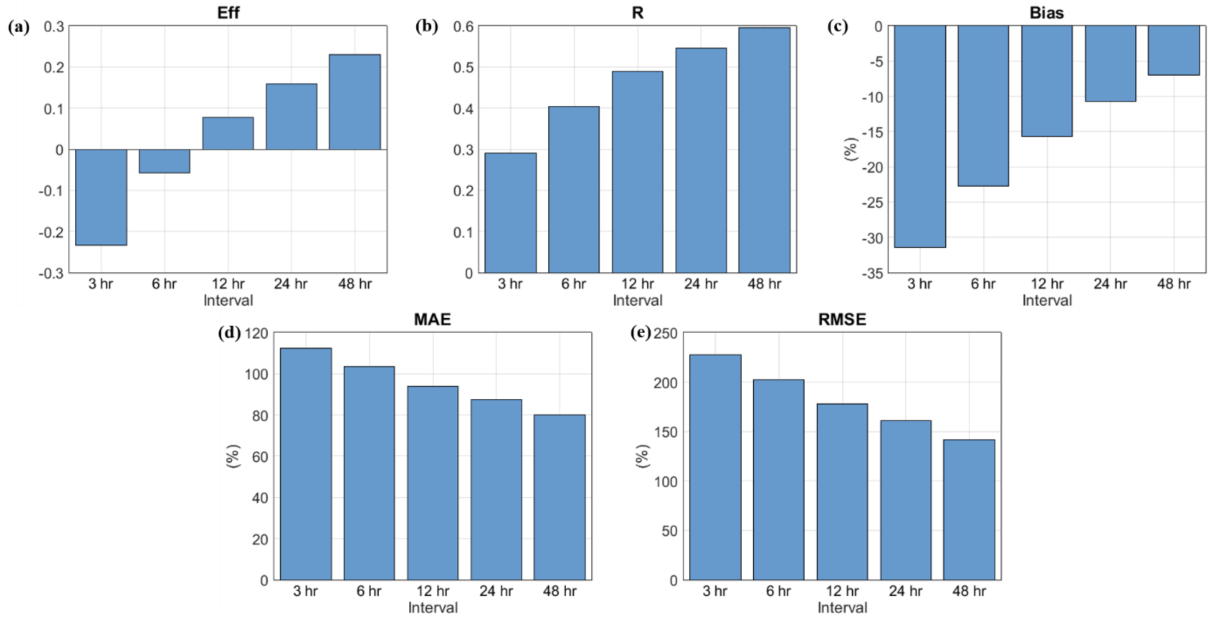

Figure 2. Quantitative error statistics: a) efficiency coefficient, b) Pearson correlation, c) bias, d) mean absolute error and e) root mean square error for Greece for the 2009-2014 period

Despite this improvement in the performance of TMPA 3B42, its reliability still remains low in all cases. The highest value of Eff calculated (~ 0.23) is much lower than 1, which shows a perfect match. In addition, the product's correspondence with ground data is poor (R is lower than 0.6 in all cases). While Bias ranges from -32% to -7% (Figure 2c), random errors in estimates result in much higher MAE (112% – 80%) and RMSE (230% – 142%) values (Figures 2d and 2e respectively).

Interestingly, the mean bias error for the whole Greek region is negative at all analysis temporal scales (Figure 2c). This indicates an underestimation of precipitation by TRMM, which can be noticed especially over the western part of the country (Figure 3c). Most of the eastern part (including the Aegean Sea islands) is characterized by negative – but close to zero – systematic errors at fine analysis timescales (e.g. 3 and 6 hrs.), which however turn to positive at coarser ones (indicating precipitation overestimation). In particular, there seems to be a natural boundary, clearly depicted in Figures 3c, 3d and 3e, which causes an East-West divide. This boundary coincides with the Pindos mountain range, which crosses the Greek peninsula from NW to SE. In fact, it is known that the most important wet air masses crossing continental Greece come from the western sectors. This source is the prevailing one and maximum precipitation is concentrated on the western part of the country, due to the orographic uplift mechanisms induced by the Pindos Mountains and the mountains of the Peloponnese (Dotsika *et al*., 2009). Based on this fact, it could be suggested that the product's response seems to differ according to the climatological characteristics of the region. TMPA 3B42 V7 underestimates precipitation over the regions with generally high precipitation amounts, contrary to those with lower, at which a slight overestimation is observed. Nevertheless, a similar geographical trend cannot be also noted in the spatial distributions of Eff (Figure 3a) and R (Figure 3b).

Finally, Figure 4 presents the verification results for POD, FAR and CSI for the five different analysis timescales and for different precipitation thresholds. Inspection of the results shows that FAR follows a specific pattern in all figures. The index is generally stable up until a threshold, above which it increases almost linearly. In all figures, this threshold corresponds to the 50th percentile of total observed precipitation (which is 1 mm, 1.4 mm, 2 mm, 2.8 mm and 4.2 mm in Figures 4a, 4b, 4c, 4d and 4e respectively). In addition, the index does not improve significantly, but only slightly, across the different analysis scales. Its values for low intensities (up until the 50th percentile precipitation threshold) are all in the range of 0.35 – 0.6 and its maximum (corresponding to the 99th percentile), are in the range of 0.78 – 0.92.

This is not the case, however, for POD and CS1, as both measures appear to be more sensitive to the time interval change. For the 0.1 mm precipitation threshold, for example, POD ranges from 0.3 (Figure 4a) to 0.72 (Figure 4e), having an overall 140% increase between 3 and 48 hr analysis scales. The same increase is noted in the values of CSI for the 0.1 mm threshold. Examining each curve separately, POD and CSI are rather stable in low intensities,

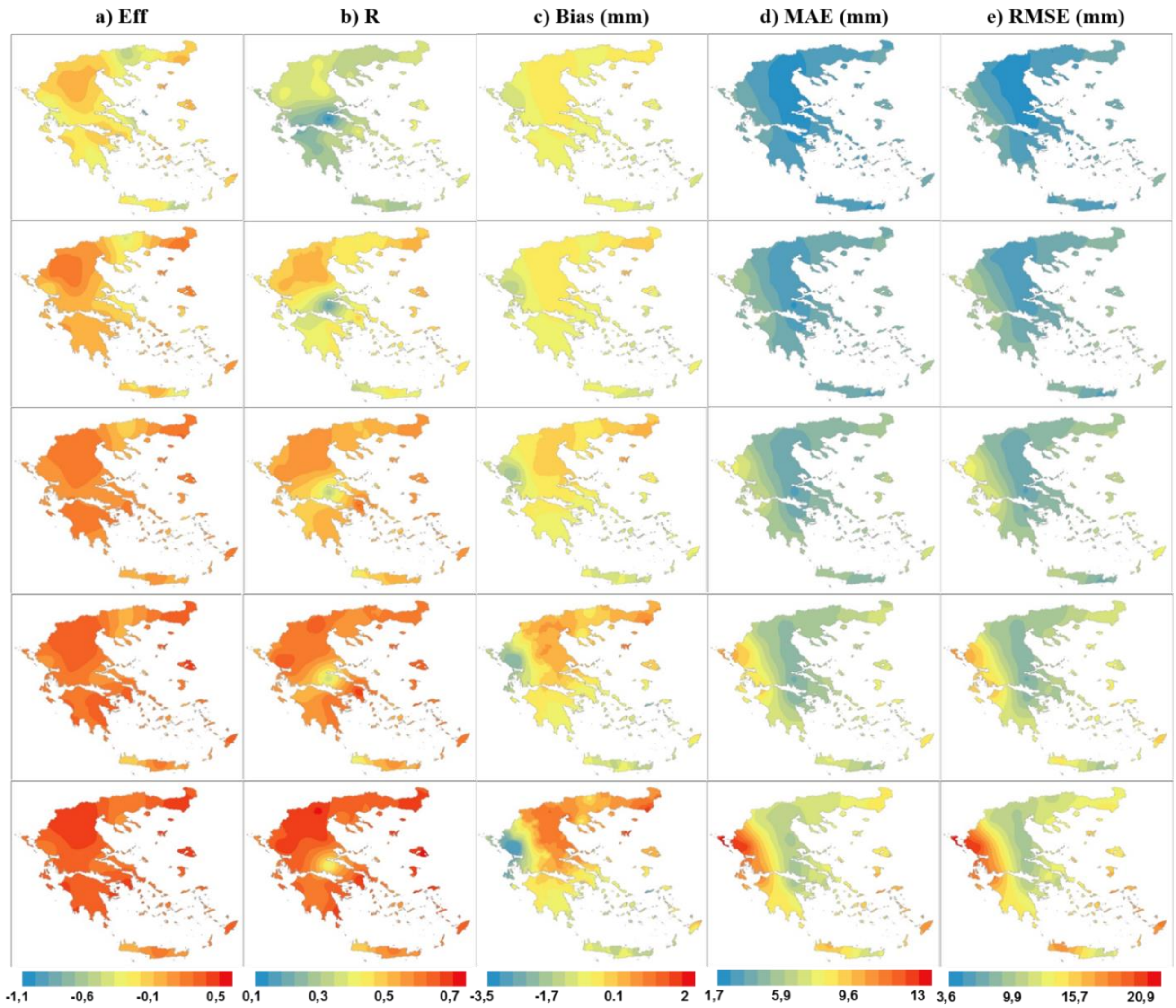

Figure 3. Spatial distribution of Eff (a), R (b), Bias (c), MAE (d) and RMSE (e) over Greece for the 2009-2014 period. From top to bottom, the figures represent the 3 hr, 6 hr, 12 hr, 24 hr and 48 hr scores' distribution

or change slightly. A rapid decrease in their values occurs in high intensities. Although a common break point for all five curves cannot be identified, it is evident that for thresholds higher than 10 mm, the performance of the product, as represented by POD and CSI, is significantly reduced in all cases.

Overall, the product's poor performance is confirmed by the values of the quality measures. FAR is higher than or equal to approximately 0.6 at the 3 hr scale, 0.5 at the 6 hr scale, 0.45 at the 12 hr scale, 0.4 at the 24 hr scale and 0.35 at the 48 hr scale for all intensities. Similarly, POD is lower than or equal to approximately 0.3 at the 3 hr scale, 0.4 at the 6 hr scale, 0.5 at the 12 hr scale, 0.6 at the 24 hr scale and 0.75 at the 48 hr scale. The same values for CSI are: 0.2, 0.28, 0.35, 0.4 and 0.48.

4. Conclusions

This study examines the performance of the latest Version 7 of the space born TRMM Multi-Satellite Precipitation Analysis (TMPA) 3B42 product for the 6-year 2009-2014 period over Greece. The product has been evaluated at five different high resolution analysis timescales – which are the 3 hr, 6 hr, 12 hr, 24 hr and 48 hr scales – and the results have been compared.

The quantitative verification of the product shows that there is a notable improvement in the quality of precipitation estimates in coarser timescales. In spite of this improvement, the product remains unreliable in all cases. The values of Eff are much lower than 1, indicating a mismatch between the observed and estimated data. The product's correspondence with ground data is also poor, while random errors, as represented by MAE and RMSE, are more important than systematic ones, as shown by Bias.

TMPA 3B42 generally underestimates precipitation over Greece. At coarser temporal scales, this underestimation decreases and even turns to an

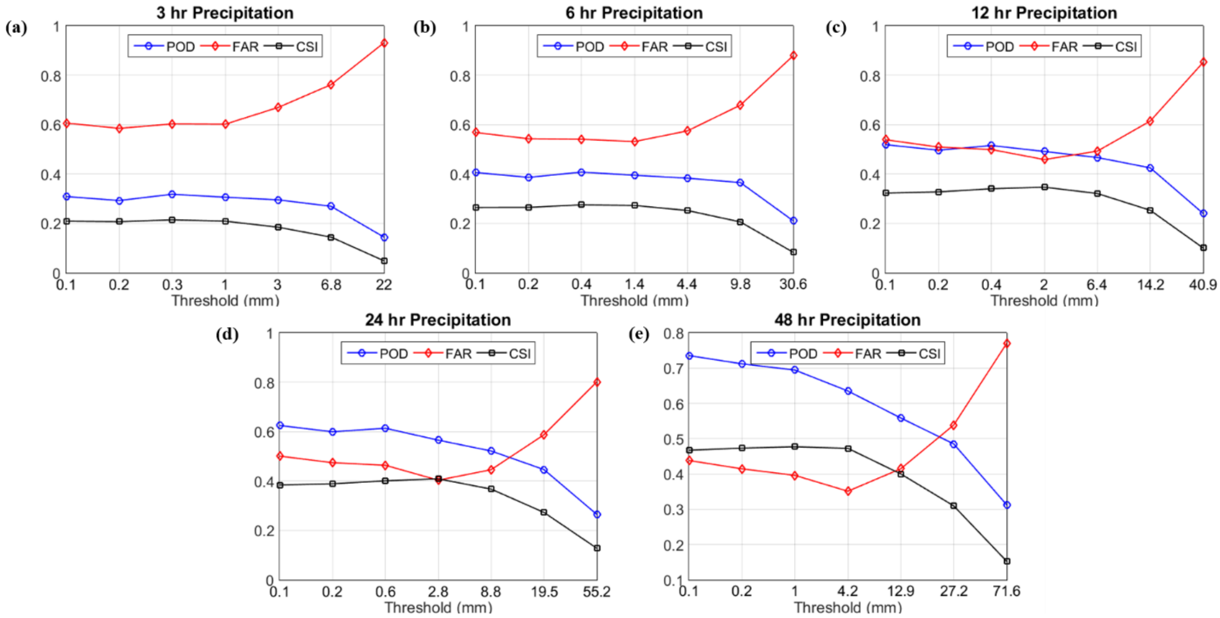

Figure 4. Qualitative error statistics based on different precipitation thresholds. The thresholds have been determined from the 1st, 10th, 25th, 50th, 75th, 90th and 99th percentiles of the total 6-year gauge precipitation

overestimation over specific regions; those which are generally characterized by lower precipitation amounts (eastern Greece, contrary to western Greece).

Finally, the quality error statistics calculated confirm the poor performance of the product. The best results are obtained for low precipitation amounts and the worst for high. In most cases, a specific precipitation threshold exists, above which the quality of the estimates decreases rapidly.

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