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Performance evaluation of CHIRPS satellite-derived precipitation product at a high-altitude Mediterranean forest*

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Abstract

The aim of this study is to investigate the accuracy of the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) satellite-derived precipitation product against rain gauge data at a high-altitude Mediterranean forest in Central Greece over a 40-year period (1981-2020). Given the difficulties of establishing and maintaining rain gauges in forested regions, satellite-derived products such as CHIRPS may offer valuable information. However, the accuracy of this precipitation product, specifically in mountainous areas remains underexplored. This study comprised the use of statistical metrics to compare the monthly, seasonal, and annual precipitation estimates from CHIRPS to those of the observed ground measures. The findings reveal that CHIRPS effectively captures the pattern of monthly precipitation, although there is in general a bias towards significantly overpredicting precipitation and strong seasonality of its performance. Thus, CHIRPS presents significant potential as an efficient source of information in the absence of ground observations for autumn and possibly summer precipitation in ungauged Mediterranean mountainous forest sites, though it should be used cautiously for winter and spring.

Keywords

Forest meteorological station, satellite precipitation, Mediterranean, statistical evaluation, Greece

1. Introduction

Precipitation plays an essential role in the hydrological cycle and influences multiple disciplines and applications. Accurate estimation of precipitation in time and space is crucial for supporting the decision-making process in various water resources, agriculture, climatology, and hydro-energy scenarios. Although rain gauges remain the most common and reliable instrument for obtaining an accurate high temporal resolution of precipitation measurement, point scale is limited, and the spatial variation effectiveness is unpractical in many parts of the world characterized by complex topology and low-density gauge network [1]. As a result, the conventional approach to areal precipitation is mainly based on spatial interpolations of the point based rain gauge data. However, this approach limitations in areas with a sparse gauge network.

Over the past few years, a large number of gridded precipitation products with different spatial resolutions and coverage periods have been developted [2,3]. These products can generally be categorized into five major types based on their methodology and attributes: satellite products (e.g., GPM, TRMM), radar-based products (e.g., OPERA), reanalysis datasets (e.g., ERA5, CERRA), station-based gridding (e.g., CRU, GPCC), and hybrid products (e.g., CHIRPS, CMORPH). Notably out of the

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aforementioned datasets, CHIRPS is known for its fine resolution and wide coverage over time [4]. Several studies have been conducted to evaluate the performance of the CHIRPS precipitation product. However, these studies typically are based in comparisons with ground data from lowland precipitation stations [5-9], and only a few of them represent a long analysis for complex mountainous terrain. These constraints arise from the difficulties involved in instalation, maintaining and monitoring stations at high elevations, in mountain regions [10].

This study aims to evaluate the performance of CHIRPS precipitation estimates at a high-altitude Mediterranean forest in Central Greece compared to rain gauge observations over a forty-year period (1981-2020).

2. Material and methods

The research area is the University Forest of Pertouli, which is situated in the Central Greece's Pindus Mountain Range. The forest is managed by the University Forests Administration and Management Fund (UFAMF), which was granted to Aristotle University of Thessaloniki in 1934 for research and education purposes. It spans approximately 3,290 hectares and extends from longitude 39°32' E to 39°35' E and latitude 21°33' N to 21°38' N (Figure 1). It consists mainly of pure fir stands (*Abies borisii regis*), with elevations ranging from 1,100 m to 2,073 m above sea level. A detailed description of the study area can be found in Stefanidis et al. [11]. Since 1961, a meteorological station has been installed (1,180 m.a.s.l.) in the forest site and operated by UFAMF. Monthly precipitation data for the period 1980 – 2020 were utilized for this study.

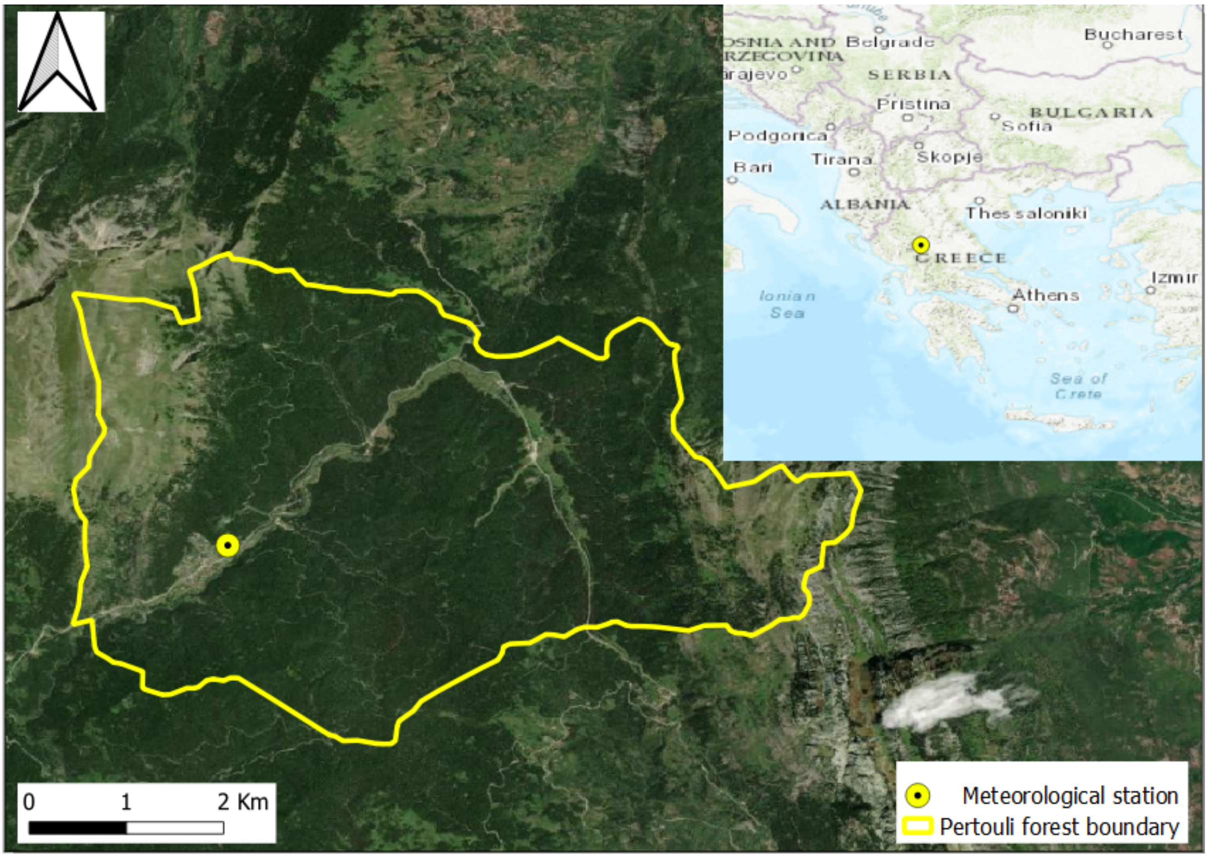

Figure 1: Location map of the study area.

Additionally, daily estimates of CHIRPS precipitation product, were retrieved through the use of Google Earth Engine (GEE) cloud computing platform (ee.ImageCollection("UCSB-CHG/CHIRPS/DAILY) from January 1, 1981, to December 31, 2020.

CHIRPS, developed collaboratively by the Climate Hazards Group at the University of California, Santa Barbara (UCSB) and the US Geological Survey (USGS), is a gridded precipitation product with quasi-global coverage (50° S–50° N, 180° E–180° W). Operating at a spatial resolution of 0.05°, CHIRPS provides precipitation estimates from 1981 to near-present, leveraging input parameters such as monthly precipitation climatology (CHPClim), infrared (IR) sensors from geostationary satellites, and ground precipitation observations. Notably, CHIRPS incorporates data from the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA 3B42) to enhance its blending process, thereby enhancing its accuracy and reliability.

A variety of statistical metrics were used to evaluate the performance of CHIRPS estimates in reproducing precipitation, compared to gauged observations at the forest site. These metrics include correlation coefficient (CC), mean bias error (MBE), mean absolute error (MAE), root-mean-square error (RMSE) and relative bias (RBIAS). The detailed description of these indices can be found in previous studies by Stefanidis et al [12] and Alexandridis et al. [13]. Additionally, MBE, MAE and RMSE were converted to %MBE, %MAE and %RMSE by dividing their initial values with means of observed values, facilitating comparison of the model's performance between seasons [14].

3. Results and Discussion

The comparative presentation of the precipitation monthly values measured by rain-gauge and simulated by CHIRPS is shown in Figure 2a, whereas Figure 2b depicts the monthly averages of all data of the time period (1981-2020). In both cases the overestimation of precipitation by CHIRPS is evident. The monthly values present an expected dispersion, with a relatively low slope *a* (0.668) and moderate offcet *b* (22.024) value of the regression line *y=ax+b*, suggesting an overestimation of about 33% of the monthly values. The coefficient of determination R^2 (0.566), can be considered as adequatefor precipitation assessments suggesting the caution use of the dataset in ungauged watersheds. The overestimations are clearly shown in Figure 2b being (on absolute) higher in winter months and lower in summer, with respect to the uneven precipitation distribution that characterizes the Mediterranean climate [15, 16].

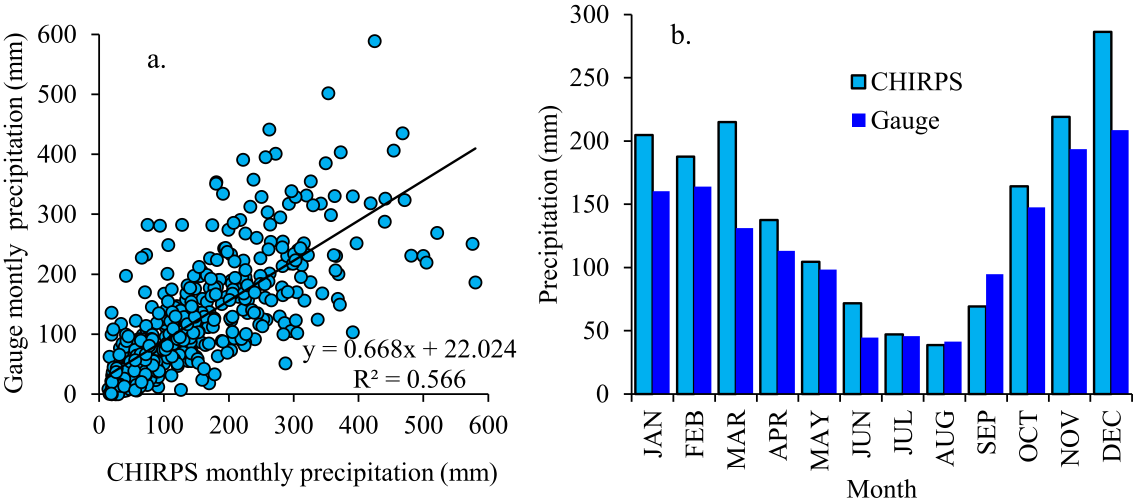

Figure 2: Regression (a) and averages (b) of monthly precipitation measured (gauge) and estimated (CHIRPS) values in the forest site of Pertouli, Greece.

The values of the annual precipitation of the two datasets present differences. The CHIRPS average annual precipitation is 1745 mm, overestimated by a percentage of +21%, compared to the ground station annual average (1443 mm), which represents an absolute difference of 302 mm. The average differences is even more variable from year to year as presented in the statistics of Table 1, where, especially, the correlation coefficient (CC) shows relatively low values (0.55) suggesting a high desprersion of the annual values.

On a seasonal basis, the differences between the two datasets are even more evident, suggesting that that the average CHIRPS precipitation of autumn is quite accurate compared to other seasons producing overestimates, but only by +4%, i.e. a precipitation magnitude of about 17 mm, which is a rather small difference considering that the CHIRPS autumn precipitation is 453 mm, very close to the respective measured value (436 mm). Compared to all other seasonal statistics presented in Table 1, autumn has the best values of RMSE (34 %), MBE (16.5mm and 4%), MAE (25%) and RBIAS (0.038). It should be noted, however, that CHIRPS dataset shows an adequate performance in summer precipitation, producing relatively accurate estimates in our forest site. The summer average precipitation is limited (132 mm) and rather overestimated by CHIRPS (157 mm) by about +19% (25 mm). However, in summer the comparison between the datasets showed best RMSE (68.4 mm) and MAE (56.4 mm) values than all other seasons. Finally, the seasonal pattern reveals that spring precipitation, though highly overestimated (by +33%), presents the best correlation coefficient (CC) value, indicating the least dispersion of precipitation during the spring months. Following spring in performance, winter displays the second-best CC value, underscoring its predictive reliability. Literature supports these findings, particularly for mountainous areas where CHIRPS demonstrated good correlation with local station data, especially during the winter months [6]. Overall, CHIRPS can be a good alternative for the autumn and probably summer precipitation in ungauged Mediterranean mountainous forest sites, however must be used cosiously for the winter and spring values. The unsatisfactory performance of CHIRPS in spring, particularly in regions with complex terrain, is also noted by Aksu and Akgül [7], who assessed the performance of CHIRPS against 77 ground station in Turkey for the period 2008-2018 and found that CHIRPS overestitmated monthly precipitation by 0 to 80 mm/month.

Table 1
Summary of spatial datasets used in this study

Month/ Season	Average (mm)		RMSE		MBE		MAE			
	CHIRPS	Gauge	(mm)	(%)	(mm)	(%)	(mm)	(%)	RBIAS	CC
Monthly										
January	205	160	100.4	63	44.5	28	67.4	42	0.277	0.696
February	188	164	76.9	47	23.7	14	57.1	35	0.145	0.679
March	215	131	100.8	77	83.7	64	87.3	67	0.638	0.641
April	138	113	60.5	53	24.4	22	48.9	43	0.215	0.661
May	104	98	44.7	45	6.0	6	33.4	34	0.061	0.608
June	72	45	39.4	88	27.3	61	32.7	73	0.612	0.657
July	47	46	28.8	63	1.2	3	22.7	50	0.026	0.640
August	39	41	36.0	87	-2.7	-7	24.5	59	-0.066	0.552
September	69	95	98.6	104	-25.6	-27	51.2	54	-0.270	0.472
October	164	148	75.2	51	16.5	11	55.6	38	0.112	0.671
November	219	194	104.5	54	25.5	13	79.4	41	0.132	0.492
December	286	209	128.6	62	77.7	37	97.9	47	0.373	0.647
Seasonal										
Winter	679	533	240.2	45	146.0	27	182.7	34	0.274	0.545
Autumn	453	436	147.3	34	16.5	4	109.3	25	0.038	0.556
Spring	457	343	147.5	43	114.1	33	127.4	37	0.333	0.583
Summer	157	132	68.4	52	25.7	20	56.4	43	0.195	0.447
Annual	1745	1443	413.4	29	302.2	21	336.1	23	0.209	0.547

The above results are, in general, confirmed by the monthly statistics. The monthly CHIRPS averages are overestimated in almost all months (by +2% or 1mm in July to +64% or 84 mm in March), with the exception of August and September, when underestimated by -5% and -27% respectively. On a monthly basis, the CHIRPS dataset generally performs well, in May, July and August producing monthly precipitation estimates different by less than 10% on absolut compared to the measured values. Additionally, during these months the values of the examined statistics indices are best compared to the other months of the year (RMSE=45% and MAE=34% in May; RMSE=28.8 mm, MBE=1.2 mm, MAE=22.7mm and RBIAS=0.026 in July). However, the poor performance of the CHIRPS dataset during other months highly affect its performance on the seasonal level. For example, the excellent performance of CHIRPS at the July and the August precipitation, when its estimates are quite accurate (with differences less than 5%) is somehow undergraded by the datasets highly overestimation in June (+60%) resulting to less accurate summer (June to August) precipitation estimates. However, even in this case CHIRPS performed adequately for summer precipitation. On the other hand, the very close estimates of autumn CHIRPS precipitation, is produced by overestimated values in October (by +11%) and November (+13%) amplified by high underestimates in September (-27%) that resulted to quite accurate seasonal values for the autumn. This is critical, for monthly climate and hydrological assessments, and can lead to high uncertainties.

4. Conclusions

The evaluation of the CHIRPS precipitation product in a high-altitude forest of Central Greece reveals significant discrepancies between satellite estimates and rain gauge observations, characterized primarily by an overestimation of precipitation. Seasonal analysis further delineated the dataset's performance, showcasing relatively better accuracy in autumn and notable overestimations in spring and winter. These findings underscore the necessity for cautious application of CHIRPS data, particularly in ungauged mountainous regions where precipitation variability is high. Future research should focus on the performance evaluation of multi-source gridded precipitation across diverse climatic conditions, evaluating also CHIRPS at extreme weather events and for multiple long-operating meteorological stations. This study highlights the potential and limitations of using CHIRPS product for environmental research and resource management in complex forested landscapes.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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