

Performance Evaluation of CHIRPS, ERA5-Land and PERSIANN-CDR Precipitation Products over the Black Sea Region of Türkiye (1984-2024)

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Abstract

Precise monitoring of precipitation in the Black Sea region of Türkiye is difficult due to rugged topography and coastal dynamics. In this study, the performance of three structurally distinct precipitation products, CHIRPS (V2.0 Final), ERA5-Land, and PERSIANN-CDR, was evaluated using a network of 135 homogenized stations between 1984 and 2024. Data extraction was conducted through a point-to-pixel matching approach, and performance was tested using continuous metrics (CC, KGE, RB, RMSE) along with categorical scores (POD, FAR, CSI) focused on the 95th percentile threshold. Additionally, performance variations were examined with respect to mean precipitation intensity, distance to the coastline, and elevation.

According to the performance metrics, CHIRPS demonstrates the highest statistical consistency with station-based observations, yielding a CC of 0.755, a KGE of 0.654, and a negligible bias (-0.007). ERA5-Land shows high correlation (CC: 0.71) and the best detection for extreme precipitation (POD: 0.50), but exhibits a significant positive bias (RB: 0.34) and high FAR (0.65). On the other hand, PERSIANN-CDR shows the weakest performance, with the lowest correlation (CC: 0.538) and very low detection scores (POD: 0.029). In conclusion, CHIRPS provides a more balanced representation, whereas ERA5-Land exhibits systematic overestimation, and PERSIANN-CDR shows limited capability in capturing rainfall timing and magnitude.

Keywords: Gridded precipitation product, Satellite rainfall, CHIRPS, ERA5-Land, PERSIANN-CDR, Evaluation metrics, Remote sensing

1. Introduction

Monitoring precipitation is challenging in complex terrains like Türkiye's Black Sea Region, where steep orographic gradients drive heterogeneous rainfall (Wu and Zhao, 2022; Wu et al., 2020; Chen and Chung, 2015). While ground stations provide accurate point-scale data (Liu et al., 2018), their sparse high-altitude distribution (Yang et al., 2020) and temporal gaps (Beck et al., 2020) limit their spatio-temporal continuity. Consequently, gridded satellite and reanalysis products have become essential (Ahmed et al., 2024; Tian et al., 2010). However, as their performance varies with topography and retrieval algorithms (Liu et al., 2019), evaluating their reliability is crucial for understanding their limitations in topographically demanding regions.

The performance of different precipitation datasets has been increasingly investigated in the literature, with a few assessments focusing on the diverse topographical conditions of Türkiye. In a more recent and extensive study, Akbaş and Özdemir (2024) evaluated 25 different precipitation products across Türkiye, concluding that reanalysis datasets, particularly ERA5-Land, offer higher reliability in complex terrains. However, they also highlighted that the sensitivity of these products fluctuates significantly in regions like the Eastern Black Sea, where steep topography and extreme rainfall events are dominant. In another recent study across Türkiye, Khorrami et al. (2024) reported that CHIRPS and ERA5-Land are among the best performing products on a climatological scale, specifically noting a monthly correlation of 0.79 for the Black Sea region. However, despite these general findings, further investigation is needed to assess their reliability in capturing extreme events and the impact of rugged coastal topography. Furthermore, as Tugrul and Oruc (2025) project an intensification of rainfall

extremes in the Black Sea region, accurately evaluating current gridded products becomes essential for reliable climate impact assessments. Additionally, Hisam et al. (2025) demonstrated that integrating multiple precipitation products with land surface features and topography through machine learning can significantly improve rainfall estimates in the Mediterranean region of Türkiye. Their findings underscore the critical role of environmental factors in reducing errors in gridded datasets, further justifying the need for a detailed examination of topographical influences in other complex regions like the Black Sea. Despite these advances, a detailed station-based evaluation focusing specifically on the Black Sea region and considering environmental gradients such as elevation and coastal proximity remains limited.

In this study, the performance of CHIRPS, ERA5-Land, and PERSIANN-CDR products is comprehensively evaluated across the Black Sea region using a station dataset covering the period 1984-2024. This study provides a region-specific evaluation of multiple precipitation products using a long-term station network, together with an analysis of extreme precipitation detection (P95 threshold) and environmental gradients such as elevation and distance to the coastline. In this context, a comprehensive assessment is conducted using both continuous and categorical metrics on overall and seasonal scales. These analyses aim to identify which precipitation dataset provides the most reliable representation of rainfall patterns in this complex coastal-mountain environment.

2. Study Area

This study focuses on the Black Sea Region in northern Türkiye (40°-42° N, 30°-43° E), covering approximately 143,537 km² (Aksu et al., 2022). The topography is characterized by a narrow coastal plain that rapidly gives way to rugged mountain ranges. Elevations rise sharply from sea level to nearly 4000 meters in the Kaçkar Mountains of the eastern Black Sea, creating steep topographical gradients across the landscape (Fig. 1).

Influenced by marine air masses, the region has a humid climate with perennial precipitation; the 1991-2020 normal is 829.3 mm, with the coastline receiving Türkiye's highest frequency of rainy days (TSMS, 2025). Significant orographic lifting over north-facing mountains drives high spatial variability. Such complex terrain makes the region a challenging environment for satellite and reanalysis-based products. Accurately representing both average conditions and extreme events is critical, as the area is highly susceptible to frequent floods and landslides (Aksu et al., 2022; Aziz et al., 2020).

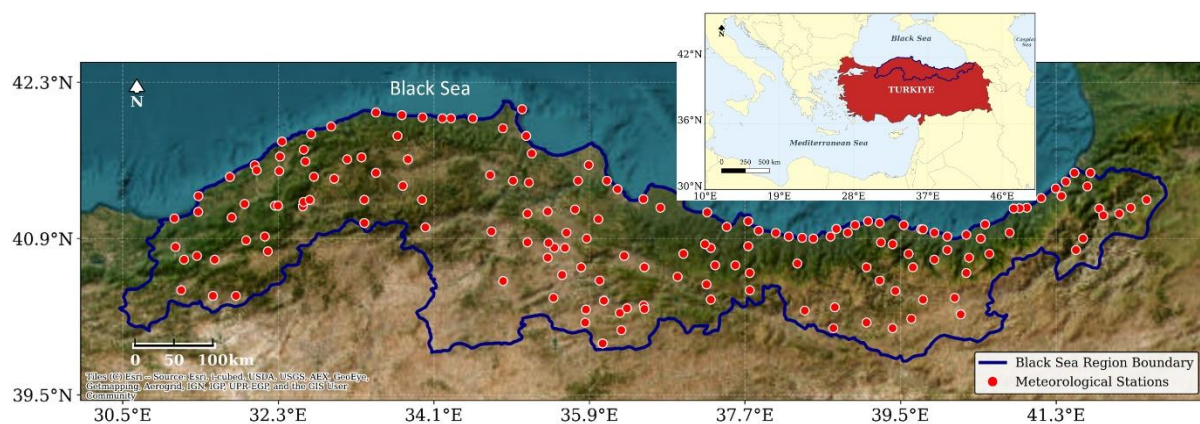


Fig. 1. Location of the study area and the spatial distribution of meteorological stations across the Black Sea Region, Türkiye.

3. Data and Methodology

3.1. Station Observations and Gridded Precipitation Datasets

The primary reference dataset for this study consists of monthly precipitation records from 163 meteorological stations distributed across the Black Sea Region (Fig. 1). These stations, managed by the Turkish State Meteorological Service (TSMS), provide point-based measurements of rainfall (TSMS, 2025). Elevation values for the meteorological stations were also provided directly by TSMS.

To evaluate distinct retrieval techniques, three gridded products were aggregated to a monthly scale (1984-2024). These include CHIRPS (v2.0 Final), a hybrid product (0.05°) merging satellite infrared (IR) cold cloud duration with station data (Funk et al., 2015); ERA5-Land, a reanalysis record (0.1°) integrating observations into numerical weather prediction models via data assimilation (Muñoz-Sabater et al., 2021); and PERSIANN-CDR, an ANN-based dataset (0.25°) that transforms geostationary IR temperatures into rainfall estimates, subsequently adjusted with global gauge products (Ashouri et al., 2015).

3.2. Data Integration and Quality Control

Station-grid matching was performed using the nearest-neighbor approach to maintain the integrity of the raw grid values. To address the issue of missing land grid cells due to land-sea masking along the Black Sea coast, bilinear interpolation was used specifically for affected coastal pixels in the ERA5-Land dataset. From an initial 163 stations, a three-stage quality control (QC) procedure was conducted: (1) 14 stations with fewer than 24 months of data were excluded, (2) P99-based outlier filtering removed erroneous records, and (3) the Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986) identified 14 non-homogeneous stations for removal (Fig. 2). Consequently, 135 stations were retained for the final analysis.

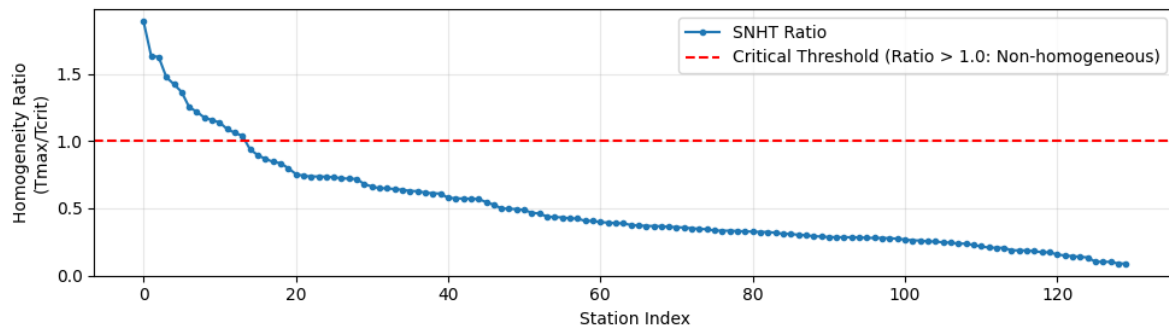


Fig. 2. SNHT homogeneity ratios for the meteorological stations. The ratio is defined as $T_{\max}/T_{\text{crit}}$, where $T_{\max}$ represents the maximum statistical test value identified for each station's time series and T_{crit} is the critical threshold at a 95% confidence level, specifically adjusted for each series' length through Monte Carlo simulations (Khaliq and Ouarda, 2007).

3.3. Statistical Evaluation Metrics

Product performance was assessed using seasonal metrics and categorical analysis of extreme precipitation. Specifically, continuous performance was assessed using the Pearson Correlation Coefficient (CC), Kling-Gupta Efficiency (KGE) (Gupta et al., 2009; Kling et al., 2012), Relative Bias (RB), and Root Mean Square Error (RMSE). Extreme precipitation skill (defined by the 95th percentile threshold) was evaluated using the Probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI). The P95 threshold was determined by pooling all monthly observations, resulting in a regional global value (185.3 mm) for overall analysis and season-specific values (e.g., 197.4 mm for DJF, 139.6 mm for MAM, 161.8 mm for JJA, 223.9 mm for SON) for seasonal categorical evaluations. Detailed mathematical

formulations for these metrics can be found in Tiwari and Garg (2025). Additionally, considering the complex topography of the Black Sea Region, station-wise analyses investigated performance variations across environmental gradients, including mean precipitation intensity, station elevation, and distance to the coastline.

4. Results and Discussion

In the study, the spatio-temporal accuracy of three gridded precipitation products is analyzed through overall and seasonal performance metrics, as well as their sensitivity to environmental gradients. Following the QC process, 135 stations were validated for the final analysis. The overall performance of the evaluated products across the entire study period is summarized in Table 1. CHIRPS demonstrated the highest statistical agreement with a CC of 0.755 and the lowest error magnitude (RMSE: 37.262 mm/month). ERA5-Land showed the strongest capability in detecting these extreme monthly events, achieving the highest POD (0.503) and CSI (0.261) values. However, ERA5-Land also exhibited a high false alarm ratio (FAR: 0.648) and a significant positive bias (RB: 0.339), indicating a tendency to overestimate precipitation in the region. PERSIANN-CDR showed comparatively lower performance, with the lowest CC (0.538) and a very limited detection probability (POD: 0.029).

Table 1. Overall performance metrics of the gridded products. RMSE is expressed in mm/month. Bold values indicate the best-performing product for each metric.

Precipitation Product	CC	RB	RMSE	KGE	POD	FAR	CSI
CHIRPS	0.755	-0.007	37.262	0.654	0.260	0.391	0.223
ERA5-Land	0.712	0.339	49.122	0.555	0.503	0.648	0.261
PERSIANN-CDR	0.538	-0.018	48.723	0.448	0.029	0.718	0.027

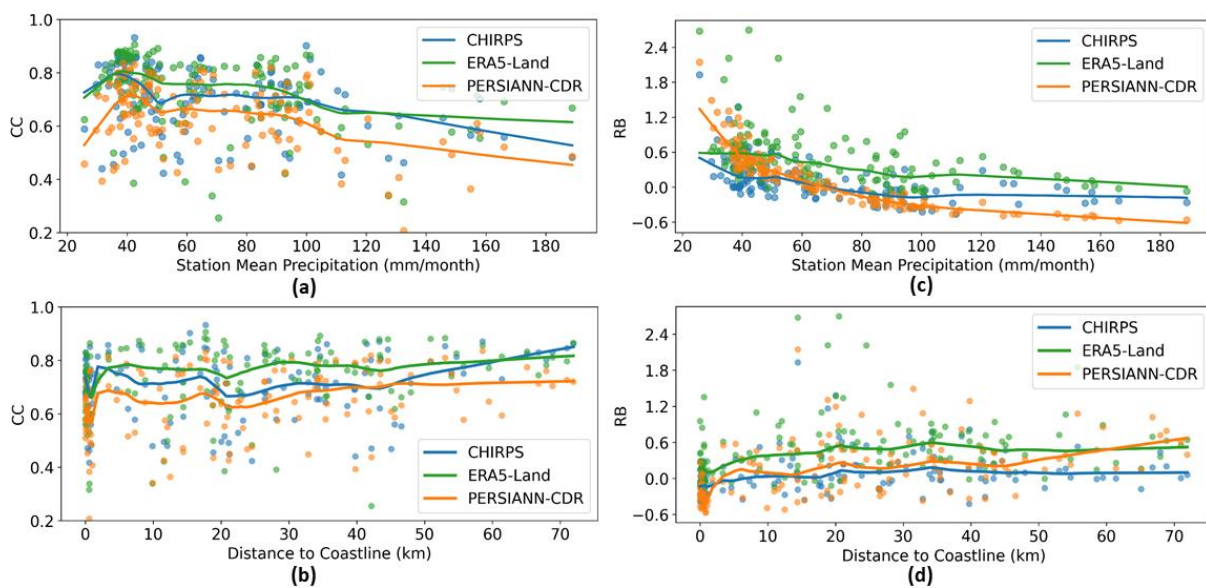
The accuracy of the precipitation products exhibits significant seasonal fluctuations, as detailed in Table 2. Winter (DJF): ERA5-Land outperforms other products during the winter season, achieving the highest correlation (CC: 0.795) and the lowest error (RMSE: 39.693 mm/month). This suggests that ERA5-Land's reanalysis framework is particularly effective at capturing large-scale frontal precipitation common in the Black Sea during winter. Spring (MAM): CHIRPS maintains a steady performance with a CC of 0.743 and the lowest seasonal RMSE (26.729 mm/month). In contrast, ERA5-Land reaches its highest detection probability (POD: 0.774) but suffers from a substantial positive bias (RB: 0.542) and a high false alarm ratio (FAR: 0.790). Summer (JJA): Performance metrics generally decline for all products during summer, likely due to the convective nature of localized rainfall. However, CHIRPS remains the most balanced product with a KGE of 0.620 and a near-zero RB (0.003). Autumn (SON): CHIRPS shows the highest agreement with observations (CC: 0.770), while ERA5-Land displays superior efficiency (KGE: 0.676) and success index (CSI: 0.278) in this transition period. PERSIANN-CDR: Across all seasons, PERSIANN-CDR consistently lags behind, particularly in detection capability, with POD values dropping as low as 0.003 in Autumn.

The performance of CHIRPS, ERA5-Land, and PERSIANN-CDR was further analyzed at the station level using LOWESS (Locally Weighted Scatterplot Smoothing) smoothing to identify trends across environmental gradients (Fig. 3). As shown in Figs. 3a and 3c, all products exhibit a general decrease in correlation (CC) as mean monthly precipitation increases beyond 60 mm/month. While ERA5-Land maintains the highest stability in CC, PERSIANN-CDR shows a more pronounced decline in accuracy and an increasing negative bias (RB) in high-precipitation regimes.

Table 2. Seasonal performance metrics of the gridded products. RMSE is expressed in mm/month. Bold values indicate the best-performing product for each metric.

Season	Precipitation Product	CC	RB	RMSE	KGE	POD	FAR	CSI
DJF	CHIRPS	0.741	-0.007	39.913	0.676	0.366	0.359	0.304
	ERA5-Land	0.795	0.223	39.693	0.632	0.388	0.366	0.317
	PERSIANN-CDR	0.485	0.146	53.673	0.352	0.025	0.742	0.024
MAM	CHIRPS	0.743	0.003	26.729	0.637	0.289	0.383	0.245
	ERA5-Land	0.666	0.542	51.333	0.317	0.774	0.790	0.198
	PERSIANN-CDR	0.654	0.099	31.074	0.560	0.132	0.635	0.107
JJA	CHIRPS	0.722	0.003	36.550	0.620	0.241	0.486	0.196
	ERA5-Land	0.631	0.417	54.883	0.415	0.525	0.745	0.207
	PERSIANN-CDR	0.516	-0.222	47.314	0.363	0.022	0.696	0.021
SON	CHIRPS	0.770	-0.023	43.975	0.631	0.131	0.385	0.121
	ERA5-Land	0.768	0.225	49.321	0.676	0.472	0.597	0.278
	PERSIANN-CDR	0.543	-0.139	58.798	0.383	0.003	0.750	0.003

The influence of maritime effects is clearly visible in Figs. 3b and 3d. In the immediate vicinity of the coastline (0-10 km), products show higher variability and lower CC values. CHIRPS and ERA5-Land show a marked improvement in correlation as the distance to the coastline increases. In terms of Relative Bias (Fig. 3d), ERA5-Land tends to slightly overestimate precipitation across most distances, while CHIRPS remains closest to the zero-bias line, particularly in inland regions.

**Fig. 3.** Station-based sensitivity of gridded product performances to environmental gradients using LOWESS. Subplots illustrate variations in CC and RB against station mean precipitation (a, c) and distance to the coastline (b, d).

Station-based CC and RB metrics reveal a clear relationship between station location and product accuracy (Fig. 4). In terms of CC Distribution (Figs. 4a-c), all products show a higher agreement with ground observations in the central and western parts of the region. CHIRPS (a) and ERA5-Land (b) exhibit a relatively uniform CC distribution, whereas PERSIANN-CDR (c) shows a significant decrease in correlation, particularly in the high-elevation areas of the Eastern Black Sea Mountains. The darker purple points in the eastern high-altitude zones indicate that all gridded products struggle to capture the precipitation patterns across these steep terrains. For RB patterns (Figs. 4d-f), the bias maps clearly differentiate the systematic errors of the products, ERA5-Land (e) shows a widespread positive bias (red points), confirming its tendency to overestimate precipitation across the entire topographic gradient, especially at

higher elevations. CHIRPS (d) maintains the most neutral bias (white/light-colored points), although it shows slight underestimation in some coastal stations. PERSIANN-CDR (f) exhibits a mixed pattern but tends toward underestimation (blue points) in the high-elevation easternmost stations.

The SRTM-derived background confirms that as elevation increases (moving from green to brown tones on the map), the reliability of satellite and reanalysis products generally decreases. This highlights the orographic effect as a primary challenge for gridded products in the Black Sea region.

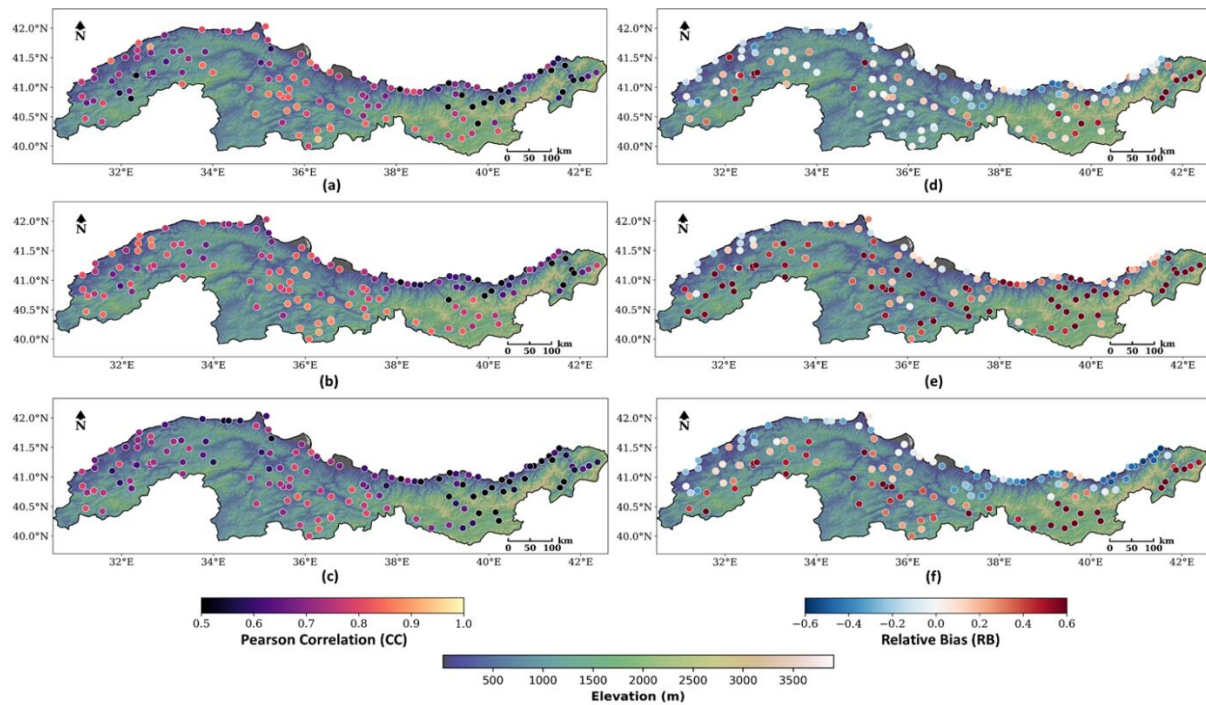


Fig. 4. Spatial performance of CHIRPS, ERA5-Land, and PERSIANN-CDR: (a-c) CC and (d-f) RB distributions. Color-coded station points are overlaid on SRTM topography to highlight the relationship between product accuracy and elevation.

5. Conclusion

This study highlights the inherent complexities of monitoring precipitation across the diverse and rugged landscape of the Black Sea region through an evaluation of CHIRPS, ERA5-Land, and PERSIANN-CDR. Based on a robust network of 135 homogenized stations, CHIRPS stands out as the most balanced and reliable product for the region. Its superior performance is largely driven by its high spatial resolution and the integration of station-based climate signals, which allow it to remain much closer to the zero-bias line than its competitors.

Our station-level analysis reveals that ERA5-Land often achieves higher correlation values than CHIRPS, particularly across gradients like distance to the coastline. However, this high agreement is accompanied by a significant caveat: ERA5-Land exhibits a persistent positive bias, systematically overestimating rainfall totals across the region. This tendency is further validated by our categorical metrics for extreme events (P95), where ERA5-Land displays a strong POD but suffers from a notably high FAR, reflecting an over-prediction of rainfall intensities.

The relatively lower performance of PERSIANN-CDR may be partly attributed to its coarser spatial resolution, which potentially limits its ability to capture the fine-scale orographic precipitation patterns of the Black Sea's steep terrain. Furthermore, the product's reliance on

IR sensors, which often struggle to detect rainfall from low-level clouds, could be another contributing factor to the observed inaccuracies in this region. In light of these findings, while CHIRPS provides the most reliable baseline, researchers must be mindful of ERA5-Land's tendency to inflate rainfall amounts and the inherent limitations of coarser products in representing complex coastal-mountain interactions.

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