COMPARISON OF DIFFERENT GRIDDED-PRECIPITATION PRODUCTS WITH OBSERVATIONS OVER TURKEY

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ABSTRACT

Climate change has become the most significant threat to environmental problems in Turkey as well as for the whole world. Considering the effects on many issues such as agriculture, water resources, and human health, it is important to determine the variations in meteorological parameters caused by climate change. This type of analysis requires long recorded and complete observations with a good areal coverage. However, the precipitation gauges operated by Turkish Meteorological Service are unevenly distributed over Turkey and biased towards the low altitudes. Some of the gauge measurements are abandoned in time while new gauges are installed, and these actions are resulted in short or incomplete precipitation records which might partially affect the analysis of precipitation-regime changes in time. In order to reduce such effects, several gridded precipitation products based on satellite observations, combination of satellite and gauge observations, re-analysis products and high-resolution atmospheric simulations can be utilized. In this study, we used three different gridded-precipitation data sets: NEWA-WRF, ERA5-Land and IMERG. NEWA-WRF precipitation data are produced by New European Wind Atlas project which aims to produce mesoscale wind atlas over Europe. The mesoscale climatology is generated by using the Weather Research and Forecasting (WRF) model with 3 km resolution. ERA5-Land data are re-analysis product of ECMWF and IMERG data are The Integrated Multi-satellitE Retrievals for Global Measurement Precipitation mission of NASA. The time periods for the first two data are between 1989 and 2018, and for the last one is between 2001 and 2018. Additionally, the precipitation observations measured at 80 meteorological stations which have relatively even distribution all over Turkey, are taken as a reference dataset. First, we compared the seasonal and annual variability of the gridded products with those of gauge observations over Turkey. Here, RMSE, MAE, and correlation coefficients are utilized as validation metrics. Although ERA5-Land has coarsest resolution among these three data sets, it is the most compatible with the observations and illustrates the lowest error values overall study area. NEWA-WRF is the second-best dataset in terms of average error values. Nevertheless, it has better results than the others in the eastern part of Turkey because of the high resolution with 3 km grid spacing which leads better representation of the high topography over eastern Turkey. IMERG ranks the last among three datasets in terms of the metrics considered, even though it has lower errors at few stations. Then, we analyzed extreme precipitation events represented by each gridded product by calculating the climate extremes indices such as R10mm, R95p and R99p. Finally, we compared them with the ones obtained from observations. The tendencies of the mean and extreme values are evaluated from 1989 to 2018, and regional variations are discussed.

Keywords: *Gridded-precipitation Products, Extreme Precipitation, Turkey*

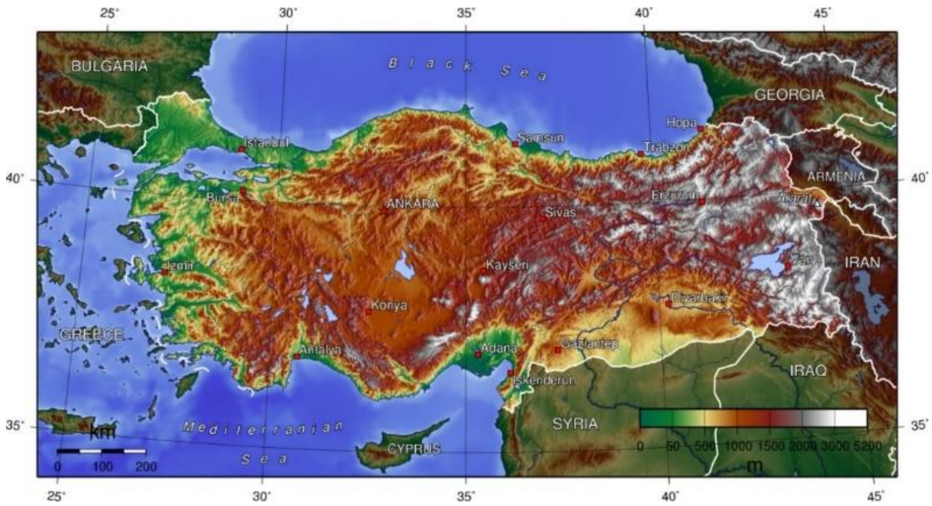
1. INTRODUCTION

Climate change has become the most important threat to environmental problems over time and has undeniable effects on both nature and people. Considering the effects on many issues such as agriculture, water resources, and human health, it is important to determine the variations in meteorological parameters caused by climate change. Due to the changes in climate, characteristics of the weather events also change. Besides the long-term changes in climatic conditions, research should be conducted to determine the effects of climate change on extreme weather events. For the aforementioned reasons, the first aim of this study is to analyze the performance of gridded precipitation products, and the second is to determine the change of long-term precipitation amount and intensity over the years. According to the IPCC (2012) report, global warming, another consequence of climate change, will cause an increase in extreme precipitation events in many parts of the world. It is a fact that, as the air temperature increases, the water vapor holding capacity of the air increases. Dai (2005) states in his study that for every 1 degree Celsius of warming in the air, the atmosphere has 4.9% more water holding capacity. The atmosphere containing more humidity may cause more intense precipitation events, as is evident in the observations. It can lead to situations such as floods and landslides that will affect human life, and moreover, that may cause loss of life and property, and the occurrence of events that are described as natural disasters. In this context, extreme precipitation event under the influence of changing climatic conditions is a meteorological event that directly affects social life, has the potential to cause economic damage to society as well as environmental damage, and can be described as a threat to living life and nature. If precipitation products are to be analyzed over a region, data with good distribution over the research area should be used to obtain accurate and consistent results. Observation stations are usually built on relatively flat lands close to residential areas. This means there are data shortages in terrains with complex topography. Research conducted with observation data, therefore; limits our understanding of characteristics of precipitation on complex terrains due to lack of data. Using gridded precipitation products allows us to make research on these regions. One of the studies conducted in this context is the study of Chen et al. (2020), which tests the spatial performance of the data sets for the Himalaya and its surroundings with different reanalysis data sets for precipitation products. In this study, ERA-Interim (0.7°), ERA5 (0.25°), ERA5-Land (0.1°), and refined HAR (0.1°) datasets are used. High resolution ERA-Interim and ERA5 had the highest correlation but produced more precipitation overall. The performance of these datasets at high altitudes is better than the other two datasets. In lower domains, all datasets perform well. While other datasets underestimate the precipitation amount, ERA5-Land, on the contrary, overestimate it. In another study, Anjum et al. (2018) analyzed the performance of IMERG, TRMM, and TMPA products. The study includes results for the 2014 – 2016 period. IMERG has the highest monthly correlation value of 0.93. The best relative bias value in the winter season belongs to IMERG with 2.61%. The RMSE value of 2.05 mm/day is the best among the others. Other datasets generally overestimate for light precipitation and underestimate for heavy precipitation. Overall, IMERG outperformed TMPA products. In order to examine and detect extreme events, precipitation data should be evaluated over daily totals rather than using average values during the study period. The method that allows us to analyze daily totals on a climatological scale using climate indices. Climate indices are simple definition tools used to make sense of the conditions of the climate and the state of the climate system within the specified period. Increasing trends have been identified in studies using extreme precipitation indices which are cover the northwest of Turkey and the Black Sea coasts (Popov et al. 2017; Croitoru et al., 2013). In the study conducted by Norrant and Douguédroit (2006) for the Mediterranean basin, it was concluded that the extreme indices of that related with the number of rainy days have a decreasing trend while the precipitation amount increased in Greece, which is located in the west of Turkey. By this result, an explanation has been given for the increase in precipitation intensities in Greece. In another study involving Turkey and the countries located in the southeast, an increasing trend was calculated for south-eastern Turkey while there is no significant trend for other countries (Zhang et al., 2005). In the study conducted for Turkey by Batıbeniz and Önol (2015), five different extreme precipitation indices were used. While there was a decreasing trend for the Aegean Region and the Mediterranean Region, an increasing trend was found for the Anatolian Peninsula in the study.

2. STUDY AREA

The study area is Turkey which is a half-island nation located in the Mediterranean Basin. In recent years, extreme precipitation events in Turkey have been increased as in number and severity, as worldwide. Turkey consists of seven geographic regions in an area of 783.562 km². More than half of the country consists of high areas with an altitude exceeding 1000 m. The surrounding by the sea on three sides (Black Sea, Aegean Sea, and Mediterranean Sea), state of the coastal mountains, and the variety of different types of landforms have led to emerging different climate and precipitation type region to region in Turkey (Sensoy, 2003). Extreme precipitation events are seen in different parts of the country due to coercive mechanisms (e.g. topography).

Figure 1. Topographical map of Turkey (Wikipedia, 2005).



3. DATA AND METHODOLOGY

3.1. Data

Two types of data sets were used in this study. The first one is station observation data and the second one is gridded data. The observed daily precipitation data from 80 gauging stations that are evenly distributed over the Turkey (Figure 2), was obtained from Turkish State Meteorological Service (TSMS) over the period of January 1979 to December 2019. Three different data sets are used in the gridded data format. These data sets are ECMWF Reanalysis 5th Generation for land variables (ERA5-Land), Integrated Multi-satellitE Retrievals for GPM (IMERG), and New European Wind Atlas WRF (NEWA WRF) data, respectively. ERA5-Land is a gridded reanalysis dataset from 1981 to the present and provides high-resolution hourly data related to land variables. IMERG is an algorithm that combines information from the GPM satellite in order to estimate the precipitation over the Earth's surface. NEWA WRF 3-km data from New European Wind Atlas Project, which is created by the consortium for Europe plus Turkey, includes 100 km offshore area and also complete North and Baltic Seas (Table 1). The data to be used are daily precipitation data covering long years, as the study aim to examine extreme precipitation events and their spatial and temporal variability. In addition, temperature data for the same period were also examined. Accordingly, all observation or gridded data sets used in the study consist of daily data that are analyzed under two different time period due to non-overlapping temporal coverages of data sets. IMERG data is available from 2000 and there is only available data between 1989-2018 for NEWA WRF. That's why the short period covers 2001-2018 and the long period covers 1989-2018.

Figure 2. Spatial coverage of selected TSMS meteorological observation stations.

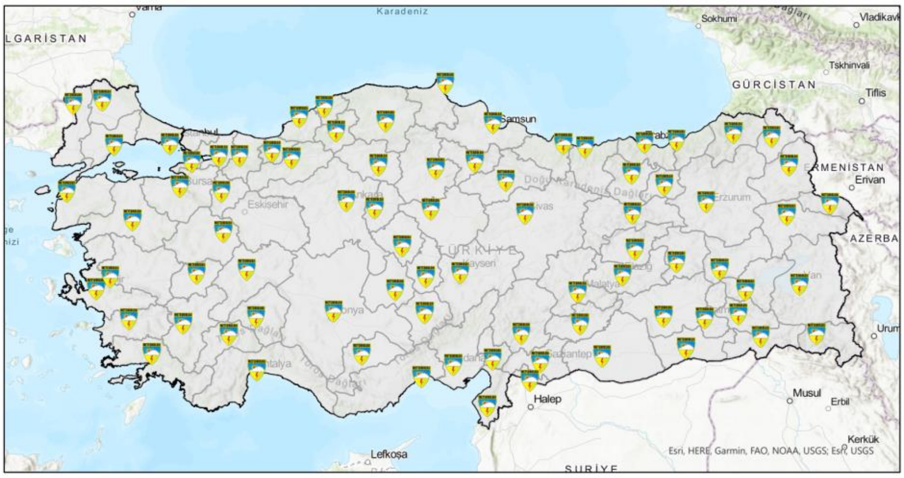


Table 1. The brief information about gridded data sets.

Product Name	**Source**	**Spatial Coverage**	**Temporal Coverage**	**Temporal Resolution**	**Spatial Resolution**
ERA5 – Land	High-resolution reproduction of ERA5 climate reanalysis of land components	Global	Jan 1981 – Present	Hourly	0.09° (~ 9 km)
IMERG	An algorithm that combines information from the GPM satellite	Global	Jan 2000 – Present	Half-hourly	0.1° (~ 10 km)
NEWA WRF-3km	WRF precipitation product that created for New European Wind Atlas	23.5269° to 47.9627° (longitude), 31.1121° to 45.809° (latitude)	Jan 1989 – 2018	Half-hourly	0.03° (~ 3 km)

3.2. Methodology

The validation metrics were used to investigate the consistency of the data sets with the observations. The metrics of Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Correlation Coefficient (*r*), bias and Standard Deviation (SD) are calculated in this work. The definitions of these mentioned metrics are provided in Table 2. MAE and RMSE measure the magnitude of error with respect to the observed data. Thus the smaller MAE and RMSE means the smaller error. The perfect score is 0. While *r* is a measure of linearity between product and observation, bias measures the difference between forecast data and observed data. Standard deviation (SD) is used to measure the dispersion of a data set from its mean. In order to obtain more specific and detailed results for extreme events in the study to be conducted after the general evaluation, daily gridded precipitation data should be analysed in this context.

Therefore, extreme precipitation indices such as R10mm R95p and R99p, were analyzed and trend analysis was performed. R10mm is the climate index used for detecting the count of days which have heavy precipitation more than10 millimeters. Besides, R95p (R99p) determines the percentage of very (extremely) wet days according to the 95th (99th) percentile of the reference period.

Table 2. Metrics for the precipitation products verification.

Name and definition	Notes
Mean Absolute Error (MAE) $MAE = N^{-1}\sum_{i=1}^{N}\lvert F_i - O_i\rvert^2$	MAE is an error analysis method that gives a measure of the average size of the error in an estimate. Best score is 0.
Root Mean Square Error (RMSE) $RMSE = \sqrt{N^{-1}\sum_{i=1}^{N}(F_i - O_i)^2}$	RMSE is an error analysis method obtained by calculating the standard deviation of the estimation errors. Best score is 0.
Correlation Coefficient (r) $r = \frac{\sum_{i=1}^{N}(F_i - F)(O_i - O)}{\sqrt{\sum_{i=1}^{N}(F_i - F)^2}\sqrt{\sum_{i=1}^{N}(O_i - O)^2}}$	Correlation coefficient (r) measures the degree of linearity between data sets and between reference data. It can vary between -1 and 1, and the best score for this method is 1
BIAS $bias\ (\%) = \frac{\sum_{i=1}^{N} F_i - O_i}{\sum_{i=1}^{N} O_i}$	Relative bias is used to calculate the percentage of this difference. Absolute minor results are defined as the best scores for this metric.
Standard Deviation $SD = \sqrt{\frac{\sum_{i=1}^{N}\lvert F_i - \overline{F}\rvert^2}{N-1}}$	Standard deviation is used to measure the dispersion of a data set from its mean. As the dispersion or variability increases, the greater SD is calculated.

4. RESULTS AND DISCUSSION

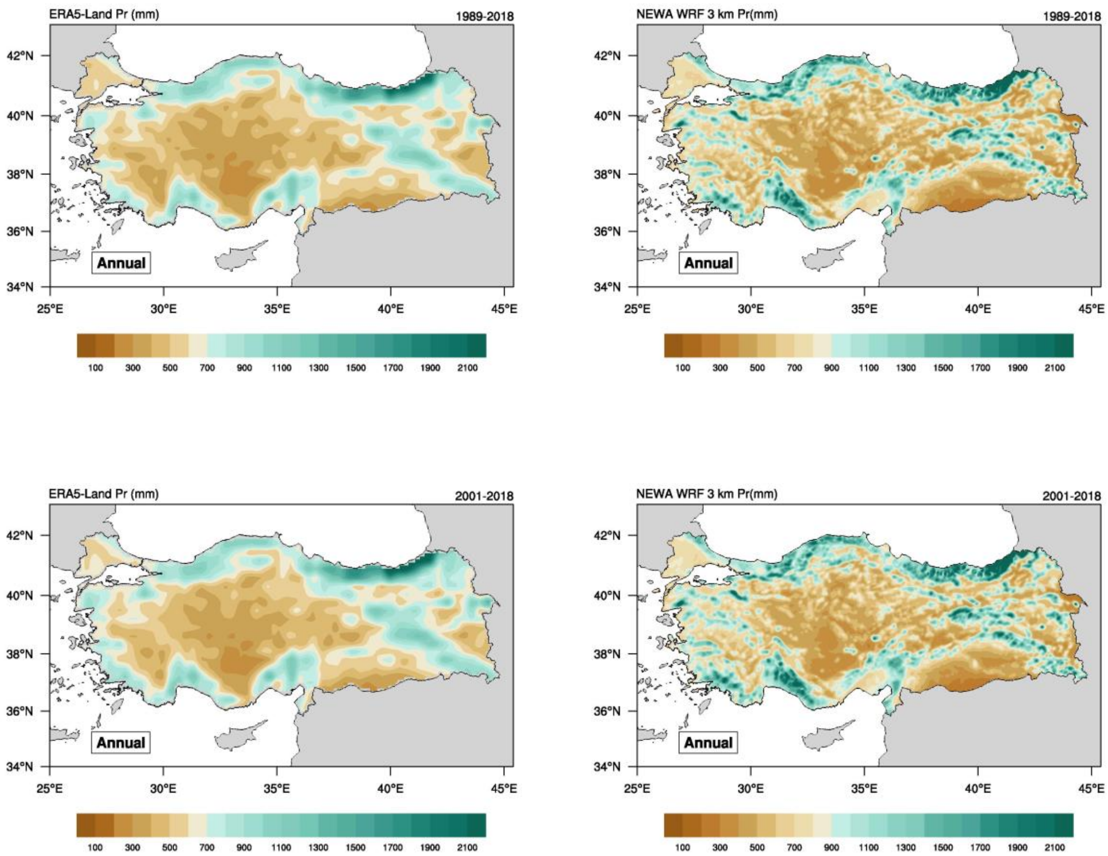
4.1. Annual Averages of Different Products

According to the 30-year precipitation averages and 18-year precipitation averages (Figure 4) maps, the driest parts of the country are roughly the Region of Central Anatolia and its surroundings with 200 mm/year average plus the Region of Southeast Anatolia with 350 mm/year average. The regions dominated by the highest precipitation amounts are the Black Sea coasts with 1100 mm/year and the eastern Black Sea with 2000 mm/year average. These regions are located where the mountains extend parallel to the sea.

4.2. Precipitation Regime Change in Periods

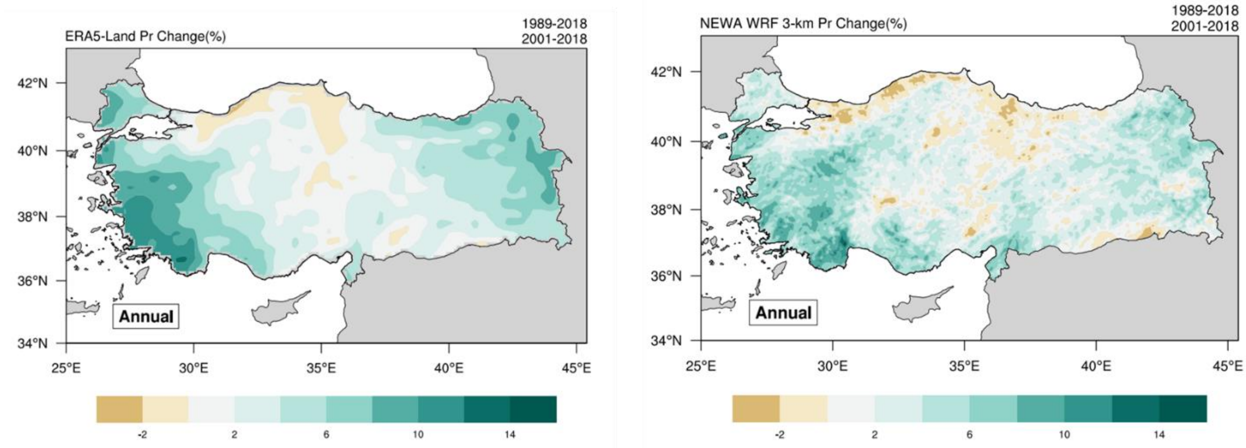
Figure 4 shows the change in precipitation regime as a percentage and indicates that there is an increase in precipitation amount in most of the country. Regionally, it can be said that for ERA5-Land, there is an approximately 12% increase in precipitation in the west of the country and the increase is also observed especially in the eastern part of the Mediterranean Region and the southern part of the Aegean Region. According to NEWA WRF, the changes reach maximum with 10%. In the Central Anatolia Region, there is no significant change, the changes vary between 1% of decrease and increase. In some locations, decreasing regime reaches more than 2%. In the east of the country, there has been an increase in annual precipitation averages of 6%, including the eastern Black Sea.

Figure 3. Annual total mean precipitation for 1989 – 2018 period (top), and 2001 – 2018 period (bottom) for ERA5-Land and NEWA WRF, respectively.



In Southeastern Anatolia, there are no significant changes but both datasets indicate a decreasing regime of 2% from Gaziantep to Mardin. The most striking change in the regime is observed over the Black Sea Region. From the east side of the Marmara Region to the middle part of the Black Sea Region, there is a consistent precipitation decrease in the coastal part, for ERA5-Land. For NEWA WRF this decreasing regime continues to even further west.

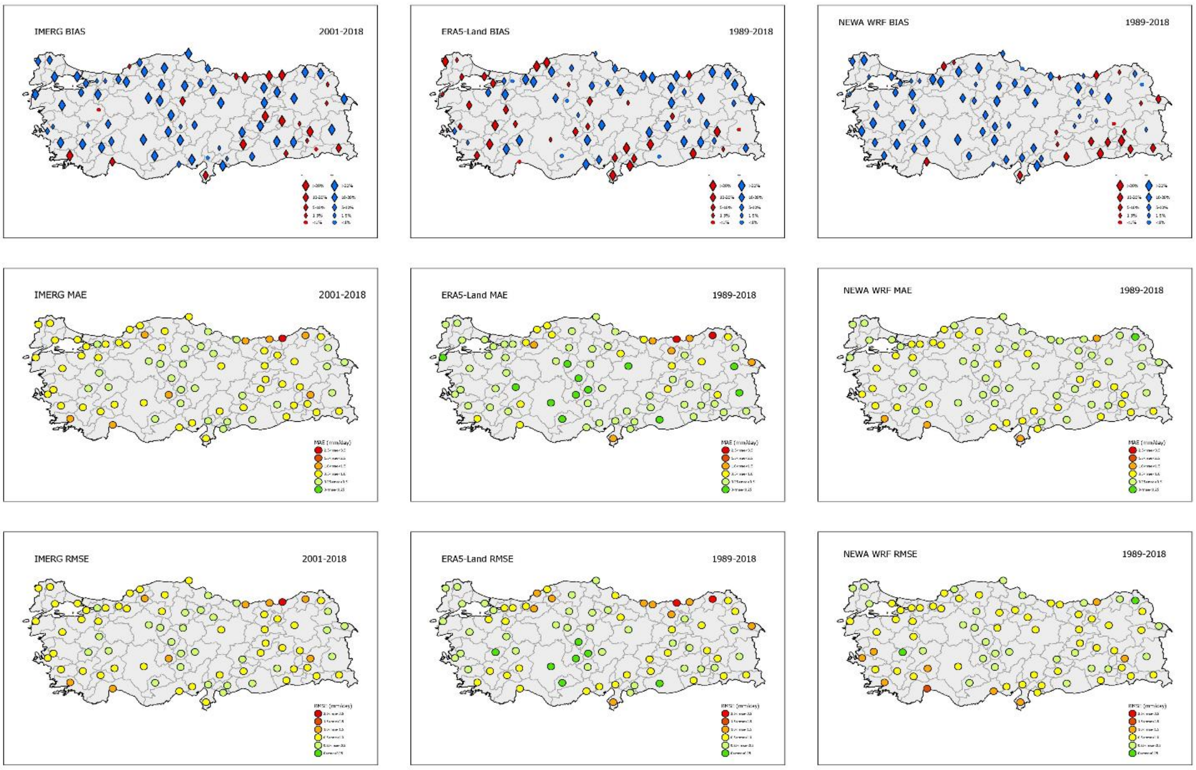
Figure 4. Annual precipitation regime changes in periods for ERA5-Land and NEWA WRF, respectively.



4.3. Comparisons of Averages

The comparisons of different precipitation products in terms of validation metrics such as BIAS, MAE, and RMSE shown in Figure 5. In BIAS maps, the blue color represents a positive percentage of BIAS and the red color represents the negative percentage of it. The values that smaller than 1% are shown with a circle shape and the bigger values are shown with a diamond shape. The larger the error, the larger the diamond shape. IMERG biases are scattered over the country, while ERA5-Land gives the best results for central part, and NEWA-WRF gives the best results for eastern part of the country. The percentages, according to the evaluation made on the selected stations; are generally positive by IMERG (+73.75%) and NEWA WRF (+75%) while ERA5-Land (+57.5% vs. -42.5%,) results are in balance. In terms of MAE results, IMERG and ERA5-Land data set have the worst results for the north-eastern part of the country particularly over Rize (2.59 mm/day) for IMERG whereas over Trabzon (2.84 mm/day) and Artvin (3.06 mm/day) for ERA5-Land. MAE errors are not high with respect to NEWA WRF. It is important to emphasize that the best results for ERA5-Land are in areas far from the sea. According to the percentage values, the error rate for all three data sets is below 1 mm/day for the great majority of IMERG (88.75%), ERA5-Land (90%), and NEWA WRF (95%) stations. In terms of RMSE results, similar with MAE, IMERG and ERA5-Land data set have the worst results for the north-eastern part of the country. Rize (2.75 mm/day) for IMERG while Trabzon (2.95 mm/day), and Artvin (3.15 mm/day) for ERA5-Land. For NEWA WRF, there is no stations that is above 2.5 mm/day error but high errors are seen mostly in south-west part of the country. The best results for ERA5-Land are represented by circles that are narrowed a little and moved through the center of the country. According to the percentage values, the error rate is similar to IMERG (88.75%) while the percentage values decrease for ERA5-Land (86.25%) and NEWA WRF (88.75%).

Figure 5. The validation metrics results for BIAS, MAE, and RMSE, respectively from top to bottom. The maps represent IMERG, ERA5-Land, and NEWA WRF data sets, from left to right.



In Table 4, there are validation metrics results shown in a single table. Our comparisons illustrate that the best results belong to IMERG for both annual and seasonal time scales. The data set that gives the worst results in winter and summer is NEWA WRF, while it is ERA5-Land that gives the worst result in spring and autumn.

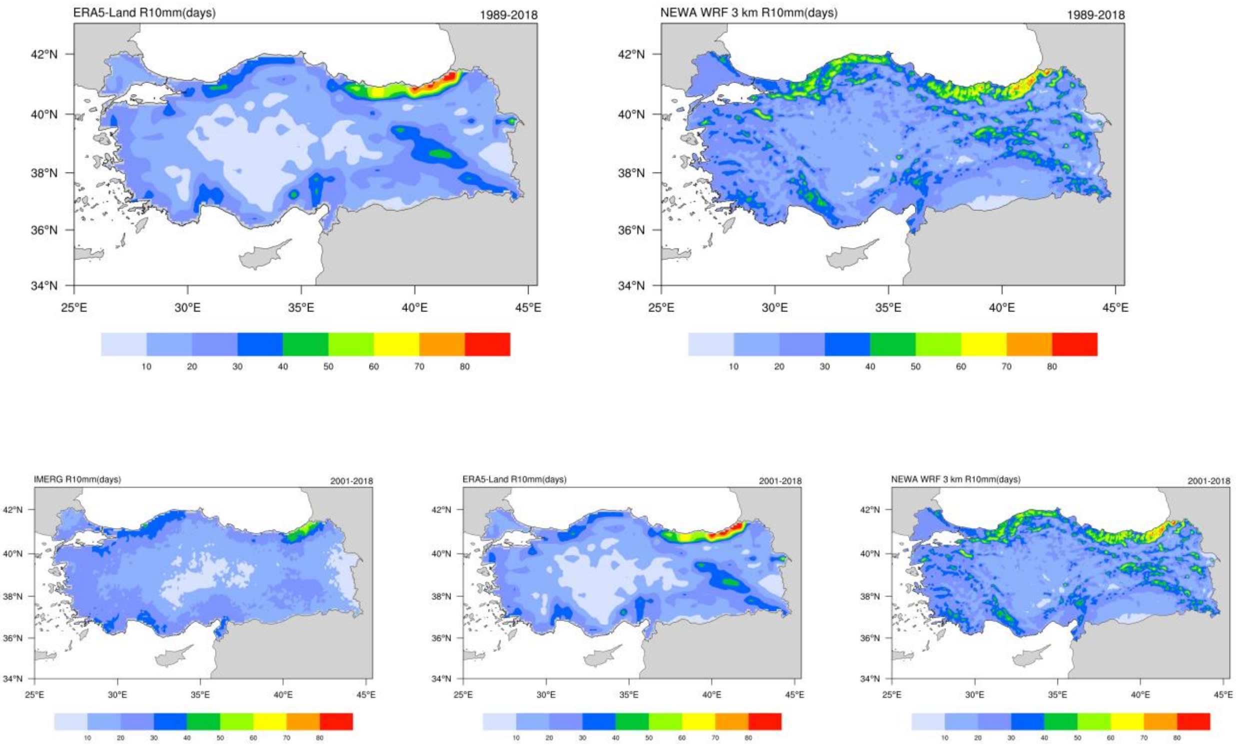
Table 3. Statistical error characteristics of daily precipitation estimates derived from gridded products in 2001 - 2018 (available data period for all products) and different seasons with reference to gauge records.

	IMERG	**ERA5-Land**	**NEWA WRF**
Entire Period (SP)			
RMSE (mm/day)	0.24	0.38	0.43
MAE (mm/day)	0.20	0.31	0.36
BIAS (%)	8.98	6.55	0.82
Winter			
RMSE (mm/day)	0.42	0.46	0.80
MAE (mm/day)	0.36	0.37	0.68
BIAS (%)	12.76	-5.51	26.13
Spring			
RMSE (mm/day)	0.20	0.49	0.32
MAE (mm/day)	0.18	0.40	0.26
BIAS (%)	7.80	16.22	5.37
Summer			
RMSE (mm/day)	0.11	0.22	0.28
MAE (mm/day)	0.09	0.19	0.24
BIAS (%)	6.00	18.01	-31.06
Autumn			
RMSE (mm/day)	0.24	0.37	0.33
MAE (mm/day)	0.20	0.29	0.25
BIAS (%)	9.35	-2.54	2.83

4.4. Variation and Trends in Precipitation Extremes

In the calculations that made on average values, the extreme values are assigned to an average value. Due to this situation, extreme values are not taken into account up to now in the present study. In order to determine the effect of climate change on extreme values, daily data should be taken into account without averaging the data set. Even if the analysis with mean values gives decreasing results, the extremes can increase or vice versa. According to R10mm index results, there are small changes for ERA5-Land and NEWA WRF in terms of this index from the 1989-2018 period to the 2001-2018 period. All three data sets, especially in the regions geographically close to the sea, has higher R10mm results. The highest number of heavy precipitation days are seen in the eastern side of the Black Sea Region for all data sets. The maximum R10mm index results are calculated as 50-60 days range for IMERG, 70-80 days range for NEWA WRF and over 80 days for ERA5-Land. On the other side, the Central Anatolia Region and surrounding areas have the lowest results. The minimum R10mm index results are calculated as 10-20 days range for NEWA WRF, 0-30 days range for IMERG, and 0-10 days range for ERA5-Land. It is possible to interpret that ERA5-Land overestimates in the eastern Black Sea Region and underestimates in the Central Anatolia Region in terms of the R10mm (Figure 6).

Figure 6. R10mm index results for 1989 – 2018 period (top) for ERA5-Land and NEWA WRF; 2001 – 2018 period (bottom) for IMERG, ERA5-Land, and NEWA WRF, respectively.



Because of the small changes in spatial coverage of R95p and R99p indices, results can be interpreted with trend analysis. Therefore, Figure 7 and Figure 8 indicate the annual increase rates for R95p and R99p indices. The count of heavy and extremely wet days increases in the red areas on the map and decreases in the blue areas over time. In the regions that marked with black dots, there are decreasing and increasing trends. It can be said that there are no coherent results between the 1989 – 2018 and the 2001 – 2018 period for ERA5-Land and NEWA WRF. In Figure 9, according to the R95p trend, there are different results among the data sets. However, they are in agreement that the trend is decreasing in the southwest part of Turkey. The southeast part of Turkey has an increasing trend for all data sets in the 2001 – 2018 period. In Figure 10, according to the R99p trend, in a similar way with R95p, there is no coherency among results for time periods. The mentioned decreasing significant trend in the southwest part of the country also was found for all data sets in R99p. There is no significant trend in the east side of the country for the IMERG data set but there is an increasing trend for the ERA5-Land and NEWA WRF.

Figure 7. R95p index trend analysis results for 1989 – 2018 period (top) for ERA5-Land and NEWA WRF; 2001 – 2018 period (bottom) for IMERG, ERA5-Land, and NEWA WRF, respectively.

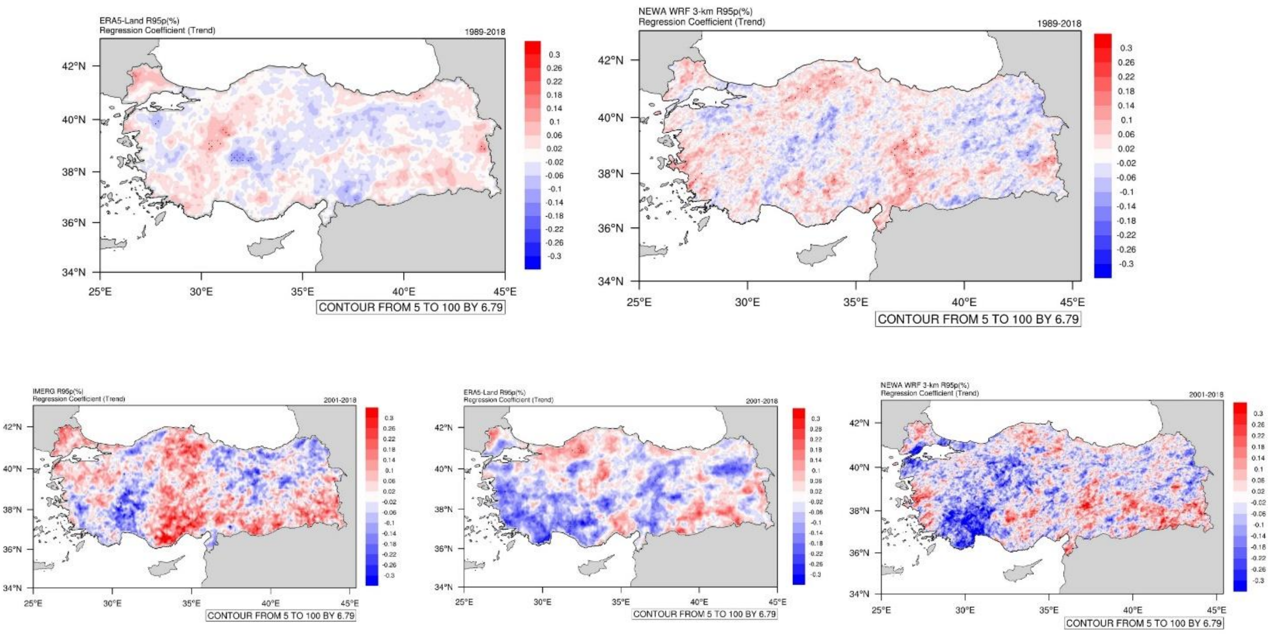
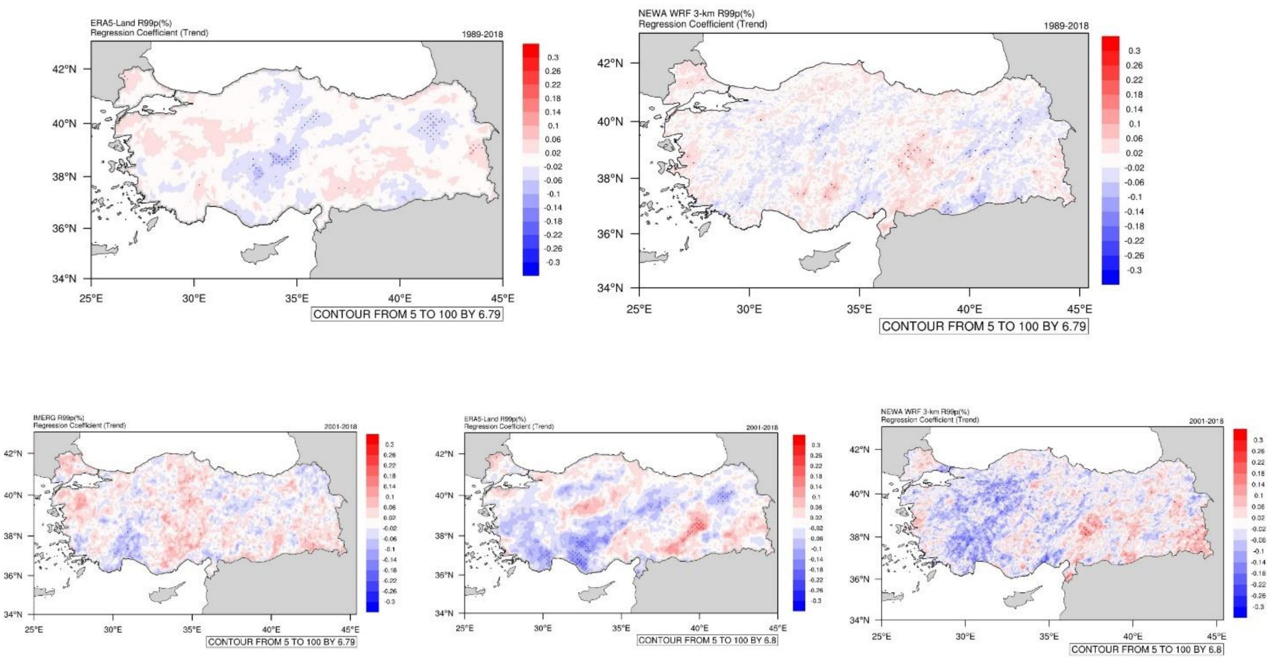


Figure 8. R99p index trend analysis results for 1989 – 2018 period (top) for ERA5-Land and NEWA WRF; 2001 – 2018 period (bottom) for IMERG, ERA5-Land, and NEWA WRF, respectively.



5. CONCLUSION

Climate studies enable to understand the character of the region and to understand the situations that cause extreme events and to have an idea about the weather events that may occur in the future. In the present study, the climate of Turkey was examined in terms of precipitation products with gridded data sets, and extreme precipitation analysis is performed with climate indices. It is deduced there is an increase in annual temperature averages for the Region of Central Anatolia and surroundings. Precipitation regime is decreased in the Region of Black Sea and there is no significant change in the Region of Central Anatolia compared to the increase of the other regions. Among the data sets compared to the observation data, IMERG performed the highest consistent results since it is based on the satellite observations. Yet, for the eastern part, NEWA WRF, and for the central part ERA5-Land are the representative ones with their high regional consistent results. According to mean values, there is increasing in precipitation amount in the south-eastern part of Turkey, while both extreme indices (R95p & R99p) indicate that the count of wet days has a decreasing trend. This situation is proof that the intensity of precipitation is increased over time. Increasing precipitation intensities, as we mentioned in the introduction, affect agriculture, water resources, the environment, and as a result, people and their living standards. In future studies, this subject can be discussed in more detail and contribution can be made to the researched subject by using different approaches or indices.

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