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Climatology of Extreme Precipitation from Observational Records in Greece †

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Abstract: Precipitation is widely considered an important parameter and a key indicator of the evolving climate change. The intensity as well as the frequency of precipitation can be largely affected by disturbances of the hydrological cycle as a result of the increasing temperature of the atmosphere and the oceans. Through a variety of statistical methods it is possible to assess changes in precipitation over the recent years both regionally and globally. In this work, precipitation data from seven WMO stations in the Greek region was studied over the period 1990–2020. By analyzing a set of extreme precipitation indices and applying the Sen and Mann-Kendall statistical methods, the trends and statistical significance of precipitation in the area of study were investigated. The results reveal an increase in the yearly number of days with extreme precipitation events as well as in the total amount of precipitation.

Keywords: precipitation; climate change; extreme events

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1. Introduction

Over the recent years, it has become more evident that precipitation events occur more frequently and with greater intensity as a result of climate change [1,2]. Indeed, under warmer global conditions caused by the induction of anthropogenically produced greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) into the Earth's atmosphere, the hydrological cycle is largely affected [3,4]. Enhanced evaporation from the oceans combined with the increased capacity of the warmer air to maintain greater amounts of water vapor leads to more intense and frequent extreme precipitation events, i.e., instances with greater than normal rainfall, hail or snow. Extreme phenomena, such as heavier than normal precipitation constitute a serious threat for the ecosystems and human societies. Floodings, landslides, water quality and food production degradation, are some of the harmful consequences that different locations around the globe may experience in the coming years [5–7]. Thus, it has become important to systematically monitor changes in precipitation at a local, regional or global level. To achieve this, a series of statistical methods and indicators has been developed over the years. The aim of this work is to analyze precipitation data from observational records in the Greek region in order to investigate recent changes in precipitation conditions.

2. Data and Methodology

Precipitation data over the period 1990–2020 from seven WMO stations in Greece were used in this work, namely Hellinikon (located near the capital of Athens), Thessaloniki, Kerkira, Samos, Larisa, and finally Souda and Herakleion (both located at the island

of Crete). The distribution of the meteorological stations as well as their geographical characteristics are presented in Figure 1 and Table 1, respectively.

Figure 1. Distribution of meteorological stations.

Table 1. List of meteorological stations.

Station	WMO ID	Lat (N)	Lon (E)	Elevation (m)
Hellinikon	16716	37.90	23.75	10.0
Kerkira	16641	39.62	19.92	11.0
Herakleion	16754	35.33	25.18	39.0
Souda	16746	35.48	24.12	146.0
Larisa	16648	39.65	22.45	73.0
Thessaloniki	16622	40.52	22.97	7.0
Samos	16723	37.70	26.92	2.0

The precipitation indices that were used can be found in the following list. For each index, yearly and seasonal data were obtained.

- RX1day: Highest 1 day precipitation amount,
- RX5day: Highest 5 day precipitation amount,
- SDII: Simple Daily Intensity Index,
- RR1: Wet Days (RR >= 1 mm),
- R10mm: Heavy precipitation days (RR >= 10 mm),
- R20mm: Very Heavy Precipitation days (RR >= 2 0mm),
- CWD: Maximum number of consecutive wet days (RR >= 1 mm),
- R95pTOT: Precipitation fraction on very wet days (>95%),
- R99pTOT: Precipitation fraction on extremely wet days (>99%),
- PRCPTOT: Total Precipitation on wet days.

Furthermore, the non-parametric Sen's slope and Mann-Kendall [8] method were applied to both the yearly and seasonal (winter, summer) data of all the above indices and for all the aforementioned stations in order to calculate the corresponding trends and their

statistical significance. For the purpose of this analysis, MAKESENS statistical tool [9] was used.

3. Results and Discussion

In Figure 2, the statistical results from the application of Sen's slope and Mann-Kendall method on the yearly time series of the RX1day index for the Hellinikon station are shown, indicatively. Similar figures were also produced for all indices and stations and for both the seasonal and yearly data.

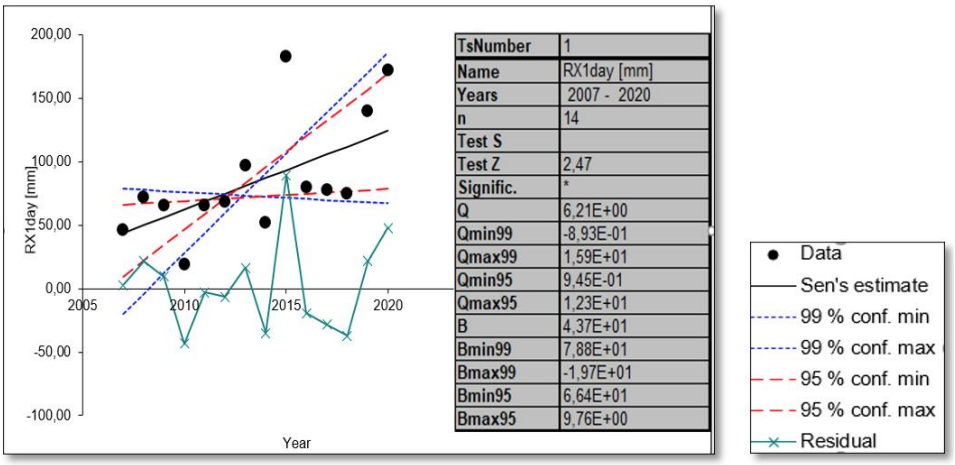

Figure 2. Example of the application of the Sen's slope *(f = Qt + B)* and Mann-Kendall method to the yearly time series of the RX1day index for the Souda meteorological station. A positive (negative) *Z* number indicates a positive (negative) trend. By *Q* and *B* the slope of the trend and intercept are denoted along with the 95% and 99% confidence levels, respectively. In case the trend is statistically significant, it is marked with a star (*).

Statistically significant positive trends of the RX1day and RX5day indices were found for the station of Herakleion and of RX1day for Souda. It should be noted that the data of the Souda station range from 2007 to 2020. The above finding signifies that the maximum 1-day and 5-day amount of precipitation has increased significantly at these locations. On the other hand, statistical significant decrease was observed for the RX1day index for the meteorological station of Samos during the period 1996–2020. Concerning the R10mm, R20mm and CWD indices, the Souda station has experienced a statistically significant increase in the values of R20mm during 2007–2020. This means that very heavy precipitation days have increased during the study period. The station of Kerkira also presents a statistically significant increase in the CWD index from 1990–2020. The SDII, R95pTOT and PRCPTOT indices have also increased in the location of the Souda station while a decrease was detected for SDII at Samos. Concerning the seasonal trends, a statistically significant increase of RX1day and R95pTOT values during winter and RX1day, RX5day, SDII, RR1, CWD values during summer was observed at Souda. This means that a greater amount of extreme precipitation occurred during winter in the study period at Souda and that even in the summer the conditions tend to be wetter. At Samos, in contrast to the yearly data, where a decrease in precipitation was observed, summer conditions tend to be wetter given the statistically significant upward trends of RX1day, RX5day, SDII, RR1 and CWD. Finally, at Thessaloniki an increase in the amount and frequency of extreme precipitation was also measured during summer.

To conclude, the trends and statistical significance of yearly and seasonal values of various indices associated with the intensity and frequency of precipitation in the Greek region were studied in this work. From the results discussed above, it can be deduced that some regions experience an important increase in precipitation with respect to intensity and duration. The trend magnitude and significance, however, vary both seasonally and

geographically depending on a series of factors such as the site's coordinates and its proximity to the sea.

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