ASSESSING CLIMATE CHANGE IN GREECE AND ALBANIA BY TEMPERATURE AND RAINFALL SPATIOTEMPORAL PATTERNS AND TRENDS

MICHALIS SIOUTAS[1], TANJA PORJA[2]

[1]Former Meteorological Applications Center, Hellenic National Agricultural Organization (ELGA & Aristotle University of Thessaloniki, Greece

[2]Department of Physics, Faculty of Natural Sciences, University of Tirana, Albania

e-mail: sioutasm@gmail.com

Abstract

The Balkan region is expected to face significant climate changes with far-reaching impacts on the region's human societies, natural resources, agriculture and ecosystems. An assessment of two primary climate indicators, namely temperature and precipitation, is carried out in this study for Greece and Albania by examining a long-term temperature and precipitation time series of the European Centre for Medium Weather Forecast Reanalysis v.5 (ERA5) data set for the 45-year period 1979-2023. Annual and monthly distributions and trends are examined at prefectural and regional scales to provide geographically representative assessments for the two countries. Spatio-temporal temperature patterns show a consistent increasing trend, which is more pronounced in the continental interior of both countries. Rainfall distributions show increasing trends, mainly due to increasing rainfall intensity, but also indicate periods of reduced rainfall or drought. The results of the observed changes are consistent with climate change projections. Other analyses included storm frequency patterns based on various sources, including lightning data. Monitoring these indicators helps us to better understand and address the challenges and impacts of climate change on ecosystems and people, and to develop mitigation and adaptation strategies.

Key words**:** *Climate change, extreme weather, temperature, rainfall, Greece, Albania.*

Përmbledhje

Rajoni i Ballkanit pritet të përballet me ndryshime të rëndësishme klimatike me ndikime të gjera në shoqëritë njerëzore, burimet natyrore, bujqësinë dhe ekosistemet e rajonit. Një vlerësim i dy treguesve kryesorë të klimës, domethënë temperatura dhe reshjet, është kryer në këtë studim për Greqinë dhe Shqipërinë, duke ekzaminuar një seri kohore afatgjate të temperaturës dhe reshjeve në serinë e të dhënave të Qendrës Evropiane për Parashikimin Afatmesëm – Rianaliza v.5 (ERA5). për periudhën 45-vjeçare 1979-2023. Shpërndarjet dhe tendencat vjetore dhe mujore shqyrtohen në shkallë prefekture dhe rajonale për të marrë vlerësime gjeografikisht përfaqësuese për të dy vendet. Strukturat hapësinore-kohore të temperaturës treguan një tendencë të vazhdueshme rritjeje më të theksuar në zonat e brendshme kontinentale të të dy vendeve. Shpërndarjet e reshjeve tregojnë tendenca në rritje që i atribuohen kryesisht rritjes së intensitetit të reshjeve, por tregojnë gjithashtu periudha me më pak reshje ose thatësirë. Rezultatet e nxjerra në lidhje me ndryshimet e vëzhguara janë në përputhje me parashikimet e ndryshimeve klimatike. Analizat e mëtejshme përfshinin modele të frekuencës së stuhive bazuar në burime të ndryshme, përfshirë të dhënat e shkarkesave elektrike. Monitorimi dhe vlerësimi i këtyre treguesve na ndihmon të kuptojmë dhe adresojmë më mirë sfidat dhe efektet e shkaktuara nga ndryshimet klimatike për ekosistemet dhe njerëzimin, si dhe për të zhvilluar strategji për zbutjen dhe përshtatjen.

Fjalë kyçe: *Ndryshime klimatike, moti ekstrem, temperature, reshje, Greqi, Shqipëri.*

Introduction

Anthropogenic climate change is a complex phenomenon influenced by many factors, including human greenhouse gas emissions, land use change, urbanisation, deforestation, intensive agriculture, transport and many other human activities (WMO, 2023). In the constantly evolving landscape of global environmental concerns, the issue of climate change has emerged as a paramount challenge with far-reaching implications for both human societies and natural ecosystems (AR6 Synthesis Report: Climate Change, 2023;). Europe, and in particular the Balkan region, is facing significant climate changes that are expected to have far-reaching impacts on the region's

natural resources, agriculture and ecosystems. Many scientific studies indicate that climate change has significantly affected weather patterns in Europe and the Balkans, leading to an increase in temperature, changes in precipitation and a significant increase in the frequency and severity of extreme weather events (Frame et al., 2020; Lolis et al., 2022). Strong signals of climate change are rising global temperatures and shifts in precipitation patterns, as these can lead to more frequent extreme and devastating weather events, sometimes resulting in loss of life (Sioutas et al., 2023; Sioutas and Siouta, 2023). Global temperatures have been rising steadily, with the last decade and especially 2023 being the warmest on record.

This warming is contributing to more frequent heat waves, longer summers and shorter winters, and changes in precipitation patterns. Precipitation trends show an increase in heavy rainfall events in some regions, while others face prolonged droughts. These changes in temperature and precipitation can have serious consequences for the Earth's ecosystems, agriculture, water resources and overall human well-being. This paper focuses on: a) the study of climatic variations of two primary climate change indicators, namely 2 m air temperature and total precipitation for Greece and Albania based on the basis of ECMWF reanalysis data (ERA5) for the 45-year period 1979-2023, b) the study of annual and monthly distributions and trends compared to climate values, and c) the presentation of spatial patterns of temperature and precipitation trends at prefecture scales.

Spatio-temporal distributions of air temperature and trends analyses

Air temperature at 2 m height, as provided by conventional weather stations, is examined for representative locations of Greece (regions) and Albania (prefectures). Spatial temperature trends are extracted using specific locations, namely the capitals of regions and prefectures, as representative points.

Mean annual temperature trends are expressed as the 5-year moving average deviation from the normal annual temperature (climatic) values as extracted from the ECMWF ERA5 dataset for the 45-year period 1979-2023. Mean annual and monthly temperature distributions and trends are extracted for Athens, Greece and Tirana, Albania as representative locations for each

country. A categorization of the months is also presented, including the classification of normal, warm and cold months according to their deviation (positive or negative or zero) from the mean climatic (normal) temperature.

Air temperature for Greece

An increasing trend in mean annual temperature was observed over the whole country (Figure 1). The most pronounced warming occurred over the northern regions of Greece, namely Western, Central, Eastern Macedonia and Thrace with a trend of +2.0°C to +2.2°C. Less warming occurred over the western regions of Greece and the Peloponnese with +1.2°C and the island of Crete with +1°C, indicating the role of the sea in cooling effects.

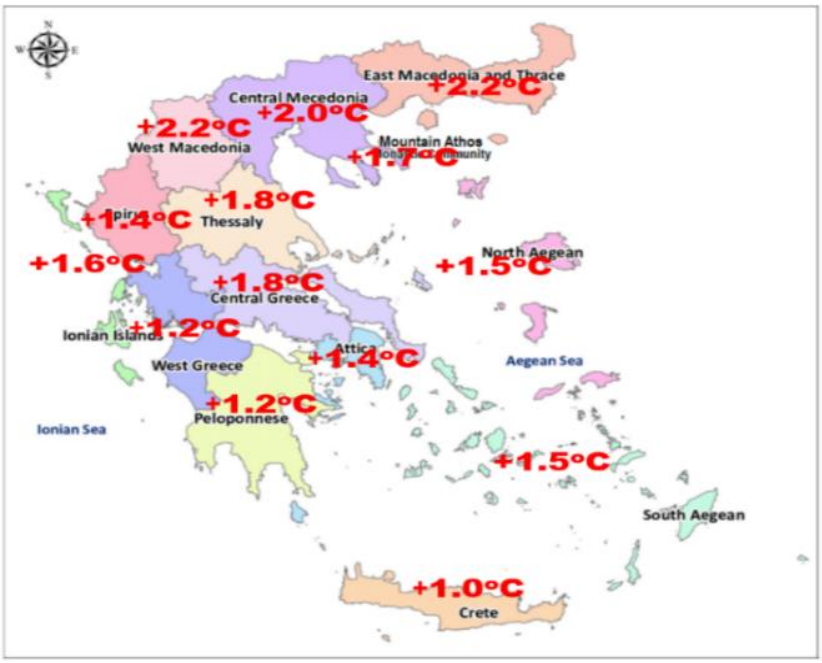

Figure 1. Annual mean temperature deviations from climatic values for the regions of Greece (ECMWF-ERA5 reanalysis of 45-year data 1979-2023)

A moderate increasing trend of 1.4°C to 1.8°C occurred over the eastern regions of Greece and the Aegean Sea. In Figure 2, the increasing trend of

the annual mean temperature appeared for Athens Greece, most pronounced from 1998 and the last two decades.

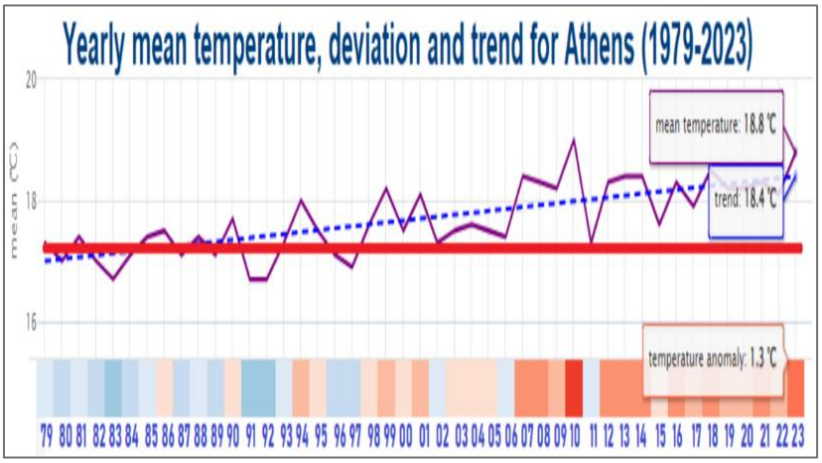

Figure 2. Annual mean temperature trend for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

Warmer than normal months occurred most frequently, as shown in Figures 3 and 4 for Athens, Greece. All months appeared most frequently as warm months except May, June and September which appeared as normal months.

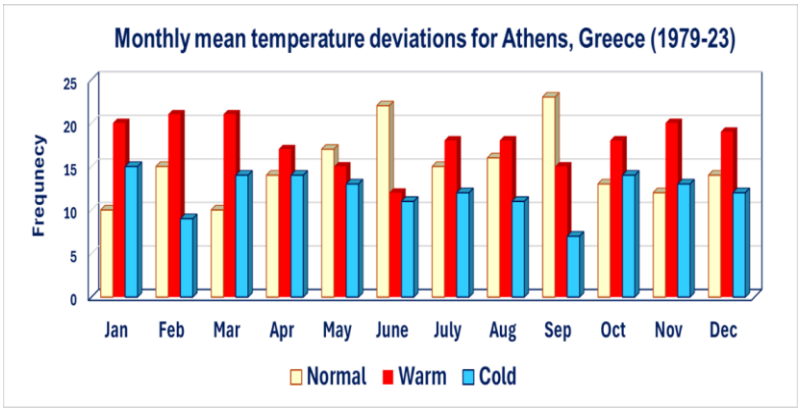

Figure 3. Frequency of occurrence of months as a function of mean monthly temperature anomaly for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

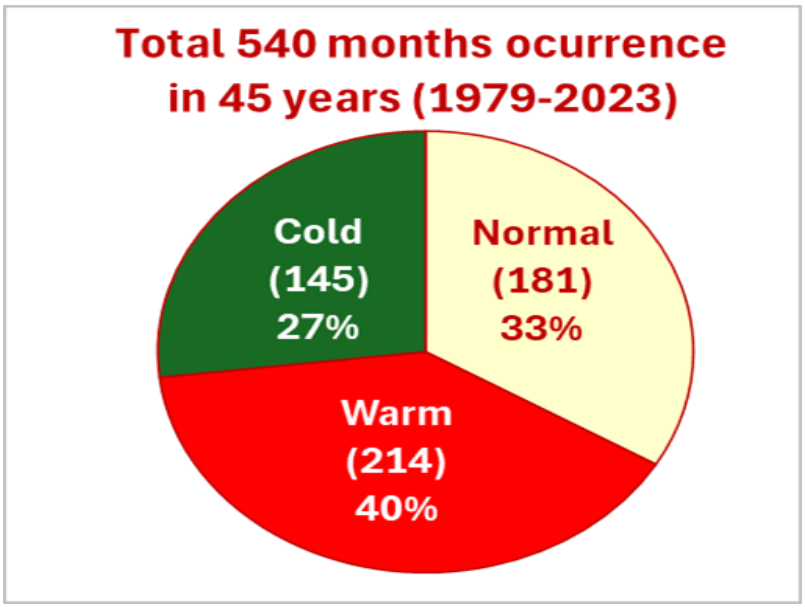

Figure 4. Frequency of temperature percentage for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

The most frequent warmer than normal months are February and March, followed by January, November and December. For Athens, Greece, out of a total of 540 months during the 45-year period 1979-2023, a majority of 40% are warm months, 33% are normal months and 27% are cold months compared to the climatic normal (mean monthly temperature) (Figure 4).

Air temperature for Albania

The map of Albania in Figure 5 shows an increasing trend in mean annual temperature over the whole country during the 45-year period 1979 – 2023. The most pronounced warming occurred over the mountainous and high-altitude parts of eastern Albania.

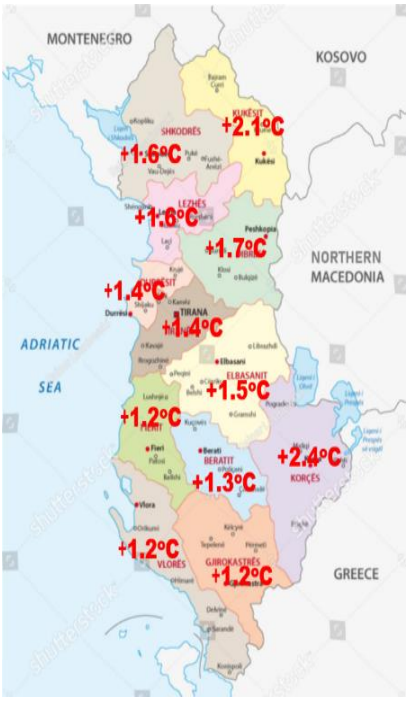

Figure 5. Annual mean temperature deviations from climatic values for Albania's prefectures (ECMWF-ERA5 reanalysis of 45-year data 1979-2023)

The prefecture of Korca showed the greatest warming with +2.4°C, followed by Kukes with +2.1°C. Moderate warming trends of 1.4°C to 1.7°C occurred over the central prefectures.

Smaller warming trends were observed over the coastal areas and the south-western parts of Albania. Figure 6 shows the increasing trend in annual mean temperature for Tirana, Albania, which is most pronounced since 1998 and over the last two decades. Warmer than normal months occurred most frequently, as shown in Figures 7 and 8 for Tirana, Albania.

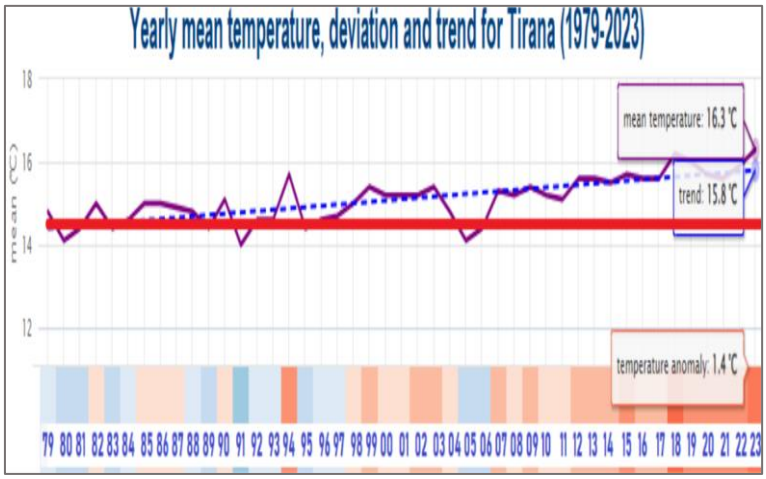

Figure 6. Annual mean temperature trend for Tirana, Albania based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

All months appeared most frequently as warm, except May and September, which appeared most frequently as normal months.

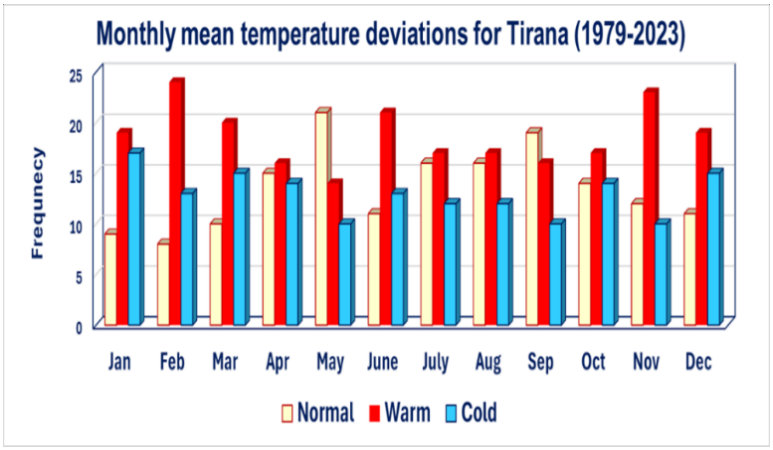

Figure 7. Frequency of occurrence of months as a function of mean monthly temperature anomaly for Tirana, Albania based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

For Tirana, out of a total of 540 months during the 45-year period 1979-2023, the majority of 41% are warm months, 30% are normal months and 29% are cold months compared to the climatic normal (mean monthly temperature) (Figure 8).

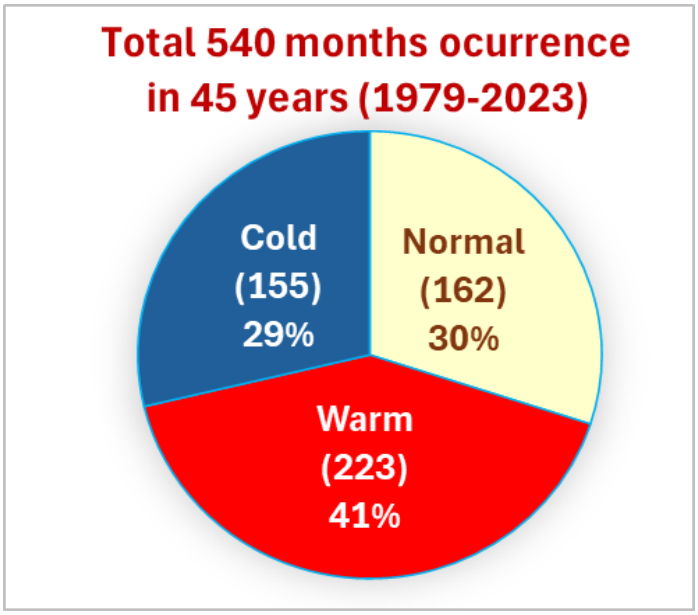

Figure 8. Frequency of temperature percentage for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

Spatio-temporal distributions of precipitation and trends analyses

The total annual and monthly precipitation is examined for representative locations in Greece (regions) and Albania (prefectures), taking into account the respective capitals.

Mean annual precipitation trends are expressed as 5-year moving averages of deviations from climatic values as extracted from the ECMWF ERA5 dataset for the 45-year period 1979-2023. Mean annual and monthly rainfall distributions and trends are also examined for Athens, Greece and Tirana,

Albania as representative locations for each country. Months were also categorized as normal, dry and wet months according to their deviation (positive, negative or zero) from climatic rainfall values.

Precipitations for Greece

An increasing trend in mean annual precipitation was observed over almost the entire country, with an average increase of 13.7%. Rainfall increases range from 3 to 24% in all areas, with a decrease of 2% expected in the southern Aegean (Figures 9 and 10). An increase of 21-266 mm in mean annual precipitation is projected for most parts of the country, except for the Southern Aegean with a decrease of 5 mm. The highest increases of 23-24% occur in the monastic area of Mount Athos and in the region of Epirus in north-western Greece.

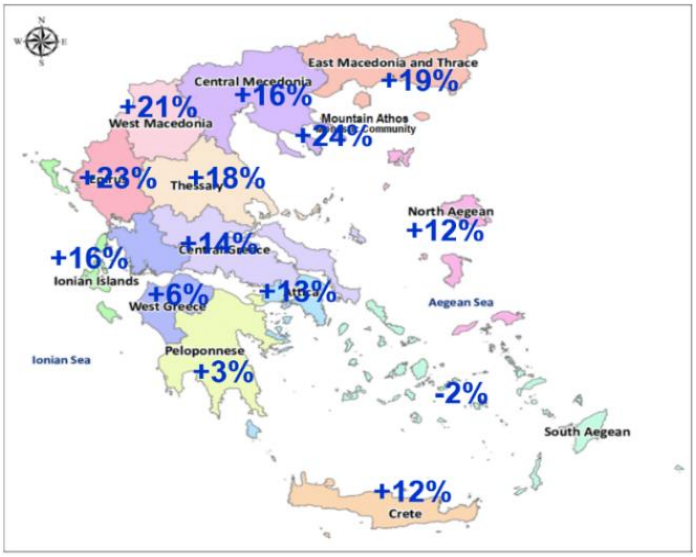

Figure 9. Annual mean precipitation deviations from climatic values for the regions of Greece (ECMWF-ERA5 reanalysis of 45-year data 1979-2023)

Moderate annual increases of 12%-19% occurred in most areas, with smaller increases of 3-6% of precipitation in the Peloponnese. Figure 10 shows the increasing trend of mean annual precipitation for Athens Greece, most pronounced since 1998 and the last two decades.

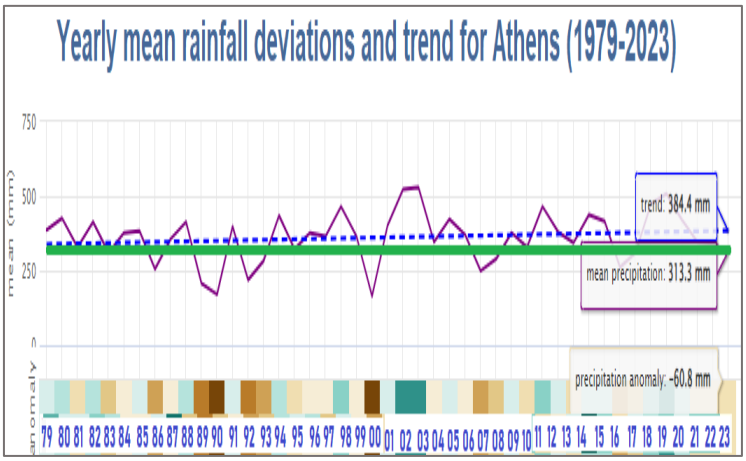

Figure 10. Annual mean precipitation, anomalies and trend for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

Dry months are the dominant category of months as shown in Figures 11 and 12 for Athens, Greece. The driest months are July, September and March, followed by February, April, October, June and August. Almost normal months are November, December, January and May.

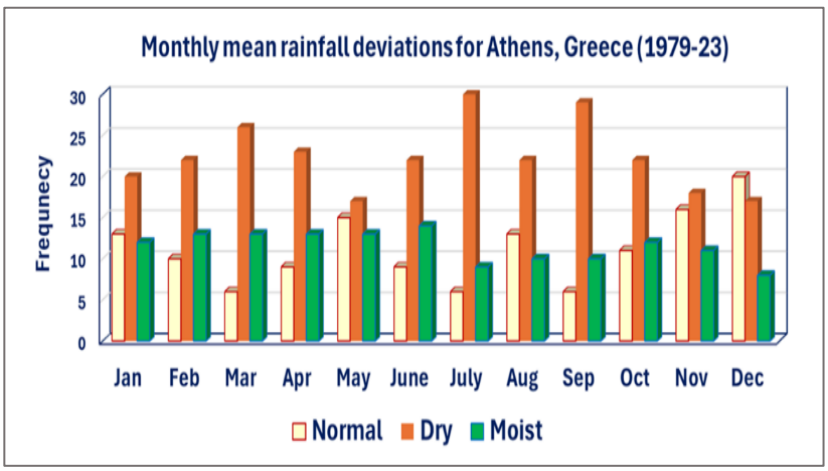

Figure 11. Frequency of occurrence of months as a function of their precipitation deviation from climatic values for Athens, Greece, based on the ECMWF-ERA5 reanalysis for 1979 - 2023

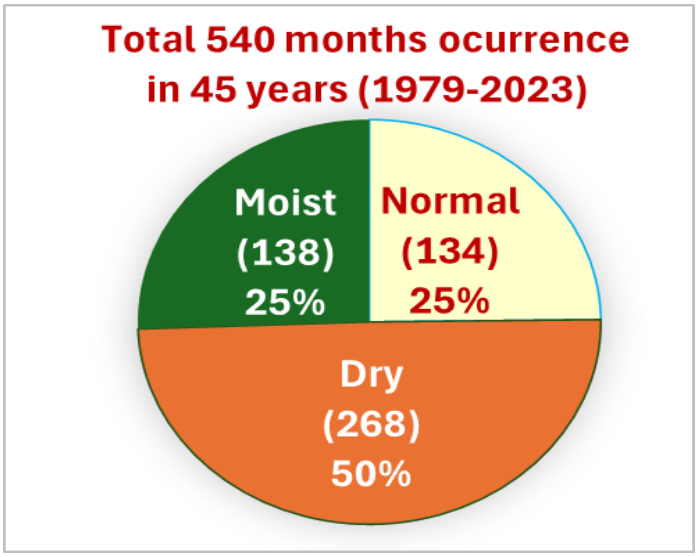

Figure 12. Frequency of percentage of monthly categories for Athens, Greece based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

Out of a total of 540 months during the 45-year period 1979-2023, the majority of 50% are dry months and the same number of 25% are wet and normal months (Figure 12).

Precipitations for Albania

An increase of 14.7% in mean annual precipitation was observed for Albania based on the ECMWF-ERA5 reanalysis 1979-2023 data set examined. The increasing trend of the mean annual precipitation over the whole country is in the range of 9-22%, corresponding to an increase of about 87-257 mm (Figures 13 and 14).

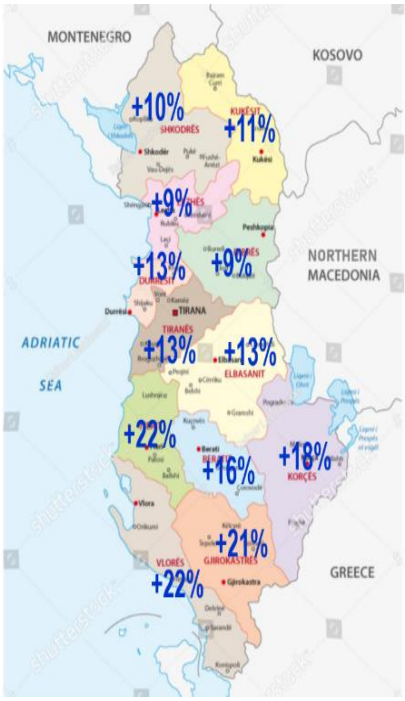

Figure 13. Annual mean precipitation deviations from climatic values for Albania's prefectures (ECMWF-ERA5 reanalysis of 45-year data 1979-2023)

The highest annual rainfall increases of 21-22% occurred in the south-western coastal areas of Fieri, Vlores and Gjirokastres. Moderate increases of 13% occurred in the central areas of Elbasant, Tirana and Durres. The smallest increases of 9% were recorded in Diber and Lezhe.

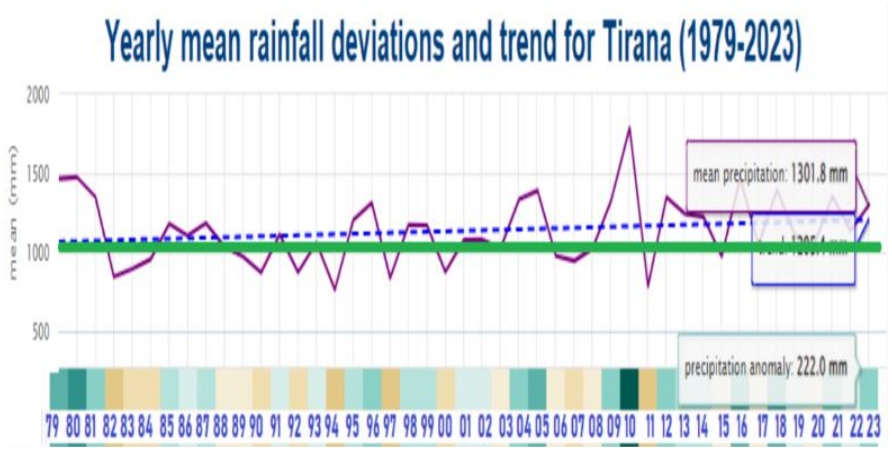

Figure 14. Annual mean rainfall variability and trend for Tirana, Albania based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

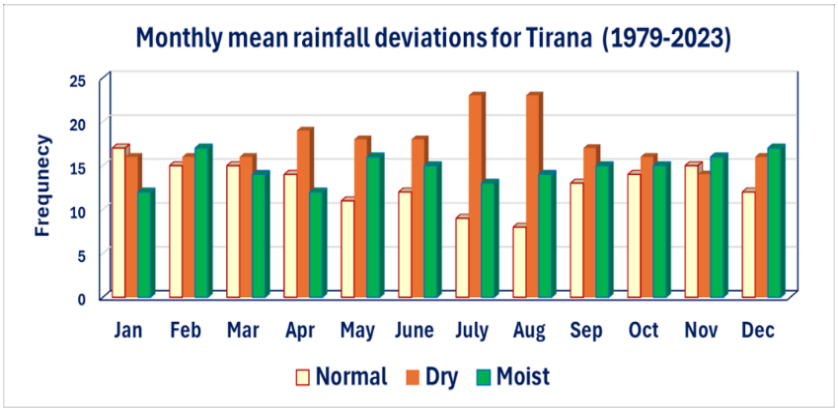

Figure 15. Frequency of occurrence of months as a function of their precipitation deviation from climatic values for Tirana, Albania, based on the ECMWF-ERA5

Although there is an increasing trend of 13% in mean annual rainfall, this increase is likely to occur in fewer rainfall episodes, as dry months are the most common.

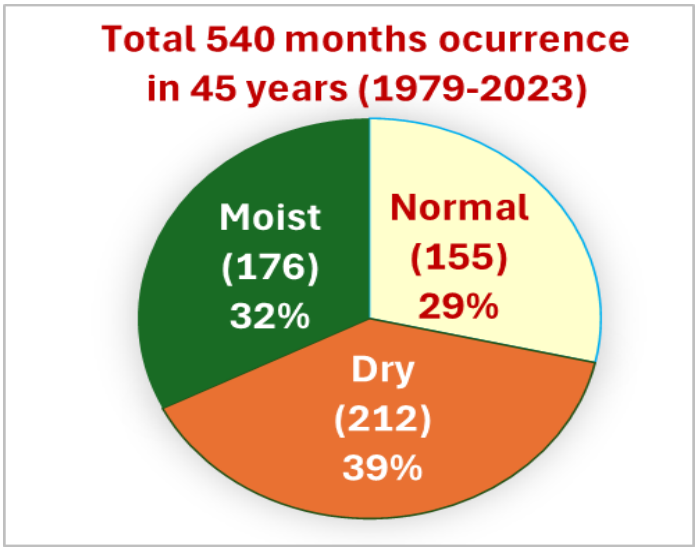

Figure 16. Frequency of occurrence of monthly categories for Tirana, Albania based on ECMWF-ERA5 reanalysis of 45 years of data (1979-2023)

The driest months are July and August, followed by April, May and June. For Tirana, out of a total of 540 months during the 45-year period 1979-2023, the majority of 39% are dry months, 32% are wet months and 29% are normal months in terms of climatic precipitation (Figure 16).

Conclusions

Analysis of the ECMWF Reanalysis v. 5 (ERA5) temperature and precipitation time series for the 45-year period 1979-2023 showed useful trends for Greece and Albania. The annual distribution showed a significant warming, expressed by an increasing trend of 1o-2o C or more, especially in the last two decades for both countries. Warmer than normal months are the majority in the 45-year period 1979-23, with 40% of the total months for Greece and 41% for Albania. These results are consistent with climate model projections of a 3-5°C increase in annual mean temperature by the end of the 21st century for both countries. Rising temperatures will lead to more frequent heat waves, longer summers and shorter winters with limited snowfall. Total annual precipitation seems to have increased over the last 45

years with 13.9% for Greece and 14.7% for Albania. However, drier-than-normal months dominate, accounting for 50% of the total months for Athens and 39% for Tirana. This result indicates that both countries may experience frequent periods of drought, but also an increased risk of isolated episodes of intense rainfall and flooding.

Drought will also negatively affect crop and livestock productivity, water resources, increase the risk of forest fires and threaten the entire ecosystem of Albania and Greece's unique flora and fauna. Under conditions of increased atmospheric instability, Greece and Albania are expected to experience more frequent and severe thunderstorms, flooding, windstorms, hail and lightning due to climate change.

These extreme weather events can have devastating consequences for human societies, economies and infrastructures. To address these challenges, it is crucial for both countries to implement climate change adaptation and mitigation strategies. This includes promoting sustainable land use, investing in renewable energy, improving disaster risk reduction and raising public awareness. about climate action.

Acknowledgements

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