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Internal Climate Variability and Extreme Temperatures over the Mediterranean †

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Abstract: In this work, the Max Planck Institute for Meteorology Grand Ensemble (MPI-GE) is used to quantify the climate system's internal variability. The MPI-GE is a large ensemble of a single state-of-the-art comprehensive climate model and its use is crucial to evaluate average changes in summer monthly means and extreme temperatures. Initially, model simulations are examined in terms of their ability to accurately reproduce the observed climatic regimes in the Mediterranean region for the historical period. The ERA5 reanalysis dataset is employed as a reference and the corresponding trends and frequencies of occurrence of temperature-extreme events are compared between these datasets. Subsequently, the MPI-GE is used as a tool for examining the effect of the climate system's internal variability focusing on the Mediterranean summer temperatures under different levels of global warming. Understanding and decoupling the effects of internal variability and anthropogenic forcing on climate trends remain a key challenge. It is found that in the rcp8.5 scenario, the frequency of summer extreme temperatures is higher than that in the rcp2.6 scenario. Especially in the Greek region, the frequency is 1.5 times higher in rcp8.5 than in rcp2.6

Keywords: climate system; internal variability; climate model; extreme temperatures

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1. Introduction

In recent years, scientists have been studying the impacts of climate change on the Mediterranean region, including rising temperatures, changing precipitation patterns, and more frequent extreme weather events such as heatwaves, droughts, and floods. These changes are expected to have significant impacts on the region's ecosystems, including changes in plant and animal distributions, alterations to food webs, and potential species extinctions.

The surface temperature in the Mediterranean region is now 1.5 °C above pre-industrial levels, with a corresponding increase in high-temperature extreme events. Droughts have become more frequent and intense, especially in the north Mediterranean. The sea surface has warmed by 0.29–0.44 °C per decade since the early 1980s with stronger trends in the eastern basin. Temperature extremes and heat waves have increased in intensity, number, and length during recent decades, particularly in summer, and are projected to continue increasing.

During the 21st century, climate change is projected to intensify throughout the region. Air and sea temperature and their extremes (notably heat waves) are likely to continue to increase more than the global average. The projected annual mean warming on land at the end of the century is in the range of 0.9–5.6 °C compared to the last two decades of the 20th century, depending on the emission scenario [1–4].

Internal climate variability is distinct from climate change, which refers to long-term shifts in the average state of the climate system due to human activities such as burning fossil fuels, deforestation, and other greenhouse gas emissions. While climate change is a global phenomenon, internal variability can have regional impacts that can lead to short-term fluctuations in weather patterns, such as heatwaves, droughts, and floods.

One of the most well-known examples of internal climate variability is the El Niño-Southern Oscillation (ENSO), a natural climate pattern that occurs in the tropical Pacific Ocean and has significant impacts on weather patterns worldwide [5]. The purpose of this paper is the study of heatwave episodes in the Mediterranean region, with the use of the MPI Grand Ensemble climate model.

2. Material and Methods

2.1. Study Area

The Mediterranean region (Figure 1) is located at the crossroads of three continents: Europe, Asia, and Africa. The Mediterranean climate is characterized by mild, wet winters and hot, dry summers. The average temperature in summer ranges from 25 to 30 degrees Celsius, while in winter, it ranges from 10 to 15 degrees Celsius. The Mediterranean region's latitudinal and longitudinal boundaries are 28° N–42° N and 10° W–40° E, respectively.

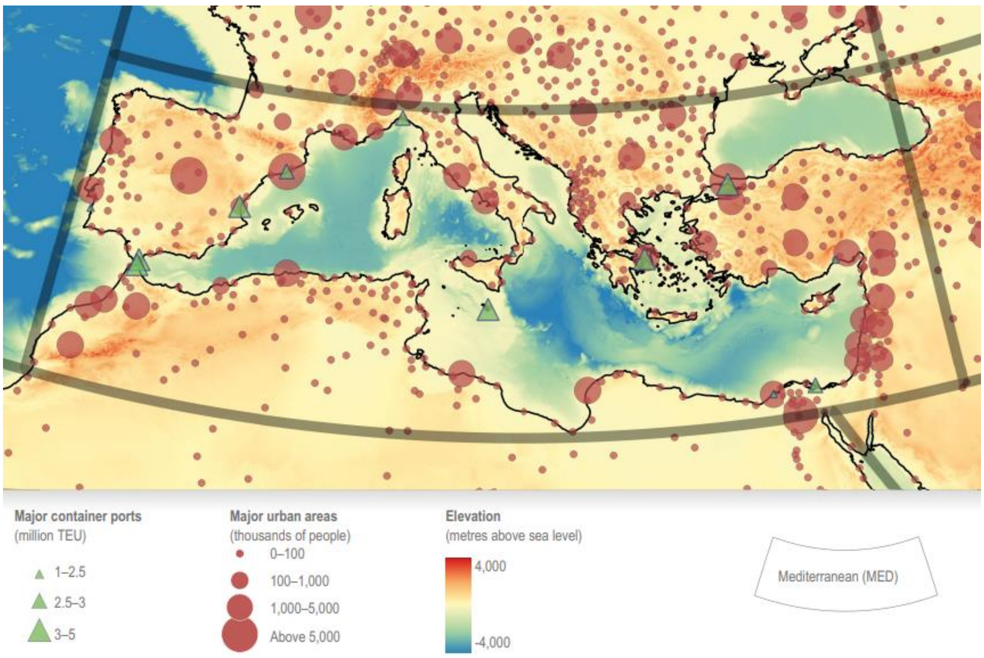

Figure 1. The Mediterranean region: Topography, bathymetry, main urban areas and borders of the Mediterranean region [6].

2.2. Data Description

ERA5 and MPI-GE are two different types of datasets used for climate modeling and analysis. ERA5 is a reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), while MPI-GE is a climate model developed by the Max Planck Institute for Meteorology. ERA5 is a global atmospheric reanalysis dataset that provides a comprehensive view of the Earth's climate system from 1979 to present. It is based on a combination of satellite observations, surface observations, and numerical weather prediction models. ERA5 provides high-resolution data on atmospheric variables such as temperature, pressure, wind, and precipitation, as well as derived variables such as heat fluxes, cloud cover, and radiation.

MPI-GE, on the other hand, is a coupled climate model that simulates the Earth's climate system over long periods of time, typically on the order of centuries. It includes representations of the atmosphere, oceans, land surface, and cryosphere (ice and snow). MPI-GE can be used to simulate past and future climate conditions under various scenarios of greenhouse gas emissions and other climate forcing factors.

Overall, ERA5 and MPI-GE are two complementary tools that are used for different purposes in climate research and analysis. ERA5 provides a detailed view of the current climate system, while MPI-GE can be used to simulate future climate scenarios and study the potential impacts of climate change.

2.3. Methodology

To reproduce the climate of the Mediterranean, what is necessary is a comparison between the historical experiment of MPI-GE for the period from 1850 to 2005 and ERA5 monthly averaged data on pressure levels at 1000 hPa from 1940 to present. In order to achieve the first objective, the trends are calculated for the temperature time-series for these 2 different datasets.

For each of the realizations of the MPI-GE historical experiment, Sen's slope is calculated, and then the average value of all these trends. Subsequently, for the same area, ERA5 reanalysis data are used to calculate the temperature trend that was recorded in the past.

The next step of this work is the detection of summer extreme temperatures in the future. The detection of summer extreme temperature in data time-series without external forcing is calculated, after removing the ensemble mean. Initially, time series from 2 different rcp scenarios, rcp2.6 and rcp8.5, are used, in order to calculate the internal variability for each one scenario. The first step is to calculate the mean temperature value for the given dataset. The mean is obtained by summing up all the temperature measurements and dividing the sum by the total number of measurements. Extreme temperatures can be identified by considering the values that significantly deviate from the mean. In this case, temperatures beyond the standard deviation from the mean can be classified as summer extreme.

3. Results and Discussion

3.1. Historical Period

When comparing these two datasets, it is important to consider the strengths and weaknesses of each approach. For example, the MPI-GE historical experiment may be more useful for studying long-term trends and natural variability in the climate system, while ERA5 reanalysis data may be more useful for studying short-term weather patterns and the impacts of climate change on specific regions. Overall, comparing historical data from the MPI-GE historical experiment and ERA5 reanalysis monthly averaged data can provide valuable insights into the Earth's climate system.

Shown below are the results regarding the mean trends for the period of 1850–2005 as produced from MPI-GE historical experiment data, for the Mediterranean area (Figure 2).

Regarding the results, it is obvious that while the Mediterranean region as a whole exhibits shared climate characteristics, the Eastern Mediterranean and Western Mediterranean showcase distinctive climate trends. The Eastern Mediterranean, and especially the region that contains Morocco and Spain, experiences larger trends in comparison with the region of Greece, Italy, and the Eastern Mediterranean Sea. These results lead to larger summer temperature extremes, reduced precipitation, increased drought conditions, and a higher risk of wildfires.

Furthermore, results from ERA5 monthly averaged data are examined in long-term temperature trends. Trends from both datasets demonstrate comparable patterns of temperature change over time. Increases or decreases in temperature over several decades exhibit consistent magnitudes and directions. This agreement reinforces the understanding of long-term climate change and provides additional confidence in the accuracy of temperature measurements.

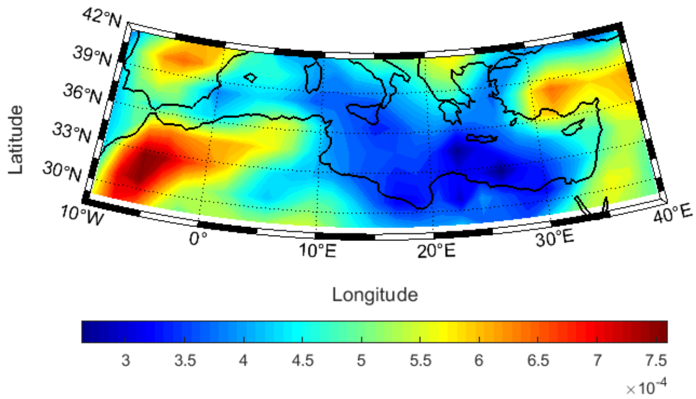

Figure 2. Mean trends for the historical period 1850–2005 from historical experiment of the MPI-GE, measured at K × month^{-1}.

3.2. Occurrence of Summer Extreme Temperature in the Future

Shown below are the results regarding the number of summer monthly extreme temperatures for the period from 2006 to 2099 as produced from MPI-GE rcp2.6 (Figure 3) and rcp8.5 (Figure 4) experiment data, for the Mediterranean area.

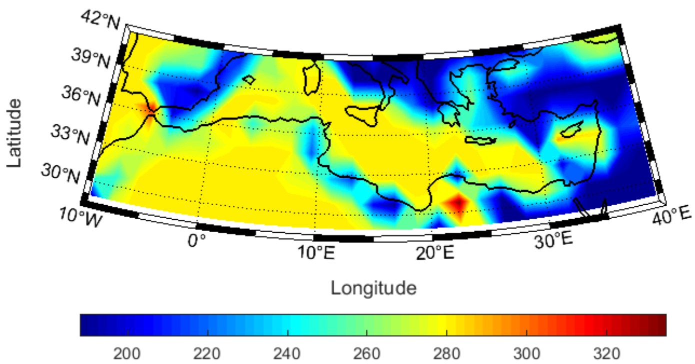

Figure 3. Number of monthly extreme temperatures for the period 2006–2099 in the Mediterranean from rcp2.6 scenario.

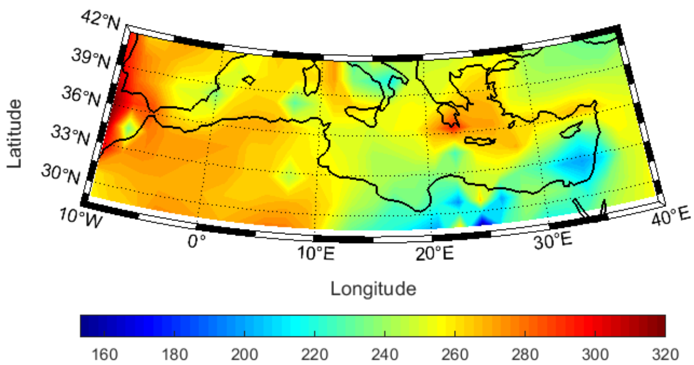

Figure 4. Number of monthly extreme temperatures for the period 2006–2099 in the Mediterranean from rcp8.5 scenario.

It is evident from the results that in the first scenario (rcp2.6), grid-points with the most extremes are in the region of North Africa and especially Egypt and South Spain. On the other hand, in the second scenario (rcp8.5), grid-points with the most extremes are in the region of Greece and Western Europe, followed by the regions of North Africa.

4. Conclusions

One of the key challenges in predicting the impacts of climate change is to understand how extreme weather events such as heatwaves will change in the future. The MPI-GE RCP experiments provide a valuable tool for estimating future changes in temperature extremes and their impacts on society and ecosystems. The results of the MPI-GE RCP experiments suggest that extreme summer temperatures are likely to become more frequent and severe in the future, particularly under higher-greenhouse-gas-emissions scenarios. These results can also be used to inform efforts to reduce greenhouse gas emissions and mitigate the impacts of climate change on the Earth's climate system.

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Conflicts of Interest: The authors declare no conflict of interest.

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