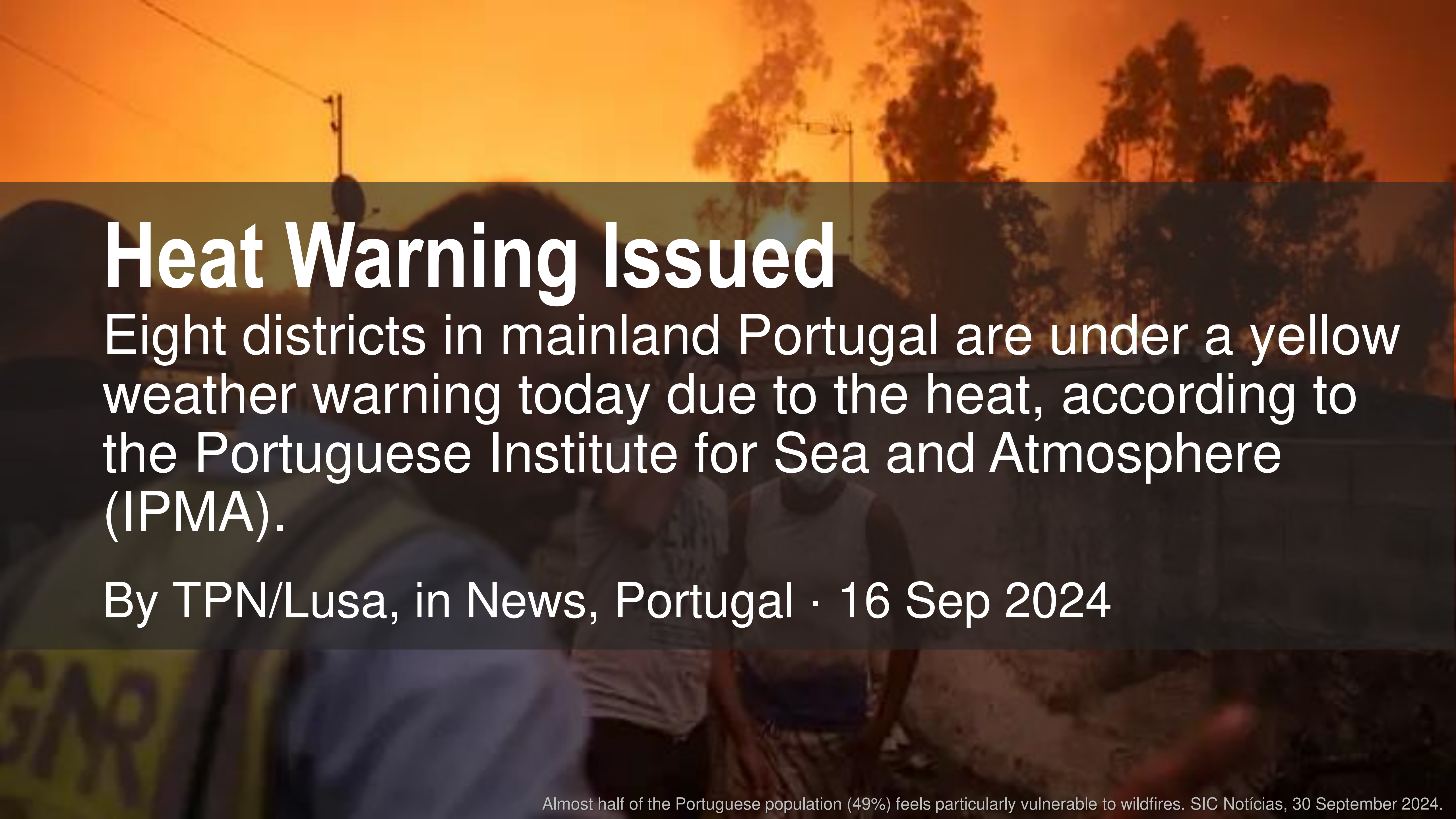
Heat Warning Issued

Eight districts in mainland Portugal are under a yellow weather warning today due to the heat, according to the Portuguese Institute for Sea and Atmosphere (IPMA).

By TPN/Lusa, in News, Portugal · 16 Sep 2024



Almost half of the Portuguese population (49%) feels particularly vulnerable to wildfires. SIC Notícias, 30 September 2024.

https://www.aa.com.tr/en/europe (2022)

Portugal's Changing Climate: Four Decades of Heatwave Evolution

Maria Manuela Portela, **Luis Angel Espinosa***

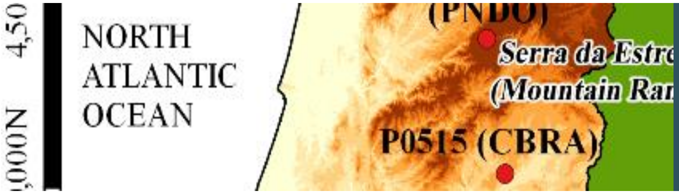
*The Association of Instituto Superior Técnico for Research and Development (IST-ID), Civil Engineering Research and Innovation for Sustainability (CERIS), Lisbon University (UL), Lisbon, Portugal

11 February 2025, Lisbon | luis.espinosa@tecnico.ulisboa.pt

This research was supported by the Fundação para a Ciência e a Tecnologia (FCT) through the funding UIDB/04625/2020 of the CERIS research unit and by the European Union's Horizon 2020 research and innovation programme,SCORE, under grant agreement No 101003534.

Quick summary of the presentation:

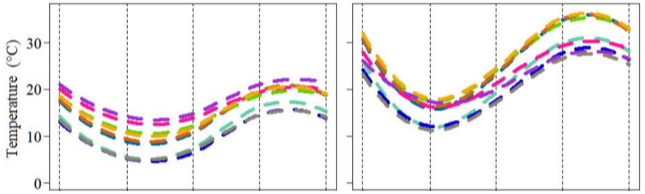
1. Introduction



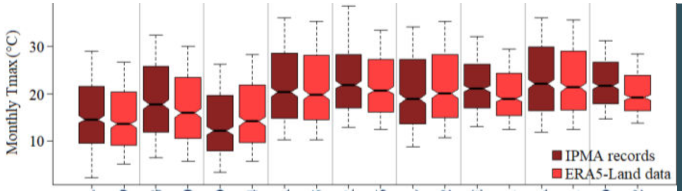
2. Study Area

$$A_d = \bigcup_{y=1980}^{2021} \bigcup_{i=d-15}^{d+15} T_{y,i},$$

3. Materials and Methods: Heatwave Magnitude Index; Analysis of Heatwave Days Frequency



4. Results: Comparison of ERA5-Land and Meteorological Stations; Threshold for Heatwaves; Frequency of Heatwave Days



5. Final Remarks

1. Introduction

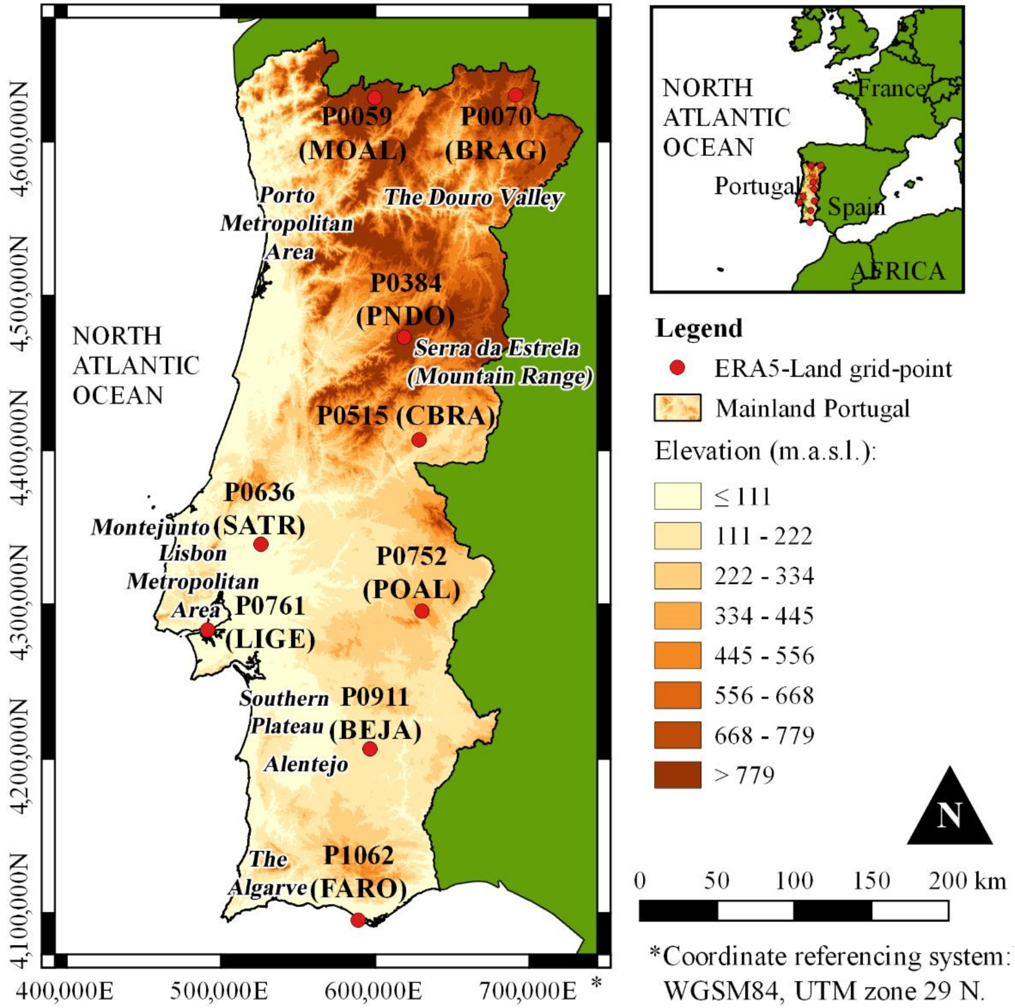
Heatwaves are nasty business: They're extreme weather events that seriously impact people's health, the natural world, and essential infrastructure, making them a complex challenge to tackle.

- Things are getting worse: Climate change is making heatwaves more frequent and more severe across the globe.
- Portugal's feeling the heat: The country's seen some really bad heatwaves lately, and is especially vulnerable due to its changing climate.
- Severe heatwaves struck Portugal in 2022: July's event caused nearly 2,400 deaths and triggered major forest fires, particularly inland.

2. Study Area

Mainland Portugal was selected as the case study in this research. It boasts a diverse topography and regional climatic variations.

- This diverse landscape makes Portugal an interesting subject for research. The country's climate can be broadly divided into two main regions: one with a temperate climate with dry, hot summers (Csa), and another with a temperate climate with dry, mild summers (Csb).
- The north of Portugal experiences a temperate maritime climate influenced by the Atlantic Ocean. In contrast, the south tends to have hotter, drier summers, more characteristic of a Mediterranean climate.



3. Materials and Methods

Heatwaves in Portugal were analysed using high-resolution daily temperature data from ERA5-Land.

- Analysis based on high-resolution daily temperature data from ERA5-Land (1980–2021).
- Validation of ERA5-Land data against surface observations from IPMA for the period 1980 to 2018 (39 years).
- Heatwaves were identified using the Heatwave Magnitude Index (HWMI), as proposed by Russo et al., 2014*.
- The frequency of heatwaves was examined using a kernel occurrence rate estimator (KORE) technique.

The HWMI is defined as the maximum magnitude of the heatwaves in a year, where a heatwave is the period ≥ 3 consecutive days with Tmin (or Tmax) above the daily threshold. The threshold is defined as the 90th percentile of daily Tmin (or Tmax), centred on a 31-day window. Hence, for a given day d, the threshold series A_d of the dataset is given by:

$$A_d = \bigcup_{y=1980}^{2021} \bigcup_{i=d-15}^{d+15} T_{y,i},$$

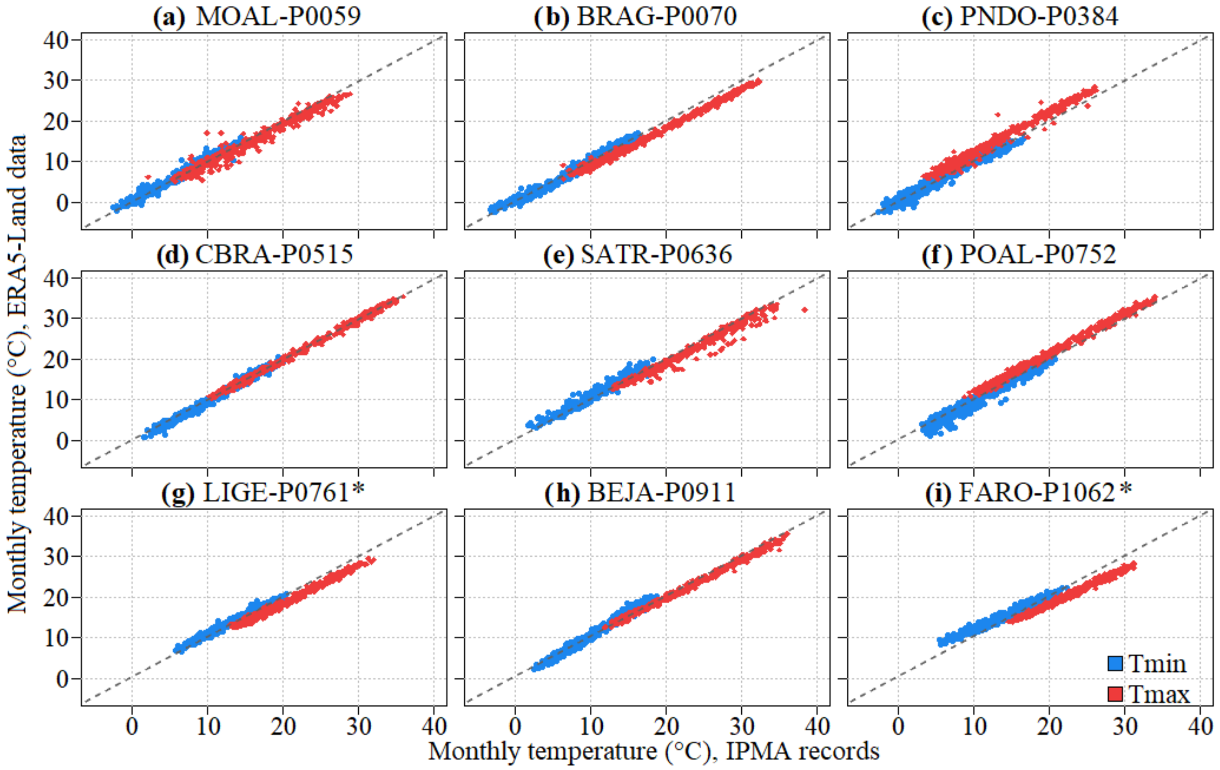
where $\bigcup$ denotes the union of sets and $T_{y,i}$ is daily temperature of the day i in the year y. To obtain A_d, the daily temperature ERA5-Land data in the 15-day period before the 1 October 1980 and after the 30 September 2021 were used.

*Russo, S., Dosio, A., Graversen, R. G., Sillmann, J., Carrao, H., Dunbar, M. B., & Vogt, J. V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. *Journal of Geophysical Research: Atmospheres*, *119*(22), 12-500.

4. Results

Comparison between ERA5-Land data and meteorological station records (IPMA) from 1980 to 2018.

- Strong agreement between data sources: A strong linear relationship was found between ERA5-Land temperature data and the data from the IPMA meteorological stations, suggesting good overall consistency.
- ERA5-Land smooths out extremes: The ERA5-Land Tmax (maximum temperature) values are generally smoother than the IPMA data due to the data retrieval method used, which can slightly dampen extreme values.



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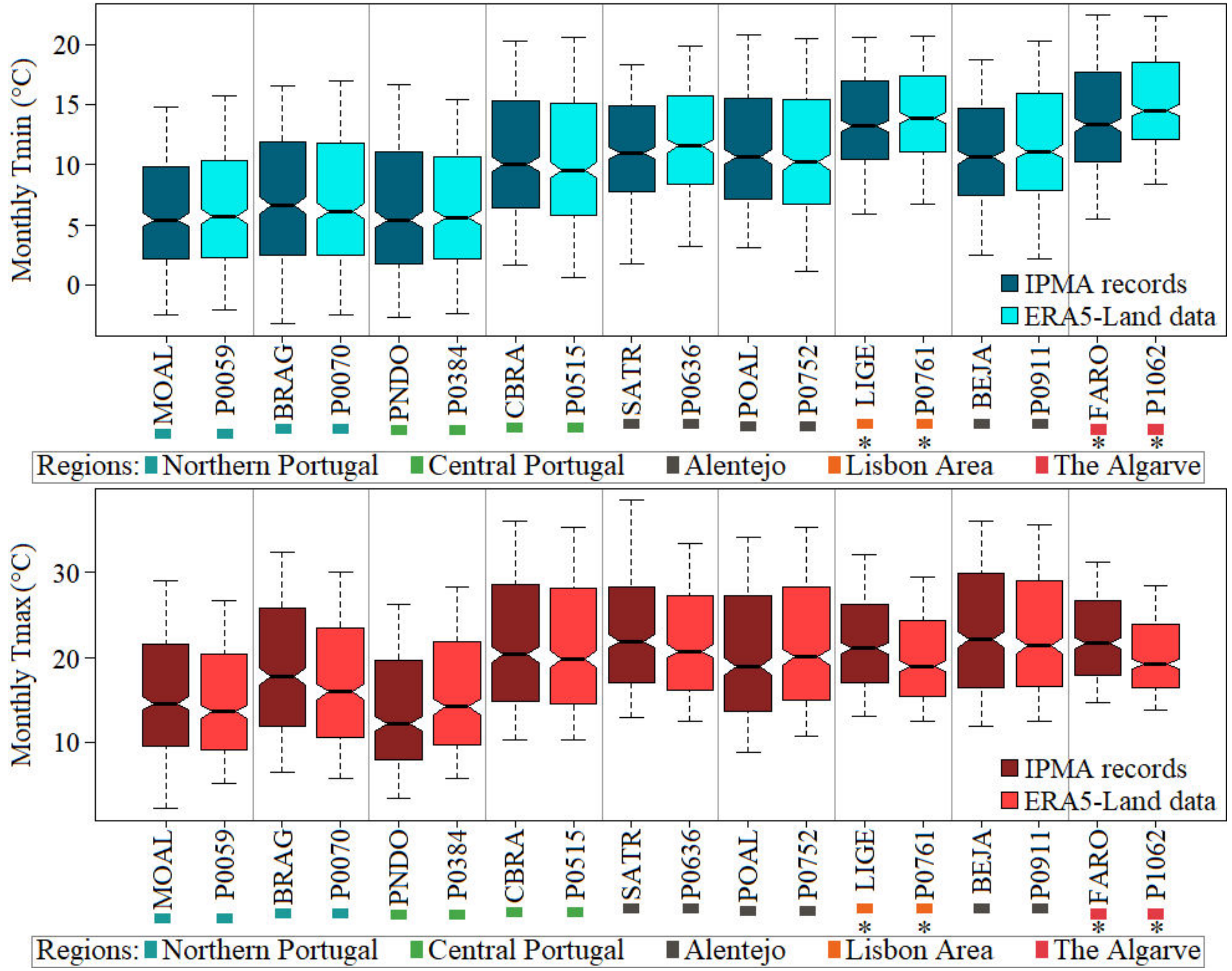
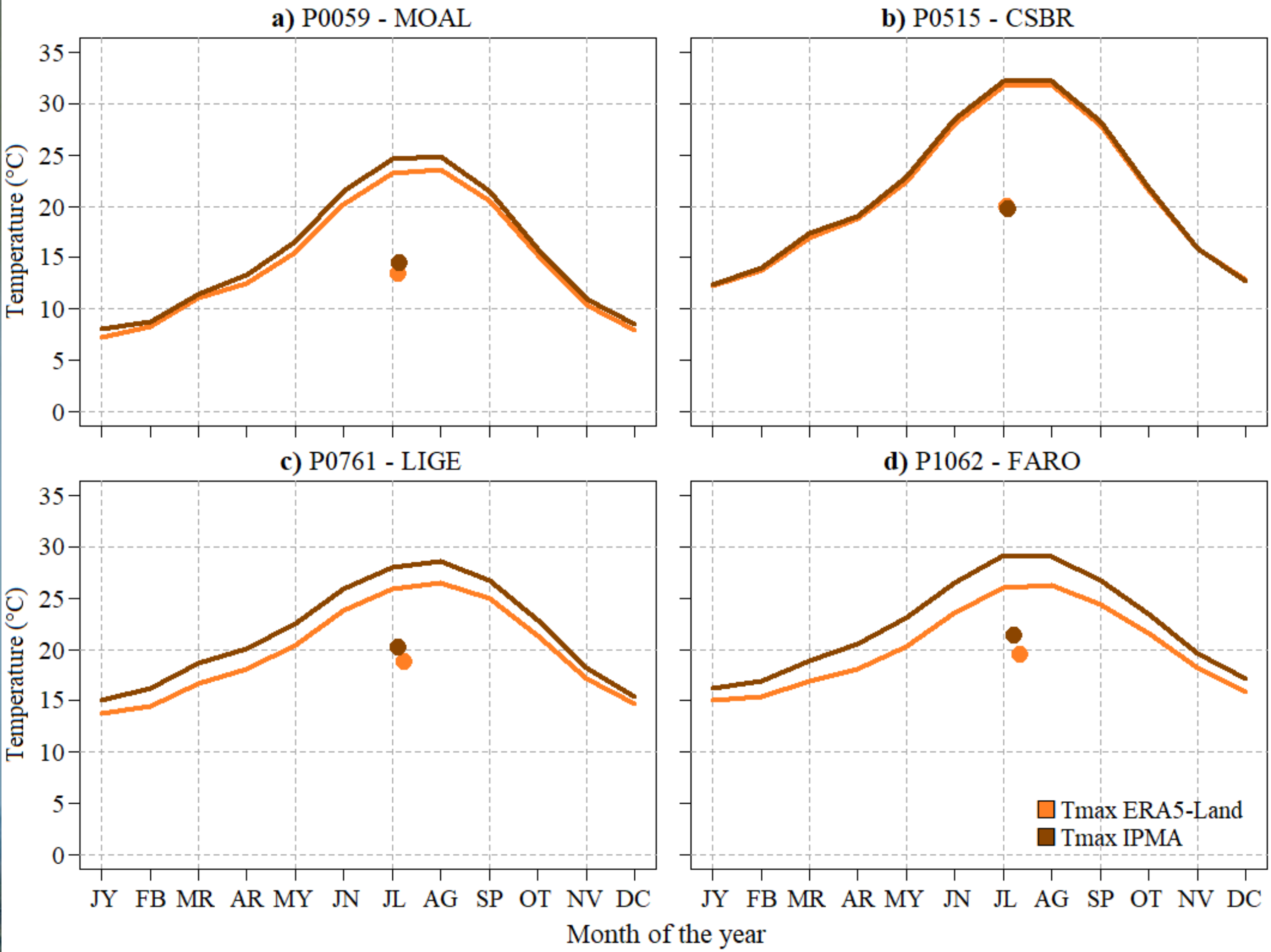


4. Results

Long-term average monthly temperature and its centroids for the period from January 1980 to December 2018.

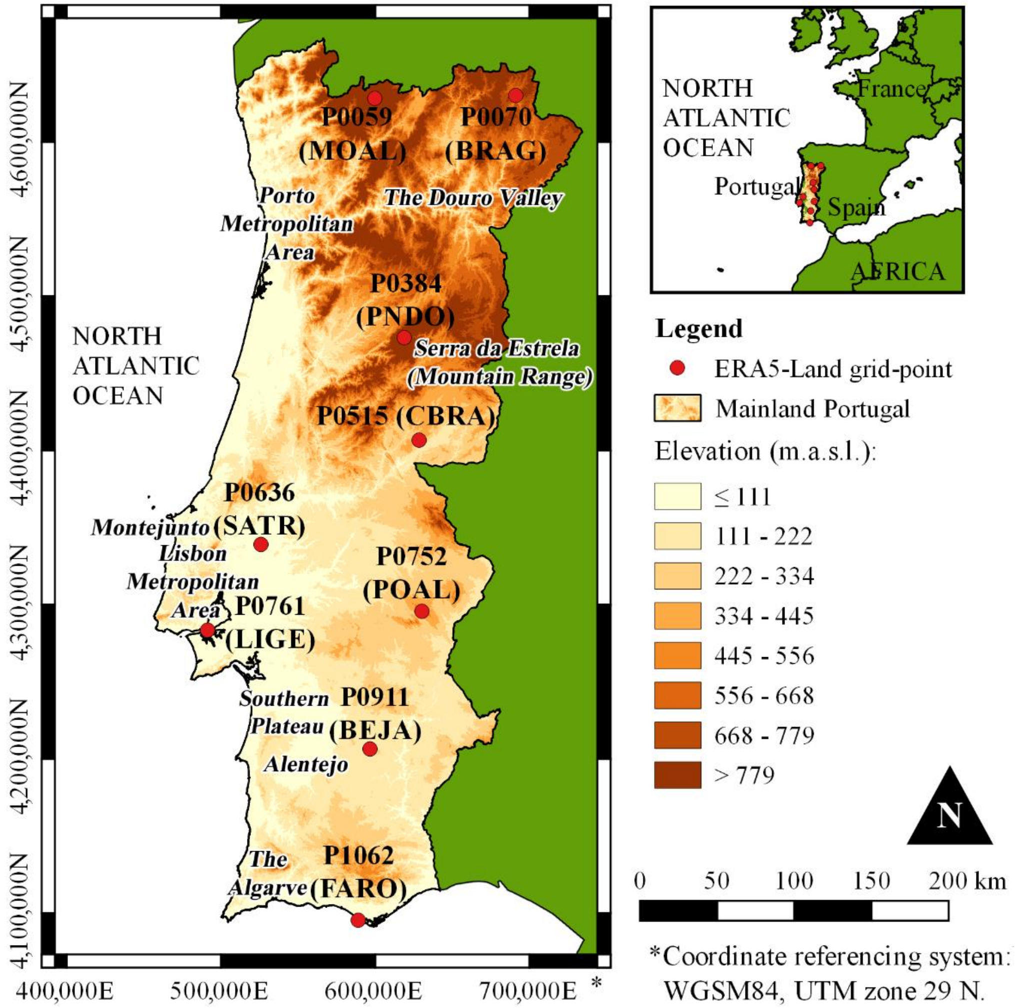
- ERA5-Land runs a tad warmer: ERA5-Land generally shows slightly higher Tmin values, except for the P0515 (CSBR) dataset, where the opposite is true.
- IPMA captures more extremes: Tmax from IPMA show greater variability and tend to reach higher values compared to ERA5-Land.
- Long-term averages tell a similar story: Line graphs of long-term average temperatures reveal consistent patterns across both datasets.



- **Strong agreement, but IPMA catches the heat: There's good agreement overall between the ERA5-Land and IPMA temperature data. While IPMA recorded higher maximum daily temperatures (Tmax), both datasets showed consistent patterns of temperature variation.**

  Moving on to heatwaves: Having validated the ERA5-Land dataset, the study then investigated heatwaves. This was done using the Heatwave Magnitude Index (HWMI), which was applied to the daily temperature data at each of the nine grid locations within the study area.

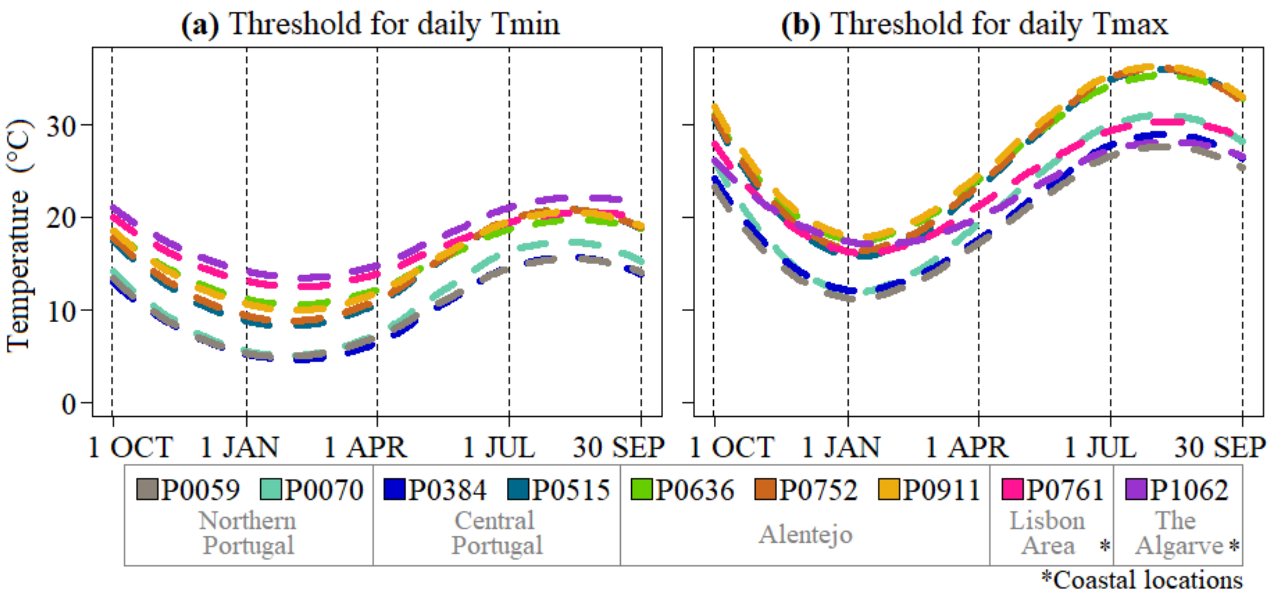
  Defining '**heatwave**': As a first step in identifying heatwaves, daily temperature thresholds were calculated. These thresholds were based on the reference period from 1 October 1980 to 30 September 2021 and were used to define what constitutes an unusually high temperature for that time of year.



4. Results

Daily temperature thresholds, A_d, for a) Tmin and b) Tmax, calculated from 1 October 1980 to 30 September 2021.

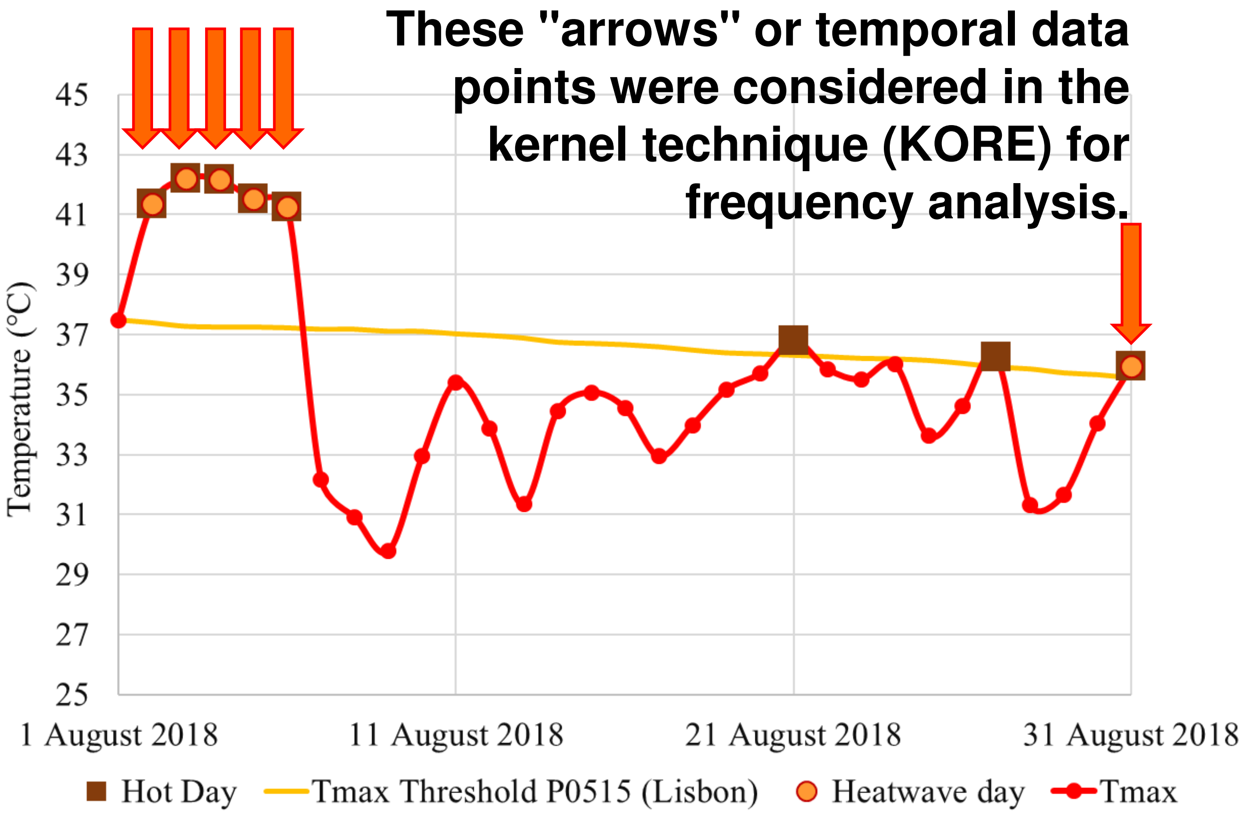
- The results indicate that P0059 (Montalegre), located inland and at the northernmost grid-point, had the lowest thresholds for both Tmin and Tmax.
- P0515 (Castelo Branco) exhibited a higher A_d, particularly for Tmax.
- During the dry period (approximately from day 180 to day 365), P0515 (Castelo Branco) had the strictest, i.e., the highest, Tmax threshold of all grid-points.



4. Results

A closer look at what constitutes a heatwave day.

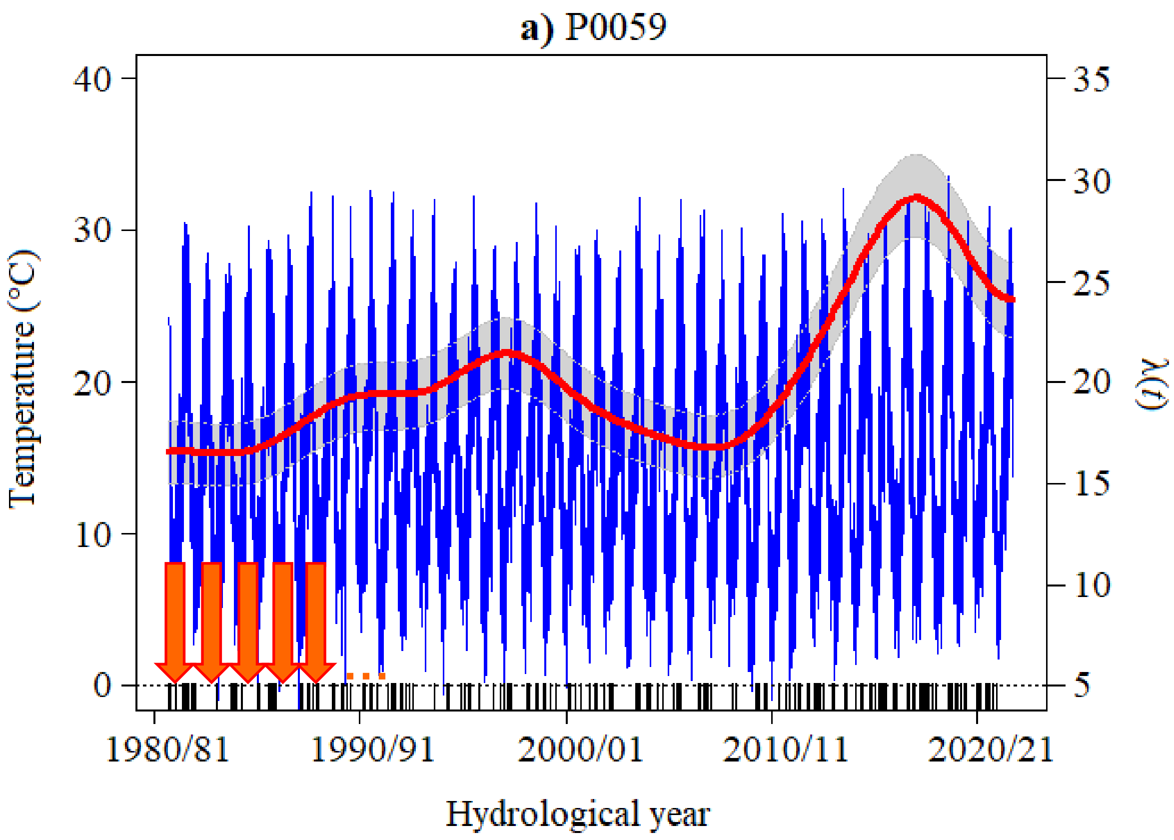
- The Heatwave Magnitude Index (HWMI) tells us how intense the worst **heatwave** of a given year was.
- To work this out, we first defined a heatwave as a period of three or more consecutive days where either the minimum temperature (Tmin) or the maximum temperature (Tmax) exceeds a specific daily threshold.



4. Results

Frequency analysis of heatwave days based on Tmin and Tmax.

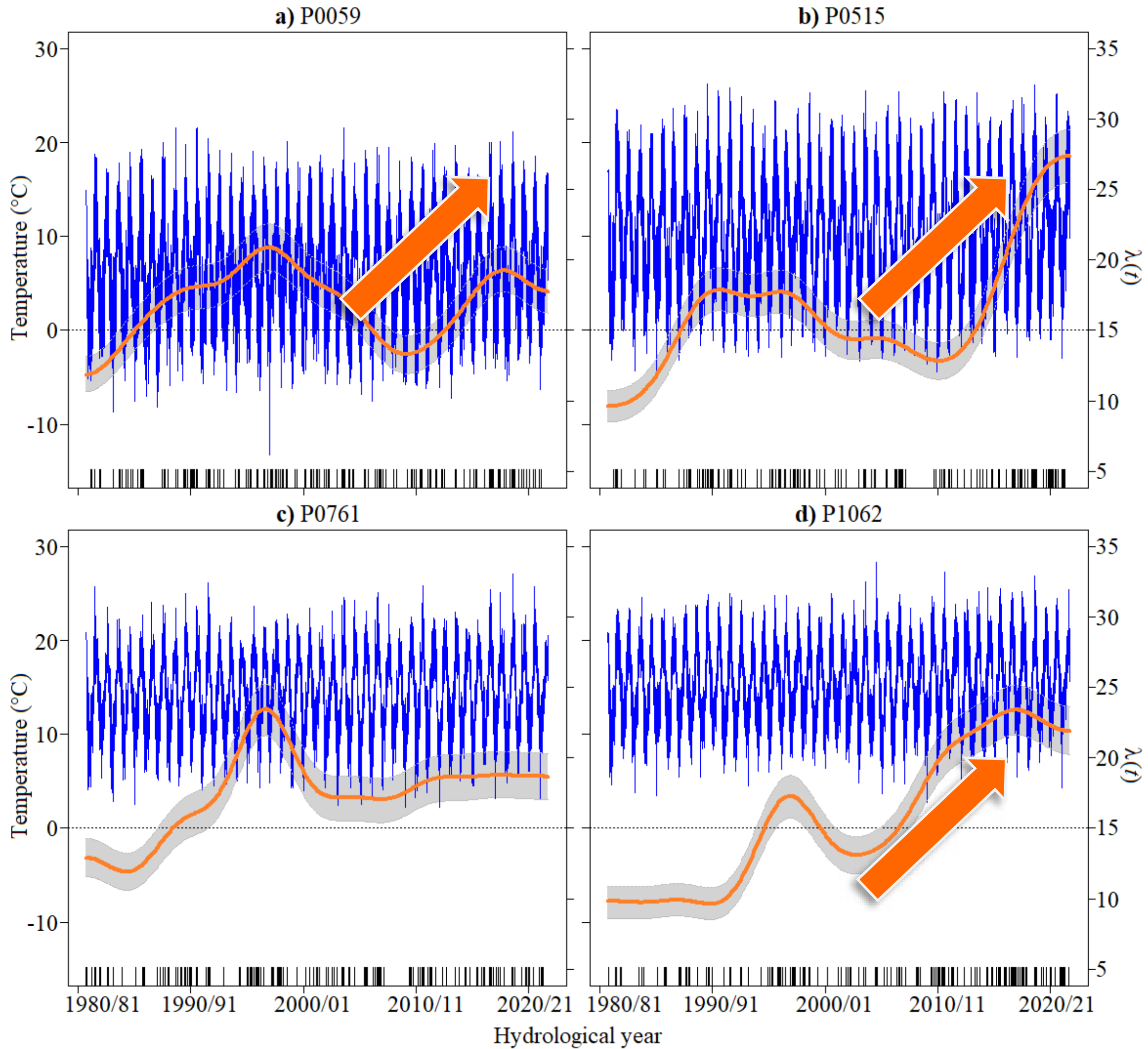
- **Heatwaves** were identified objectively using the Heatwave Magnitude Index (HWMI). This index relies on comparing daily temperatures to predetermined daily thresholds, allowing to pinpoint periods of unusually high temperatures.
- The KORE Technique: To understand how often heatwaves occur each year, we employed the kernel rate estimation (KORE) technique. This method allows us to estimate the annual frequency of heatwave events.



4. Results

Frequency analysis of heatwave days based on Tmin and Tmax.

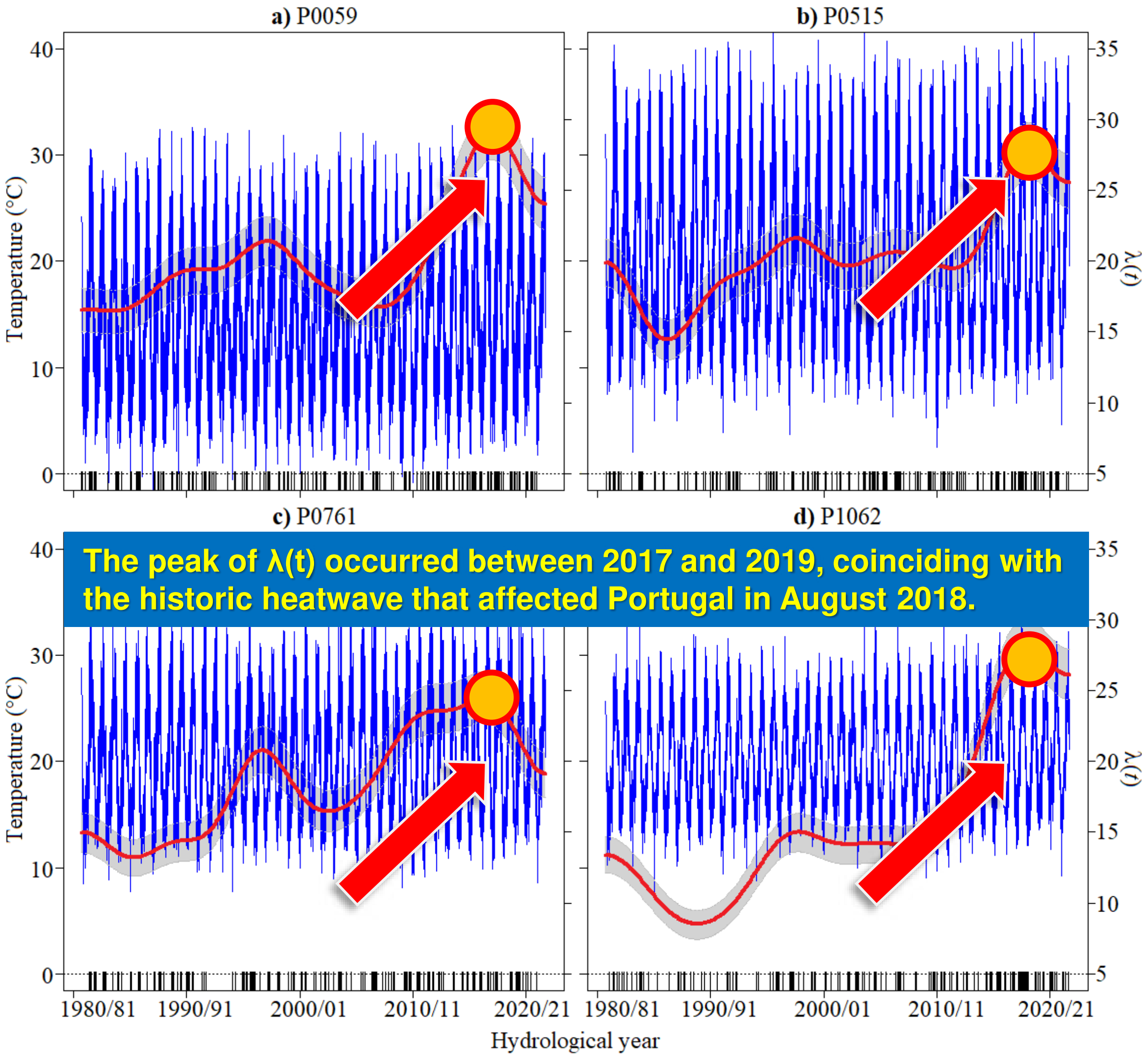
- Heatwaves were identified using the HWMI based on daily thresholds.
- KORE was used for annual frequency analysis.
- Time-dependent occurrence rates of **Tmin** heatwave days from October 1980 to September 2021 were analysed. The occurrence dates of heatwave days are indicated by vertical markers.



4. Results

Frequency analysis of heatwave days based on Tmin and Tmax.

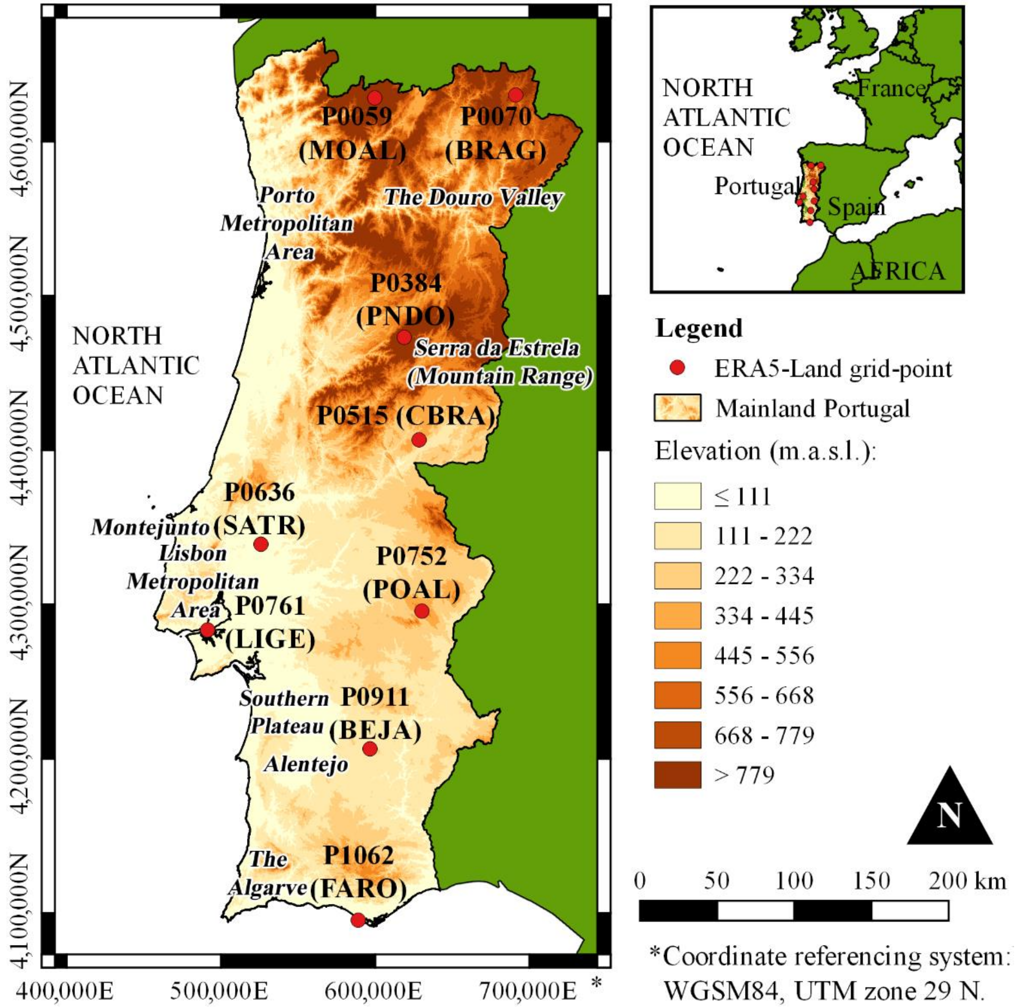
- Heatwaves were identified using the HWMI based on daily thresholds.
- KORE was used for annual frequency analysis.
- Time-dependent occurrence rates of **Tmax** heatwave days from October 1980 to September 2021 were analysed. The occurrence dates of heatwave days are indicated by vertical markers.



5. Final Remarks

Significant increase in Tmax heatwave days over the past two decades.

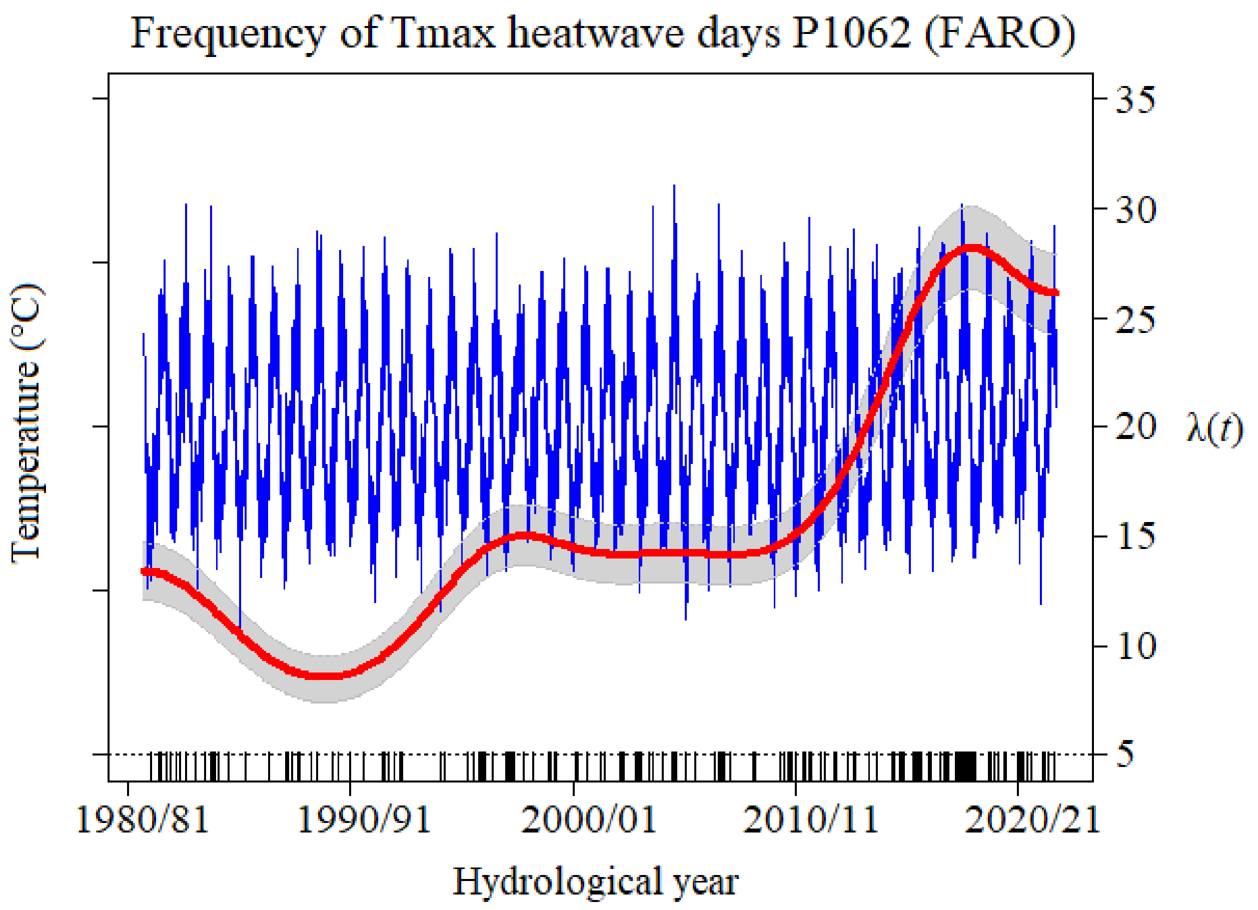
- Clear increase in the frequency of heatwave days in Portugal.
- Geographical variations in heatwave occurrence, with southern locations experiencing a greater increase in Tmax heatwave days.
- Heatwaves pose health risks (respiratory problems) and impact ecosystems and infrastructure.



5. Final Remarks

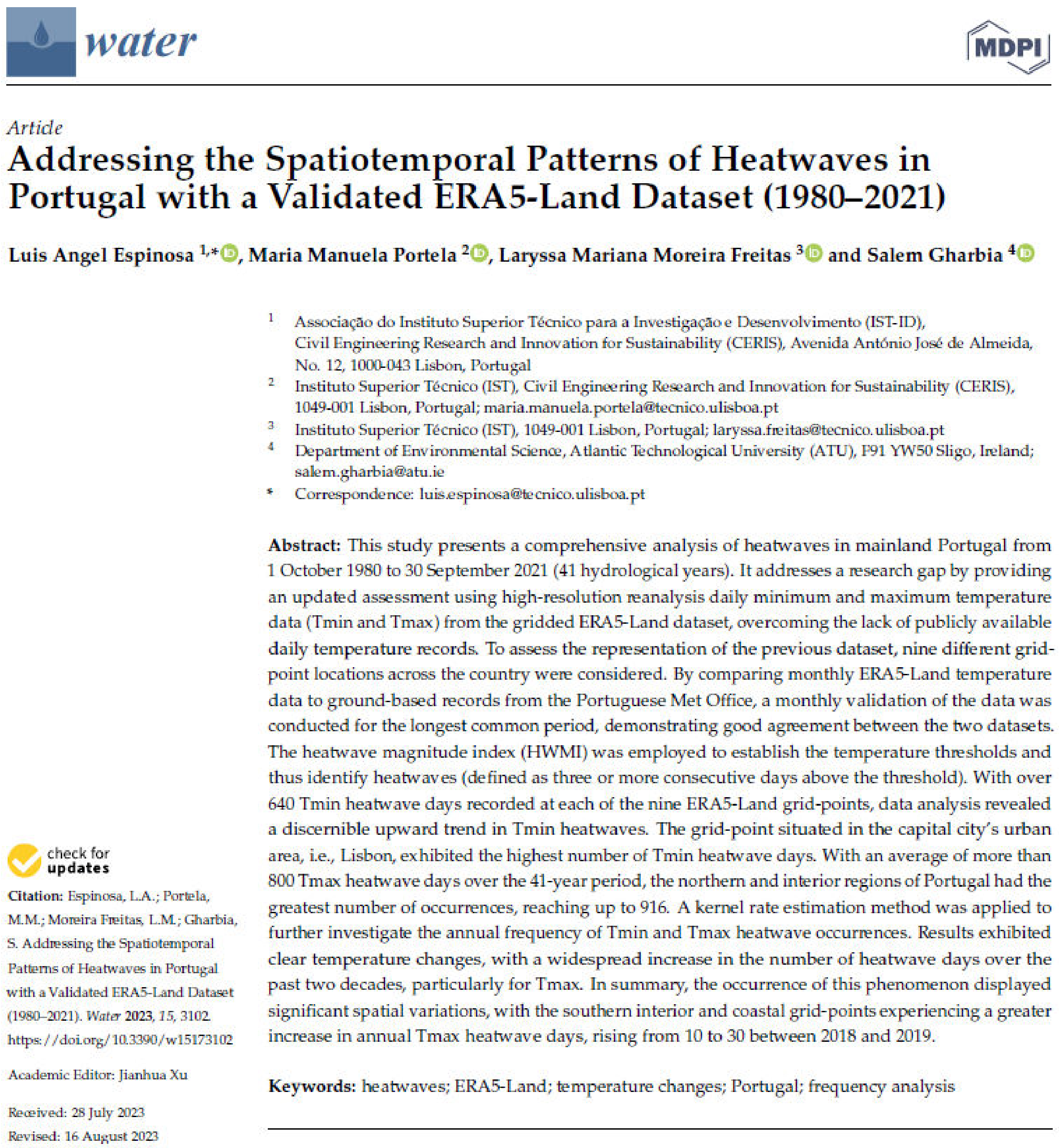
Significant increase in Tmax heatwave days over the past two decades.

- Greater vulnerability of certain population groups, highlighting the need for targeted support and interventions.
- Heatwaves are becoming more frequent, posing an increasing threat to public health and the environment.
- ERA5-Land provides valuable data and insights for analysing heatwave trends.
- Urgent need for more research, adaptation measures, and **increased climate awareness**.



Reference

Espinosa, L.A.; Portela, M.M.; Moreira Freitas, L.M.; Gharbia, S. Addressing the Spatiotemporal Patterns of Heatwaves in Portugal with a Validated ERA5-Land Dataset (1980–2021). Water 2023, 15, 3102.



water MDPI

Article

Addressing the Spatiotemporal Patterns of Heatwaves in Portugal with a Validated ERA5-Land Dataset (1980–2021)

Luis Angel Espinosa [1,*], Maria Manuela Portela [2], Laryssa Mariana Moreira Freitas [3] and Salem Gharbia [4]

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* Correspondence: luis.espinosa@tecnico.ulisboa.pt

Abstract: This study presents a comprehensive analysis of heatwaves in mainland Portugal from 1 October 1980 to 30 September 2021 (41 hydrological years). It addresses a research gap by providing an updated assessment using high-resolution reanalysis daily minimum and maximum temperature data (Tmin and Tmax) from the gridded ERA5-Land dataset, overcoming the lack of publicly available daily temperature records. To assess the representation of the previous dataset, nine different grid-point locations across the country were considered. By comparing monthly ERA5-Land temperature data to ground-based records from the Portuguese Met Office, a monthly validation of the data was conducted for the longest common period, demonstrating good agreement between the two datasets. The heatwave magnitude index (HWMI) was employed to establish the temperature thresholds and thus identify heatwaves (defined as three or more consecutive days above the threshold). With over 640 Tmin heatwave days recorded at each of the nine ERA5-Land grid-points, data analysis revealed a discernible upward trend in Tmin heatwaves. The grid-point situated in the capital city's urban area, i.e., Lisbon, exhibited the highest number of Tmin heatwave days. With an average of more than 800 Tmax heatwave days over the 41-year period, the northern and interior regions of Portugal had the greatest number of occurrences, reaching up to 916. A kernel rate estimation method was applied to further investigate the annual frequency of Tmin and Tmax heatwave occurrences. Results exhibited clear temperature changes, with a widespread increase in the number of heatwave days over the past two decades, particularly for Tmax. In summary, the occurrence of this phenomenon displayed significant spatial variations, with the southern interior and coastal grid-points experiencing a greater increase in annual Tmax heatwave days, rising from 10 to 30 between 2018 and 2019.

Keywords: heatwaves; ERA5-Land; temperature changes; Portugal; frequency analysis

check for updates

Citation: Espinosa, L.A.; Portela, M.M.; Moreira Freitas, L.M.; Gharbia, S. Addressing the Spatiotemporal Patterns of Heatwaves in Portugal with a Validated ERA5-Land Dataset (1980–2021). *Water* **2023**, *15*, 3102. https://doi.org/10.3390/w15173102

Academic Editor: Jianhua Xu

Received: 28 July 2023
Revised: 16 August 2023

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Policy Brief

Heatwaves in Portugal: Understanding, Mitigation, Adaptation

Summary

- This policy brief summarises a comprehensive analysis* of heatwaves in mainland Portugal from October 1980 to September 2021, utilising high-resolution ERA5-Land daily temperature data. The study aims to address the increasing occurrence of heatwaves in Portugal, a phenomenon that will be exacerbated by climate change.
- Key findings include a noticeable upward trend in both minimum and maximum temperatures (Tmin and Tmax) heatwave days, with notable spatial variations across different regions of Portugal.
- The results emphasise the urgent need for effective adaptation and mitigation strategies to alleviate the negative impacts of extreme temperatures on public health, agriculture, energy consumption, and ecosystem functioning. Additionally, recommendations for climate capacity building and raising public awareness are highlighted.

Introduction

Heatwaves (often associated with extreme heat warnings) are becoming more frequent and intense worldwide, posing significant challenges to societies and ecosystems (see Box 1). Portugal has experienced severe heatwaves in recent years, with notable impacts on various sectors. However, the absence of local long-term temperature records impedes comprehensive analysis and monitoring of heatwaves. To address this gap, the study utilises high-resolution ERA5-Land daily temperatures. Its goal is to offer insights into the frequency, intensity, and spatial distribution of heatwaves in Portugal, crucial for developing effective adaptation and mitigation strategies to address the adverse effects of such extreme events.

Policy briefs offer information on current issues, presenting precise recommendations to contribute to ongoing policy discussions.

This policy brief was written by Luis Angel Espinosa (luis.espinosa@tecnico.ulisboa.pt), and Maria Manuela Portela (maria.manuela.portela@tecnico.ulisboa.pt).

Box 1. Definitions:

Heatwave is a prolonged period of exceptionally hot weather, typically marked by either Tmax or Tmin surpassing specific thresholds for several consecutive days (e.g. three or more days). Throughout a heatwave, temperatures may persist significantly above average, presenting risks to human health, particularly vulnerable groups such as the elderly, young children, and individuals with pre-existing health conditions.

Extreme Heat Warnings (also known as orange or red alerts) are issued by meteorological agencies such as the IPMA (*Instituto Português do Mar e da Atmosfera*) during periods of exceptionally high temperatures. These alerts represent a severe risk to human health due to extreme heat conditions, typically associated with prolonged heatwaves.

Adapted from the IPMA website. https://www.ipma.pt/en/index.html

*This policy brief is based on: Espinosa, L.A.; Portela, M.M.; Moreira Freitas, L.M.; Gharbia, S. Addressing the Spatiotemporal Patterns of Heatwaves in Portugal with a Validated ERA5-Land Dataset (1980–2021). *Water* 2023, 15, 3102. https://doi.org/10.3390/w15173102

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Methodology

This study employs validated high-resolution ERA5-Land daily temperature data covering a 41-year period from October 1980 to September 2021. Nine climatological locations across Portugal are selected for analysis. The Heatwave Magnitude Index (HWMI) is utilised to identify heatwave events based on temperature thresholds, with a focus on both Tmin and Tmax. The methodology ensures robust analysis and accurate representation of heatwave occurrences in Portugal, providing valuable insights for climate change awareness.

Research, Results, and Conclusions

The analysis reveals a significant increase in the frequency of both Tmin and Tmax heatwave days across Portugal over the 41-year period. Spatial variations are observed, such as the higher number of Tmax heatwave days in the northern and interior regions compared to the coastal areas (see Figure 1). The study emphasises the importance of utilising high-resolution reanalysis datasets like ERA5-Land for comprehensive heatwave analysis, overcoming limitations of traditional ground-based datasets. The findings underscore the urgency of implementing proactive measures to mitigate the impacts of heatwaves, including enhancing temperature monitoring and forecasting, developing early warning systems, implementing urban heat island mitigation strategies, and promoting sustainable practices.

Policy Recommendations

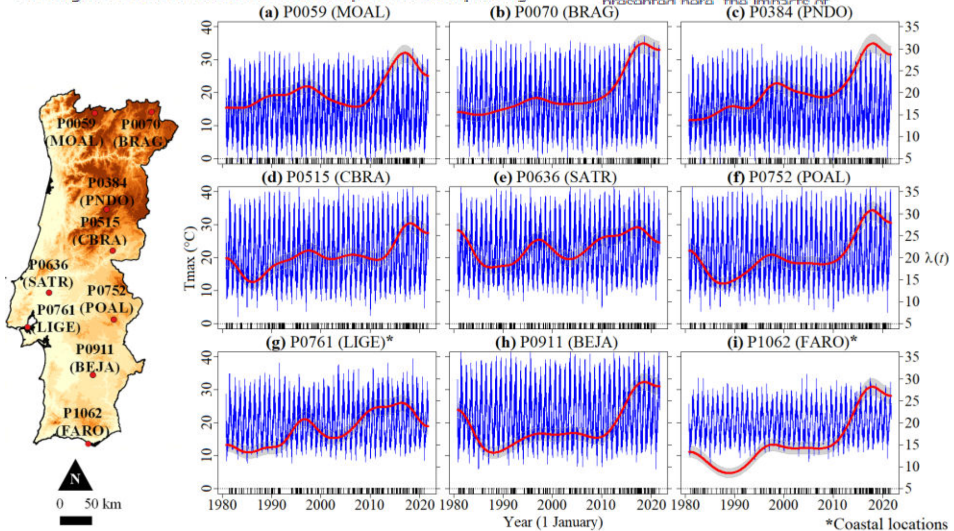
1. Enhance Temperature Monitoring and Forecasting: Invest in continuous monitoring and data processing to enhance the accuracy and timeliness of temperature predictions, thus improving early intervention during heatwaves and raising awareness of climate risks.
2. Implement Early Warning Systems: Establish comprehensive heatwave early warning systems at national and regional levels, integrating meteorological data, health indicators, and vulnerability assessments to ensure timely dissemination of alerts and advisories to the public and relevant stakeholders.
3. Mitigate Urban Heat Island Effect: Implement urban planning

4. Promote Sustainable Practices: Encourage sustainable practices such as reducing greenhouse gas emissions, promoting energy-efficient technologies, and adopting climate-resilient agricultural practices to mitigate the long-term impacts of climate change and reduce the frequency and intensity of heatwaves.

Expected Outputs

- Improved public health outcomes through proactive heatwave preparedness and response measures.
- Enhanced resilience of critical infrastructure and ecosystems to extreme heat events.
- Reduced economic losses associated with heatwave-related impacts on agriculture, energy consumption, and tourism.
- Improved quality of life and well-being for vulnerable populations through targeted interventions and community engagement.

To conclude, proactive measures to tackle the growing frequency and intensity of heatwaves in Portugal are crucial for safeguarding public health, preserving ecosystems, and enhancing resilience to climate change. By implementing the recommended policies and strategies



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Horizon 2020 Grant agreement ID: 101003534

TÉCNICO LISBOA | ISTID

POLICY BRIEF

Red Flags on the Map: A Policy Brief on Exceptional Rainfall and Temperature Events in Portugal

Luis Angel Espinosa[1], **and Maria Manuela Portela**[2]

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[2] Instituto Superior Técnico (IST), CERIS; Portugal: **maria.manuela.portela@tecnico.ulisboa.pt**

Context and Importance: Climate change awareness is crucial for understanding the increasing severity of exceptional weather events. Portugal, characterised by diverse topography and climatic variations, has experienced significant shifts in extreme rainfall and temperature patterns over recent decades. These changes pose substantial risks to water resources, infrastructure, agriculture and ecosystem stability. This policy brief summarises key findings from two studies that utilise severity heat maps—as proposed by Espinosa, Portela, and Gharbia [1]—to analyse exceptional rainfall and temperature events in Portugal. The findings highlight the intensification of extreme weather events throughout the past four decades and provide insights into their regional impacts. Furthermore, the brief outlines implications for climate adaptation strategies and policymaking, emphasising the need to strengthen resilience against escalating climate risks.

* This brief was supported by FCT (UIDB/04625/2020, CERIS) and EU Horizon 2020 (grant No. 101003534).

1 Introduction

Extreme weather events, including exceptional rainfall and maximum temperature (Tmax), have intensified due to climate change, profoundly impacting hydrological forecasting, disaster risk management, and infrastructure planning. Understanding the spatiotemporal distribution of these extremes is critical for developing effective climate adaptation policies. This brief presents insights from two studies using ERA5-Land reanalysis data at 1,012 evenly distributed centroids to map changes in exceptional rainfall and Tmax across Portugal. The studies provide a comparative analysis of these events' evolution over late and recent phases, using severity heat maps to quantify their impacts.

2 Findings

Exceptional Rainfall (1981–2023). Using the retrieved reanalysis rainfall data, this study identified exceptional rainfall events based on three high quantile thresholds (Q99, Q99.5, Q99.9), revealing:

- A severity heat map (see Figure 1) that classifies regions based on changes in occurrence and cumulative rainfall over threshold from the late and recent phases, highlighting a shift in exceptional rainfall occurrences from the southern to northern regions.
- Increased severity of rainfall events, particularly in urban areas such as Lisbon and Porto, which exhibit higher frequencies of exceptional rainfall events and cumulative rainfall above threshold in the recent phase.

Exceptional Tmax (1980–2024). Examining Tmax data over the late and recent phases, the study illustrated shifts in exceptional Tmax events in Portugal (see Figure 2) for the thresholds Q90, Q99, Q99.9:

- Northern and central regions showed the most significant increases in occurrences and temperature excess (More & More, Case 1), while some areas, such as Alentejo, exhibited increased frequency but less temperature excess at higher thresholds (More & Less).
- A few regions, such as Braga and Guarda, showed less occurrences or temperature excess, indicating localised improvements (Cases 3 and 4 for Q99).

3 Policy Implications

The findings highlight urgent climate adaptation needs:

- **Improved monitoring systems:** Expanding hydrometeorological networks to enhance early detection and forecasting of extreme events.
- **Resilient Infrastructure and Land-Use Planning:** Develop flood defences, heat-resistant materials, and urban strategies to mitigate extreme weather impacts, integrating shifting climate patterns into development policies.
- **Climate education and awareness:** Strengthening knowledge-sharing initiatives to enhance public and policymaker awareness of climate change risks and adaptation measures.

Red Flags on the Map: A Policy Brief on Extreme Rainfall and Temperature Events in Portugal | February 2025 1

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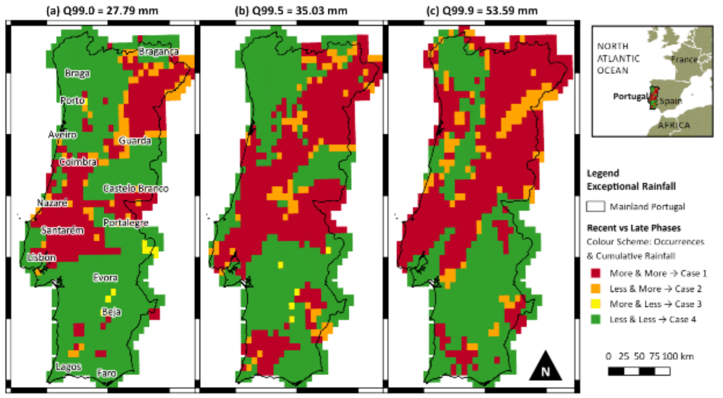

Fig. 1 Severity heat map of exceptional rainfall events—rainfall above Q—for the late (1981–2002) and recent (2002–2023) phases.

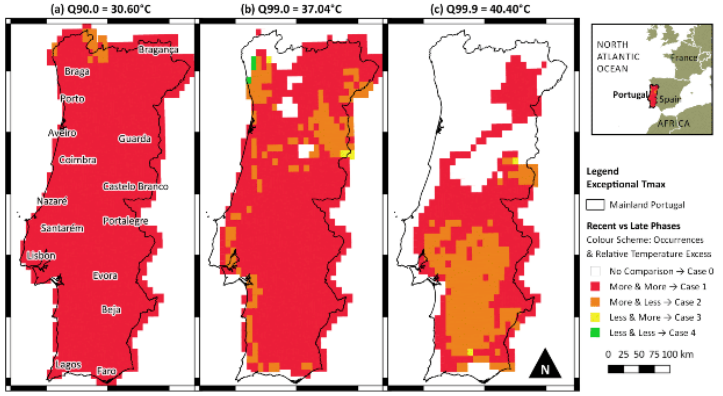

Fig. 2 Severity heat map of exceptional Tmax events—Tmax above Q—for the late (1980–2002) and recent (2002–2024) phases.

4 Conclusions

Climate change is altering Portugal's hydrological and temperature regimes, increasing the severity of exceptional rainfall and Tmax events, as highlighted by severity heat maps that provide essential insights for understanding and mitigating extreme weather risks. Policymakers, engineers, and scientists must collaborate to strengthen resilience and ensure sustainable water and climate governance.

References

[1] L. A. Espinosa, M. M. Portela, and S. Gharbia, "Assessing Changes in Exceptional Rainfall in Portugal Using ERA5-Land Reanalysis Data (1981/1982–2022/2023)," *Water*, vol. 16, no. 5, p. 628, 2024.

https://www.aa.com.tr/en/europe (2022)

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