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Evaluating Climate Change Risks for Greek Tourism Destinations: A Bioclimatic Approach †

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Abstract

Tourism in Greece is directly influenced by bioclimatic conditions, with thermal comfort being a key determinant of destination suitability. This study quantifies projected changes in outdoor thermal stress across 25 representative Greek tourism locations using the Physiologically Equivalent Temperature (PET) index. The analysis employs daily outputs from four EURO-CORDEX regional climate model simulations at ~11 km spatial resolution, covering the period 1970–2100 under three Representative Concentration Pathways (RCP2.6, RCP4.5, RCP8.5). Predominant PET classes were derived for a reference period (1971–2000) and two future horizons (2031–2060, 2071–2100) to evaluate the spatiotemporal evolution of thermal comfort. The results reveal a consistent upward shift toward higher PET classes, indicating intensifying thermal stress. During the baseline, moderate to strong heat stress (29–35 °C) dominated summer months, with cold stress (<8 °C) restricted to northern and high-altitude stations. By mid-century, even under RCP2.6, summer PET values increasingly exceed 35–41 °C, while RCP8.5 simulations show the first occurrence of extreme PET (>41 °C). By late century, RCP2.6 stabilizes heat stress, whereas RCP4.5 exhibits widespread dominance of strong stress classes and elimination of cold stress. Under RCP8.5, July–August are uniformly categorized as extreme (>41 °C) across nearly all stations, and transitional months shift toward high stress, leading to a homogenization of summer conditions. These findings underscore the high sensitivity of Greek tourism destinations to climate change, highlighting both the critical benefits of global emissions mitigation and the urgent need for locally tailored adaptation strategies.

Keywords: Physiologically Equivalent Temperature; EURO-CORDEX simulations; thermal stress; Representative Concentration Pathways; tourism climatology

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1. Introduction

Tourism is one of the sectors most directly influenced by climatic conditions, with outdoor thermal comfort shaping destination attractiveness, visitor well-being, and seasonal demand [1]. The Mediterranean basin has long been recognized as a global climate change "hotspot," characterized by above-average warming, intensification of hot extremes, and a reduction in cold extremes [2]. As one of the world's leading tourism regions, the Mediterranean is particularly vulnerable to such shifts. Studies have shown that peak-summer conditions are likely to become increasingly unfavorable due to excessive heat stress, while

the transition seasons (spring and autumn) may become more climatically suitable for tourism activities [3,4].

Within this context, Greece as part of the Eastern Mediterranean region, on one hand experiences climate vulnerability [5,6] and on the other hand it is a country where tourism is a significant pilar of the national economy. The dependence of Greek destinations on favorable climate conditions makes them highly sensitive to projected changes in outdoor thermal comfort.

Bioclimatic indices have become significant tools for assessing the interaction between climate and human thermal perception. Physiologically Equivalent Temperature (PET) [7], modified PET (mPET—[8] and Universal Thermal Climate Index (UTCI) [9], are particularly suitable to interpret the thermal bioclimatic conditions [10,11]. Many studies have been contacted in Greece evaluating present and future bioclimatic conditions [12–14] indicating the anticipated increase in thermal stress.

The present study extends this research by conducting a national-scale PET-based assessment of climate change impacts on 25 representative Greek tourism destinations, by employing daily outputs from four EURO-CORDEX regional climate model simulations at ~11 km spatial resolution, covering the period 1970–2100 under three Representative Concentration Pathways (RCP2.6, RCP4.5, RCP8.5). The objectives are to quantify temporal and spatial shifts in thermal comfort categories, assess changes in the tourism-relevant "comfort window," and provide scientific evidence to support adaptation strategies in Greece's tourism sector.

2. Materials and Methods

The applied procedure to simulate the thermal bioclimate in 25 Greek tourism destinations (Figure 1) was based on daily outputs from four high-resolution (~11 km) EURO-CORDEX (https://euro-cordex.net/ accessed on 20 July 2025) regional climate model simulations (Table 1), for three thirty-year time periods: the reference period 1971–2000, the near future 2031–2060 and the far future period 2071–2100, under three different emission scenarios RCP2.6, RCP4.5, and RCP8.5.

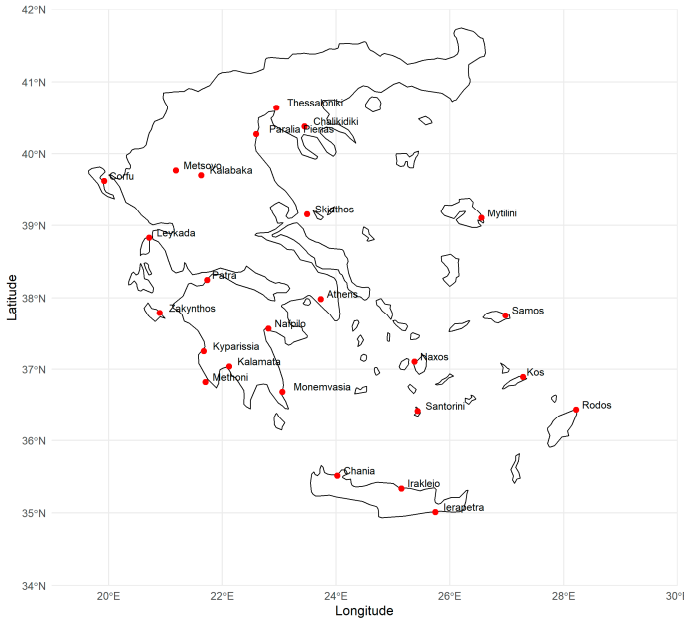


Figure 1. The 25 Greek tourism destinations.

Table 1. List of the simulations whose results are used in the present study.

Simulation	Regional Climate Model (RCM)	Earth System Model (ESM)
CNRM-CERFACS-CNRM-CM5_KNMI-RACMO22E	RACMO22E	CNRM-CM5
ICHEC-EC-EARTH_DMI-HIRHAM5	HIRHAM5	EC-Earth
MOHC-HadGEM2-ES_KNMI-RACMO22E	RACMO22E	HadGEM2-ES
MOHC-HadGEM2-ES_SMHI-RCA4	RCA4	HadGEM2-ES

Daily datasets of air temperature, relative humidity, wind speed, and cloud cover were employed to estimate PET, derived from the human energy balance, through application of the RayMan model [15].

3. Results and Discussion

The analysis of Physiologically Equivalent Temperature (PET) distributions for 25 representative Greek destinations during the reference period 1971–2000 reveals clear seasonal and spatial contrasts in thermal comfort and stress, which directly affect tourism seasonality and destination attractiveness (Figure 2). Three key thermal categories are considered: thermal comfort (18–23 °C), strong cold stress (<8 °C), and strong heat stress (>35 °C). Across all locations, spring (April–May) and autumn (September–October) emerge as the periods with the highest frequencies of thermal comfort, offering the most favorable bioclimate for cultural activities, sightseeing, and outdoor leisure. The Aegean and Ionian islands (Santorini, Naxos, Skiathos, Corfu, Mytilini) are particularly advantageous, as their maritime climates extend the comfort window well into May and October, with up to half of the days falling in the neutral range. Crete and the Dodecanese (Chania, Herakleio, Ierapetra, Rodos, Kos) also exhibit extended spring and autumn comfort, making them highly suitable for tourism during these periods. In contrast, mainland cities and basins such as Athens, Nafplio, Kalamata, Patra, Thessaloniki, and Kalabaka display a much narrower comfort period, often limited to April and October, as summer heat and winter cold dominate the remainder of the year. During winter (December–February), the distribution of strong cold stress (<8 °C) reveals a sharp geographic contrast. In northern and continental regions (Kalabaka, Thessaloniki, Paralia Pierias), up to 40% of days in January and February fall below this threshold, producing severe thermal discomfort but creating favorable conditions for winter and mountain tourism such as skiing and hiking. Central urban basins (Athens, Nafplio, Patra) exhibit moderate winter cold stress, around 20–30% of days in mid-winter, which reduces comfort but does not prevent year-round tourism. By contrast, the southern islands (Crete, Rodos, Kos, Santorini, Naxos) experience very low cold stress, often less than 20% even in January, highlighting their potential for off-season cultural and wellness tourism in mild Mediterranean winters. In summer (July–August), strong heat stress (>35 °C) dominates many parts of Greece, yet its intensity and duration vary regionally. The mainland basins and urban centers (Athens, Nafplio, Kalamata, Patra, Thessaloniki, Chalkidiki, Lefkada) experience the highest frequencies, with more than 70% of days exceeding 35 °C and prolonged heat stress often lasting from June into September. These conditions strongly constrain daytime outdoor activities and shift tourism toward evening or coastal settings. Crete, Kos, Rodos, Monemvasia, Kyparissia, and Samos exhibit substantial but more moderate heat stress (40–60% of summer days), with sea breezes and coastal influence tempering extremes. The maritime islands (Santorini, Naxos, Skiathos) show the lowest frequency of strong heat stress, rarely exceeding 20%, which makes them comparatively attractive even in midsummer, when continental Greece suffers from extreme heat.

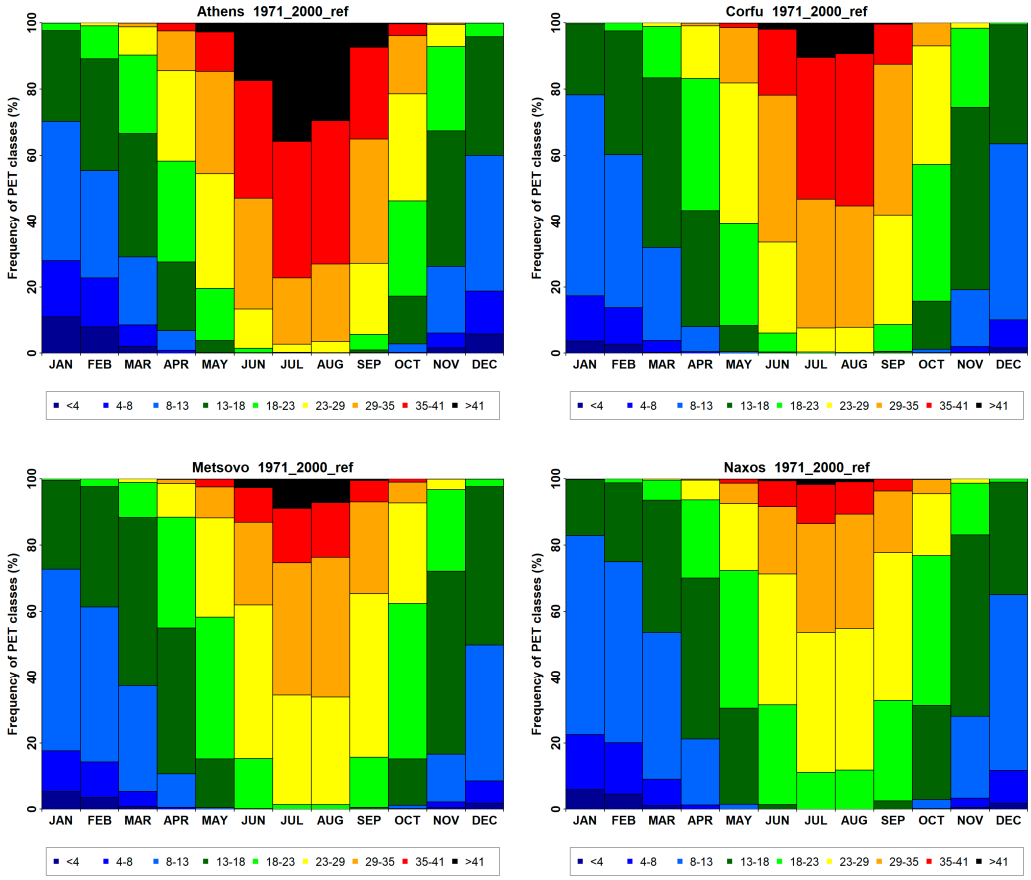


Figure 2. Bioclimatic diagrams for representative touristic destinations (Athens, Corfu, Metsovo and Naxos) for the reference period 1971–2000.

The national heatmaps of predominant Physiological Equivalent Temperature (PET) classes for 25 representative stations across Greece provide a clear picture of the spatial and temporal evolution of thermal comfort conditions under climate change. The analysis spans the historical reference period (1971–2000) and two future horizons (2031–2060 and 2071–2100) under three Representative Concentration Pathways (RCP2.6, RCP4.5, RCP8.5). The results consistently demonstrate a progressive shift toward higher PET classes, indicating increasing exposure to thermal stress across the country.

During the historical baseline, the heatmaps confirm the typical Mediterranean climate signal. Winter and transitional months are characterized by lower PET classes, with cold stress (<8 °C) limited to northern and high-altitude stations, while summer months (June–August) are dominated by moderate to strong heat stress (29–35 °C), occasionally exceeding 35–41 °C in the south. This regime reflects the balance between mild winters and hot, dry summers, with significant geographical differentiation between northern and southern stations.

By the mid-21st century (2031–2060), all scenarios indicate a notable intensification of heat stress. Under RCP2.6, winter conditions remain broadly comparable to the baseline, but summer months increasingly fall within the 35–41 °C PET class. Under RCP4.5, the warm season expands, with higher PET values occurring earlier in spring and persisting later into autumn. RCP8.5 projects the first emergence of extreme PET classes (>41 °C) during peak summer at several stations, marking the onset of unprecedented conditions relative to the baseline. These changes indicate a contraction of the thermal comfort window and an extension of the period of elevated heat stress.

By the end of the century (2071–2100), the divergence between emission pathways becomes pronounced. Under RCP2.6, mitigation stabilizes the upward shift, with PET

classes rarely exceeding 35–41 °C and some cooler months preserved. RCP4.5, however, is characterized by widespread dominance of the 35–41 °C class during summer and a near disappearance of cold stress classes in winter (Figure 3, upper graph). The most dramatic transformation is observed under RCP8.5, where July and August are uniformly classified in the extreme > 41 °C PET category across nearly all stations. Transitional months such as May and September also shift toward high stress categories, while winter becomes uniformly mild, eliminating the presence of low PET classes altogether. This outcome points toward a near-subtropical regime, with extreme and spatially homogeneous summer conditions (Figure 3, lower graph).

Spatially, lowland and southern stations exhibit a more rapid transition to higher PET classes, but by the late century, even northern and mountainous areas lose their relative cooling advantage. The convergence of stations into higher PET classes suggests a homogenization of summer thermal stress across Greece. This homogenization, combined with the persistence of extreme classes under RCP8.5, poses a major challenge for public health, urban livability, and energy systems. In terms of societal implications, the intensification of heat stress is expected to elevate risks of morbidity and mortality, increase cooling energy demand, reduce heating needs in winter, and necessitate large-scale adaptation measures in urban and rural settings. At the same time, the contrast between the RCP2.6 and RCP8.5 pathways illustrates the critical importance of global emission reductions: under low-emission scenarios, extreme heat stress remains limited, and adaptation is more manageable, whereas under high emissions, thermal stress reaches levels unprecedented in the observational record.

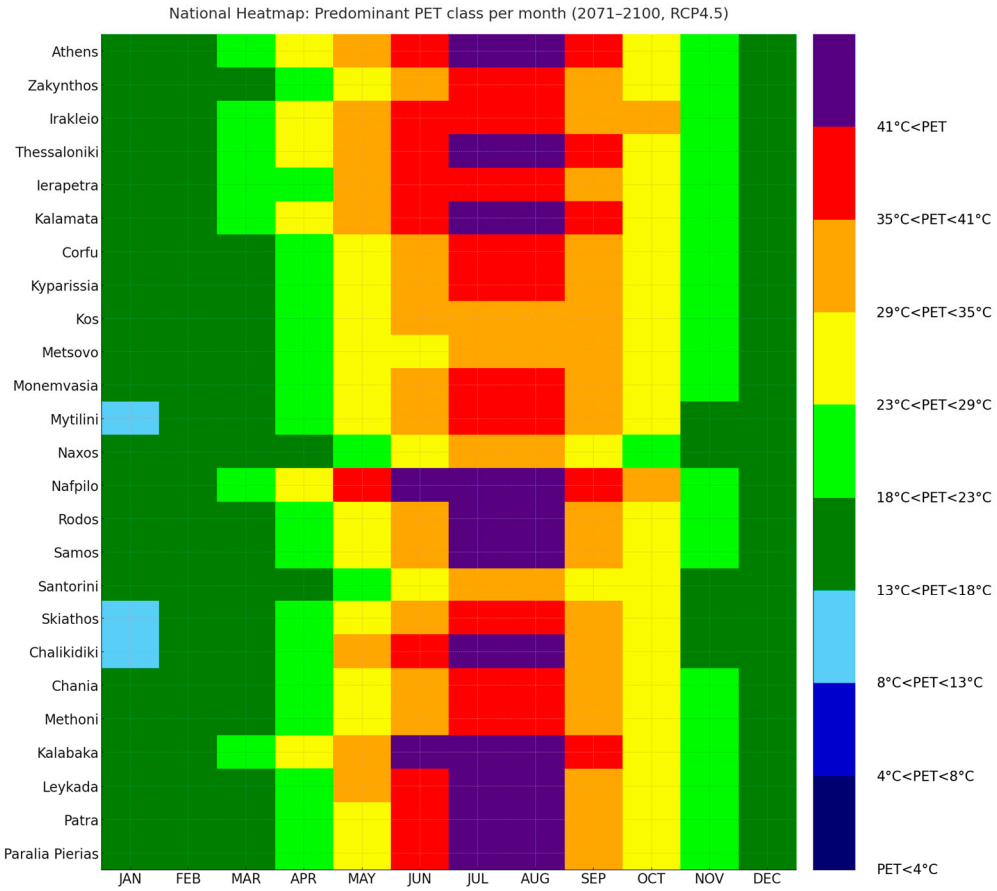


Figure 3. *Cont.*

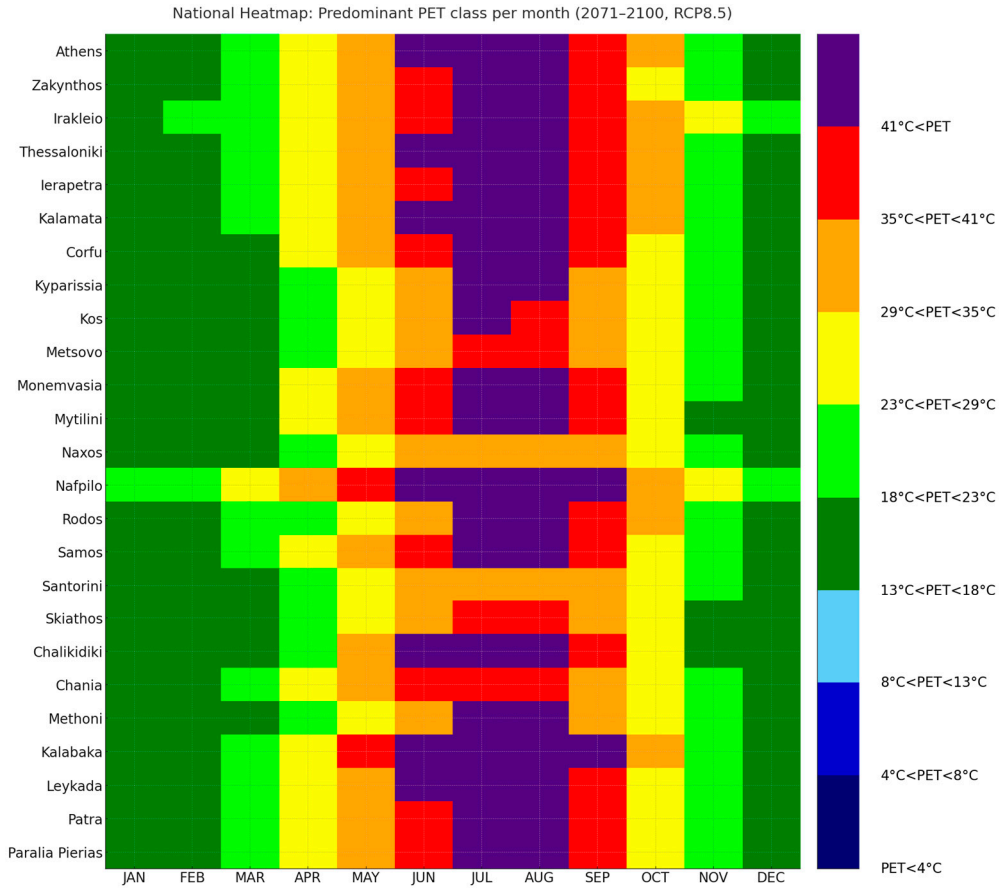


Figure 3. National Heatmap of the predominant PET class per month, for 25 representative Greek touristic destinations, for the period 2071–2100, RCP4.5 (upper graph) and RCP8.5 (lower graph).

Overall, the national PET heatmaps highlight the vulnerability of Greece to climate-induced thermal stress. The projected shifts toward higher PET classes represent not only a pressing challenge for public health and infrastructure resilience but also a critical factor shaping the sustainability and long-term viability of the tourism product, with direct relevance for climate adaptation and mitigation policies. By the end of the century, Greece faces either a stabilized but warmer Mediterranean regime under strong mitigation or an extreme and near-uniform thermal stress environment under continued high emissions.

4. Conclusions

The performed bioclimatic analysis provided a better understanding of the spatial patterns of human thermal perception in Greece: northern and continental regions face extreme winters and increasingly hot summers, while southern and insular areas enjoy milder, more balanced conditions. This creates distinct seasonal tourism opportunities. Mainland cities and basins are most attractive in spring and autumn, northern and mountainous areas support winter tourism but suffer in midsummer, and the Aegean and Ionian islands—especially Crete—offer extended comfort seasons. Climate projections show a shift: by the mid-century, July–August will be dominated by heat stress, with April–May and September–October emerging as the most favorable periods; by the end of century, midsummer comfort will be largely lost under RCP8.5. For tourism, this means challenges for peak-season destinations but opportunities for inland and highland areas. Greece's strategy can benefit from seasonal diversification, promoting spring and autumn travel and positioning southern islands as attractive off-season destinations.

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