

Climate change impacts in Greece in the near future

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Introduction

The Mediterranean region is vulnerable to climate change particularly due to its sensitivity to drought and rising temperatures. Climate change is related to changes in the frequency and intensity of extreme climate events, which may adversely affect vital economic sectors, such as agriculture and tourism, and have substantive impacts on local communities. In addition, extreme climate events can be destructive to human health, while climate change may also have a direct impact on local people's lives as it affects sectors such as water resources and energy. For all these reasons, in recent years the scientific community has developed a special interest in studying potential future climate changes. In this study an attempt is made to investigate potential implications of climate change in the near future (2021-2050) in Greece. Urban, touristic, agricultural and forest areas are selectively examined to estimate future climate change impacts. In order to achieve this, the Greek region was divided into sub-regions which are considered vulnerable to climate shocks such as extreme temperatures, droughts, floods. Subsequently, several extreme climate

indicators, associated to extreme climate, were calculated for each selected area. The impacts of climate changes are expected to be related with changes in the frequency of extreme climate events than to changes in mean conditions. This is partially attributed to the fact that a change in the 'mean' climate could cause disproportional changes in the extreme climate events. Records from the National Statistical Service of Greece were consulted in order to set criteria and then select the 10 representative sub-regions for each economic sector in question. In particular, the urban regions research focused on the 10 largest Greek cities based on their population size. Regarding the agricultural regions, the 10 regions occupying the largest numbers of agricultural workers were selected. The 10 most important Greek tourist destination sites were defined according to the official accommodation capacity (higher number of beds available). Finally, the 10 largest natural conservation parks in Greece were studied. Present and future model data from the Regional Climate Model RACMO2 were used in this study.



The model was developed within the framework of the EC-FP6 ENSEMBLES Project (www.ensembles-eu.org), by the Royal Netherlands Meteorological Institute (KNMI), at 25km horizontal resolution and under the IPCC emission scenario A1B. Two 30-year periods were considered in this study. The present period is constrained to the years 1961-1990 and the future covers the period 2021-2050. For each of the selected regions, maps produced illustrating the change in extreme climate indices between the two 30-year periods (2021-2050 - 1961-1990).

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Urban areas

Climate projections for the Mediterranean suggest that the region will become warmer and drier with more frequent and extreme weather events. This presents a threat to urban areas in the form of increased risks for flash floods and heatwaves. These climate hazards will inevitably aggravate other environmental issues, such as water resource availability, saltwater intrusion, air pollution and peri-urban forest fire risk. Socio-economic sectors will also be impacted. Human health will be a major issue of concern under climate change together with the challenges of rising energy demand for cooling and shifts in the seasonal pattern of tourism. Vulnerability to climate change is greater for urban areas with limited economic resources, rapid population growth and poor planning and regulation. Increased frequency of heatwaves and persistence of high temperatures are the key aspects of climate change common to all urban areas.

Urbanization itself greatly affects surface characteristics and their interaction with the wider atmosphere. This leads to distinct urban climates that differ substantially from rural environments. The most apparent consequence of this is the urban heat island. The capacity for the built environment to store heat during the day and release it at night, along with the direct release of heat through human activity (for example heating or cooling of buildings, traffic, and human metabolism) can contribute to higher temperatures within cities compared to their rural surroundings. The urban heat island is also sensitive to the ambient weather and climate. In an urban area study, an integrated approach is required across multiple temporal and spatial scales and sectors. In the spatial dimension, work needs to extend from the inner city boundaries to the surrounding mountains and forests. In the temporal dimension, research

needs to range from the current observed time period (using available meteorological and sector data) to future time periods using data from several climate change projections. In addition, a multi-sector approach to climate change impacts has to be adopted. Impact sectors range from direct climate impacts on natural ecosystems (such as flash floods and forest fire risk) to indirect impacts resulting from combined climate-social-economic linkages (such as energy demand, tourism and health). Furthermore, the dynamics of the climate system needs also to be examined in an integrated fashion. An indicative analysis of climatic parameters with direct or indirect implications for urban areas has been undertaken for the 10 largest Greek cities. The locations of urban areas appear in Figure 1, while Table 1 shows their populations.

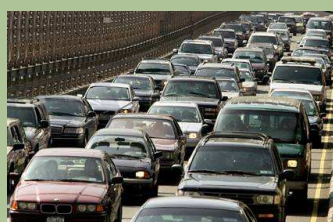


Figure 1: The 10 largest Greek cities

Table 1: The 10 largest Greek cities and their populations.

Urban area	Population
Inner Athens	789166
Thessaloniki	385406
Patras	171616
Iraklion	142112
Larissa	132779
Volos	85001
Ioannina	75550
Kavala	63572
Lamia	62452
Kalamata	61373

Number of days with $T > 35^{\circ}\text{C}$

In Figure 2 the changes in the number of days where temperature is above 35°C are plotted, which is also expected to have an impact in population discomfort in the urban areas. It is evident that this parameter increases in all selected Greek cities. The largest changes seem to occur in the cities of Thessaloniki, Patras, Kalamata, Larissa and Lamia

where more than 20 hot days per year are expected. Modest changes appear in Athens, Ioannina and Volos with increases that do not exceed 15 days, whereas Iraklion reveals smaller increases of up to 10 days. Regarding this parameter, the influence of the nearby sea is playing a dominant role in tempering the fierce summer heat.

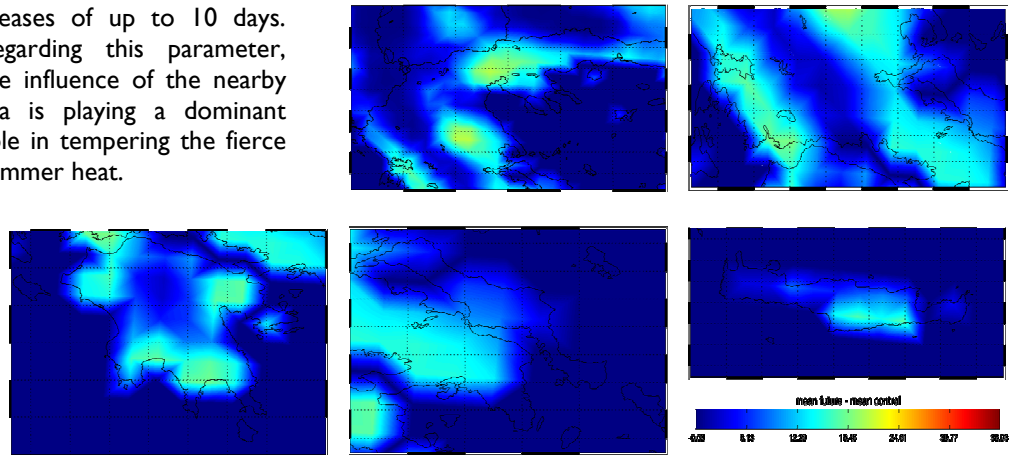


Figure 2: Changes in the number of days above 35°C between 2021-2050 and 1961-1990 for selected regions in Greece.

Number of nights with $T > 20^{\circ}\text{C}$

Another parameter very important for the urban areas is the change in the number of warm nights per year. We define these as nights where night-time temperature is above 20°C and characterise them 'tropical nights'. In addition, this parameter is closely associated with population health, since a 'tropical' night following a 'heatwave' day can lead to increased levels of population heat stress and discomfort. Figure 3 displays changes in this parameter for the selected urban sites in Greece. It becomes clear from this figure that tropical nights increase almost everywhere and it is interesting to note that coastal urban sites are more affected than continental cities. According to the findings of this figure, all selected urban sites except Ioannina will experience about an extra month per year of warm nights. In Ioannina, the increase will be less than 20 days, possibly due to the cooling effects of the breezes from the nearby Pindos mountains.

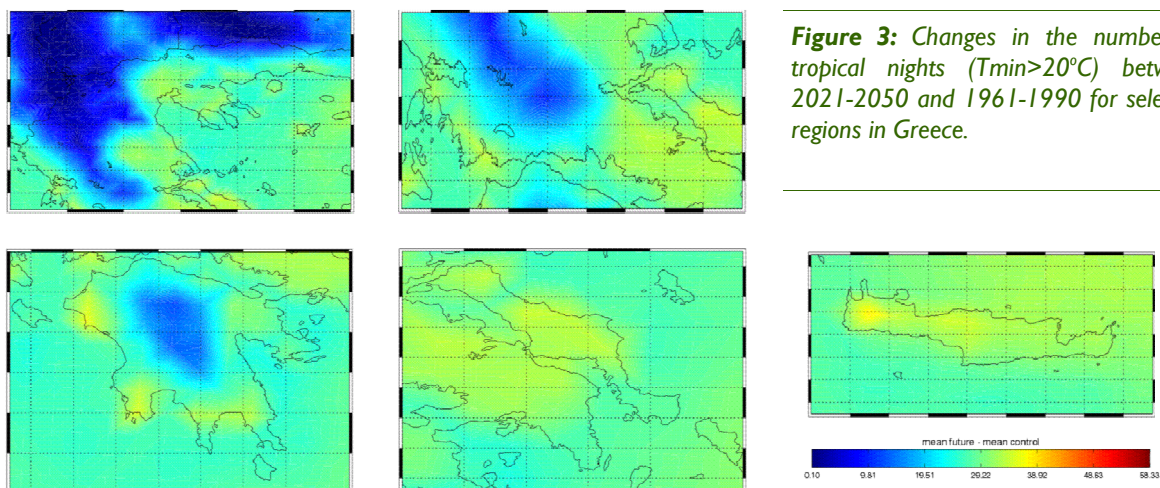


Figure 3: Changes in the number of tropical nights ($T_{\min} > 20^{\circ}\text{C}$) between 2021-2050 and 1961-1990 for selected regions in Greece.

Energy demands



An important implication of climate warming in urban areas is the increased demand of electricity for cooling in summer. This increased demand may cause disruptions and overloading in the electricity network of the country, which may not be able to meet these levels of demand. In Figure 4 the changes in the number of days per year requiring heavy cooling per year are plotted. It is evident that more days per year will

require cooling, i.e. an increased use of air conditioning. More specifically, 15 extra days per year will require cooling in Thessaloniki, Larissa and Lamia and 10 extra days in Athens, Kavala, Volos, Patras, Iraklion and Kalamata. The city with the smallest increases is Ioannina with only 5 extra days requiring cooling per year.

A positive aspect of climate change in the urban regions may be the reduced energy

demand for heating during the cold period of the year. From this analysis became apparent that practically all urban areas in Greece will experience a decline of the heating requirements in winter season (not shown). More specifically we expect that there will be 15 fewer days per year that will require heavy heating in all areas.

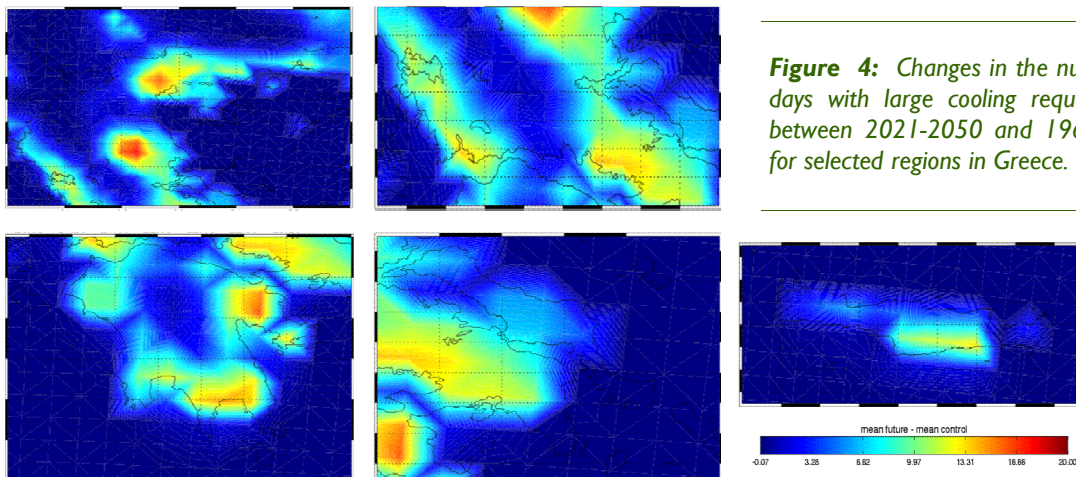


Figure 4: Changes in the number of days with large cooling requirements between 2021-2050 and 1961-1990 for selected regions in Greece.

Summary for urban areas (red: increase, blue: decrease)

	No of hot days	No of tropical nights	3day rainfall (%)	Energy cooling demand (days)	Energy heating demand (days)
Inner Athens	10-15	30	10	10	15
Thessaloniki	15-20	30	10	15	15
Patras	15-20	30	-	10	15
Iraklion	<10	30	-	10	15
Larissa	15-20	30	15	15-20	15
Volos	10-15	30	15	10	15
Ioannina	10-15	15	-	5	15
Kavala	10-15	30	-	10	15
Lamia	15-20	30	20	10-15	15
Kalamata	15-20	30	-	10	15

Tourist areas

Tourism is closely linked to climate, in terms of the climate of the source and destination countries of tourists and climate seasonality, i.e., the seasonal contrast that drives demand for summer vacations in Europe. Conditions for tourism are expected to improve in northern and western Europe, which might lead to a gradual shift of tourist destinations further north and up the mountains affecting the preferences of sun and beach lovers from western and northern Europe for the Mediterranean. Mountainous parts could become more popular because of their relative coolness. Higher summer temperatures may lead to a gradual decrease in summer tourism in the Mediterranean but an increase in spring and perhaps autumn. Scientific research has shown that Greece and Spain will experience a

lengthening and a flattening of their tourism season by 2030. Occupancy rates associated with a longer tourism season in the Mediterranean will spread demand evenly and thus alleviate the pressure on summer water supply and energy demand. Water availability and supply may also be heavily impacted on future climate change conditions as well as energy supply and demand. Specifically with increased energy demand to meet air conditioning needs, alternative ways for energy supply and generation must be sought.

An indicative analysis of climatic parameters with direct or indirect implications for tourist areas has been undertaken for the most important tourist destinations in Greece (Figure 5). These areas together with the number of available beds appear in Table 2.



Table 2: The 10 most important Greek tourist destination sites.

Tourist area	No of beds
1. Dodecanese	120,768
2. Attica	63,749
3. Iraklion	63,484
4. Halkidiki	59,882
5. Cyclades	50,500
6. Corfu	46,182
7. Chania	34,452
8. Rethymno	29,329
9. Pieria	29,192
10. Zante	27,629

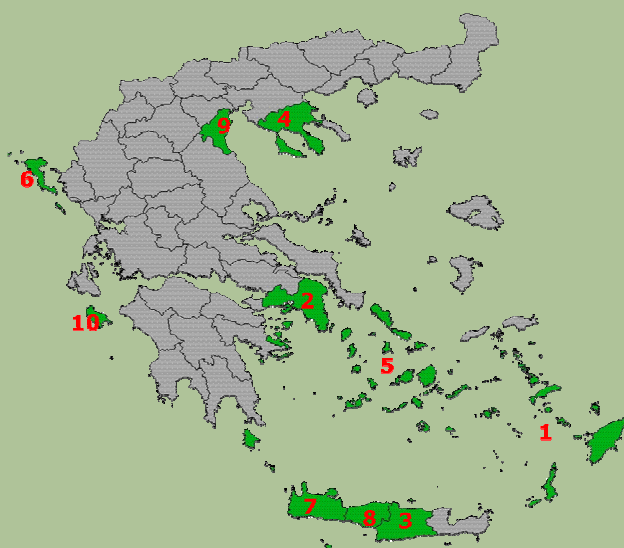


Figure 5: The 10 most important Greek tourist destination sites

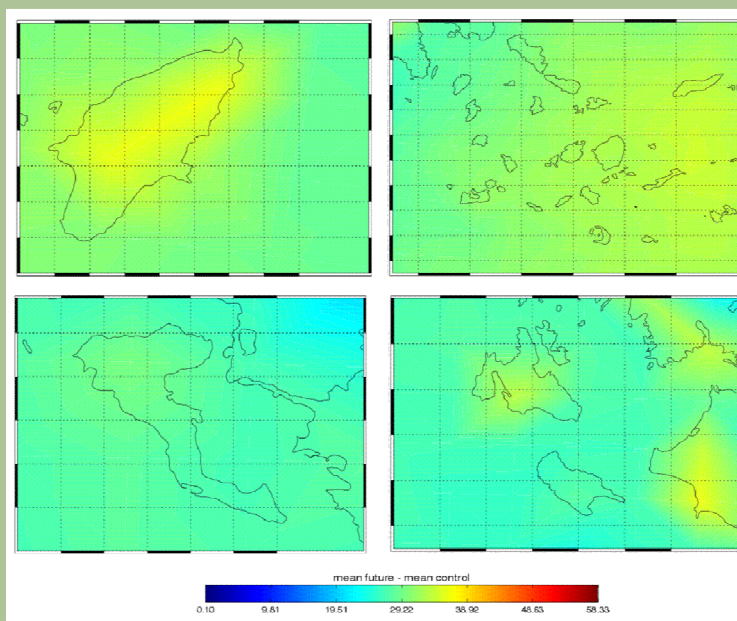


Figure 6: Changes in the number of tropical nights ($T_{min} > 20^{\circ}\text{C}$) between 2021-2050 and 1961-1990 for selected regions in Greece.

Hot days and tropical nights

The changes in the number of days, with temperature above 35°C , were examined, which are also expected to have an impact in population discomfort in the tourist areas. It became clear that tourist sites with a more continental influence will experience the largest changes (not shown). For instance, Attica shows a 15-day increase and Iraklion a 10-15 day increase. Smaller island sites with more pronounced the sea influence, present smaller changes. Zante and Corfu show an increase of about 5-10 hot days, which is nevertheless important if one considers the fact that such temperatures have not been recorded in the present day period in these sites.

Tropical nights tend to increase almost everywhere and in this case island sites are affected even more than continental areas (Figure 6). All selected tourist sites will experience about an extra month of warm nights per year. This coupled with increased humidity levels close to the sea will add to the discomfort of tourists.

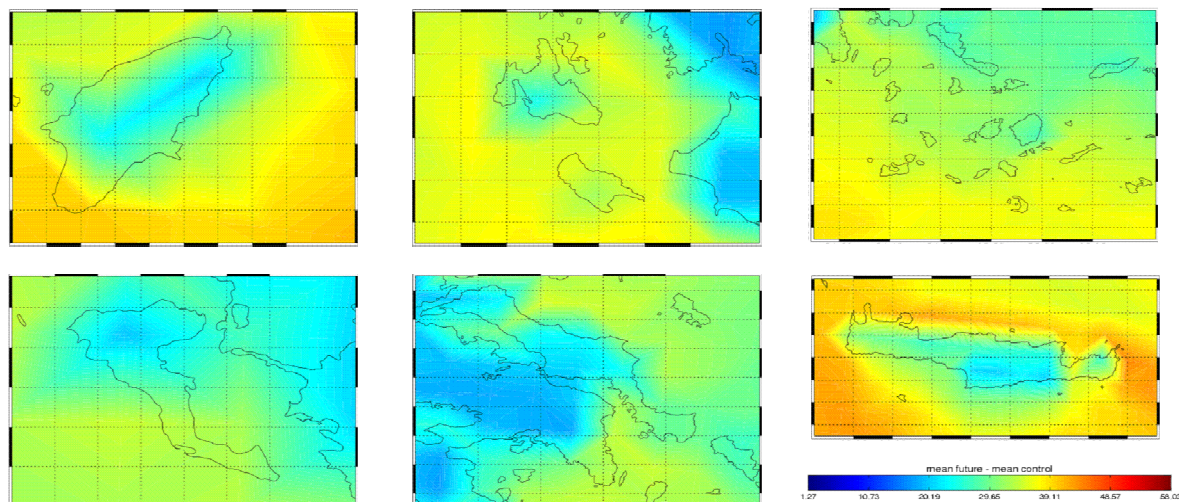


Figure 7: Changes in the number of summer days ($T_{max} > 25^{\circ}\text{C}$) between 2021-2050 and 1961-1990 for selected regions in Greece.

Number of summer like days ($T > 25^{\circ}\text{C}$)

Changes in the number of summer-like days per year have also been examined. A summer day is defined as a day with maximum temperature (T_{max}) above 25°C . Changes in this parameter might consist a positive impact of climate change in tourist areas, since an increase may lead to a lengthening of the tourism season and consequently a relief of the pressure in the peak summer months of July and August. Figure 7 presents the changes in summer days for selected tourist areas in Greece. More than 20 additional summer days are expected by 2050 in all tourist areas of Greece. This figure may increase to 30 (i.e. an extra month per year) in coastal areas. This practically means that the tourism season may be extended by as much as 1 month.

Another important implication of climate warming in tourist areas is the increased demand of energy for air conditioning in summer. It became evident that more days per year will require cooling, implying an increased use of air conditioning (not shown). For instance, 15 extra days will require cooling in Pieria and 10 extra days in Athens, Iraklion and the north part of Rhodes.

Summary for tourist areas (red: increase, blue: decrease)

	No of hot days	No of tropical nights	No of summer days	Forest fire risk (days)	Energy cooling demand (days)
Rhodes	5-10	30-40	20-30	10	5-10
Attica	15	30	20-30	15	10
Iraklio	10-15	30	20-30	10	10
Halkidiki	10	30	20-30	10	5
Cyclades	-	30	25	5-10	-
Corfu	5-10	30	20-25	10	5
Chania	10	30-40	30	10	5
Rethymno	10	30	30	10	5
Pieria	10	30	20	10	15
Zante	5	30	25	5-10	-



Agriculture

An extensive analysis of climatic parameters associated with agricultural and water demand needs, such as mean precipitation and drought duration are presented for the most important agricultural areas in Greece, which are shown in Table 3 below. Changes in the number of wet and dry spells as well as drought duration have been investigated. Such changes should

be very important to assess possible future water shortages over the region and to provide a basis for associated impacts on the agricultural sector. Substantial changes in some of these indices exhibit significant environmental implications in the domain of study. For example, increasing trends in the number of consecutive dry days can be indicative that the problem of

drought and desertification gets intensified. Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from a combination of climate effects (persistent hot and dry conditions) and human activities (such as overcultivation, overgrazing, deforestation and poor irrigation practices).



Table 3: Agricultural areas in Greece and number of people working in agriculture in each area.

Agricultural area	Population of workers
1. Iraklion	79,182
2. Aitolokarnania	71,635
3. Messinia	53,236
4. Larissa	50,459
5. Ilia	48,662
6. Achaia	47,561
7. Evia	44,710
8. Serres	43,249
9. Fthiotida	42,809
10. Pella	41,166

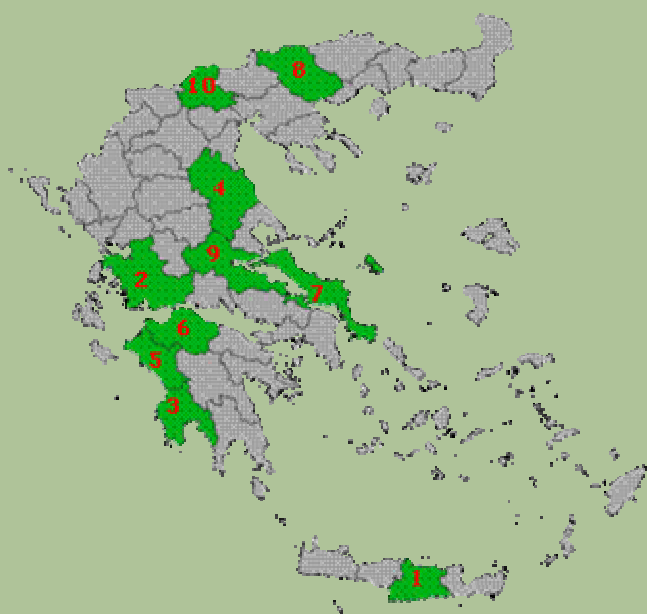


Figure 8: The 10 agricultural areas studied in this report (numbers are assigned to regions according the Table 3)

Max length of drought spell (<1mm)

Figure 9 shows the changes in dry spell length over the selected agricultural areas in Greece, i.e changes in the length of the spell where precipitation is less than 1mm per day. It becomes evident from Figure 9 that the length of dry period tends to increase. Small increases of less than 10 days appear in the agricultural areas of western Greece (Achaia, Ilia, Messinia, Aitolokarnania). Larissa and the southern part of Iraklion present an increase of around 10 days, whereas Serres, Pella and the northern part of Iraklio show increases of 15-20 days. Large increases are revealed for the areas of Fthiotida and Evia, especially in the northern parts where around 25 more dry days are expected.

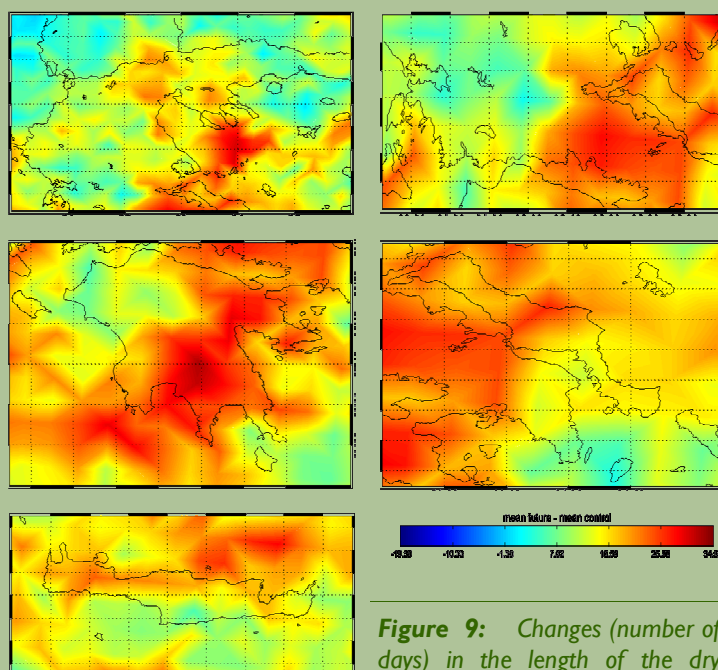


Figure 9: Changes (number of days) in the length of the dry period between 2021-2050 and 1961-1990 in selected regions in Greece.

Fire Risk

Figure 10 presents the changes for the number of days with fire risk, a parameter important for agricultural areas with trees (such as olive, orange, peach trees). It becomes evident that fire risk increases substantially everywhere. However, the most considerable increases occur in the agricultural regions of Serres, Pella, Fthiotida and Larissa where up to 20 more

days of fire risk per year are expected. An extension of the fire risk period by 15 days is evident in the areas of Evia and Iraklion whereas modest increases by around 10 days are shown for areas in the western part of Greece: Achaia, Ilia, Messinia, Aitolakarnania. In addition, we have investigated the changes in the number of days where temperature is above 35°C,

which is also expected to have an impact in the productive stage of crops. This parameter seems to increase in all selected agricultural areas (not shown). As expected, the inland prefectures of Serres and Larissa exhibit large changes that reach 20 days. Modest changes of about 15 days occur in the remaining areas.

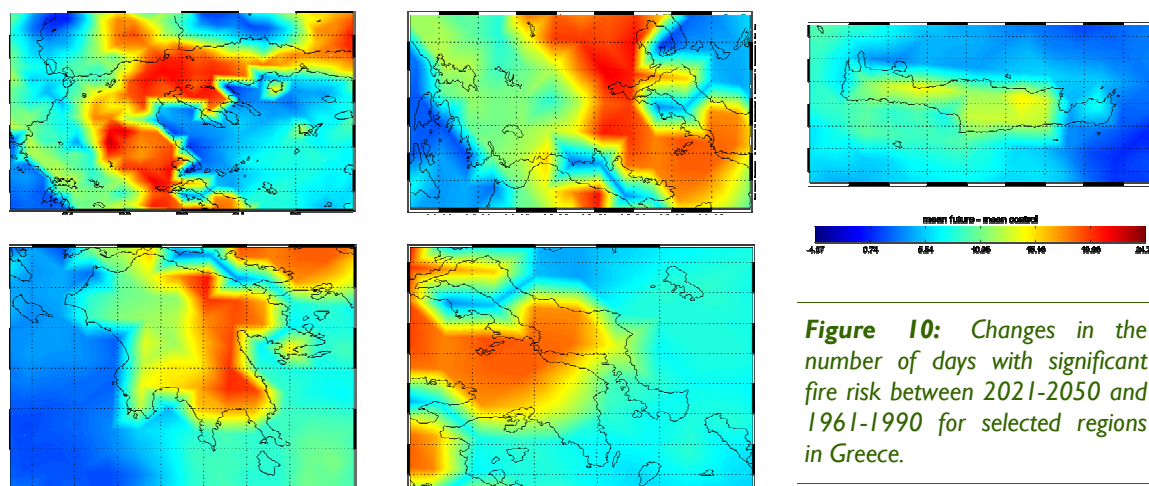


Figure 10: Changes in the number of days with significant fire risk between 2021-2050 and 1961-1990 for selected regions in Greece.

Frost nights

In Figure 11, changes in the number of frost nights are illustrated. This is very important for agricultural areas, especially where sensitive crops exist, such as orange and lemon groves. Reductions in the order of more than 15 days are evident in Pella, followed by 10-to-15 days in Serres, Larissa and Fthiotida. Small reductions occur in the other examined regions, although we should point out that they do not experience many frost nights at the first place.

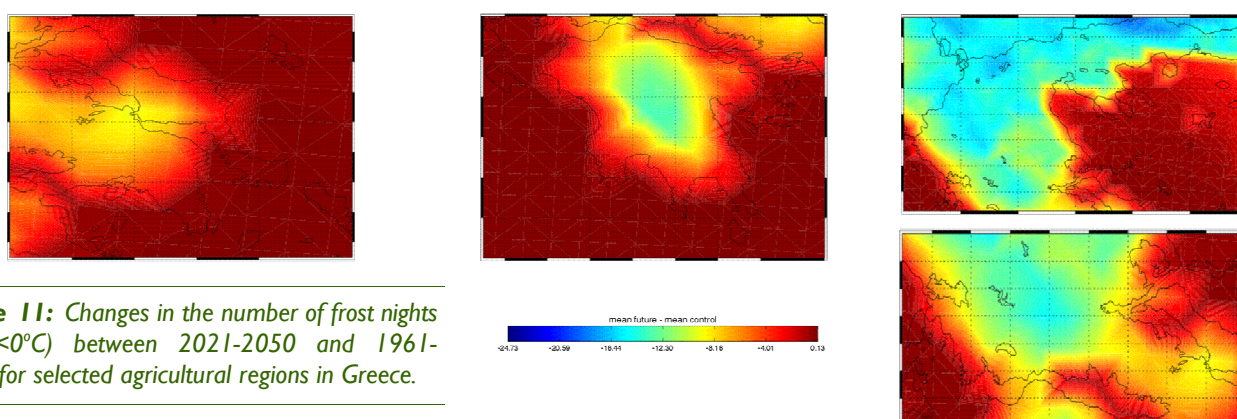


Figure 11: Changes in the number of frost nights ($T_{min} < 0^{\circ}\text{C}$) between 2021-2050 and 1961-1990 for selected agricultural regions in Greece.

Seasonal Precipitation

The percentage changes in seasonal precipitation were calculated for the selected agricultural regions in Greece. The patterns are different for each season. In particular, winter precipitation decreases in the selected agricultural areas with more substantial decreases of 15% occurring in the areas of Serres, Pella and Iraklion. The other areas show decreases of about 5-10% (Figure 12). The percentage changes in autumn precipitation are different from those in winter (not shown). In most of the agricultural areas an increase of precipitation is projected. More specifically, the areas of Larissa and southern Evia will experience increases of up to 20%, whereas Pella and Iraklion will see increases of around 15% followed by Fthiotida with a 10% increase. In the other seasons (not shown), reductions similar to winter are projected but to a smaller degree. The general picture results in small overall reductions in annual precipitation for all areas.

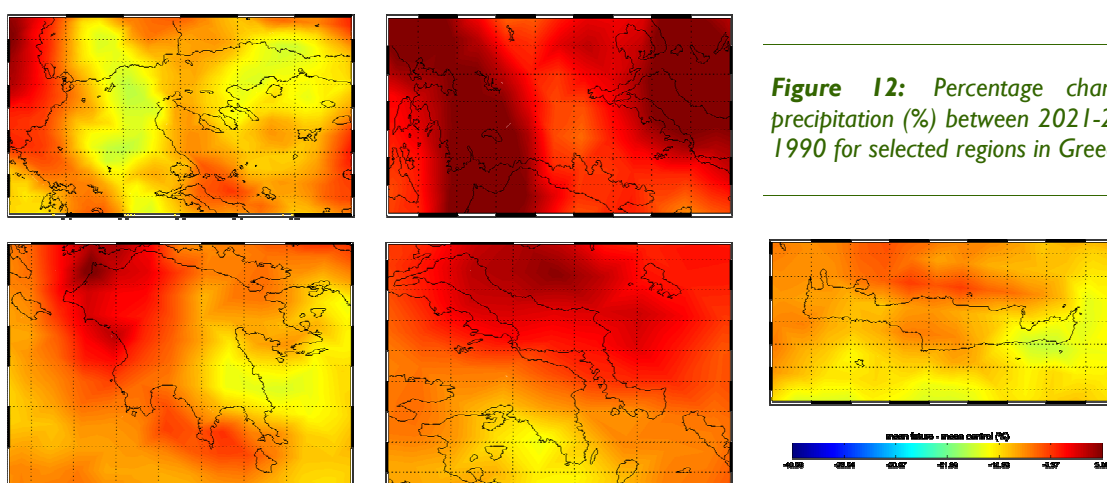
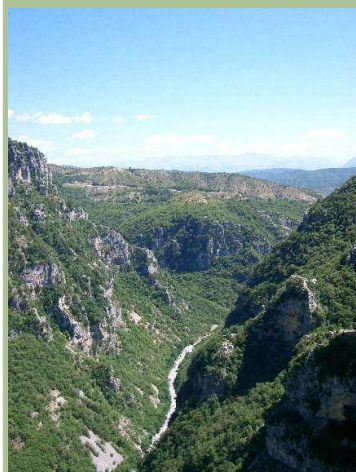


Figure 12: Percentage changes in winter precipitation (%) between 2021-2050 and 1961-1990 for selected regions in Greece.

Summary for agricultural areas (red: increase, blue: decrease)

	Length of dry period (days)	Fire risk (days)	Days >35° C	Frost nights	Winter precipitation (%)	Autumn precipitation (%)
Iraklion	10-20	15	15	-	15	15
Aitolokarnania	10	10	15	-	5-10	-
Messinia	10	10	15	-	5-10	-
Larissa	10-15	20	20	10-15	5-10	20
Ilia	10	10	15	-	5-10	-
Achaia	10	10	15	-	5-10	-
Evia	>25	15	15	-	5-10	20
Serres	15-20	20	20	10-15	15	-
Fthiotida	20	20	15	10-15	5-10	10
Pella	15-20	20	15	15	15	15

Forestry



Mediterranean forests are regularly subject to a large number of fires. An average of 50,000 fires sweep away from 700×10^3 to 1000×10^3 ha of Mediterranean forests per annum, causing enormous economic and ecological destruction. In particular, the data collected reveal that, according to the average burnt area per fire, Greece has the most severe forest fire problems among the European Union countries. It has been estimated that the average area burnt per fire was 39.4 ha in Greece, 28.47 ha in Spain, 19.74 in Italy and 15.29 in Portugal. The destruction of forests is of great

concern, since it might lead to many 'side effects', such as floods, soil erosion and consequent loss of fertility. Furthermore, forest fires play a fundamental role in determining the net carbon balance of the forest. Thus, they may affect greenhouse gas emissions with consequent direct repercussions on climate change.

Forest fires, as any other ecosystem process, are highly sensitive to climate change because fire behaviour responds immediately to fuel moisture, which is affected by precipitation, relative humidity, air temperature and wind speed. Thus, the projected

increase in temperature will increase fuel dryness and reduce relative humidity and this effect will worsen in those regions where rainfall decreases. Accordingly, increases in climate extreme events are expected to have a great impact on forest fire vulnerability.

An extensive analysis of climatic parameters with direct or indirect implications for forested areas has been undertaken for the most important natural conservation areas in Greece. These areas are marked in Figure 13, while together with their occupied area in hectares appear in Table 4.

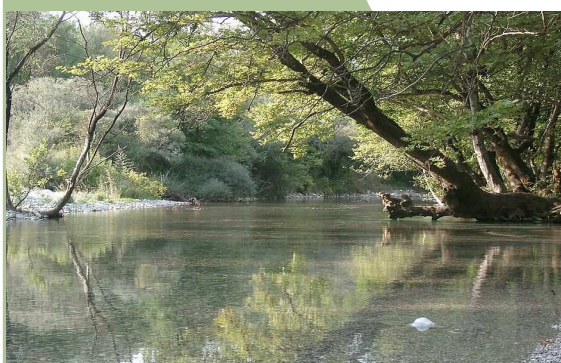
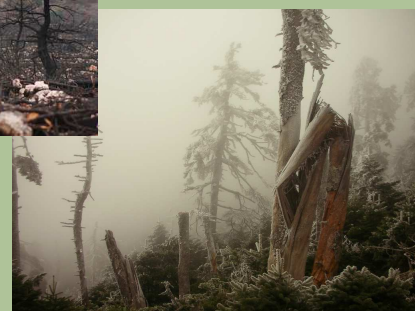


Figure 13: The 10 largest natural conservation parks in Greece

Table 4: Natural conservation parks in Greece and the area they cover.

Conservation park	Area	Hectares
Vikos-Aoos	Ioannina	9300
Prespes	Florina	4900
White Mountains	Chania, Crete	4850
Olympos	Pieria	3988
Parnitha	Attica	3812
Pindos	Ioannina	3534
Parnassos	Viotia, Fokida	3513
Iti	Fthiotida	3010
Ainos	Cephalonia	2862
Sounio	Attica	2750



Fire Risk

Regarding fire risk, as evidenced by Figure 14 (left panels), most areas show increases in the number of days with extreme fire risk of the order of 10 days (Prespes, Vikos-Aoos, Pindos, Olympus, Parnassos, Sounio, White Mountains). Substantial increases of approximately 15 days or more will be evident in Iti and Parnitha whereas Ainos in Cephalonia has negligible changes (5 days increase) in fire risk occurrence.

The risk for forest fires is intensified by lack of rain and occurrence of long dry periods therefore, we examined the changes in the length of dry spells. As shown in Figure 14 (right panels), the high mountain parks in the interior of the country, such as Olympus, Iti, Vikos-Aoos, Pindos reveal small increases of about 7 days. In the other parks (Parnitha, Prespes, Parnassos, Ainos, White Mountains), the increases are more significant and the dry spell length increase by 15 days or more. Sounio shows a 7-day increase.

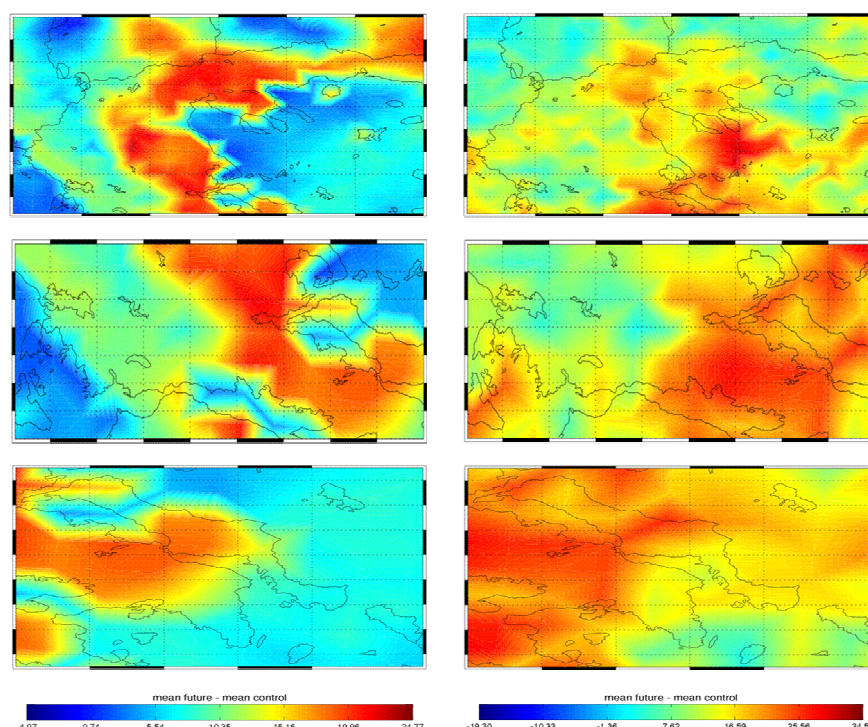


Figure 14: Changes in the number of days with extreme fire risk (left panels) and changes in the maximum length of dry spells (right panels) between 2021-2050 and 1961-1990 in selected regions in Greece.

Summary for forestry (red: increase, blue: decrease)

	Winter min temps (°C)	Summer max temps (°C)	Winter precipitation (%)	Autumn precipitation (%)	Fire risk (days)	Dry spell length (days)
Ainos	1	1.5	15	-	5	15
Vikos-Aoos	1.3	2	-	10	10	7
Pindos	1.3	2	-	10	10	7
Olympus	1.3	2	15	15	10	7
Iti	1	2	10	15	15	7
Parnassos	1.3	1.5	10	15	10	15
Parnitha	1	1.5	10	15	15	15
Sounio	1	1	10	15	10	7
Prespes	1.3	2	15	15	10	15
White Mountains	1	1.5	15	10	10	15



Conclusions

This study presented future projections of potential climate change impacts. In the near future, i.e. the period 2021-2050, climate conditions are expected to deteriorate compared to the reference period (1961-1990) conditions.

Climate change is expected to result in warmer temperatures in urban areas which are translated into more days with maximum temperature above 35°C and night temperatures exceeding the 20°C. In some cases, flash floods events are expected to become more frequent. Unpleasant high temperature and relative humidity combined with high levels of aerosol pollution of the atmosphere, as well as the lack of green spaces will increase the feeling of discomfort in the citizens of big cities. For instance, Thessaloniki, Patras, Lamia and Larissa are expected to experience up to 20 more heatwave days, and almost an additional month with night-time temperatures higher than 20°C. The total annual precipitation is found to decrease in Lamia, Larissa, Volos, Thessaloniki and Athens, however the amount of a 3-day precipitation event seems to increase by 10-20%. Hence, extreme rainfall episodes tend to occur more frequently. Another impact of climate change in urban regions is the increase energy demand for cooling in summer and a decrease demand for heating in winter. However, the winter and summer loads do not counterbalance each other, as the energy consumption required for cooling in summer is greatest at specific days and times of the day.

The tourism industry is a vital economic sector and occupies a dominant position in the Greek economy. Fully understanding its importance, this study has investigated potential impacts in tourist areas due to climate change. It was found that continental tourist areas of the Greek mainland will more often face heatwave episodes. In most of the studied regions 5 to 15 more days exceeding the 35°C will occur every year. The largest increases are found in 'summer' days (>25°C) and 'tropical' nights (>20°C). The former can be considered as a positive impact as it may prolong the tourist period. The number of 'tropical' nights per year seems to substantially increase especially in the islands. For example, Rhodes and Chania expect a

sum of 40 additional 'tropical' nights. In coastal regions, such warm conditions in combination with high levels of relative humidity can result in uncomfortable conditions for foreigners and the local people.

Regarding agriculture, the duration of dry days is expected to increase in most of the studied regions. In Evoia and other sub-regions in the northern part of the country, at least 20 additional dry days tend to occur every year in the period 2021-2050. The changes in the number of days with fire risk, is also an important parameter for agricultural areas with trees (such as olive, orange, peach trees). It became evident that fire risk increases substantially everywhere. The most considerable increases are estimated in the agricultural regions of Serres, Pella, Fthiotida and Larissa with up to 20 more days of fire risk per year. As far as precipitation is considered, winter precipitation generally decreases with more substantial decreases of 15% occurring in the areas of Serres, Pella and Iraklion. In contrast, an increase of autumn precipitation is projected in most agricultural areas. In particular, the areas of Larissa and southern Evia will experience increases of up to 20%, whereas Pella and Iraklion will see increases of around 15%.

Devastating forest fires in Greece occurred in summer 2007, with the loss of human lives, destruction of many villages and hundreds of square kilometres of forest burned. Changing climate conditions related to increased minimum temperatures (approximately 1.3°C) and decreased winter precipitation by 15% on average suggest that the risk for forest fires is intensified in the future. It is estimated that the number of days with extreme fire risk will increase by 10 to 15 days per year.

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