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Discussions

Extreme temperature days and potential impacts in Southern Europe

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Abstract

Extreme temperature events have consequences for human health and mortality, forest disturbance patterns, agricultural productivity, and the economic repercussions of these consequences combined. To gain insight into whether extreme temperature events are changing in light of global climate dynamics, the annual numbers of high temperature days (those with temperatures higher than 20, 22.5 and 25 °C at 850 hPa) were analyzed across Southern Europe from years 1978–2012. A significant increase in the frequency of these days was found in many areas over the time period analyzed, and patterns in the spatial distribution of these changes were identified. We discuss the potential consequences of the increases in high temperature days with regards to forest fire risk, human health, agriculture, energy demands, and some potential economic repercussions.

1 Introduction

Heat wave events play a role in determining human health and episodic mortality patterns, and are also recognized as having marked impacts on agriculture, forestry, wildland fire and socio-economic activities (Poumadère et al., 2005; Mills, 2005; Trigo et al., 2006; Kuglitsch et al., 2010; Cardil et al., 2013). Multiple heat waves have been recorded in Southern Europe in recent years, including 2003 where summer temperatures across Europe were the highest of the last 500 years (Luterbacher et al., 2004). Extreme temperature days and heat waves were linked to above-average human mortality in the cities of Madrid and Lisbon (García-Herrera et al., 2005), and in France in 2003 (Poumadere et al., 2005). In addition, large wildland fires are more likely during heat wave events, burning thousands of hectares across multiple ecosystems in the Mediterranean region (e.g. 1994 in Spain, 2003 in Portugal, 2007 in Greece). In Russia in 2010, unusual temperatures around 40 °C were recorded and the resulting drought was linked to wildfires that were responsible for hundreds of human deaths, covering

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much of the region with toxic smog (Gobin et al., 2013). An unprecedented spring heat wave in the US and Canada peaked in intensity during March of 2012 (Gobin et al., 2013), followed by a summer of destructive and even fatal wildfires in North American forests.

Extreme temperature events can also exacerbate other effects of global climate change. For example, climate change-related increases in average temperatures have been linked to widespread insect outbreaks in North American forests (Safranyik, 2004), which coupled with wildfires propagated by extreme temperature events, can have an multiplied effect on forest persistence. The synergistic effects of extreme temperatures and their repercussions have been identified as possible mechanisms for the development of a positive feedback cycle of global warming and continued loss of greenhouse gases to the atmosphere.

Climate change projections for the Mediterranean Basin show a higher variability in weather conditions and an increase in extreme weather events, with longer, more frequent, and even more intense heat waves (Moriondo et al., 2006; Diffenbaugh et al., 2007; Giorgi and Lionello, 2008; Regato, 2008; Giannakopoulos et al., 2009; Barriopedro et al., 2011). The Mediterranean is widely considered a climate change "hot spot" (Giorgi, 2006), meaning that the region is a sensitive indicator of changes which have already occurred, and is expected to be a sensitive responder to predicted changes due to its location at the intersection of tropical and mid-latitude atmospheric and oceanographic processes. Although numerous authors have explored the relationships between predicted climate change and expected increases in temperatures (e.g. Giorgi and Lionello, 2008; Giannakopoulos et al., 2009), few have identified spatial patterns and differences in magnitude of recent change in extreme temperature day frequencies. In order to explore trends in extreme temperature events over time across Southern Europe, we analyzed (i) annual number of high temperature days and their spatial distribution, and, (ii) temporal trends of extreme temperature events to identify and quantify significant changes over the 1978–2012 period.

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Although extreme events can be interpreted using a variety of metrics, we focused on air temperature at 850 hPa as a reference (the air temperature at approximately 1500 m a.s.l. where pressure is 850 hPa) because it is used by many forecast agencies and is an indicator of heat waves or the evolution of temperatures in successive days (AEMET – Spanish Meteorological Agency; Trigo et al., 2006). In addition, some problems that affect near surface reanalysis do not occur when using temperatures at this altitude (Ogi et al., 2005). We assessed trends in the number of high temperature days (HTD) with three different temperature thresholds: 20, 22.5, and 25 °C. Because the 95th percentile weather, or the "hot tail" has been identified as an important metric for predicting future heat stress and amplification by soil moisture loss in the Mediterranean Basin (Diffenbaugh et al., 2007), we also analyzed this variable using the summer period from June–September from 1978–2012.

2 Methods

2.1 Study area

This work focused on Southern Europe because it is expected to be the most susceptible European area to a significant increase in extreme temperature events, and to sustain some of the most significant impacts (Giorgi, 2006; Giannakopoulos et al., 2009). Thirty-four points were used for the analysis, distributed systematically across the region (Fig. 1). This region comprises Portugal, Spain (Mediterranean Coast, points 2, 3, 4, 8, 9 and 14; Interior Spain, points 6, 7 and 13; North Spain; 10, 11 and 12) South France, Italy (Italian Peninsula, points 22, 23, 25, 26, 27 and 28; Italian islands, points 19, 20 and 21) and Greece. These points were chosen in order to capture a representation of trends for all of Southern Europe bellow the 45th parallel.

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2.2 High temperature days (HTD)

We used NCEP reanalysis data from the National Centers for Environmental Prediction and the National Center for Atmospheric Research (Kalnay et al., 1996) to characterize the high temperature days on a synoptic scale. NCEP output data has a horizontal resolution of 2.5° latitude-longitude. We analyzed the 34 points distributed in the study area as shown in Fig. 1. Daily air temperature data at 850 hPa pressure level at 00:00 UTC were analyzed from 1978 to 2012. We chose the air temperature at 850 hPa as reference because it is used by Meteorological Services to forecast and display heat-waves or the trend of temperatures in successive days (AEMET, Spanish Meteorological Agency). It is also used by different agencies across Southern Europe (i.e. Aragón Forest Service, Castilla-La-Mancha Forest Service, Catalonia Fire-Fighting Service, Valencia Fire-Fighting Service, CFVA in Sardinia – Italy) to analyze past fire weather events and to forecast daily potential fire occurrence and behavior (Trigo et al., 2006; Garcia-Ortega et al., 2011). In this manner, it provides adequate regional coverage and it is representative of the surface, avoiding some of the problems that affect near surface reanalysis (Ogi et al., 2005; Trigo et al., 2005, 2006).

We used several HTD categories considering different temperature thresholds: (1) HTD_{20}, those days with an air temperature higher than 20 °C at 850 hPa, (2) $HTD_{22.5}$, those days with an air temperature higher than 22.5 °C at 850 hPa and, (3) HTD_{25}, those days with an air temperature higher than 25 °C at 850 hPa, (4) HTD_{p95}, 95th percentile of air temperature at 850 hPa in the June–September period from 1978 to 2012. The use of the 95 % percentile helps capture the different implications for human health, energy systems, and natural vegetation and disturbances for temperature extremes in different locations. For example, in the northern section of the study area, where mean temperatures are generally lower, a temperature above 20 °C would exceed the 95th percentile, while the same temperature would be nearly five degrees below the 95th percentile in the southern latitudes.

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The limit of 20 °C of air temperature at 850 hPa was chosen because it provides high temperatures in surface and typically low relative humidity in the territory, and is associated with heat waves in many zones in the study area (Montserrat, 1998; Cardil et al., 2013). We analyzed temporal trends in relation to the annual number of HTD in all four categories using least squares fitted linear regression models and tested whether slopes differed significantly from zero ($p < 0.05$). For those locations where significant temporal changes were found to exist, we further investigated spatial patterns of change. To determine whether significant differences in number and changes in high temperature days across latitudes and longitudes, we used one-way ANOVA followed by Tukey's HSD test.

3 Results

The annual number of HTD differed in relation to the different areas and countries. Generally, points with higher latitude had fewer HTD in all categories (Fig. 2). The points with a higher annual number of HTD_{20}, $HTD_{22.5}$, HTD_{25} are located in Mediterranean Spanish Coast (points 2, 3 and 4) and in the South of Portugal (point 1; Fig. 2). However, points located in Greece at the same latitude had a significantly lower number of these days. The island of Sardinia (point 21) and Balearic Islands (point 9) had higher numbers of extreme temperature days in relation to other locations at the same latitude. The same results were obtained in relation to the 95th percentile in terms of temperature during the June–September period from 1978 to 2012.

Temporal trends in terms of annual number of HTD_{p95}, HTD_{20}, $HTD_{22.5}$, and the 95th percentile for all analyzed points are shown in Table 1 and Fig. 3. Note that the HTD_{25} category is not in Table 1 because no significant trends were found at any point, mainly due to the low number of these days. A significant increase in the annual number of HTD_{20} was found in locations around the Mediterranean Spanish Coast (Fig. 1 and Table 1). However, in other parts of Spain and in Portugal, the annual number of HTD did not change in any analyzed temperature threshold. In South France,

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no significant changes over the study time period analyzed were detected. However, significant increases of the annual number of HTD_{20} and/or the 95th percentile were found in the majority of sites in Italy and Greece (except in Sicily). Extreme weather days are becoming more frequent in these areas. Additionally, the highest increases in terms of annual number of HTD_{20} were found in Greece and along the Mediterranean Spanish Coast (0.60 HTD_{20} more per year over the entire period). In Italy, significant increases were found but lower than in Greece or along the Mediterranean Spanish Coast (0.35 HTD_{20} more per year).

When all sites were considered HTD_{20} was higher overall in coastal vs. inland locations (8.8 vs. 5.1 days increase in days over time, $p = 0.005$), Percent change in HTD_{25} differed between locations, being negative along the coast (−4.4 %) and positive inland (+41.6 %, $p < 0.05$). Other differences associated with proximity to the Mediterranean coast were not detected. Although significant primarily for political planning, some overall differences among countries were detected. Italy had a higher change in HTD_{95} than Spain (4.1 vs. 2.3 days, $p < 0.05$), and Spain had a greater relative change in HTD_{25} than Italy (43.3 % vs. −25.9 %, $p < 0.05$). Greece had more than three times the increase in HTD_{20} than France (9.6 vs. 2.3 days, $p < 0.05$). Regarding $HTD_{22.5}$, there is a difference among Northern locations (points 14 and 28) vs. Southern locations (3, 4, 22 and 23) in Spain and Italy. The Southern locations displayed a significant increase (0.3 $HTD_{22.5}$ more per year) in the number of $HTD_{22.5}$.

In higher latitudes, the increase in number of days with an air temperature at 850 hPa higher than 20 and 22.5 °C was less than in lower latitudes (Fig. 4). However, the relative increase in HTD_{20} was significantly higher in higher latitudes (Fig. 5), considering only sites where significant temporal changes were evidenced. However, considering 22.5 and 25 °C thresholds, the relative increase in HTD did not change consistently with latitude. In relation to those days that exceeded the 95th percentile, in higher latitudes there was an increase in both number of days and relative increase in number of days (Figs. 4 and 5). In most points included within the study scope, there was an increase in both the number of days in HTD_{20}, $HTD_{22.5}$, and 95th percentile and the

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relative increase in these categories from 1978–1987 to 2002–2012. The highest relative increases were found in Italy and Greece with values higher than 100 %; in other words, more than a doubling in the number of days (Table 2).

4 Discussion

Mean, maximum and minimum temperatures have increased and will likely continue to increase in Southern Europe in the future (Moriondo et al., 2006; IPCC, 2007; Giorgi and Lionello, 2008; Giannakopoulos et al., 2009). Our study showed that there was also a trend towards more frequent HTD in summer (June to September) in Mediterranean coastal areas and in more southerly latitudes across the study area. This is in agreement with other studies on temperature trends, which have been shown to be correlated to wildfire size and occurrence (Cardil et al., 2013, 2014). Overall, in Southern Europe, most high temperature days are related to the weather system that brings hot dry air masses from North Africa (Rodriguez-Puebla et al., 2010; Pereira et al., 2011). However, we did not find the same HTD trends in NW Iberia, where other reports have documented increased warming of surface temperatures from 1974–2006 (Gómez-Gesteira et al., 2011), or in interior Spain. It is plausible that air fluxes from North Africa do not reach this area as frequently as in other regions, or that their influence is mitigated by other weather systems associated with Atlantic currents. Some HTD might simply be caused by summer heating in Central Spain (Spanish plateau, 800 m a.s.l.).

Areas with the highest increases in terms of annual number of HTD_{20} (June–September period) were found both in Greece and along the Mediterranean Spanish Coast. These areas are likely to be especially susceptible to the variety of impacts associated with heat-wave episodes, including ecological, social, and economic impacts. While higher latitudes (more northern) sites exhibited a smaller increase in the number of days with $HTD_{22.5}$ and HTD_{20} than lower latitudes, the number of days exceeding the 95th percentile increased with increasing latitude. This finding is corroborated by the higher *relative* increase in HTD 95 and HTD_{20} with latitude. It may be that the affected vegetative, social, and economic systems in the lower latitude sites have already experienced some of the pressures of adapting to, or mitigating, the repercussions of, extreme temperatures. It is important to consider the relative increase in extreme temperature days in these higher latitudes, as a greater degree of change usually equates to a higher severity of challenge. Some authors suggest that the consequences of heat waves is closely tied to a culture's prior conditioning and adaptation to climate, including behavior (e.g. siesta on hot afternoons), characteristics of buildings (e.g. exterior sun shades) and communities (orientation of windows away from afternoon sun), and even social attitudes about health risks (Poumadere et al., 2005; deCastro et al., 2011). This suggests that although the absolute increase in extreme temperature days is less severe at the higher latitudes, the relevance of the effects of the change may be greater in more northern populations lacking prior conditioning and adaptation.

In all cases, where HTD 95 increased, additional synergistic repercussions are likely to already be occurring. For example, Diffenbaugh et al. (2007) use downscaled climate model predictions of heat stress in the Mediterranean region to show that increases in 95th percentile maximum temperatures are amplified by a reduction in soil moisture and 2 m relative humidity levels. These changes are relevant to human health, wildfire risk, energy demand, and perpetuity of existing ecological systems as detailed below.

4.1 Human health

Human health and mortality is affected by extreme temperature days. Many examples have been reported in recent years. During the summer of 2010 in Russia, temperatures of 40 °C were reached and the resulting drought caused extensive wildland fires. These fires were responsible for hundreds of human deaths, and toxic smog covered Moscow for weeks (Gobin et al., 2013). Other works show that human mortality increases when maximum daily temperatures exceed a given threshold (García-Herrera et al., 2005; deCastro et al., 2011). In France alone in 2003, 15 000 excess deaths were attributed to an extreme heat wave (Poumadère et al., 2005). If the annual number of

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extreme temperature days continues to increase, mortality rates could respond similarly in the future. It may be necessary to take preventive measures to reduce these impacts on populations, preventing heat strokes and other heat-related illness. Such measures typically include increased cooling during these periods, which can also result in peak demands for energy consumption.

4.2 Energy demands

Energy demand is closely linked to climatic conditions (Giannakopoulos and Psiloglou, 2006) and energy demand and temperature have a non-linear, somewhat complex relationship. The unevenness of ambient air temperature is associated with energy consumption, whose maximum values correlate with the extreme values of air temperature (maximum or minimum). In January, in the Mediterranean region, highest values of energy consumption are correlated to the onset of minimum temperatures. During the transitory season of March–April, energy intake levels remain nearly constant until about May when air temperatures are consistently rising. From mid-May onwards and during the summer period, an increase in air temperature aligns with a rise in energy consumption, mainly due to the wide use of air conditioning elements. It is during these early summer months that our data suggest increased number of HTD will have the greatest impact on energy demands. By August, when many people take their summer vacation, the demand for air conditioning is lower, especially in large Mediterranean metropolises. An additional transitory period is from September through October when energy demand is stable. From this time onward there is a continually increasing energy demand with a peak before the Christmas season. As a result, it is expected that warmer climate circumstances will lead to reduced demand in winter, while increased demand should have an impact during the early summer months (Giannakopoulos and Psiloglou, 2006).

Furthermore, higher temperatures in summer are likely to cause a larger peak energy demand and not only an increase on net demand. This may require the development of additional, or more efficient, energy generating capacity.

4.3 Forest fire risk

Frequent heat waves in last decade or so (2000–2012) triggered the occurrence of large wildland fires (Mills, 2005; Trigo et al., 2006; Barriopedro et al., 2011; Cardil et al., 2013) in the Euro-Mediterranean region (Italy and Greece, 2007; Portugal, 2003 and 2005; Spain, 2006 and 2009) and overall the world (Australia, 1983 and 2009; Canada, 2004; Russia, 2010; USA, 2000, 2006 and 2007). On hot days, usually related to very dry fine dead fuel, ignition probability is higher and wildland fire behavior could be extreme (i.e. increasing flame length, rate of spread, crown fire activity, and spotting activity). As a result, fires may burn quickly and intensely and make large wildland fires difficult to contain as they exceed the firefighting capabilities (Riaño et al., 2007; Salis et al., 2012; Cardil and Molina, 2013). Such fires are more costly to local communities, and in some cases may accrue bills that exceed a country's planned resource allocations.

Recent analysis has shown that high temperatures days account for the majority of area burned in recent years in some regions in Spain and Italy, where the average daily number of large fires and daily area burned was higher in HTD than in non-HTD (Cardil et al., 2013, 2014). Therefore, if extreme conditions (HTD) are more frequent in the future, the forest fire risk will most likely increase considerably. The resilience of forests to disturbance may also be influenced by extreme temperatures. Touchan et al. (2014) analyzed long-term tree chronologies in the eastern Mediterranean to find that growth rates were sensitive to, and negatively related to, summer month temperatures. The trends reported here suggest that, in certain areas, forests have been increasingly stressed by extreme temperatures during the summer months over the last 34 years. Evidence of such stress has been documented in increased climate-linked mortality of forests across Europe (Allen et al., 2010). As summer temperatures continue to increase (Giorgi and Lionello, 2008), and soil moisture contents decrease (Diffenbaugh, 2007), the resilience of forests injured by wildfire may be reduced (e.g. van Mantgem et al., 2013), compounding wildfire impacts and costs.

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4.4 Agricultural losses

Investigation reports suggest that the consequences of climate change on farming and forestry is likely to be more severe in the Mediterranean areas than in northern temperate areas (Gobin et al., 2013). Some weather related dangers such as drought and floods have a systemic component, i.e. they affect most growers within a whole region. Others are more location specific, i.e. storms. Undoubtedly, agriculture as a profitable segment is exposed to and sensitive to weather events, affecting multiple related economic systems.

Harvest unevenness is likely to increase due to more recurrent extreme weather excesses (at least at the individual farm level) (IPCC, 2012). Understanding of extreme events and hardships is a pre-requisite for the implementation of adaptation strategies and risk mitigation in the context of climate change. Extreme events will have higher impacts on sectors with closer links to climate, such as agriculture and food security. A diversity of research publications since 2010 present evidence that the present warming tendencies have started to have deleterious impacts on agriculture through intensification in the probability of extreme temperatures during the growing period (Gobin et al., 2013). Our data provide quantification of these extreme temperatures, which can be informative for agricultural planning and decision making specifically in each location analyzed.

Risk management should be active in anticipating potential problems, and planning to mitigate their consequences, rather than reacting to unfavorable events after they happen. The two main aspects of risk management are first anticipating that an unfavorable event may occur and acting to decrease the probability of its happening, and second, taking actions which will moderate the harmful costs should the unfavorable episode occur. Both structural and non-structural measures are vital to reducing the impact of climate unevenness including extreme weather on farm production (Lobell, 2011). Although the structural actions include strategies, such as irrigation, water harvesting, creation of windbreaks, the non-structural measures include the practice of

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the medium range weather forecasting and crop insurance. We hope that the data presented here can be useful for planning for risk reduction.

5 Conclusions

Even though we did not find significant increases in South France, Interior Spain and the Northwestern Iberian Peninsula, the annual number of HTD increased significantly in many areas across Southern Europe including the Spanish Mediterranean Coast, Italy, and Greece. The highest increases in terms of annual number of HTD were found in both Greece and along the Spanish Mediterranean Coast. In these areas, extreme temperature conditions are becoming more frequent now and could become more common in the future. In addition, in areas where temporal increases were detected, relative increases in 95th percentile temperatures were higher at higher latitudes. Where social, infrastructure, and economic systems are not preconditioned to high temperature days and heat waves, the severity of increased temperature effects may be elevated. Heat wave days have been linked to negative impacts in terms of forest fire risk, human health, agriculture, energy demands, and economic repercussions. Adaptive measures should be instituted in an attempt to diminish the negative consequences for human populations and the environment.

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Table 1. Simple linear regression analysis of significant trends in annual number of HTD_{p95}, HTD_{20}, $HTD_{22.5}$, over time in the study area during the June–September period from 1978 to 2012. Point locations are mapped in Fig. 1.

Point	Latitude/Longitude	Country	(P values) and/**slope coefficients**		
			HTD_{20}	$HTD_{22.5}$	HTD_{p95}
1	37.5°/352.5°	Portugal	n.s (0.480)/**0.111**	n.s (0.090)/**0.156**	n.s (0.370)/**0.057**
2	37.5°/355°	Spain	n.s (0.107)/**0.295**	n.s (0.083)/**0.199**	n.s (0.646)/**0.031**
3	37.5°/357.5°	Spain	+(0.009)/**0.525**	+(0.029)/**0.344**	n.s (0.182)/**0.103**
4	37.5°/0°	Spain	+(0.008)/**0.531**	+(0.002)/**0.545**	n.s (0.084)/**0.142**
5	40°/352.5°	Portugal	n.s (0.354)/**0.118**	n.s (0.375)/**0.054**	n.s (0.552)/**0.048**
6	40°/355°	Spain	n.s (0.296)/**0.115**	n.s (0.836)/**−0.012**	n.s (0.651)/**0.028**
7	40°/357.5°	Spain	n.s (0.072)/**0.248**	n.s (0.884)/**0.009**	n.s (0.893)/**0.008**
8	40°/0°	Spain	+(0.003)/**0.484**	n.s (0.173)/**0.118**	n.s (0.278)/**0.084**
9	40°/2.5°	Spain	+(0.001)/**0.600**	+(0.018)/**0.222**	n.s (0.238)/**0.094**
10	42.5°/352.5°	Spain	n.s (0.870)/**0.015**	n.s (0.963)/**0.002**	n.s (0.878)/**0.011**
11	42.5°/355°	Spain	n.s (0.710)/**0.032**	n.s (0.805)/**0.011**	n.s (0.684)/**0.032**
12	42.5°/357.5°	Spain	n.s (0.273)/**0.092**	n.s (0.550)/**0.020**	n.s (0.381)/**0.067**
13	42.5°/0°	Spain	n.s (0.078)/**0.147**	n.s (0.251)/**0.038**	+(0.044)/**0.139**
14	42.5°/2.5°	Spain	+(0.010)/**0.246**	n.s (0.486)/**0.025**	n.s (0.058)/**0.131**
15	45°/0°	France	n.s (0.305)/**0.051**	n.s (0.301)/**0.031**	n.s (0.319)/**0.077**
16	45°/2.5°	France	n.s (0.159)/**0.085**	n.s (0.178)/**0.037**	n.s (0.081)/**0.142**
17	45°/5°	France	n.s (0.108)/**0.115**	n.s (0.297)/**0.022**	n.s (0.114)/**0.135**
18	45°/7.5°	France	n.s (0.111)/**0.102**	n.s (0.240)/**0.146**	+(0.044)/**0.167**
19	37.5°/12.5°	Italy	n.s (0.181)/**0.219**	n.s (0.179)/**0.154**	n.s (0.513)/**0.054**
20	37.5°/15°	Italy	n.s (0.166)/**0.222**	n.s (0.051)/**0.186**	n.s (0.369)/**0.073**
21	40°/10°	Italy	+(0.022)/**0.371**	+(0.032)/**0.183**	n.s (0.096)/**0.125**
22	40°/15°	Italy	+(0.014)/**0.354**	+(0.014)/**0.182**	+(0.014)/**0.200**
23	40°/17.5°	Italy	+(0.006)/**0.374**	n.s (0.978)/**−0.001**	+(0.019)/**0.190**
24	42.5°/10°	Italy	+(0.011)/**0.278**	n.s (0.459)/**0.023**	+(0.032)/**0.200**
25	42.5°/12.5°	Italy	+(0.003)/**0.354**	+(0.047)/**0.090**	+(0.014)/**0.211**
26	42.5°/15°	Italy	+(0.002)/**0.353**	n.s (0.452)/**−0.008**	+(0.005)/**0.213**
27	45°/10°	Italy	n.s (0.080)/**0.088**	n.s (0.610)/**−0.008**	+(0.013)/**0.240**
28	45°/12.5	Italy	+(0.038)/**0.097**	n.s (0.353)/**−0.009**	+(0.023)/**0.198**
29	37.5°/20°	Greece	+(0.011)/**0.362**	n.s (0.065)/**0.160**	n.s (0.169)/**0.097**
30	37.5°/22.5°	Greece	+(0.003)/**0.447**	n.s (0.060)/**0.130**	n.s (0.052)/**0.125**
31	37.5°/25°	Greece	+(< 0.001)/**0.605**	+(0.025)/**0.168**	+(0.009)/**0.165**
32	40°/20°	Greece	+(0.001)/**0.431**	+(0.032)/**0.153**	+(0.005)/**0.231**
33	40°/22.5°	Greece	+(< 0.001)/**0.449**	n.s (0.081)/**0.108**	+(0.010)/**0.223**
34	40°/25°	Greece	+(0.001)/**0.413**	n.s (0.078)/**0.087**	+(0.012)/**0.218**

+: Significant increase over time (p value < 0.05), n.s: not significant trend (p value < 0.05) and value in parenthesis means the p value in the analyzed trend. The slope of the regression line is also shown in bold.

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Table 2. Increase from 1978–1987 to 2002–2012 decades in both number of days and relative increase in number of days of HTD_{20}, $HTD_{22.5}$, and HTD_{p95} (June to September period).

Point	Latitude/Longitude	Country	Increase of days/ relative increase (%) HTD_{20}	Increase of days/ relative increase (%) $HTD_{22.5}$	Increase of days/ relative increase (%) HTD_{p95}
1	37.5°/352.5°	Portugal	5.3/19.1	6.4/85.3	3.5/85.4
2	37.5°/355°	Spain	9.2/25.5	7.1/61.7	1.9/40.4
3	37.5°/357.5°	Spain	14.2/31.4	9.7/58.1	3.1/68.9
4	37.5°/0°	Spain	13.0/25.6	13.3/58.6	2.9/58
5	40°/352.5°	Portugal	4.8/35.8	3.4/178.9	12.8/108.8
6	40°/355°	Spain	4.9/32.5	0.9/30.0	2.2/55
7	40°/357.5°	Spain	7.5/42.9	1.1/22.5	1/18.9
8	40°/0°	Spain	12.7/62.0	2.8/41.8	1.7/29.8
9	40°/2.5°	Spain	14.9/68.7	5.1/68.9	1.7/30.9
10	42.5°/352.5°	Spain	2.1/31.8	0.9/75.0	1.9/45.2
11	42.5°/355°	Spain	1.9/27.5	1.0/71.4	1.8/40.9
12	42.5°/357.5°	Spain	2.9/45.3	0.7/41.2	2.5/54.3
13	42.5°/0°	Spain	4.0/53.3	0.7/33.3	3.8/84.4
14	42.5°/2.5°	Spain	6.5/94.2	0.4/16.7	3.1/63.3
15	45°/0°	France	1.6/51.6	0.8/88.9	2.4/47.1
16	45°/2.5°	France	2.3/74.2	0.7/77.8	3.8/82.6
17	45°/5°	France	2.9/93.5	0.5/83.3	3.7/74
18	45°/7.5°	France	2.4/88.9	2.4/12.4	4.3/91.5
19	37.5°/12.5°	Italy	4.3/10.9	3.0/19.6	0.6/9.8
20	37.5°/15°	Italy	3.9/11.7	4.4/53.0	1.3/22.4
21	40°/10°	Italy	8.3/36.7	4.1/66.1	2.9/53.7
22	40°/15°	Italy	8.2/46.3	4.1/107.9	4.6/95.8
23	40°/17.5°	Italy	8.2/59.0	−0.2/−9.5	4.1/85.4
24	42.5°/10°	Italy	7.6/97.4	0.5/22.7	5.5/107.8
25	42.5°/12.5°	Italy	9.0/111.1	1.9/111.8	5.3/106
26	42.5°/15°	Italy	8.9/127.1	−0.3/−60	5.4/125.6
27	45°/10°	Italy	1.8/66.7	−0.3/−60	6.4/148.8
28	45°/12.5	Italy	2.2/95.6	−0.3/−75	5.2/108.3
29	37.5°/20°	Greece	6.8/34.0	2.9/40.3	1.6/27.1
30	37.5°/22.5°	Greece	9.3/54.4	2.2/34.9	2.2/39.3
31	37.5°/25°	Greece	12.8/75.3	3.3/61.1	3.3/68.8
32	40°/20°	Greece	9.4/94.9	3.0/107.1	4.6/102.2
33	40°/22.5°	Greece	10.3/143.1	1.8/75.0	4.3/91.5
34	40°/25°	Greece	9.1/128.2	1.5/75.0	4.6/97.9

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Extreme temperature days and potential impacts in Southern Europe

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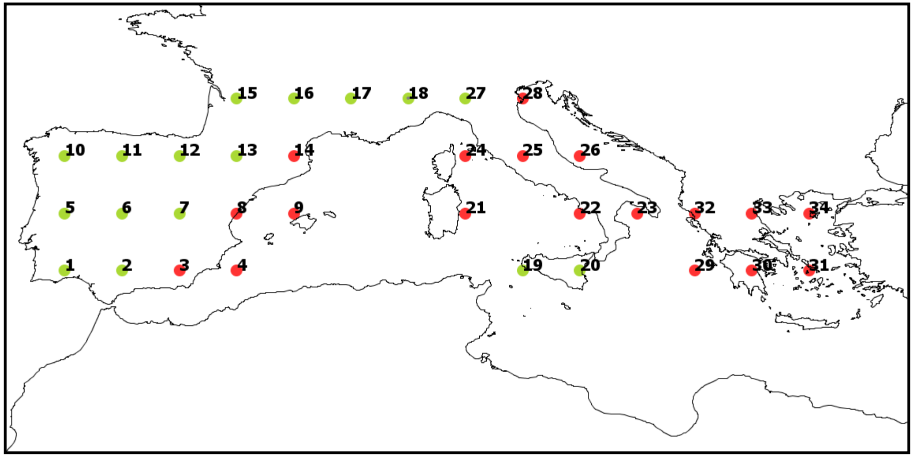

Figure 1. Identification of the NCEP reanalysis analyzed points (National Center for Environmental Prediction) in the study area (Portugal, Spain, South France, Italy and Greece). Red points mean a significant increase (p value < 0.05) in the annual number of days with an air temperature higher than 20 °C at 850 hPa (HTD_{20}) in the June–September period from 1978 to 2012. Green points mean that there were no significant changes in terms of annual number of HTD_{20}.

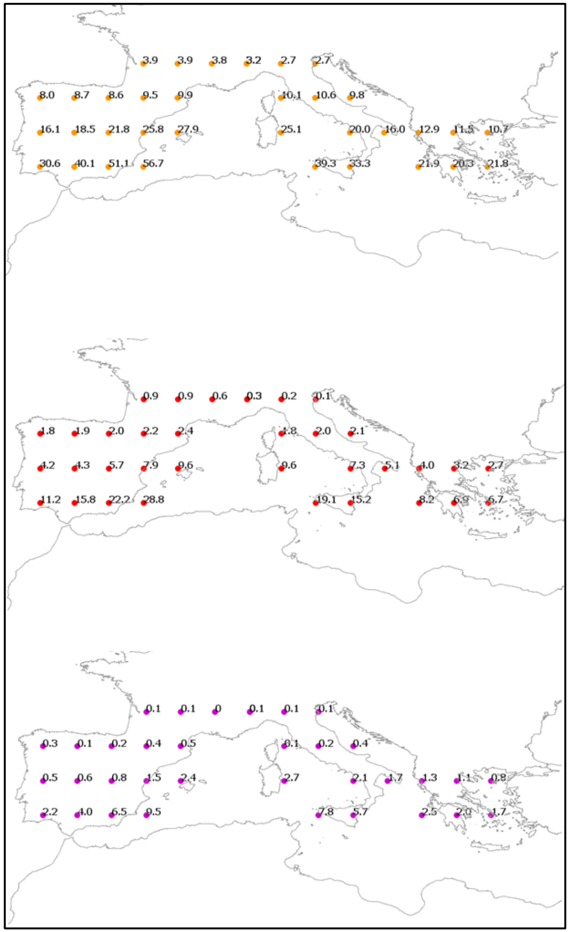

Figure 2. Mean annual number of days with an air temperature higher than 20 °C (orange points), 22.5 °C (red points) and 25 °C (purple points) at 850 hPa in the June–September period from 1978 to 2012.

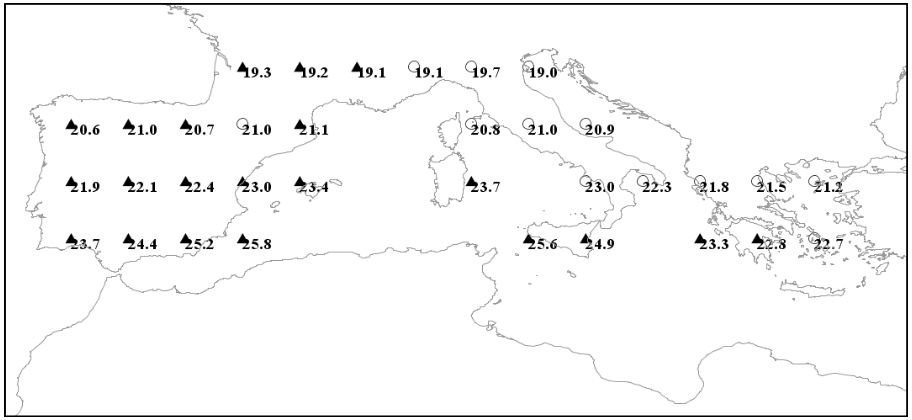

Figure 3. 95th percentile of maximum daily air temperature in degrees Celcius in the June–September period from 1978 to 2012. Circle points mean a significant increase (p value < 0.05) in the annual number of days with an air temperature higher than 95th percentile at 850 hPa in the June–September period from 1978 to 2012. Triangle points mean that there were no significant changes.

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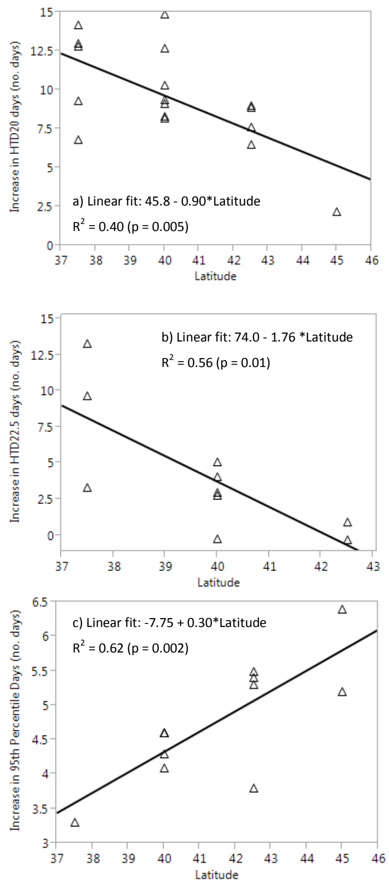

Figure 4. Linear regression showing the relationship between latitude and change in number of days with an air temperature at 850 hPa higher than **(a)** 20 °C (HTD_{20}), **(b)** 22.5 °C ($HTD_{22.5}$), and **(c)** the 95th percentile at 850 hPa in the June–September period from 1978 to 2012. Only sites where significant temporal changes were identified were included in the analysis.

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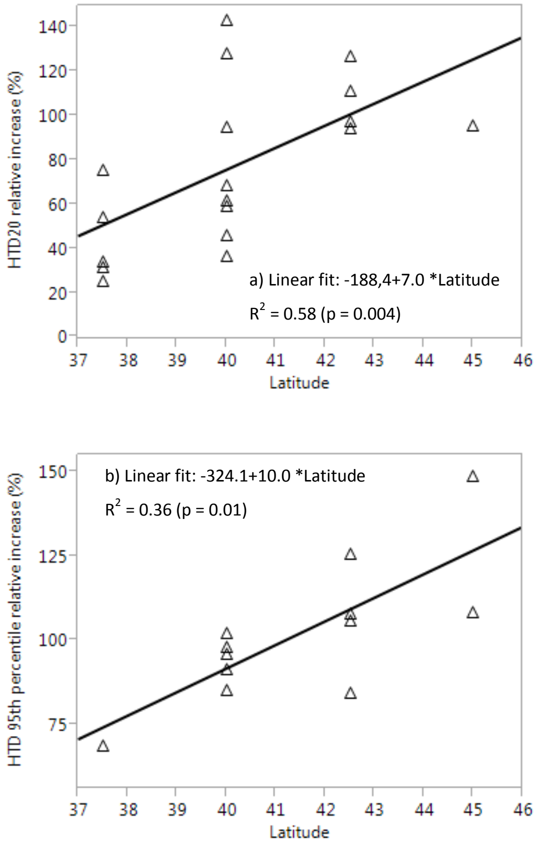

Figure 5. Linear regression testing relationship between latitude and percent change ("relative increase") in number of days with an air temperature at 850 hPa higher than **(a)** 20 °C (HTD_{20}), **(b)** exceeding the 95th percentile at 850 hPa in the June–September period from 1978 to 2012. Only sites where significant temporal changes were identified were included in the analysis. $HTD_{22.5}$ did not change consistently with latitude.

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