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Climate change in two Mediterranean climate areas (Spain and Chile): evidences and projections

Cambio climático en dos áreas de clima mediterráneo (España y Chile): evidencias y proyecciones

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Abstract

Climate change is the most important environmental problem facing humanity in this century. And it has become the great axis of public policies and private actions in developed societies. The effects of altering the planetary energy balance due to anthropogenic greenhouse gas emissions are already becoming evident in some regions of the planet. Among them, the evidence is already significant in the areas with a Mediterranean climate. This paper collects, as a review paper, the evidence and trends that are being recorded in two areas with a Mediterranean climate (the Spanish Mediterranean coast and the central sector of Chile) to assess the effect of the global warming process. The impact that the current climate change is having on the main elements of the climate and on specific environmental processes in both of these geographical spaces has been analysed. The study seeks to update, through an evaluative summary, the state of the issue of climate change in Mediterranean areas, indicating its future impact on elements of the natural environment and on the functioning of the societies that exist in these regions.

Keywords: climate change, Mediterranean climate, evidence, trends.

Resumen

El cambio climático es el problema ambiental más importante al que se enfrenta la humanidad en el presente siglo. Y se ha convertido en el gran eje de políticas públicas y acciones privadas en las sociedades desarrolladas. Los efectos del proceso de alteración del balance energético planetario por la incorporación de gases de efecto invernadero de causa antrópica ya están siendo manifiestos en algunas regiones del planeta. Entre ellas, de forma evidente, en los ámbitos de clima mediterráneo. El presente trabajo recoge, a modo de revisión de investigaciones y documentos oficiales, las evidencias y tendencias que se están registrado en dos áreas de clima mediterráneo (litoral mediterráneo español y sector central de Chile) para valorar el efecto del proceso de calentamiento planetario. Se ha analizado el impacto que está teniendo el cambio climático actual en los elementos principales del clima, así como en algunos procesos ambientales en ambos espacios geográficos. Se pretende poner al día en una aportación de síntesis valorativa, el estado de la cuestión del cambio climático en ámbitos mediterráneos, señalando su impacto futuro en elementos del medio natural y en el propio funcionamiento de las sociedades que están implantadas en estas regiones.

Palabras clave: cambio climático, clima mediterráneo, evidencias, tendencias.

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1. Introduction

Climate change is the greatest threat faced by the global population in the twenty-first century. It has been caused by human activity, and its effects have accelerated and worsened since the 1980s. According to the Intergovernmental Panel on Climate Change (IPCC) (2013, 2018, 2019), areas with a Mediterranean climate are particularly vulnerable to the effects of climate change, where the socio-economic consequences are more notorious than in other spaces of the planet. This fact is directly related to the increase of the frequency and intensity of extraordinary natural phenomena (Agencia Estatal De Meteorología [AEMET], 2020) and the geographical uniqueness of the territories where this type of climate prevails. The two principal climate elements (temperatures and rainfall) have already displayed significant alterations in regions with a Mediterranean climate. In the case of temperatures and the overall increase experienced throughout the world, the Mediterranean basin has its specific characteristics (MedECC, 2020; AEMET, 2022; Chazarra-Bernabé et al., 2022). Variations can be observed in the behaviour of the maximum temperatures and, particularly, the minimum temperatures (Olcina Cantos et al., 2019).

Over the last few decades, temperatures have shown clear and permanent changes toward a warmer climate due to anthropogenic forcing (IPCC, 2013). However, not only the mean temperatures but also extreme episodes evidence these changes in response to radiative forcing (Katz & Brown, 1992). The effects of extreme temperatures can influence several environmental aspects, such as crop growth, agro-ecological regionalisation, and food supply (Ye et al., 2013; Tian et al. 2017). Extreme temperatures over critical thresholds may also cause a rise in the incidence of mortality and the discomfort of human beings (Keellings & Waylen, 2012; Royé, 2017). Among all the effects of this global warming context, heat waves represent one of the extreme events that adversely impact human health and change its characteristics under increasing temperatures (Perkins-Kirkpatrick & Gibson, 2017). Such events are particularly harmful in areas affected by water scarcity, leading to adverse effects on water resources and agriculture (Zittis et al., 2016). Night-time events also have negative consequences on grain yields (Hatfield & Prueger, 2015). Different studies show that these events are increasing worldwide (Amengual et al., 2014; Piticar, 2018; Wang et al. 2018) and will keep increasing (Barrera-Escoda et al., 2014).

The occurrence of warm episodes has been linked to sea surface temperature (SST) anomalies and both local and remote conditions (Purich et al., 2014) but are mainly focused on oceanic scales (Deng et al., 2018; Ham & Na, 2017). Air masses leading to temperature extremes in the Western Mediterranean region are first transported from the north Atlantic towards Europe for all categories. While there is a clear relationship with large-scale circulation patterns in winter, the Iberian thermal low, i.e., the low-level depression, directly related to a positive temperature anomaly, is important in summer (Michaelides et al., 2018; Santos et al., 2015).

The negative impacts of heat waves will be aggravated in urban environments due to the urban heat island (UHI) effect. Urban factors define higher temperatures than rural environments, and night-time cooling is slower, generating more discomfort in cities than in their surroundings (Royé & Martí Ezpeleta, 2015), leading to very warm nights. In recent years, the recording of minimum temperatures above 20º C, with growing frequency, has led to the use of expressions such as "equatorial nights" or "torrid nights" (Martín León, 2018), to emphasise the relevance of these types of very warm nights. However, these concepts are not universally accepted, and their application depends on the climate area of study. In moderate global warming scenarios (below +1.5ºC), tropical nights will be less frequent than in warmer levels (Teichmann et al., 2018). Unlike hot days, where the affected area covers most of the land parts in the Mediterranean region, tropical nights occur in specific geographical regions. Such an index may lead stakeholders and policymakers to assess the development of urban planning policies (De Groot-Reichwein et al., 2018). The study area is the Spanish Mediterranean coast, which, over the last three decades, has experienced an increase in the number of nights with a temperature equal to or higher than 20ºC (Royé, 2017), together with an increase in temperatures of the water of the Mediterranean Sea (Pastor et al., 2017). In this region, "sun and beach" tourism is a fundamental economic activity, accounting for, on average, 10% of the regional GDP in each of the autonomous regions of the area (Saurí et al., 2011). Therefore, changes in climate conditions generated and which could take place in the coming decades will condition the development of this activity and the need to implement adaptation measures in tourist destinations, in terms of both urban planning and building design (Olcina Cantos & Miró Pérez, 2017; Sanz & Galán, 2021). Hence, the importance of studying this climate phenomenon that generates thermal discomfort and favours changes in other climate elements (precipitation) (Olcina Cantos, 2017).

Furthermore, the increase in tropical nights and their relationship with the rise in the frequency of heat waves directly affects aspects of human health (Royé et al., 2021) and can condition the design of healthcare strategies in tourist destinations.

On the other hand, climate change is causing changes in precipitations in different regions of the world. Rainfall is an element that is particularly sensitive to variations in temperature and the regional modifications of atmospheric circulation. Hence the difficulty in modelling it in climate change scenarios. The Mediterranean region is an area where rainfall is highly relevant, due to its importance for the development of economic activities of a territorial and economic nature (agriculture and tourism) (Cramer et al., 2018). The 6th report of the IPCC identifies the Mediterranean area as a geographical space that is greatly affected by climate change due to the impact of the warming process on rainfall. It also points to the high probability that more intense droughts will occur together with more frequent intense rain episodes (IPCC, 2021). The studies on changes in precipitations in the Mediterranean region have analysed both the impact of warming on regional atmospheric circulation and the effect on the volume and intensity of the precipitations. However, precipitation is the climatic element that presents less certainty about its future evolution, as indicated by the 6th IPCC Report. This research collects the latest trends that occur in the two areas of Mediterranean climate analyzed and various effects of climate warming can be observed in rainfall in relation to specific geographic features (mountains, seawater temperature, layout of the coastline) (see section 3).

The alteration in atmospheric circulation is evident, particularly in the northern hemisphere, due to the greater effect that warming is having, particularly at polar and sub-polar latitudes. This fact is connected to the loss of speed of the jet stream (in this case, the polar jet of the northern hemisphere) which would cause a considerable increase of adverse episodes (heat waves and cold snaps, intense droughts and torrential rains) at middle latitudes, where the Mediterranean area is located. These effects are caused by a lower thermal gradient between the latitude ranges as a result of global warming, which would imply a lower speed of the jet stream. Some studies indicate that the average speed of the polar jet stream has reduced by 14% since 1980 (Francis & Vavrus, 2012; Martín León, 2019). This implies a greater undulation of the jet stream, that is, the more frequent generation of planetary waves (peaks and valleys) with faster displacements of hot air masses towards northern latitudes and polar or Arctic air towards the south. Muñoz, Schultz & Vaughan (2020) have recently confirmed the increase in "cut off low" ("gota fría") atmospheric circulation at middle planetary latitudes, which, in the northern hemisphere, has increased by 20% between 1960 and 2017. Furthermore, in the European sector of the middle latitudes, the areas where these isolated depressions are concentrated at high levels of the atmosphere correspond to the Gulf of Cadiz and Western Mediterranean. For the specific area of the Spanish Mediterranean coast, Ferreira (2021) has analysed the relationship between intense rainfall and the formation of "cut off low" in the Region of Valencia in the period 1998-2108, based on the Weather Research and Forecasting (WRF) model. The results show an increase in intense rainfall for the coming decades in this region, due to the increase in thermodynamic processes in a warmer atmosphere, which contrasts with the overall decreasing trend in rainfall in the Iberian Peninsula in recent decades within the context of climate change.

Concerning the evolution of rainfall, Zittis et al. (2021), using the "up-to-date" data processing procedure with a group of 33 regional climate simulations of the EURO-CORDEX initiative, with a resolution of 0.11°, analyse the importance of the trends for 1951-2000 and 2001-2100 according to a 'business-as-usual' (RCP8.5) scenario, concluding an increase in extreme rainfall events within an overall context of a decrease in annual rainfall in the whole of the Mediterranean basin. In Spain, studies have been conducted on the recent evolution of precipitations to validate the hypothesis of the increase in the intensity of rainfall recorded in recent decades. In this respect, Oria Iriarte (2021) indicates that the most extreme episodes (around the 98th and 99th percentiles) are increasing their probability of occurring and that the intensity of the rainfall is also increasing as the total amount of accumulated rainfall in the episodes exceeding the 98th percentile (and higher percentiles) grew considerably in the period analysed (1965-2020). The report on the future evolution of intense rainfall in Spain (Centro de Estudios y Experimentación de Obras Públicas [CEDEX], 2021), which takes the period 1971-2000 as a reference and uses the climate projections of EURO-CORDEX (2100 horizon), indicates an increase in torrential rain, with extreme rains associated with short episodes of RCP 8.5 scenarios in the east of the Iberian peninsula. Cardoso et al. (2020) evaluate the future changes in precipitation in the Iberian peninsula (IP) according to the RCP8.5 scenario. The changes are analysed for two future climate periods, namely (2046–2065) and (2081–2100). The study indicates that, in the climate change scenario, it is expected that a good part of the region will experience a reduction in annual rainfall of approximately 20-40%, reaching 80% in the summer at the end of the twenty-first century. These results imply that climate change will probably influence the annual quantity of rainfall and the torrential rain episodes throughout the twenty-first century, particularly in the southern regions of the peninsula, which would increase the erosive processes in this area. Merino et al. (2016) conducted a synoptic study of the extreme rainfall events between 1960 and 2011. Applying a non-hierarchical K-means clustering, they characterise six principal synoptic types with which extreme rainfall events are developed. The study highlights that these events in the west of the peninsula are basically related to zonal circulations. In contrast, those in the east are associated with the development of "cur off low" at middle layers of the atmosphere. Based on the analysis of the spatial and temporal variability of daily rainfall in Spain in the period 1950-2012 and on the high-resolution daily gridded data set, SPREAD at a spatial resolution of 5×5 km., Serrano-Notivoli et al. (2018), find the following significant facts: 1) a slight global increase in the duration of the rainfall events, particularly along the Mediterranean strip; 2) an increase in the frequency of low rainfall events and a reduction in the frequency of high and very high events (inversed on the Mediterranean coast); and 3) a slight reduction in the intensity of unique events (duration of 1 or 5 days), but a significant negative trend in mean and median rainfall when considering all of the days of rainfall (p> 0), particularly on the Mediterranean coast. Miró et al. (2021), in their study on the evolution of rainfall in the Jucar and Segura river basins, based on the use of CMIP% GCMS Local Downscaling, in an RCP 4.5 and 8.5 scenario and contemplating 900 rainfall series, indicate an increasing trend in the frequency of torrential rain episodes in the coastal areas of the field of study, as opposed to the considerable reduction in the headwaters of these rivers.

The climate warming process seems to have triggered the warming process and the associated extreme manifestations on a global scale and in the areas of study selected (Levin, 2019; World Meteorological Organization [WMO], 2022). The 6th IPCC Report describes the Mediterranean climate regions as "hotspots" of climate change on a global level due to the acceleration of the evidences and alterations experienced in the climate elements and the occurrence of extreme weather events (IPCC, 2022). Therefore, the knowledge of the current climate reality in Mediterranean climate areas is of great interest in order to gauge the impact of current climate change and its future projection (Sanz & Galán, 2021). The objective of this study is to present the effects of climate change in two Mediterranean climate areas based on the research carried out in recent years. It must be made clear that this is a review article, which, however, includes results of recent research in which the authors have participated.The evolution of the principal climate elements (temperatures and precipitations) is analysed, together with the effects of their trends on the development of environmental processes, also with a significant impact (droughts, behaviour of marine waters, effects on the coast). The analysis seeks to show the consequences in the two Mediterranean climate areas, identifying common and unique effects in each of them.

2. Methodology

As the article is a review of the existing information, the method is based on the consultation of existing studies on climate change for the two areas of study. A period of study from the year 2000 to the present day has been selected. This year, as previously indicated, is when the global warming process seems to have begun, with considerable effects in the selected Mediterranean climate areas. The official climate change reports by the IPCC and Spanish and Chilean meteorological agencies have been consulted. Furthermore, the topic of climate has been tracked in the international and national journals for the period 2010-2022 so as to identify the topics and results of the research undertaken for the analysis of climate change in the different areas of study.

Official documents and research papers published in recent years have been consulted, although some previous important references have also been consulted. This is an interval in which the effects of the current climate warming process become more evident in the two areas of study analysed. The selection criteria chosen have been the reliability of the official organizations and the rigor of the results of the investigations carried out by the authors of the scientific articles consulted. Table 1 lists the organizations and documents consulted for the preparation of this research. It should be noted that the authors of this study have participated in various reviewed investigations, due to their research specialization.

Table 1. Official sources and research consulted for the development the present research (2010-2022)

RESEARCH SOURCES	DOCUMENTS CONSULTED
International official organizations	-5th and 6th IPCC Report (2014 and 2021-22) -Report on climate change in the Mediterranean (MedECC) -ESPON Climate project
National and regional official organizations	-State of Spanish climate. Annual report (AEMET) -Annual Meteorological Calendar (AEMET) -Report to the Nation (Chile). Megadrought -Report Country State of the Environment (Chile). -Report "Climate Change and Tourism activity" in C. Valenciana. -Catalonia Climate Change dossier (3th report) -Mediterranean Sea superficial water temperature reports (Centro De Estudios Ambientales Del Mediterráneo [CEAM]).
International scientific journals consulted (JCR and SCOPUS)	-Climate Research -Climatic Change -Nature Climate Change -Journal of Climate -Weather and Climate Extremes -Atmospheric Resarch -Atmosphere -Advances on Atmospheric Science -Atmosphere-Basel -Regional Environmental Change -Journal of Geophysical Research Atmospheres -Geophysical Research Letters -Science -International Journal of Climatology -International Journal of Biometeorlogy -Journal of Hydrology: Regional Studies -Hydrology and Earth System Sciences -Review of Geophysics -Global and Planetary Change -Hydrological Processes -Hydrological Sciences Journal -Ecosphere -Water -Boletín de la Asociación Española de Geografía (BAGE) -Revista de Geografía Norte Grande

Own elaboration

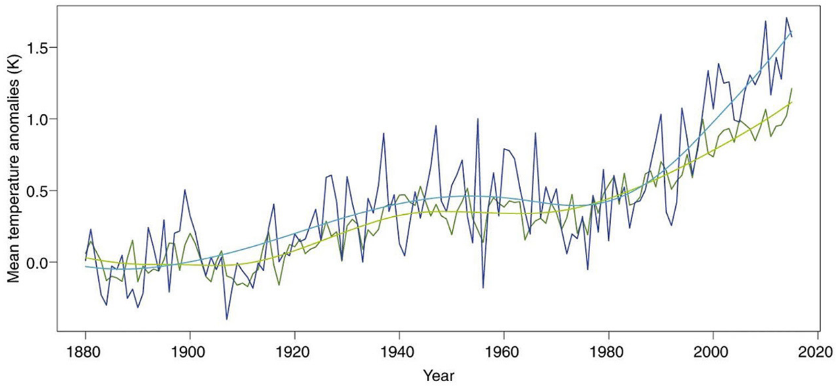
The work method consists in the study of the documentary sources (reports, articles, monographs) consulted, the determination of the principal aspects highlighted in them for the areas of study and a critical assessment of their conclusions. This critical assessment is also based on the results obtained by research on climate change in Mediterranean areas in which the authors of this study have participated directly. It should be noted that there has been an increase in the studies on climate change in Mediterranean areas since 2010 related to the stimulation of this warming process being experienced in these territories, as noted.

3. Results

3.1. Effects of climate change on the Spanish Mediterranean coast

The Spanish Mediterranean coast is one of the areas of the world where the effects of global warming are more evident, particularly since 2010. In this geographic space, which can be defined as a risk region, an intensive use of the territory (population and economic activities) together with the physical conditions of the physical environment lead to a high pressure on the natural resources (water, land, and vegetation). Any alteration in the climate conditions leads to a rapid manifestation in the rest of the elements of the physical environment. The 6th IPCC Report (2022) indicates the Mediterranean basin as a "hotspot" on a global level in terms of climate change, due to the speed with which some climate and environmental elements are altering and the associated socio-economic impact. The report "Risks associated to climate and environmental changes in the Mediterranean region" (MedECC, 2020) reveals that the increase in temperatures experienced in this region has been higher than that recorded in the rest of the planet (1.5ºC since 1880, as opposed to 1.1º C for the rest of the planet's surface) (Figure 1).

Figure 1. Comparison of the increase in temperatures between the Mediterranean basin (blue) and the rest of the earth's surface (yellow) (1880-2019)



Source: MedECC (2020)

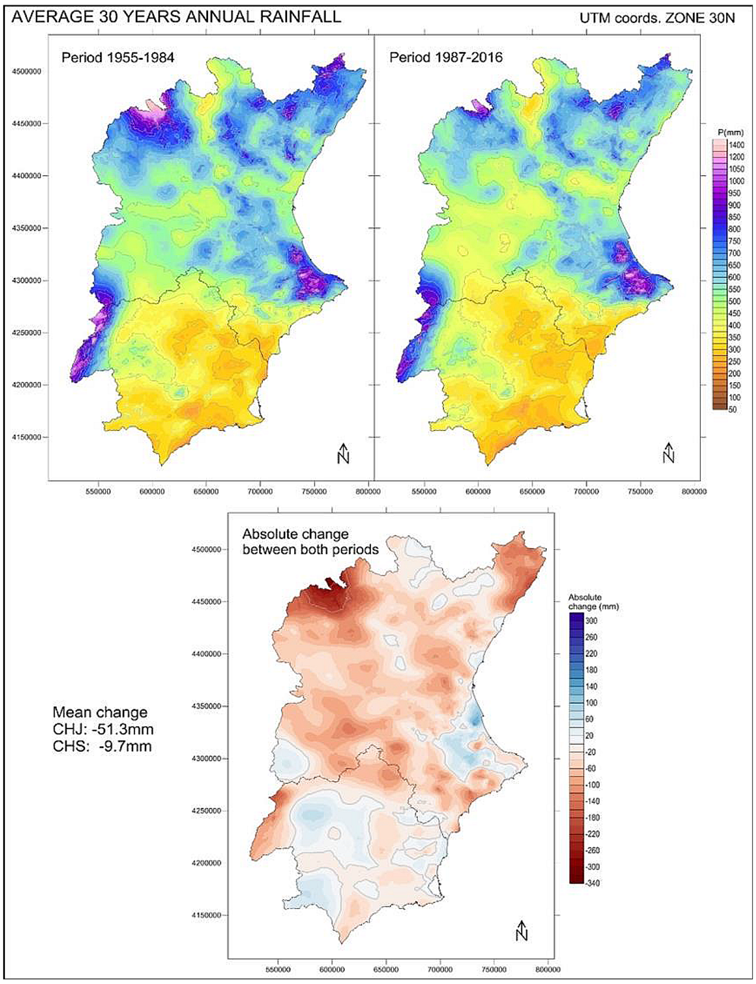
The Spanish Mediterranean coast has its own characteristics that make the effects of current climate change unique in this geographical space. Basically, the fact that there is a sea bathing its coasts that has been experiencing a rapid warming process over the last few decades, conditions the functioning of the two most important climate elements for characterising weather and climate (temperatures and precipitations) (Chazarra-Bernabé et al., 2020; Romero Fresneda et al., 2020). The climate of the Spanish Mediterranean coastline has been experiencing highly significant alterations in temperatures and rainfall over the last three decades. This fact has been proven with scientific data. On the Mediterranean coast, four processes are closely related to the global warming mechanism: 1) seasonal variations in precipitations and the intensification of the rainfall; 2) the increase in the average temperature, and particularly, night heat, manifested in the so-called "tropical nights" (Tª > 20º C) and "equatorial nights" (Tª > 25º C); 3) the development of extreme weather events with a higher frequency than that before the year 2000; and 4) the rise in the temperature of the central part of the western Mediterranean sea in its central section (Algero-Balearic Basin), which, undoubtedly, constitutes the origin of the three previously mentioned alterations in precipitations, temperatures, and extreme weather manifestations. Scientific data corroborate the four processes: they are clear manifestations of climate change on the Spanish Mediterranean coast.

3.1.1. Changes in precipitation

The first process, changes in precipitation, generates the most uncertainty in the medium and long term, as we should not forget that rainfall irregularity is one of the distinctive features of the climate of the Mediterranean coast. In general terms, in the principal climate series between Girona and Málaga there is not yet a clear overall decreasing trend in rainfall. However, a trend can be observed in the distribution and intensity of the rains, particularly in the areas close to the coastline. Therefore, the current trends in annual average rainfall show sectors where it rains slightly less than the average (1980-2010) and others where the rainfall is, curiously, somewhat higher than the average (e.g. Southern coastline of Valencia and the north of Alicante) (Figure 2).

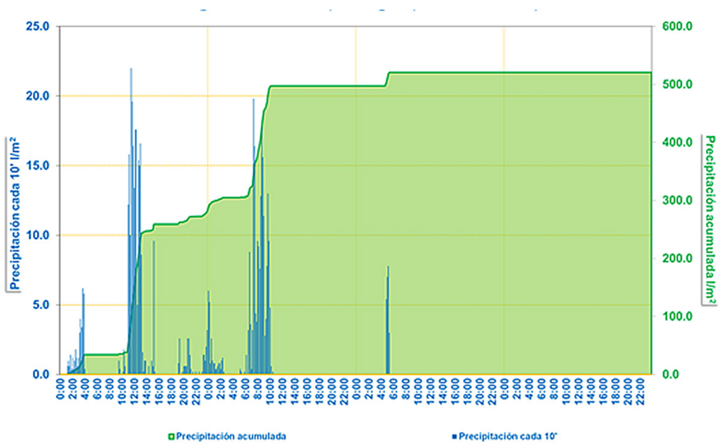
A change in the type of precipitation has been recorded. From the beginning of this century, the convective precipitations (particularly those associated with the presence of "cut off low" situations in the middle-high layers of the troposphere) have gained importance with respect to the Atlantic frontal precipitations (Figure 3). In addition, the calendar of intense hourly rainfall events is being modified and they can now occur in any season of the year. They are not limited to autumn, which is the season traditionally considered to have a high flood risk. Events of around or above 100 mm can occur in barely one or two hours in any month of the year. Even in the summer, particularly in the second half of August, an increase in torrential rains on the coast of the Gulf of Valencia, associated with events of the so-called "warm rains," is a symptom of the intense warming process experienced by the Balearic sector of the Mediterranean Sea at this time of year.

Figure 2. Change in rainfall (1955-2016) in the Jucar and Segura river basins (Spanish Mediterranean coast, central sector)



Source: Miró et al. (2021).

Figure 3. Rainfall recorded in the meteorological station of Orihuela (CHS) between 12 and 15 September 2019. Intense rains in two specific moments accumulated 500 mm throughout the episode



Source: https://twitter.com/aemet_cvalencia?lang=es

These changes in precipitations are not only reflected in rains, but also in snowfalls. Paradoxically, while the annual average number of days with frost is decreasing in line with the overall warming process, the episodes of "intense snowfalls" is increasing. In other words, this is explained by the increase of episodes of snow related to "cut off low" circulations and the entry of easterly surface winds that, in a few hours, leave very high amounts of solid precipitation on the Mediterranean mountains. This is the case of the intense hourly snowfall of 2017 and January 2000 ("Gloria" blizzard) in different provinces of the Mediterranean coast or the "intense" snowfalls recorded in the city of Barcelona in recent years (March 2010, February 2018).

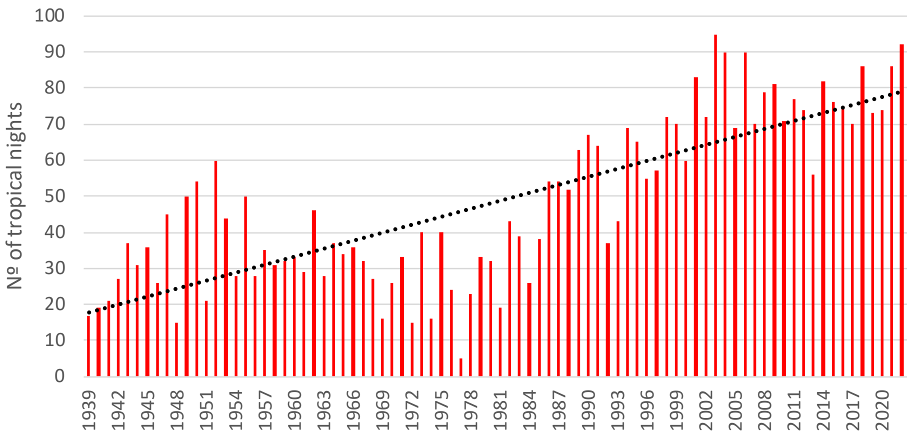
Also relevant is the seasonal modification of precipitation patterns because the spring rains are diminishing in favour of those in the autumn in the annual distribution. This is particularly significant in the extreme south of the Iberian System, where the sources of some of the most important rivers of Spain can be found, with their mouths either in the Mediterranean Sea (Júcar, Turia) or the Atlantic (Tajo). This has been indicated in different studies (De Luis et al., 2010; Miró, 2014) which point to the progressive spread of territorial extension of typically Mediterranean rains (maximum rainfall in autumn) from the Mediterranean coast to the interior of the Iberian Peninsula, where the principal peak in rainfall generally occurs in the spring (eastern section of the Iberian mountain range). This fact directly impacts hydrological planning, given that the spring rains are crucial for the normal development of agricultural activity and the accumulation of water reserves in reservoirs and aquifers, enabling the increase in consumption in the warmer months of the year to be met.

The changes indicated in the intensity and seasonality of the precipitations in the Spanish Mediterranean area are related to the alterations being experienced in the atmospheric circulation at middle latitudes of the northern hemisphere. There is an increasing number of studies that indicate that the loss of speed of the jet stream (in this case, the polar jet of the northern hemisphere) would cause a considerable increase of adverse episodes (heat waves and cold snaps, intense droughts and torrential rains) at middle latitudes, where the Mediterranean area is located. This is caused by a lower thermal gradient between the latitude ranges as a result of global warming, which would imply a lower speed of the jet stream. At the same time, different studies indicate that the average speed of the polar jet stream has reduced by 14% since 1980 (Francis & Vavrus, 2012; Martín León, 2019). This implies a greater undulation of the jet stream, that is, the more frequent generation of planetary waves (peaks and valleys) with faster displacements of hot air masses towards northern latitudes and polar or Arctic air towards the south. Muñoz et al. (2020) has recently confirmed the increase in "cut off low" atmospheric circulation at middle planetary latitudes, which, in the northern hemisphere, increased by 20% between 1960 and 2017. Furthermore, in the European sector of the middle latitudes, the areas where these isolated depressions are concentrated at high levels of the atmosphere correspond to the Gulf of Cadiz and Western Mediterranean as a whole. Taking as a reference the level of 200 hPa, in Europe the number of DANAs per year between 1960 and 1990 remained stable, at almost 30 each year. However, from 1990, this number has risen significantly, currently at around 35-40. The current global warming process seems to account for a large part of this, as it has been shown that the jet streams have been shifting towards the poles, as have the Hadley cell and the intertropical convergence zone; without forgetting the contraction of the polar vortex and the cooling of the stratosphere. With a more wavy jet stream, blockings appear, favouring the emergence of weaker subtropical and weaker polar branches. This is closely connected to the increase in cold fronts observed in Europe.

3.1.2. Increase in temperatures, loss of thermal comfort, notable increase in "tropical nights"

Meanwhile, the increase in the annual average temperature on a global level is undeniable. The Spanish Mediterranean coast is no exception in this process. The recordings of the group of observatories of the Mediterranean territories between Catalonia and the Mediterranean provinces of Andalusia show that the increase in temperatures has been 0.8º C over the last hundred years, with a very pronounced increase from 1980. However, the most evident manifestation of the loss of thermal comfort in this region has been the highly notable increase in the so-called "tropical nights," when the thermometer does not fall below 20º C for the whole night. From 1970 to the present day, the number of tropical nights in many cities of the Mediterranean region has tripled, from 20 tropical nights per year to 60 or 70 (in some cases more) (Figures 4 and 5).

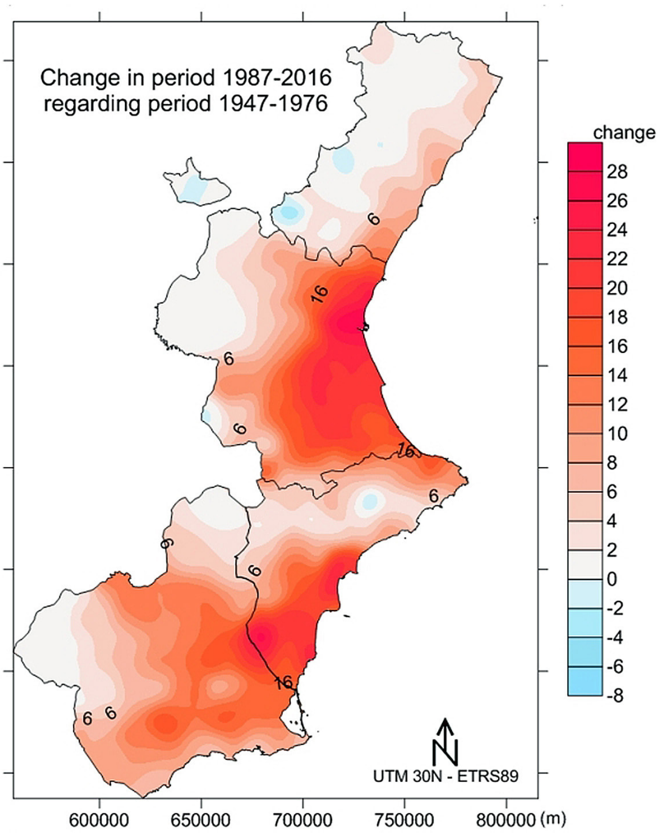
Figure 4. Evolution of "tropical" nights in the city of Alicante (1939-2022)



Source: AEMET Comunidad Valenciana. Own elaboration

Furthermore, since the year 2000, an increase in nights where the thermometer does not fall below 25º C has been observed, and in recent years there have been some days when the minimum daily temperature has not fallen below 29-30ºC. In addition to these high night temperatures, there is also a high relative humidity level in coastal towns. This indicator is important given that with relative humidity values of 70% or more, the temperature that the human body really feels is around 4-7º higher with respect to the thermometer reading. This is the aspect that generates more thermal discomfort as a result of global warming in the Mediterranean area.

Figure 5. Increase in the number of tropical nights in the Region of Valencia and Murcia. 1987-2016 with respect to the period 1947-1976



Source: Olcina Cantos et al. (2019)

Several factors explain this increase in the minimum temperatures in this region. First, the increase in temperatureis a result of the global warming process. In recent years, we can observe that the summers have lengthened, beginning at the end of spring and ending at the beginning of autumn on the Mediterranean coast. Another factor to consider is the aforementioned increase in temperature of the Mediterranean Sea. The most palpable consequences of this are the increase in minimum temperatures and relative humidity and the variations in rainfall patterns, particularly on the coast and pre-coastal area of the Valencian coastline. The final factor is decisive for the increase in temperatures (particularly at night) in the population nuclei of the coast and those of a larger size. We are referring to the effect of the "urban heat island" which modifies the climate characteristics on a local level (temperatures, precipitation, and emergence of atmospheric pollution problems, among others). The asphalt or cement retains the heat of the day, while, at night, the temperature falls gradually and this heat is transmitted into the air. This situation becomes less pronounced as we move away from the city centre. Sometimes, the difference between the periphery and the town centre on the Spanish Mediterranean coast can be 4-5ºC or even more.

The maximum temperatures display an increasing trend in the interior districts of the Mediterranean coast. This increase is greater between the spring and the first half of the summer, particularly during June, when there is a sharper increase in the maximum temperatures. The temperature projections on the Mediterranean coast for the end of this century reveal a sharp loss of thermal comfort during the summer, which can be associated with temperatures above the optimum level of thermal comfort, either due to excessively high maximums (mainly in the interior) or the frequency of tropical nights (mainly on the coast) (Olcina Cantos & Miró Pérez, 2017). This directly affects agricultural activities (crop cycles) and tourism activities (high season), which should adapt to the new predicted climate scenario.

3.1.3. Increase in extreme weather events in a territory with high exposure

One of the consequences with the greatest socio-economic impact of the global warming process is the occurrence of extreme weather events, which, moreover, have a unique behaviour in the western basin of the Mediterranean due to the increase in the sea surface temperature. The official data of the meteorological observatories of this climate region and the reports of the SINOBAS portal (AEMET) show an increase in reports on these extreme weather episodes occurring from the beginning of this century on the coast of the Iberian peninsula and Balearic Islands. On the Mediterranean coast, there has been an increase in rains with a high hourly intensity, days with prolonged heat, sea storms with effects on the coastline, and the more frequent occurrence in the last decade of marine storms and torrential snowfalls in mountainous areas.

Figure 6. Occupation of the maritime-terrestrial public domain and maritime storm effects on the Spanish Mediterranean coast (2017-2021)

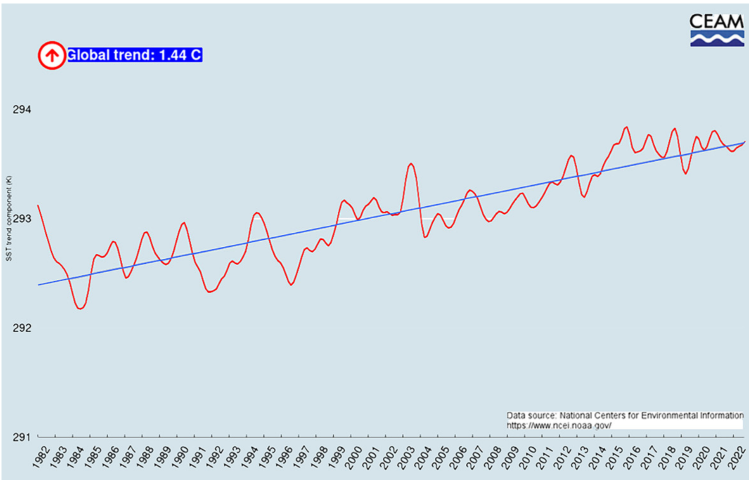
Source: Ministry of Ecological Transition. Own elaboration

The episodes of heavy rain, which generate intense precipitations (up to 100 mm in 1 hour) have been shown an increasing trend since 2000. In fact, large volumes of torrential rain are not necessary to generate considerable economic damage in the affected territories. This aspect reveals another element of risk analysis that has also been increasing over the last twenty years on the Mediterranean coast: the vulnerability and exposure to extraordinary atmospheric events due to the establishment of housing and facilities in floodable areas. The recent sea storms on the Spanish Mediterranean coast have been particularly intense. Since 2015, there have been three storms (2017, 2020, 2021) with severe effects for the facilities and housing located on the coastline. The storm caused by the "Gloria" blizzard (January 2020) was particularly vigorous, causing significant economic losses along the Mediterranean coast. The effects of these storms contrast with the permissiveness of the Spanish coastal legislation (Coast Law of 2013), which authorised the prolongation of concessions in the maritime-terrestrial public domain for up to seventy-five years. Recently, the Climate Change Law (Law 7/2021) opened the possibility of reviewing the occupation of the public domain in the current context of climate change (Figure 6).

3.1.4. A warmer Mediterranean Sea

Finally, a highly relevant fact and a clear manifestation of the change in the climate conditions of the Spanish Mediterranean coast is the increase in the sea surface temperature of the Mediterranean. The Mediterranean Sea has experienced a warming of its waters throughout the basin, particularly in the eastern and western extremes. In the western sector, the CEAM (2022) data show a warming of 1.4 º C between 1980 and 2022 (Figure 7). This warming means that the heat accumulated in the marine basin is higher than the warming experienced in the air in the same time interval, according to the data recorded in the observatories of the Spanish Mediterranean coast.

Figure 7. Increase in the de-seasonalised sea surface temperature of the Western Mediterranean (1982-2022)



Source: CEAM (2022)

The Mediterranean Sea, therefore, is warmer than three or four decades ago, in a process of heat accumulation, particularly from the end of spring (May-June) extending throughout the summer as well into the autumn (October and beginning of November). It is noteworthy that from 2000, peaks of up to 30ºC have been observed during the summer in the waters close to the Balearic Islands and Algeria, a value more typical of tropical seas. In short, the annual period of warm waters on the coast of the Spanish Mediterranean is much more extended than a few decades ago, and these waters are also warmer. This has two direct effects on the climate elements of the Spanish Mediterranean coast: a loss of thermal comfort, particularly in the summer, due to the increase in the number of warm nights between the spring and beginning of autumn; and the occurrence of intense precipitation due to the transfer of heat from the surface of the sea to the atmosphere in the convection processes.

Together with these evidences revealed by the data on climate elements on the Mediterranean coast, some uncertainties must be researched over the coming years. The evolution of precipitations is, undoubtedly, the great unknown, given that the warming of the atmosphere and the Mediterranean Sea could give rise to the more frequent formation of convective clouds and storms. The climate change models indicate an overall reduction in precipitations, which will condition water circulation in the rivers and its infiltration in the aquifers. So, for example, in the Jucar and Segura basins and moderate emission scenarios, this reduction is estimated at 8-10% with respect to the current scenario until the middle of this century. As previously indicated, until now, the trend of the last few decades in this respect is the accumulation of greater volumes of rain in the coastal strip than in the interior territories. A significant increase in the south of the province of Valencia and north of Alicante can be observed. Still, it will be necessary to study the evolution of this climate element over the next two decades, at least to confirm the current trends on the Mediterranean coast as a whole. The wind is another element that is difficult to model. We do not know the behaviour that breezes can have in a warmer atmosphere and a warmer Mediterranean Sea, between spring and autumn. On the other hand, the energy readjustment processes will theoretically be stronger in a warmer atmosphere. This could give rise to the more frequent formation of "energetic" squalls that pass through the Iberian latitudes on their way to the Mediterranean, therefore also affecting the Mediterranean coast due to the greater presence of strong winds, having an impact on the agricultural activity and urban furniture. Also unclear is the behaviour of oceanic-atmospheric oscillation mechanisms that affect the territory of the Region of Valencia, such as the NAO (North Atlantic Oscillation) and the weMO (Western Mediterranean Oscillation), given that the trend of the pressure systems at sea level are unknown in warmer waters (Martin-Vide & López-Bustins, 2006). If the expansion of the Hadley cell continues towards the northern latitudes of our hemisphere, we can estimate a climate with much fuzzier seasonal changes and the presence of two contrasting moments throughout the year: a very long warmer season with storms and another season which is less cold than the current winter and that will last barely one or two months of the year. An even more sub-tropicalised Mediterranean climate. However, this assumption has to be corroborated with scientific data over the coming decades.

The water-atmosphere ratio is manifested in a rise in the sea level and its consequences on the coastal strip. The IPCC sectoral report on oceans and the cryosphere (IPCC, 2019) expresses great concern about the effect of the rising sea level, which is already being recorded in coastal areas of large ocean basins (Pacific and Atlantic). For the Mediterranean basin, the problem is not so evident yet. Still, the report indicates the effect that the dilation of the seawater (warming) will have and the higher frequency of sea storms (eastern storms on the Spanish Mediterranean coast) on the coastal strip. These conclusions are supported by the study on the effects of climate change on the world coasts (Kulp & Strauss, 2019) and the report on the effects of climate change on the Spanish coast (Losada et al., 2014). In this respect, on the Mediterranean coast, the forecasted increased frequency of extreme weather events that give rise to sea storms on the coastal strip is of great concern. The episodes occurring in January 2017 and January 2020 ("Gloria" blizzard) have revealed the risk existing in different areas of the Mediterranean coast with the occupation of the maritime and terrestrial public domain, either with buildings constructed prior to the more recent coastal legislation (1988, 2013), or due to administrative concessions in this domain which have been extended by the latest regulations of this environment (2013 and regulations of 2014). Therefore, the facilities in areas of the Mediterranean coast that are at risk to sea storms and the forecast effect of the rising sea level at the end of the century need to be adapted.

3.2. Climate change in the Mediterranean climate of central Chile

Continental Chile has a wide variety of climates. This is due to its vast latitudinal extension, between 17°S and 56°S, making it the second longest country in the world in latitude, after Canada. Another characteristic that diversifies the climates of Chile is its relief, as in its short longitudinal length, from the coast it reaches a height of more than 6.000 m ASL. Considering these geographical constraints, the atmospheric action centres are highly important, defined as synoptic-scale circulation patterns. For the case of Chile, these surface circulation patterns correspond to: the Inter-Tropical Convergence Zone (ITCZ), the South-Eastern Pacific Anticyclone (APSO), and the westerlies wind belt or low subpolar pressure belt (CBPP). The APSO explains the conditions of climate stability and the rainfall deficit of central-northern Chile during most of the year. The CBPP gives rise to a fairly rainy centre-south, particularly on the west coast. The ITCZ gives rise to an austral summer and copious rainfall on the plateau of Chile's Big North, enabling the advection of moist air in a region of high solar radiation. In short, this means that continental Chile has up to 25 different types of climates according to the Köppen-Geiger classification, from the aridest parts of the north to polar climates in the south and the higher elevations (Sarricolea et al., 2017). Among this wide climate diversity is the Mediterranean climate, which prevails between 33°S and 39°S. Most of the the country's population is concentrated on this latitudinal strip (more than ten million inhabitants), where most agricultural activities are carried out.

3.2.1. Overall trends toward warming

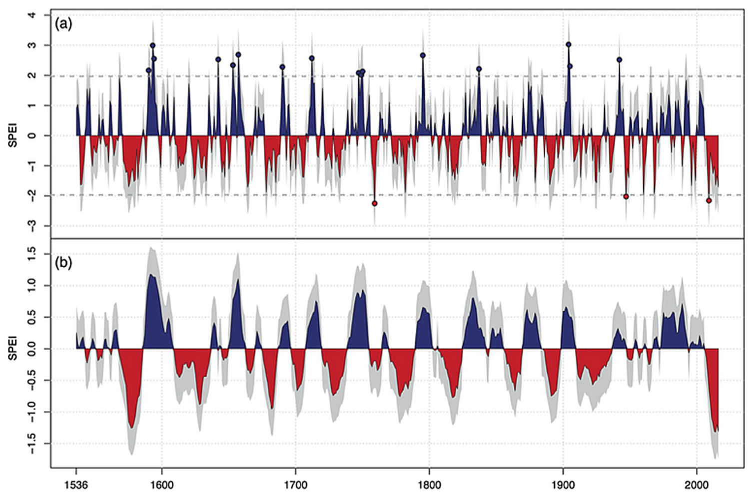
In this respect, there is evidence that shows how extreme temperatures have displayed a clear trend towards warming from the last third of the twentieth century. The study of extreme temperatures' spatial and time behaviour is highly relevant, particularly in a country such as Chile, which has a wide variety of climates and environments. Within the context of global warming, the different climate (and geographical) regions of continental Chile have different behaviours in terms of (a) latitudinal location of seasons, (b) lowland/coastal seasons, and (c) highland seasons. The month-by-month study of extreme temperatures and, according to the 14 indices of the Expert Team on Climate Change Detection and Indices facilitates their representation. It also contributes to highlighting the importance of these studies. In this way, the results obtained for central Chile coincide with those identified by other authors in neighbouring regions. The overall warming trends are more evident due to the increase in minimum temperatures (and the related indices). However, a clear pattern cannot be identified, which indicates that the altitude and latitude modify the trends. Finally, a coastal/interior influence can also be observed: the maximum temperatures increased more notably in the stations further away from the coast, showing that the role of the ocean is essential, taking into account the temporary changes in the teleconnection patterns that can affect the Pacific Decadal Oscillation (PDO) (Piticar, 2018; Meseguer-Ruiz et al., 2019).

In general, warming trends have been identified in the area of study but with some exceptions that depend on the behaviour of the minimum temperature. However, the heterogeneity of the temporary trends of the indices and the numerous factors that affect the high altitude areas mean that this conclusion has yet to be confirmed. Therefore, the exact mechanism that influences the variability of the temporary trends of the indices cannot be generalised for the whole area. The lack of a dense network of stations limits understanding the higher areas' warming trend. Therefore, it is difficult to predict the future patterns of these trends. Furthermore, different responses of the extreme temperatures have been identified depending on the latitude and/or elevation, illustrating the effect of the complex orography of the region on temperatures and, therefore, on the climate.

3.2.2. The mega-drought of central Chile

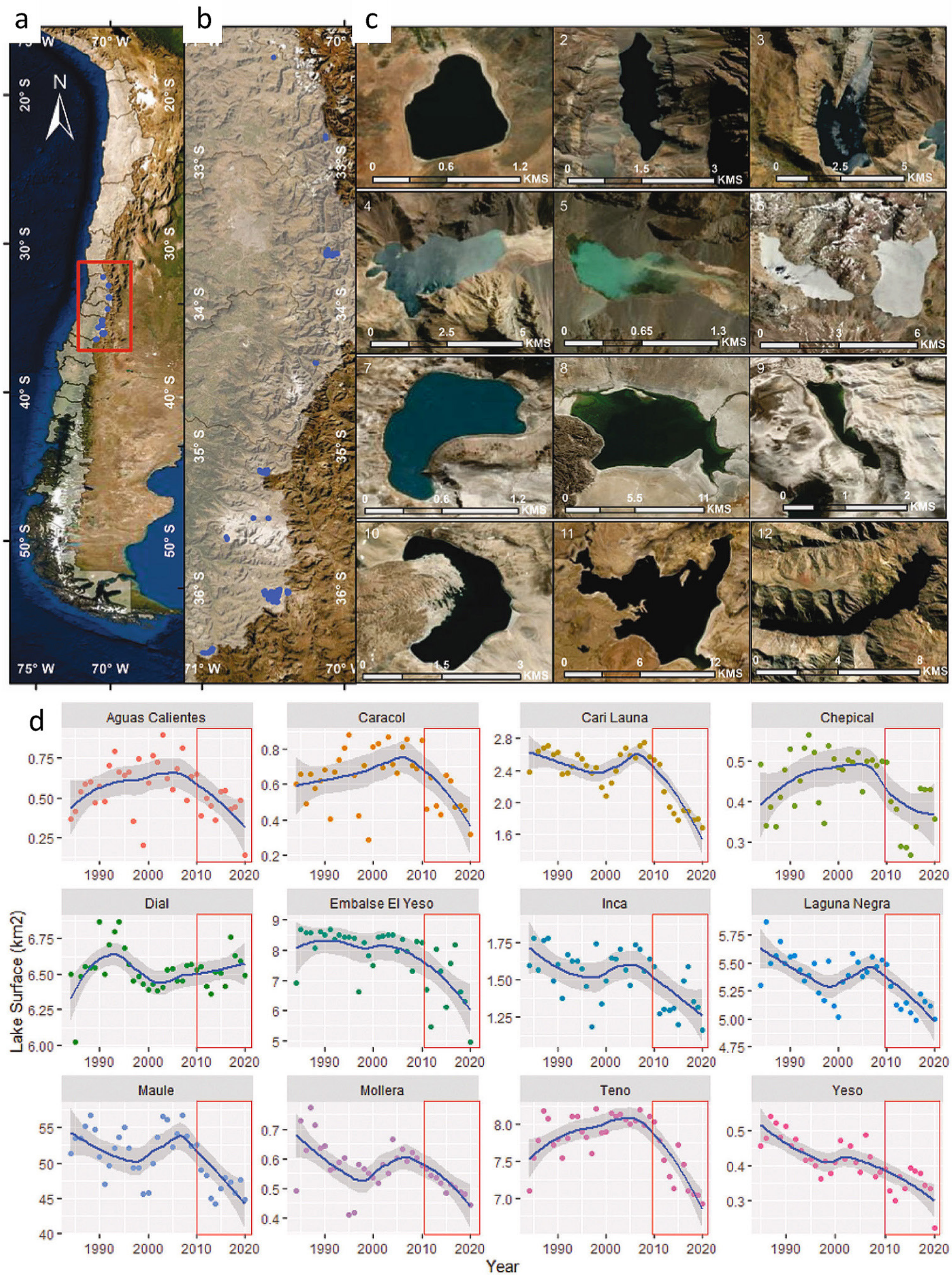
The phenomenon connected to climate change which has the greatest impact and on which most studies have been carried out is, undoubtedly, what is known as the Mega-drought that has affected central Chile since the year 2010 (Garreaud et al., 2017, 2020; Muñoz, Klock-Barría et al., 2020; Oertel et al., 2020; Peña-Guerrero et al., 2020; Fuentealba et al., 2021). This drought has been identified as the most intense in the last five centuries, in accordance with the Standardized Precipitation Evaporation Index (SPEI) (Serrano-Notivoli et al., 2021) (Figure 8). The SPEI that showed the best adjustment was August, with a window of 14 months ($SPEI_{Aug}14$).

Figure 8. Reconstruction $SPEI14_{Aug}$ from 1536 CE for Central Chile. (A) Annual values of negative anomalies (red) and positive anomalies (blue). The wettest years (blue points) and driest years (red points) that exceed the SPEI ± 2 threshold (dotted grey line in bold) are shown. (B) The same as (a) but aggregated in an eleven-year moving average



Source: Serrano-Notivoli et al. (2021)

Figure 9. a. Map showing the general location of the lakes in the Andes of central Chile (32-36°S). b. The distribution of the lakes with a surface area greater than 0.5 km². c. The lakes from left to right: 1. Chepical, 2. Laguna del Inca, 3. Laguna Negra, 4. Embalse El Yeso, 5. Yeso, 6. Teno, 7. Mollera, 8. Aguas Calientes, 9. Caracol, 10. Cari Launa, 11. Laguna del Maule, and 12. Dial. d. Fluctuations of the surface area of the lakes of the Andes of central Chile (32-36°S) from 1984 to 2020. In general, the lakes display one of the three principal patterns, the "humped back" (that is, Chepical, Caracol, Teno, Aguas Calientes) with an initial increase until 2000, followed by a considerable reduction, a "linear" pattern, characterised by a linear decrease, with a slight increase in the 2000s, followed by a decrease (that is, Cari Launa, Embalse El Yeso, Laguna del Inca, Laguna del Maule, Mollera, Yeso) or an overall increase (for example, Lago Dial). The mega-drought is also shown as a reference (red dotted rectangle)



Source: Fuentealba et al., 2021. Own elaboration

This mega-drought has generated progressive water deficits in different basins (Álvarez-Garreton et al., 2021) with adverse effects on diverse landscapes and ecosystems of the region (Garreaud et al., 2017; Muñoz, Klock-Barría et al., 2020; Barría et al., 2021; Fuentealba et al., 2021). This dry episode has been the most intense in central Chile since the sixteenth century (Garreaud et al., 2020; Serrano-Notivoli et al., 2021). This trend has been detected in Santiago since the mid-twentieth century (González-Reyes, 2016) and it is expected to continue in the future, as the regional climate projections consistently indicate a reduction in the annual average precipitation (up to 40% in relation to the current values) for the second half of the century in high emission scenarios (Bozkurt et al., 2018). The south of Chile (43ºS-56ºS) concentrates the largest freshwater reservoirs of South America (Reynhout et al., 2019). However, in recent years, they have experienced severe drought episodes, which compromise human activity development (Garreaud, 2018; McNamara et al., 2021). Therefore, improving the knowledge of the space-time patterns of drought episodes and their impacts on water availability is vitally important to support human activities and the maintenance of the ecosystems. In this respect, one of the ecosystems that has had the most impact is the Andean Lake District in the centre of Chile. The use of satellite images and the Normalized-Difference Water Index are useful tools for evaluating the inter-annual changes on the surface of the lakes and offer a reliable and fast way of comparing these changes with the available climate data. Almost all of the lakes in the Andes of central Chile analysed display an overall decreasing trend in terms of their surface area during the period 2010-2020. These decreases coincide with the principal regional climate trends, such as the reduction in precipitations and the increase in temperatures (Fuentealba et al., 2021) (Figure 9).

The changes reported here pose serious challenges for the water managers and local and regional agents. A good management of this resource is needed to combat climate change and the severe and current water crisis in the central area of Chile. These results can facilitate the management of this resource and improve our understanding of the future water availability in the region. This research addresses the changes in the entry of water to the lakes through the variations in the amount of annual precipitation in each location studied. However, to improve our knowledge of the dynamics of these lakes, other variables must be incorporated. For example, the surface and groundwater flows. Future research should also consider the incorporation of the bathymetrics of the lakes to better estimate the volume of water lost during the recent (and current) mega-drought.

3.2.3. More fires and more intense fires

The changes in fire activity within a context of high inter-annual variability, such as that prevailing in the Mediterranean climate of Chile, reveal certain anomalies that can persist for several seasons and even years. Given that the activity of the fires (according to the number of fires or area burnt) in the most Mediterranean areas is positively correlated with the autumn-winter precipitation but negatively with the spring-summer rainfall, the response of fires to a multiseasonal drought is not clear. The intense pluri-annual drought, which has affected the central and part of the central-southern area of Chile since 2010, provides some perspective in this respect. During the period 2010-2015, a rainfall deficit was observed that oscillated between 10% and 30% in almost all of the stations between Valparaíso and Araucanía. A preliminary report revealed an increase in the number of large fires (≥200 ha), and in the area affected was, respectively, 27% and 69% in the period 2010-2015 in comparison with 1990-2009 period (Center for Climate and Resilience Research [CR2], 2015). This indicates that the spring-summer sign (which leads to more fires) has compensated the autumn-winter sign (which leads to fewer fires). The overall warming during the last few decades throughout the interior valleys of central Chile (Vuille et al., 2015) has probably accentuated even more the trend of greater fire activity during the drought, given the significant relationship between the average maximum spring-summer temperature and the number of fires/area burnt (Urrutia-Jalabert et al., 2018).

The climate change projections indicate a trend towards a drier and warmer climate during the whole of the year in central and southern Chile, which could lead to a 40% reduction in precipitations and an increase in temperature of 4°C by the end of the twenty-first century (Fuenzalida et al., 2007). Within this context, prolonged droughts, such as the one occurring from 2010 should be more frequent in the near future (Boisier et al., 2016). Taking into account our findings related to the inter-annual variability and the evidence during the recent pluri-annual drought, we could expect an increase in the occurrence of and the area affected by the fires (González et al., 2011). In conclusion, the climate, which represents the average meteorological conditions, is undoubtedly related to the occurrence of fires in the study area, as shown in this article. However, in the scenario of climate change with which we are facing, it is important also to consider the extreme weather events that are currently more common. Furthermore, it is crucial to consider the dramatic changes in land use that have occurred due to the mass conversion of the native vegetation to pine forests and exotic eucalyptus trees. These changes have not only modified the type of fuel and its load but also the shaping of the landscape, creating large homogeneous areas of the same species, increasing the risk of the occurrence and propagation of catastrophic fires (González et al., 2011; Lara et al., 2016; Martínez-Harms et al., 2017). New legislation that imposes regulations regarding land use and promotes the restoration of the native forests to create more heterogeneous landscapes would reduce the propagation of fires caused by humans, and the associated economic, social and environmental losses. Furthermore, active education, public awareness-raising programmes and a stricter legislation that imposes greater sanctions on those who start fires (intentionally or due to negligence) would reduce the incidence of fires caused by humans. The effects of climate change on fires will ultimately depend on how climate combines with human actions. Therefore, the national environmental policies should consider the expected behavior of fires within a scenario of climate change to help reduce the risk of forest fires (Urrutia-Jalabert et al., 2018).

4. Discussion and conclusions

The results of the studies carried out by the authors and those consulted by other authors confirm that Mediterranean climate areas in Europe and South America are already experiencing significant alterations in the principal climate elements. Temperatures and precipitations display changes that respond, on the one hand, to global processes but also show alterations concerning regional mechanisms (marine waters, land uses). The temperatures are experiencing an increasing trend in the two areas of study analysed. However, the higher minimum temperatures have become a factor of regional thermal differentiation on the Spanish Mediterranean coast, given that the number of tropical nights has risen and the average temperature of warm nights is also displaying an increasing trend. This generalised warming is consistent with the trends of most of the indices related to temperature, not only in our study area but also in the rest of the Mediterranean basin (Miró et al., 2006; Xoplaki et al., 2006; Hertig et al., 2010; Efthymiadis et al., 2011). Furthermore, the projected changes indicate that this trend will continue with different magnitudes depending on the climate change scenario considered (Barrera-Escoda et al., 2014; Zittis et al., 2016). Tropical night (TN) frequency and persistence have increased over time with a major influence of sea surface temperature (SST), which is weak when considering the temporal evolution of long duration events. TN frequency showed a clear dependence on the coastline, as did TN trends, which also exhibited an especially strong coastal pattern at the southern part of the Spanish Mediterranean coastline. The atmospheric mechanisms behind the increasing frequency of this phenomenon are both large and synoptic in scale (Sánchez-Lorenzo et al., 2011). In the Western Mediterranean region, some circulation types transport towards Europe air masses from the north Atlantic, mostly in summer, when the Iberian thermal low, linked to a positive temperature anomaly, appears (Michaelides et al., 2018; Santos et al. 2015). The increase of these overnight warm episodes has especially been proven over the Mediterranean coast, where the increase has been greater than other areas. The regions of Valencia and Murcia, in the central area of the Spanish Mediterranean coast, have experienced a significant rise in TN over the last three decades. The causes are related to the global increase in temperatures due to the climate change process. Still, TNs have also acquired unique characteristics in this area due to the warming of sea surface temperatures of the central area of the Western Mediterranean basin (maritime sectors of Algiers and Gulf of Valencia). The increase of TNs in this Mediterranean sector spawns a loss of nocturnal thermal comfort, acting as a regional factor to a potential reduction of tourism competitiveness, which is added to the long-term climate projections already made (Ciscar et al., 2018; Greiving 2011). Together, these reasons have forced policy makers to look for short-term adaptation solutions with a high cost of energy (i.e. air conditioning in housing and hotels), which, in the future, will be related to the building and urban layout design to include "coolness islands" (i.e. green areas and green infrastructure) in the planning processes.

Meanwhile, precipitations are experiencing changes, although with different sizes and trends. On the Spanish Mediterranean coast, the general trend is an incipient decrease in precipitations, but there are some territories (south of the province of Valencia and the north of Alicante) that have been displaying an increase in precipitations in recent decades. What can be confirmed is that the "way" it rains is changing. The rainfall is more intense in the Spanish Mediterranean areas, which seems to be clearly related to the warming experienced by the waters of the Mediterranean Sea (Pastor et al., 2017) and the greater mobilization of energy in the instability processes (Tamayo Cardona & Núñez Mora, 2020) (Table 2).

Atmospheric “cut off low” configurations are increasing their presence in Mediterranean latitudes, which generates an increase in the risk factor with respect to intense and torrential rainfall episodes. Miró et al. (2022) indicate that these episodes show that a significant number of the torrential rainfall situations were related to cut-off-low configurations, as determined in the previous work of Muñoz, Schultz & Vaughan (2020), which highlights that these kinds of situations have had an increased frequency of 20% in recent years. In this warming context, a rise in SSTs in the Western Mediterranean is expected, increasing moisture inputs under advection trajectories over this area (as detected in this study) that may lead to an increase in convective precipitation (Llasat et al., 2021). This has also been detected in the eastern part of the Western Mediterranean Basin. This coincides with the higher frequency of these events in the autumn months (September–November), when the SSTs in the Mediterranean are at their highest. Water vapour transport seems to be a significant factor in the occurrence of extreme rainfall events when the moisture trajectories originate in the Western Mediterranean, an area with high SSTs, meaning a greater moisture supply. Meanwhile, the seasonality analysis reveals greater losses in precipitation are projected for spring and summer on the Spanish Mediterranean coast (Miró et al., 2021). In the two Mediterranean climate areas analysed, we can observe a trend towards prolonged drought periods. Finally, in both of these areas, forest fires show a clear increasing trend in size. The evolution of the number of fires shows a clear decreasing trend in the Spanish Mediterranean coast, but an increase in the size of the events (Úbeda et al., 2022). In both areas, future modelling indicates an increase in the annual fire risk period in relation to the rise in temperatures and the higher frequency of dry spells (Jones et al., 2022). In short, these territories are clearly manifesting alterations in climate elements and components of the natural environment (seawater, vegetation), whose future evolution bodes greater risk due to an increase in climate hazard within the context of global warming.

Table 2. Synthesis of changes registered in main climatic elements and in other environmental processes of the Mediterranean climate areas analyzed (Spain and Chile)

CLIMATE ELEMENT or ENVIRONMENTAL PROCESS	SPANISH MEDITERRANEAN COAST	MEDITERRANEAN CLIMATE REGION OF CHILE
Air Temperature	Increase in air temperature. Notable increase in night heat (tropical nights). Loss of thermal comfort in summer.	Increase in air temperature. Loss of thermal comfort due to an increase in minimum temperatures. Increase in maximum temperatures in stations further from the coast.
Rainfall	Regional differences in the annual rainfall record. General tendency to decrease in rainfall, but some regions have increased the annual amount registered (for example, south of Valencia and north of Alicante). Increased episodes of heavy rain	Significant reduction in rainfall. Effects on water supplies.
Atmospheric extreme events	Increase in the frequency of development of extraordinary range atmospheric episodes (heat waves, “levante” storms, heavy rains)	Increase in dry periods. Megadrought in Central Chile since 2010.
Forest fires	Increase in large-scale fires	Increase in the number of fires and their intensity.
Sea Surface temperature	Significant increase in sea surface temperature in the western Mediterranean basin (1.4º C, between 1982-2022). Effects on temperatures and precipitation.	Most significant El Niño effects on sea surface temperatures off the coast of Chile during years of negative SOI index.

Own elaboration

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