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Original research article

Climate change impacts on the tourism sector of the Spanish Mediterranean coast: Medium-term projections for a climate services tool

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HIGHLIGHTS

- Impact of climate change on tourism is studied with regional air-sea coupled models.
- Temperature and precipitation extremes will be more frequent in the area.
- Urgent adaptation measures are needed to ensure the sector's sustainability.
- A possible adaptation measure is the extension of the high season to spring/fall.
- Results here shown have been generated whilst creating a new climate service tool.

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ABSTRACT

The Mediterranean Sea is a climate change hotspot since it provides a magnified warming signal. Heavily populated areas (e.g., Spanish Mediterranean coasts) are vulnerable to negative socio-economic impacts. This is particularly important for climate-related economic sectors such as coastal tourism, the focus of this paper. To promote a sustainable development of these activities and provide key information to stakeholders, it is necessary to anticipate changes in climate. Thus, it is fundamental to use climate modelling tools which account for air-sea interactions, which largely determine the climate signal of the Mediterranean coasts. In this paper, a set of regional air-sea coupled climate model simulations from Med-CORDEX are used to (i) study the climatic conditions on the Spanish Mediterranean coasts in the next decade(s) and (ii) to assess the possibility of extending the coastal tourist season towards spring-fall. We show that climate conditions are getting warmer and drier in the area, especially in summer. Heat waves and heavy precipitation will become more frequent. Thermal discomfort will increase in summer and summer conditions are extending towards spring and fall. Our work remarks the urgent need of adaptation measures of the sector, including the extension of the high tourist season to spring-fall, especially in the long term. We make a special effort to compile a set of adaptation measures for stakeholders. This study is part of the project ECOAZUL-MED, which aims to create a climate service tool to optimize the management of relevant sectors of the blue economy in the Spanish Mediterranean coasts.

Practical implications

Climate change is causing important alterations in the main climatic elements in the coming decades and the Mediterranean region is one of the world areas with already evident effects of climate warming (Tuel and Eltahir, 2020). Coastal tourism has a great weight in the GDP of the Mediterranean countries and a great territorial imprint (Galeotti, 2020; Fosse, 2021). To promote a sustainable development of the coastal tourism sector it is urgent to provide stakeholders climate change information and recommendations for an effective adaptation. In the Mediterranean

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Table 1
Summary of the simulations used in this work. More information about the MEDATLAS initial conditions is found in Rixen et al. (2005).

INSTITUTE	CNRM	LMD	CMCC	AWI/ GERICS
Model characteristics				
RCSM name	CNRM-RCSM4	LMDZ-MED	COSMOMED	ROM
Driving GCM	CNMR-CM5	IPSL-CM5A-MR	CMCC-CM	MPI-ESM-LR
Med. Sea Model	NEMOMED8	NEMOMED8	NEMO-MFS	MPIOM
Ocean Res.	9–12 km	9–12 km	6–7 km	10–18 km
Num. of z-levels (ocean)	43	43	72	40
Atmosphere model	ALADIN-climate	LMDZ	CCLM	REMO
Atmosphere Res.	50 km	30 km	50 km	25 km
Coupling frequency	Daily	Daily	80 min	60 min
Numerical Simulations				
Spin up	130 years	40 years	25 years	56 years
Initial Conditions	MEDATALAS	MEDATLAS	MEDATLAS	MEDATLAS
CONTROL	1950–2005	1950–2005	1950–2005	1950–2005
RCP4.5	2006–2100	2006–2100	–	2006–2099
RCP8.5	2006–2100	2006–2100	2006–2099	2006–2099
References	Sevault et al. (2014)	L'Hévéder et al. (2013)	Cavicchia et al. (2015)	Sein et al. (2015)

region, where air-sea interactions determine to a large extent climate conditions, the use of air-sea coupled climate modelling tools is required. In this paper, the short and medium-term climate change in the Spanish Mediterranean coast has been analyzed using a set of high-resolution air-sea coupled regional climate model simulations from Med-CORDEX (Ruti et al., 2016; https://www.medcordex.eu/).

The aim of this novel analysis is (i) to gain insight into the climate conditions in the next decade(s) on the Spanish Mediterranean coast and (ii) to quantitatively assess the possibility of extending the coastal tourist season towards the months adjacent to summer. We assume the rcp (representative concentration pathways) 4.5 and rcp8.5 climate scenarios and focus on the 2025–2034 decade - although attention is given to the longer-term climate i.e., 2055–2064. Our results show a rise of the daily maximum 2-m air temperature (T2MAX) regardless of the season. T2MAX increases between 1 and 2 °C in 2025–2034 and up to 3–4 °C in 2055–2064. The number of days with heat wave conditions will increase in the future. In 2025–2034, precipitation will experience small changes. Both scenarios project, generally, drier conditions regardless of the season, especially in the rcp8.5. The decrease in summer precipitation will intensify in future decades. However, the % of days with high precipitation for 2025–2034 will increase between 2 and 4 % per season, approximately, in all scenarios. The fact that, on average, for 2025–2034, precipitation remains similar to the control but the frequency of days with heavy precipitation increases, aggravates the current situation.

Results obtained allow us to conclude that the current high tourist season in the region will undergo changes that affect its duration. These may imply a possible extension of the high tourist season towards late spring/early fall, the maintenance of the Easter holiday and the possibility of establishing a winter tourist season due to anticyclonic conditions, although care should be taken with heavy precipitation, which is projected to increase in frequency in all seasons. These changes relate to the temperature rise of both the air and the sea water. In the Mediterranean basin, the warming in marine waters conditions the functioning of temperatures (loss of thermal comfort) and precipitation (more days with heavy precipitation). Summer months will lose thermal comfort; The change in temperature during the months of April-May and September-October will make it possible to enjoy the beach more regularly, favoring the extension of the tourist season. Changes analyzed in this paper point the need to urgently promote mitigation measures (change in the energy model) and, above all, adaptation (López Palomeque et al., 2022).

Administrations and tourist private companies should carry out accelerated changes in the tourist destinations e.g., sustainable planning, promotion of green areas, reinforcement of public fountains, construction of sustainable drainage systems to handle intense precipitation. Tourism companies must improve their facilities (hotels, apartments) and promote energy and water savings (Olcina Cantos et al., 2021). Public administration must favor these changes by approving regulations and plans for the adaptation of the sector to climate change (MITERD, 2020). In various territories of the study area, regional and local governments are developing actions in this regard. Changes in the summer climatic conditions analyzed in this paper and the probable extension of the high tourist season in the area of study, will also require medium-term changes in labor regulations to allow vacation periods in other months other than July and August and, likewise, the adaptation of the school calendar (Woetzel et al., 2020; Agulles et al., 2022). The insights from this work, which offer relevant information for stakeholders, allow us to propose that a similar analysis could be performed in other Mediterranean regions in which the blue economy is key. Therefore, a similar analysis could be potentially transferred and/or scaled-up to other regions.

This study has been conducted in the context of the project ECOAZUL-MED, which aims to develop a climate service tool that provides climate information for the next decades for the Spanish Mediterranean coasts. This will serve stakeholders to optimize the management of relevant sectors of the blue economy in the area using, for the first time, air-sea coupled simulations from Med-CORDEX.

References PI chapter

Agulles, M.; Melo-Aguilar, C., Jordà, G., 2022. Risk of loss of tourism attractiveness in the Western Mediterranean under climate change. Front. Clim., 4, 1019892. https://https://doi.org/10.3389/fclim.2022.1019892.

Fosse, J., 2021. The future of Mediterranean tourism in a (post) covid world, Zenodo, 1–13. https://doi.org/10.5281/zenodo.4616983.

Galeotti, M., 2020. The economic impacts of climate change in the Mediterranean. IEMed: Mediterranean yearbook, 46–54. Available on: https://www.iemed.org/wp-content/uploads/2021/01/The-Economic-Impacts-of-Climate-Change-in-the-Mediterranean.pdf.

López Palomeque, F., Vera Rebollo, J. F., Torres Delgado, A., Ivars Baidal, J.A., 2022. El turismo, ¿fin de época? Desafíos de España como destino turístico en un nuevo escenario. Valencia. Publicaciones de la Universitat de València.

Ministerio de Transición Ecológica y Reto Demográfico, MITERD, 2020. Climate Change Adaptation Plan, 2021–2030. Available on: https://www.miteco.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/pnacc-2021–2030-en_tcm30-530300.pdf.

Olcina Cantos, J., Baños Castiñeira, C. J., Rico Amorós, A.M., 2021. Medidas de adaptación al riesgo de sequía en el sector hotelero de Benidorm (Alicante, España). Revista de Geografía Norte Grande, 65, 129–153. https://doi.org/10.4067/S0718-34022016000300007.

Ruti, P., Somot, S., Giorgi, F., Dubois C, Flaounas, E., Obermann, A., Dell'Aquila, A., Pisacane, G., Harzallah, A., Lombardi, E., et al. 2016. MED-CORDEX initiative for Mediterranean climate studies, BAMS, 97, 1187–1208. https://doi.org/10.1175.Tech. rep., BAMS-D-14–00176.1.

Tuel, A., Elthair, E.A.B, 2020. Why is the Mediterranean a Climate

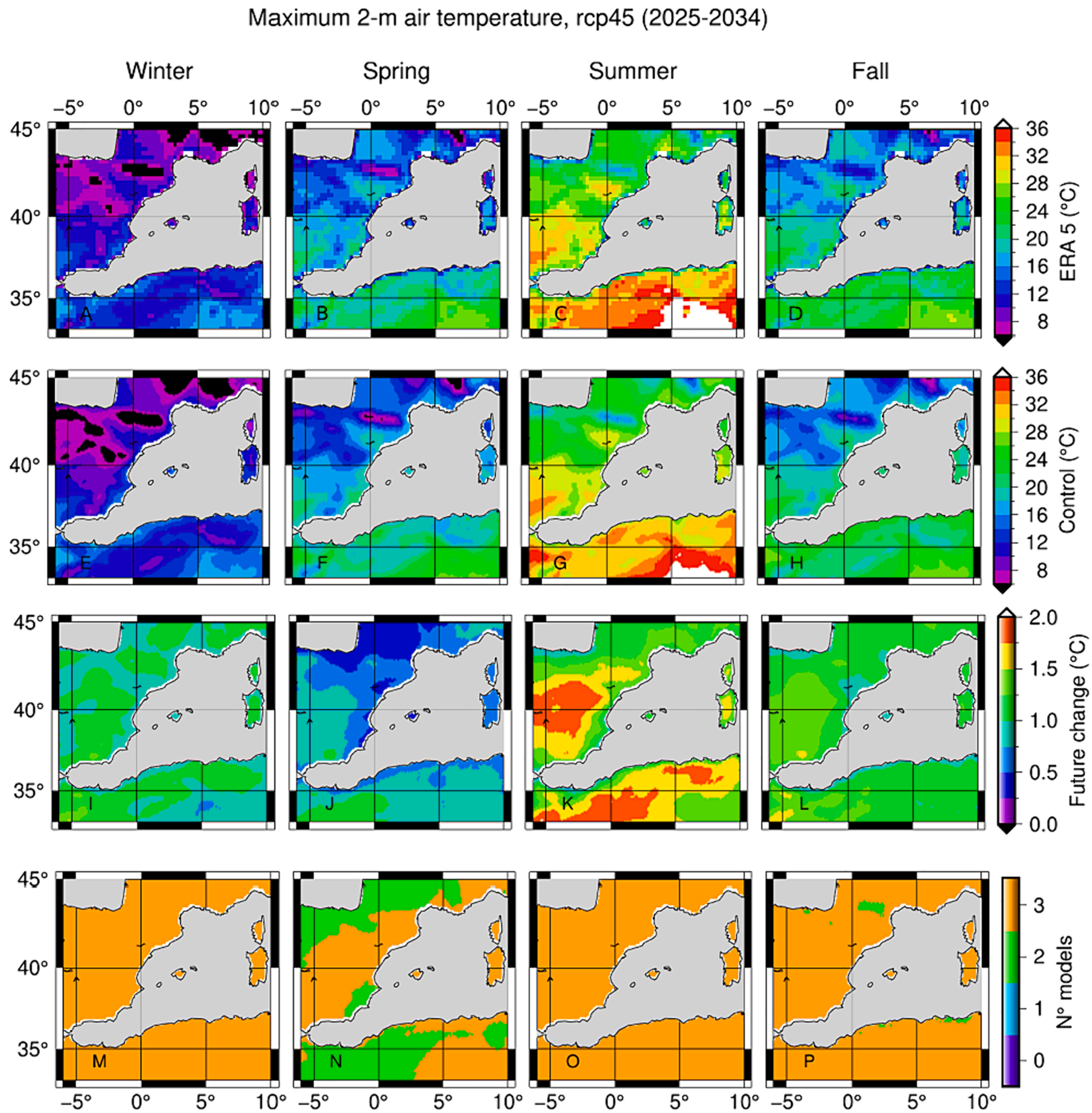

Fig. 1. First row: seasonal, ensemble mean of the daily T2MAX (°C) in the control (1976–2005) in ERA-5. Second row: as for the first row, but computed with the model ensemble. Third row: future decadal change (2025–2034) in the daily T2MAX with respect to the control assuming the rcp4.5 scenario. A positive sign indicates a temperature rise. Fourth row: number of the ensemble models (0–3) that project a future increase in the daily T2MAX. In this figure, and elsewhere in the text: Winter: December, January, February. Spring: March, April, May. Summer: June, July, August. Fall: September, October, November.

Change Hot Spot?, J. Clim. 33(14), 5829–5843. https://doi.org/10.1175/JCLI-D-19-0910.1.

Woetzel, J., Pinner, D., Samandari, H., Engel, H., Krishan, M., Vasmel, M., von der Leyen, J., 2020. A Mediterranean basin without a Mediterranean climate? Case study. McKinsey Global Institute, 1–24. Available on: https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/a%20mediterranean%20basin%20without%20a%20mediterranean%20climate/a-mediterranean-basin-without-a-mediterranean-climate.pd.

1. Introduction

The Mediterranean region is considered a climate change hotspot (Tuel and Eltahir, 2020), frequently affected by high-impact weather phenomena e.g., heat waves, droughts, heavy precipitation, flash floods (Scoccimarro et al., 2016; Rainaud et al., 2017; Khodayar et al., 2021; Khodayar and Paredes-Fortuny, 2023). In the coming decades, climate models project an increase in the frequency and/or intensity of these extreme events (Darmaraki et al., 2019; IPCC, 2019; Molina et al., 2020; Gutiérrez-Fernández et al., 2021; Miró et al., 2021). This makes the heavily populated Mediterranean coasts especially vulnerable to future climate conditions, hence to extremely damaging socio-economic impacts (e.g., Giorgi, 2006; Peterson et al., 2008). These economic damages strongly affect climate-exposed sectors e.g., fishery, energy, and tourism, with adverse effects on gender and social equity (IPCC, 2023). Blue economy, defined as those activities associated with seas, oceans and coasts, key for the Mediterranean region, is particularly vulnerable. This includes coastal tourism, fisheries or aquaculture. In the region,

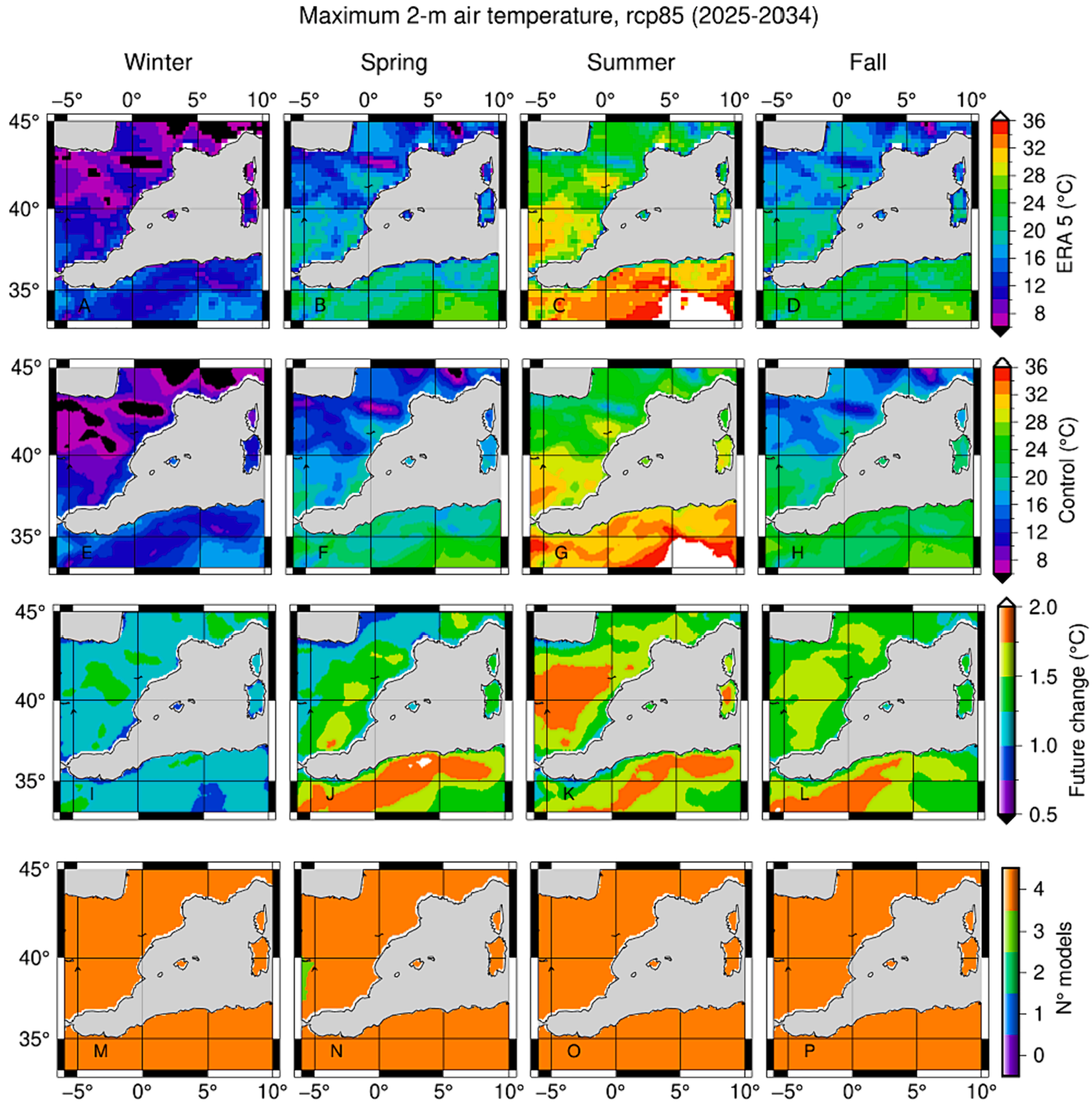

Fig. 2. As Fig. 1, but computed for the rcp8.5 scenario. Please, note that in the rcp8.5 scenario the ensemble is always composed by 4 models (not 3, as in the rcp4.5).

blue economy provides opportunities for growth, employment and investments. A strategic view for a sustainable development, policies and actions to promote blue economy are essential in the context of climate change.

Coastal areas are attractive for tourism, which is an essential component of the economic backbone of the Mediterranean countries, e. g., Spain. Tourism was about 12.4 % of the Spanish GDP in 2019 (INE, 2020), with a more important weight over coastal areas. The favorable conditions for coastal tourism in the Mediterranean region rely on mild climate conditions and the high quality of the beaches. Temperature is a crucial factor choosing a touristic destination since it affects, among others, thermal comfort. The possibility to perform recreational activities outdoors significantly affects the destination selected (see e.g., Salata et al., 2017; Olcina Cantos and Miró Pérez, 2017). Under climate change, the Mediterranean region suffers a temperature increase which is more intense than in the rest of the globe (MedECC, 2020). The region is frequently affected by heat waves (Khodayar and Paredes-Fortuny, 2023), the severity, duration, intensity and frequency of which, are projected to rise (Lorenzo et al., 2021). These progressive changes may have negative effects on coastal tourism. In summer, when the warmest temperatures occur, tourists may prefer destinations with a softer climate.

Parallel to this, every year, heavy precipitation events (HPEs) cause innumerable damages to coastal areas (e.g., Stampoulis et al., 2013). HPEs, are a recurrent phenomena in the Western Mediterranean, producing immense costly and deadly consequences in the region (Ferretti et al., 2000; Delrieu et al., 2005; Nuissier et al., 2011; Buzzi et al., 2014; Khodayar et al., 2022) during fall (Insua-Costa et al., 2021). An extremization of HPEs has been observed in recent decades in the region (Benetó and Khodayar, 2023) and a further intensification is projected for the future (e.g., Scoccimarro et al., 2016; Colmet-Daage et al., 2018; Tramblay and Samuel, 2018). One of the reasons behind this is the warming of the Mediterranean Sea during late summer and early fall (Pastor et al., 2001, 2015, 2018, 2020), which acts as a heat and moisture reservoir from where low-level jets transport moisture and instability towards the HPEs areas (Khodayar et al., 2018).

Under increasingly adverse conditions, the sector should urgently adapt to the future climate conditions, taking effective adaptation

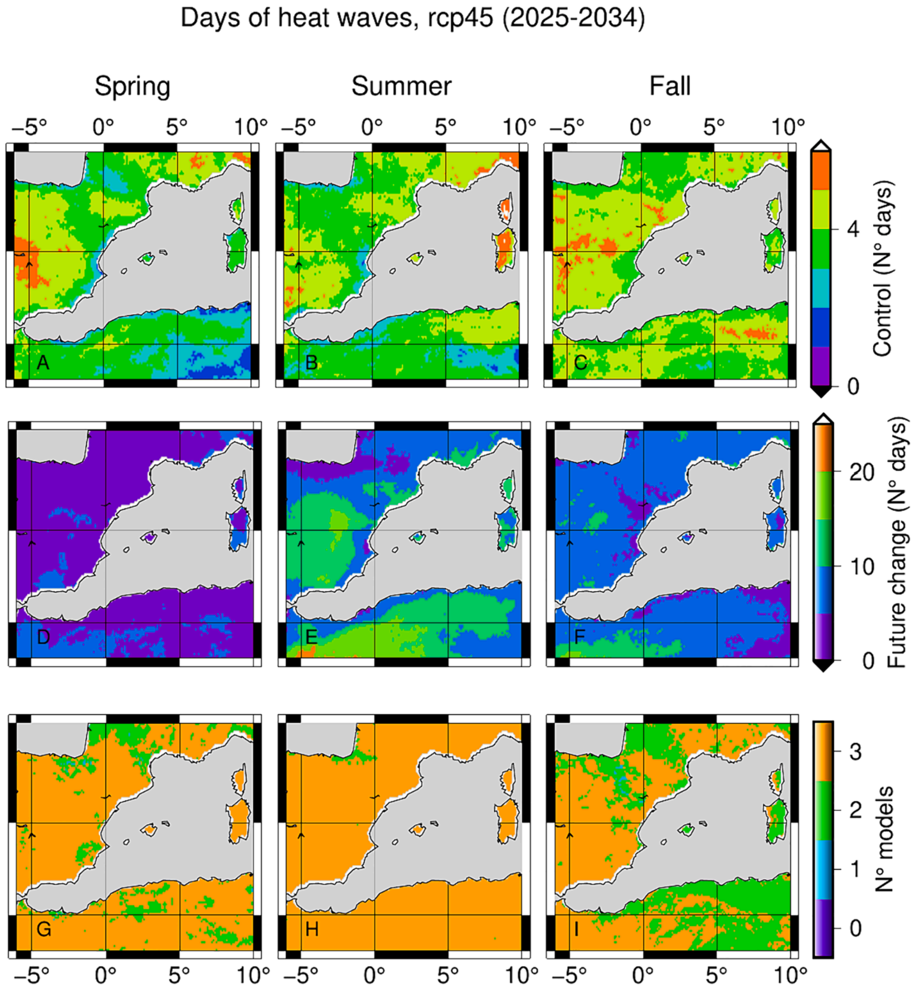

Fig. 3. First row: seasonal, ensemble mean number of warm spell days per season computed with the HWFI index for the control (1976–2005). Second row: future decadal change (2025–2034) in the number of warm spell days in the rcp4.5. A positive sign indicates an increase in the number of days with warm spells. Third row: number of ensemble models that project an increase in the warm spell days.

measures based on climate projections to ensure its sustainable development. An adaptation possibility is the extension of the high tourist season, presently centered on summertime, towards the adjacent months (Lam-González et al., 2019). In the Iberian Peninsula, the so-called "extended season" has started being considered among the tourist sector (from May to September). However, this may not be plausible if, e.g., HPEs become more frequent in these months. Whilst future climate information is essential for adaptation, solid scientific information regarding the impact of climate change on the blue economy, and in particular, coastal tourism, is scarce (e.g., Arabadzhyan et al., 2021). The only tool available to obtain information about future scenarios are climate models that allow us to perform future climate projections. For regional studies, such as this case, it is preferable to use regional climate models at high resolution rather than global climate models to accurately reproduce the oceanic and atmospheric signal. Also, for Mediterranean coastal areas, where air-sea interactions play a major role, the use of air-sea coupled simulations, which provide a physically consistent signal in both components of the climate system and better represent their interactions and their feedbacks, is essential. Therefore, in this study we use an ensemble of regional atmosphere–ocean coupled climate model simulations from Med-CORDEX (Ruti et al., 2016; https://www.medcordex.eu/), which has been used in former works (e.g., Darmaraki et al., 2019), assuming the rcp (representative concentration pathways) 8.5 and rcp4.5 IPCC radiative scenarios to raise awareness in stakeholders and provide them recommendations for adaptation in the Spanish Mediterranean coasts. Recommendations are based on a former comprehensive scientific analysis.

This work has been produced in the context of the project ECOAZUL-MED, which aims to develop a climate service tool with climate information for the next decades for the Spanish Mediterranean coasts. This information will be public and will serve stakeholders to optimize the management of key sectors of the blue economy in the area using, for the first time, air-sea coupled simulations from Med-CORDEX. This work is part of the Med-CORDEX initiative (https://www.medcordex.eu) supported by the HyMeX programme (https://www.hymex.org).

In Section 2, the Methodology is presented. In Section 3, we show the control, near future changes and robustness of the results obtained for the maximum 2-m air temperature, heat waves, precipitation and heavy precipitation. In Section 4, we discuss the possible extension of the high season towards spring and fall, and we provide policy recommendations for stakeholders. Conclusions are presented in Section 5.

2. Methodology

2.1. Model simulations

We use an ensemble of four coupled ocean–atmosphere regional climate system models (RCSM's). Data are provided by four different research institutes that participate in Med-CORDEX (see Table 1). Simulations include data between 1950 and 2005 for the historical experiments and from 2006 to 2100 under the rcp8.5 and rcp4.5 scenarios. The

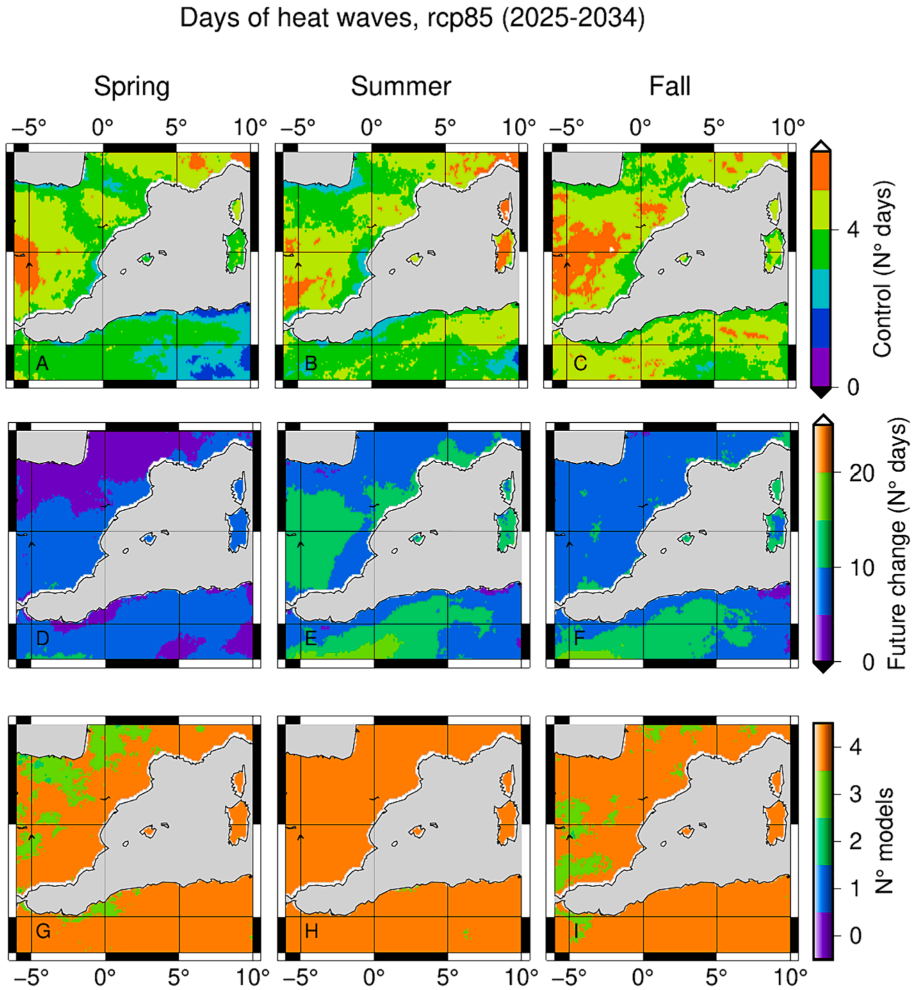

Fig. 4. As Fig. 3, but for the rcp8.5.

rcp4.5 is a stabilization scenario and thus expected to be the most realistic one. The rcp8.5 has the highest radiative forcing and provides an amplified climate change signal. All models use boundary conditions from the Coupled Model Intercomparison Project 5, CMIP5 (https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip5) and the results from these simulations have been validated in previous works (see e.g., Darmaraki et al., 2019 and Table 1). In our analysis, we define a 30-year control time period that expands from 1976 to 2005 and the near future spanning from 2025 to 2034.

2.2. Post-process of climate data

Model data are interpolated from their original grids with a varying horizontal resolution (Table 1), into a common regular grid of a slightly higher horizontal resolution (circa 10 km). This allows us to have a common grid and to operate with data from the ensemble, as well as to achieve an appropriate resolution to provide climate services (e.g., de la Hoz et al., 2018). For the interpolation we use the Climate Data operators package (CDO, https://code.mpimet.mpg.de/projects/cdo). The remapdis operator uses 4 source values by default to interpolate the destination value. Thus, remapdis is the implementation of Inverse Distance Weighting method (IDW) with 4 source points and the power set to 1. Regridding can have an impact on the statistical properties of precipitation and should be used with caution (Abdelmoaty et al., 2021). However, the use of models with different resolutions and the need to provide users data with higher resolution makes it convenient the use of the IDW, which offers a good and fast performance with results comparable to other interpolation methods. This method has been widely used to interpolate climate data at different temporal and spatial scales (Stahl et al., 2006). In Hossain et al. (2021), the performance of eight interpolation methods (bi-linear, nearest neighbor, distance weighted average, first-order conservative, second order conservative and bi-cubic interpolation) for re-gridding of CMIP5 data to a catchment scale (0.05°) was assessed using CDO. In Hossain et al. (2021) the authors conclude that no significant differences were found between the results obtained with the different interpolation methods when compared at observed stations. Also, Yang et al. (2015) compared four methods with the model generated daily precipitation data and reported that IDW performed slightly better than spline, kriging and ANUDEM. Along this line, Dirks et al. (1998) did not find any advantage in using kriging over IDW. For the validation of the capability of the ensemble to reproduce the control time period maximum 2-m air temperature (T2MAX) and daily precipitation we use the high-resolution ERA-5 reanalysis (see description in Hersbach et al., 2020). The domain considered includes the area of interest, the Spanish Mediterranean coast and Western Mediterranean Sea (from 10°E until the Strait of Gibraltar, approximately). The possibility of model outliers within the RCSM's for the studied variables i.e., T2MAX and precipitation, has been ruled out (see Supplement).

For the definition of heat waves we use the Warm Spell Days Index, HWFI (Almazroui et al., 2021), defined as the number of days with at least 6 consecutive days in which T2MAX exceeds the 90th percentile of the T2MAX in a 5-days moving window during the control (1976–2005). Heavy precipitation conditions are defined as single daily events with a

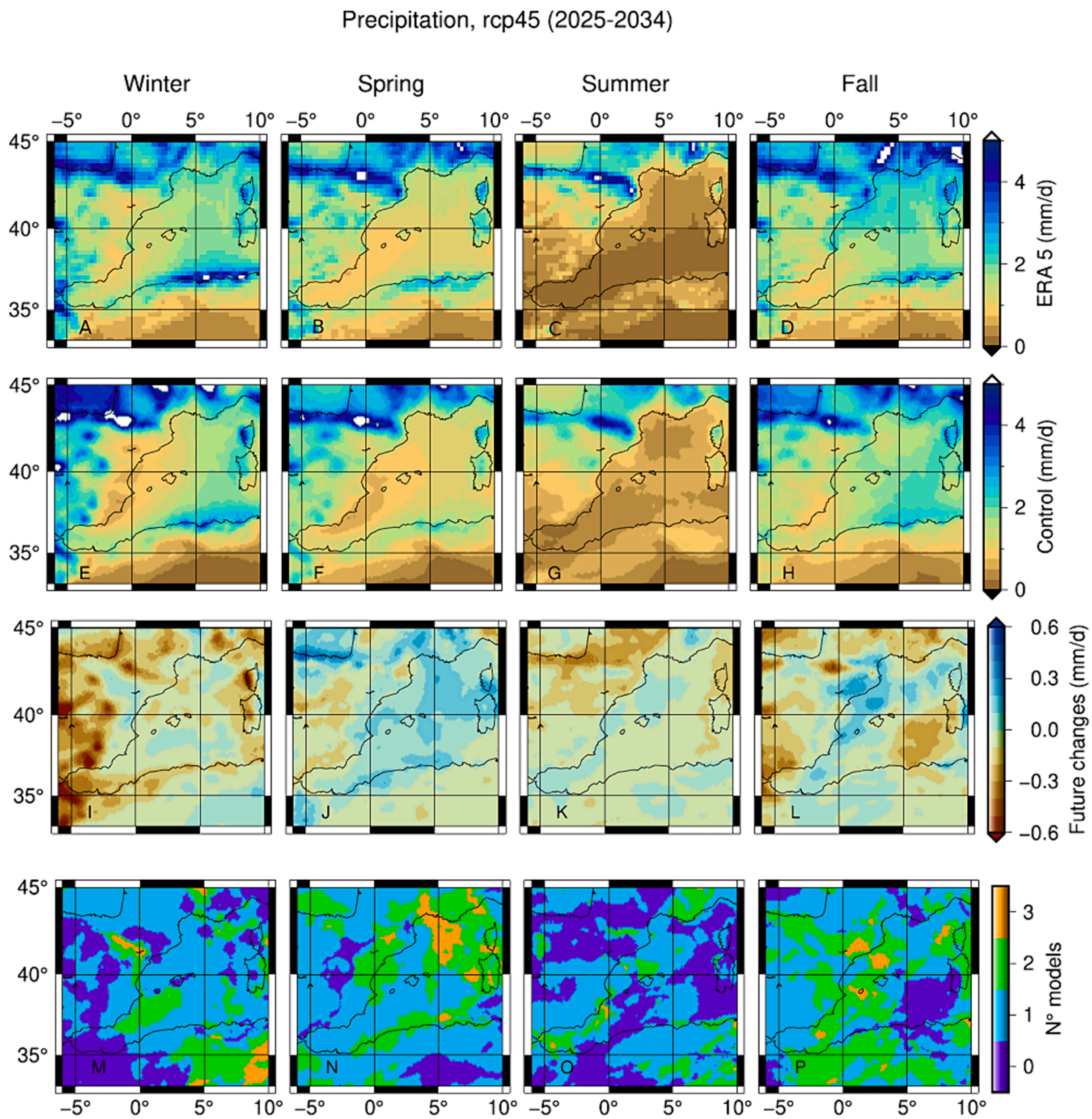

Fig. 5. First row: seasonal, ensemble mean of the daily precipitation (mm/day) in the control (1976–2005) in ERA-5. Second row: as for the first row, but computed with the model ensemble. Third row: future decadal change (2025–2034) in daily precipitation (mm/day) with respect to the control assuming the rcp4.5. A positive sign indicates wettening. Fourth row: number of ensemble models that project a precipitation increase.

precipitation amount greater than the daily 90th percentile computed for the control (see e.g., Kostopoulou and Jones, 2005). In our work we also study thresholds which set the conditions for the beginning of coastal tourism (Martínez-Ibarra et al., 2019). On the one hand, the number of days with summer conditions, defined as those in which T2MAX reaches, at least, 25 °C. On the other hand, the number of days in which the sea-surface temperature (SST) attains, at least, 18 °C, which corresponds with the SST from which thermal conditions for swimming occur. In the Discussion, a set of adaptation measures is proposed based on an extensive literature review and our model results.

3. Results

Since temperature is a crucial factor to choose a touristic destination, Section 3.1 is dedicated to the study of future changes of T2MAX and the number of days of heat waves (see Methodology). In Section 3.2, changes in the days with precipitation and heavy precipitation are examined. These are important because precipitation neglects the opportunities to perform outdoor activities and HPEs can severely damage coastal areas with a reduction of the affluence of tourists due to the damage to civil and tourist infrastructures.

3.1. Future changes in temperature

3.1.1. Maximum 2-m air temperature

We first analyze the seasonal patterns of T2MAX in the Spanish Mediterranean coast. We focus on the control (1976–2005), the near future anomalies (2025–2034) and the robustness of the modeled changes for the rcp4.5 and rcp8.5. For the control, T2MAX represented by the model ensemble shows, in line with ERA5 (Hersbach et al., 2020), the combined effect of latitude and topography (Fig. 1A-H). Furthermore, models are able to capture the seasonal variability derived from

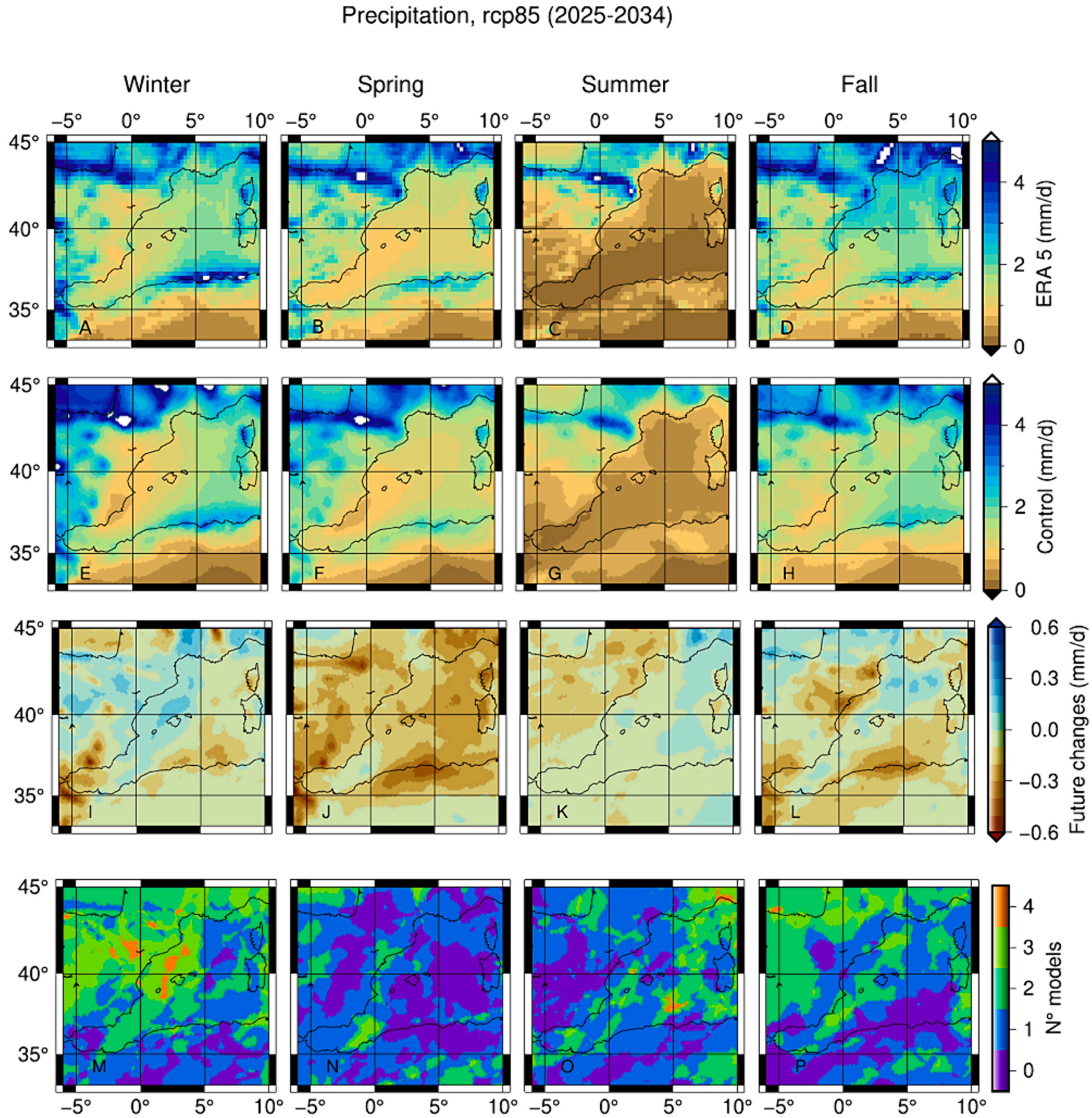

Fig. 6. As for Fig. 5, but for the rcp8.5.

ERA5 in a quantitative and qualitative way. Thus, the model ensemble adequately represents T2MAX for the control.

In the rcp4.5 (Fig. 1I-L), in all seasons, T2MAX increases between 1 and 2 °C, especially in summer. In this season, the temperature rise ranges between 1 and 1.5 °C, approximately. In all seasons the projected increase is robust, since it is common to all the models from the ensemble (3 in total, see Table 1; Fig. 1M-P), with the exception of spring, where in the SE of the peninsula this rise is shared by 2 of the 3 ensemble models. Under the rcp8.5 (Fig. 2), as expected - since this is more radiative than the rcp4.5 case, T2MAX increases more sharply, this being also greater in summer (Fig. 2I-L). Again, all ensemble models (4 in total, see Table 1 from the Methodology) project a temperature rise (Fig. 2M-P).

We conclude that in 2025–2034, the rise in T2MAX varies between 1 and 2 °C in all seasons, approximately. This will lead to warmer (more unpleasant) summer temperatures which may reduce the thermal comfort and even have a negative impact on health, coinciding with the current tourist high season. Whilst the increase is not extreme, the increase in T2MAX is sustained and robust for the coming years. In the next decades, this rise will become of a greater magnitude, especially in summer, reaching up to 3 °C in the rcp4.5 and close to 4 °C in the rcp8.5 (see Figure S1 and Figure S2 of the Supplement) in 2055–2064. An enhanced future summer temperature increase has also been found in e.g., Carvalho et al. (2021) using EURO-CORDEX projections. Our findings show a subtle increase of T2MAX in 2025–2034, but that will be sharper with time, especially in summer regardless of the scenario. This increase may not have a direct impact on the tourist sector in the short term, but may affect the affluence of tourists in the medium term due to thermal discomfort. According to Amelung et al. (2007), by 2080's the the most comfortable regions for summer tourism in the northern hemisphere will shift from the Mediterranean coastlines of Spain, France, Italy, Greece, and Turkey to include northern France, southern parts of the United Kingdom, Germany, The Netherlands, and southern Scandinavia.

3.1.2. Heat waves

We focus on the number of days with heat wave conditions (in which

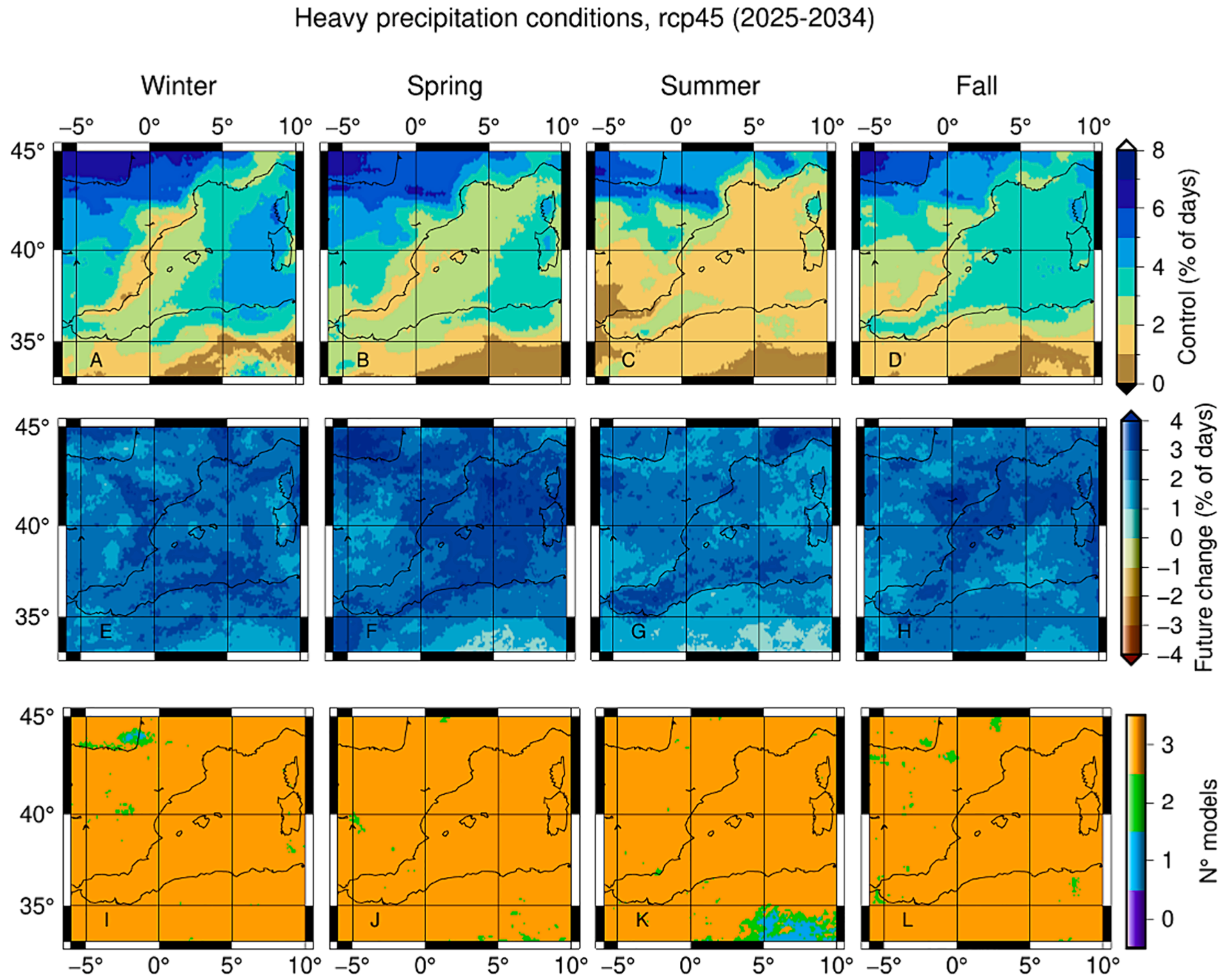

Fig. 7. First row: seasonal, ensemble mean % of days with high precipitation for the control (1976–2005). Second row: future decadal change (2025–2034) in the % of days with high precipitation relative to the control period assuming the rcp4.5 scenario. Third row: number ensemble models that project an increase in the days with high precipitation.

T2MAX meets the HWFI criteria) in the control, the changes in 2025–2034 and the robustness of the results for the rcp4.5 (Fig. 3) and rcp8.5 (Fig. 4) scenarios. We concentrate on summer, the current high tourist season, and the months adjacent to it, since they are potential candidates for coastal tourism.

In Figs. 3 and 4, the multi-annual mean number of days in which the HWFI criteria is met (T2MAX above the 90th percentile of temperature during at least 6 consecutive days) is shown. A value below 6 indicates that in some years of the period there are not heat waves. For the control, in the Spanish Mediterranean coast, the number of days with heat wave conditions does not exceed 6 days regardless of the season (Fig. 3A-C). Heat waves also occur in spring and fall because we do not take a fixed temperature threshold, but we use the 90th percentile. In 2025–2034, the number of days in which heat waves occur goes up. The increase takes place in all the studied seasons but is sharper in summer, when the number of days with heat wave conditions can reach up to 15 in the Spanish Mediterranean coasts. In the studied seasons, the greater frequency of warm spells is a robust feature. Results for this scenario also apply to the rcp8.5 case (Fig. 4), in which the increase in the frequency of heat waves with respect to the control has even the same magnitude. This increment in the days with heat wave conditions is robust and sustained over time, reaching in the longer term e.g., 2055–2064, up to 25 in the rcp4.5 and 40 in the rcp8.5 scenarios, respectively (Figure S3 and Figure S4 of the Supplement). This pronounced and robust increment in the days with heat wave conditions would enhance the thermal discomfort and may have harmful potential due to heat related mortality (Vicedo-Cabrera et al., 2021; Zhao et al., 2021). Some case studies have analyzed the tourist policy preferences to ameliorate the impact of these events and these include early warning systems and information for vulnerable people, as well as proper cooling systems in public places (León et al., 2021).

3.2. Future changes in precipitation

3.2.1. Accumulated daily precipitation

We analyze the ability of the model ensemble to reproduce the climatological seasonal signal from ERA-5 for the control, the decadal anomalies for 2025–2034 and the robustness of the results. Fig. 5A-H shows that the model ensemble is capable of quantitatively and qualitatively reproducing the seasonal patterns of precipitation from ERA-5. Models capture the effect of topography on precipitation, with the highest values in the mountain ranges, e.g., the Pyrenees, where values close to 4 mm/day are reached in all seasons. For the control, in line with ERA-5, the models show low precipitation in the Western Mediterranean Sea and the eastern Iberian Peninsula. The highest values take place in winter and fall, while precipitation is scarce in summer. In winter there is a gradient from west to east, with the lowest values on the east of the peninsula, which generally do not exceed 1 mm/day. In summer, precipitation is close to 0 mm/day in the south of the domain, especially over the sea.

Turning to precipitation changes for 2025–2034 in winter, following the rcp4.5 scenario, they are small, with a magnitude that usually does

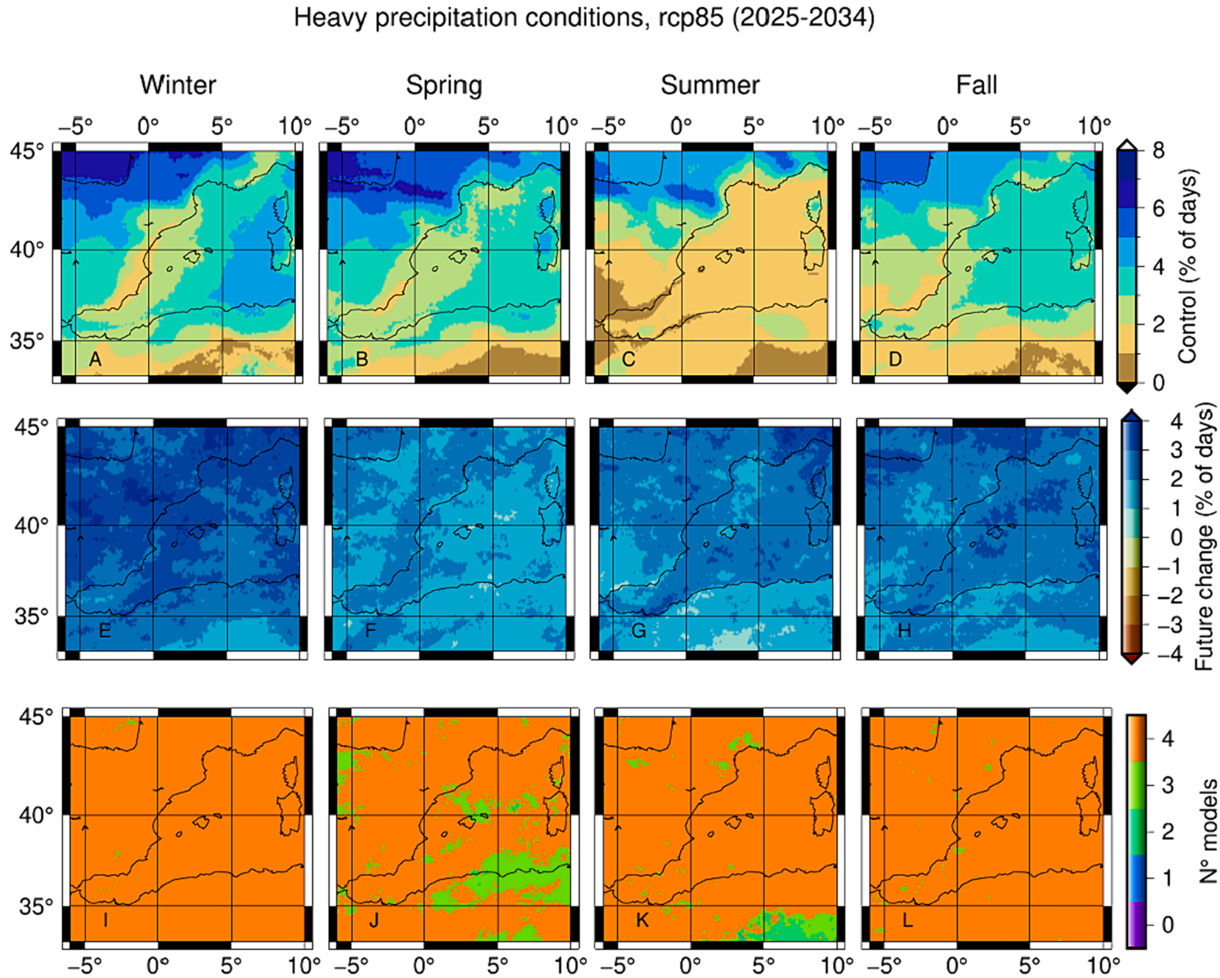

Fig. 8. As for Fig. 7, but for the rcp8.5.

not exceed 0.3 mm/day (Fig. 5I-L). There is a general precipitation decrease over the sea and in most of the Spanish Mediterranean coast. This is pronounced in the SE of the peninsula, ranging between 0.4 and 0.6 mm/day. The reduction in this area is robust, since all models project a reduction in precipitation (see seasonal robustness of results in Fig. 5M-P). In spring, over the sea and most of the coastline, there is a small wettening that does not exceed 0.1–0.2 mm/day. In areas where the increase is around 0.2 mm/day, changes are generally more robust. In the SE of the peninsula there is a decrease in precipitation of up to 0.2 mm/day. Again, these changes are robust. In summer, changes are of a small magnitude and precipitation decreases approximately 0.1 mm/day in coastal areas. In fall, precipitation increases in coastal areas in the northern Mediterranean portion of the peninsula and decreases in the southern portion, in both cases, the magnitude is up to 0.3 mm/day. As in winter, the most pronounced decrease (greater than 0.3 mm/day) occurs in the SE of the peninsula.

In Fig. 6I-L, as in the rcp4.5, under the rcp8.5, changes in winter precipitation are small, except in the SE of the peninsula, where the decrease is more pronounced and robust (Fig. 6M-P). In spring, unlike in the rcp4.5, there is a general decrease that oscillates between 0.1 and 0.3 mm/day over the sea, which is also quite robust, since it is supported by all (or most of) the models. In summer, again, changes are close to 0, with a slight decreasing trend. In coastal areas the decrease is around 0.1–0.2 mm/day. In fall, there is a general decrease in coastal areas and this is more pronounced in the SE and NE of the peninsula, with changes of magnitude close to or greater than 0.3 mm/day. These changes are robust and supported by most of the ensemble models.

3.2.2. *Heavy precipitation*

Fig. 7A-D shows that in the control, the greatest number of days with heavy precipitation in the area of study occur in winter and fall, and these are less frequent in spring and summer. In 2025–2034, models project a general increase of between 2 and 4% of days with heavy precipitation, approximately, in all seasons (Fig. 7E-H). This increase is supported by all the models in the ensemble (Fig. 7I-L). This is greater in winter, spring and fall, with summer being the season with the lowest increase.

Under the rcp8.5 (Fig. 8E-H) there is an increase of a similar magnitude compared to the rcp4.5 case, with an increase that oscillates between approximately 2 and 4 % of the days of heavy precipitation per season. Along with the rcp4.5, changes are robust (Fig. 8I-L) and in winter there is a more pronounced increase than in other seasons. Thus, all models project an increase in the % of days with heavy precipitation for this decade, regardless of the season or scenario. This increase oscillates between 2 and 4 % of days for each season (Figs. 7 and 8). In both scenarios, the change is particularly intense and widespread in winter, with the rest of the seasons presenting a more variable magnitude. This trend is also visible in the coming decades. The fact that in general, on average, precipitation remains similar or slightly reduced relative to the control (not shown), but the frequency of days with heavy precipitation increases, aggravates the current situation. The increase in extreme rainfall would potentially damage coastal infrastructures and resources, causing possible socio-economic damage, especially in fall and winter.

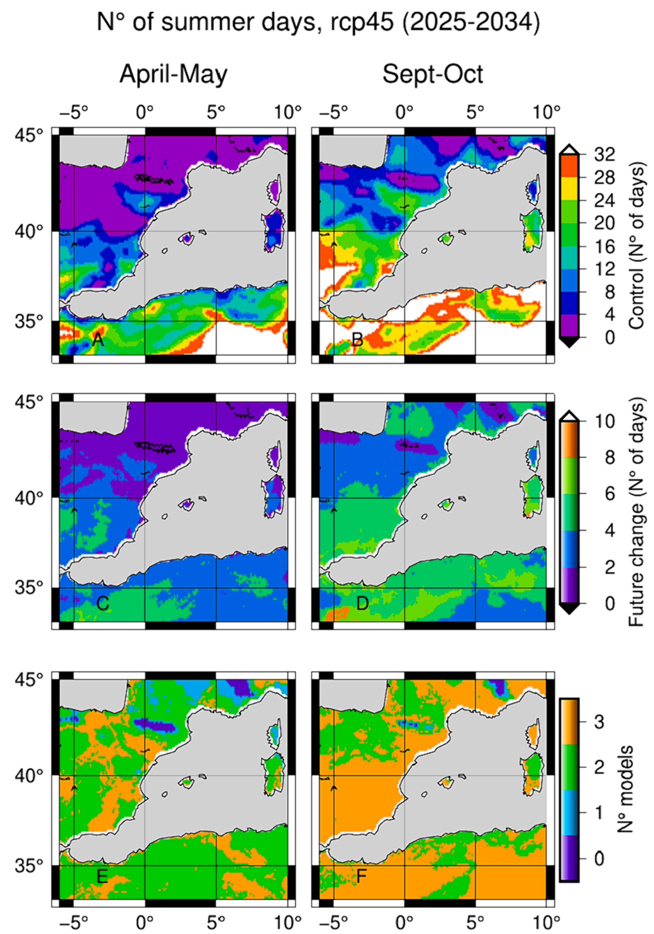

Fig. 9. First row: seasonal, ensemble mean of the number of summer days in the control (1976–2005). Second row: future decadal change (2025–2034) in the number of summer days with respect to the control period assuming the rcp4.5. A positive sign indicates an increase in the summer days. Third row: number of ensemble models that project an increase in the number of summer days.

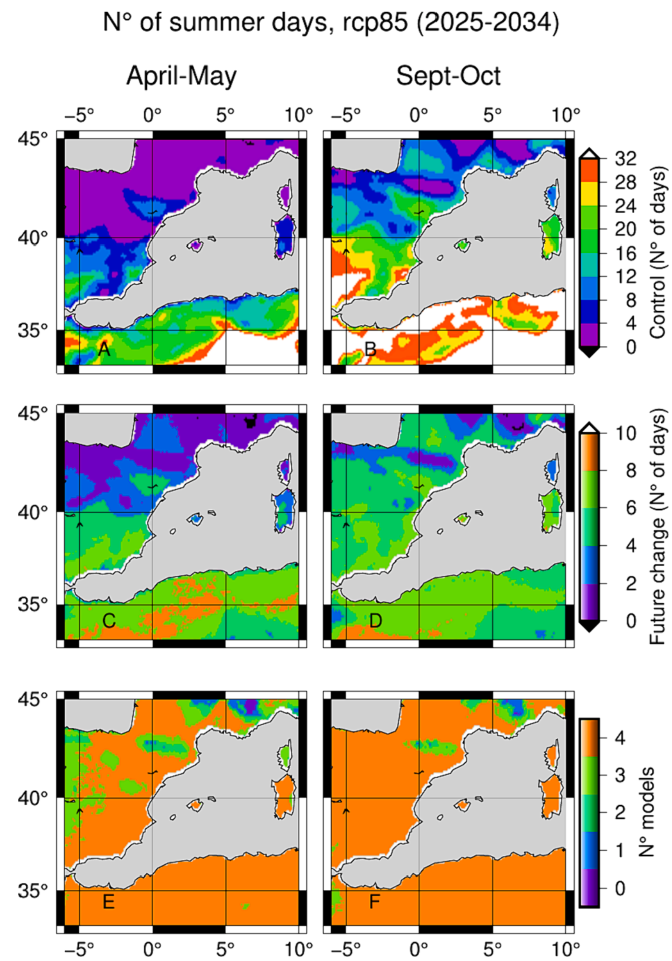

Fig. 10. As Fig. 9, but for the rcp8.5.

4. Discussion

Our results indicate less favorable conditions for the coastal tourism sector in summer in the near- (2025–2034 decade) and medium-term (2055–2064) future scenarios. The latter reveals more extreme conditions in a few decades regarding temperature and precipitation. Even though changes for 2025–2034 are subtle (e.g., the increase of summer T2MAX is not greater than 2 °C), these highlight the need to implement adaptation measures. In this Section we shed light on the possibility of extending the high tourist season to late spring and/or early fall.

4.1. Is it feasible to extend the high tourist season to late spring-early fall?

To start, we should note that both T2MAX and the % of days with heavy precipitation will increase in all seasons. The question that arises is if in the months adjacent to the summer, conditions will be adequate for coastal tourism. We examine the days in which T2MAX reaches, at least, 25 °C (i.e., summer days), as well as the days when the SST attains, at least, 18 °C. These thresholds set the conditions for the beginning of coastal tourism (Martínez-Ibarra et al., 2019). In the discussion we focus on April-May and September-October, since they are the candidates for a possible extension of the tourist season.

4.1.1. Optimal thermal conditions: Number of summer days and sea-surface temperature

We first focus on the summer days, which are defined following the climate index from the Expert Team on Climate Change Detection and Indices (ETCCDI; e.g., Sillmann et al., 2014), according to which a summer day is one in which T2MAX reaches or exceeds 25 °C. This index is chosen because this sets the air temperature from which the coastal tourism activity is suitable (Martínez-Ibarra et al., 2019).

In the control, the number of summer days is higher in September-October than in April-May (Fig. 9A-B). The spatial distribution of summer days follows a latitudinal pattern (higher frequencies to the south) in which the effect of topography is also appreciated (higher occurrences in low-lying areas and vice versa). In April-May, the number of days oscillates between 8 and 20, the latter located in specific areas to the SE of the peninsula. In September-October, values range between 12 and 32 (greater to the interior of the peninsula), with this maximum also occurring within the area of interest in the SE of the Iberian Peninsula. Regarding the change in the number of summer days in the rcp4.5, the increase is slight, with a maximum close to 4–6 days on the Spanish Mediterranean coast in April-May and close to 8 (southern portion of the domain) and 4 days (northern portion) in September-October (Fig. 9C-D). The robustness of the increase is more variable in April-May and stronger in September-October (Fig. 9E-F). In the rcp8.5 (Fig. 10), the increase is close to 4–6 days in April-May in the northern portion of the domain and 8–10 to the south, whilst in September-October it is around 6–8 days throughout the region of interest (Fig. 10C-D). Results obtained are robust regardless of the season (Fig. 10E-F).

Although the number of summer days is relatively low in April-May to promote beach tourism, the number of summer days will increase

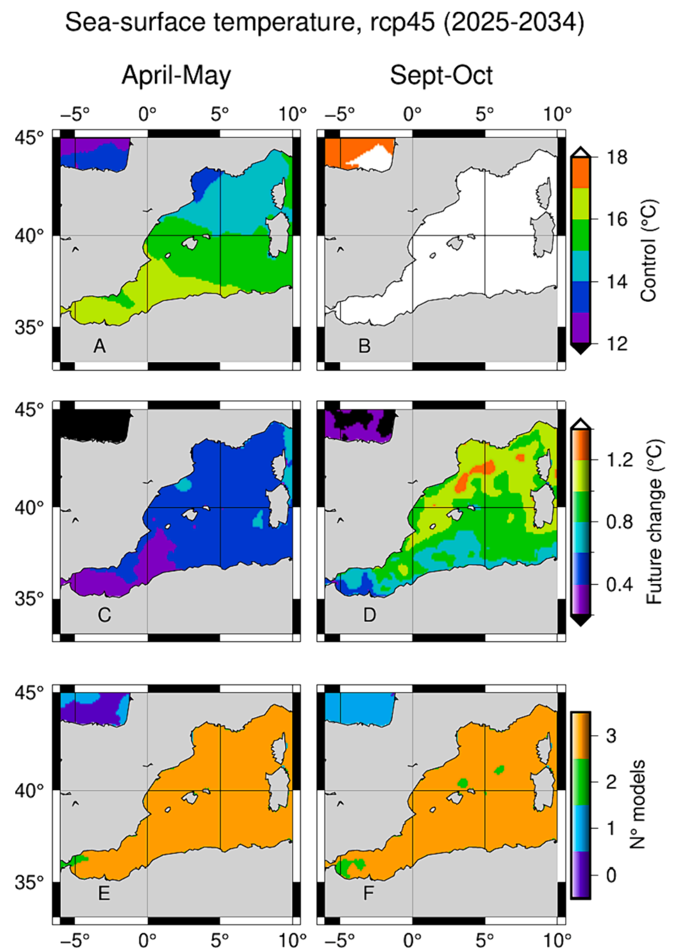

Fig. 11. First row: Ensemble mean SST for late spring (April-May) and early fall (September-October) for the control (1976–2005). Second row: future decadal change (2025–2034) of SST relative to the control for the rcp4.5. A positive sign indicates a temperature rise. White values correspond to temperatures greater than 18 °C. Third row: number of models from the ensemble that project an increase of the SST.

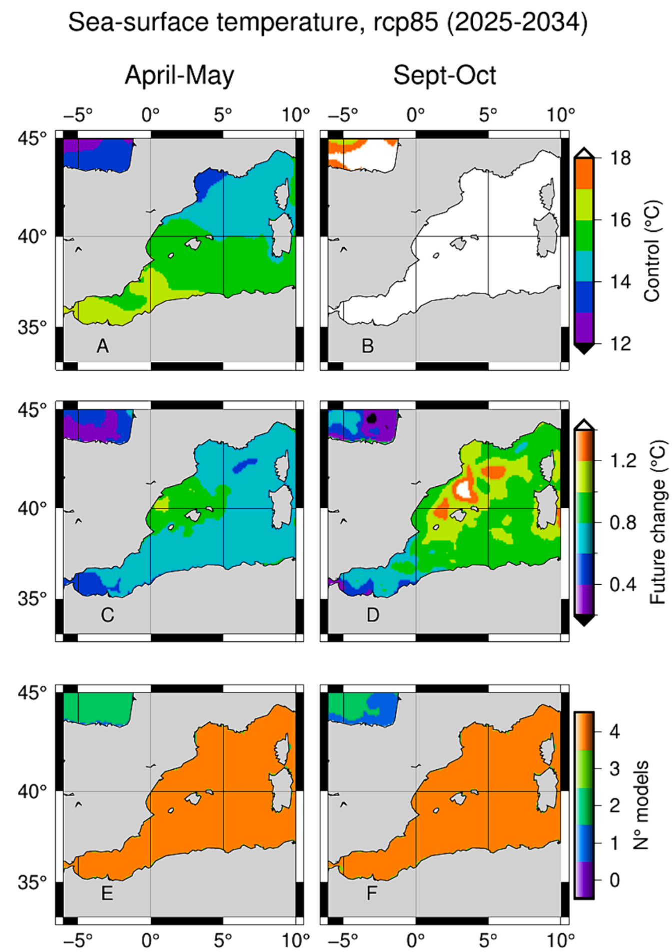

Fig. 12. As Fig. 11, but for the rcp8.5.

successively in the coming decades, with an increase in 2055–2064 up to 8–10 days in the rcp4.5 and up to 16 days in the rcp8.5 (see Figure S5 and Figure S6 of the Supplement). Even though in the control the summer days are not too many in April-May, given the increasing trend in the number of summer days in the coming decades, these months will be, in the medium term, more favorable for the beginning of tourist activity from a thermal comfort perspective, especially to the SE of the peninsula.

We now concentrate on the next determining factor for the start of the bathing season: the SST.

Fig. 11A-B shows that in September-October, in the control, the SST exceeds 18 °C all over the area of interest (white colors), which is regarded as the starting temperature for baths (Besancenot, 1991; Morgan et al., 2012). In April-May, the SST oscillates between 14 and 15 °C in the north of the domain and 16–17 °C to the south. In 2025–2034, in April-May, the models project a generalized increase of about 0.4–0.6 °C in the rcp4.5 (Fig. 11C-D) and of around 0.4–0.6 °C to the south and about 0.8–1 °C to the north in the rcp8.5 (Fig. 12C-D). This means that potentially in this decade SSTs suitable for bathing conditions will be reached (or close to) under both scenarios with the exception of the northernmost Mediterranean domain of the Iberian coast, where temperatures are lower. In all cases, the SST increase is supported by all ensemble members and will be sustained over time. In 2055–2064, the SST increase in the rcp4.5 is up to 1.6 °C, with a greater increase of the SSTs to the NE coast of the Iberian Peninsula close to 2 °C under the rcp8.5 (Figure S7 and Figure S8 of the Supplement). In April-May, by the middle of the century, the rise would make conditions more suitable for beach tourism, at least in the southern portion of the area of interest, with values close to 18 °C to the north.

4.1.2. Heavy precipitation

In the control, heavy precipitation days develop in both April-May and September-October, with a higher prevalence in September-October in the area of interest (Fig. 13A-B). In both seasons, an increase in the % of days with heavy precipitation occurs (Fig. 13C-D and 14C-D). This varies between 2 and 4 % of the days and is robust in both periods and scenarios (Fig. 13 and Fig. 14). Whilst for the coming decade it is difficult to determine whether the increase is larger in April-May or September-October, from 2045 until 2064 (see e.g., 2055–2064 decade in Figure S9 and Figure S10) the increase is slightly larger in September-October. This seems to indicate slightly less favorable conditions for the extension of the tourist season in these months than in April-May, from this perspective.

We can conclude that September-October are thermally more comfortable and prone to the development of coastal tourism (air and sea temperature) than April-May. Notwithstanding, in the near-future (2025–2034), the % of days with heavy precipitation increases about 2–4 % days in April-May and September-October and this is observed in the longer term (e.g., 2055–2064) as well. Whilst the extension of the high tourist season towards late spring-early fall is doable, the possible interferences between the thermal comfort and heavy precipitation should be carefully examined. If a tourist knows that there is a high prevalence of heavy precipitation over certain months, they will avoid

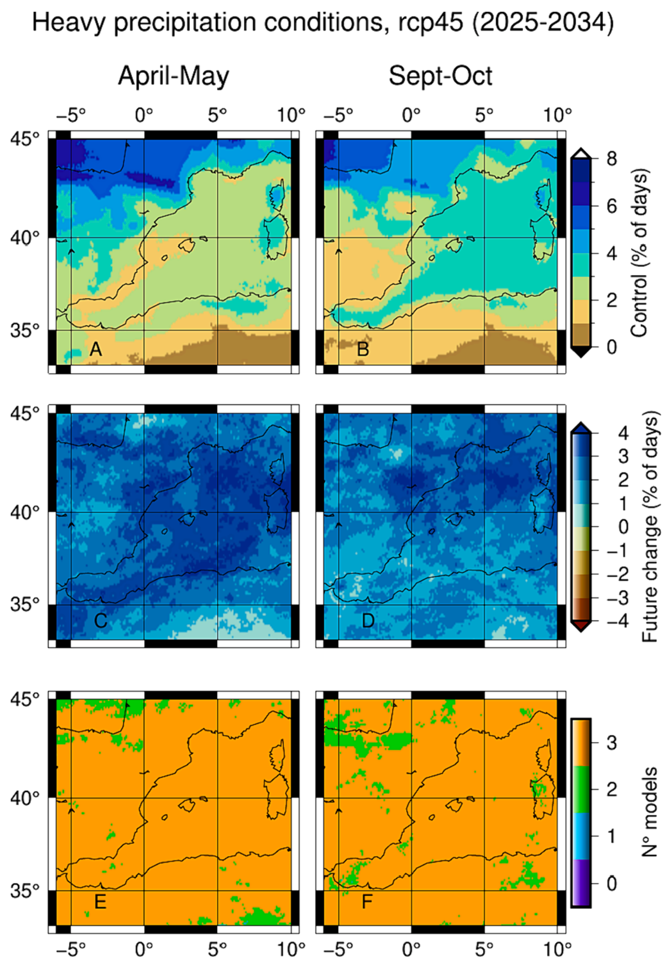

Fig. 13. First row: seasonal (April-May, September-October, respectively), ensemble mean % of days with high precipitation for the control (1976–2005). Second row: future decadal change (2025–2034) in the % of high precipitation events relative to the control period assuming the rcp4.5 scenario. Third row: number of ensemble models that project an increase of the days with heavy precipitation.

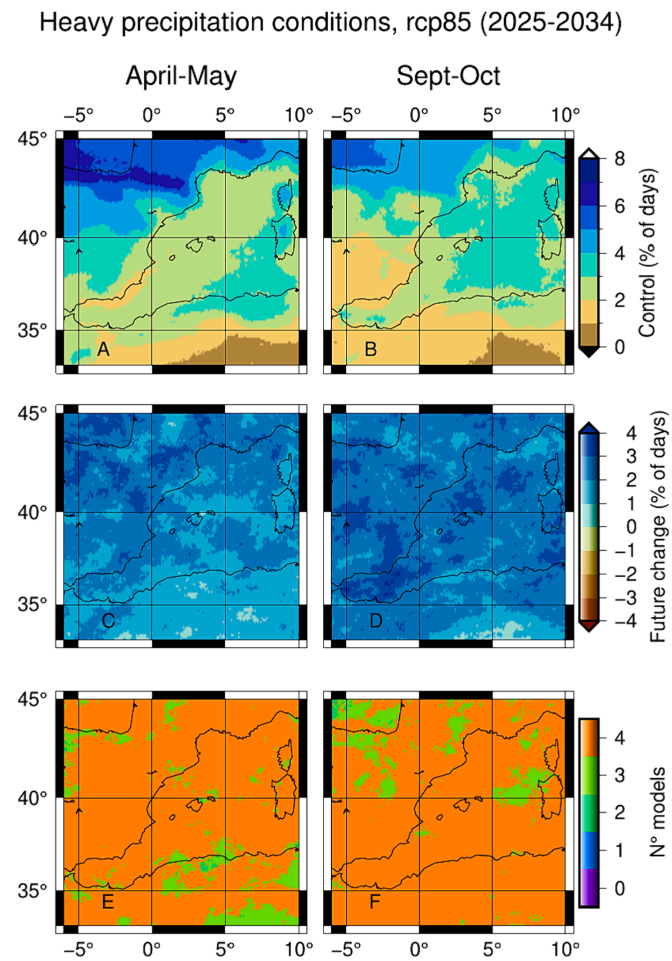

Fig. 14. As for Fig. 13, but for the rcp8.5.

making their reservation (Gomez Royuela, 2016).

4.2. Adaptation and mitigation recommendations for stakeholders

Coastal tourism in the region will face in the coming years transformations to adapt to climate change (Gómez-Martín et al., 2014; OECC, 2016; Olcina Cantos and Vera-Rebollo, 2016a,b; MITECO, 2021). Whilst traditional adaptation measures (i.e., no climate change scenario) basically included actions oriented to save water and energy and air conditioning in hotels and tourist apartments, recently more adaptation actions have been developed in tourist destinations along the several strategic lines e.g., spatial planning in tourist destinations, buildings, normative, calendar changes and monitoring (Table 2).

Adaptation measures began to be implemented at the end of the last century, when the rise in temperatures from the current heating process began to manifest and the effects of a significant drought that occurred in Spain in the first half of the 1990 s had been suffered. In the current context of climate change and its projection in the medium term, efficient adaptation measures should be quickly developed. In fact, adaptation plans and actions have already started in municipalities and regions of the Spanish Mediterranean coast. For instance, sustainable mobility plans and actions to implement solar parks to supply buildings and public facilities are being developed in several municipalities (López-Dóriga Sandoval et al., 2019; Torres et al., 2021; Agulles et al., 2022). Sustainable drainage systems (SDUs) are being implemented to adapt urban sewerage to intense precipitation, which our results project to increase in frequency (Sánchez-Almodóvar et al., 2023). Also, there are numerous initiatives to promote water saving in tourist destinations throughout the Mediterranean coast (Torres-Bagur et al., 2020; Olcina Cantos et al., 2021).

Presently, and in the coming years, regional and local governments will play a key role in the approval of climate change laws (state and

Table 2
Compilation of climate change adaptation actions in Spanish Mediterranean coastal tourism destinations based on literature review. Source: own elaboration.

STRATEGIC LINES	ACTIONS
Spatial planning in tourist destinations	- Sustainable urbanism ("green infrastructure", sustainable mobility, SDUs) - Climate change adaptation plans with spatial planning measures - More urban green areas - Fountains in parks and gardens
Buildings	- Air conditioning and energy efficiency in buildings - Water saving measures
Normative	- Approval of climate change and energy transition laws - Development of adaptation plans to climate change (regional and local scale)
Calendar changes	- Tourism promotion actions in non-summer seasons - Adaptation to climate change, tourism quality label
Monitoring	- Carbon footprint and water footprint monitoring - Municipal tourism sustainability indicators

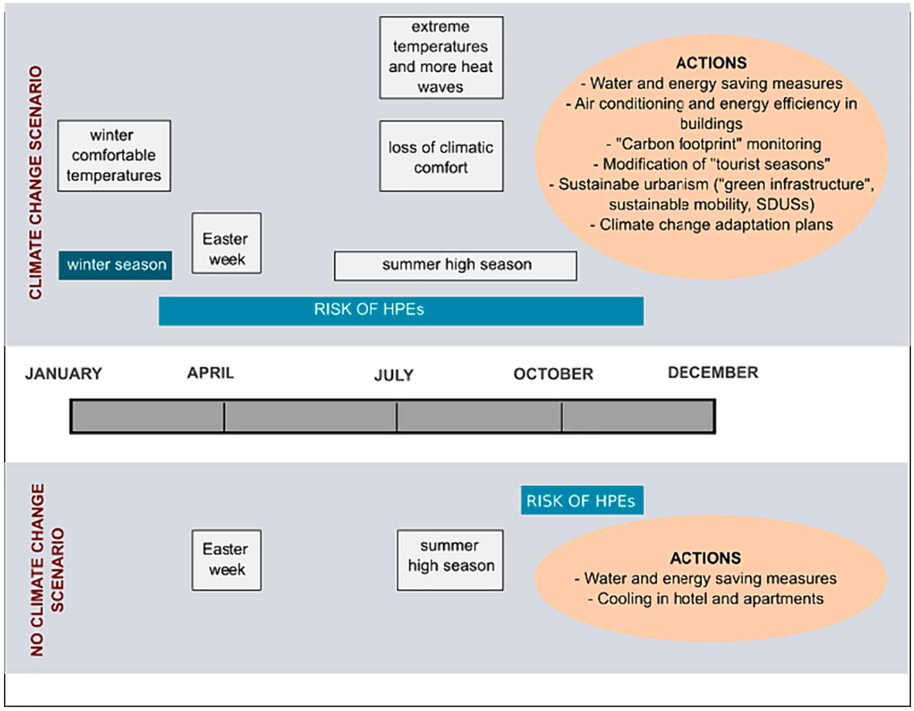

Fig. 15. Tourist calendar change in the Spanish Mediterranean coast as it was in the previous decades (no climate change scenario) and in the future (Climate change scenario). HPEs = heavy precipitation events. Source: own elaboration.

regional scale), which is essential for the development of mitigation and adaptation activities in the tourism sector. Likewise, reports have been developed on the status of climate change and its effects on the economic sectors (Catalonia) and adaptation plans (Catalonia, the Balearic Islands, Valencian Community, Murcia, Andalusia). In the Valencian region, a guide has been prepared for the adaptation of tourist destinations to climate change, with specific recommendations at the local scale (Invatur, 2020). In this regard, the municipality of Benidorm is the first major tourist destination in the Spanish Mediterranean that has approved a climate change adaptation plan with eighty concrete measures to be implemented in tourist activities and facilities in the coming years (Ayuntamiento de Benidorm, 2022). Also, CO_2 monitoring systems have been implemented, in compliance with these regulations.

Traditionally, the end of the summer tourist season was marked, in terms of social perception, with the possibility of heavy rain starting in September. In the medium term, changes in the tourist calendar should be planned because they entail transformations in the offer and in the vacation work calendar, currently focused on July and August and, to a lesser extent, Easter holidays (Olcina Cantos and Miró Pérez, 2017). Our results show that summer is extending towards the adjacent seasons. Projections indicate an increase in T2MAX and the frequency of heat waves. Thermal comfort tends to worsen in summer, while it improves towards the adjacent seasons (Miró Pérez and Olcina Cantos, 2020). Thus, the loss of thermal comfort in summer forces the development of adaptation actions to minimize the effects of increased heat. We could say that the new climatic reality that is already being experienced and climatic projections for the coming decades favors the extension of the high summer season towards the adjacent months (April-May, September-October), the maintenance of the Easter holiday and the possibility of establishing a winter tourist season, due to the intensification of anticyclonic conditions in January and February. However, care should be taken with heavy precipitation, which is projected to increase in all seasons which, in turn, raises the need to implement adaptation actions in tourist destinations to minimise its possible negative impacts. See a summary of the information presented in this Section in Fig. 15.

5. Conclusions and recommendations

To promote a sustainable development of coastal tourism in the Spanish Mediterranean coast, it is necessary to anticipate changes in future climate to provide relevant information to stakeholders and promote effective adaptation measures. In this respect, it is fundamental to use appropriate climate modelling tools which account for air-sea interactions, which play a major role in the climate signal of Mediterranean coastal areas. In this work, results from a set of high-resolution air-sea coupled regional climate model simulations from Med-CORDEX are used to (i) study the foreseen climatic conditions in the next decade(s) on the Spanish Mediterranean coast and (ii) quantitatively assess the possibility of extending the coastal tourist season towards the months adjacent to summer (April-May, September-October) in relation to the projected changes in the climatic conditions in the region. The rcp4.5 and rcp8.5 climate scenarios are considered. The most relevant results and associated recommendations of this work are:

- In the next decades thermal discomfort will enhance in summer given the projected generalized increase in the maximum 2-m air temperature (T2MAX). We obtain an increase in the summer mean T2MAX between 1 and 2 °C for 2025–2034. In 2055–2064, the increase reaches up to 3–4 °C.
- The number of days with heat waves will increase in all studied seasons in the future. In summer, regardless of the scenario chosen, the increase can reach up to 15–20 days in the 2025–2034 decade. In the longer term (2055–2064), the rise in the number of days with heat wave conditions can reach up to 40 days or more, which could become the new normality. Adaptation measures should be deployed urgently to guarantee the sustainable development of the sector.
- In 2025–2034, precipitation experiences small changes with respect to the control. Both scenarios project drier conditions regardless of the season, especially in the rcp8.5. This decrease in summer precipitation will intensify in future decades. A proper management of water resources is crucial, especially in summer, when coastal municipalities currently have a greater influx of tourists.

- The % of days with high precipitation in 2025–2034 will experience a generalized increase that varies between 2 and 4 % per season regardless of the scenario. Although the average precipitation remains similar to the control period, or is slightly reduced, the frequency of days with heavy precipitation increases. This aggravates the current situation and will make it necessary to improve early warning systems. These should be adapted to the needs of the tourism sector and offer continuously monitored information to reduce exposure to heavy precipitation.
- Based on our results, we propose a tourist calendar change in the Spanish Mediterranean coast. This would entail the extension of the high summer season towards April-May, September-October, the maintenance of the Easter holiday and the potential establishment of a winter tourist season because of anticyclonic conditions. However, care should be taken with heavy precipitation, which is projected to increase in frequency in all seasons. This, in turn, would make it necessary to implement adaptation actions in tourist destinations to minimise potential negative impacts.

Insights from this work, allow us to conclude that a similar analysis could be successfully performed in other Mediterranean regions in which the blue economy is key. Although results obtained with this model ensemble are here applied to costal tourism, a continuation of this work could include other relevant sectors e.g., fisheries, aquaculture or energy or be even cross-sectorial. Also, a similar analysis could be performed once a regional coupled model ensemble from Med-CORDEX, using boundary conditions from CMIP6, is available.

CRediT authorship contribution statement

Alba de la Vara: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **William Cabos:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Claudia Gutiérrez:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Jorge Olcina:** Investigation, Writing – original draft, Writing – review & editing. **Alba Matamoros:** Investigation, Writing – original draft, Writing – review & editing. **Francisco Pastor:** Investigation, Writing – original draft, Writing – review & editing. **Samira Khodayar:** Investigation, Writing – original draft, Writing – review & editing. **Maite Ferrando:** Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2024.100466.

References

Abdelmoaty, H.M., Papalexiou, S.M., Rajulapati, C.R., AghaKouchak, A., 2021. Biases beyond the mean in CMIP6 extreme precipitation: a global investigation. Earth's Future 9 (10), e2021EF002196.

Agulles, M., Melo-Aguilar, C., Jordà, G., 2022. Risk of loss of tourism attractiveness in the Western Mediterranean under climate change. Front. Clim. 4, 1019892. https://doi.org/10.3389/fclim.2022.1019892.

Almazroui, M., Saeed, F., Saeed, S., et al., 2021. Projected changes in climate extremes using CMIP6 simulations over SREX regions. Earth Syst. Environ. 5, 481–497.

Amelung, B., Nicholls, S., Viner, D., 2007. Implications of global climate change for tourism flow sand seasonality. J. Travel Res. 45 (3), 285–296. https://doi.org/10.1177/0047287506295937.

Arabadzhyan, A., Figini, P., García, C., González, M.M., Lam-González, Y.E., León, C.J., 2021. Climate change, coastal tourism, and impact chains–a literature review. Current Issues in Tourism 24 (16), 2233–2268. https://doi.org/10.1080/13683500.2020.1825351.

Benetó, P., Khodayar, S., 2023. On the need for improved knowledge on the regional-to-local precipitation variability in eastern Spain under climate change. In Atmos. Res. 290, 106795 https://doi.org/10.1016/j.atmosres.2023.106795.

Besancenot, J.P., 1991. Clima y turismo. Masson, Barcelona, p. 224.

Buzzi, A., Davolio, S., Malguzzi, P., Drofa, O., Mastrangelo, D., 2014. Heavy rainfall episodes over Liguria in autumn 2011: numerical forecasting experiments. Nat. Hazards Earth Syst. Sci. 14 (6), 1325–1340. https://doi.org/10.5194/nhess-14-1325-2014.

Carvalho, D., Cardoso Pereira, S., Rocha, A., 2021. Future surface temperature changes for the Iberian Peninsula according to EURO-CORDEX climate projections. Clim. Dyn. 56, 123–138. https://doi.org/10.1007/s00382-020-05472-3.

Cavicchia, L., Gualdi, S., Sanna, A., Oddo, P. et al., 2015. The regional ocean-atmosphere coupled model COSMO-NEMO_MFS. CMCC Research Paper, RP0254.

Colmet-Daage, A., Sanchez-Gomez, E., Ricci, S., Llovel, C., Borrell Estupina, V., Quintana-Seguí, P., Llasat, M.C., Servat, E., 2018. Evaluation of uncertainties in mean and extreme precipitation under climate changes for northwestern Mediterranean watersheds from high-resolution med and euro-CORDEX ensembles. Hydrol. Earth Syst. Sci. 22 (1), 673–687. https://doi.org/10.5194/hess-2017-49.

Darmaraki, S., Somot, S., Sevault, F., Nabat, P., Cabos Narvaez, W.D., Cavicchia, L., et al., 2019. Future evolution of marine heatwaves in the Mediterranean Sea. Clim. Dyn. 53 (3), 1371–1392.

Ayuntamiento de Benidorm, 2022. Plan de Adaptación ante el Cambio Climático. Benidorm. Área de Alcaldía. Available on: https://benidorm.org/es/ayuntamiento/concejalias/obras/ingenieria/proyectos-ingenieria/plan-de-adaptacion-ante-el-cambio-climatico-de-benidorm.

de la Hoz, C.F., Ramos, E., Acevedo, A., Puente, A., Losada, I.J., Juanes, J.A., 2018. OCLE: a european open access database on climate change effects on littoral and oceanic ecosystems. Prog. Oceanogr. 168 (222–231), 2017. https://doi.org/10.5194/hess-2017-49.

Delrieu, G., Ducrocq, V., Gaume, E., Nicol, J., Payrastre, O., Yates, E., Kirstetter, P.E., Andrieu, H., Ayral, P.A., Bouvier, C., Creutin, J.D., Livet, M., Anquetin, S., Lang, M., Neppel, L., Obled, C., Parent-Du-Châtelet, J., Saulnier, G.M., Walpersdorf, A., Wobrock, W., 2005. The catastrophic flash-flood event of 8-9 September 2002 in the Gard Region, France: a first case study for the Ć evennes-Vivarais Mediterranean Hydrometeorological Observatory. J. Hydrometeorol. 6 (1), 34–52. https://doi.org/10.1175/JHM-400.1.

Dirks, K.N., Hay, J.E., et al., 1998. High-resolution studies of rainfall on Norfolk Island. J. Hydrol. 208 (3–4), 187–193.

Ferretti, R., Low-Nam, S., Rotunno, R., 2000. Numerical simulations of the piedmont flood of 4–6 november 1994. Tellus Dyn. Meteorol. Oceanogr. 52 (2), 162–180. https://doi.org/10.1034/j.1600-0870.2000.00992.x.

Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett. 33 (8) https://doi.org/10.1029/2006GL025734.

Gomez Royuela, M., 2016. Impacto, vulnerabilidad y adaptación al cambio climático en el sector turístico. Plan Nacional de Adaptación al Cambio Climático. Oficina Española de Cambio Climático, p. 85.

Gómez-Martín, M., Armesto-López, X., Cors-Lglesias, M., Muñoz-Negrete, J., 2014. Adaptation strategies to climate change in the tourist sector: the case of coastal tourism in Spain. Tourism 62, 293–308.

Gutiérrez-Fernández, J., González-Alemán, J.J., de la Vara, A., Cabos, W., Sein, D.V., Gaertner, M.Á., 2021. Impact of ocean–atmosphere coupling on future projection of

medicanes in the Mediterranean Sea. Int. J. Clim. 41 (4), 2226–2238. https://doi.org/10.1002/joc.6955.
Hersbach, H., et al., 2020. The ERA5 global reanalysis. Q. J. r. Meteorol. 146, 1999–2049. https://doi.org/10.1002/qj.3803.
Hossain, M.M., Garg, N., Anwar, A.F., Prakash, M., 2021. Comparing spatial interpolation methods for CMIP5 monthly precipitation at catchment scale. J. Indian Water Resour. Soc 41 (2), 28–34.
INE, 2020. Revisión estadística 2019. Notas de prensa. Available on:https://www.ine.es/prensa/cst_2019.pdf.
Insua-Costa, D., Lemus-Cánovas, M., Miguez-Macho, G., Llasat, M.C., 2021. Climatology and ranking of hazardous precipitation events in the western Mediterranean area. Atmos. Res. 255, 105521 https://doi.org/10.1016/j.atmosres.2021.105521.
Invat·tur, 2020. Guía para la adaptación de los destinos turísticos al cambio climático. Valencia, Generalitat Valenciana. 85 p. Available at: https://invattur.es/uploads/entorno_37/ficheros/626913f3572001394984318.pdf.
IPCC, 2019: Summary for Policymakers. Available at: https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/.
IPCC, AR6 SYR (2023). Synthesis report of the IPCC sixth assessment report (AR6)–Summary for Policymakers. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/.
Khodayar, S., Paredes-Fortuny, L. On the Magnification of Heatwaves on a Western Mediterranean Climate Change Hotspot in the Present Climate. Available at SSRN: https://ssrn.com/abstract=4231920 or https://doi.org/10.2139/ssrn.4231920.
Khodayar, S., Davolio, S., di Girolamo, P., Lebeaupin Brossier, C., Flaounas, E., Fourrie, N., Lee, K.-O., Ricard, D., Vie, B., Bouttier, F., Caldas-Alvarez, A., Ducrocq, V., 2021. Overview towards improved understanding of the mechanisms leading to heavy precipitation in the western Mediterranean: lessons learned from HyMeX. Atmos. Chem. Phys. 21 (22), 17051–17078. https://doi.org/10.5194/acp-21-17051-2021.
Khodayar Pardo, S., Kalthoff, N., Kottmeier, C., 2018. Atmospheric conditions associated with heavy precipitation events in comparison to seasonal means in the western mediterranean region. Clim. Dyn. 51, 951–967. https://doi.org/10.1007/s00382-016-3058-y.
Khodayar, S., Pastor, F., Valiente, J.A., Benetó, P., Ehmele, F., 2022. What causes a heavy precipitation period to become extreme? the exceptional october of 2018 in the Western Mediterranean. Weather Clim. 38, 100493 https://doi.org/10.1016/j.wace.2022.100493.
Kostopoulou, E., Jones, P.D., 2005. Assessment of climate extremes in the eastern Mediterranean. Meteorol. Atmos. Phys. 89, 69–85. https://doi.org/10.1007/s00703-005-0122-2.
L'Hévéder, B., Li, L., Sevault, F., Somot, S., 2013. Interannual variability of deep convection in the northwestern Mediterranean simulated with a coupled AORCM. Clim. Dyn. 41 (3–4), 937–960. https://doi.org/10.1007/s00382-009-0691-8.
Lam-González, Y.E., León, C.J., de León, J., 2019. Assessing the effects of the climatic satisfaction on nautical tourists' on-site activities and expenditure decisions. J. Dest. Mark. Manage 14, 100372. https://doi.org/10.1016/j.jdmm.2019.100372.
León, C.J., Giannakis, E., Zittis, G., Serghides, D., Lam-González, Y.E., García, C., 2021. Tourists' preferences for adaptation measures to build climate resilience at coastal destinations. Evidence from Cyprus. Tour. Plan. Dev. 1–27.
López-Dóriga Sandoval, U., Jiménez, J., Bisaro, A., Hinkel, J., 2019. Financing and implementation of adaptation measures to climate change along the Spanish coast. Sci. Total Environ. 712, 135685 https://doi.org/10.1016/j.scitotenv.2019.135685.
Lorenzo, N., Díaz-Poso, A., Royé, D., 2021. Heatwave intensity on the Iberian Peninsula: future climate projections. Atm. Res. 258, 105655 https://doi.org/10.1016/j.atmosres.2021.105655.
Martínez-Ibarra, E., Gómez-Martín, M.B., Armesto-López, X.A., Pardo-Martínez, R., 2019. Climate preferences for tourism: perceptions Regarding ideal and unfavourable conditions for hiking in Spain. Atmosphere 10, 11–646. https://doi.org/10.3390/atmos10110646.
MedECC, 2020. Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632pp. ISBN: 978-2-9577416-0-1 / DOI: 10.5281/zenodo.7224821.
Miró, J.J., Estrela, M.J., Olcina-Cantos, J., Martin-Vide, J., 2021. Future projection of precipitation changes in the Júcar and Segura River basins (Iberian Peninsula) by CMIP5 GCMs local downscaling. Atmosphere 12, 879. https://doi.org/10.3390/atmos12070879.
Miró Pérez, J.J., Olcina Cantos, J., 2020. Cambio climático y confort térmico. efectos en el turismo de la comunidad Valenciana. Investigaciones Turísticas 20, 1–30. https://doi.org/10.14198/INTURI2020.20.01.
MITECO (2021) Plan Nacional de Adaptación al Cambio Climático, 2021-30. Madrid. Oficina Española de Cambio Climático. Available at: https://www.miteco.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/pnaccpreguntasyrespuestas_tcm30-534791.pdf.
Molina, M.O., Sánchez, E., Gutiérrez, C., 2020. Future heat waves over the Mediterranean from an euro-CORDEX regional climate model ensemble. Sci. Rep. 10, 1–10.
Morgan, R., Gatell, E., Junyent, R., Micallef, A., Erdal, O., Allan, W., 2012. An improved user-based beach climate index. J. Coast. Conserv. 6, 41–50. https://doi.org/10.1007/BF02730466.
Nuissier, O., Joly, B., Joly, A., Ducrocq, V., Arbogast, P., 2011. A statistical downscaling to identify the large-scale circulation patterns associated with heavy precipitation events over southern France. Q. J. R. Meteorol. Soc. 137(660), 1812-1827. https://doi.org/ 10.1002/qj.866.
OECC (2016). Impactos, vulnerabilidad y adaptación al cambio climático en el sector turístico. Madrid, Ministerio de Agricultura, Alimentación y Medio Ambiente. Available on: https://www.miteco.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/impactosvulnerabilidadyadaptacionalcambioclimaticoenelsectorturistico_tcm30-178443.pdf.
Olcina Cantos, J, Miró Pérez, J.J., 2017. Actividad turística y cambio climático en la Comunidad Valenciana. Alicante: Universidad de Alicante, Instituto Universitario de Investigaciones Turísticas; Valencia: Agència Valenciana del Turisme, 130. https://doi:10.14198/2017-Actividad-Turistica-Com. Valenciana.
Olcina Cantos, J., Vera-Rebollo, J.F., 2016a. Cambio climático y política turística en españa: diagnóstico del litoral mediterráneo español. Cuadernos De Turismo 38, 327–363. https://doi.org/10.6018/turismo.38.271471.
Olcina Cantos, J., Vera-Rebollo, J.F., 2016b. Adaptación del sector turístico al cambio climático en españa. la importancia de las acciones a escala local y en empresas turísticas. Anales De Geografía De La Universidad Complutense 36 (2), 321–349. https://doi.org/10.5209/AGUC.53588.
Olcina Cantos, J., Baños Castiñeira, C.J., Rico Amorós, A.M., 2021. Medidas de adaptación al riesgo de sequía en el sector hotelero de Benidorm (Alicante, españa). Revista De Geografía Norte Grande 65, 129–153. https://doi.org/10.4067/S0718-34022016000300007.
Pastor, F., Estrela, M.J., Peñarrocha, D., Millán, M.M., 2001. Torrential rains on the spanish Mediterranean coast: modeling the effects of the sea surface temperature. J. Appl. Met. 40 (7), 1180–1195. https://doi.org/10.1175/1520-0450(2001)040<1180:TROTSM>2.0.CO;2.
Pastor, F., Valiente, J.A., Estrela, M.J., 2015. Sea surface temperature and torrential rains in the Valencia region: modelling the role of recharge areas. NHESS 15, 1677–1693. https://doi.org/10.5194/nhess-15-1677-2015.
Pastor, F., Valiente, J.A., Palau, J.L., 2018. Sea Surface temperature in the Mediterranean: trends and spatial patterns (1982–2016). Pure Appl. Geophys. 175, 4017–4029. https://doi.org/10.1007/s00024-017-1739-z.
Pastor, F., Valiente, J.A., Khodayar, S., 2020. A warming Mediterranean: 38 years of increasing sea surface temperature. Remote Sensing 12 (17), 2687. https://doi.org/10.3390/rs12172687.
Peterson, T.C., et al., 2008. Weather and climate extremes in a changing climate. Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Is-lands. In: Karl, TR. (Ed.), Synthesis and Assessment Product 3.3. US Climate Change Science Program, Washington, DC, pp. 11–34.
Rainaud, R., Brossier, C.L., Ducrocq, V., Giordani, H., 2017. High-resolution air–sea coupling impact on two heavy precipitation events in the Western Mediterranean. Q. J. r. Meteorol 143 (707), 2448–2462. https://doi.org/10.1002/qj.3098.
Rixen, M., Beckers, J.M., Levitus, S., Antonov, J., Boyer, T., Maillard, C., Fichaut, M., Balopoulos, E., Iona, S., Dooley, H., et al., 2005. The Western Mediterranean deep water: a proxy for climate change. Geophys. Res. Lett. 32 (12) https://doi.org/10.1029/2005GL022702.
Ruti, P., Somot, S., Giorgi, F., Dubois, C., Flaounas, E., Obermann, A., Dell'Aquila, A., Pisacane, G., Harzallah, A., Lombardi, E., et al., 2016. MED-CORDEX initiative for Mediterranean climate studies. BAMS 97, 1187–1208. https://doi.org/10.1175/BAMS-D-14-00176.1.
Salata, F., Golasi, I., Proietti, R., de Lieto Vollaro, A., 2017. Implications of climate and outdoor thermal comfort on tourism: the case of Italy. Int. J. Biometeorology 61 (12), 2229–2244.
Sánchez-Almodóvar, E., Olcina-Cantos, J., Martí-Talavera, J., Prieto-Cerdán, A., Padilla-Blanco, A., 2023. Floods and adaptation to climate change in tourist areas: Management Experiences on the coast of the province of Alicante (Spain). Water 15, 807. https://doi.org/10.3390/w15040807.
Scoccimarro, E., et al., 2016. Heavy precipitation events over the Euro-Mediterranean region in a warmer climate: results from CMIP5 models. Reg. Environ. Change 16, 595–602.
Sein, D.V., Mikolajewicz, U., Gröger, M., Fast, I., Cabos, W., Pinto, J.G., Hagemann, S., Semmler, T., Izquierdo, A., Jacob, D., 2015. Regionally coupled atmosphere-ocean-sea ice-marine biogeochemistry model ROM: 1. description and validation. J. Adv. Model Earth Syst. 7, 268–304. https://doi.org/10.1002/2014MS000357.
Sevault, F., Somot, S., Alias, A., Dubois, C., Lebeaupin-Brossier, C., Nabat, P., Adloff, F., Déqué, M., Decharme, B., 2014. A fully coupled Mediterranean regional climate system model: design and evaluation of the ocean component for the 1980–2012 period. Tellus a: Dyn. Meteorol. Oceanogr. 66, 23967. https://doi.org/10.3402/tellusa.v66.23967.
Sillmann, J., Kharin, V.V., Zwiers, F.W., Zhang, X., Bronaugh, D., Donat, M.G., 2014. Evaluating model-simulated variability in temperature extremes using modified percentile indices. Int. J. Climatol. 34, 3304–3311. https://doi.org/10.1002/joc.3899.
Stahl, K., Moore, R.D., Floyer, J.A., Asplin, M.G., McKendry, I.G., 2006. Comparison of approaches for spatial interpolation of daily air temperature in a large region with complex topography and highly variable station density. Agric. for Meteorol. 139 (3–4), 224–236. https://doi.org/10.1016/j.agrformet.2006.07.004.
Stampoulis, D., Anagnostou, E.N., Nikolopoulos, E.I., 2013. Assessment of high-resolution satellite-based rainfall estimates over the Mediterranean during heavy precipitation events. JHM 14 (5), 1500–1514. https://doi.org/10.1175/JHM-D-12-0167.1.
Torres, C., Jordà, G., de Vílchez, P., et al., 2021. Climate change and its impacts in the Balearic Islands: a guide for policy design in Mediterranean regions. Reg. Environ. Change 21, 107. https://doi.org/10.1007/s10113-021-01810-1.
Torres-Bagur, M., Ribas, A., Vila-Subirós, J., 2020. Understanding the key factors that influence efficient water-saving practices among tourists: a mediterranean case study. Water 12 (8), 2083. https://doi.org/10.3390/W12082083.

Tramblay, Y., Samuel, S., 2018. Future evolution of extreme precipitation in the Mediterranean. Clim. Change 151, 289–302.

Tuel, A., Eltahir, E.A.B., 2020. Why is the Mediterranean a climate change hot spot? J. Clim. 33 (14), 5829–5843. https://doi.org/10.1175/JCLI-D-19-0910.1.

Vicedo-Cabrera, A.M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., Astrom, C., Guo, Y., Honda, Y., Hondula, D.M., Abrutzky, R., Tong, S., Coelho, M. de S.Z.S., Saldiva, P.H.N., Lavigne, E., Correa, P.M., Ortega, N.V., Kan, H., et al., 2021. The burden of heat-related mortality attributable to recent human-induced climate change. Nat. Clim. Change 11 (6), 492–500. https://doi.org/10.1038/s41558-021-01058-x.

Yang, X., Xie, D.L., Liu, F.J., Wang, L., 2015. Spatial interpolation of daily rainfall data for local climate impact assessment over greater Sydney region. Adv. Meteorol. 1–12.

Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., Urban, A., Schneider, A., Entezari, A., Vicedo-Cabrera, A.M., Zanobetti, A., Analitis, A., Zeka, A., Tobias, A., Nunes, B., Alahmad, B., Armstrong, B., Forsberg, B., Pan, S.C., et al., 2021. Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. Lancet Planet. Health 5 (7), e415–e425. https://doi.org/10.1016/S2542-5196(21)00081-4.