Climate Change and Morphological Stability

Spanish scale

ENI CBCMED
Cooperating across borders in the Mediterranean

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Co-Evolve4BG

Analysis of Threats and Enabling Factors for Sustainable Tourism at Pilot Scale

Climate Change and morphological stability

Spanish scale

UNIVERSIDAD DE MURCIA

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OVERVIEW

This document was prepared in the framework of the project "Co-evolution of coastal human activities & Med natural systems for sustainable tourism & Blue Growth in the Mediterranean in relation to Threats and Enabling Factors for maritime development and coastal tourism on a national scale" Co-funded by ENI CBC Med Programme (Grant Agreement A_B.4.4_0075).

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REVIEW

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Abstract

This report aims to illustrate the climatic conditions and to identify the different threats of the morphological stability of the Spanish coastal zones. It is developed through the review of existing data at the national and regional scales. The document is structured as follows:

Section 1 provides an overview of the present and future possible trends of climate, sea surface temperature and sea level rise at the Mediterranean Spanish coast, in the light of climate change.

Section 2 focuses on reporting the trend of evolution of the Spanish coastal zones considering the foreseen relative Sea Level Rise scenarios and the present erosion trend.

Section 3 describes the methodology and characteristics of the climate change and morphological stability parameters selected in this project.

I. Introduction

This document constitutes a deliverable relating to the climate change (CC) and morphological stability in Spanish tourist areas which is part of the project of the Analysis of Natural Ecosystems evolution in relation to threats and favorable factors for maritime development and coastal tourism on a national scale.

The country is currently witnessing a global change in the global climate is an unquestionable fact. Among the scientific community there is a very broad consensus that the terrestrial climate system, made up of the atmosphere, the oceans, the biosphere, the lithosphere and the cryosphere, is undergoing changes that are attributable only to the internal variability of the system itself. The external forcing of physical factors (variability of solar activity, volcanic eruptions, etc.), are insufficient to satisfactorily explain the observed alterations, which can only be understood if anthropogenic type forcing are considered. These are very diverse and range from emissions of different types of greenhouse gases, such as carbon dioxide, methane, etc., to change in land use or the emission of aerosols.

The accelerating effects of climate change have exacerbated existing environmental problems in the Mediterranean Basin caused by a fatal combination of changes in land use, increased pollution, and the decline of biodiversity. The consequences of global warming will therefore be much more severe for the countries of this region, such as Spain, than for other parts of the world.

II. Characteristics of climatic changes in Spain

II.1. Evolution of temperatures

The Spanish Climate Change Office (OECC) is amongst others responsible for coordinating the research activities carried out by universities and research institutes. Research on climate change scenarios is mainly performed by the State Agency of Meteorology (AEMet, 2021). The increase in temperature per decade in Spain has been estimated at 0.3 °C since the 1960s. The warming is more significant in summer than in the rest of the seasons and is slightly higher than that detected for all the continents in the period 1850-2012. The year 2019 has been the sixth warmest in Spain since the beginning of the series in 1965. Eight of the ten warmest years have occurred in this century and five of the six with the highest temperatures have been recorded in the previous decade. Annual average in our country has experienced a moderate decline in the last 50 years. 2019 was the second warmest year in the World and the warmest in Europe. The years around 2010 have been the warmest on Earth for as long as there are records. In addition, since the 80s, each decade has been warmer than the previous. In April 2019, AEMet's Izaña Atmospheric Research Centre registered an average daily CO_2 concentration of 415 ppm, an unprecedented value since humans have inhabited the Earth.

The year 2019 has been very warm in Spain, with an average temperature of 15.9 °C, a value that is 0.8 °C higher than the average annual value (reference period 1981-2010). It has been the sixth warmest year since 1965 and the sixth warmest so far in the 21st century, behind the years 2017, 2011, 2015, 2014 and 2006. Of the ten warmest years since the beginning of the series, eight correspond to the years of the 21st century and six of them belong to the decade 2011-2020 (Fig. 1).

The year 2019 has had a very warm character in most of mainland Spain, becoming extremely warm in some parts of the center and east of the peninsula (Fig. 2). In the Balearic Islands, temperature was ranging from warm to very warm, except in Ibiza where it had a normal climate.

Temperature anomalies close to + 1 °C were observed in large areas of Cataluña, Comunidad Valenciana, Murcia and Andalucía. In the rest of the Spanish mainland, the anomalies were close to 0 °C. In the Balearic Islands, the anomalies were mainly between 0 and + 1 °C, while in the Canary Islands they took values around 0 °C.

The daily maximum temperatures averaged +1.2 °C above normal, with 2019 being the third year with the highest average temperature since the beginning of the series in 1965, behind 2017 and 2015. On the other hand, the minimum daily temperatures were only +0.3 °C higher than the normal value, resulting, therefore, a daily thermal oscillation +0.9 °C higher than normal.

The year 2019 began with January as a normal month, with an average temperature in Spain of 0.1 °C lower than the normal value for this month. February was warmer, with an average temperature of 1.2 °C above the average for this month.

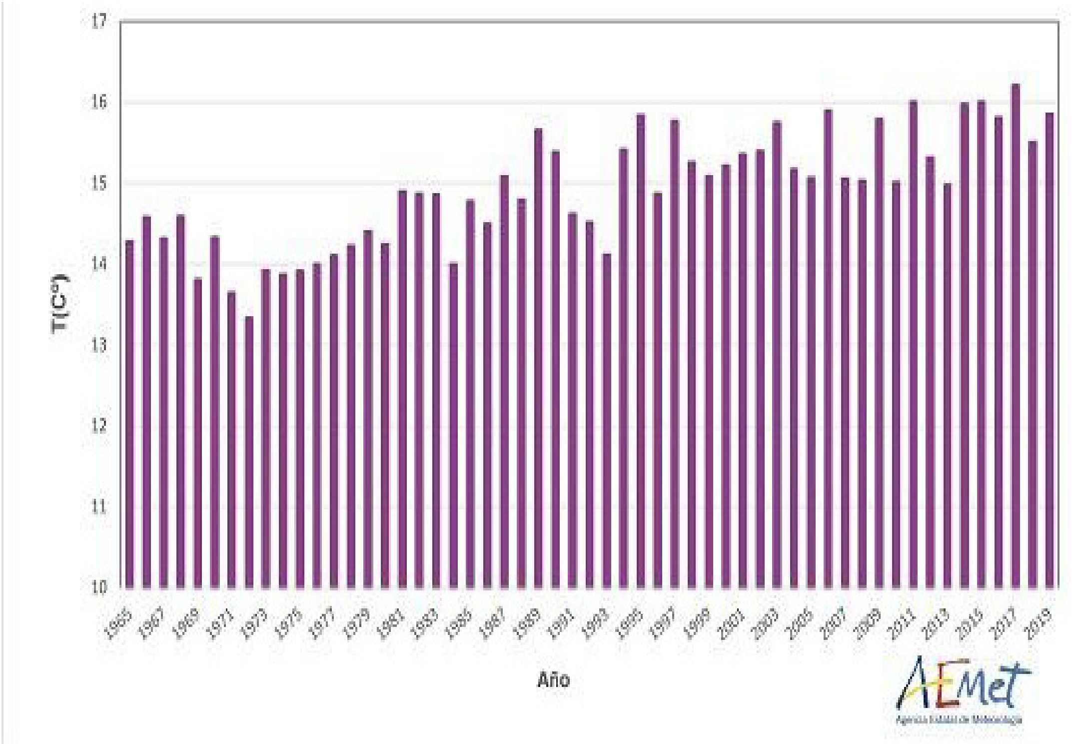

Figure 1. Series of annual average temperatures over Spain since 1965 (AEMet (2021). State Meteorological Agency. Ministry of Ecological Transition)

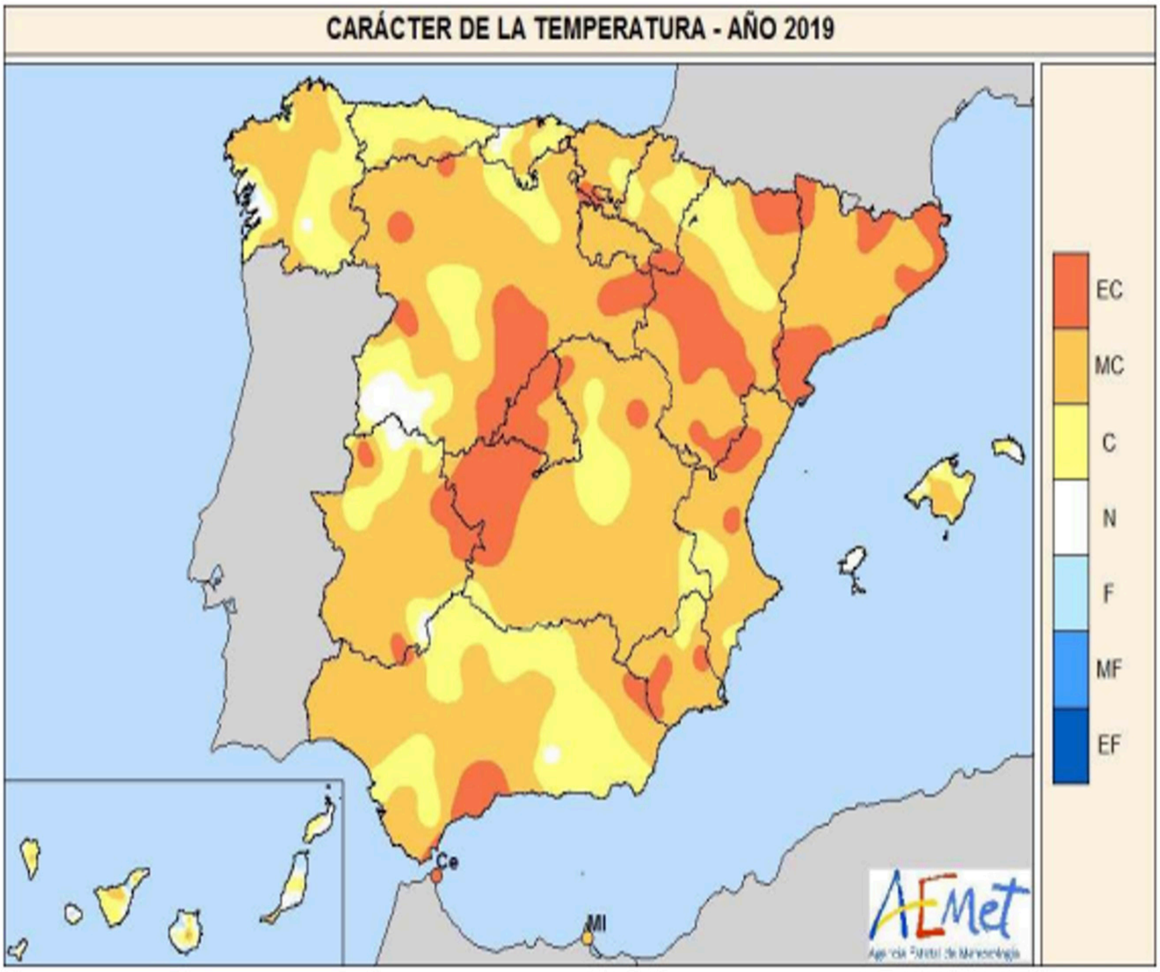

Figure 2. Temperature mean of 2019. (AEMet, State Meteorological Agency, 2021. Ministry of Ecological Transition (2021))

EC = Extremely Warm: Temperatures exceed the maximum value recorded in the reference period 1981-2010. MC = Very warm: f <20%. The temperatures recorded are in the interval corresponding to 20% of the most recent warm years. C = Warm: 20% ≤ f <40%. N = Normal: 40% ≤ f <60%. The recorded temperatures are around the median. F = Cold: 60% ≤ f <80%. MF = Very Cold: f ≥ 80%. EF = Extremely cold: The temperatures do not reach the minimum value recorded in the reference period 1981-2010

Spring (period between March 1 and May 31) had a warm temperature, averaging 14.2°C, a value that is 0.5°C above the average for this season. It began with a warm month of March, with an average temperature that was 0.7°C above the normal for the month. April was normal, with an average temperature that coincided with normal, while May was warm, with a temperature of 1.0°C higher than the average for the month.

Summer (June 1 to August 31) was very warm, with an average temperature of 23.8°C, a value that is 0.8°C above the average for this season. The three months of summer were very hot, with an average temperature that was 1.2°C above normal in June and July, and 0.9ºC above normal in August.

Autumn 2019 (September 1 to November 30) was warmer than 2018, with an average temperature of 16.5°C, 0.7°C above the average for this season. Autumn began with a warm September, with an average temperature that was 0.7 °C above the normal for the month. October was very warm, with a temperature 1.3 °C above normal, while November was normal, with a temperature 0.1° C higher than the average for the month.

The month of December was warmer than 2018, with an average temperature, in Spain, of 9.9°C, a value that is 1.9°C above the average for the month, resulting in the 4th warmest December since 1965 and the third since the beginning of the 21st century (Fig. 3).

II.2. Episodes of extreme temperatures

Throughout the summer, episodes of temperatures above normal were frequent, registering three heat waves. A heat wave lasted from June 26 to July 1 and affected a large part of the Iberian Peninsula and the Balearic Islands, due to very warm and dry continental tropical air masses from North Africa. In this episode, 40 °C was exceeded in large areas in the center and northeast of the peninsula, reaching values above 43º C in some points. The other two heat waves, with less intensity, lasted from July 20 to 25 and August 6 to 10; respectively.

Regarding cold episodes, two cold waves were observed during the winter months: the cold wave of January 4-8, in which generalized low minimum temperatures were registered, although the maximums in many areas reached values for above normal; and the cold wave of January 11-13, shorter but more intense than the previous one, during which the lowest temperatures of the year were reached. There was also a significant cold episode on February 1-4.

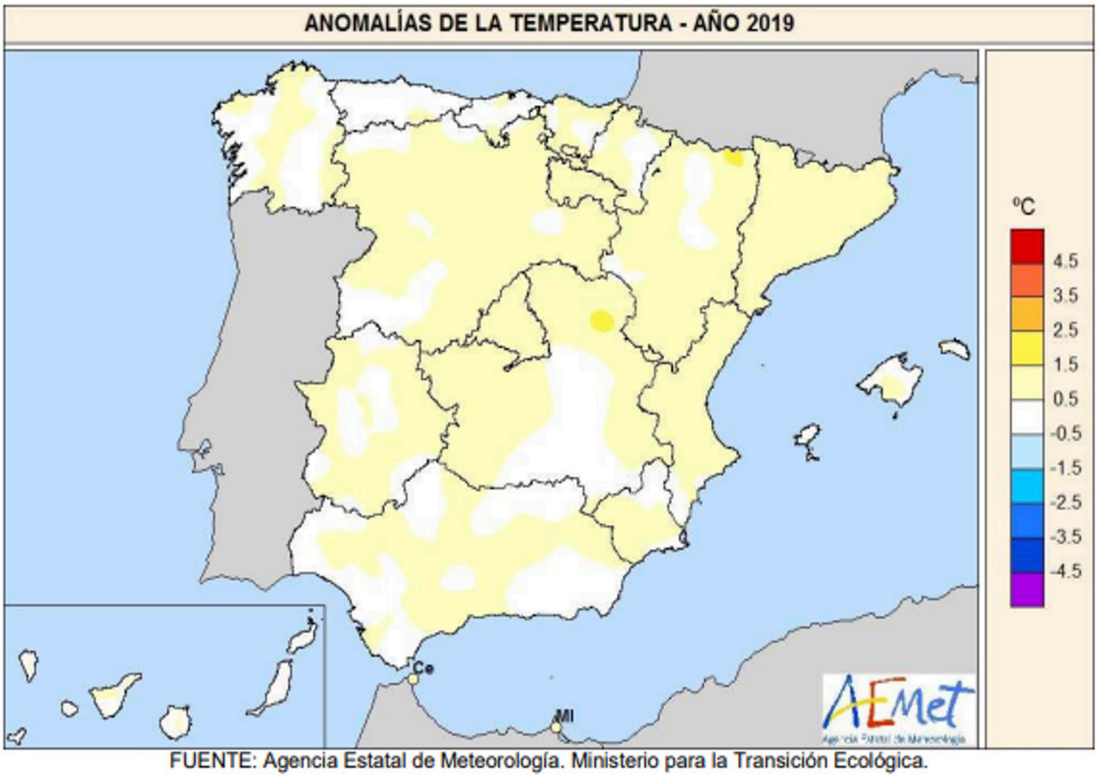

Figure 3. 2019 temperature anomalies (AEMet, State Meteorological Agency. Ministry of Ecological Transition (2021))

II.3 General rainfall characteristics

The year 2019 has been in terms of amount of precipitation, a normal year on the whole in Spain. Average rainfall was 628 mm, a value that is 3% below the annual average related to the 1981-2010 reference period (Fig. 4). After a very humid November and December, the year has turned out to be normal despite that the first period of the year from January to October had been very dry.

The year was humid or very humid in the southeast of the peninsula between Alicante and Murcia, while it has been dry in extensive areas of Andalusia, Valencia and Catalonia. It has become very dry in the region between Tarragona and Castellón, being in the southwest of Andalusia where it has been extremely dry.

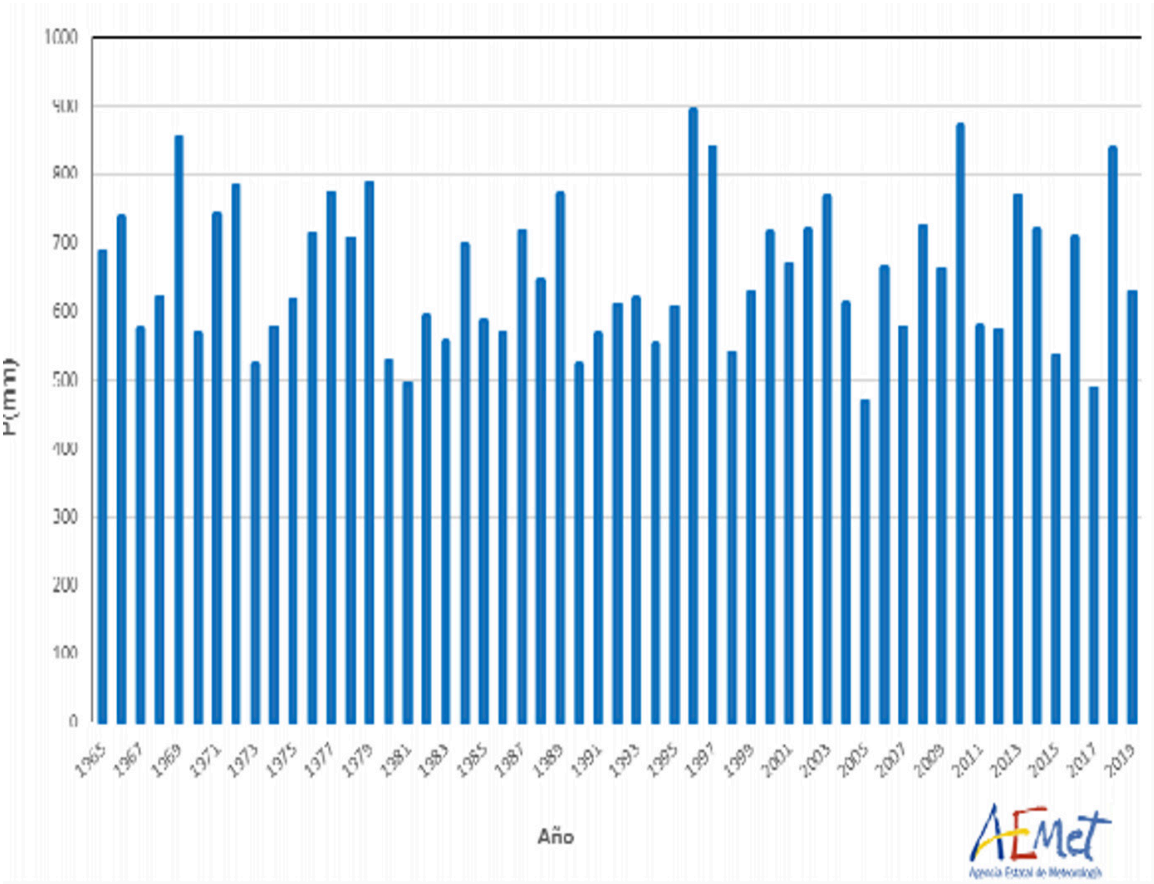

Figure 4. Series of mean annual rainfall over Spain since 1965 (AEMet, State Meteorological Agency. Ministry for Ecological Transition (2021))

II.4. General rainfall characteristics

The year 2019 began with a normal month of January, with precipitation over Spain 14% lower than the average for the month (reference period 1981-2010), followed by a very dry month (how much?) of February with precipitation of 72% below the normal value. With the information available, February 2019 has turned out to be the driest month so far in the 21st century, and the fourth driest since 1965 (Fig. 5).

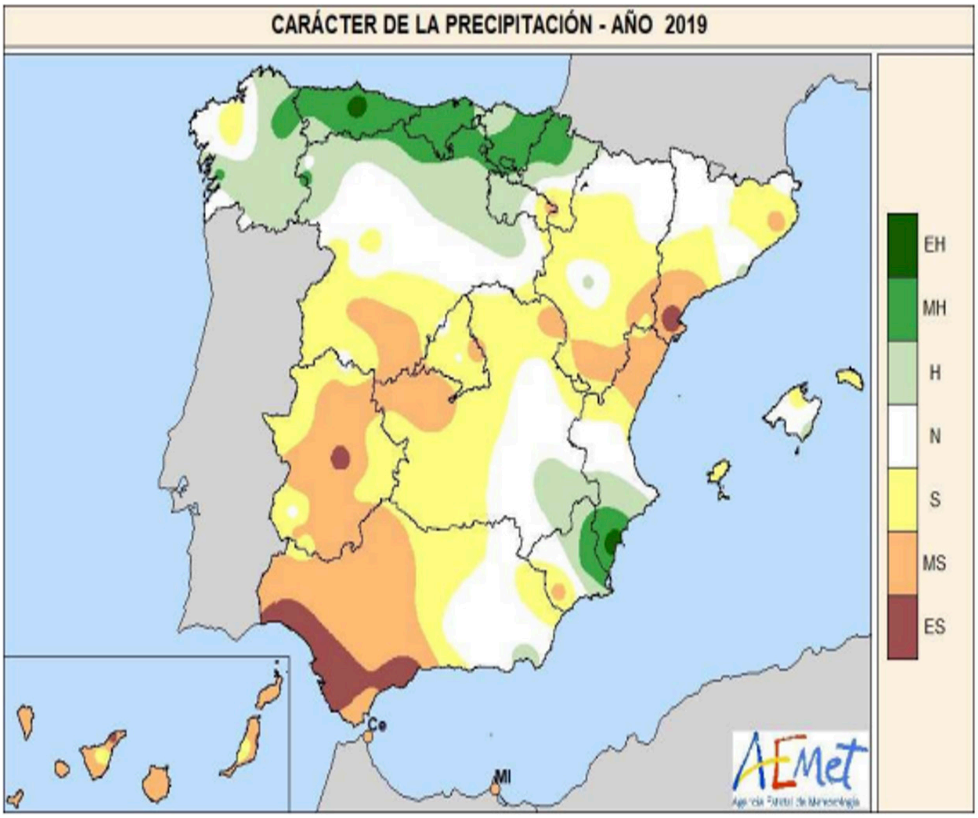

Figure 5. 2019 Precipitation means (AEMet, State Meteorological Agency. Ministry of Ecological Transition (2021))

EH = Extremely humid: Rainfall exceeds the maximum value recorded in the reference period 1981- 2010. MH = very humid: f <20%. The precipitations are in the interval corresponding to 20% of the wettest years. H = Moist: 20% ≤ f <40%. N = Normal: 40% ≤ 60%. Recorded rainfall is around the median. S = Dry: 60% ≤ f <80. MS = Very dry: f ≥ 80%. ES = Extremely dry: Rainfall does not reach the minimum value recorded in the reference period 1981 – 2010

II.5. Episodes of heavy rainfall

Water scarcity is a significant issue in many regions throughout Spain; and climate change may aggravate the problem, with longer periods of dry weather. Supply problems regularly occur in the Jucar basin during summer. In the Segura basin, water scarcity has resulted in an increase of the water prices by 30% for households.

The most extraordinary episode of the year of intense and persistent rainfall that gave rise to an extensive area of flooding, took place in September 2018, between days 10 and 15, both due to the accumulated amounts of precipitation that exceeded 200 mm, as well as the extension to other affected areas (> 300 km^2), especially the southeast of the peninsula. All over this episode in some areas of the provinces of Alicante and

Murcia, more than 400 mm were accumulated, and in more than 100 stations of the AEMet network more than 100 mm were accumulated, with more than 85 of these stations being located in the provinces of Valencia, Alicante and Murcia (Fig. 6).

Regions in the south-east of Spain are particularly vulnerable to water shortages due to the hot weather and intensive urbanization of the coastline by the tourism industry and holiday homes. These regions have furthermore an intensive agricultural sector requiring significant irrigation networks. Large areas of the Mediterranean are affected by saltwater intrusion as a result of groundwater over-abstraction for public water supply, followed by agricultural water demand and tourism-related abstractions.

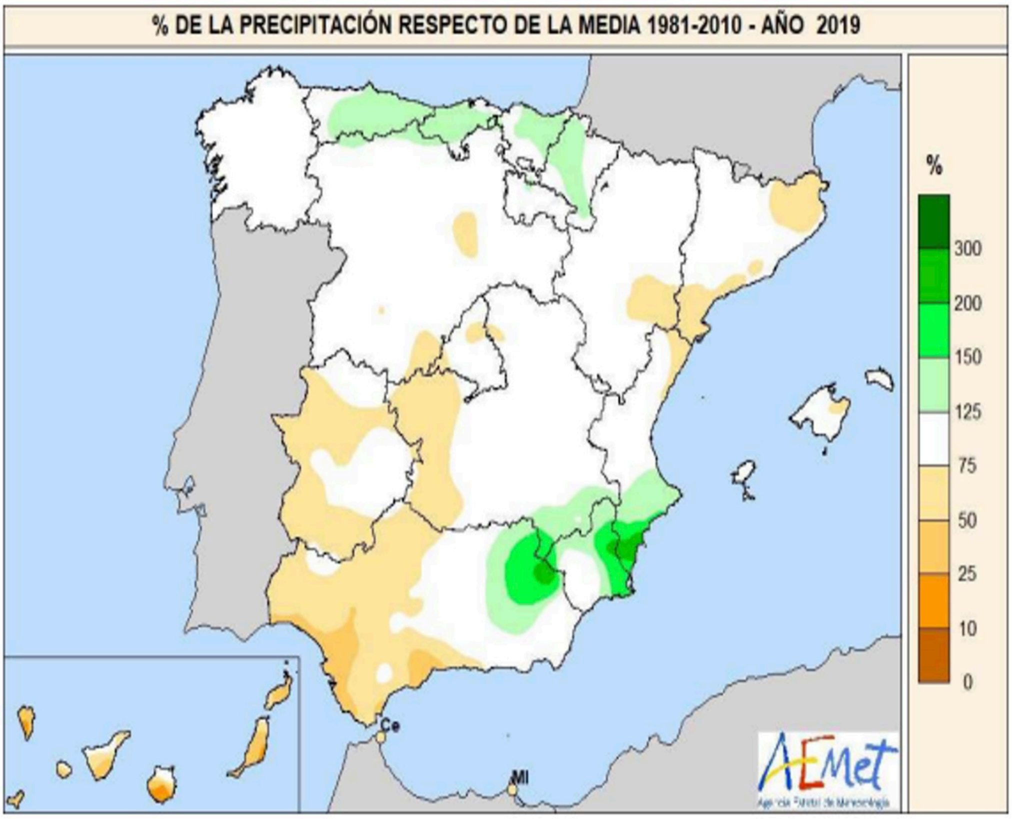

Figure 6. Precipitation Percentages with respect to the means of 2010 (AEMet, State Meteorological Agency. Ministry of Ecological Transition (2021))

III. Climatic future trends in Spain

The frequent effects of climate change have exacerbated and resulting environmental problems in the Mediterranean Basin caused by a fatal combination of changes in traditional land use, increased pollution, and biodiversity decline. The consequences of global warming will therefore be much more severe for the countries of this region, such as Spain, than for other parts of the world.

Like many regions worldwide, Spain is getting warmer and drier because of the climate crisis. The Mediterranean coast of Spain has already warmed about 1.5 °C – more than the global average of 1.1°C – since the Industrial Revolution (1760-1840). And according to a recent report from Mediterranean Experts on Climate and Environmental Change (MedECC, 2021), without urgent climate action, Spain and other Mediterranean countries are likely to see dramatic temperature increases in the decades to come. Without additional mitigation, regional temperature increases will be 2.2°C in 2040, possibly exceeding 3.8°C in some regions in 2100.

Several critical aspects, such as access to water, ecosystems, food, health and safety, present risks, with a tendency to worsen in the coming decades, to continue with the current trend. Sustainable development policies in Mediterranean countries must address these problems. However, there has not been a systematic collection of information, nor sufficient impact models on the risks posed by climate change in the region. All these changes could carry risks. For example, the average surface temperatures: today, they are one and a half degrees above those recorded in the pre-industrial era, when the average global warming was 1.1°C. If this trend is not mitigated, by 2040 the increase will reach 2.2°C and by the end of the century, it will be 3.8°C above, in some parts of the region - including the center of the Iberian Peninsula.

Rainfall during the summer months will drop between 10% and 30% across the Mediterranean. Extreme events, such as heat waves, droughts, wildfires, and floods and river overflows will become more frequent.

The sea surface temperature (a factor related, among others, to the extinction of marine species and extreme storms such as the recent DANA (Isolated Depression at High Levels) in the southeast of the peninsula, has been increasing at an average of 0.4°C per decade. The DANA is the closed encirclement of cold air in the higher layers of the atmosphere. This phenomenon can be dangerous in late summer and early autumn when the accumulation of heat and humidity collide with the cold of the upper layers and therefore that impact causes storms and major downpours. Thus, the projections for 2100 vary between 1.8 and 3.5 °C above the temperatures recorded between 1960 and 1990.

As for sea level, it will increase by 3 mm per year. There is great uncertainty regarding the global average increase for the future: the range covers a rise in water that would go from 52 to 190 cm by 2100 at the global level. With this level the acidification of the water would increase.

If temperatures in the Mediterranean basin rise by 2 °C, most of Spain and Southern Europe would have a climate similar to that of current North Africa. For an already hot and dry area, this added heat could prove disastrous.

Summer seasons in Spain are expected to warm more than winters, creating space for periods of excessively hot weather to become more frequent and more severe. Extreme heat waves will expose people to all kinds of dangerous health impacts, including respiratory problems and even heat stroke.

This temperature rise is likely to happen at the same time as a trend towards reduced rainfall in coming decades – as much as 10-15% less precipitation if we see 2°C of global temperature rise – and a possible increase of extreme droughts. This combination of rising temperatures and less rain may result in desertification of wide swaths of Spain, leading to devastating agriculture. At the same time those parts of southern Spain are dramatically drying out, climate disruption could lead to severe flooding in other parts of the country, particularly its northernmost regions, because of increased severe storm activity. Spain also must contend with sea level rise and destruction of its celebrated coastline. Already, in the north of Spain, there is mounting soil erosion along the coast where 90% of all tourists spend their vacations.

IV. Coastal morphodynamics and potential impact of climate change in touristic Spanish Coast

IV.1. Coastal evolution in Spain

Spain has a high overall vulnerability to flooding and erosion. Nevertheless, vulnerability varies depending on the region. As to the problem of erosion, the Mediterranean coast is said to be most at risk. The total coastline subject to erosion is 11.5% or 757 km. The most vulnerable regions in this respect are Andalucía with erosion along 41% of its coastline, Cataluña with 33% and Valencia with 26% despite these regions having defense works and artificial beaches along 25% of their coastline (National Institute for Coastal and Marine Management of the Netherlands, 2004).

When taking different factors into account (*e.g.*, SLR, erosion, wave height and direction) the regions with the highest exposure to climate change are Andalucía and Valencia followed by Cataluña, the Baleares and Cantabria (Uceda et al. 2005). The diverse geographic distribution of sediment along the coast reflects the differences in river basins, which have historically provided heavy discharges to the coast, later reworked by wave action. Beaches located close to the mouth of the main river present sediment finer than for beaches fed by ephemeral stream flows (usually very short).

This general pattern has been modified in the last decades by the supply of allochthonous sediments (of marine and terrestrial origin) in a considerable number of beach nourishment operations that have created an artificial morpho-dynamic signature in most of the beaches. As an example of this alteration, only in the central part of the Catalan coast, with more than 10 million tons of sand have been supplied through different beach nourishment operations, during the last 20 years (Gracia et al. 2013).

In the Catalonia region, the average beach has a width of about 37 m, with a mean sand size ranging from 0.2 to 1.8 mm (median value of about 0.7 mm) and a foreshore slope steeper than 1/10. The shoreline changes for the period 1995–2004 show a general retreat, with more than 70% of Catalan beaches eroding (CIIRC, 2010), with average rates of about –2.1 m/y and of about –3.3 m/y when the Ebro delta is considered.

Only 24% of the beaches have experienced accretion with an average rate of about +1.5 m/y and mainly correspond to areas located at the end of coastal cells which bank up the sediment from the upstream part of the cell or, in the particular case of the Ebro delta, from its ending spits (Sánchez-Arcilla et al. 2006). A study carried out by Enriquez et al. (2017) in Balearic Islands shows that beaches would suffer a coastal retreat between 7 and up to 50 m, equivalent to half of the present-day aerial beach surface, under the climate scenarios considered.

Long-term coastline change rates (erosion/accumulation) analysis in this work is justified by the fact that long-term rates of erosion would condition the potential impacts of an expected sea level rise (and regardless of magnitude of this) in the sense of: at higher rates of negative erosion greater vulnerability, and greater positive erosion rates, less vulnerability.

Erosive processes in the Mediterranean coast of Spain show different degrees of affection (Fig. 7), with high values observed in Barcelona, Tarragona, Castellón, Alicante, Almería y Málaga, with moderate values prevailing in the Nuts 3 of Girona, Valencia, Granada and Murcia; and the low values in the Balearic Islands and Cádiz. For example, the coast of the Region of Murcia has undergone significant changes between 1956 and 2013.

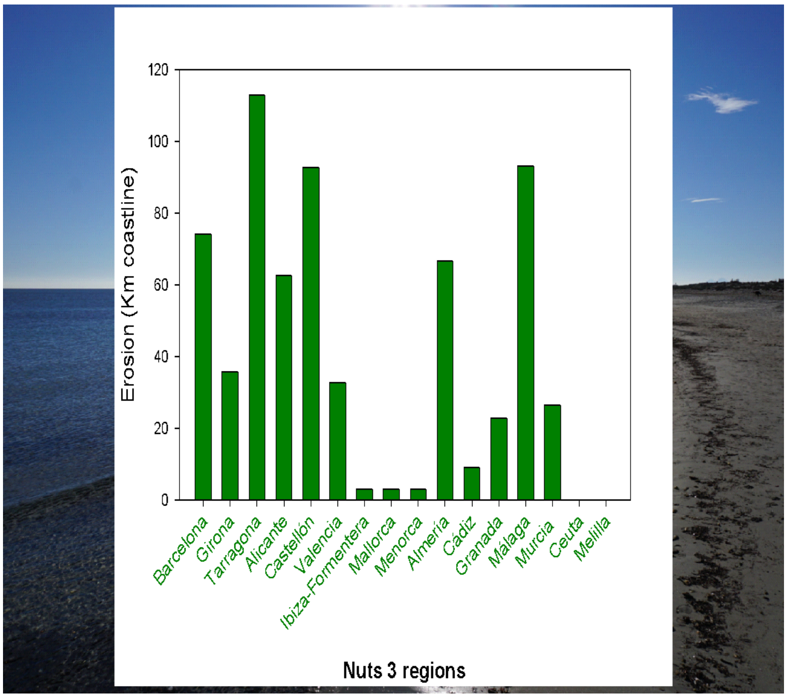

Figure 7. Erosion of the Spanish Mediterranean coast at Nuts 3 regions

Ibarra-Marinas et al. (2012) demonstrated significant changes with high spatial and temporal differences between the cities of Águilas and San Pedro del Pinatar (Fig. 8). These changes are mainly related to transformations in land use from the 80s of the last century, from traditional to modern agriculture which have resulted in reduced sediment yields that contributed to the coastal system in the region. The uses and watershed hydrology of the southern region are those that have experienced the biggest changes; translated into big losses of beach surface.

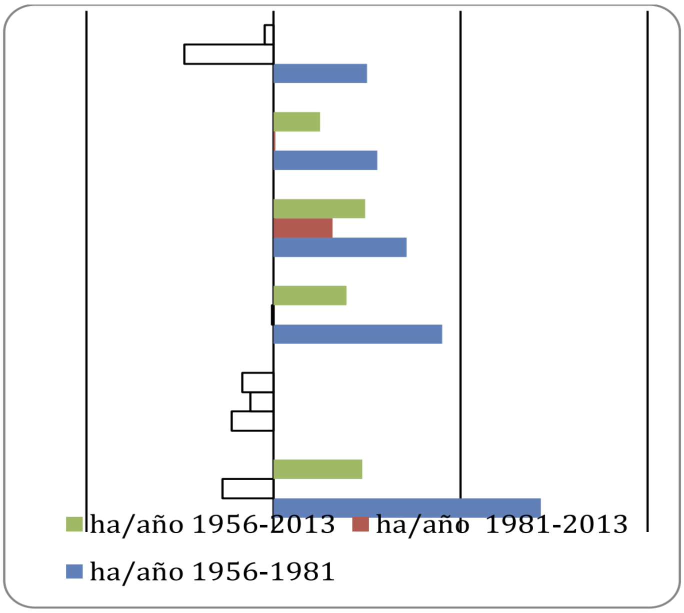

Figure 8. Annual rate of lost beach area of Cartagena, Mazarrón (Nut 3: Murcia Región) for 1956-1981, 1981-2013 and 1956-2013 intervals (Modified from Ibarra-Marinas et al. (2012))

The coast stability in the Mediterranean coast of Spain show a different degree of affection, with high values (60-80%) being observed in the Balearic islands, with moderate values in the provinces of Girona, Alicante, Valencia, Almería, Granada, Cádiz and Murcia; and very low in Barcelona and Castellón, Ceuta and Melilla (Fig. 9).

The term progradation refers to the growth of the coastline farther out into the sea over time. The results obtained in relation to the parameter progradation, show very low values on the Spanish coast, except in Barcelona, Tarragona, Castellón, Valencia, Almería, Cádiz and Murcia (Fig. 10).

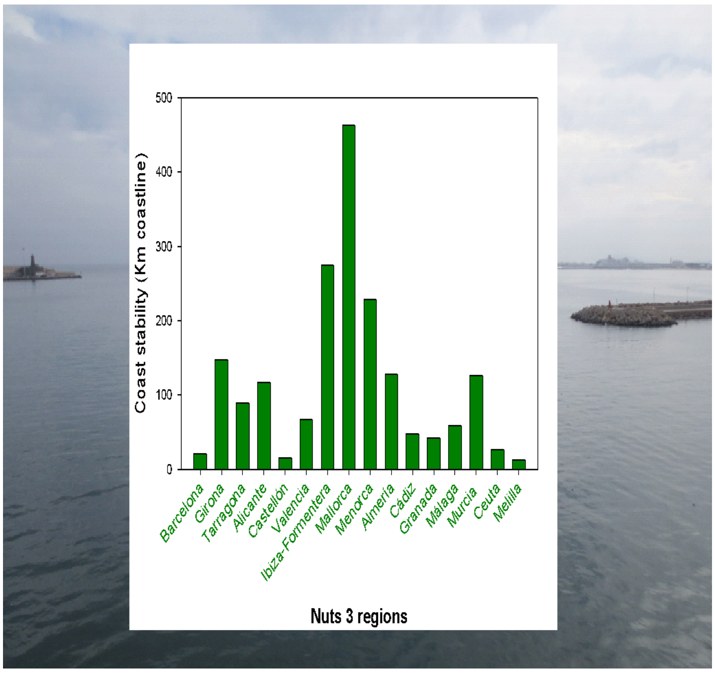

Figure 9. Coastal stability of the Spanish coastline at Nuts 3 regions

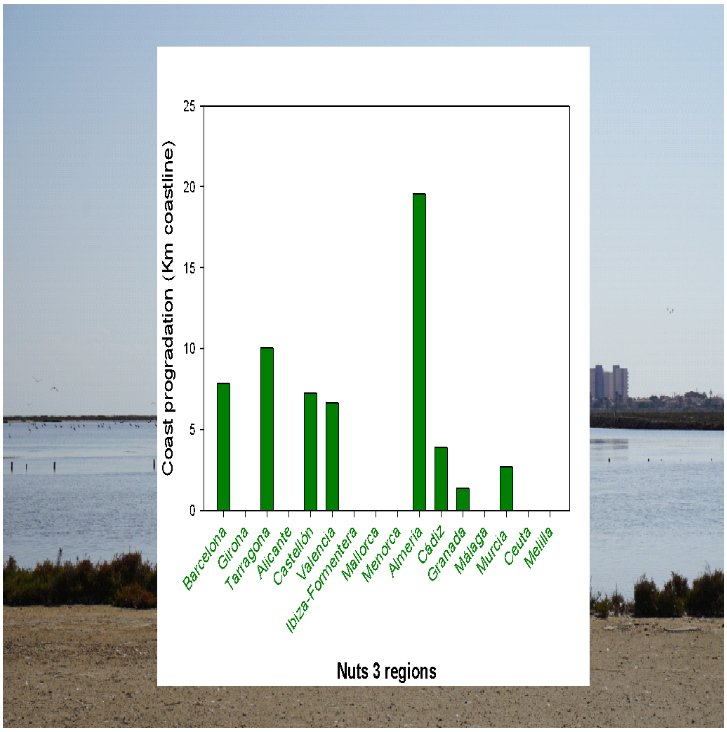

Figure 10. Progradation of the Spanish coastline by Nut 3 regions

IV.2. Type of coastline in Spain

The percentage of sandy beaches on the Mediterranean coast of Spain is close to 30% in many regions (Fig. 11), with low values in Barcelona, Mallorca, Menorca, Almeria and Melilla. River mouths, deltas, estuaries and soft sedimentary strands in the Mediterranean coast of Spain show a higher percentage in Barcelona, Mallorca, Menorca, Almería and Melilla. The other Nuts 3 regions have a percentage between 30-20% (Fig. 12).

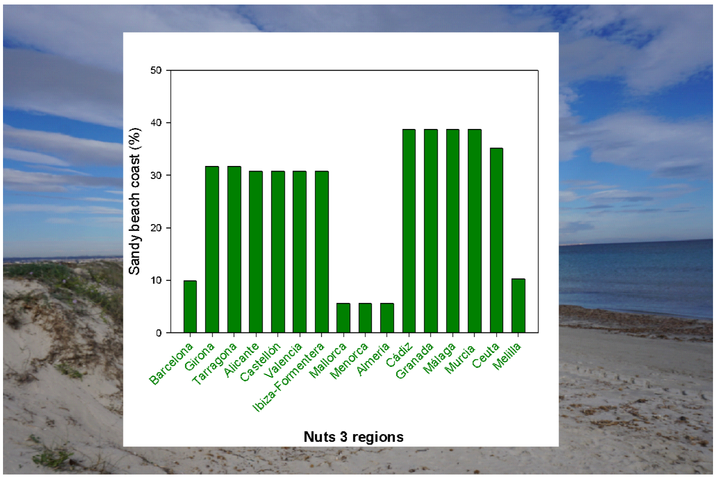

Figure 11. Percentage of sandy beaches on the Spanish coastline by Nut 3 region

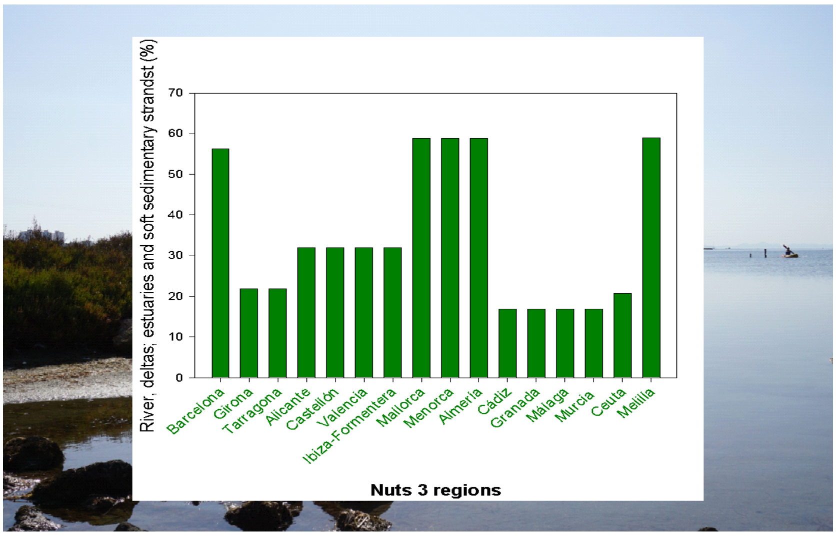

Figure 12. Percentage of "River, deltas, estuaries and soft sedimentary strands" coastline type on the Mediterranean coast of Spain by Nut 3 region

The EUROSION project (2004) calculated that 11.7% of Europe's coastline is characterized by soft rocks, where conglomerates and cliffs made of erodible rocks (*e.g.*, chalk) and characterized by the presence of rock debris and sediments (sand or pebbles) on the strand".

The plot of "soft rock shores" type of coastline, exhibits similar percentages in the majority of the Nuts 3 regions (13-21%), except in Melilla with the highest percentage (58.9%) and Alicante, Castellón, Valencia and Ibiza-Formentera with the lowest values (< 2.5%; Fig. 13).

The distribution of artificial structures and artificial frontage present a high homogeneity throughout the coast of Spain, with a very low percentage (Fig. 14). The highest values are in Girona and Tarragona.

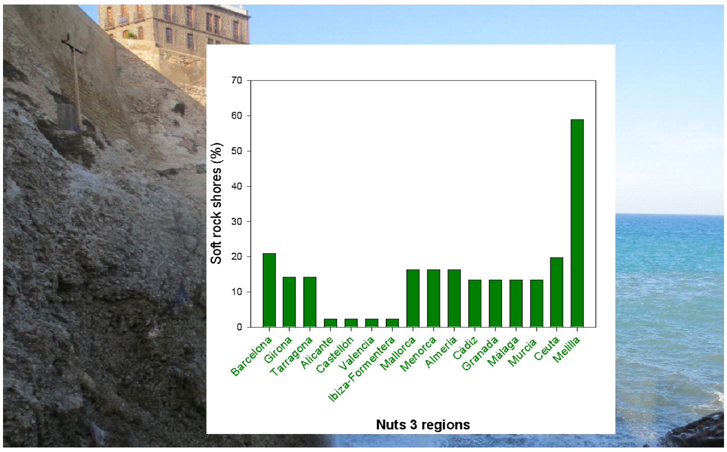

Figure 13. Percentage of "Soft rock shores" coastline type on the Mediterranean coast of Spain by Nut 3 region

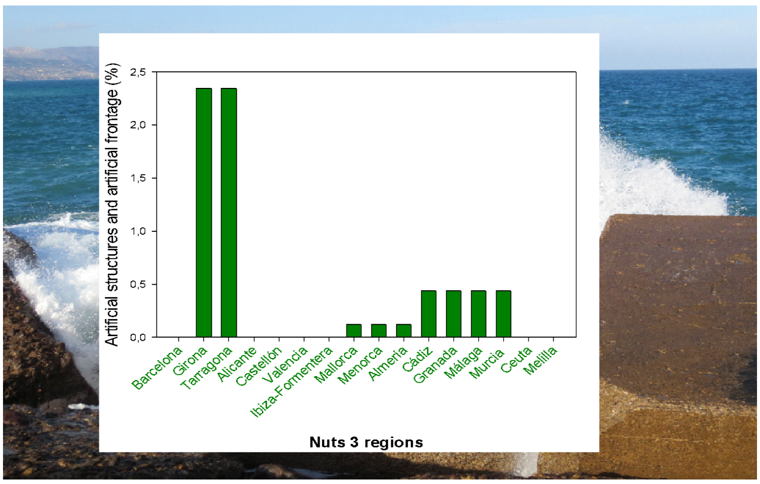

Figure 14. Percentage of "Artificial structures and artificial frontage" coastline type in the Mediterranean coast of Spain by Nut 3 region

IV.3. Change of sea surface temperature in Spain

Recent studies showed that sea surface temperature (SST) in the Mediterranean plays a relevant role in the genesis and/or intensification of torrential rains across the whole basin, especially in the Western Mediterranean Basin. A consistent warming trend has been found for Mediterranean SST from 1982 and 2016 (Pastor et al. 2018).

Analysis of decadal trends has shown a clear increase of the warming trend from 1993 to date. The 35-year data series was divided in three "almost decadal" periods, yielding a trend of (1.67 ± 0.53) × 10–4 °C/day for the first decade (1982–1992) and higher values of (2.82 ± 0.47) × 10–4 °C/day and (3.08 ± 0.47) × 10–4 °C/day for the 1993–2004 and 2005–2016 decades (Pastor et al. 2018). The warming rate in the last decade accelerated to a 1.8 ratio in respect to the 1982–1992 trends. Besides not being homogeneous on an inter-annual scheme, SST trend is neither homogeneous nor on an intra-annual basis (Pastor et al. 2018). The last three decades the Mediterranean Sea has experienced an estimated increase in its global surface temperature of 0.6-1°C.

Some predictions based on these data, and considering the trends of recent years, suggest that this increase could reach 5.8°C by 2100 (Sakalli, 2017; Fig. 15).

The predicted changes on sea water temperature displays homogeneity throughout the coast of Spain (Fig. 15), in all Nut 3 regions, the estimated change of values is ranging between 2.5 and 3 °C per year, these changes can be considered as moderate if they are compared with the Eastern Mediterranean Basin (Sakalli, 2017).

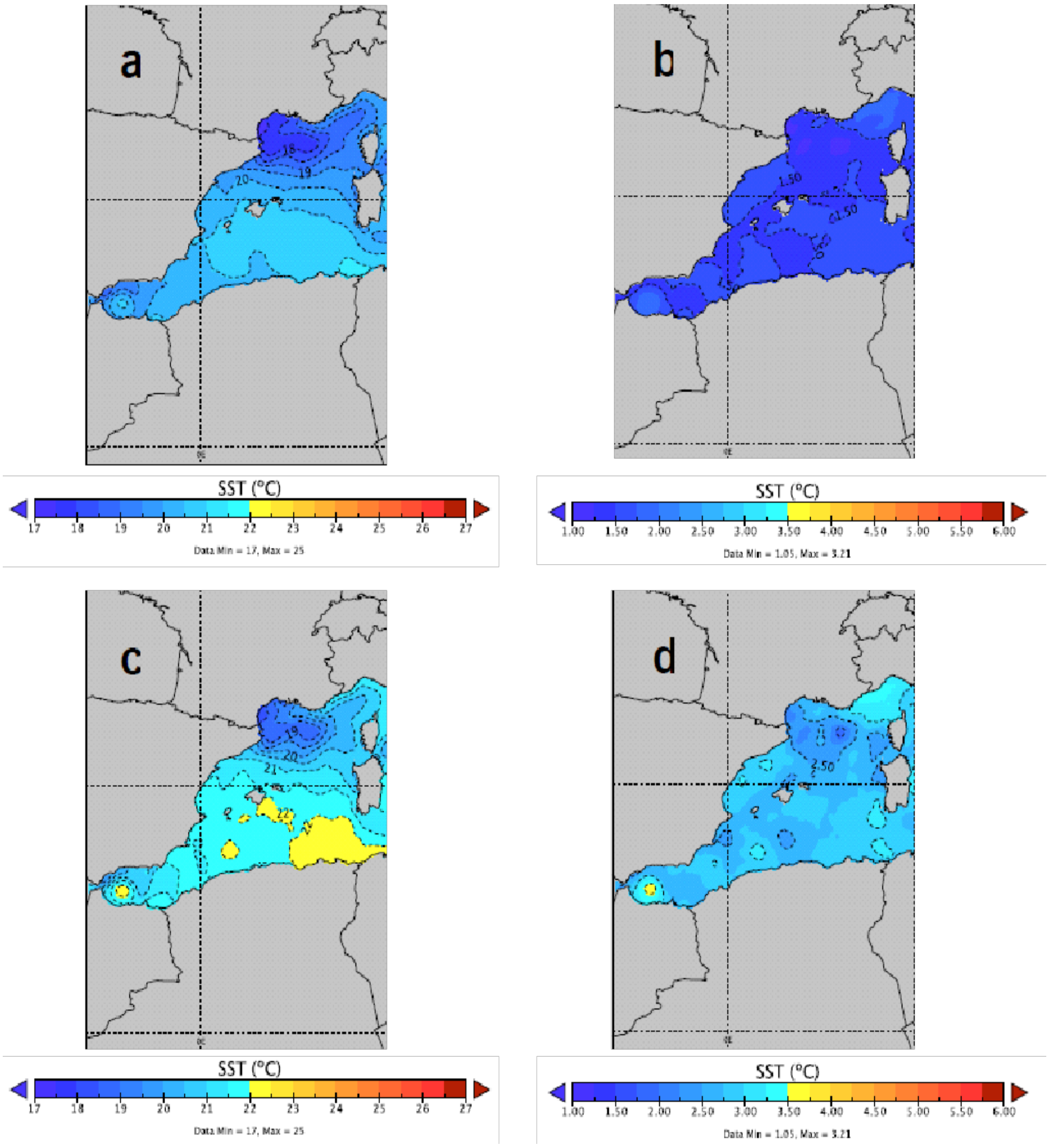

Figure 15. Distribution of the predicted 30-year, *i.e.*, a) 2031-2060 and b) 2071-2100 average sea surface temperature in the Mediterranean Sea, and the relative differences (c and d) to the 30-year study period (1986-2015), respectively (modified from Sakalli (2017))

IV.4. Sea level rise in Spain

Studies projecting meteorological changes and assessing their potential impact, often take the reports of the Intergovernmental Panel for Climate Change (IPCC, 2021) as a baseline which estimate SLR by 2100 of 0.88 m. Sea level rise, as one of the most important Climate Change effects, will have serious implications in relation with agriculture, natural resources, tourism and industry in our case study.

In the case of a widespread SLR, the most vulnerable areas are the deltas and enclosed beaches. Studies have indicated that without beach nourishments, a 0.5 m SLR, which is a reasonable scenario for Spain by 2100, could result in the disappearance of a high percentage of Mediterranean beaches. The projected SLR would result in the disappearance of about 50% of the Ebro Delta in the region of Cataluña (Sánchez-Arcilla et al. 2008). The mean sea level rising in Spain is shown in Figure 16. The Ebro Delta is already extremely vulnerable because the levels of sediment have been drastically reduced (mainly due to the river regulation) so that coastal fringes have become fragile and the direct hinterland is very near the present sea level. Consequently, coastal areas may experience more frequent flooding events.

The other serious effects of subsidence and relative sea level rise have been resulting in erosion and saltwater intrusion in coastal areas, thus can lead in the future in a greater loss of inhabitable and arable land as well as a serious change (or damages) to ecosystems, suggesting that increasing protection will be essential.

SLR models of the Mediterranean Basin indicated infra-regional differences due to differences in the elevation rate, which is more significant in the eastern part of the basin (between +5 and +15 mm per year, compared to less than +5 mm per year in the western region). SLR will be also modulated by specific characteristics from the Mediterranean Sea, which will also be affected by climate evolution, leading to a modification of the general conditions; and therefore; to changes in water volume.

Factors of particular importance are salinity, the action of atmospheric pressure, water balance (evapotranspiration, water inflows from rivers, exchanges with the Atlantic) or the influence of dominant currents (Hallegatte et al. 2007). There is homogeneity throughout the coast of Spain, in all Nut 3 regions with a high rate of 0-5 mm per year (Fig. 20).

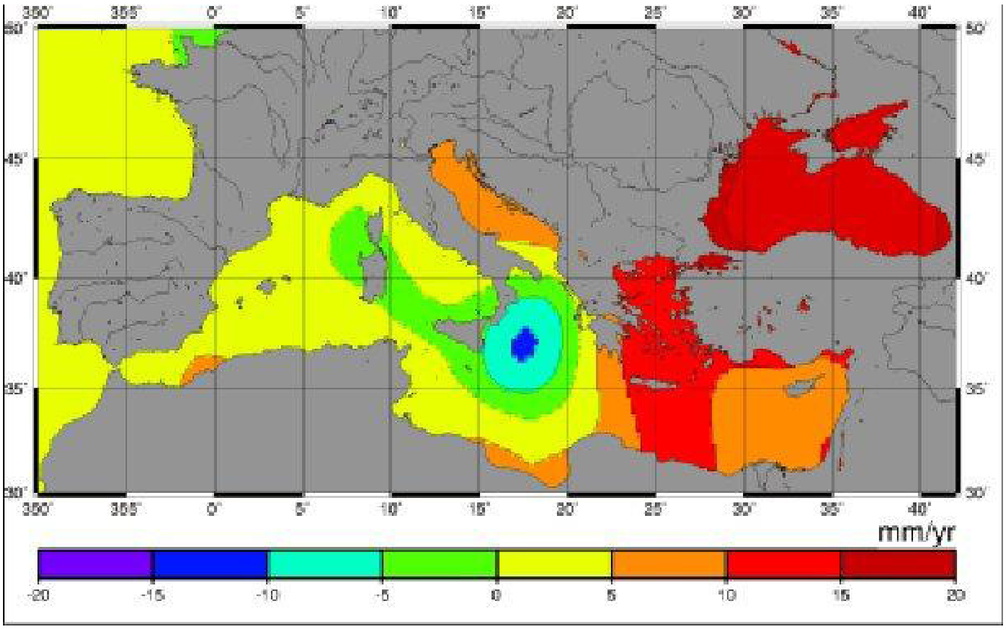

Figure 16. Sea level variations observed between 1992 and 1998 by the TOPEX/ Poseidon programme (LEGOS-GRGS-CNES (2021))

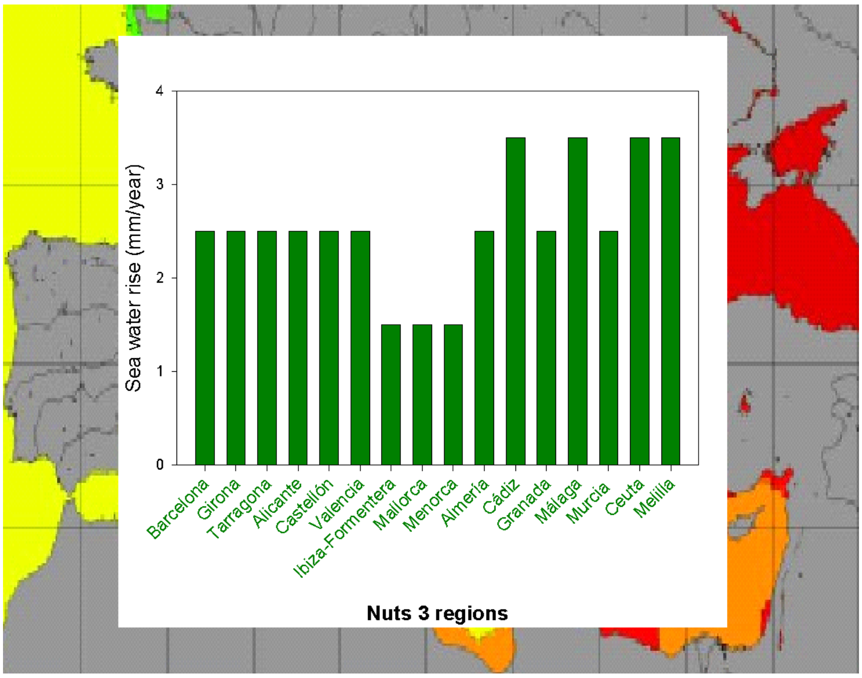

Figure 17. Annual rates of sea water rise on the Mediterranean coast of Spain by Nut 3 regions (mm/year)

V. Climate change and morphological stability parameters

V.1. GIS database

Geographic Information System (GIS) is applied in computer systems aimed at managing spatial data that visually allows us to analyze, manage and interpret geographic data. The methodology of this study was to find and process layers of shapefiles (i.e. geospatial data), and their subsequent analysis GIS shapefiles. Shapefile layers have been downloaded from official national statistical platforms (Ministry of Ecological Transition and Demographic Challenge; MITECO, 2021) and from European platforms such as the European Marine Observation and Data Network (EMODnet, 2021).

The Spatial Reference System has the ETRS89 datum with UTM projection in the 30 North zone, with EPSG code: 25830. These have been based on official statistical platforms or rigorous studies, which guarantee the soundness of the information expressed. The GIS results were expressed by NUTS administrative boundaries from the EU (EUROSTAT https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-20-092).

The NUTS classification subdivides the economic territory of the EU States into territorial units (regions; Fig. 18). The classification was made up of three hierarchical levels: each State and the UK are divided into NUTS 1 regions, which in turn are subdivided into NUTS 2 regions and then divided further into NUTS 3 regions. Each of these regions is allocated a specific code and name. Since several different regions within Europe have the same name, a distinction has been made by adding to each of these, the abbreviation assigned for each country.

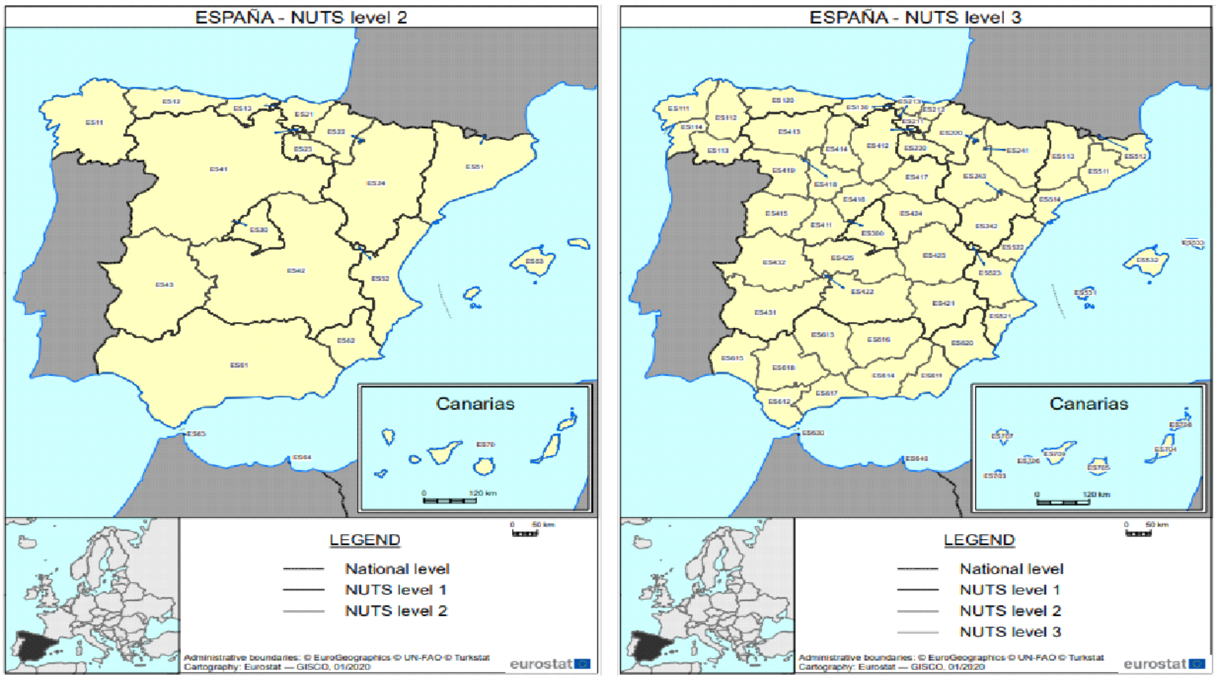

Figure 18. Spain (España): level 2 and 3 NUTS (EUROSTAT (2021)) https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-20-092)

V.2. Data Records

This report includes a csv file with all the information at Nuts 3 level into the repository. The database was updated and expanded as new and improved data has become available. The database presented here has been created using several publicly available data sets, which are thoroughly documented and described in reports or scientific articles (Table 1). Thus, these data sets have undergone rigorous quality control and validation. In addition, new data sets were generated for those parameters where consistent information for the studied area were not available.

V.3. Climate Change and Morphological stability parameters

A panel of external experts and the working group at the Mediterranean level of the Co-Evolve4BG project selected the following parameters of climate change and morphological stability, which will be analyzed on the National and Mediterranean scale (Table 1). In the supplementary material is located the excel table with the values of the parameters selected at the level of Spain.

Table 1. Climate Change and Morphological stability parameters

Parameters	Variable	Description	Source
Coastal evolution	Erosion (km)	Coastal erosion is the loss or displacement of land, or the long-term removal of sediment and rocks along the coastline	- Co-Evolve project: https://co-evolve.interreg-med.eu/ - CEDEX: http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/
	Stable (km)	Coastal stable is the lack of loss or displacement of land	- Co-Evolve project: https://co-evolve.interreg-med.eu/ - CEDEX http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/
	Progradation (km)	Progradation is the growth of the coastline farther out into the sea over time.	- Co-Evolve project: https://co-evolve.interreg-med.eu/ - CEDEX http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/ - Junta de Andalucía - http://www.juntadeandalucia.es/medioambiente/site/rediam/
	Coastal erosion rate (m/year)	Rate of erosion process by time	- CEDEX http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/ - Junta de Andalucia - http://www.juntadeandalucia.es/medioambiente/site/rediam/
	Coastal stability rate (m/year)	Rate of stability process by time	- CEDEX http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/ - Junta de Andalucia - http://www.juntadeandalucia.es/medioambiente/site/rediam/
	Coastal Aggregation rate (m/year)	Rate of aggregation process by time	- CEDEX http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/ - Authors' elaboration

Type of coastline	Rocky (km)	Intertidal area of seacoasts where solid rock predominates.	- Wolff et al. 2017
	Sandy (km)	Sandy shores or beaches are loose deposits of sand, including some gravel or shells, that cover the shoreline in many places.	- Authors' elaboration
	Cliff (km)	It is steeply sloping surface where elevated land meets the shoreline.	- Wolff et al. 2017 - Authors' elaboration
	Dune (km)	It is a landform composed of wind-driven sand.	- Wolff et al. 2017
	Coastal marshes (km)	It is a coastal ecosystem in the upper coastal intertidal zone between land and open saltwater or brackish water that is regularly flooded by the tides.	- Wolff et al. 2017
Water temperature	water temperature Means (°C)	Current average annual value of sea water temperature.	- AEMet http://www.aemet.es/en/portada (accessed 25.01.2021). GHRSST https://www.ghrsst.org/ (accessed 25.01.2021).
	Rising temperature of water (°C)	Rate of rising temperature of sea water per year.	- Sakalli, 2017; - Pastor *et al*. 2017 - AEMet http://www.aemet.es/en/portada (accessed 25.01.2021).

Sea Level Rise	Max Sea Level (cm NGT)	Current maximum sea level	- AVISO https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html (consulted 27.01.2021). - Puertos del Estado http://www.puertos.es/es-es (consulted 25.01.2021).
	Sea Level Rise (cm/Year)	Sea level increased in one year time. Satellite altimetry data provides accurate measures for a limited time range expressed in cm/y.	- AVISO https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html (consulted 27.01.2021). Puertos del Estado http://www.puertos.es/es-es (consulted 25.01.2021).
Atmospheric temperature	Atmospheric temperature (°C)	Current average annual value of atmospheric temperature.	- AEMET http://www.aemet.es/en/portada (consulted 25.01.2021). - Institut d'Estudis Catalans (2017)
	Atmospheric temperature rise (°C)	Rate of atmospheric temperature rising per year.	- Giorgi and Lionello, 2008 - AEMET http://www.aemet.es/en/portada (consulted 25.01.2021). - Institut d'Estudis Catalans (2017)

VI. Conclusions

In this report we present the main climatic and morphodynamics characteristics of the Mediterranean Spanish coasts and the potential changes associated with climate change. Spain is witnessing a warmer climate because of the climate change. This combination of rising temperatures with decreased rain may result in desertification of vast swaths of Spain. Without additional mitigation, regional temperature increases will be 2.2°C in 2040, possibly exceeding 3.8°C in some regions of Spain by 2100.

The Mediterranean Region of Spain has already warmed about 1.5°C – more than the global average of 1.1°C – since the Industrial Revolution. The increase in temperature per decade in Spain has been estimated at 0.3°C since the 1960s. The warming rate is more significant in summer than in the other seasons. The year 2019 was the warmest in Spain, with an average temperature of 15.9°C, a value that is 0.8°C higher than the average annual value (for the reference period 1981-2010). Extreme climatic events, such as heat waves, droughts, wildfires, and floods are expected to be more frequent. The Spanish coast has periodic episodes of catastrophic intensive rainfalls. These intense and persistent rainfalls during several days produce an extensive area of flooding (> 300 km^2), with accumulated amounts of precipitation that exceeded 200 mm, especially in the southeast of the Iberian peninsula.

The sea surface temperature (a factor leading, among others, to the extinction of marine species and extreme storms such as the recent DANA (Isolated Depression at High Levels) in the southeast of the peninsula) has been increasing at an average of 0.4ºC per decade. The main climate change impacts on the coastal zones, as pointed out by EEA (2008) and others are: flooding and erosion, saltwater intrusion and freshwater shortage, notably groundwater depletion, and the loss of coastal ecosystems. Mediterranean Spanish beaches are subject to high touristic pressure, especially during the summer season, and thus there is a concentration of valuable assets and infrastructures. Since tourism constitutes the main economic activity of a large fraction of Spain; the social, environmental and economic negative repercussions of sea level rise are anticipated if no adaptation measures are implemented.

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