CLIMATE SCENARIOS AND FUTURE THREATS

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4.1

IDENTIFICATION AND PRIORITISATION OF CLIMATE HAZARDS

To select the climate hazards to be considered in the Adaptation Plan, it is necessary to have updated contextual information on the existing/observed climate hazard scenario in the municipality, together with the most relevant associated climate parameters in each case and at the specific level. In addition, databases on climate-related disasters or hazards, together with multi-scale indicators of climate vulnerability and human development, or climate action plans, often compose a main and close source of information. Finally, this early detection of climate risks is technically complemented by local support tools, such as the consultation of experts and the analysis of the social perception of climate risks.

In this case, the procedure to identify the climatic hazards with the greatest incidence and relevance in the municipality of Santander consisted of the compilation and analysis of four basic sources of information:

Consultation through existing knowledge and adaptation support tools. Contextual and European level.

Documentary information sources, including regional and local territorial strategies and plans, scientific articles and university publications, among others. Regional and local level.

Public consultation through group workshops with relevant stakeholders. Local level.

Historical records of documented adverse weather damage in the municipality. Local level.

Once each of these sources has been evaluated, climate hazards in the municipality are prioritised using the multi-criteria analysis method, which consists of a semi-quantitative combination of a set of objective criteria that represent the specific incidence of each of the hazards in the territory, including their magnitude and frequency, as well as the damage caused in human and material terms. This process also takes into account two major types of climate hazards:

Direct, i.e., clearly associated with the occurrence of extreme weather events and climate variability, such as heat waves, droughts or extreme rainfall.

Derived, those that are influenced by the climate, generally as an exacerbating factor, but do not have an essentially meteorological or climatic origin, such as disease transmission.

The following sections analyse in detail the results obtained for each of the information sources and, finally, show the procedure and criteria used in the final prioritisation of climate hazards to be considered in this framework.

Preliminary Consultation through Climate Screening Tools

The European Climate Adaptation Platform (Climate-ADAPT)[1] aims to help Europe adapt to climate change by making it easier for users to access and share data and information on expected climate change, climate vulnerability and risk, and adaptation strategies and actions. At the level of climate impacts, coastal areas and floodplains in the western parts of Europe are specifically defined as multi-sectoral hotspots. The Atlantic region in particular is likely to present various challenges related to increased extreme precipitation events, river and coastal flooding or winter storms, among others.

Climate-ADAPT also makes tools available to the public that support adaptation planning. Among the latter, as a case in point, the Urban Adaptation Support Tool (UAST) aims to help cities, towns and other local authorities develop, implement and monitor climate change ad-

[1] The European Climate Adaptation Platform (Climate-ADAPT) is the result of a partnership between the European Commission and the European Environment Agency (AEMA).

aptation plans. The tool provides access to various sets of information generated in European cities, specifically the map viewer collects information from various sources on the observed and predicted spatial distribution and intensity of high temperatures, floods, water scarcity, forest fires and vector-borne diseases. The results of the basic screening of the tool for the city of Santander are shown below:

TABLE 4.1. *Climate-ADAPT climate dataset for Santander.*

TYPE OF HAZARD	INDICATOR USED	VALUE FOR SANTANDER
Extreme Temperatures	Projected number of extreme heatwaves (2020-2052; RCP 8.5; number in 33 years)	1 - Low level
	Annual number of degree-days of cooling or refrigeration (1990 - 2015 average)	31 - Low level
	Variation in the percentage of summer days classified as heatwave[A] between 1951-2000 and 2051-2100	High impact scenario (90th percentile): 40-50 Medium level
Coastal Flooding	Sea level rise in metres (2081-2100)	For RCP 8.5: 0.6-1m Very high level
		For RCP 2.6: 0.2-0.4m Medium level
	Percentage of the city centre flooded in a 1m sea level rise scenario (without defences)	2.08% of the urban core flooded Low level
Pluvial flooding[B]	Projected percentage change in extreme winter precipitation events (from 1971-2000 to 2071-2100; RCP8.5)	5 Low or Moderate level
Shortage, Water Scarcity	Projected trends in drought frequency (2071-2100; months per 30-year period)	5.98 Medium level RCP 8.5
Fires	Wildfire danger (1981-2010; seasonal severity index)	1.15 Low level RCP 8.5
	Predicted wildfire danger (2071-2100; seasonal severity index)	0.99 Low level RCP 4.5

[…/…]

Continuation **TABLE 4.1**

TYPE OF HAZARD	INDICATOR USED	VALUE FOR SANTANDER
Climate suitability for diseases	Climatic suitability for the tiger mosquito (*Aedes albopictus*) 2008-2009	99.96 Very high level (reference city: Bilbao)

Source: CINCc (UC) - FIC, 2024 based on data from the Urban Adaptation Support Tool (UAST) of the European Climate-ADAPT platform.[C]

Available at: https://climate-adapt.eea.europa.eu/en/knowledge/tools/urban-adaptation

A Heat waves are defined as three consecutive days in which both the maximum and minimum temperatures exceed their respective 95th percentiles of the historical period. The analysis is based on 50 climate model projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012), under the RCP8.5 climate scenario.

B Pluvial flooding in urban areas is the result of a combination of heavy rainfall and a high proportion of impervious surfaces. When water cannot infiltrate into the ground, the high amount of surface runoff can exceed the capacity of the drainage system and lead to flooding. Due to climate change, heavy rainfall is likely to become increasingly frequent in many parts of Europe.

C The aim of this tool is to provide an overview of current and future climate hazards facing European cities, rather than at a specific level. The information associated with each indicator can be found at the following link: https://climate-adapt.eea.europa.eu/en/knowledge/tools/urban-adaptation/Urban-Adaptation-viewer-datasets

In Santander, the time series of maximum temperature observed for the period of record from 1971 to 2005 shows a clear trend towards a sustained increase. As it can be seen in figure 11, the observed annual maximum temperature records show averages of 14 - 15°C for the 1970s, reaching averages of around 16.5°C for the last five years of the 20th century.

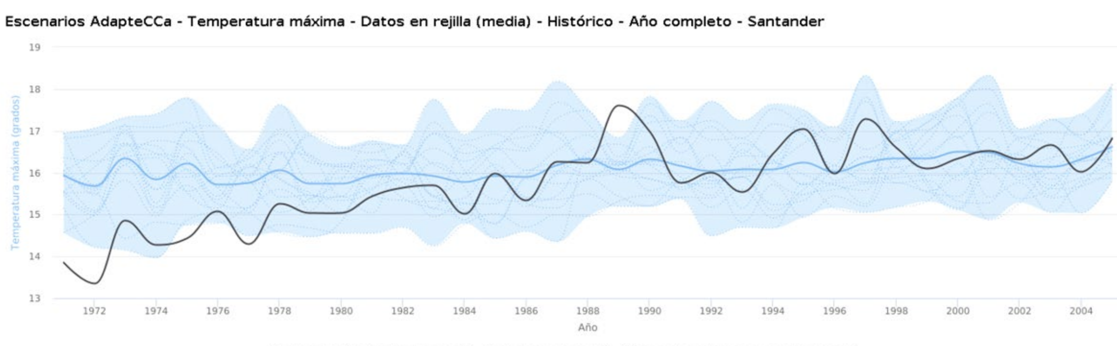

Figure 4.1. *Medium temperature, Adaptecca Scenarios*

Source: Adaptecca, 2022. http://escenarios.adaptecca.es

In 2010, the University of Cantabria prepared the Regional Probabilistic Scenarios of Climate Change in Cantabria in collaboration with the Spanish State Meteorological Agency, based on the outputs of the global models of the 4th IPCC Report, which are considered in the Climate Change Strategy currently in force. The results of these scenarios indicate average temperature increases of 3°C by the end of the century (4 ± 2°C for the worst scenario, A2), wich are somewhat milder for the coastal region. They also confirm a decrease in precipitation throughout the region in the second half of the century with low uncertainty, reaching decreases of 20% throughout the region. They also indicate changes in the distribution of precipitation, with larger decreases in spring and autumn. Consequently, the climate classification for the end of the century based on such projections with the intermediate and pessimistic scenarios indicate a clear trend towards a Mediterranean-type climate for the eastern region, with Mediterranean-oceanic transition climates progressively shifting from the coastal to the current Atlantic climate (Gutiérrez et al., 2010)[2].

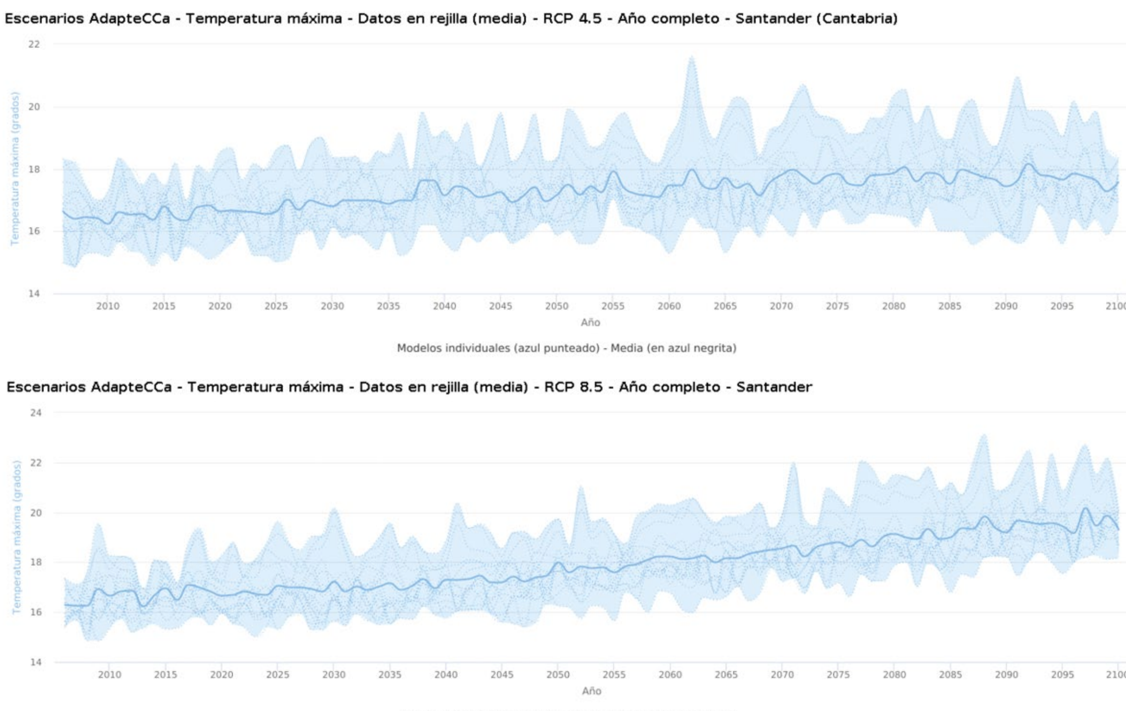

Figure 4.2. *Comparison of RCP4.5 and RCP8.5 Maximum Temperature Scenarios, Adaptecca*

Source: Adaptecca, 2022.

Subsequently, regionalised climate change projections for the whole of Spain were published on the Adaptecca[3] platform, based on the global projections of the IPCC's Fifth Assess-

[2] Gutiérrez, J.M., Herrera, S., San Martín, D., Sordo, C., Rodríguez, J.J., Frochoso, M., Ancell, R., Fernández, J., Cofiño, A.S., Pons, M.R. & Rodríguez, M.A. (2010). Escenarios Regionales Probabilísticos de Cambio Climático en Cantabria: Termopluviometría. Universidad de Cantabria, Consejería de Medio Ambiente, Gobierno de Cantabria.

[3] See the following website: https://escenarios.adaptecca.es/#&model=EURO-CORDEX-EQM.average&variable=tasmax&scenario=rcp85&temporalFilter=year&layers=AREAS&period=MEDIUM_FUTURE&anomaly=RAW_VALUE

ment Report, within the framework of the PNACC Scenarios initiative, particularly the 2017 PNACC Scenarios collection. The available data was mainly drawn from two sources: point projections from the Spanish State Meteorological Agency (AEMET) and gridded projections from the international Euro-CORDEX[4] initiative (CORDEX, 2023). The average maximum temperature observed in the last decade was around 16.5°C in Santander, which according to these scenarios will increase by approximately 1°C according to the RCP4.5 (intermediate) scenario by the end of the century, and by approximately 3°C according to the RCP8.5 (pessimistic) scenario.

These changes, in the case of coastal areas like in Santander, will have an impact on the occurrence of adverse climatic events, such as sea level rise, variations in wave height and intensity, extreme rainfall or increases in water temperature (Gobierno de Cantabria, 2018).

According to the Santander tide gauge, in a period of 55 years (between 1945 and 1999) the sea level has risen by 2mm per year. Identical conclusions are reproduced in the work entitled 'Climate Change on the Spanish Coast' published by the Institute of Environmental Hydraulics and the University of Cantabria (IH Cantabria - UC, 2014), which indicates increases in mean sea level in the Atlantic-Cantabrian area of between 1.5 and 1.9 mm/year during 1900-2010, following the observed global average trend. Considering this average trend scenario, the sea level in 2040 would have risen by 6 cm, which would mean average retreats of close to 3m, including some beaches in Santander.

Santander is also exposed to coastal flooding or sea surges along beaches, and surrounding estuaries and marshes, which serve as flood plains. Flooding in these areas is even more accentuated when the flood peak coincides with the high tide. Especially strong waves affect the northern and eastern coastal areas of the municipality owing to swell, and the interior of the bay mainly due to the southerly wind. The most sensitive areas correspond to Avenida García Lago and the area around 2nd Sardinero Beach (Ayuntamiento de Santander, 2016).

On the other hand, general flooding occurs in the municipality due to *in situ* or pluviometric precipitation, which causes temporary flooding of public roads, infrastructure and buildings. This is mainly due to the accumulations caused by heavy rainfall, which can cause the collapse of the sewerage network, especially when associated with strong tides that act as a risk intensification factor (Ayuntamiento de Santander, 2016).

[4] See the following link: https://www.euro-cordex.net/

4.1.1. Participatory workshops with local stakeholders for hazard screening

In December 2022, the first Technical Workshop on Climate Change Risk Perception in Santander was held as an initial step for the drafting of this Adaptation Plan. This is the first of a series of participatory meetings developed throughout the project, accompanying the different phases of the study, focused on both technicians and citizens.

The main objective of the event was to gather key information from relevant actors in relation to the perception of climate change-related threats in the municipality of Santander. The session was attended by 22 people representing, among others, Civil Protection force and firefighters, in charge of directly managing the risks; the Departments of Environment, Tourism and Health of Santander City Council; CIMA of the Government of Cantabria; AEMET; as well as researchers on climate change, health, urban planning and land use planning, and entities specialised in nature, such as SEO/BirdLife.

The first questionnaire of this consultation process consisted of assessing a long list of plausible hydrometeorological hazards (direct and derived) for the municipality with the final objective of prioritising the importance and frequency of each of them, specifically for Santander.

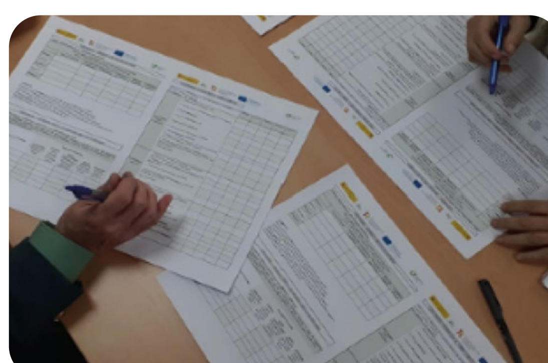

Figure 4.3. *Participatory session, risk perception workshop*

Source: CINCc (UC) - FIC, 2024.

Results

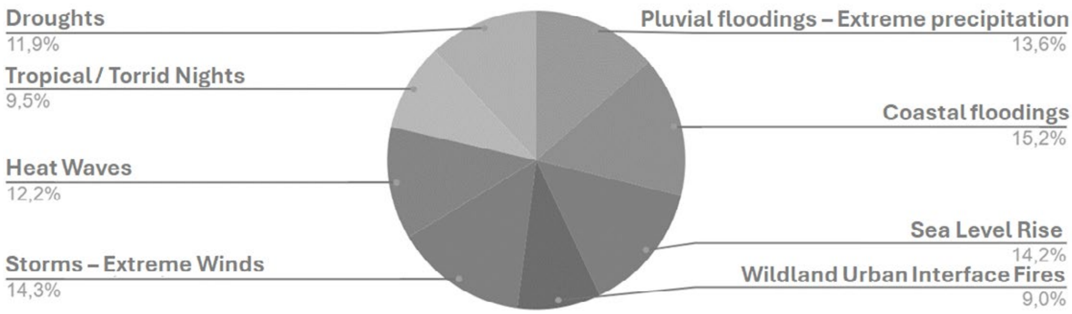

Figure 4.4. *Percentage final score for direct climate hazards, frequency and intensity*

Source: CINCc (UC) - FIC, 2024.

The aggregate rating of all respondents (a total of 21) indicates a higher relevance for **coastal climate hazards**, including coastal flooding and sea level rise, along with **windstorm events accompanied by extreme wind**, followed by pluvial flooding from extreme precipitation events, followed by heat waves, droughts, and tropical nights, and lastly by peri-urban fires. These levels of relevance remain almost unchanged for both criteria analysed, the magnitude and frequency of the hazard.

Regarding the incidence of climate-related hazards, the aggregate assessment of all respondents indicates a higher relevance for the **increase of invasive species** together with an **increase of new disease vectors**, with a final score of 23% and 22%, respectively. This is followed by a proliferation of allergenic pollens and insect pests, both with a final score of approximately 19% and, in last place, an increase in the incidence of Saharan dust, with almost 17% of the final score.

Analysis of Historical Records

Historical records of hazardous weather events in the municipality of Santander were collected through the Transparency Portal of the Insurance Compensation Consortium (*Consorcio de Compensación de Seguros,* CCS)[5], attached to the Ministry of Economic Affairs and Digital Transformation. The databases were provided for the period 1996-2021 and include records of floods, sea surges and atypical cyclonic storms (TCA).

[5] Consorcio de Compensación de Seguros (CCS) is a public business entity attached to the Ministry of Economic Affairs and Digital Transformation, through the Directorate General of Insurance and Pension Funds. It performs multiple functions in the field of insurance, including those related to the coverage of extraordinary risks.

A total of 6,573 damage files have been processed for the registration period, of which almost 77% belong to TCA files. These files correspond to a total of 133 events, of which almost 70% correspond to pluvial floods derived from extreme rainfall, which is the most frequent type of event in the municipality, with an average annual occurrence of between 3 and 4 events, while sea surges and TCA have annual frequencies of less than 1.

In terms of **economic impact**, in the municipality of Santander, the recorded events have caused costs of almost 18.3 million euros, of which 47% are derived from pluvial flooding, 40% from TCA events and around 13% from sea surges.

The information provided by the CCS also makes it possible to analyse the location of the events recorded by postcodes and the types of assets or goods that have been affected by each type of event. Based on their location, about 93% of the accumulated costs due to sea surges occur in Postal Code (PC) 39005, which coincides with the coastal area of the eastern area of the municipality. 75% of economic damage due to flooding occurs in postal codes 39011, 39001, 39005 and 39002, which coincide with the south-western sector and densely populated areas, mainly in the central districts of the capital. Finally, 73% of economic damage due to TCA occurs in PCs 39011, 39001, 39012, with a similar distribution to the previous one.

As for the types of assets or goods that have been affected by each type of event: more than 70% of the costs caused by sea surges occur in shops and warehouses, more than 15% in dwellings and about 13% in vehicles and automobiles. Flooding costs also occur mainly in shops and warehouses causing more than 58% of the total costs. This is followed by costs caused by civil works (almost 17%). TCAs cause the highest costs in housing, shops and warehouses, with 35% and 40%, respectively, and about 23% in industrial buildings.

In addition to the information provided by the Insurance Compensation Consortium (CCS), some **historical records** or ephemerides, defined as relevant meteorological events due to their historical, anecdotal or climatological value, are presented below (AEMET, 2023).

- 10 September 1581. Heavy downpours in Santander, with great loss of life and property.
- 29 December 1777. A strong tornado hit the city of Santander and nearby towns. A letter of the time relates that 'it came out as a kind of volcano with such a strong wind that everyone thought that most of the houses in Santander were going to the ground'.
- 5 February 1915. Southerly windstorm causes the sinking of the steamship 'Alfonso XIII' in Santander.
- 15 February 1941. An Atlantic storm with 951.9 mb, the lowest pressure ever recorded in Santander, produces a *surada* (south winds episode), with winds in excess of 150 km/h, which fanned a fire until it caused a great fire in the city, consuming buildings in 37 streets.
- 7 August 1943. High of 40.2°C in Santander.

- 10 March 1955. In Cantabria, clouds eclipse the sun and it becomes completely dark three times during the morning. The phenomenon is observed in Santander and in a coastal area of about 30 km.
- 27 August 1983. Santander airport recorded 96.2 mm in one hour.
- 7 June 1987. Strong gale along the Cantabrian coast, from Galicia to the French coast, 90 km/h recorded in Santander.
- 16 December 1989. Southern storm with winds reaching 147 km/h at Santander airport.
- 27 December 1999. Gusts of 172 km/h at Santander and 167 km/h at Santander airport.
- 3 October 2006. Gusts of 161 km/h at Santander and 118 km/h at its airport.
- 14 February 2007. Gusts of 130 km/h in Santander.
- 7 March 2007. Wind gusts of 140 km/h in Santander.
- 2014, 2016 and 2018, major impacts on the coast due to winter storms.

In 2016, the municipality of Santander, together with the Fire Brigade, developed a contingency plan to deal with the diversity of phenomena that has occurred in the city throughout its history. In terms of response and defence against risks, including those arising from adverse weather conditions, the **Santander Municipal Emergency Plan** (PEMUSAN) addresses both a risk analysis and a battery of local response measures to the magnitude of the weather events observed. Within this classification, the PEMUSAN first makes a general identification and a final assessment of those risks that have an impact on the municipality of Santander.

Below is a summary table of the climate-related risks analysed in the PEMUSAN, together with their corresponding assessment:

TABLE 4.2. *Risk analysis, PEMUSAN*

CLIMATE-RELATED EVENT	RISK ASSESSMENT [A]	PROBABILITY INDEX [B]	PREDICTED DAMAGE INDEX [C]
Pluvial floods	IR: 15 Medium Risk	3	5
Gravitational movements	IR: 4 Low Risk	2	2
Adverse weather events	IR: 12 Low Risk	6	2
Vegetation fires	IR: 30 Medium Risk	6	5

Source: CINCc (UC) - FIC, 2024 based on PEMUSAN (2016).

A Risk Index (IR): High (A): Greater than or equal to 40. Medium (M): 15 to 30. Low (B): Less than or equal to 12.

B Probability Index (PI): 2 No recorded occurrence. 3 Some occurrence recorded every ten years. 6 More than five recorded occurrences per year.

C Predicted Damage Index (ID): 0 No damage. 2 Minor damage to property and/or a few people slightly affected. 5 Major material damage or many people affected.

For each of these events, the PEMUSAN includes a fact sheet, which also identifies vulnerable sectors, exposed areas, potential damage, risk indicators and preventive measures to be adopted. Pluvial floods have the potential to cause circulatory collapse and a variety of multiple damages.

In the case of adverse meteorological phenomena, these events have the potential to cause housing evictions, possible health impacts on at-risk population groups, and other social and economic implications. Specifically for wind-related phenomena, those with an intensity of more than 80 km/h, or gales, which in turn can be from the sea or land, are indicated as adverse, while vegetation fires have the potential to cause damage to people, property and the environment due to the destruction of flora and fauna in the burnt areas.

Prioritisation of Climate Hazards in the Municipality

The methodology used to prioritise and select the main hydrometeorological hazards in the municipality is based on the **multi-criteria analysis** method, whose objective is to determine the degree of incidence of each hazard based on its occurrence

This method also considers the frequency and magnitude of the hazard, and the potential impact or damage it causes, including human damage in terms of human lives, injuries or casualties, material damage to housing and infrastructure,or the economic and environmental damage caused to the **municipality**.

For each hazard, the final value and order of relevance is obtained according to its occurrence. The formulation used has two advantages:

- (i) It implies that the final assessment depends to a large extent on the scores assigned in the local workshop, because this source of information is local, is developed specifically in the context of climate hazard analysis, and integrates the social and institutional vision of the municipality in a multidisciplinary way.
- (ii) It allows for smoothing of the inherent divergences arising from the use of multiple sources of information with different occurrence indicators, some of which are also subject to interpretation under expert judgement.

The results of the multi-criteria analysis indicate an occurrence of highest relevance for coastal flooding, followed by **windstorms**, **sea level rise** and **pluvial flooding**. Droughts are ranked second, followed by peri-urban fires and, finally, heat waves and tropical nights.

In terms of derived hazards, the emergence of **new disease vectors** is followed by the emergence of **new invasive species** and increased levels of **allergenic pollens**. It is worth mentioning that it is possible that certain threats, mainly those of slow onset such as heat waves, may become more relevant in the future. Therefore, these initial results are combined with the results of the climate analysis, which will improve the level of knowledge on emerging hazards in Santander.

4.2 CLIMATE ANALYSIS AND LOCAL SCENARIO GENERATION

4.2.1. Current Climate Analysis

The coastal location of the municipality provides a mild climate, both in winter and summer, without marked climatic extremes. According to the Köppen climate classification, Santander has a characteristic **oceanic climate of type Cfb** (West Coastal Maritime), with a temperate climate marked by cool summers (average temperature of the warmest month below 22°C), abundant and well-distributed rainfall throughout the year. The annual thermal oscillation of mean monthly temperatures is low (Δ8°C).

Rainfall is abundant in spring and autumn in particular, although significant reductions have been detected in recent years. Variations in the percentage of humidity can be significant, although high values predominate. Temperatures are mild throughout the year and there are very few episodes of extreme cold or heat. Summers are generally mild, with mild temperatures and winters are cold, but not extreme due to the thermoregulatory effect of the sea, with temperatures rarely dropping below 0°C and an average of one snow day per year. In general terms, average temperatures in the municipality range from a mean in maximums of 24.5°C in August to a mean in minimums of 5.8°C in February. A characteristic phenomenon in Santander are the episodes of south winds, with a notable intensity of more than 80 km/h, which cause high temperatures and low humidity, with a particular effect on the health of some groups of the population.

4.2.2. Generation of Local Climate Change Scenarios (CMIP6)

Introduction

The most robust tool for simulating climate are **Climate Models** (CMs), by means of which it is possible to simulate the general atmospheric circulation in an efficient way. However, due to their resolution (around 100 km) they are unable to simulate smaller-scale atmospheric phenomena that are of great importance in local climatology. In order to overcome this and other limitations of CMs, what are known as **regionalisation or downscaling techniques** are used.

TABLE 4.3. *Current climate variables in Santander*

CLIMATE PARAMETERS SANTANDER (REFERENCE PERIOD: 1991-2020, EXTREMES: 1957-2016)													
MONTH	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AGO.	SEP.	OCT.	NOV.	DEC.	ANNUAL
Abs. max Temp. (°C)	25.1	29.9	31.3	30.6	36.8	37.8	37.2	37.3	37.6	33.5	30.0	25.4	**37.8**
Average max Temp. (°C)	13.7	13.9	15.8	16.9	19.4	21.8	23.7	24.5	22.9	20.6	16.5	14.4	**18.7**
Average Temp. (°C)	10.0	9.9	11.6	12.9	15.6	18.1	20.1	20.8	18.9	16.5	12.8	10.8	**14.8**
Average min Temp (°C)	6.3	5.8	7.4	8.7	11.7	14.4	16.6	17.0	14.8	12.3	9.2	7.0	**10.9**
Abs. min Temp. (°C)	–5.4	–5.2	–3.0	0.6	2.6	5.6	6.0	6.0	2.8	1.4	–3.5	–5.2	**–5.4**
Total precipitation (mm)	114.4	97.6	95.9	98.7	76.0	62.6	53.7	57.6	90.8	121.1	172.3	128.3	**1,169**
Days of precipitation (≥1 mm)	12.3	11.1	11.1	11.9	10.4	7.6	7.3	7.6	8.9	11.1	13.3	12.1	**123.6**
Days of snowfall	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	**0.9**
Sun hours	85	104	135	149	172	178	187	180	160	129	93	75	**1,647**
Relative humidity (%)	72	72	71	72	74	75	75	76	76	75	75	73	**74**

Source: State Meteorological Agency. Parayas Airport Observatory (Camargo)

This project proposes to use a two-step statistical regionalisation methodology developed by the Climate Research Foundation (Ribalaygua et al., 2013) and widely tested in a multitude of national and international projects. This methodology has been applied to the variables temperature (both maximum and minimum) and precipitation.

The method works in **two successive steps**:

- The first step, called **analogue stratification**, consists in selecting, from a reference data bank, those days with atmospheric configurations most similar to those of problem day 'X'. The similarity measure used compares the resemblance between the predictor variables used to characterise the atmospheric synoptic situations. These variables determine the synoptic forcing causing the descents and ascents of air, which generate cloudiness and precipitation. The aim is also to provide information on the direction of the surface wind, which makes it possible to study the effects that topography has on the rising air masses and, therefore, on the spatial distribution of cloudiness and precipitation.
- The second step applies different methods depending on the variable to be calculated:
    - To estimate daily minimum and maximum temperatures, a **multiple linear regression** with automatic forward and backward predictor selection is performed for each variable.
    - In the case of precipitation, it is estimated by **simple averaging** of the k analogous days most similar to 'X'.

The FICLIMA methodology, shown in the figure 4.5 below, has some advantages over other statistical methodologies, which are reflected in the table 4.4 below:

TABLE 4.4. *Advantages of the FICLIMA methodology over other statistical downscaling methodologies*

The problem of stationarity is minimised by the selection criterion of predictors, based on theoretical considerations, reflecting the physical relationships between predictors and predictands, physical relationships that should not change over time.
When using the analogue selection method alone, and given that the final simulation will be based on the most analogue days, the value assigned to the studied meteorological variable will be limited by the observed value it has on those analogue days, i.e., its margin of variability will be given by the variability of the past itself (higher or lower values would never be calculated). However, the second step introduced in the FICLIMA methodology allows us to overcome this limitation: the daily linear relationships established for temperature and the redistribution of precipitation based on the distribution function allow us to simulate values that can exceed the limitation of the initial observed values.

[…/…]

Continuation **TABLE 4.4**

The verification results are considerably better than those of the vast majority of statistical and dynamic methodologies with which they have been compared in various national and international projects. These excellent verification results have been verified in the different areas of the planet where it has been tested, and are justified by the solid theoretical foundations on which FICLIMA is based.

Source: FIC.

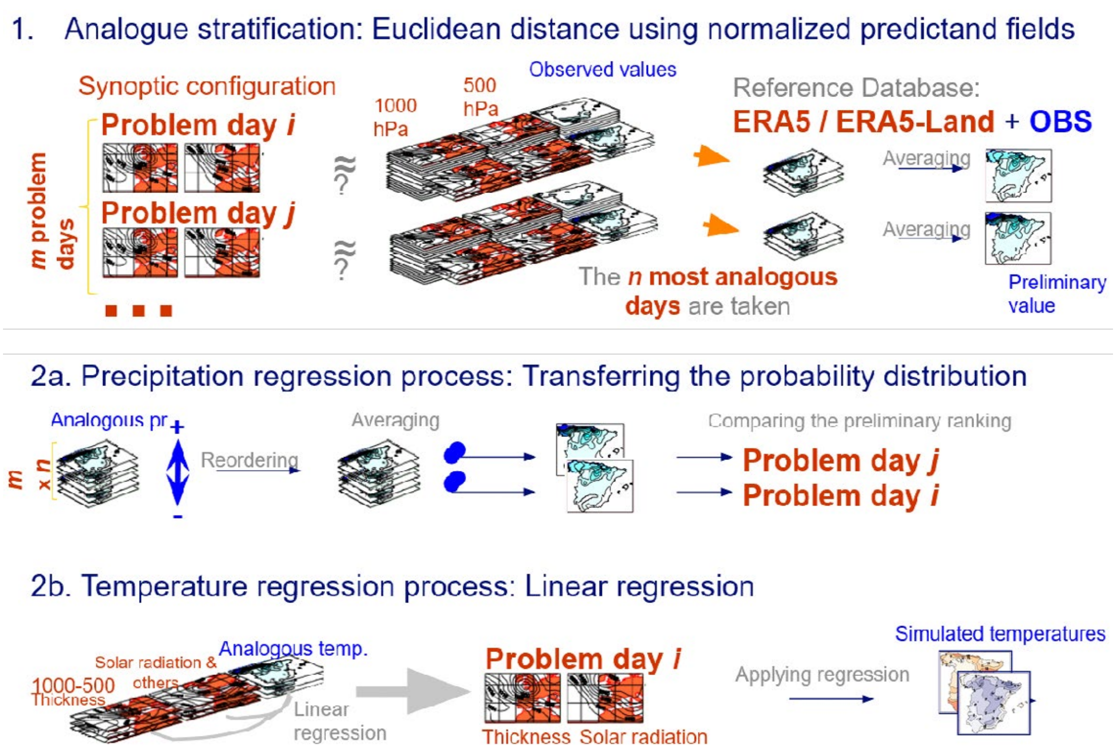

Figure 4.5. *Outline of FICLIMA methodology*

Source: FIC.

Data and study area

The location of the municipality in the north of the Iberian Peninsula, bordering the Cantabrian Sea, implies climatic characteristics of the temperate oceanic type, with mild, rainy winters and cool, relatively rainy summers. In order to carry out the regionalisation process, it is necessary to have a set of data, which are summarised in figure 4.6.

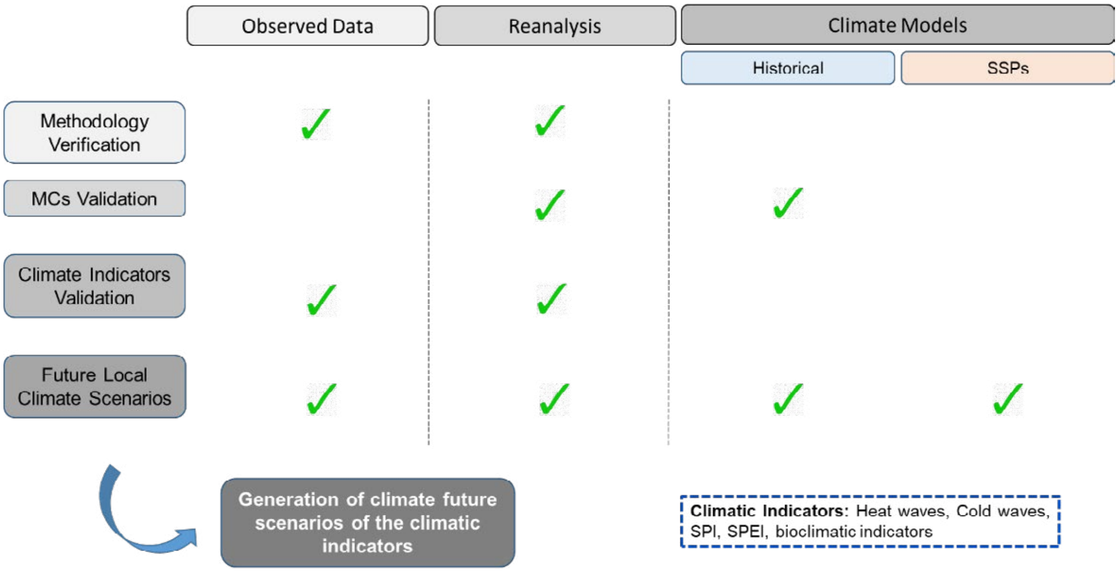

Figure 4.6. *Outline of data required for the study.*
Source: FIC.

For the study, a set of observed data obtained from meteorological stations of the network of the State Meteorological Agency (AEMET) is available. figure 4.7 shows the location of the observatories with data for each of the variables.

TABLE 4.5. *Set of Climate Observatories*

VARIABLE	NUMBER OF OBSERVATORIES
Temperature	28
Precipitation	18
Wind	8
Relative Humidity	9
Pressure	4

Source: FIC.

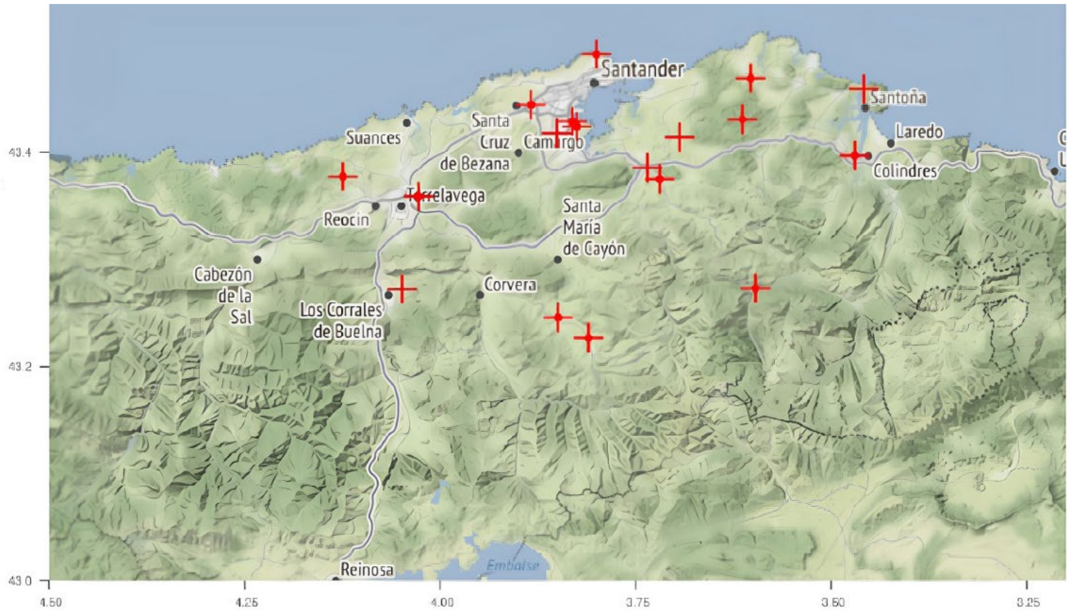

Figure 4.7. *Available observatories of the AEMET network*

Source: FIC.

The observed data are subjected to strict quality control and homogenisation (Monjo et al., 2013), discarding such data that do not exceed the established quality standards.

The ERA5 and ERA5-Land Reanalysis database and the different climate models complete the generation of scenarios.

Climate Models

The project has been developed with the climate models of the 6th phase of the CMIP **(CMIP6)** as well as the emissions scenarios defined within this phase, the **Shared Socioeconomic Pathways (SSPs)**. Statistical techniques, due to their computational speed, allow working with a large number of climate models (n) and SSPs (m), so that a set of (n x m) climate projections will be obtained. The climate models are run continuously from the past into the future; once the control period is simulated, the run is separated into as many runs as SSPs are considered. For each climate model there is, therefore, a control simulation called 'Historical' for the period 1951-2014 (although the reference period here is taken as 1985-2014) and 4 SSPs for the period 2016-2100 (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5).

Ten daily resolution climate models, collected within CMIP6, have been used. Throughout the different phases of this project, improvements have been made to the quality of the climate models up to the current **Earth System Models** (ESM) (Benestad, 2010). Furthermore, new emission scenarios have been defined in each of the phases, adjusting to the new adaptation and mitigation needs in the face of climate change. CMIP6 has a common set of future scenarios comprising land use and emissions, as required for future SSPs (Eyring et al., 2016).

TABLE 4.6. *Set of models from CMIP6 used in the study*

CMIP6 MODELS	RESOLUTION	RESPONSIBLE AGENCY	REFERENCES
ACCESS-CM2	1.258° x1.8758°	Australian Community Climate and Earth System Simulator (ACCESS), Australia	Bi et al. (2020)
BCC-CSM2-MR	1.125° x 1.121°	Beijing Climate Center (BCC), China Meteorological Administration, China	Wu et al. (2019)
CanESM5	2.812° x 2.790°	Canadian Centre for Climate Modeling and Analysis (CC-CMA), Canada	Swart et al. (2019)
CESM2-WACCM	0.95° × 1.25°	National Center for Atmospheric Research (NCAR), USA	Gettleman et al. (2019)
CNRM-ESM2-1	1.406° x 1.401°	CNRM (Centre National de Recherches Meteorologiques), Meteo-France, France	Seferian (2019)
EC-EARTH3	0.703° x 0.702°	EC-EARTH Consortium	EC-Earth Consortium (2019)
MPI-ESM1-2-HR	0.938° x 0.935°	Max-Planck Institute for Meteorology (MPI-M), Germany	Gettelman et al. (2017)
MRI-ESM2-0	1.125° x 1.121°	Meteorological Research Institute (MRI), Japan	Yukimoto et al. (2019)
NorESM2-MM	1.250° x 0.942°	Norwegian Climate Centre (NCC), Norway	Bentsen, M. et al. (2019)
UKESM1-0-LL	1.875° x 1.250°	UK Met Office, Hadley Centre, United Kingdom	Good et al. (2019)

Source: Author's elaboration.

Note: The models were provided by the Climate Model Diagnostics and Intercomparison Programme archives (PCMDI).

Results of the Climate Projections

The climate projections have been generated for each of the observatories available for each variable. The results obtained in the generation of **future climate scenarios** for the different variables are shown below, based on the results presented below by the medians of each SSP (thick lines). The '1109X' observatory at Santander Airport is taken as a reference:

- Both maximum and minimum temperatures are expected to **increase progressively** throughout the 21st century. In the case of **maximum** temperatures, increases of between 1.38°C and 2°C are expected by mid-century, depending on the emissions scenario considered, and between 1.41°C and 3.83°C by the end of the century. These increases would mean that the average maximum temperature would increase from around 18.94°C to between 20.32°C and 21.02°C by mid-century and between 20.35°C and 22.77°C by the end of the century.
- In the case of **minimum temperatures**, the expected mid-century increases range from 1.65°C in the most favourable case to 2.41°C in the least favourable case, which would mean that the average minimum temperature would reach values of between 11.94°C and 12.70°C. By the end of the century, the average minimum temperature is expected to rise between 1.67°C and 4.63°C, so that the average minimum temperature values would be between 11.96°C and 14.92°C.
- No significant changes in annual accumulated **precipitation** are expected. All emission scenarios show a similar behaviour in terms of the future evolution of precipitation, so that it will be around 1200-1300 mm/year. The rainfall distribution is expected to be altered with respect to the current distribution. Rainfall is expected to be more intense and concentrated over time than evenly distributed over longer periods.
- **Humidity** is expected to behave very similarly to the current climatic situation in the region, without significant changes, especially in the middle of the century. Depending on the model and the scenario considered, at the end of the century, maximum humidity may vary between -2.5% and 1%, while minimum humidity may vary between -5% and 2.5%.
- The expected **pressure** behaviour is very similar to that observed today with oscillations of ±1 hPa at the end of the century.
- For the mean **wind**, very slight decreases are observed, ranging from 0.25 m/s (0.9 km/h) to 0.5 m/s (1.8 km/h). The expected variations in the maximum gust, both mean and maximum, are expected to be very similar to those expected in the mean wind. In the case of **maximum gusts**, these will decrease from a maximum intensity of about 93-94 km/h to 88-92 km/h by the end of the century.

Future climate scenarios for temperature (maximum and minimum)

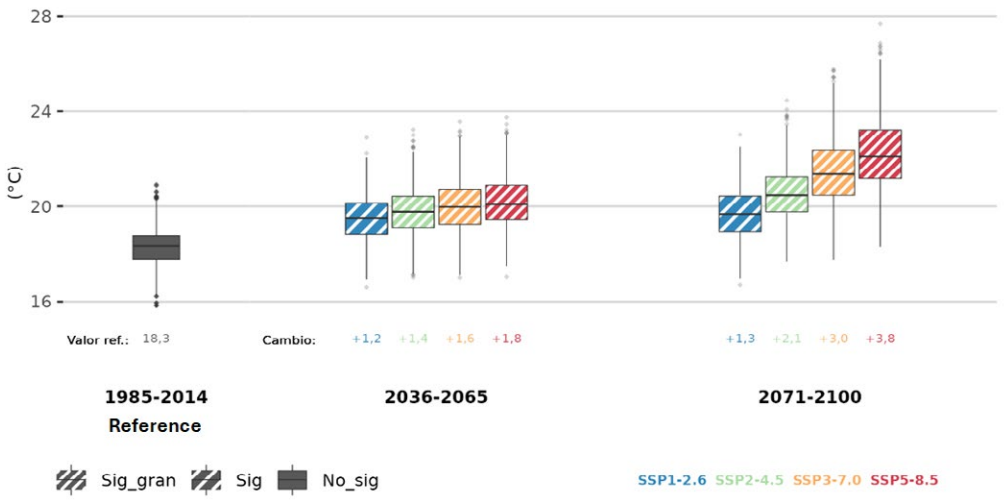

Figure 4.8. *Expected maximum temperature increases for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models on the observatory '1109X'. The lines show the median of all values for each SSP; the shadows cover from the 10th to the 90th percentile.

Source: FIC.

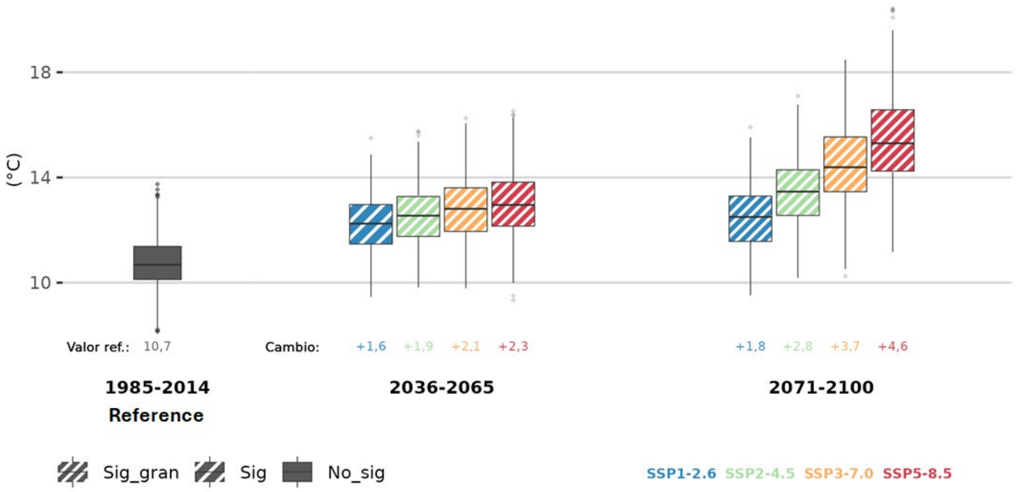

Figure 4.9. *Expected minimum temperature increases for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models on the observatory '1109X'. Lines show the median of all values for each SSP; shadows cover from the 10th to the 90th percentile.

Source: FIC.

Future climate scenarios for precipitation

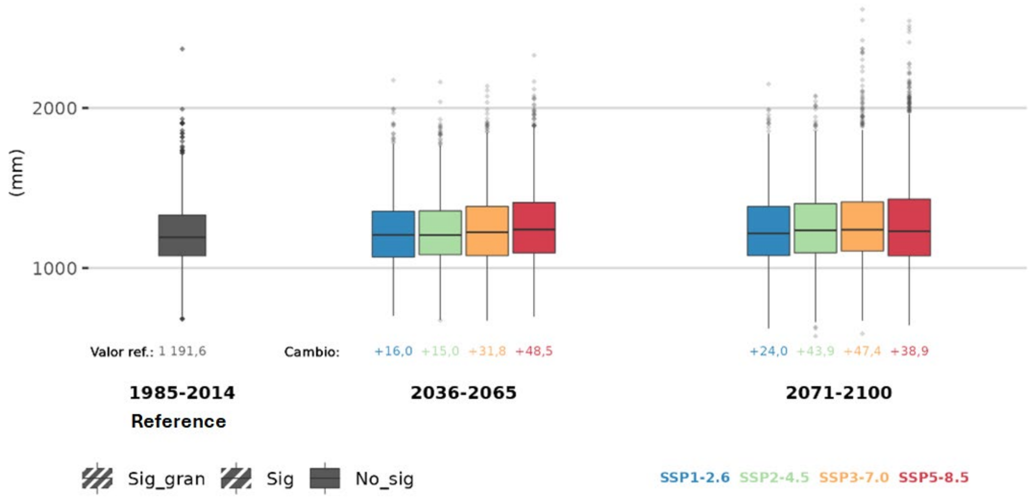

Figure 4.10. *Expected absolute precipitation values (mm) for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models on the observatory '1109X'. The lines show the median of all values for each SSP; the shadows cover from the 10th to the 90th percentile.

Source: FIC.

Future climate scenarios for relative humidity

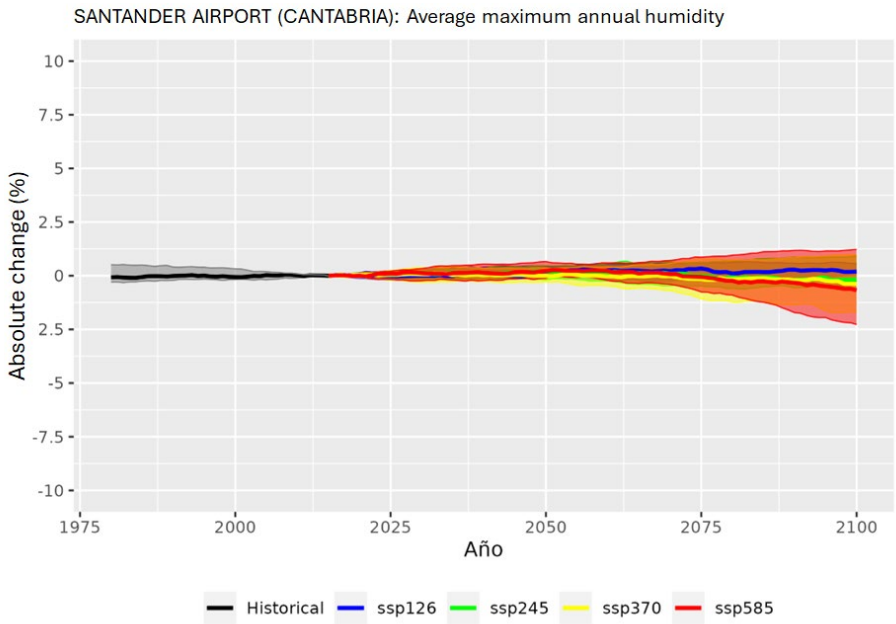

Figure 4.11. *Expected increases in maximum humidity for the 21st century*

Source: FIC.

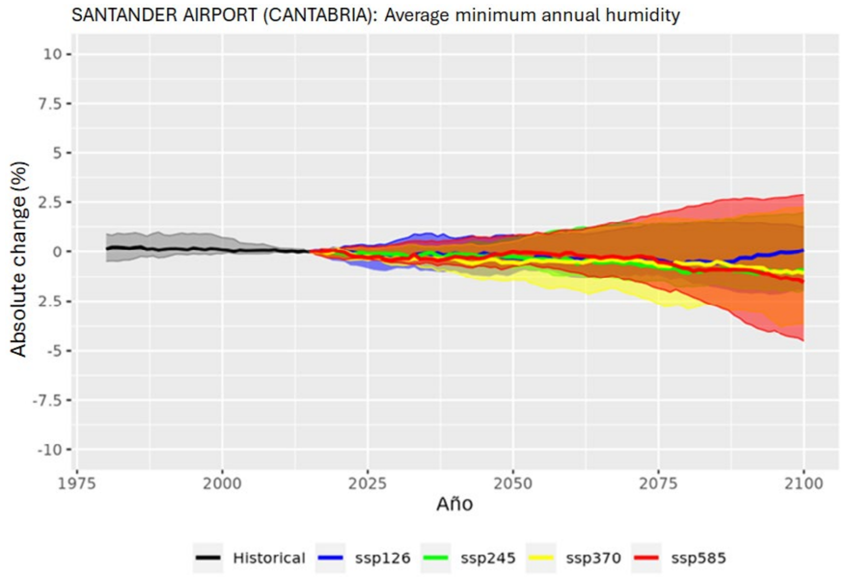

Figure 4.12. *Expected minimum humidity increases for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models on the observatory '1109X'. Lines show the median of all values for each SSP; shadows cover from the 10th to the 90th percentile.

Source: FIC.

Future climate pressure scenarios

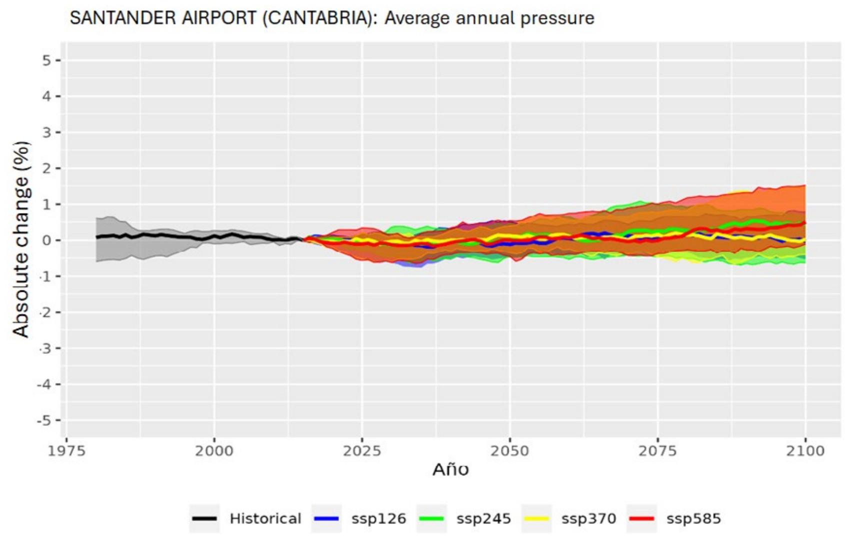

Figure 4.13. *Expected pressure changes for the 21st century*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models over the observatory '1109X'. Lines show the median of all values for each SSP; shadows cover from the 10th to the 90th percentile.

Source: FIC.

Medium wind future climate scenarios

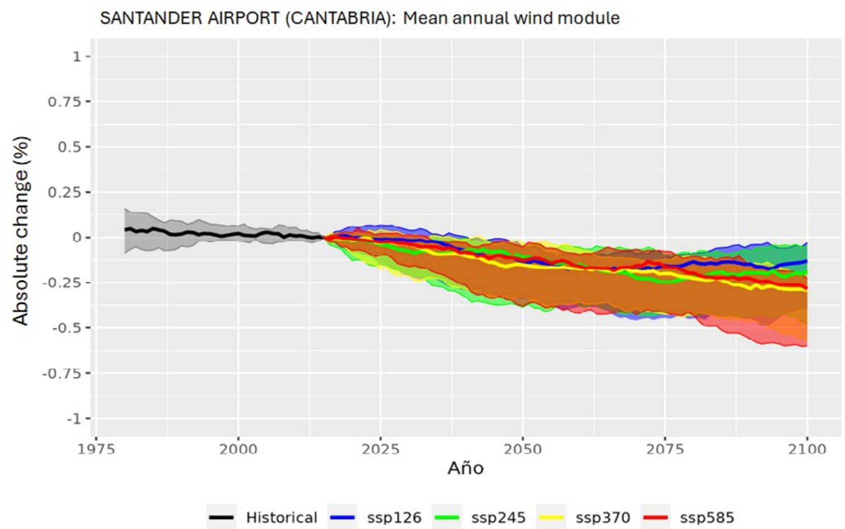

Figure 4.14. *Expected average wind increases for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all ace models over the '1109X' observatory. The lines show the median of all values for each SSP; the shadows cover from the 10th to the 90th percentile

Source: FIC.

Future climate scenarios for maximum wind speed

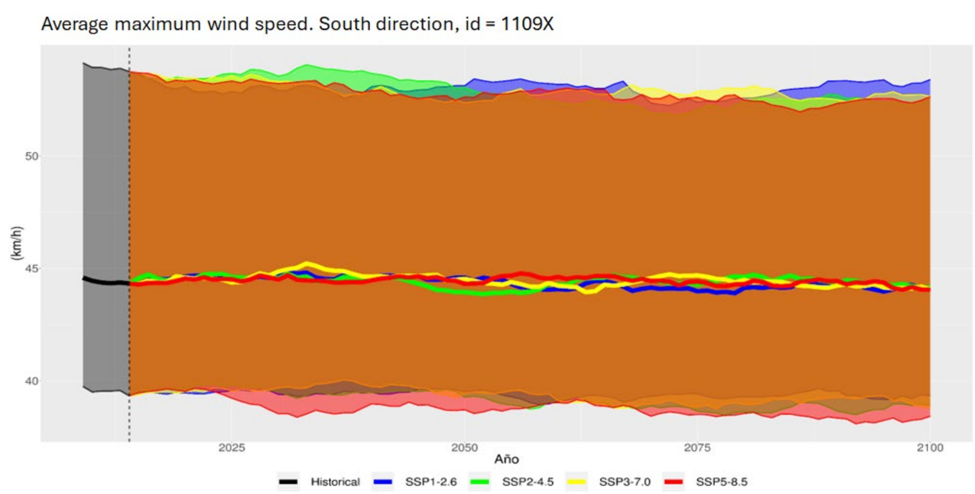

Figure 4.15. *Expected values of average maximum southerly wind gust for the 21st century.*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as reference). Simulations of all models on the '1109X' observatory. Lines show the median of all values for each SSP; shadows cover from the 10th to the 90th percentile.

Source: FIC.

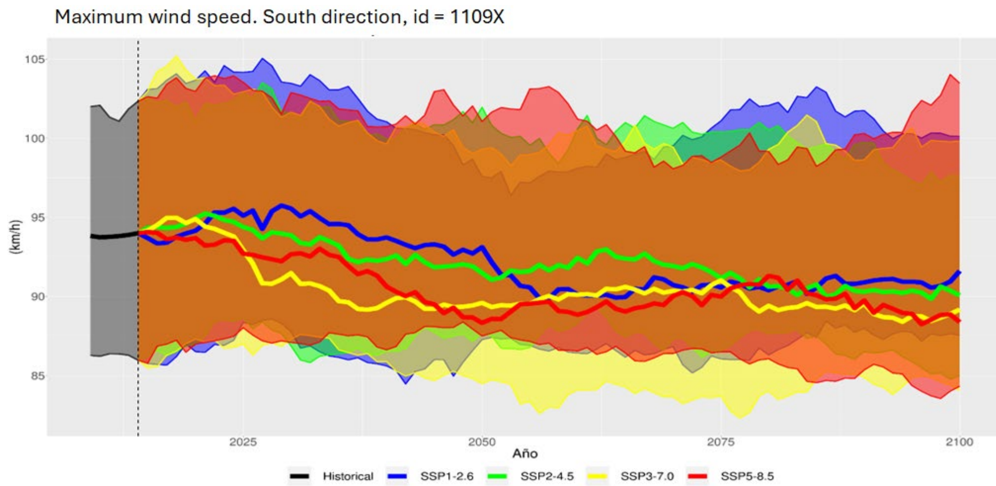

Figure 4.16. *Values of maximum wind gusts from the South for the 21st century*

Note: Represented as 30-year moving averages, according to the SSPs represented with respect to the average of the period 1976 - 2015 (taken as Reference). Simulations of all models on the observatory '1109X'. The lines show the median of all values for each SSP; the shadows cover from the 10th to the 90th percentile.

Source: FIC.

4.2.3. Climate Scenarios Summary

According to the climate data obtained from the historical period and projected to 2100, the anallysis conclude the following values for all climate scenarios:

- **Average maximum temperature:** From a historical value between 16-19°C, a maximum temperature range of 21-23°C is projected for 2100.
- **Average minimum temperature:** From a historical value between 8-11°C, a minimum temperature range of 13-15°C is projected for 2100.
- **Precipitation:** Averages similar to the present are maintained with slight variations. The annual distribution may be altered, with total precipitation concentrated in shorter periods.
- **Heat waves:** From a historical value between 3-4 days, an increase to 9-10 days of heat wave duration is projected for 2100.
- **Temperature heat wave (intensity):** From a historical value between 26-29°C, a temperature of 29-32°C is projected for 2100, implying an increase in total intensity.
- **Torrid Nights:** From a historical value between 0-1 day/year, a notable increase to 6-9 days/year is projected for 2100.

In summary, results state that the future climate context in Santander will continue the following pattern:

- Progressive temperature increases throughout the 21st century, 1.3°C-3.8°C in 2100.
- Slight variations in rainfall patterns, but more torrential rainfall.
- Increases in the number of hot days with a consequent increase in the frequency of heatwave episodes, as well as in their duration and maximum intensity.
- Significant increases in the number of progressively tropical, equatorial and torrid nights throughout the 21st century.

4.3 CLIMATE HAZARD ANALYSIS AND PROJECTION

The objective of this phase is to analyse the selected climate hazards for the municipality of Santander for both the historical or current period and for projected future periods.

The hazards selected from the participatory process and the analysis of historical events are as follows:

- Pluvial Flooding from Extreme Precipitation
- Atypical Cyclonic Storm (TCA)
- Fluvial Flooding
- Urban Heat Islands
- Heat Waves
- Episodes of Warm Nights
- Meteorological Drought
- Extreme Wind, *Galernas* and South Wind
- Coastal Flooding

The **occurrence** (distribution, intensity, duration and frequency) of these events is modelled through the main climate variables analysed (temperature, precipitation, wind and humidity) from the regionalised climate change scenarios for Santander, based on the CMIP outputs of the IPCC 6th Report. This modelling process is specifically applied to climate hazards such as **droughts**, **heat waves**, **extreme wind events**, and **pluvial floods**, among others. For coastal flooding and sea level rise hazards, the assessment is based on the recent results obtained by the **PIMA-Adapta**[6] Costas project, within the framework of the Climate Change Adaptation Strategy.

[6] PIMA Adapta Costas (2020). Conocimiento y acción frente a los riesgos derivados del cambio climático. Oficina Española de Cambio Climático. Ministerio para la Transición Ecológica y el Reto Demográfico, Madrid.

EXTREME PRECIPITATION EVENTS

This block analyses the roads in the municipality with a **probability of flooding** due to the occurrence of extreme precipitation events, defined as episodes when the accumulated precipitation in one hour or less is of an intensity equal to or greater than 15mm/h, or whose accumulated precipitation in 12 hours is of an intensity equal to or greater than 40mm/h (Ayuntamiento de Santander, 2016). It is important to consider that this procedure does not address a detailed modelling of the flood hazard for roads, which should consider, among others, the municipal drainage system at a detailed scale, as well as the runoff and accumulation of flow generated by extreme precipitation events considering current and future conditions for different return periods. However, with the consideration of the CMIP6 climate scenarios, it will be possible to delimit a valid cartography that allows the calculation of the potential exposure to this hazard.

The methodology proposed for the analysis of roads with a high probability of flooding in the municipality of Santander includes the following steps:

- (i) Analysis of topographic subsidence conditions in the longitudinal profile of the municipality's roads (**Blue Spots**[7] modelling).
- (ii) Analysis of the documented areas of waterlogging, obtained from the mapping provided by the Santander City Council (2016), and from the records of interventions carried out by the Fire Brigade of the municipality from 2018 to 2022 due to extreme rainfall events.
- (iii) Validation and final delimitation of areas of **high probability** of road flooding in the municipality, based on the results of Blocks 1 and 2.
- (iv) Assessment of the trend of extreme rainfall events in the municipality under climate change conditions in the short, medium and long term, based on local scenario outputs derived from CMIP6 models.

In the last step of this procedure, a rigorous assessment of the **projected trend** in the occurrence of extreme rainfall events in the municipality of Santander is provided, in terms of intensity, duration and frequency, as well as for each of the local-scale climate change scenarios, based on the recent outputs of the IPCC 6th Assessment Report.

The Hazard Index for rainfall events in Santander is obtained by normalising the mean frequency value obtained for the different climate scenarios for each time horizon. As shown in table 4.7, the normalised index presents values above 0.6 for all periods, which implies that the mean frequency of extreme rainfall events does not double for the long-term climate projections with respect to their historical frequency. The mean annual frequency of extreme rainfall events for the set of climate scenarios is almost 3 events/year, with mean Hazard Index scores for the Santander census sections around 0.63 in the historical peri-

[7] https://climate-adapt.eea.europa.eu/en/metadata/tools/the-blue-spot-model-a-key-tool-in-assessing-flood-risks-for-the-climate-adaptation-of-national-roads-and-highway-systems

od. For the projected periods, absolute increases of around 0.5 events/year on average are expected, reaching a frequency of 4.5 events/year for the long-term projection period.

TABLE 4.7. *Mean annual frequency and mean hazard indexes*

	AVERAGE FREQUENCY OF EVENTS	MEDIUM HAZARD INDEX
HISTORICAL PERIOD (1985-2014)	2.97	0.63
SHORT TERM (2016-2040)	3.58	0.77
MEDIUM TERM (2041-2070)	4.05	0.87
LONG TERM (2071-2100)	4.49	0.96

Source: CINCc (UC) - FIC 2024.

Results show the average values of extreme rainfall events and the following Normalised Hazard Index for the municipality of Santander (figure 4.17).

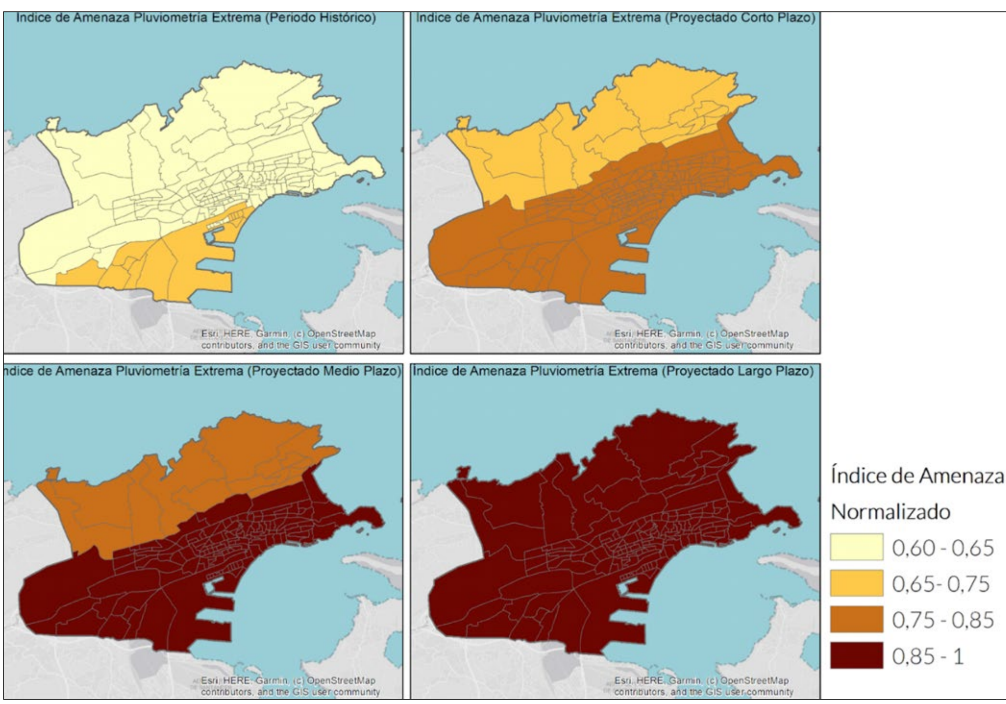

Figure 4.17. *Normalised Hazard Index for extreme rainfall events*

Note: obtained by averaging the frequency for the different climate scenarios and for each time horizon per census section; for historical (top left), projected short (top right), medium (bottom left) and long term (bottom right).

Source: CINCc (UC) - FIC, 2024.

ATYPICAL CYCLONIC STORM

Atypical cyclonic storm (Tormentas Ciclónicas Atípicas [TCA]), is defined as an extremely adverse atmospheric event, including tornadoes and extraordinary winds. For the present study, the TCA phenomena in the municipality of Santander have been analysed as episodes that combine extreme winds, above 84 km/h, and intense precipitation, of more than 40 mm accumulated in one day. For such episodes, two indices of frequency and duration have been analysed:

- Frequency, analysed as the average number of days with TCA per year.
- Average duration of the event, analysed as the average number of consecutive days in the year with TCA.

The **measurement of TCA** occurrence is analysed for the historical period (1985-2014) and projected into the future, for the short (2016-2040), medium (2041-2070) and long term (2071-2100). Future projections are obtained from the average of the outputs of 10 climate models for a total of 4 emission scenarios, as set out in the IPCC 6th Report (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5). The representation of these phenomena by census section is based on the average number of nights per year for each time horizon, as a representative measure.

The **results** for each of the TCA occurrence indices in the municipality of Santander are presented below (table 4.8).

TABLE 4.8. *Average number of TCA per year in Santander*

HISTORICAL AVERAGE: 0.141575	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	0.124126	0.139725	0.152720	0.140067
Medium Term (2041-2070)	0.134185	0.178395	0.130459	0.125216
Long Term (2071-2100)	0.109309	0.140246	0.167540	0.126663

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios from the outputs of the sixth IPCC report

With regard to the **average temporal frequency**, TCA episodes in Santander occured on average once every 7 years in the historical period, and are expected to have a moderately stable frequency in the future, with an event occurring every 5 to 9 years depending on the scenario considered. In the case of the average duration of the TCAs, no table of values is included for each scenario, since it remains at 1 both for the historical period as well as for all the projected scenarios, i.e., they are one-off events, or events that occur on specific, non-consecutive days.

FLUVIAL FLOODING

The hazard of fluvial flooding is considered on the basis of the flooding results generated within the National Floodplain Mapping System for return periods of 10, 100 and 500 years (MITECO, 2020). Fluvial flooding has a relatively low incidence within the municipality of Santander, with flood zones only appearing in the west of the municipality, coinciding with areas bordering the Otero Stream, which is approximately 1.3 km in length, belonging to the Pas-Miera System of the Western Cantabrian Hydrographic Demarcation.

The fluvial flood area, in particular, covers a total surface area of 8.22 ha within the municipality, of which 5.72 ha correspond to areas with a return period of 10 years (high probability), 1 ha corresponds to areas with a return period of 100 years (medium probability), and the remaining 1.50 ha corresponds to areas with a return period of 500 years (low probability). The fluvial flood area would affect a single census section of the municipality, where the percentage of threatened surface area would be 0.027%.

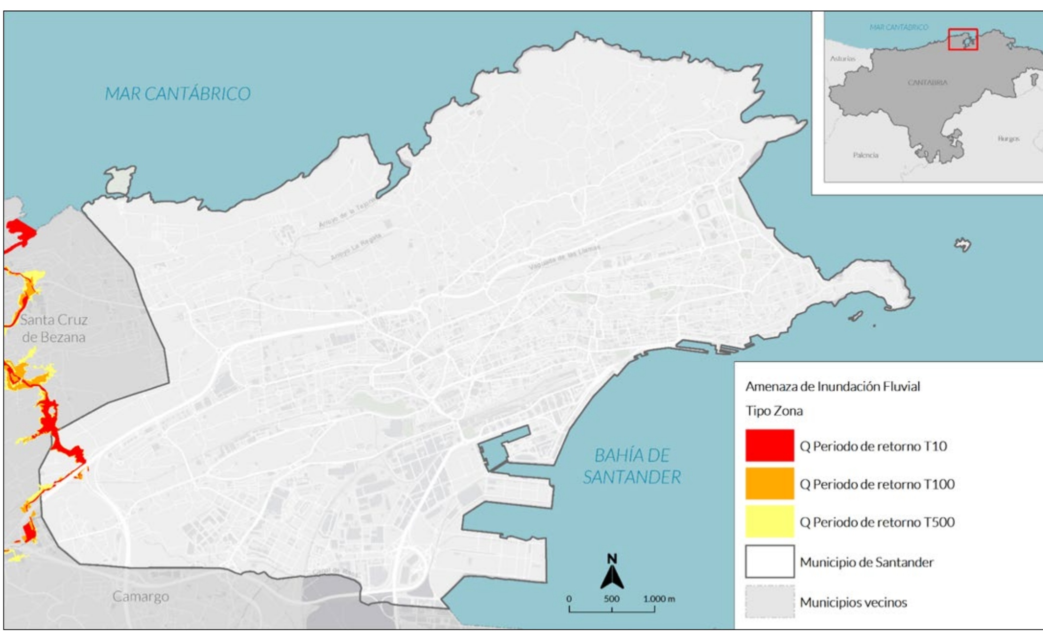

Figure 4.18. *Fluvial Flood Hazards 10, 100 and 500 year return periods*
Source: CINCc (UC) - FIC, 2024 based on SNCZI data (MITECO, 2020)

URBAN HEAT ISLANDS

Heat islands are a phenomenon of urban areas that experience higher temperatures than the surrounding areas due to human activity. The heat island effect is characterised by higher temperatures in cities than in the surrounding areas and is more pronounced at night.

The **main causes** are the heat accumulation on structures, such as buildings, pavements or asphalt, which absorb more heat and release it more slowly. Added to this is the heat and air pollution generated by traffic and industry, which trap solar radiation and prevent heat dissipation, which in turn increase air temperatures.

This exacerbates the consequences of climate change in cities and reduces the quality of life of city residents. High temperatures, especially, can affect the health of urban citizens, causing general unrest, respiratory problems, sunstroke, dehydration, fatigue and even increased mortality from heat stroke. In addition, they have direct energy and economic impacts. Mainly in summer, heat islands generate an increase in energy demand from air conditioning, which in turn increases the price of electricity.

The detection of **Urban Heat Islands** (UHI) can be approached from ambient temperature data collection with remote sensors such as weather stations or tools that allow temperature records on the ground, or from obtaining data through satellite images. In this sense, the use of remote sensing images allows the calculation of **Land Surface Temperature** (LST). The LST data collected from the satellite, in this case, have been compared and correlated with selected ambient temperature data from nearby surface weather stations. As a result of this correlation, it has been possible to apply the equation for the conversion of LST values to ambient temperature per pixel, cropped to the municipal area of Santander. Finally, the geometry of the islands in areas of high urbanisation has been spatially delimited, applying the criterion of selecting areas with an ambient temperature 2ºC above the peripheral ambient temperature. Finally, a validation procedure has been carried out by applying the Expert Criteria, using temperature data taken in Santander by the Smart City project.

As a result, the LST has been obtained through Landsat 8 images for 1 July as an example scenario to subsequently address the delimitation of potential heat islands (figure 4.19).

Finally, a **validation** process of the potential areas delimited in the previous step has been carried out, which includes validation through the temperature data taken in Santander by the Smart City project from 2012 to 2023, and a validation based on expert criteria. This procedure consisted in testing the results of the potential delimitation of heat islands by the team of local experts with extensive knowledge of the subject. Taking into account the two previous aspects and considerations, the delimitation of the UHI proposed for Santander should be considered as a first analytical approximation that should, in any case, be complemented with ambient temperature data in the city with adequate coverage and distribution in future initiatives.

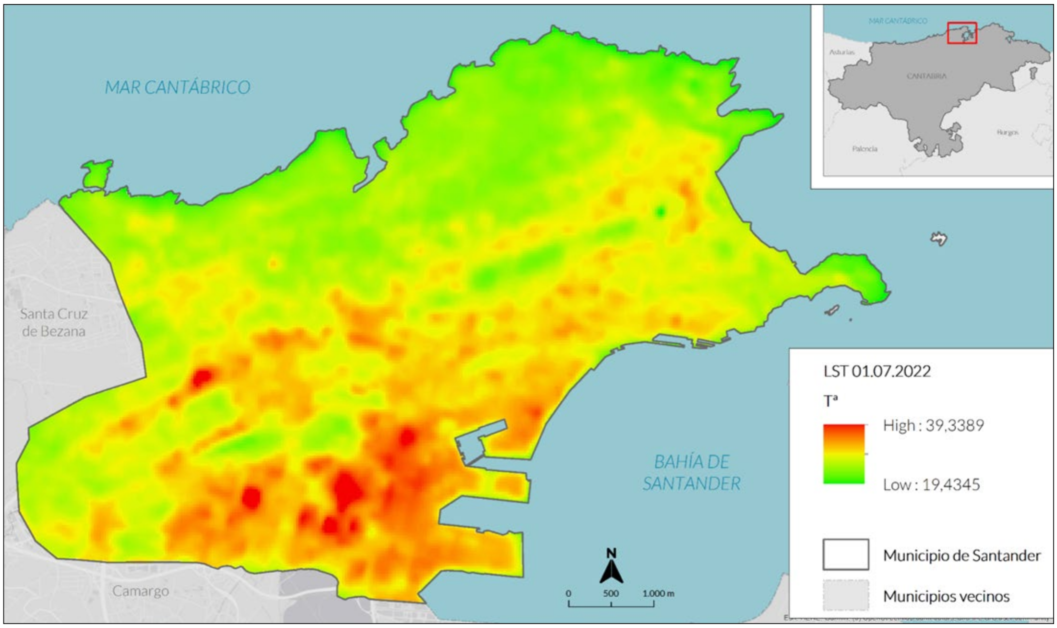

Figure 4.19. *Results of the Land Surface Temperature calculation*

Source: CINCc (UC) - FIC, 2024 based on Landsat 8 image (01/07/2022)

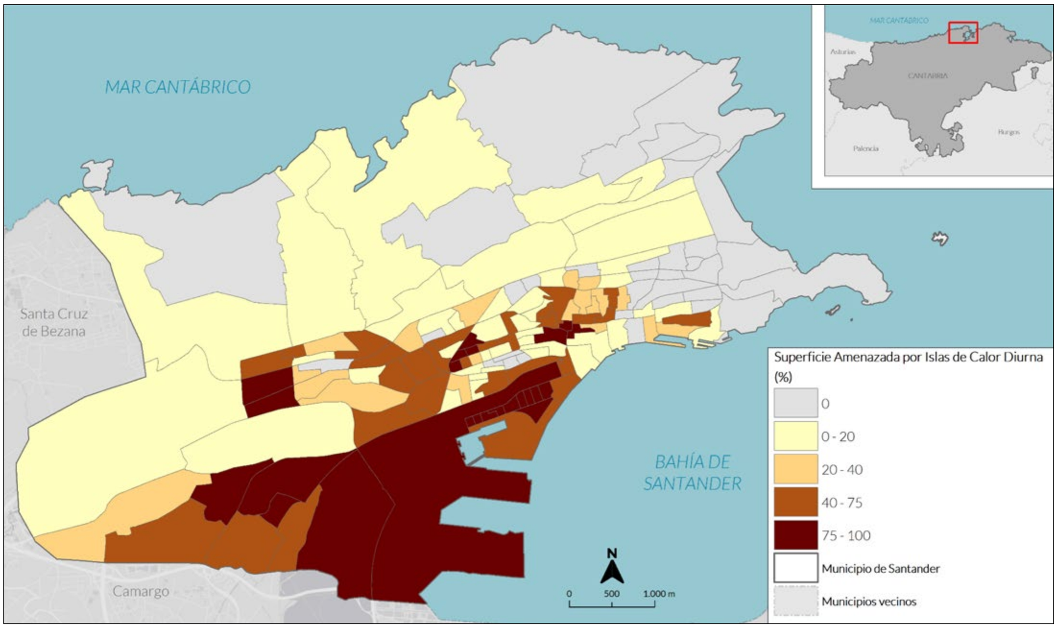

Figure 4.20. *Percentage of Area Threatened by Potential Diurnal Heat Islands by Census Sections*

Source: CINCc (UC) - FIC, 2024.

The hazard of Urban Heat Island episodes in Santander is represented in figure 4.20 by the percentage of surface area threatened by the Diurnal Urban Heat Island phenomena through the census section. The areas with the highest percentages of surface area threatened by UHI, above 75% of their surface area, are concentrated in the south, southwest and centre of the municipality. The coastal sections to the east, southwest and east, on the other hand, show no or very low values of threatened surface area.

HEAT WAVES

Heat waves have been defined as episodes of at least three consecutive days with maximum temperatures above the 95th percentile of the historical series of maximum daily temperatures for the months from April to September.

The following heat wave threat indices have been analysed within this framework:

- Number of heat waves per year
- Average duration of heat wave
- Number of heat wave days per year
- Average and maximum heat wave intensity

In order not to extend the information related to this type of event, the project shows the most characteristic indices that display the future dynamics of the phenomenon (number of heat waves and average duration). According to the historical series observed for the period 1985-2014, the average number of heat waves per year in the municipality of Santander is approximately 1.2. The scenarios projected in the short term predict a **notable increase in the average number of heat waves per year**, rising to values between 2 and 2.5 heat waves per year for the most optimistic scenario, SSP1-2.6, and the pessimistic scenario, SSP5-8.5, respectively. That is, the occurrence of these occurrence of these episodes will double in the coming years. In the medium term, the number of heat waves per year is around 3, reaching 4 for the SSP5-8.5 scenario. This trend continues towards the end of the century, reaching 6 heat waves per year for the SSP3-7.0 scenario, and exceeding 7 heat waves per year for the most pessimistic scenario, SSP5-8.5 (table 4.9).

The **average duration** of heat wave episodes in Santander, according to the average of the climate models for the period 1985-2014, is approximately 4.5 days. The projected scenarios also indicate an increasing trend in the average duration of such episodes in the medium and long term, albeit more moderately. For the short term, the climate scenarios predict an average duration between 5 and 5.5 days, with this threshold being maintained for the middle and end of the century in the most optimistic scenario. For the intermediate scenarios, SSP2-4.5 and SSP3-7.0, the mid-century and end of the century periods are expected to last between 6 and 7 days on average, respectively. In the most pessimistic scenario, SSP5-8.5, the average duration of the heat wave could double compared to the historical average, reaching values of 9.7 days of average duration of these episodes (table 4.10).

TABLE 4.9. *Average number of heat waves per year in Santander*

HISTORICAL AVERAGE: 1.22717	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	2.19313	2.09226	2.45672	2.55703
Medium Term (2041-2070)	2.65326	3.10226	3.96508	4.22697
Long Term (2071-2100)	2.77366	4.32831	5.99306	7.01242

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

TABLE 4.10. *Average duration of heat wave episodes in Santander*

HISTORICAL AVERAGE: 4.45443	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	5.13939	4.80084	5.20159	5.52596
Medium Term (2041-2070)	5.65013	6.09086	6.04402	7.03383
Long Term (2071-2100)	5.38460	6.82348	7.38716	9.7208

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

Two combined indicators have been used to represent the threat of heat wave events in Santander by census sections:

(i) **Number of heat wave days** per year which, in turn, includes forecasts of the average duration and frequency of such episodes.

(ii) **Maximum intensity** of the heat wave. For each of the time horizons considered, average values representative of the set of scenarios analysed, previously normalised, are obtained and combined.

Both heat wave days and maximum intensities show significant changes for all projected climate scenarios in each time scenario compared to the historical average. This means that the normalised heatwave threat levels tend to almost double by the end of the century compared to historical values.

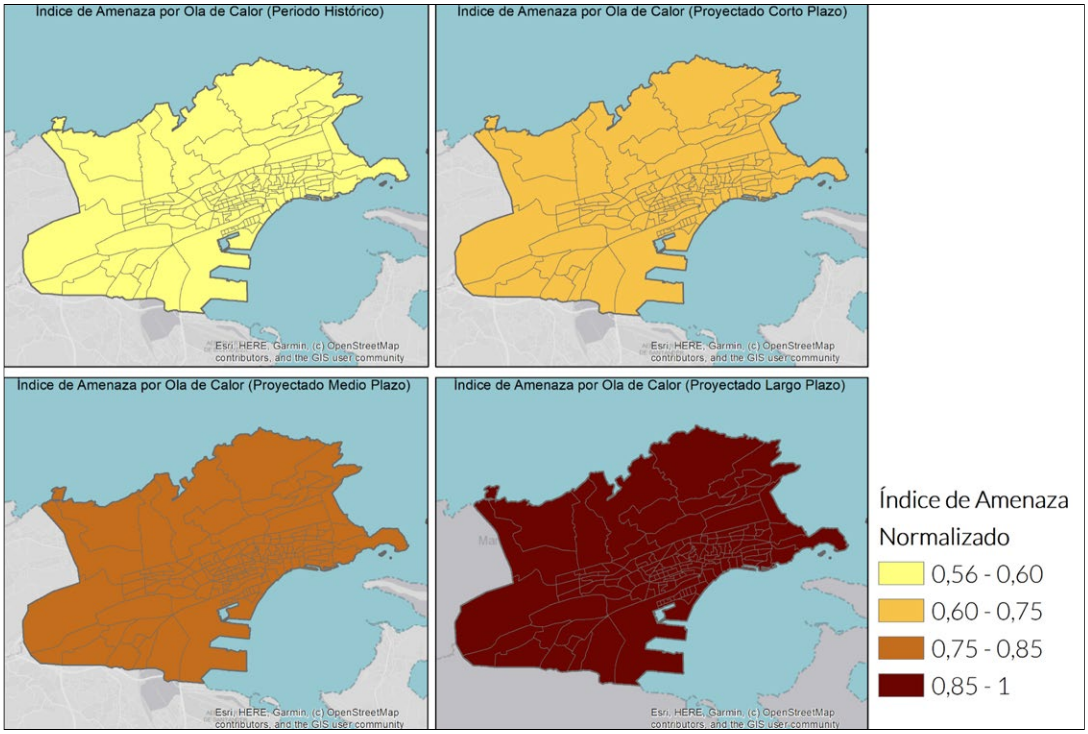

Figure 4.21. *Heat wave Hazard Index for Santander*

Note: Historical period (top left), projected short (top right), medium (bottom left) and long term (bottom right).

Source: CINCc (UC) - FIC, 2024.

TABLE 4.11. *Average values per time horizon of maximum intensity and heatwave days per year*

	HEAT WAVE DAYS PER YEAR	MAXIMUM HEAT WAVE INTENSITY	HEAT WAVE HAZARD INDEX
Historical Average (1985-2014)	10.23	29.06	0.57
Short Term (2016-2040)	19.41	29.52	0.66
Medium Term (2041-2070)	30.02	29.79	0.77
Long Term (2071-2100)	51.48	30.19	0.95

Source: CINCc (UC) - FIC, 2024.

Note: For set of climate scenarios and average results of the combined Hazard Index.

TROPICAL AND TORRID NIGHTS

A tropical night is one in which minimum temperatures do not fall below 20°C, while equatorial or torrid nights are those in which the minimum temperature does not fall below 25°C, according to the AEMET.

Results of the Analysis of Tropical Nights in Santander

The average annual frequency of tropical nights in Santander, referring to **consecutive day** events, for the series observed in the historical period from 1985 to 2014 is 1.160349. According to local climate change scenarios, based on recent IPCC outputs (6th IPCC Report), the projected mean frequency of tropical nights in Santander for the short term is around annual mean values close to 3, for all emission scenarios. For the medium term, it is around annual mean values between 3 and 6; and for the long term, it is around annual mean values between 3 and 10 consecutive nights.

TABLE 4.12. *Average frequency of Tropical Nights events with minimum temperature of 20°C in Santander*

	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	2.787025	3.190978	3.348073	3.036371
Medium Term (2041-2070)	3.636427	4.493451	5.924965	6.181109
Long Term (2071-2100)	3.475246	6.361529	9.097015	9.889041

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

The **mean annual duration**, referring to consecutive days, of tropical nights or nights with minimum temperatures of 20°C in Santander for the series observed in the historical period from 1985 to 2014 is 1.837181. According to local climate change scenarios, based on recent IPCC outputs (6th IPCC Report), the projected average duration of tropical nights in Santander for the short term is around 3 to 4 annual mean values, depending on the emission scenario; for the medium term, it is around 4 to 6 annual mean values; and for the long term, it is around 4 to 9 annual mean values.

TABLE 4.13. *Average duration of Tropical Nights with a minimum temperature of 20°C in Santander*

	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	3.458352	3.331906	3.822967	3.823205
Medium Term (2041-2070)	4.042616	4.578436	5.205120	5.751033
Long Term (2071-2100)	3.792237	6.093193	7.215842	8.758299

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

Results of the Equatorial or Torrid Nights Analysis in Santander

The average climate projections for the medium term increase the values to approximately 0.8 hot nights per year on average in Santander, with projected minimum values of around 0.23 for the SSP1-2.6 scenario, and maximum values of 1.78 for the SSP5-8.5 scenario (table 4.14).

For the long term they increase the values to approximately 4 torrid nights per year on average in Santander, with projected minimum values of around 0.19 for the SSP1-2.6 scenario, and maximum values of 9 for the SSP5-8.5 scenario (table 4.15).

TABLE 4.14. *Average frequency of Torrid Night events with minimum temperature of 25°C in Santander*

HISTORICAL = 0.005508	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	0.046056	0.053913	0.091899	0.05374
Medium Term (2041-2070)	0.089231	0.222254	0.314885	0.494965
Long Term (2071-2100)	0.076732	0.350549	1.490410	2.632053

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

TABLE 4.15. *Average duration of Torrid Nights with a minimum temperature of 25°C in Santander*

HISTORICAL = 0.005508	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term (2016-2040)	0.126627	0.116973	0.134218	0.09728
Medium Term (2041-2070)	0.138409	0.314264	0.49166	0.895114
Long Term (2071-2100)	0.135956	0.554091	2.181558	3.03577

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios based on the outputs of the sixth IPCC report

METEOROLOGICAL DROUGHT

The importance of drought lies in its impact and the sectors it affects. What differentiates the different types of droughts are the **intensity**, **duration** and **spatial coverage** of the phenomenon and the sector it affects (Hayes et al., 2011). Understanding the short-term behaviour of these phenomena is of great importance to minimise negative impacts. The risk associated with a drought event is a consequence of the natural characteristics of the event itself and the vulnerability of society to it.

The analysis of meteorological drought episodes, by their very nature, is not limited to the administrative areas of a municipality. Its incidence has a regional character with a direct implication on the availability of water resources for human consumption.

The mean values expected for the SPI (Standardised Precipitation Index) have a general negative trend but are considered normal. The mean values expected for SPI are estimated to be normal for the short and medium term and moderately dry and very dry for the long term. As shown in the figure 4.22, the short-term drought hazard level presents a negative trend but within the threshold of natural climate variability in Santander. This negative trend increases in the medium term. Finally, for the long term, a severe threat level is expected, showing a moderately dry drought threshold with respect to the medium-term accumulated drought.

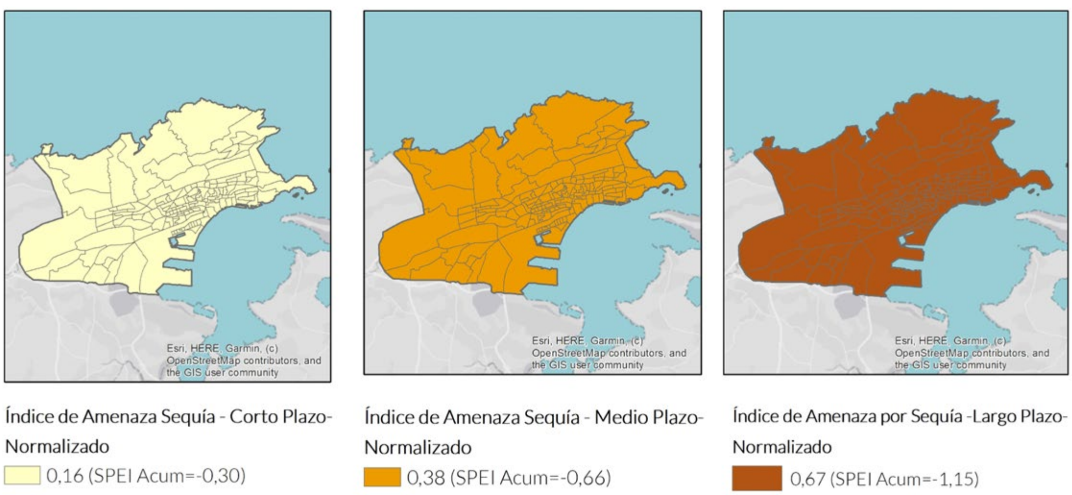

Figure 4.22. *Drought Hazard Index*

Source: CINCc (UC) - FIC, 2024.

EXTREME WIND, *GALERNAS* AND SOUTHERLY WIND

In the municipality of Santander, the predominant wind direction is west, with north-westerly winds also being very frequent, having average speeds of 13.87 km/h and 13.43 km/h respectively (Ayuntamiento de Santander, 2016). Winds of more than 91 km/h occur between September and April. Every year there are storms from both the north-west and south-west, with gusts of over 100 km/h. In general, the wind conditions two types of weather situations:

- **Humid situations:**

They are produced when winds blow from the north to the west, laden with humidity due to their maritime origin. These, when they meet the Cantabrian mountain range, rise and cool down, producing condensation phenomena. This causes clouds to form and stagnate against the mountain range, causing more or less persistent rainfall.

- **Dry situations:**

Originating from north-easterly and easterly winds, these are of continental origin, dry and cold. In this situation the sky is usually clear, although heavy frosts occur.

When caused by southerly winds, these situations are dry with an abnormal increase in temperature. Humidity can drop to 40% and the temperature can reach 30ºC, even in the middle of winter.

Any area of the municipality is exposed to episodes of extreme wind, although to a greater extent in coastal areas and exposed slopes. It should be noted that the upper area of the municipality is divided into the northern and southern slopes, so that more interventions are recorded along the southern slope when the wind blows from this side and vice versa. Specifically, southerly winds represent the most common risk situations in the municipality. According to the PEMUSAN, extreme winds are defined as winds with an intensity of more than 80 km/h, regardless of their direction. Winds in Santander have an impact on the occurrence of coastal storms F7, (50-61 km/h), rough seas, swells of 3 to 4 metres, and the occurrence of *galernas*, a characteristic wind storm of the Cantabrian sea, consisting in the shift from south winds or calm conditions to:

- At sea, sudden change of wind, increasing and turning north-west with F7.
- On land, a sharp turn of the wind to the north-west, increasing suddenly with strong gusts of more than 60 km/h along the coast.

For the present study, both types of episodes have been analysed: (i) winds of intensity greater than 80 km/h, and (ii) gusty winds from a southerly direction. For each of these variable intensity events, the following frequency and duration indices have been analysed:

- Frequency, analysed as the average number of extreme wind events per year.
- Average duration of the event, analyzed as the average number of consecutive days per year that extreme wind events occur.

In order to represent the threat from extreme wind events in Santander by census sections, the mean normalised value per census section of the maximum gust of a southerly component has been used. As shown in the figure 4.23, the level of hazard due to the occurrence of episodes of extreme wind shows geographical variability within the municipality, generally tending towards relatively higher values for the north-eastern sections, but nevertheless remaining with values between 0.86 and 1, i.e., with a low amplitude range. This is due to the fact that, as a result of the analysis carried out, the average or maximum south wind gusts, as well as, in general, the extreme wind episodes will have a very slight **downward trend** in both absolute and relative terms, with respect to the historical period, where the maximum values are reached.

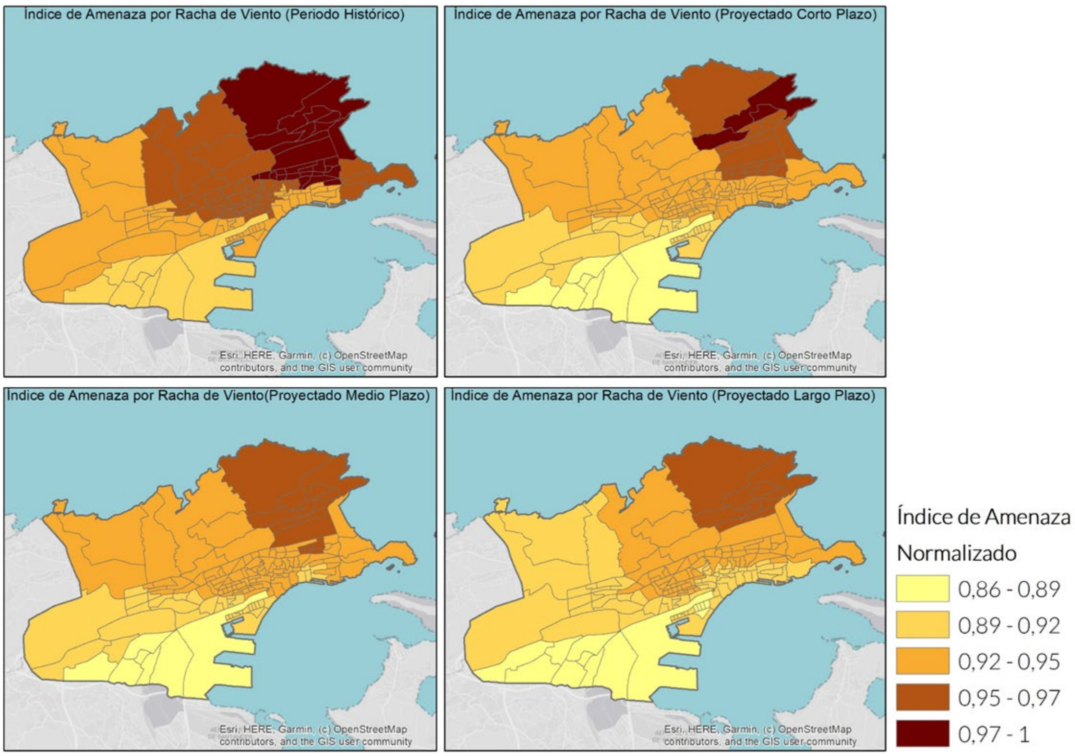

Figure 4.23. *Extreme wind hazard index for Santander*

Note: Historical period (top left), projected short (top right), medium (bottom left) and long term (bottom right).

Source: CINCc (UC) - FIC, 2024.

Therefore, the occurrence of extreme winds and maximum gusts of the southern component for the set of climate scenarios projected in each time scenario does not present very notable changes with respect to the historical average, which means that the normalised hazard levels for extreme wind episodes tend to remain above 0.86 in all the time scenarios.

TABLE 4.16. *Mean values of maximum gust in km/h and Combined Threat Index*

	MAXIMUM GUST (AVERAGE)	MAXIMUM GUST (RANGE)	MEDIUM HAZARD INDEX
Historical Period (1985-2014)	103.21	96.67-108.27	0.95
Short Term (2016-2040)	100.67	94.53-105.49	0.93
Medium Term (2041-2070)	100.32	94.46-104.97	0.92
Long Term (2071-2100)	99.44	93.54-104.10	0.92

Source: CINCc (UC) - FIC, 2024.

Note: By time horizon and for set of climate scenarios

COASTAL FLOODING

In the field of coastal areas, **PIMA Adapta**[8] has been developing a wide range of coastal habitat restoration and shoreline stabilisation actions along the entire Spanish coastline. This initiative, framed within the Spanish Coastal Climate Change Adaptation Strategy, which was approved in 2017, has a repository of high-resolution databases generated for the assessment of coastal flooding, including areas of coastal flooding and flood depth for both the historical period and the future for the 2050 and 2100 horizons with a return period of 100 years. This future modelling is also established for the RCP4.5 and RCP8.5 emissions scenarios, intermediate and pessimistic, respectively.

For the Community of Cantabria, the results of the Adapta Costa Report (2019-2021) are accessible through the official Geographic Information Viewer of the Government of Cantabria. The areas and depths of coastal flooding for the historical period and for the most pessimistic scenario (RCP8.5 in the period 2100) are shown in figure 4.24 and table 4.17.

At the municipal level, the area of coastal flooding for the historical period and with a 100-year recurrence is 108 ha with maximum depth levels close to 10 m in the lowest areas.

The mid-century projections indicate increases in flood area of approximately 5%, being a few tenths higher for the RCP8.5 scenario. And finally, the projection scenarios for 2100 indicate increases in coastal flood area of approximately 24% for RCP4.5 and 30% for RCP8.5, with maximum flood depth levels close to 11.4m. The results of the incidence of coastal flooding in the municipality of Santander for each of the scenarios considered are shown in figure 4.24 and table 4.17.

8 See: https://www.miteco.gob.es/es/cambio-climatico/planes-y-estrategias/pima-adapta.html

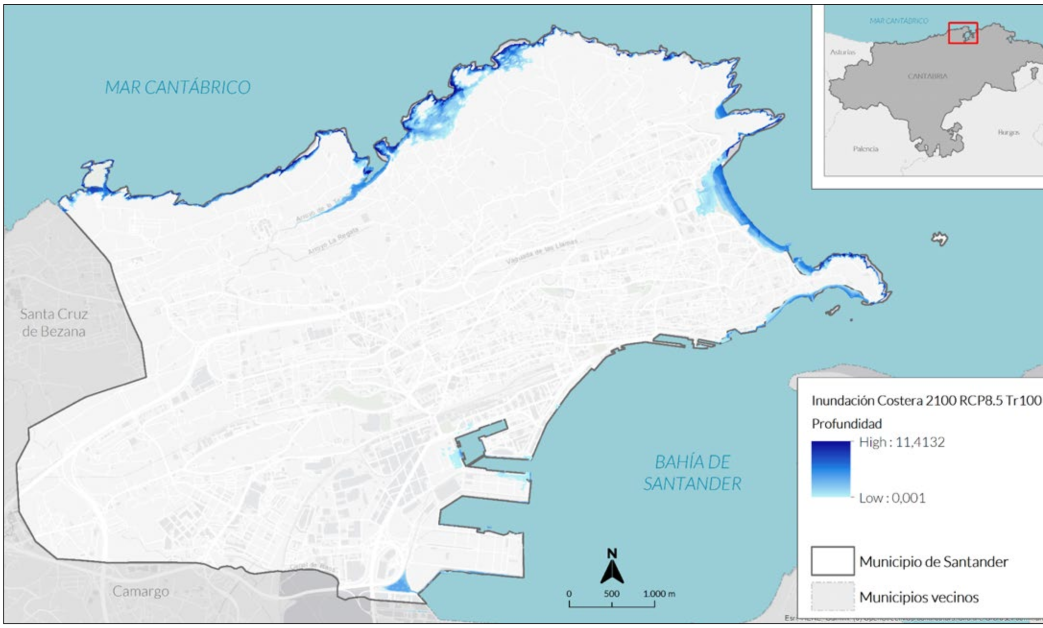

Figure 4.24. *Coastal Flood Areas and Flood Depth 2100 RCP8.5*

Source: CINCc (UC) - FIC, 2024 based on data from the Adapta-Costa Cantabria Report (2019-2021)

TABLE 4.17. *Index changes due to sea level rise*

MEDIUM SCENARIO (TR100 YEARS)	FLOOD AREA (Ha)	RANGE DEPTH (m)	CHANGE FROM HISTORICAL (Ha)	%CHANGE FROM HISTORICAL
Historical	108.34	0.001 - 9.9008		
Projection RCP4.5 2050	113.37	0.001 - 10.059	+5.03	+4.64%
Projection RCP8.5 2050	114.24	0.001 - 10.1473	+5.90	+5.44%
Projection RCP4.5 2100	131.90	0.001 - 10.8353	+23.56	+21.75%
Projection RCP8.5 2100	141.35	0.001 - 11.4132	+33.01	+30.47%

Source: CINCc (UC) - FIC, 2024 based on data from the Adapta-Costa Cantabria Report (2019-2021)