Ref. Ares(2016)6633856 - 25/11/2016

This Project has received funding from European Comission by means of Horizon 2020, The EU Framework Programme for Research and Innovation, under Grant Agreement no. 700174

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RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

# Deliverable D.1.1

## Data collection and quality control. Summary of studies on climate variables at the research cities

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**31 October 2016**

| | |
|---|---|
| **DELIVERABLE NUMBER:** | D1.1 |
| **DELIVERABLE NAME:** | Data collection and quality control. Summary of studies on climate variables at the research cities |
| **WP:** | WP1 |
| **DELIVERY DUE DATE:** | 31/10/2016 |
| **ACTUAL DATE OF SUBMISSION:** | 18/11/2016 |
| **DISSEMINATION LEVEL:** | Public |
| **LEAD BENEFICIARY:** | FIC |
| **RESPONSIBLE SCIENTIST/ADMINISTRATOR:** | Robert Monjo (FIC) |
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## Abstract

Exhaustive climate hazard identification was performed for Barcelona, Lisbon and Bristol in order to properly drive the research about possible climate change impacts on their urban areas. In particular, past climatic trends and future projections were examined according to previous studies. Climate change drivers and their related climate variables were evaluated taking into account several risk matrixes. Therefore, a level of importance was proposed for each climate variable for ordering priority and efforts in the climate module (Work Package 1) of the RESCCUE project.

Once identified all climate variables, data collection was performed for the three cities. CMIP5 data and observed data were considered for both atmospheric and oceanic variables. Climate change simulations, decadal outputs and seasonal models have been collected for the project. For the observed variables, the greatest database collected consists of temperature, precipitation, humidity, pressure, wave height and tide.

Before the beginning of the study about the climate change in the studied areas, we have carried out an analysis of the provided observed data in those areas to ensure that the quality of those data is good enough for subsequent studies and conclusions. For this purpose, a set of tests were applied over all time series: general consistency, outliers and inhomogeneities. The results of the tests showed an acceptable quality for most of the datasets.

# 1 Introduction

## 1.1 Motivation and objectives

### 1.1.1 RESCCUE project context

Climate change will cause pressures and uncertainties that will pose challenges to urban living at a time when the world is becoming increasingly urbanized (ARUP & Rockefeller Foundation 2015). These challenges can affect basic urban services, such as water or energy supply, thereby stressing cities' capacity to provide of continuously functioning services for an increasing population.

In this context, RESCCUE aims to improve urban resilience of three pilot cases, Barcelona, Lisbon and Bristol, through an assessment of climate change impacts in several sectors, and then interconnects them to assess urban resilience.

### 1.1.2 Deliverable objectives

According to the goal of the RESCCUE project, exhaustive hazard identification was required for the three cities in order to properly drive the research about possible climate change impacts on their urban areas. That includes identification of historical climate hazards, past trends and future projections, according to previous studies.

Having identified all climate drivers, it was possible to define the main climate variables and their importance and requirements for different urban services considered in the RESCCUE project (WP2 and WP3).

Therefore, the main objective of the deliverable D1.1 is to present all results of the first two tasks of WP1. Recalling the general structure of the WP1, we can distinguish four tasks:

Task 1.1: Climate change drivers (reported in this deliverable)
Task 1.2: Data collection & quality control (reported in this deliverable)
Task 1.3: Generation of climate simulations
Task 1.4: Projection of extreme events

The first task contains four subtasks: climatic hazards identification, climatic variables definition, data requirements and previous studies on climate change impacts. The second task corresponds to the data collection of the climate models and observations, with a quality control for error detection and inhomogeneity corrections.

One of the most difficult tasks in any research is the collection of all required data for the different subsequent tasks. The analysis of some hazards as flooding and severe weather requires a high spatial and temporal resolution of data, which is difficult to achieve. Administrative deadlines are often very slow, which cause significant delays in data collection. In this first deliverable, a great effort has been carried out to collect the largest possible data volume.

Another of the difficulties entailed by the targets set is the identification of climate drivers. Typically, each city uses different criteria to define arrays of climate risks, so it is difficult to compare with each other. Moreover, there are not even common criteria for defining what is a climate extreme event, or a heat/cold wave. Therefore, another objective is to identify differences and similarities between all criteria in order to approach a starting point as a global view of the state of art.This will mark the way to establish common criteria for the task 1.4 (Deliverable D1.3), which is essential for defining and projecting the climate extreme events.

# 1.2 Studied areas

## 1.2.1 Barcelona

### 1.2.1.1 Metropolitan area

*Geophysical features*

Located on the Mediterranean coast 41°23’ N/02°12’ E, 166 km from the French border and 120 km south of the Pyrenees, Barcelona is on a plain bordered by two rivers: the Llobregat in the south and the Besòs in the north. The Collserola ridge (part of the SerraladaLitoral) borders the west side of the city, with pine and oak woodland, fields and meadows, as well as wetland vegetation (Figure 1a). The city has five small hills (Monterols, Putxet, Carmel, Rovira and Peira) and was once full of streams and small marshes. The promontory of Montjuïc is also by the coast, rising to a height of 191.7 metres.

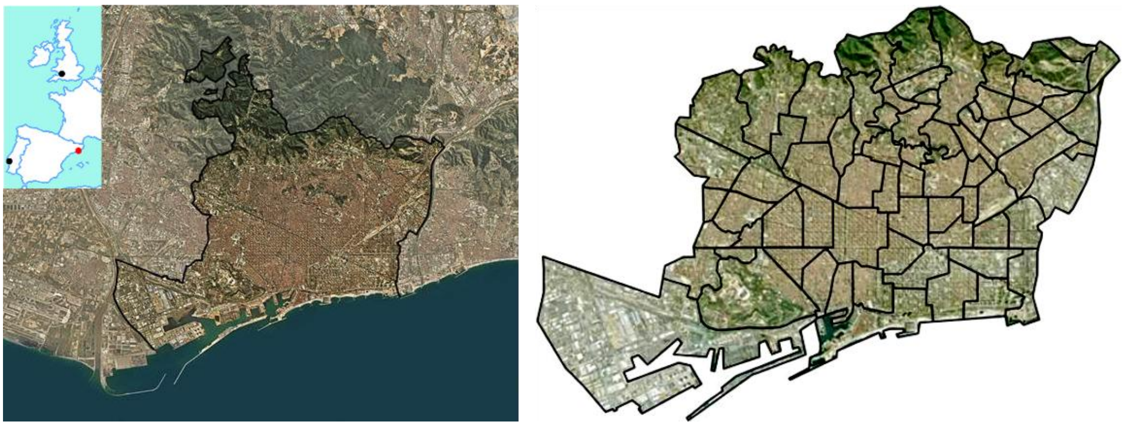

**Figure 1**.Barcelona urban area: a) Satellite image of the city, b) Distribution of the 73 neighborhoods.

The city’s climate is Mediterranean, with hot and humid summers and warm winters. Rainfalls occur mostly during spring and autumn reaching a total of 598mm/year and the average temperature is about 16.5°C with 2,483 hours of sun and solar radiation of 1,502 kWh/m$^2$. The Mediterranean rainfall pattern presents rain events with high intensity, short duration and high spatial variability. It is not rare that 50 % of the annual precipitation occurs during few rainfall events.

*Political features*

Barcelona is a dense and compact settlement: on a surface area of 100.4 square kilometres, a population of 1.619.337 inhabitants is established, which implies a density of 15,570 inhab./km$^2$.

Its territory is divided into 73 neighborhoods grouped in ten administrative districts: Ciutat Vella, Eixample, Sants-Montjuïc, Les Corts, Sarrià-SantGervasi, Gràcia, Horta-Guinardó, NouBarris, SantAndreu and SantMartí, each of them being represented by its own district council. The roots of the current division can be found in the history of the city. The district of Ciutat Vella is the old centre of the city and the Eixample is the area where the city was expanded after the city walls were knocked down. The other districts correspond to municipal areas which were around the old city, outside the walls and which became partof Barcelona during the 19th and 20th centuries. Each district is divided into different wards.

#### 1.2.1.2 Watershed

In the Catalonia internal basins, there are 18 exploitation units defined, which can be treated independently. A high number of units are required due to the climate variations in the studied area. More generally, the internal basins of Catalonia are divided into four big areas: Muga, Fluvià, Ter-Llobregat and Sud. From these basins, the one that is relevant for the water supply on the Barcelona area is the Ter-Llobregat basin.

There is a drought indicator for each one of the exploitation units, which analyses the most representative variables and offers instantly a proposed status, either hydrological normality, pre-warning state, or drought (warning, exceptionality or emergency).

There are three different units, depending on the type of indicator used:

- Units regulated by reservoirs: In these units, water supply depends almost completely on the reservoir levels. Drought levels depend on the volumes stored in the reservoirs which serve the unit. Ter-Llobregat system is an example of this kind of units.
- Units not regulated, with piezometric index: water supply depends mainly on subsurface waters form aquifers, in which the piezometric levelsare controlled in a continuous manner.
- Units not regulated, with cumulative rainfall index: water supply depends on small non-controlled aquifers, or superficial abstraction from non-regulated rivers. Drought state is here defined by rainfall accumulated in the previous months.

Ter-Llobregat basin is one of the six regulated units, which comprises all the municipalities which are supplied by the Ter-Llobregat reservoirs, including Barcelona and its metropolitan area (number 13 in Figure2).

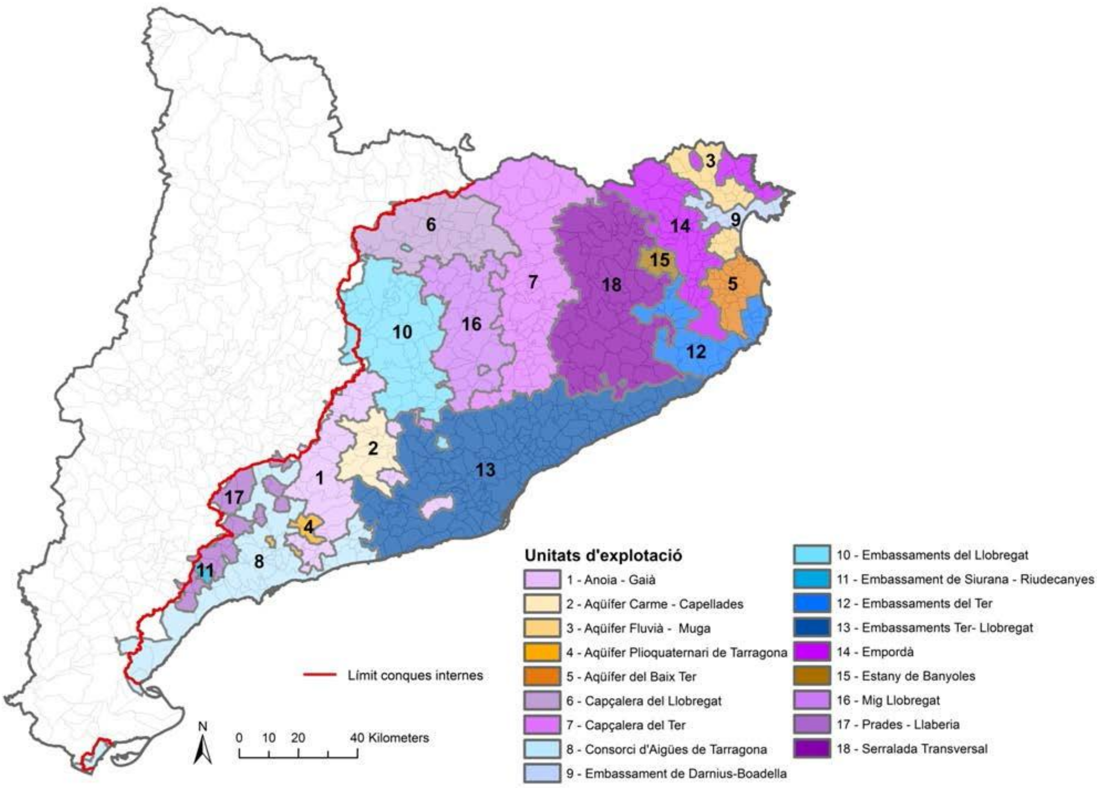


**Figure 2**. Delimitation of the 18 explotation units for the Ter-Llobregat system

## 1.2.2 Lisbon

With an extensive waterfront washed by the Tagus Estuary, Lisbon is a city that has been shaped by great human influences of a large number of cultures over time. The city enjoys a Subtropical-Mediterranean climate (Köppen climate classification: Csa), with short and very mild winters and warm summers.

Lisbon city, with 24 neighbourhoods, covers an area of around 100 km$^2$, of which 85.8 km$^2$ are continental area and 14.2 km$^2$ submersed areas. The area is classified as urban soil (100%), 90% is classified as consolidated area and 10 km$^2$ as urban forest (11.7%).

The Lisbon's Metropolitan Area encompasses 18 municipalities of Greater Lisbon and Setúbal Peninsula (http://www.aml.pt/index.php). It is the most populous metropolitan area of Portugal (NUTS III), with 2 821 876 inhabitants (2011), and the second most populous region (NUTS 2), following the Northern Region.

a) b)

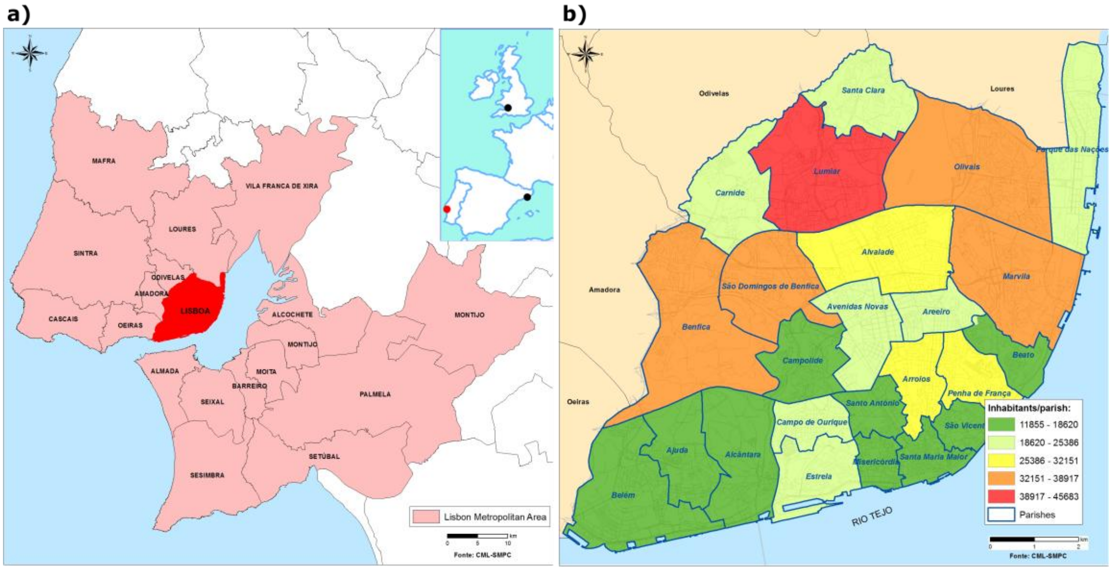


**Figure 3**.a) The Lisbon's Metropolitan Area. b) Lisbon´s boundaries and parishes and population. Source: CML (SMPC 2016). Source. CML (SMPC) 2016.

Lisbon has boundaries with three other municipalities: Loures at north, Odivelas at north-west, Amadora and Oeiras at West. Tagus riverfront is emplaced at south and east. Morphologically, the city is quite steep (average slope of 5.7° and maximum slope of 81°) with an average altitude of 76.3 meters, ranging from sea level to 216.4 meters.

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## 1.2.3 Bristol

### 1.2.3.1 Metropolitan area

Bristol is located in south-west England. The estimated population of city in 2016 is 449,300 making it the eighth most populous city in the UK, with Bristol City Council the 10th largest local authority in England. It is one of the most densely populated parts of the UK and after London the second largest city in the southern region. BCC operates as a unitary authority for the region and the city boundary also marks the county boundary. This Local Authority system of governance means that it is managed under a one tier structure and there are no further divided parishes or separate areas of governance. The city council area is divided in to 34 wards represented by 70 councilors (Figure 4).

Most of the urban extent of Bristol is based around the watercourses and river network explained in the following section. The main central area is based adjacent to the River Avon that runs from east to west through the city, which flows through flood plains and areas which were marshes in the past. The River Frome joins this in the central area, running from north to south.

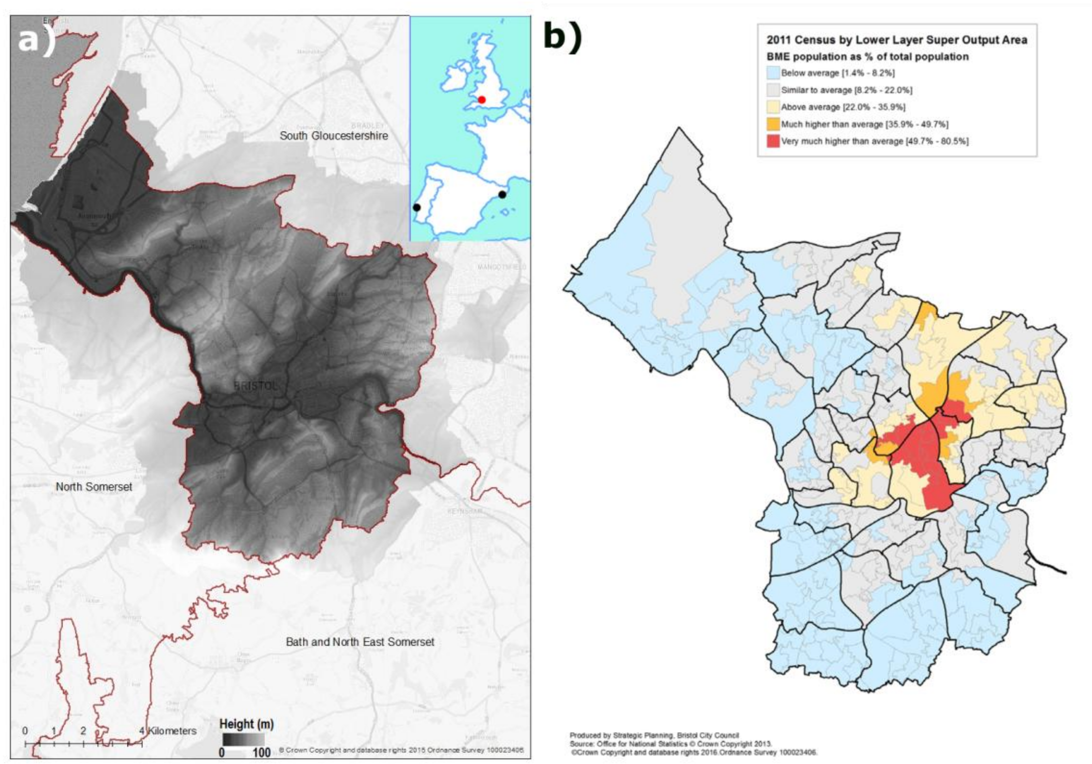


**Figure 4**.Bristol urban area: a) Elevation map, b) Distribution of the Bristol population.

The very hilly landscape of Bristol isheavily urbanised and as such much of the surface cover is predominantly impermeable. This brownfield land can result in more rapid runoff of surface water during heavy rainfall events.

### 1.2.3.2 Watershed

Bristol is located in the south-west of England near to the Severn Estuary and the Bristol Channel. There are two major rivers flowing through Bristol, the River Avon and the River

Frome. Due to the proximity to the sea (Severn Estuary), the River Avon is influenced by the tide throughout Bristol.

The flow of water through Bristol is heavily influenced by the topography. The northern and southern extents of the city are located on high ground that both slope down towards the city centre. Therefore the rivers in the north and south follow this topography and flow down to the River Avon, which defines the lowest lying areas of the city. The most northerly extent of Bristol, in the vicinity of Avonmouth, is also low lying as it is located on a coastal plain of the Severn Estuary (Figure 5).

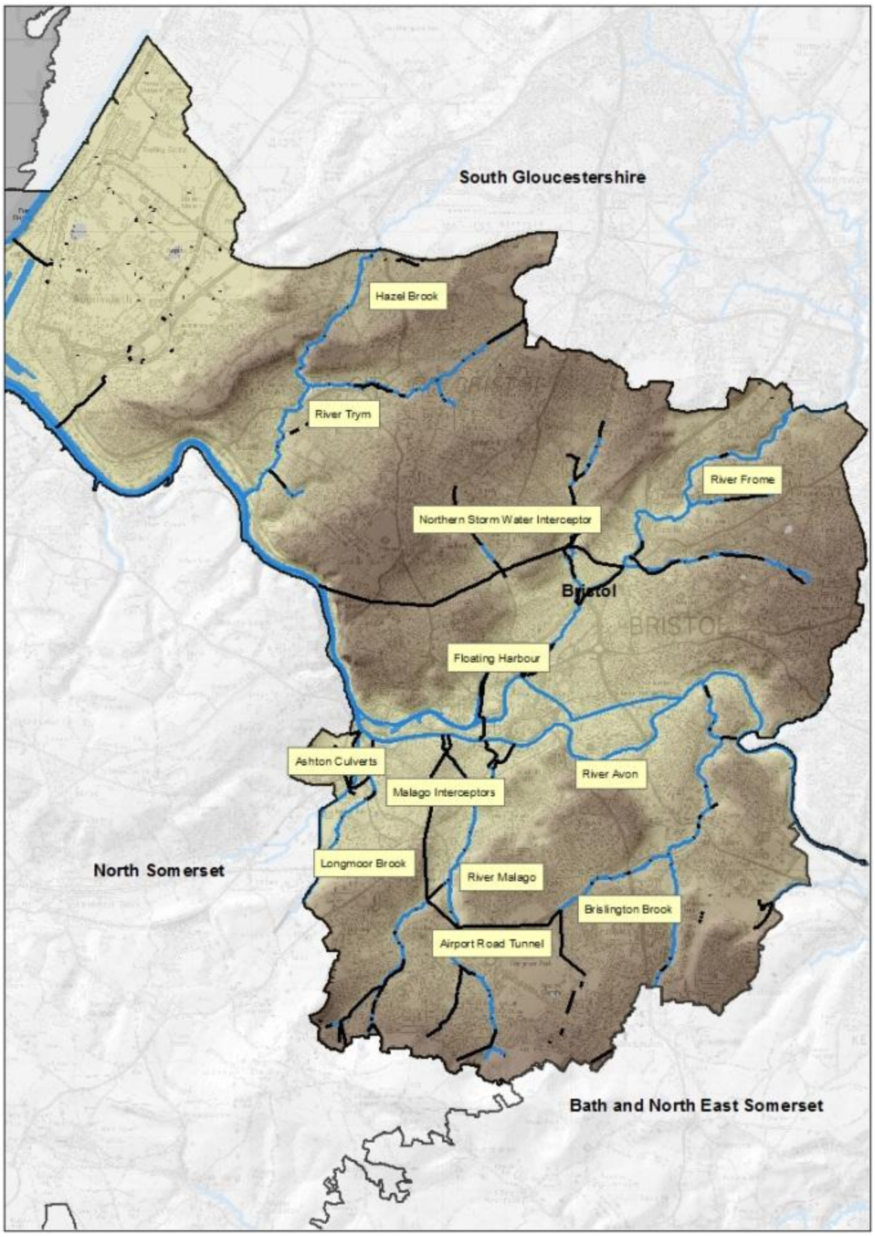


**Figure 5**. Identification of the significant drainage network and location of the major rivers (blue) and culverts (black) in the BCC area (excluding Avonmouth).

At Avonmouth, in West Bristol, the River Avon flows into the Severn Estuary from which tidal waters encroach from the Bristol Channel. A network of drainage ditches drains this area.

The Severn Estuary is reported to have the second highest tidal range in the world of 14m. This leads to extreme high and low tides.

As an island nation with temperate maritime climate, the UK is prone to variable weather conditions. These are influenced by weather systems from the North Atlantic Ocean and from mainland Europe. Conditions at sea are particularly influential on the weather experienced in the southwest of England, where Bristol is located (Figure 4).

In comparative terms, the impacts are not felt as much in Bristol compared to rest of the south-west region but their effects are still quite apparent. The influence from the Atlantic Ocean generally keeps the average temperature in Bristol maintained above freezing point throughout the year. With this it also brings rainfall and prevailing south-westerly winds. In the summer season, the region will sometimes benefits from the far extents of the Azores high pressure system, bringing warmer and drier conditions. Hot weather warming the surrounding waters, however, inevitably brings with it accompanying rainfall at some stage. This is when summertime thunderstorms then arise. The high weather variability within the temperate maritime climatic environment that Bristol is situated means a certain lack of seasonal consistencies. It also produces fluctuations and variation in the weather patterns day to day.

# 2 Recent studies on climate variables at the research cities

## 2.1 Historical trends and future climate change

### 2.1.1 Changes in Barcelona

Between 1917 and 1998, mean maximum temperature has experienced a significant trend of +1.4°C/100y at the observatory of Fabra (Barcelona). The trend is higher for the autumn and winter period, up to +2.0°C/100years (Serra et al. 2001).

For precipitation, two trends have been found depending on the region analysed. For example, Lana et al. (2003) found an increase of +2.0 mm/year at 1950-1994 period when studying Barcelona's Fabra station, while Luis et al. (2009) found a decrease (-1.7 mm/year) at 1950-2000 period when studying the province of Barcelona, both for the annual precipitation amount. Lana et al. (2003) attribute this to the Urban Effect that enhances precipitation over cities, being the decreasing trend general to the rest of regions.

There is a greater consensus for sea level rise, which presented an increase of +5.58±0.15 mm/year at 1992-2009 (Montañés 2012) and about +6.6 mm/year at 1993-2011 (Fraile and Fernández 2016).

The Spanish State Meteorology Agency provides climate change scenarios for Spain based on CMIP5 climate models (AEMET, 2016). In order to obtain local projections, AEMET used two statistical downscaling methods: analogue and linear regression. Projected changes in temperature and precipitation are summarized for two climate periods, at the middle of century and at the end of century (Figure 6).

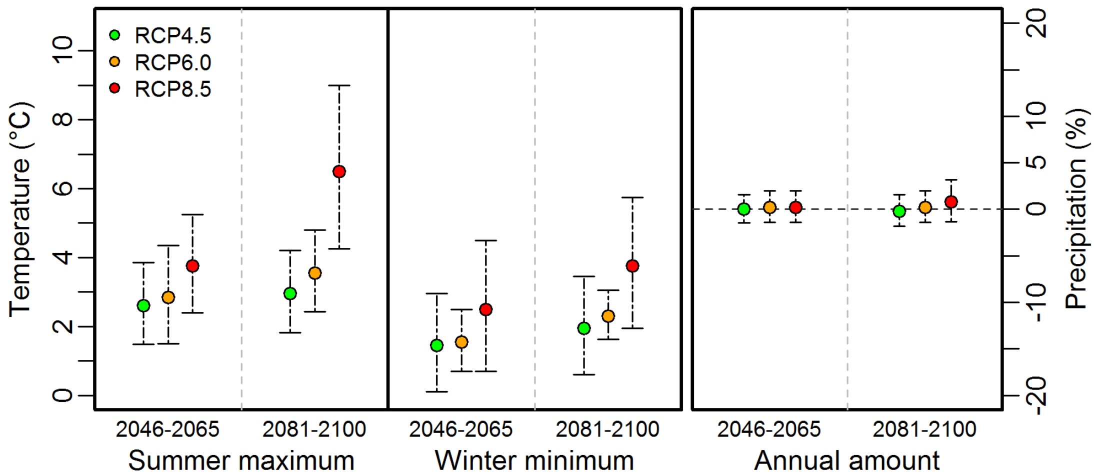


**Figure 6**. Projected changes on Barcelona for summer maximum temperature, winter minimum temperature and annual precipitation (respect to 1960-1990) according to official climate change scenarios.

Results show that summer maximum temperatures could increase between 3 and 9°C at the end of century, while winter minimum temperatures will increase noticeably less, so the thermal amplitude will be greater.

According to the AEMET (2016), the number of freezing days (with minimum temperature lower than 0°C) will decrease about 15±7%. Meanwhile, the heat days (maximum temperature above the summer's 90th percentile) will experience an increase between the +20±10% under the RCP4.5 scenario and the +40±15% under the RCP8.5 scenario. In addition, heat waves (events with at least 5 consecutive heat days) will lengthen between +10±5 days under the RCP4.5 scenario and +20±10 days under the RCP8.5 scenario.

On the other hand, the projected changes in mean and extreme precipitation are generally not statistically significant. The large natural variability of precipitation in the Mediterranean climate causes possible climate changes to be masked (Monjo *et al.* 2016).

However, some authors have found possible changes about +10±8% for extreme daily amounts and +20±12% for extreme hourly precipitation (Rodríguez *et al.* 2014).

Regarding to future sea level, projections show Barcelona could suffer a rise of the sea level of 1.3±0.3 m at the end of century (Fraile and Fernández 2016). This increase is slightly lower for the lowest scenarios (about 0.8 m) and it is almost double (up to 2.4 m) under the highest scenario of some models (Pfeffer*et al.* 2008). All these projections are much greater than the observed trend at recent years (Montañés 2012, Fraile and Fernández 2016).

## 2.1.2 Changes in Lisbon

Regarding the city of Lisbon, historical trends have been found for both maximum and minimum temperature as is published in the Portuguese SIAM II project (Santos & Miranda 2006). For the mean annual maximum temperature it has been observed a raise of +2.8°C/100y between the years 1975-2004, and of +3.6°C/100y during 1910-2004. For the mean annual minimum temperature, the increase registered was of +5.3°C/100y between 1975 and 2004, with a consequent diminished thermal amplitude. According to Santos & Miranda (2006) andde Lima *et al.* (2005), no historical trend was found for precipitation neither in annual nor seasonal period.

Daily rainfall data from 1864 until 2013 at the D. Luís observatory show high inter-annual and intra-annual variability in the rainfall regime in Lisbon (Kutiel &Trigo 2014). This variability increases the uncertainty on characterization of the rainfall regime in Lisbon. However, there has been a significant net increase in the annual totals since the 1960s compared to the first half of the previous century. This increase is mainly due to more intense events in the last 50 years (Kutiel &Trigo 2014). Rainfall tends to accumulate earlier in the year in the last decades as compared to the first half of the previous century. The long-term climate variability context of this 150-year period is characterized by a drier period in the first half of the twentieth century, when several consecutive droughts affected Iberia, particularly between the 1920s and 1940s.

For the period 1941-2007, seasonal precipitation exhibits significant decreasing trends in spring precipitation, while extreme heavy precipitation events have become more pronounced in autumn (de Lima *et al.* 2012, 2013).

A positive trend is obtained for historical sea level rise, with a +1.6mm/year trend for Cascais' buoy. Successive increase of the mean sea level rise has been monitored, showing acceleration from 2.2 mm/year rate at 1992-2004 to 4.1 mm/year at 2005-2016 (Antunes 2016).

In regard to future climate trends, the Sea and Atmosphere Portuguese Institute offers a detailed regionalized study of climate change AR5 scenarios and their effect in several variables across the country (IPMA 2016a). To that purpose the ENSEMBLE4 method, gathering four regional models, was used, projecting changes for 2041-2070 and 2071-2100 periods.

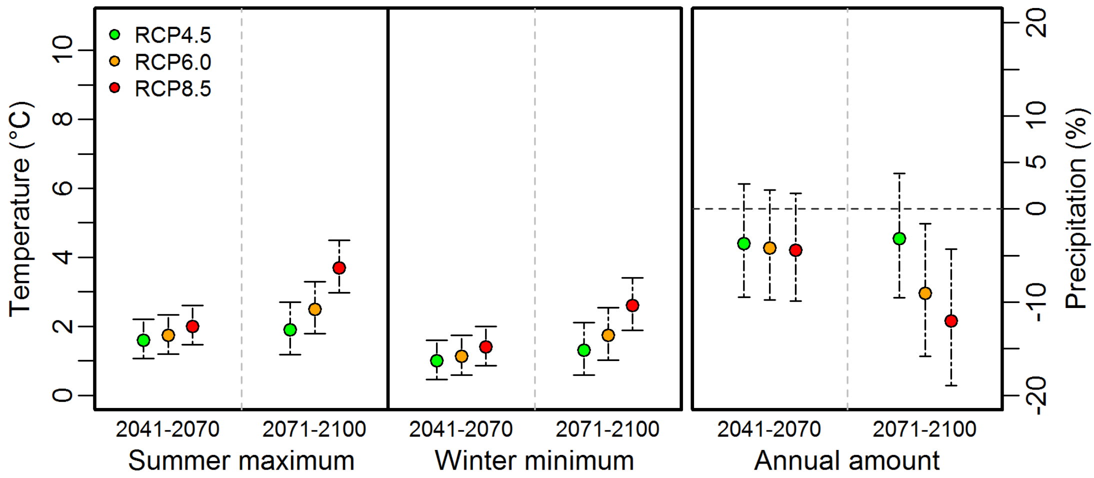


**Figure 7**. Projected changes on Lisbon for summer maximum temperature, winter minimum temperature and annual precipitation (respect to 1960-1990) according to official climate change scenarios (IPMA 2016a).

Results, depicted in Figure 7, show a general positive trend for temperatures, and a negative trend for precipitation. In respect of annual maximum temperatures, summer maximum temperatures are expected to rise between +1.1 to +2.5°C in 2041-2070 period, and from +1.2 up to +4.5°C in 2071-2100 depending on scenarios. Winter minimum temperatures are expected to elevate about the same values. Heat wave events duration (considered as 6 consecutive days with temperatures 5°C above period's daily average) could experience a change about +38% to +69% (±8%) for 2041-2070, raising to +54% (±8%) to +115% (±15%) in 2070-2100 (IPMA 2016a).

Projections for annual amounts of rainfall show a general decrease, being smaller in 2041-2070, about -3.7% to -4.4% (±6.2%). The diminishing in the amounts is greater in 2071-2100, about -3.2% to -12.0% (±7.3%). Its Atlantic climate shows a strong response to atmospheric patterns changes due to warming, the bigger the radiative forcing, the bigger the decrease.

Regarding future sea level, projections for Cascais' buoyindicate a general raise that depending on the model and method, ranges from +0.47±0.27m by 2100, with a trend extrapolation (Antunes & Taborda 2009) to +0.95±0.45m for a Rahmstorf scenario (Antunes et. al 2013).

## 2.1.3 Changes in Bristol

Mean temperature has experienced a significant rise of 1.6°C in Bristol city area between 1961 and 2006 (Jenkins et al. 2016). Similar trend is observed for both maximum and minimum temperatures, having an uncertainty range of ±0.2°C/year. However, no trend has been found for precipitation at the same period, taking into account a confidence level of 95%.

Changes in other variables have been measured by Jenkins et al. (2016). For example, the days of frost (days whose minimum temperature falls below 0°C) have decreased in 20 days between 1961 and 2006. As for sea level, Philips and Crisp (2010) have found a remarkable trend of +2.4mm/year in the Bristol Channel for the period 1993-2007.

The Met Office provides climate change scenarios based on CMIP3 climate models

(Murphy *et al.* 2009). Projected changes in temperature and precipitation are summarized for two climate periods, at the middle of the century (2041-2060) and at the end of the century (2071-2090), having obtained for Bristol the results as follows (Figure 8).

Results for show that maximum temperatures could rise between 3°C and 5°C at the middle of the century and between 5°C and 7°C at the end of the century. As for winter minimum temperature, all scenarios agree with an increase of 2°C between 2041 and 2060 while the increase could be slightly higher, reaching between 3°C and 5°C at the end of the century. Regarding precipitation, scenarios B1 and A1B show an increase of 5% in both periods studied, whereas scenario A1FI shows a decrease of 5% in the middle of the century and an increase with a massive uncertainty level at the end.

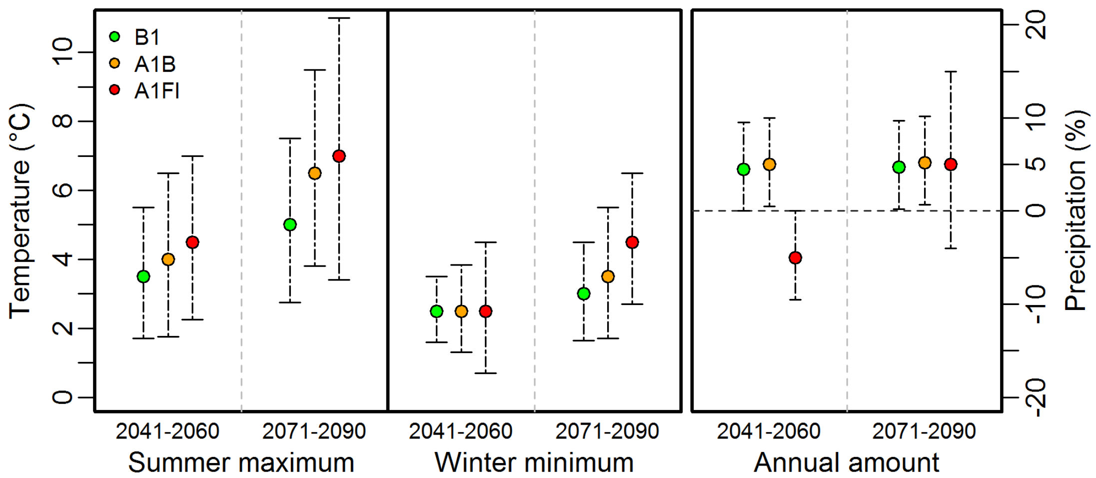


**Figure 8**. Projected changes on Bristol for summer maximum temperature, winter minimum temperature and annual precipitation (respect to 1960-1990) according to official climate change scenarios.

Every sea level projection shows no exception an increase in the sea level in Cardiff (Bristol Channel) for the next century (Lowe *et al.* 2009). This rise differs slightly depending on the scenario, reaching between 0.18m and 0.26m in 2050 and between 0.37m and 0.53m in 2099.

The scenario A1B predicts a decrease of 85% in number of days of snow in winter for the period 2071-2099 (Brown *et al.* 2010) and an increase of 2 days in number of thunderstorm days in summer and autumn with a very high uncertainty level (Boorman *et al.* 2010).

## 2.2 Climate impacts on theresearch cities

### 2.2.1 Barcelona previous studies

#### 2.2.1.1 Extreme temperature

*Heat waves and urban island*

Taking into account the urban area handled, heat island effect must be taken into consideration (Moreno 1994, 2007). Barcelona city centre, especially Eixample district, suffers from a significant Urban Heat Island (UHI) effect all year long, in comparison to its outskirts.The intense UHIs have acquired the status of risk during heat waves in urban mid-latitude agglomerations. They intensify the conditions of excessive heat at night, with harmful effects on the health of the old or sick people (Martin-Vide *et al.* 2016).

Martin-Vide *et al.* (2015) made an extensive characterization of its nature by the realization of more than 30 transects with a thermohygrometer, at different days, through Barcelona and its metropolitan area. The result was a value that goes generally from +1.0°C to +2.7°C at night, with a maximum observed value of +7.5°C.

The same authors have studied the dependence of theUHIs intensity on geographical, urban, temporal and meteorological factors. A general conclusion is that intense UHIs occur with light winds or calm, and clear skies or slightly cloudy, that are associated with anticyclonic conditions. In the case of the Barcelona Metropolitan Area, Martin-Vide *et al.* (2016) used an objective weather-types classification of Jenkinson and Collison, based on a grid of 16 points, for the period 2004-2010, and defined an indicator of UHI intensity according to the differences between the minimum daily temperatures of the meteorological stations of Barcelona (Vila Olimpica) and Barcelona airport (AEMET) for the days of the same period. The study concludes that the synoptic type with a highest average of differences is the anticyclonic southwest advection, with 2.7°C.

In the context of climate change, this effect could be strengthened due to projected temperature changes, resulting in added danger to local inhabitants especially at summer nights (Martin-Vide 2015, 2016).

#### 2.2.1.2 Extreme precipitation

*Intensity Duration Frequency curves*

Climate change could affect extreme precipitation. However, given the natural variability of the precipitation, it is necessary tofocusonits historical extreme values. A method for analyzing natural variability of extreme precipitation is based on the Intensity Duration Frequency (IDF) curves. The commonly used equation for the IDF curves is the proposed by Sherman (Sherman 1931, Chen 1983, Rodríguez et al. 2014)

$$I(t,T) = \frac{a(T)}{(b+t)^n} \qquad \text{Eq. 1}$$

where$I(t, T)$ is the maximum rainfall rate for a return period $T$ and a duration$t$, while$a(T)$, $b$, and $n$ are fitting parameters. For high durations ($t>>b$), the IDF curve is the same formulae than the Maximum Averaged Intensity (MAI) used in meteorology to classify the rainfall types (Moncho et al. 2009, Monjo 2016):

$$\frac{I(t)}{I(t_0)} = \left(\frac{t_0}{t}\right)^n \quad \text{Eq. 2}$$

Where $I(t)$ and $I(t_0)$ are MAIs for a duration $t$, and $t_0$. The scaling parameter $n$ is an indicator of the temporal irregularity of rainfall into an event ($n$ takes values between 0 and 1), and can be interpreted as a fractal dimension of the intensity (Monjo 2016). Therefore, the index $n$ is a useful tool for measuring the irregular behavior of extreme rainfall in the IDF curves (Koutsoyiannis & Foufoula-Georgiu 1993, Moncho *et al.* 2009).

The first IDF curve for the city of Barcelona was estimated using 1927-1980 data from Jardí rain gauge of the Fabra Observatory (Redaño *et al.* 1986). In these cases, IDF curves were achieved considering durations from 5 minutes up to 60 minutes and using Talbot-Montana function. Raso et al. (1995) improved the design storms for the New Drainage Master Plan (DMP) of Barcelona, considering 1927-1993 data from the Fabra Observatory.

Casas et al. (2004) studied the maximum rainfall rate corresponding to time intervals between 5 minutes and 24 hours. In order to improve the representativeness of the Barcelona IDF curves and the related design storms, Casas *et al.* (2010) extended their previous work using data from all the rain gages of the city network.The new generalized intensity-duration-frequency relationship for Barcelona was obtained as:

$$I(t,T) = \frac{9.5\log T + 12.5}{(7+t)^{0.75}} \quad \text{Eq. 3}$$

Where $I(t, T)$ is in mm/h, $T$ in years and $t$ in minutes. Comparing the maximum intensities obtained in this last study with the values obtained by Raso*et al*. (1995), it could be observed that differences are ranged between 0.4 and 8.4% for return period between 10 and 100 years.

*Synthetic storms*

One of the first synthetic project storms for Barcelona was elaborated for the DMP of 1988 considering a modified Chicago methodology. In this case two project storms with return period of 10 years were elaborated: one with 5-minute peak intensity and other one with 10-minute peak intensity (finally adopted for the Plan).

Some references showed an overestimation of maximum discharges produced by synthetic storms elaborated using Keifer-Chu (or Chicago) method. For this reason, Raso*et al.* (1995) updated the Barcelona synthetic project storm. In fact the DMP design storm based on the Chicago methodology was considered too unfavorable as it had all its maximum medium intensities (for all the time intervals: 5, 10, 15, minutes) corresponding to design return period (10 years in Barcelona), which is not realistic. The authors cited several references that demonstrate the overestimation of the flows using this type of procedures (Marsalek 1978, Arnell 1982).

Raso et al. (1995) analysed all the recorded rains whose intensity was at least greater than a one-year return period and evidenced similarities in the relationship between duration and maximum intensities. The events with some return period greater than 10 years (19 rainfall events) presented three envelopecurves according to the duration. However, maximum rainfall intensities occur at an instant between the 1/3 and 1/2 of the total duration. For example, a rain event of 1 hour has a maximum intensity at 20-30 minutes.

Once new IDF curves were achieved new design storms were elaborated by Casas et al.

(2010) in order to update the design storms for the EU CORFU (Collaborative Research on Flood Resilience in Urban areas; http://www.corfu7.eu/) in which Barcelona was involved.

All the rainfall data from the whole rain gauge network collected between 1927 and 2009 were considered and rainfall intensities during periods from 5 minutes to 120 minutes (with increment of 5 minutes) were calculated for each storm event.

*Climate change effects on extreme rainfall*

According to Rodríguez et al. (2014), changes in extreme rainfall were expected for Barcelona. The study considered spatial and temporal downscaling of climate models in order to estimate climate change at local scale.

In general, results showed great variability depending on the general circulation model used, yet it has found a trend of increasing daily maximum rainfall intensity between 1% and 4% for the time period 2033-2065 and a 10yr return period, depending on the scenario (A1B, A2, B1 and B2). The information on the variation of the annual maximum daily rainfall was used to update the 10yr return period design storm by applying two different methods (Rodríguez et al. 2014): invariance of climate change factors and scale invariance (fractal properties of the rain).

According to the method of invariance of climate change factors, the percentage of relative variation is directly used to uplift the design storm. Using this method, the maximum uplift factor for 10yr return period design storm was 4%.

The scale invariance method looks for relations between two temporal scales of rainfall data, such as hourly and daily rainfall, according to the MAI curves (Eq. 2). These relationships were used to downscale the daily information provided to hourly information. As a result, the uplift factors for different time periods and return periods were calculated. Table 1 presents the results for the time period 2033-2065.

**Table 1**. Variation (%) of the annual maximum daily and hourly rainfall for the time period 2033-2065 (all scenarios) respect to the control period (Rodríguez et al. 2014).

| Time | Scenario | Return period (years) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **1** | **5** | **10** | **20** | **50** | **100** | **500** |
| Daily rainfall | **A1B** | 0 | 3 | 4 | 5 | 6 | 6 | 8 |
| | **A2** | 0 | 0 | 1 | 1 | 1 | 1 | 2 |
| | **B1** | 1 | 2 | 2 | 3 | 3 | 4 | 5 |
| | **B2** | 0 | 1 | 1 | 1 | 2 | 2 | 3 |
| Hourly rainfall | **A1B** | 8 | 11 | 12 | 13 | 14 | 8 | 11 |
| | **A2** | 9 | 9 | 10 | 10 | 10 | 9 | 9 |
| | **B1** | 3 | 3 | 4 | 4 | 5 | 3 | 3 |
| | **B2** | -5 | -4 | -4 | -3 | -3 | -5 | -4 |

Finally, the results of the scale invariance (which are more conservative and more scientifically based than the first method) were used to define the design storm for the future scenario. The maximum uplift factor (1.12) of the time period 2033-2065 was chosen to uplift the current design storm (10 year return period). This design storm was used in the hydraulic simulation to represent the future rainfall condition over Barcelona (year 2040) and was named Plubarna 2040 A1B (Rodríguez et al. 2014).

On the other hand, Monjo et al. (2014, 2016) found no significant changes in daily extreme precipitation but index *n* could experience an increase of 14% (from 0.71 to 0.72). Therefore, a greater concentration over time is expected for subdaily precipitation in Barcelona.

#### 2.2.1.3 Drought risk assessment and management

*Basin plans and water availability in drought periods*

The Catalan Water Agency (AgènciaCatalana de l'Aigua, ACA) has developed a plan which defines how to proceed in case of a drought period (ACA 2015, 2016).

This plan applies to the internal basins of Catalonia (Districte de Conca fluvial de Catalunya), which have suffered different drought periods in the past decades, some of which have threatened the water supply to the population. The purpose of the plan is to ensure an appropriate management of drought periods, by allowing involved actors to know well in advance the measures to be applied, ensuring better anticipation and security.

A threshold level for the Ter-Llobregat basin is adopted according to the criteria of obtaining a sufficient guarantee of supply for the reservoirs and for the different units. The thresholds are defined to guarantee that, once the Emergency level is applied, the worse twelve-month contribution series can be overcome without reaching the most severe drought level (Emergency III).

The Plan sets three drought scenarios which involve management actions for each one in a stronger increase: Alert, Exception and Emergency. For reservoir units, three sublevels are includedin Emergency Level.

The level thresholds for the Ter-Llobregat basin are defined by three indicators

- Reservoirs Ter and Llobregat
- Reservoirs Ter
- Reservoirs Llobregat

Each indicator is compared with the threshold, and as a result of that, a partial drought level is defined for each one (Figure 9). The definitive drought level is the worst of the three of them, due to the strong link which is done between both catchment areas. This significant connection causes that a critical situation in one of them involves an equivalent situation for the other ones.

The main indicator to monitor the drought episodes is the threshold for both reservoirs, because this indicator has the higher threshold and, therefore, it will set the drought level in the main situations. In general terms, the basins management should avoid these imbalance situations.

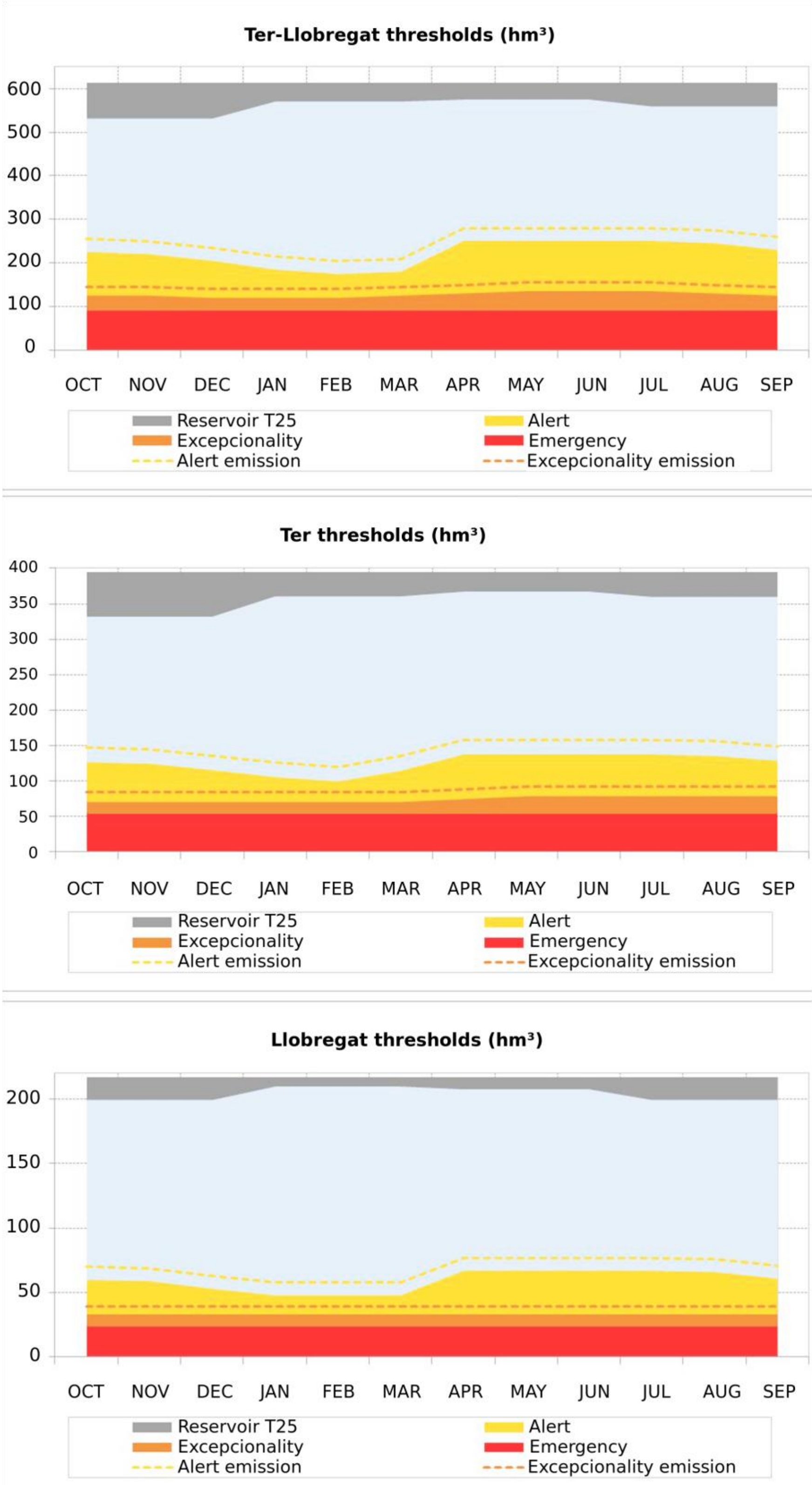


**Figure 9**. Level thresholds for Ter-Llobregat system (up), Ter basin (middle) and Llobregat (down). Source: Adapted from ACA (2016).

*ACA Catchment Management Model*

The ACA uses the SSMA model (Sacramento Soil Moisture Accounting model, of U.S. National Weather Service River Forecast System, NWS RFS), conceptual mathematical model for continuous simulation of catchment area hydrologic management. The model is fed by the rain and runoff records of the all climatic stations with more data length.

The model simulates the daily rainfall-runoff transformation process in a basin with a soil type and as a result it provides the contributions series for a complete period (1940-2008) to 364 units or subbasins. By means of this approach, it is also possible to differentiate the infiltration flows to aquifers, taking them into account in the general framework for system flows (Figure 10).

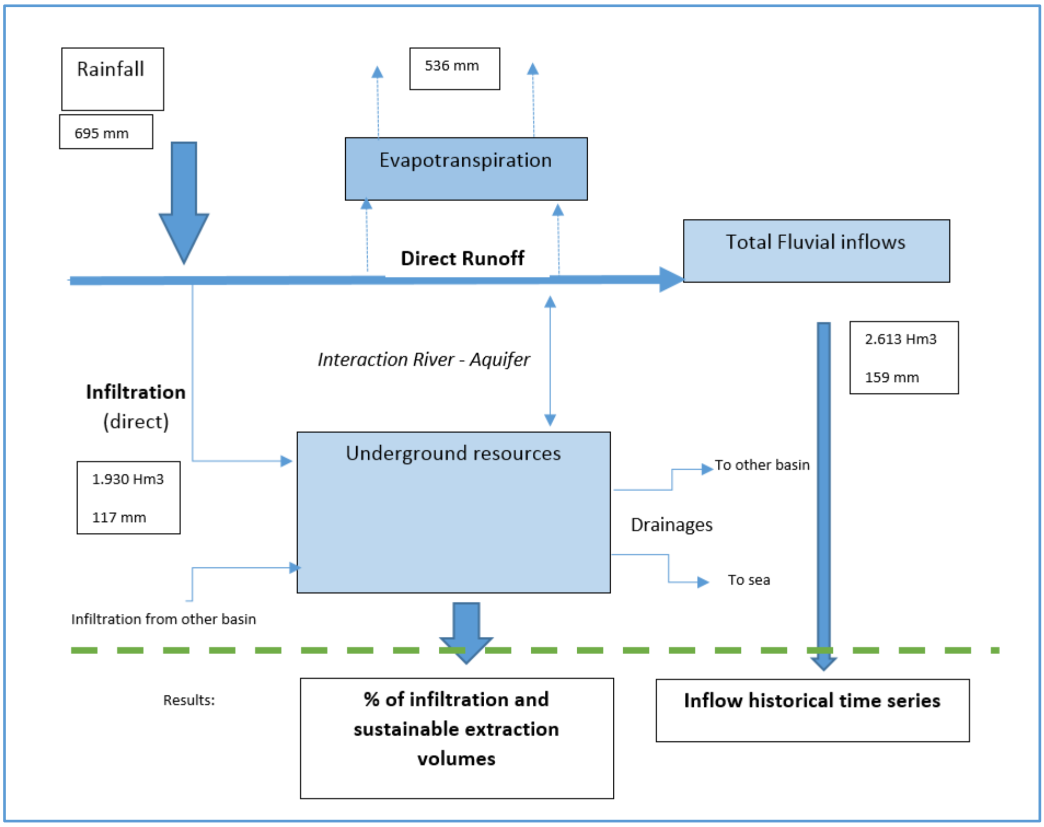


**Figure 10**. Main water flows in hydrologic circle in DCFC. Source: ACA.

With the introduction of daily rainfall and runoff in the model, the inflows and volumes of reservoirs and simulated deficits are obtained. The final flow corresponds with the complete contribution, which includes the superficial component and the underground component that eventually appears superficially with a delay in relation to the rainfall that caused it.

These partial additions in single units and sub-basins are aggregated in order to obtain upstream the whole addition of contribution to each bigger unit or sub-basin.

For the model calibration, the main criterion is the adjustment of average contributions, according to the observations in several gauging stations.

## 2.2.2 Lisbon previous studies

*Heat waves and Urban Heat Island*

Some of the most recent heat waves suffered at Lisbon were those of 2003 or 2005. Lisbon is a city of mild temperatures thanks to the influence of both Tagus River and the Atlantic Ocean. However, heat waves appear mainly due to African intrusions and south-east winds. These increase risk for a population that is not used to extreme hot temperatures. To that purpose of adapting to high temperatures, several studies and projects have been performed regarding Lisbon's Urban Heat Island considering the extension of the city.

Alcoforado *et al.* (2005) summarised all studies on Lisbon's UHI, merging them with others concerning wind distributions in Lisbon so as to improve urban planning in future times. The most used methodology to elaborate this works is based on interpolation techniques as multiple regressions. Alcoforado and Andrade (2006) made a total of 554 local measurements (14 locations x 10 days + 69 locations x 6 days) plus several other occasional campaigns at night to collect temperature data throughout Lisbon's metropolitan area. Using all these information, maps of Lisbon's UHI were created (Figure 11). Considering as reference stations Lisbon's Airport and Lisbon's Baixa district close to historic city centre, it results in a mean value of +2.5°C, being greater to even a mean of +4.0°C at winter nights. UHIs are more intense at night, even at summer days can be observed. Therefore, the combination of UHIs and heat waves events may suppose an extra hazard for Lisbon's inhabitants.

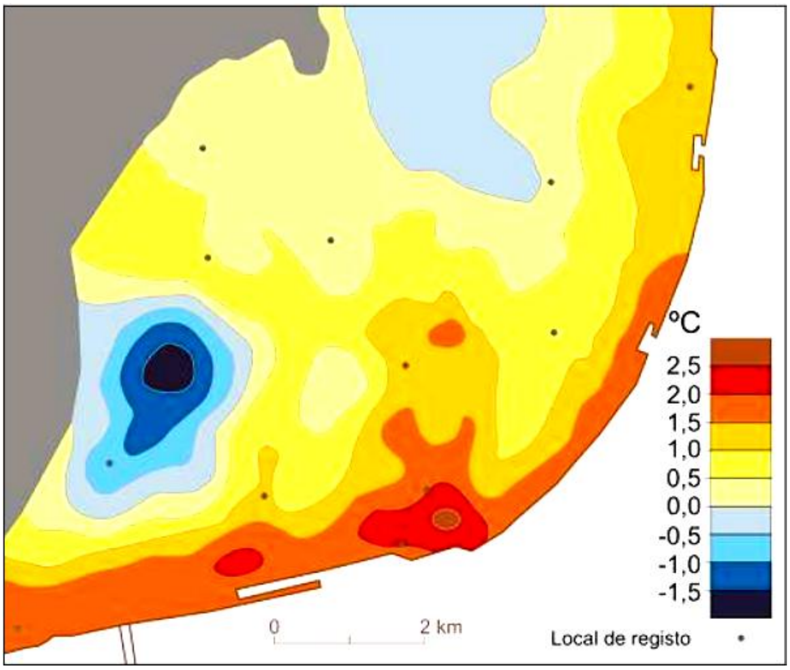


**Figure 11**. Distribution of normalized temperature anomalies associated to Lisbon's Urban Heat Island during a night with moderate North wind.

The Municipal Master Plan concludes on the need of reinforced environmental concerns. This promotes actions to improve air quality and to provide better ventilation in order to mitigate the urban heat island for a higher comfort bioclimatic and health.

*Extreme precipitation and climate change*

Due to location and climate of Lisbon, some episodes of floods have been recorded over the years, particularly in places in the edge of Tagus River and in lower areas.

Lisbon´s history is associated with reports of floods occurrences that interfered in the normal functioning of the city. These have implications in living and mobility of the population and damage on the buildings, critical infrastructures and heritage, in the public space (in terms of mobility and urban furniture), vital points of the city, among other structures located in specific areas, located both at the surface as in underground. Generally floods in Lisbon are associated to events of extreme local rainfall, resulting in superficial flooding that interact with street and buildings distribution. The combination of tidal effect, reducing the discharge capacity of the sewer outlets in the estuary, is a major factor in the worsening of floods in low-lying areas. Sometimes the Tagus River also causes fluvial floods due to excess of flow, although the flooded areas are located upstream of Lisbon and nowadays the river is highly regulated.

However, not only floods are a serious threat to the city of Lisbon, but droughts are a hazard that must be taken into account, especially taking future rainfall projections (section 2.1.2). These projections show moderate to high decrease in annual rainfall that could, paradoxically, be associated to more extreme rainfall events. This could lead to a scenario of more intense droughts interrupted by local flooding.

Some projects are aligned with the European and National Strategies for Adaptation and intend to promote adaptation at local level in Portugal. For example, Lisbon City Councilhas participated in projects of urban renewal and adaptation to floods like FloodCBA. Some other projects have been performed to adapt the existing structures and future constructions or urban projects to flood risk along river and brooks areas (ANPC 2016). In this sense, some maps of flood-prone areas were developed by studying the topography and soil structure, and by analyzing the soil and human structures drainage capability in events of severe precipitation.

Regarding drought risk, Lisbon participated in the European PREPARED project (http://www.prepared-fp7.eu/prepared-lisbon-portugal), being assessed in drought and climate change possible effects on the water supply, salinity of aquifers, etc, implementing strategies to deal with possible future hazards. Another project pursued to raise awareness about climate change is ClimAdaPT (http://climadapt-local.pt/en/), which aims to create several groups of technical units to maintain different Portuguese cities connected into a Climate Change Adaptation Network.

## 2.2.3 Bristol previous studies

2.2.3.1 Extreme temperature events.

According to the definition of the Heat Wave Duration Index (HWDI) by the World Meteorological Organization (WMO 2001), Met Office (UK) considers that a heat/cold wave occurs when the daily maximum temperature of at least six consecutive days exceeds/underlies the average maximum/minimum temperature by 5°C of the reference period.

Heat/cold waves in Bristol area were studied by Brown *et al.* (2008) using Empirical Cumulative Function (ECDF) for their duration. The analysed duration ranges between 4 and 14 days, with five return periods corresponding to 5, 10, 25, 50, 100 years (Figure 12). The mathematical relationship of Temperature-Duration-Frequency is similar to the Intensity-Duration-Frequency curves of the Section 2.2.1.2, but without the logarithm scale. For heat waves, temperature threshold is between 26°C and 29°C for duration of 6 days in heat haves. While for cold haves the threshold is between –6°C and –3°Cfor the same duration.

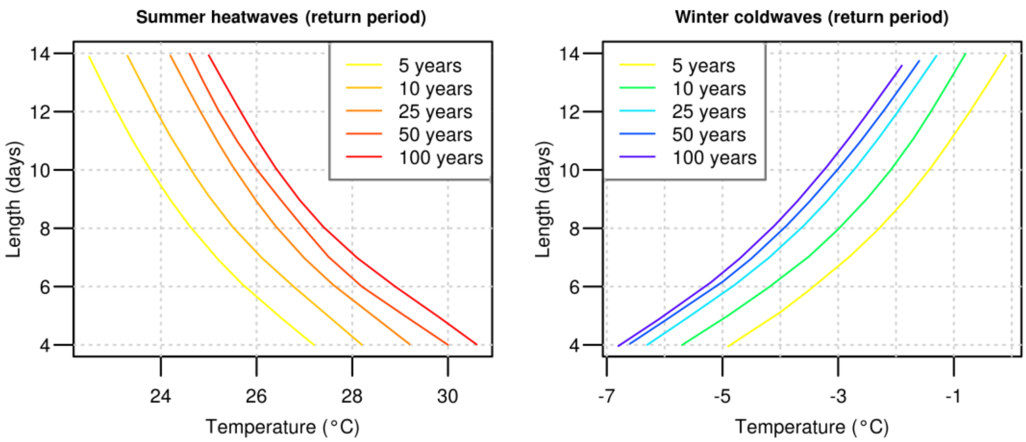


**Figure 12**.Length in days of the typical heatwaves (left) and coldwaves (right) on Bristol area (adapted from Brown *et al*. 2008).

2.2.3.2. Urban and regional flooding

The city of Bristol, placed at the southwest of England between the confluence of Avon River and Frome River, close to where Avon River flows into the Atlantic Ocean at Severn Estuary, is prone to suffer floods due to several reasons. The wet Bristol climate, with low insolation hours and frequent rain events, helps in keeping high soil moisture so that even long light rain periods easily saturate the soil, resulting in increased river flows and eventual flooding events. Summer warm temperatures sometimes lead to severe local thunderstorms with heavy showers that might result in local surface flooding events. Last, the proximity of the city to the Severn Estuary, home of one of the world's greatest tides, and facing the frequent southwest storm winds that might develop intense storm surges, eventually result in the partial or total flooding of Avonmouth council, and an increased risk of flood for Bristol's city center. To avoid these situations, great effort is made by BCC to keep rivers and streams clean and contained. This is summed to the diverse infrastructures built for diverging possible water flows throughout the city till Avon's last segment, which have lately reduced material consequences of recent foods.

In order to analyze the city's risk to suffer different types of floods, various Flood Risk Assessment Reports have been made by BCC. Regarding extreme precipitation rates, an extensive study was developed (ARUP 2012) taking into account the local topography, underground drainage systems as well as surface roughness and material type. Considering a mean high water springs tide level as boundary conditions, the model was run with Met Office rain alert levels: 100m/3h, 200mm/3h, 100mm/6h, 200mm/6h. As a result is observed that a significant urban area is prone of suffering from flash flood when occurring intense rainfall events (see example of 200mm/3h inFigure 13).

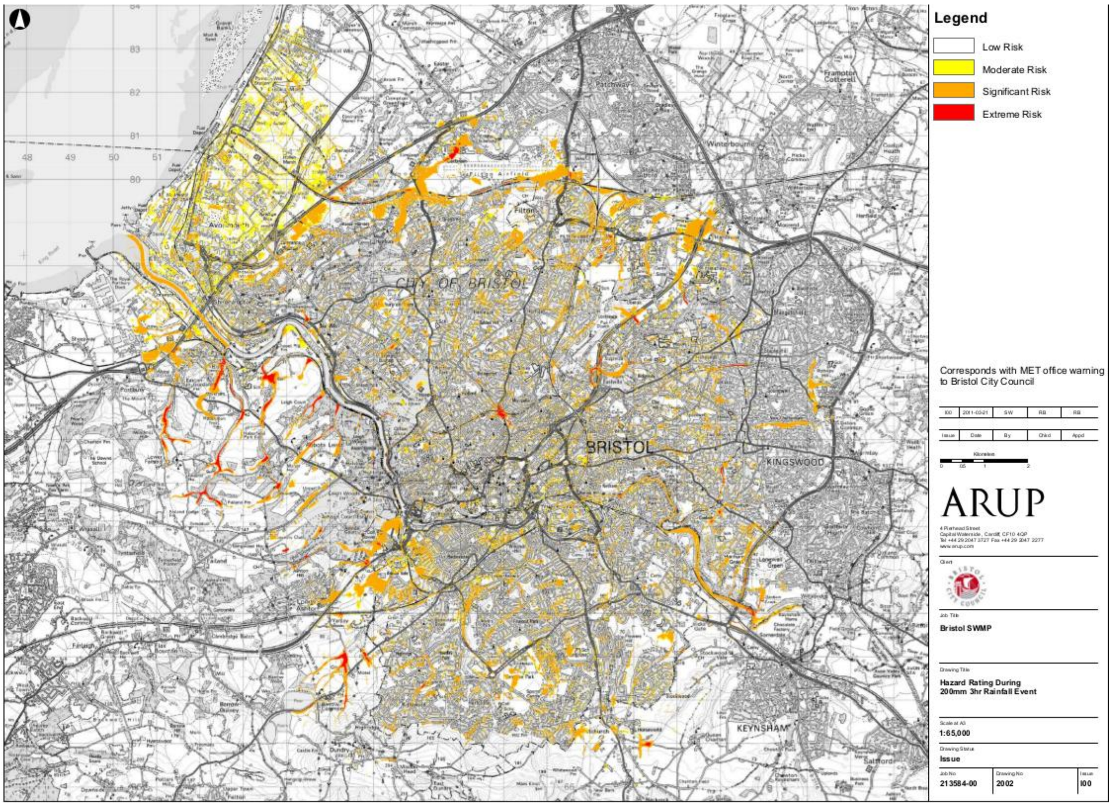


**Figure 13**. Risk areas of surface flooding for the City of Bristol due to severe rainfall associated to precipitation registers of 200mm/3h. Yellow orange and red colors refer to moderate, significant and extreme risk, respectively

Regarding other types of floods, the Central Area Flood Risk Assessment (CAFRA) project was developed (Hyder 2013), merging the associated flood risk due to long rain events and increased river flow, and that due to increased river level because of high tide or intense storm surge. High tides events, especially spring tides may result in Avonmouth flooding, causing the entering of the sea upstream into Avon River, raising its level, adding an extra risk in the case of a river flooding situation. Considering the basins, flows and fluvial flood estimates of rivers Avon, Frome, Malago, Trym and several other brooks and streams, together with tidal curves and many other recorded data, the model was built up, enabling the representation ofboth hazard zones of the city and the height of the flood. In Figure 14 it is shown the flood height over Bristol city center with a 0.5% AEP tidal event with a 50% AEP fluvial flow.

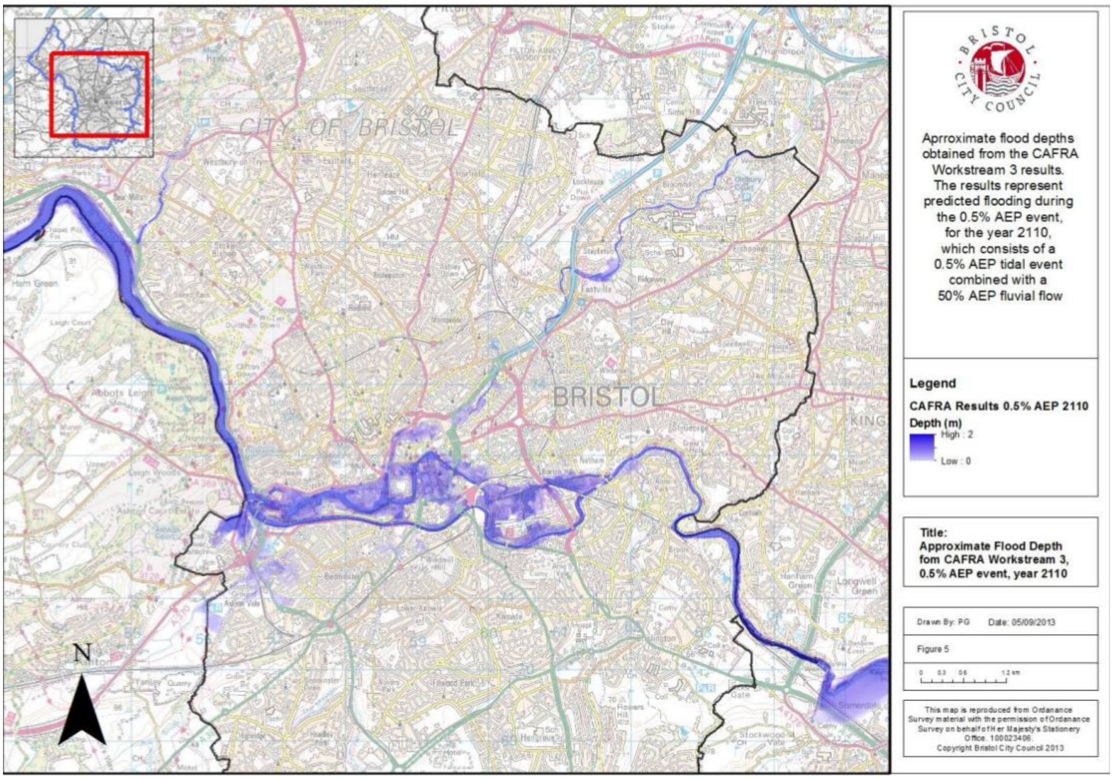


**Figure 14**. Risk areas of fluvial flood for the City of Bristol due to the increase of Bristol's rivers flow and its combination with certain tide level. Blue color points the height of the flood (darker tones indicate greater flood).

Both projected changes in rainfall and in the number of summer and autumn thunderstorms due to climate change show an increase. Therefore, the risk of future events of floods in Bristol increases. It is remarkable the importance of these projects and the reinforcements needed in the city for further cases of severe or sustained rainfall

# 3 Data collection

## 3.1 Climate variables definition

### 3.1.1 Climate hazards identification

*General considerations*

Common criteria for the three cities, regarding each climate hazard, are required in order to compare the natural variability and the future projections under climate change (particularly for task 1.4). However, this requires disposing all the observed data, homogenized and filtered with quality controls (which corresponds to task 1.2). As the hazard identification is prior to the data collection, this task focuses on identifying climate hazards through the collection of historical events. Therefore, important inhomogeneities are assumed for this task. In many cases, the criteria have been changed for each city throughout history. For example, weak floods are now recorded, whereas in the past only the most severe were recorded (historical events).

In this section, climate hazards were identified through the collection of the main historical extreme events and other critical climate phenomena that could extend or intensify due to climate change (Table 1). A special case is the heat burst, which has been registered in several points of Spain including northern areas, for example in Comillas (Cantabria) on 3rd August 2003 (from 27° to 40°C in one hour). Therefore, although it has not been registered in Barcelona, could appear in the future. This phenomenon is differentiated of the other heat extreme events due to its origin (local severe weather), in contrast with heat waves and other synoptic heat events.

*Heat/cold events*

The criteria to define a heat wave are different for each city and for the climatic period considered. According to the definition of the Heat Wave Duration Index (HWDI) by the World Meteorological Organization (WMO 2001), Met Office (UK) and IPMA (Instituto Português do Mar e da Atmosfera) consider that a heat wave occurs when the daily maximum temperature of at least six consecutive days exceeds the average maximum temperature by 5°C of the reference period. For cold waves, WMO does not use the equivalent definition.

The Spanish State Agency of Meteorology (AEMET 2016b) defines heat waves as an episode of, at least, three consecutive days in which at least 10% of the stations considered record peak above percentile 95% of its series of daily maximum temperatures in July-August of the period 1971-2000. Likewise, AEMET defines cold waves as an episode of, at least, three consecutive days in which at least 10% of the stations considered record peak below 5% percentile of its series of daily minimum temperatures in January-February of the period 1971-2000. However, for climate change projections, AEMET uses other criterion based on at least five consecutive days above and below the percentile 90% and 5%, respectively (AEMET 2016c). The Meteorological Service of Catalonia (SMC) establishes that the threshold for the city of Barcelona is 33.1°C for heat waves and 0.7°C for cold waves, which correspond respectively to percentiles 98 and 2% (during at least three consecutive days).

According to the IMPA, cold wave on Lisbon has been considered as an event with temperatures below 3°C during at least 48 hours. Particularly, this corresponds with the criterion for activation of the contingency plan for the homeless against cold weather. In

Lisbon, no records are registered considering the criterion of daily minimum temperature of at least six consecutive days below the average minimum temperature by 5°C of the reference period. Snowfall events are rare and almost irrelevant in the city of Lisbon. However, such small events may have some impact in the normal operation of the city. The last remarkable snowfalls in Lisbon city were in 1945 and 1954, although most of the covered areas in 1954 were not urbanised yet. In contrast, heavy snowfalls are relatively common in Barcelona.

For this inventory, extreme maximum/minimum temperatures have been defined as the three absolute maximum/minimum values recorded for historical series of at least 50 years.

*Synoptic and local severe weather*

Records on windstorms were considered from synoptic low pressure systems if their maximum gust exceeded 100km/h for Barcelona and Lisbon, and exceeded 120km/h for Bristol. Criteria for drought definition are very variable according to the analysed study. In some cases, largest dry spells are considered as drought events, and in other cases, drought is considered when a set of months or years recorded a precipitation amount below specific percentiles or with extreme negative values according to the Standardized Precipitation Index (SPI).

Regarding to flooding, reports on Lisbon refer to urban flooding due to rainwater, sometimes aggravated by the tide effect in downtown and some low lying areas. The city is located on the north bank of the Tagus estuary, which has a large area, so it is not subject to river-basin floods.This is an important difference with Barcelona and Bristol, which have suffered some remarkable river-basin floods (Table 2).

Tornadoes have been recorded in the three cities. For example, Lisbon recorded a tornado on 14 April 2010. The second most likely place to be caught-up in a tornado is a strip of the UK running from Bristol through Birmingham and up to Manchester, according to a team of researchers at the University of Manchester (Mulder & Schultz 2014)

Studies on Barcelona show a high density of vortex events (tornadoes and waterspouts), close to 20 cases per year in an area of 50km×50km for the period 1980–2009. The highest concentration of tornadoes is from August to October, with a growing positive trend in the heavily populated coastal areas that is likely more closely linked to an increase in observation and perception rather than a real climatic trend (Gayà et al 2011).

**Table 2**.Main climatic hazards identified for the three cities and examples of historical events. Dates are expressed as YYYY/MM/DD-DD, according to the start and end of each event.

| Hazards | Barcelona | Lisbon | Bristol |
|---|---|---|---|
| **Heat events** | | | |
| Heat waves | Heat waves (SMC)<br>1982/07/06-08<br>1983/07/14-16<br>1987/08/12-16<br>1990/08/02-06<br>1991/07/20-21<br>2003/08/06-14<br>2006/07/24-26<br>2009/07/22-24 | Heat waves (IPMA)<br>1981/06/10-20<br>1991/06/10-18<br>2003/07/29-<br>2003/08/15<br>2005/05/30-<br>2005/06/11<br>2005/06/15-23<br>2006/07/07-17 | Heat spells<br>(MetOffice, 2016a)<br>1976/07<br>1990/08/01-04<br>2003/08/09-10<br>2006/07/16-26 |

| | | | |
|---|---|---|---|
| | 2012/08/17-23<br>2015/07/04-06 | 2013/07/03-13<br>2016/08/05-13 | |
| Extreme max. temp. | Temperatures above 37°C<br>1982/07/07: 39.8°C<br>2003/08/13: 38.4°C<br>2010/08/27: 37.4°C | Temperatures above 40°C<br>1981/06/14: 41.5°C<br>2003/08/01: 41.8°C | Temperatures above 33°C<br>1976/07/02: 33,8ºC<br>2006/07/19: 34.7ºC<br>2015/07/01: 34.1ºC |
| **Cold events** | | | |
| Cold waves | SMC (2015, 2016a)<br>1985/01/05-10<br>1985/01/13-17<br>1987/02/18-20<br>2001/12/22-24<br>2011/01/22-24<br>2012/02/03-06 | Cold waves (IPMA)<br>2009/01/07-10<br>2011/01/22-25<br>2012/02/03-09<br>2014/12/29-<br>2015/01/04<br>2015/02/06-09 | Severe winters (MetOffice, 2016b)<br>1962/12/26- 1963/02<br>2009/12/17-<br>2010/01/15<br>2010/12/17-26 |
| Extreme min. temp. | Temperatures below -5°C<br>1956/02/11: –10.0°C<br>1962/12/28: –6.2°C<br>1985/01/09: –7.2°C | Temperatures below -1°C<br>1956/02/11: –1.2°C<br>1985/01/12: –1.0ºC<br>2009/01/09: –1.0ºC | Temperatures below -8°C<br>2010/01/07: –10.3ºC<br>2010/12/20: –8.8ºC<br>2010/12/25: –10.5ºC |
| Freezing/Frozen rain[1] | Unreported | Unreported | Suri (2001)<br>1996/01/23-24 |
| Snowstorm[2] | Snowfalls above 10 cm (Redolat&Moncho 2011,Vanguardia 2016,SCM 2016b)<br>1914/01/14: 24cm<br>1920/01/17: 30cm<br>1933/12/16: 30cm<br>1942/02/18: 10cm<br>1962/12/25: 50cm<br>1983/02/12: 10cm<br>1985/01/05: 10cm<br>1985/01/11: 12cm<br>1986/01/30: 25cm<br>1987/02/18: 20cm<br>1993/03/01: 15cm<br>2001/12/15: 10cm<br>2005/02/28: 25cm<br>2010/03/08: 25cm | Snowfalls above 1 cm<br>1945/02/16: 1cm<br>1954/02/03: 1cm | Snowfalls above 10 cm<br>2005/01/22: 22 cm<br>2010/01/07: 13 cm |
| **Synoptic severe weather** | | | |
| Windstorm | Events with maximum gust > 100 km/h<br>2009/01/24: 110km/h | Events max. gust > 100 km/h (CML 2016a, IPMA 2016b)<br>1941/02/15: 127km/h<br>2013/01/19: 104km/h<br>2014/01/09: 108km/h | Events max. gust > 120 km/h (MetOffice, 2016d)<br>1981/12/13: NA<br>1987/10/16: 122 km/h<br>2002/10/27: 146 km/h<br>2014/02/13: 120km/h |
| Drought | Rogativas 'pro pluvia' (CEDEX 2005, Barriendos 2012):<br>1402/03/31<br>1441/01/25<br>1567/04/27<br>Dry episodes (ACA 2008): | Droughts (Pires et al. 2010):<br>1943-1946<br>1980-1983<br>2004-2006<br>1990-1992 | Cox (1978), Marsh (2007), MetOffice (2016c)<br>1975-1976<br>2004/11-2006/07<br>2010/01- 2012/03 |

| | | | |
|---|---|---|---|
| | 1812-1825<br>1928/04/22-1928/08/14<br>1944-1945<br>1953,1973<br>1986-1986<br>1988-1989<br>1999-2003<br>2007-2008<br>2015/11/04-2016/02/10 | | |
| River-basin flooding | SMC (2012, 2016c);<br>La Vanguardia (2016)<br>1926/08/31: 176 mm<br>1943/12/16: 130 mm<br>1944/02/23-26<br>1962/09/26 | The Tagus river does not cause floods in Lisbon. | Surface water flooding:<br>1890-1900, 1980-1990<br>1968/07/10: 127mm/2h<br>1969/08/09: NA<br>1975/08/08-09: NA<br>2012/11/21-22: 192mm |
| **Local severe weather** | | | |
| Flash flood<br>(rainwater flooding) | 1591/10/28<br>1794/04/08<br>1862/09/14<br>1995/09/21<br>2002/07/31<br>2008/07/12<br>2009/09/14<br>2009/10/22<br>2011/03/15<br>2011/07/30 | Main events &return periods<br>1967/11/25: 100y<br>1983/11/19: 500y<br>1997/10/18: 100y<br>1997/11/02: 100y<br>2008/02/18: 20y<br>2008/10/18: 10y<br>2010/10/29: 50y<br>2014/10/13: 20y<br>2014/11/26: 10 y | 2014/07/16<br>2015/07/15<br>2016/06/15: 25mm/1h |
| Severe wind[3] | Tornadoes (Gayà et al. 2001; Morales et al. 2009)<br>2005/09/08: 1 EF2<br>2006/09/13: 3 EF1 | Tornadoes &others<br>2010/04/14: tornado<br>2015/06/09: outflow | (Mulder & Schultz, 2014)<br>4% chance per year of a tornado occurring within 10km. |
| Heat burst | Unreported | Unreported | Unreported |
| Thundersnow | 2010/03/08 | Unreported | 2005/01/22 |
| Hail | 2014/11/03<br>2015/03/14 | 2011/04/29<br>2014/01/17 | Unreported |
| **Maritime hazards** | | | |
| Storm surge&similars[4] | Unreported | 2012/11/17<br>2014/04/1-2<br>2014/09/09-10<br>2014/10/08-09<br>2016/05/07 | 1604: 2m<br>1607/01/30: 2.40m<br>1896/03/02: 1.0m<br>1981/12/13: 1.6m<br>2014/01/03: 0.8m |
| Sea-level rise | Satellite data (EEA 2016):<br>1992-2013: 1.5mm/year | Cascais (NOAA 2016):<br>1888-1993: 1.3mm/year<br>Satellite data (EEA 2016):<br>1992-2013: 2.0mm/year<br>Cascais (Antunes 2016):<br>2005-2015: 4.1mm/year | Newlyn (NOAA 2016):<br>1915-2011: 1.8mm/year<br>Satellite data (EEA 2016):<br>1992-2013: 1.5mm/year<br>Philips & Crisp (2010)<br>1993-2007: 2.4mm/year |

[1]include: ice pellet events
[2]include: blizzard and events of graupel (snow pellets)
[3]include: tornado, waterspout, downburst, microburst, outflow, gustnado, derecho and similar
[4]include: estuary effects, fluvial agitation and tide effects

## 3.1.2 Climate variables evaluation

Main climatic drivers were identified according to the potential hazards enumerated in the above section (Table 3). In order to estimate an importance level for each climatic variable, all hazards have been evaluated considering cascading effects, and assuming constant exposure & vulnerability. Three importance levels were considered: Low, medium and high.

The importance level (risk) is obtained combining probability/severity matrix. Probability is considered according to three levels: low (< 0.01 events/year), medium (0.01 to 0.1 events/years) and high (>0.1 events/years). Nuances of very low/high probability were not taken. The severity scale considers negative consequences in the population, environment and socio-economic and financial impacts. Waiting for a unified criterion to be defined later on the project (e.g. in task 1.4), the approach selected for this task is based on the Lisbon's Emergency Municipal Plan of Civil Protection (CML 2016b). Because of the difficulty in comparing cities/variables, Table 3 is the result of a discussion of a working group.

**Table 3**. Evaluation of the climatic variables according to the main climatic hazards identified, assuming constant exposure and vulnerability. The considered variables are Temperature (T), Precipitation (P), Evapotranspiration (E), Wind (W), Atmospheric pressure (A) and Flood coverage (F) which includes both sea level and river-basin flows (surface and subsurface flows). The sign of variables indicates if their influence is by excess (+) or defect (–).

| Variables | | | | | | Hazards | Barcelona | | | Lisbon | | | Bristol | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | P | E | W | A | F | | Probability | Severity | Risk | Probability | Severity | Risk | Probability | Severity | Risk |
| | | | | | | **Heat events** | | | | | | | | | |
| + | | + | | | | Heat waves | Med. | Med. | Med. | Med. | Low | Med. | Low | Low | Low |
| + | | | | | | Extreme max. temp. | Med. | Med. | Med. | Med. | Low | Med. | Low | Low | Low |
| | | | | | | **Cold events** | | | | | | | | | |
| – | | | | | | Cold waves | Med. | Low | Med. | Med. | Low | Med. | Med. | Low | Med. |
| – | | | | | | Extreme min. temp. | Low | Low | Low | Med. | Low | Med. | Low | Med. | Low |
| – | | | | | | Freezing/Frozen rain[1] | Low | Low | Low | Low | Low | Low | Low | Low | Low |
| – | + | | + | | | Snowstorm[2] | Low | Med. | Low | Low | Low | Low | Low | Low | Low |
| | | | | | | **Synoptic severe weather** | | | | | | | | | |
| | | | + | – | | Windstorm | Low | Med. | Low | Med. | High | High | High | High | High |
| | – | + | | + | – | Drought | High | High | High | Low | Low | Low | Low | Low | Low |
| | + | – | | | + | River-basin flooding | Low | High | Med. | Null | Null | Null | Med. | Med. | Med. |
| | | | | | | **Local severe weather** | | | | | | | | | |
| | + | – | | | + | Flash flood | High | High | High | Med. | High | High | Low | Low | Low |
| | | | + | | | Severe wind[3] | High | High | High | Med. | High | High | Low | Low | Low |
| + | | + | + | | | Heat burst | Low | Low | Low | Low | Low | Low | Low | Low | Low |
| – | + | | | | | Thundersnow | Low | Med. | Low | Low | Low | Low | Low | Low | Low |
| | + | | | | | Hail | Low | Low | Low | Low | Low | Low | Low | Low | Low |
| | | | | | | **Maritime hazards** | | | | | | | | | |
| | | | + | – | + | Storm surge&similars[4] | Low | Low | Low | Low | Low | Low | Low | High | Med. |
| | | | | | + | Sea-level rise | Med. | Low | Low | Low | Low | Med. | Med. | Med. | Med. |

From a meteorological point of view, climate hazards have been distinguished according to their synoptic/local origin. This is because local extremes are often more stochastic than synoptic extremes, then it is more adequate to analyse each model requirement (e.g fluvial and pluvial flooding).

## 3.1.3 Climate variables requirements

Data requirements were evaluated for each climatic variable (Table 4). Spatial and temporal specifications were evaluated according to the hazard assessment requirements, i.e., the links between work packages 1, 2 and 3 were analysed.

**Table 4.** Data requirements for climate variables related with the identified potential hazards, and variable importance according to the previous evaluation (see Table 3).

| Variables | City | | | Spatial coverage | Spatial resolution ($km^2$/station) | Time series length (years) | Temporal resolution | Potential hazards | Variable importance |
|---|---|---|---|---|---|---|---|---|---|
| | Barcelona | Lisbon | Bristol | | | | | | |
| **Temperature** (mean, maximum, and minimum) | X | | X | Watershed | 10-1000 | > 5 | Daily | Drought | High |
| | X | X | X | Urban | 1-10 | > 5 | 5-10 min | Heat / Cold events and heat burst | Med. |
| **Precipitation** (liquid and solid) | X | | X | Watershed | 10-1000 | > 5 | Daily | Drought and flooding | High |
| | X | X | X | Urban | 1-10 | > 5 | 5-10 min | Flash flood and hail | High |
| **Snow** (observed and estimated) | X | | X | Watershed | 10-1000 | > 5 | Daily | Snowstorm | Med. |
| | X | | X | Urban | 1-10 | > 5 | 5-10 min | Thundersnow | Low |
| **Wind** (mean and gust) | | X | X | Ocean areas | 10-1000 | > 20 | Daily | Windstorm | Med. |
| | X | X | X | Urban | 10 | > 20 | Hourly | local severe wind | High |
| **Potential Evapotranspiration** | X | | X | Watershed | 10-1000 | > 5 | Daily | Drought and flooding | Low |
| **Atmospheric pressure** | | X | X | Coastal waters | 10-1000 | > 20 | Daily | Surge storm and windstorm | Med. |
| **Sea level** | X | X | X | Urban | 10-100 | > 20 | Daily | Sea level rise and surge storm | Med. |
| **Wave height** (mean and extremes) | | X | X | Urban | 10-100 | > 20 | Hourly /daily | Storm surge and sea storm | Low |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **River flow** | X | | X | Watershed | 100-1000 | > 20 | Hourly /daily | River-basin flooding | Med. |
| **Flood coverage** | | X | X | Urban | 10 meters / pixel | > 20 | Daily | Drought and flooding | Med. |

In order to simulate temperature and precipitation using statistical downscaling, time-series length must have at least 5 years of observations (Ribalaygua et al. 2013). For the rest of the variables, time-series should ideally have at least 20 years with observations. However, analysis of extreme events requires of at least one time-series (for each variable/city) with at least 50 years of length.

Due to the low availability of certain data, some variables must be semi-observed, i.e. are supplemented with statistical estimations by using other observed variables. For example, potential evapotranspiration is usually simulated using temperature, solar radiation (e.g., astronomical formulae) and wind. Snow can be estimated with temperature and precipitation, wave height is estimated by using the wind, and the storm surge is calculated using pressure and wave properties.

The importance level of each variable depends on the considered climate hazard and on the analysed city (Table 3). Nevertheless, a total importance has been determined as the maximum level for all cases to fix a priority and its corresponding effort in the WP1 (Table 4).

On the other hand, precipitation is the main variable according to the RESCCUE goals. The project focuses on the water sector due to the importance of water-related risks in the correct functioning of a city and the diversity and quantity of data that the water sector manages in its everyday activity. For example, extreme precipitation events are very impactful for drainage and wastewater, while annual precipitation is more relevant for water supply purposes, and groundwater recharge is generally influenced by both.

Finally, one of the ideas that have emerged is the bottom up approach, where thresholds for different variables (or stressors) are identified and then the climate projections are queried with those thresholds in mind.

## 3.2 Observed variables

### 3.2.1 Barcelona

Five different sources have been considered to obtain observed data for Barcelona and its watersheds (Figures 16 and 17). In particular, they are the Spanish Meteorological Agency (AEMET, for *AgenciaEstatal de Meteorología*), Catalan Meteorological Service (SMC), Meteogrid, Spanish State Ports (PE, for *Puertos del Estado*) and *Barcelona Cicle de l'Aigua* (BCASA), company created by the City Council to manage the entire water cycle in Barcelona:

1. AEMET has provided daily data for the Ter-Llobregat system, which is the hydrological area of influence of Barcelona. These data cover precipitation, temperature, wind, relative humidity, pressure and evaporation. Hourly wind is only provided for the metropolitan area of Barcelona.
2. SMC has provided wind and temperature hourly data for the metropolitan area.
3. Meteogrid provides an accurate database of 10-minutal temperature for the metropolitan area.
4. PE provides hourly data of waves from the buoy located in the Barcelona Harbor.
5. BCASA has provided precipitation hourly data for the metropolitan area.

A summary of the available stations and the data sources is shown in Table 4, including temporal resolution and number of stations. It must be noted that the final number of useful stations showed in that table is calculated based only in their temporal intervals (number of available years of data), but later quality controls changed the final number of useful stations (see Section 4).

**Table 5.** Stations provided for the meteorological variables to study for the city of Barcelona and its watersheds (Ter and Llobegat river basins). The variable name, its temporal resolution, the original number of provided stations, the final number of useful stations and the source of the data are showed.

| Variable | Temporal resolution | Number of provided stations | Number of useful stations | Source |
|---|---|---|---|---|
| Precipitation | Daily | 632 | 300 | AEMET |
| Temperature | Daily | 366 | 196 | AEMET |
| Wind | Daily | 65 | 65 | AEMET |
| Relative Humidity | Daily | 58 | 58 | AEMET |
| Evaporation | Daily | 97 | 97 | AEMET |
| Wind | Hourly | 14 | 14 | AEMET |
| Precipitation | 5-minute | 26 | 26 | BCASA |
| Wind | Hourly | 6 | 6 | SMC |
| Temperature | Hourly | 6 | 6 | SMC |
| Temperature | 10-minute | 6 | 6 | Meteogrid |
| Waves | Hourly | 1 | 1 | PE |

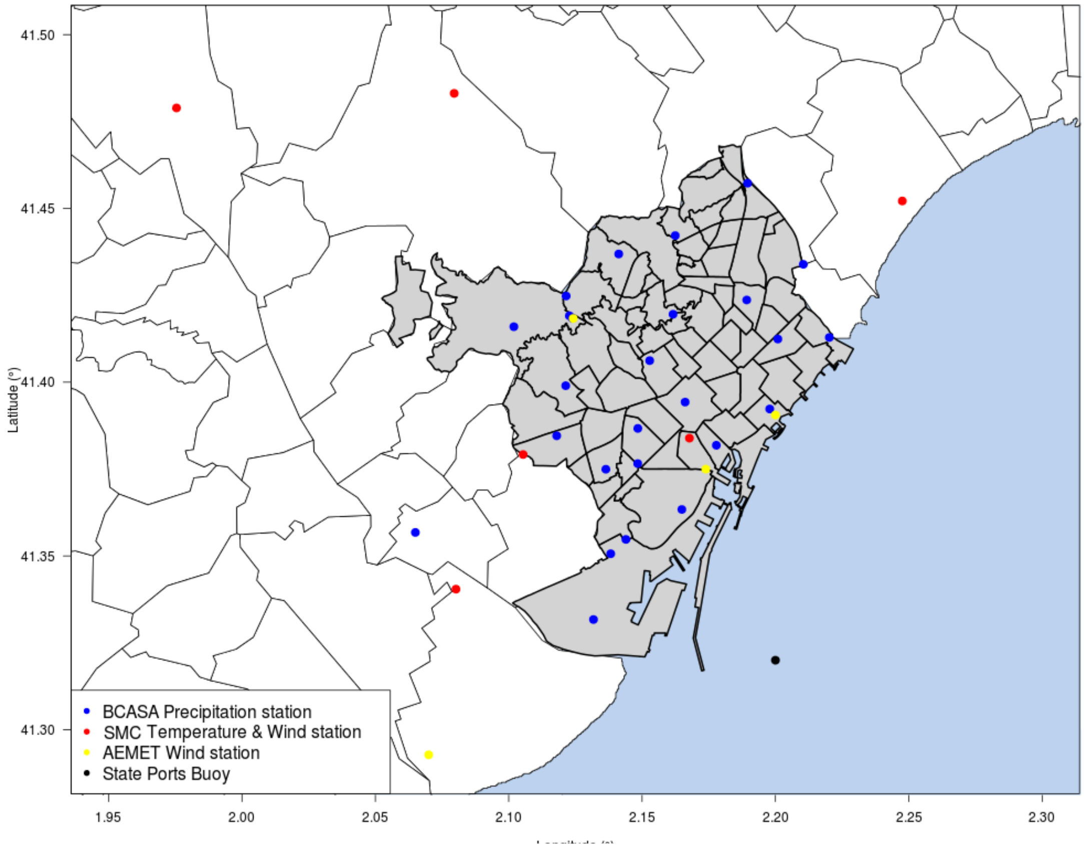


**Figure 15.** Sub-daily stations located in Barcelona area for precipitation (BCASA), temperature (SCM and Meteogrid) and wind (SCM and AEMET), and the waves buoy (PE). Barcelona and its main districts are showed gray-shaded; the area limits of the close towns are also shown.

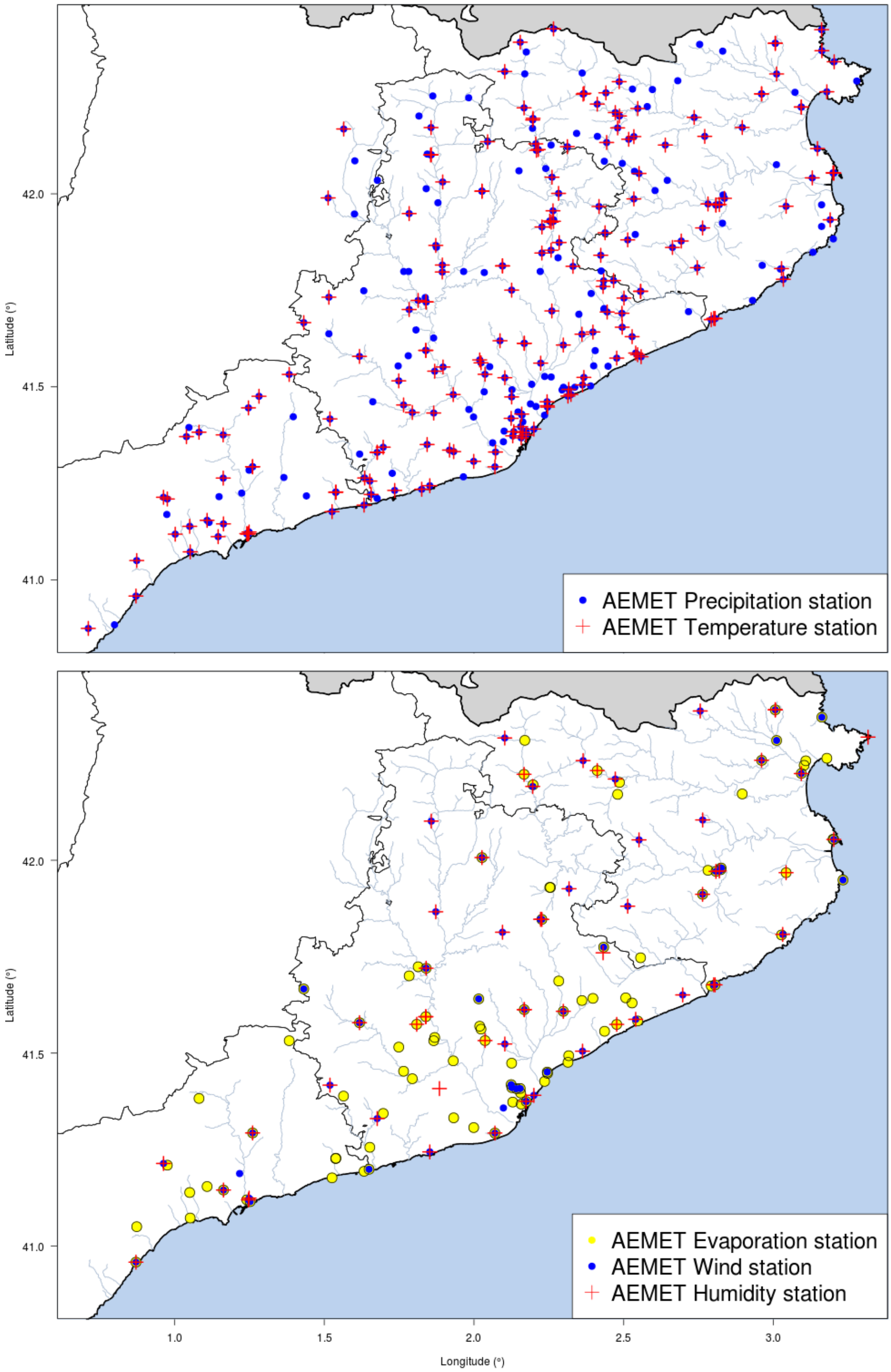


**Figure 16**. Daily stations located in Ter-Llobregat System, provided by AEMET forprecipitation and temperature **(top)**, andfor evaporation, wind and humidity **(down)**.

### 3.2.2 Lisbon

The Portuguese Institute for Sea and Atmosphere (IPMA) provided subdaily data from two weather stations, Lisboa-Geofísico and Gago Coutinho, both corresponding to the Lisbon urban area. However, other daily data were collected from the Global Surface Summary of the Day (GSOD), an initiative of the National Oceanic and Atmospheric Administration (NOAA), the US Meteorological Agency. GSOD is a repository of several worldwide meteorological stations which provide daily data (not always updated) of some meteorological variables – these data can be freely downloaded (NOAA 2016b). Its spatial coverage is limited but some stations are close to the Lisbon metropolitan area, so these were selected (Table 6 and Figure 17).

**Table 6.** Stations provided for the meteorological variables to study for the city of Lisbon. The variable name, its temporal resolution, the original number of provided stations, the final number of useful stations and the source of the data are showed.

| Variable | Temporal resolution | Number of provided stations | Number of useful stations | Source |
|---|---|---|---|---|
| Precipitation | Daily (subdaily) | 5 (2) | 5 (2) | IPMA/NOAA-GSOD |
| Temperature | Daily (subdaily) | 6 (2) | 6 (2) | IPMA/NOAA-GSOD |
| Wind | Daily (subdaily) | 6 (2) | 6 (2) | IPMA/NOAA-GSOD |
| Relative Humidity | Daily (subdaily) | 6 (2) | 6 (2) | IPMA/NOAA-GSOD |

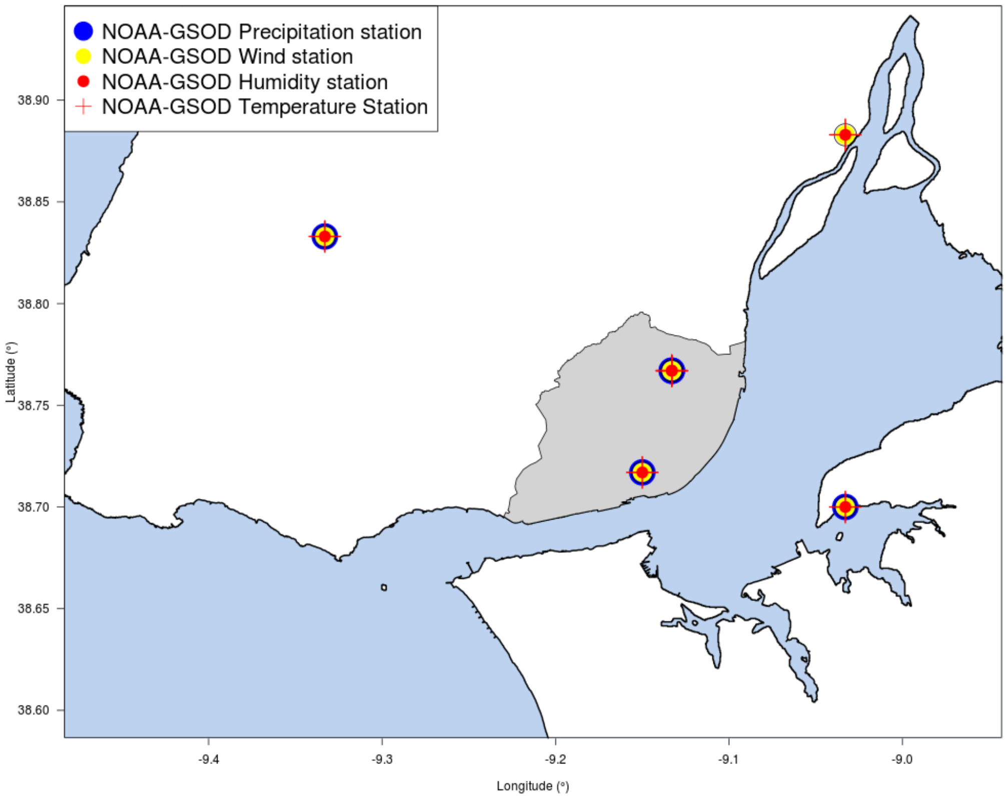


**Figure 17.** Geographic location of the provided precipitation, wind, temperature and humidity stations with daily values from the NOAA-GSOD for the city of Lisbon.

### 3.2.3 Bristol

Regarding Bristol, observed data was obtained from four different sources (Table 7 and Figures 18 and 19): Global Surface Summary of the Day (GSOD), National River Flow Archive (NRFA), Bristol City Council (BCC) and Channel Coastal Observatory (CCO), which monitors data for the National Network of Regional Coastal Monitoring Programmes of England:

1. GSOD data cover the daily values of precipitation, temperature, wind and relative humidity needed for categorizing the climatic region.
2. NRFA, the UK's focal point for river flow data, has provided 15-minutes river flow data for all hydrographical areas close to Bristol region.
3. CCO has provided tide (10-minutes) and waves (30-minutes) data for the climatic region of Bristol.
4. BCC has provided tide (5-minutes) and precipitation (5-minutes) data for the Bristol metropolitan area.

It is remarkable that, due to the impossibility of getting daily data for the hydrographical area of influence of Bristol from any national or regional meteorology agencies, we have used the freely-distributed daily data from the Global Surface Summary of the Day (GSOD).

As in the previous sections, we must remark that the final number of useful stations showed in that table is calculated based only in their temporal intervals (number of available years of data), but later quality controls can change the final number of useful stations.

**Table 7.** Stations provided for the meteorological variables to study for the city of Bristol and its climatic and hydrographical area of influence. The variable name, its temporal resolution, the original number of provided stations, the final number of useful stations and the source of the data are showed.

| Variable | Temporal resolution | Number of provided stations | Number of useful stations | Source |
|---|---|---|---|---|
| Precipitation | Daily | 64 | 54 | NOAA-GSOD |
| Temperature | Daily | 112 | 86 | NOAA-GSOD |
| Wind | Daily | 112 | 86 | NOAA-GSOD |
| Relative Humidity | Daily | 109 | 83 | NOAA-GSOD |
| River Flow | 15-minutes | 232 | 232 | NRFA |
| Tide | 10-minutes | 4 | 4 | CCO |
| Waves | 30-minutes | 10 | 10 | CCO |
| Tide | 5-minutes | 1 | 1 | BCC |
| Precipitation | 5-minutes | 2 | 2 | BCC |

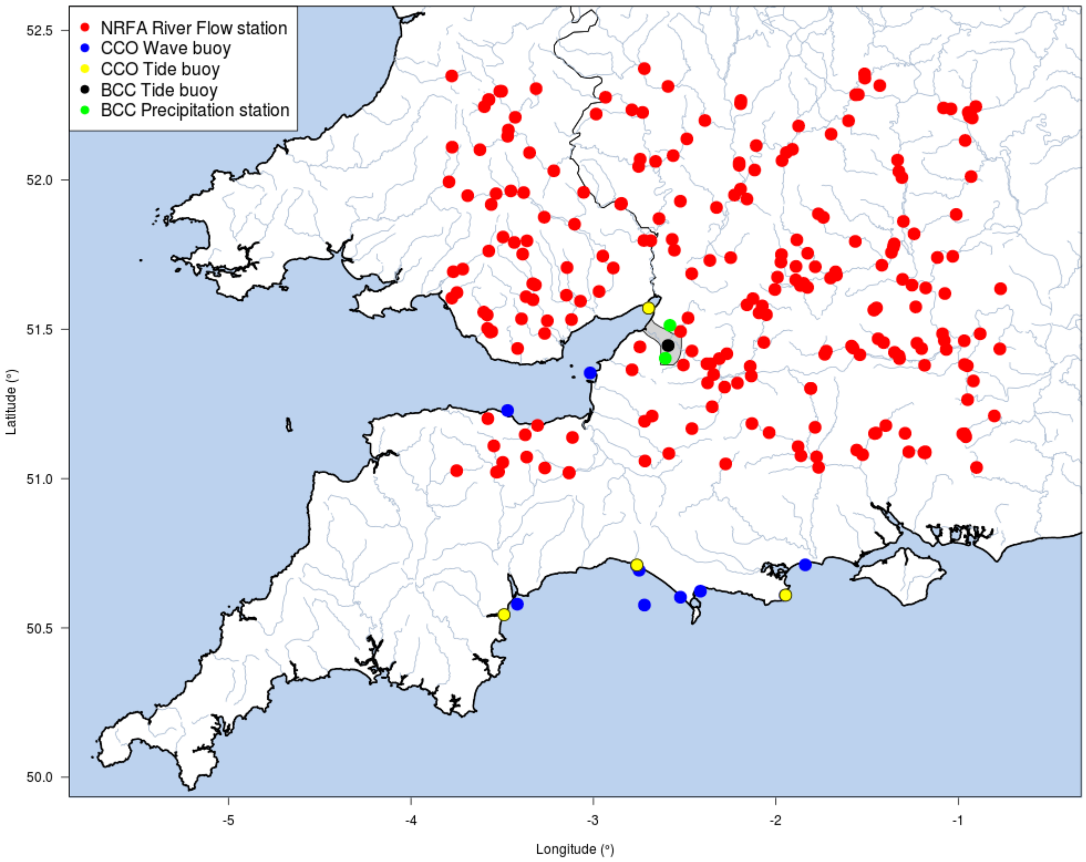


**Figure 18.** Geographic location of the provided precipitation (BCC) and river flow (NRFA) stations and the waves (CCO) and tides (CCO and BCC) buoys with sub-daily values for the city of Bristol and its climatic and hydrographical area of influence. Bristol area limits are showed gray-shaded.

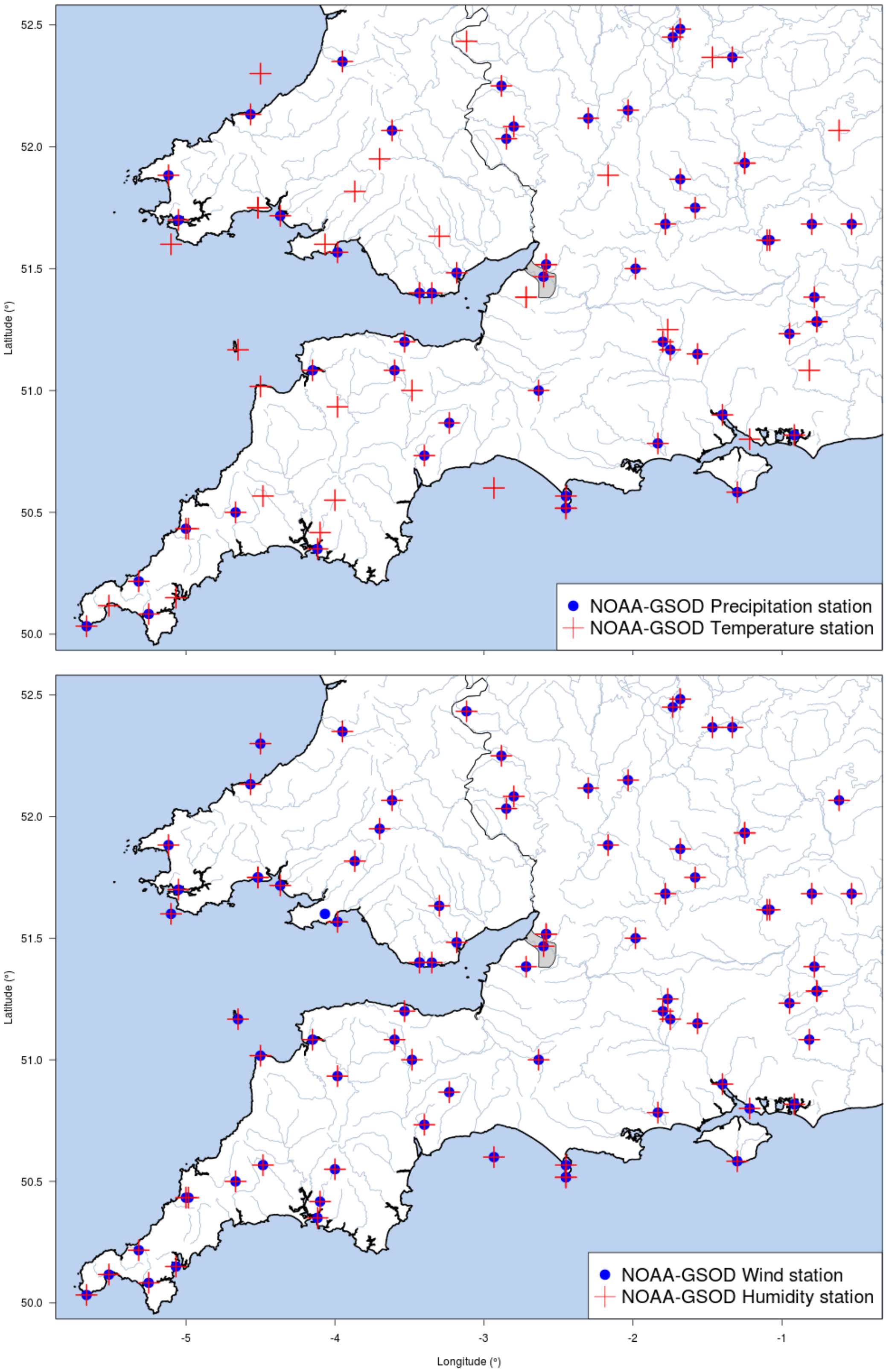


**Figure 19**. Daily stations located in Bristol climatic region, provided by NOAA-GSOD forprecipitation and temperature **(top)**, andfor wind and humidity **(down)**. Bristol is showedgray-shaded.

## 3.3 Climate models

### 3.3.1 CMIP5 models inventory

In order to group the models available for this study, it is necessary to distinguish between climate simulations (up to 100 years, Table 4) and decadal simulation (up to 30 years, Table 5). The measure of the uncertainty associated with different causes is an important issue for the project. The main uncertainty sources are: the dynamical/statistical method (model/output), the emission scenario (RCP) and the natural variability.The way chosen to evaluate the uncertainty is the ensemble strategy: combinations of models/RCPs/horizons for climate simulations and models/runs/horizons for decadal simulations are expected.

**Table 8.** Available CMIP5 climate models. The table shows the model name, the responsible institution, the model references, its spatial resolution for the AGCM, the run code used in this study, the available RCPs and the projection period.

| Model | Institution | Reference | AGCM resolution (Lon×Lat) | Run | RCP | | | | Projection period |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2.6 | 4.5 | 6.0 | 8.5 | |
| ACCESS1-0 | CSIRO, BOM | Bi et al. (2013) | 1.87°×1.25° | r1i1p1 | | X | | X | 2005-2100 |
| BCC-CSM1-1 | BCC | Xiao-Ge et al. (2013) | 2.8°×2.8° | r1i1p1 | X | X | X | X | 2005-2100 |
| CanESM2 | CC-CMA | Chylek et al. (2011) | 2.8°×2.8° | r2i1p1 | X | X | | X | 2005-2100 |
| CNRM-CM5 | CNRM-CERFACS | Voldoire et al. (2013) | 1.4°×1.4° | r1i1p1 | X | X | | X | 2005-2100 |
| GFDL-ESM2M | GFDL | Dunne et al. (2012) | 2°×2.5° | r1i1p1 | X | X | X | X | 2005-2100 |
| HADGEM2-CC | MOHC | Collins et al. (2008) | 1.87°×1.25° | r1i1p1 | | X | | X | 2005-2099 |
| MIROC-ESM-CHEM | JAMSTEC, AORI, NIES | Watanabe et al. (2011) | 2.8°×2.8° | r1i1p1 | X | X | X | X | 2005-2100 |
| MPI-ESM-MR | MPI-M | Marsland et al. (2003) | 1.8°×1.8° | r1i1p1 | X | X | | X | 2005-2100 |
| MRI-CGCM3 | MRI | Yukimoto et al. (2011) | 1.2°×1.2° | r1i1p1 | X | X | X | X | 2005-2100 |
| NorESM1-M | NCC | Bentsen et al. (2012), Iversen et al. (2012) | 2.5°×1.9° | r1i1p1 | X | X | X | X | 2005-2100 |

**Table 9.** Available CMIP5 decadal models. The table shows the model name, the responsible institution, the model references, its spatial resolution for the AGCM, its temporal resolution (D: daily or M: monthly) for each projection period and the number of runs available for the longer projection.

| Model | Institution | Reference | AGCM resolution (Lon×Lat) | 2011-2020 | 2012-2021 | 2006-2035 | Runs |
|---|---|---|---|---|---|---|---|
| BCC-CSM1-1 | BCC | Xiao-Ge et al. (2013) | 2.8° × 2.8° | | | D,M | 4 |
| CanCM4 | CC-CMA | von Salzen et al. (2013) | 2.8° × 2.8° | D,M | D,M | D,M | 20 |
| CMCC-CM | CMCC | Scoccimarro et al. (2011) | 0.75°× 0.75° | | | D,M | 3 |
| CNRM-CM5 | CNRM-CERFACS | Voldoire et al. (2013) | 1.4° × 1.4° | | | D,M | 10 |
| HadCM3 | MOHC | Collins et al. (2001) | 3.75° × 2.5° | | | D | 20 |
| IPSL-CM5A-LR | IPSL | Dufresne et al. (2013) | 3.75° × 1.9° | | | D,M | 6 |
| MIROC5 | JAMSTEC, AORI, NIES | Tatebe et al. (2012) | 1.4° × 1.4° | M | | D,M | 6 |
| MPI-ESM-LR | MPI-M | Marsland et al. (2003) | 1.88°×1.87° | D,M | | D | 3 |
| MRI-CGCM3 | MRI | Yukimoto et al. (2011) | 1.88°×1.87° | D,M | D,M | D | 3 |

**Acronyms:**

| | |
|---|---|
| AORI: | Atmosphere and Ocean Research Institute (Japan) |
| BCC: | Beijing Climate Center, China Meteorological Administration (China) |
| BOM | Bureau of Meteorology (Australia) |
| CC-CMA: | Canadian Centre for Climate Modelling and Analysis (Canada) |
| CERFACS: | Centre Europeen de Rechercheet Formation Avancees en CalculScientifique |
| COLA: | Center for Ocean-Land-Atmosphere Studies (US), |
| CMCC: | Centro Euro-MediterraneosuiCambiamentiClimatici (Italy) |
| CNRM: | Centre National de RecherchesMeteorologiques (France) |
| CSIRO | Commonwealth Scientific and Industrial Research Organisatio, (Australia) |
| IPSL: | Institut Pierre-Simon Laplace (France) |
| JAMSTEC: | Japan Agency for Marine-Earth Science and Technology (Japan) |
| GFDL: | Geophysical Fluid Dynamics Laboratory (USA) |
| MOHC: | Met Office Hadley Centre (UK) |
| NIES: | National Institute for Environmental Studies (Japan) |
| MPI-M: | Max Planck Institute for Meteorology (Germany) |
| MRI: | Meteorological Research Institute (Japan) |
| NCC: | Norwegian Climate Centre (Norway) |
| NCEP: | National Centers for Environmental Prediction (USA) |

## 3.3.2 Climate variables

Oceanic variables are only available for monthly outputs. In particular, the oceanic outputs extracted from the CMIP5 models are three:

ZOS Sea Surface Height Above Geoid
ZOSTOGA Global Average Thermosteric Sea Level Change
ZOSGA Global Average Sea Level Change

Regarding the atmospheric variables, all fields are available at daily resolution (Table 6). However, some climatic variables are not offered by the CMIP5 experiment portal and therefore a derivation is expected for them using other climatic variables (Table 7). Note the need to distinguish between climate simulations (up to 100 years, Table 6) and decadal (up to 30 years, Table 8). Unlike the climate simulation, the decadal projections do not offer fields as: geopotential height, relative humidity and specific humidity. This means that the statistical downscaling methods used for climate simulation must be adapted to the available variables for the decadal case.

**Table 10.** Available daily fields from CMIP5 climate models for the study phase of statistical downscaling of atmospheric variables (precipitation, temperature and wind)

| Variable | ID | First level available | 1000 hPa | 925 hPa | 850 hPa | 700 hPa | 500 hPa |
|---|---|---|---|---|---|---|---|
| Sea Level Pressure | P | Sea level | - | - | - | - | - |
| Geopotential height | ZG | 1000hPa | X | X | X | X | X |
| Relative Humidity | RH | Superficie | X | X | X | X | X |
| Specific humidity | Q | Superficie | X | X | X | X | X |
| Wind | W | 10m | X | X | X | X | X |

**Table 11.**Daily derivation of no available variables in daily outputs of some CMIP5 climate models.

| Variable relations | | Base variables | | | |
|---|---|---|---|---|---|
| | | Precipitation | Temperature | Wind | Pressure |
| Derivated variables | Snow | X | X | | |
| | ET | | X | X | |
| | Wave height* | | | X | |
| | Storm surge | | | X | X |

*Including wave extreme events (tides + run-up)

**Table 12**. Daily and monthly fields extracted from decadal model outputs. Table shows the available projection period (10: ten years; 30: thirty years; X: both) for each combination variable/model.

| | Variable | Decadal model | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **BCC-CSM1-1** | **CanCM4** | **CMCC-CM** | **CNRM-CM5** | **HadCM3** | **IPSL-CM5A-LR** | **MIROC5** | **MPI-ESM-LR** | **MRI-CGCM3** |
| **Daily** | Sea Level Pressure | 30 | X | 30 | 30 | 30 | 30 | 30 | X | X |
| | Precipitation | 30 | X | 30 | 30 | 30 | 30 | 30 | X | X |
| | Convective Precipitation | | 10 | 30 | | | 30 | 30 | | |
| | Solid Precipitation | | 10 | 30 | | | 30 | 30 | | |
| | Daily Maximum Near-Surface Air Temperature | 30 | X | 30 | 30 | 30 | 30 | 30 | X | X |
| | Daily Minimum Near-Surface Air Temperature | 30 | X | 30 | 30 | 30 | 30 | 30 | X | X |
| | Near-Surface Air Temperature | 30 | X | 30 | 30 | 30 | 30 | 30 | X | X |
| | Air Temperature | | | 30 | | 30 | 30 | 30 | | |
| | Sea Surface Temperature | | 30 | | | | | | X | X |
| | Daily Maximum Near-Surface Wind Speed | | 10 | 30 | | 30 | 30 | 30 | | |
| | Daily-Mean Near-Surface Wind Speed | | X | | | 30 | 30 | 30 | X | X |
| | Eastward Wind | | | 30 | | 30 | 30 | 30 | | |
| | Northward Wind | | | 30 | | 30 | 30 | 30 | | |
| | Eastward Near-Surface Wind | | 10 | 30 | | | 30 | 30 | | |
| | Northward Near-Surface Wind | | 10 | 30 | | | 30 | 30 | | |
| **Monthly** | Sea Surface Height Above Geoid | 30 | X | 30 | 30 | | 30 | X | 10 | X |
| | Global Average Thermosteric Sea Level Change | 30 | X | 30 | 30 | | 30 | X | 10 | X |
| | Global Average Sea Level Change | 30 | X | 30 | 30 | | 30 | X | 10 | X |

## 3.4 Seasonal models

### 3.4.1 Climate Forecast System

Seasonal forecasting is a useful 'meteorological product' for anticipating climatic anomalies in a particular region, especially for temperature and precipitation. This includes prediction horizons from 30 days to 12 months. One of main systems for the seasonal forecasting is the Climate Forecast System (CFS) model, developed by the National Centers for Environmental Prediction (NCEP).

The NCEP CFS is a fully coupled model representing the interaction between the Earth's atmosphere, oceans, land and sea-ice. It uses 4-time initializations for each prediction. Seasonal predictions have some skill in horizons of between 1 and 3 months. That is, from the third month, forecast ensembles tend to show practically equivalent values to the climatic averages for each day, with a range equal to the typical climate variability (when this happens, it is said that there is "no signal" in the prediction). However, any signal prediction albeit small is welcome, since it may provide some benefits in planning of certain activities that depend on climatic anomalies. In any case, these forecasts are experimental, so at this early stage of development it is needed to go deeper into the verification of the models.

RESCCUE uses an ensemble strategy based upon the Climate Forecast System (CFS). Each ensemble is composed of the last 25 available CFS forecasts integrating 7 simulations with 4 different time initializations. The predicted variables are minimum and maximum temperature, maximum and mean 10 m wind, probabilistic and deterministic precipitation, and other atmospheric variables as the 850h temperature or the 500hPa geopotential height. The final information is provided in 10, 25, 50, 75 and 90th percentiles.

As an added value, RESCCUE applies a method of microclimatic feedback correction. The advantage of this product is that it offers a range of predicted values that can be used to estimate derived variables for urban services and their corresponding risk management.

### 3.4.2 Integrated Forecast System

Probably the best model for seasonal prediction is the Integrated Forecast System (IFS) provided by the European Centre for Medium-Range Weather Forecast (ECMWF).

ECMWF uses the last version of the IFS, the System 4, based on the model cycle 36r4. Atmosphere model uncertainties are simulated using the 3-time level stochastically perturbed parameterized tendency (SPPT) scheme and the stochastic back-scatter scheme (SPBS) operational in the Ensemble Prediction System (EPS).

The Climate Research Foundation (FIC) has purchased access to the historical archive of the IFS, and therefore its products are available for the hindcast analysis (backtesting) of next tasks.

# 4 Data Quality Control

## 4.1 General Concepts of Quality Control

### 4.1.1 Quality Control

Before beginning our study about the climate change in the studied areas (Bristol, Lisbon and Barcelona), we have carried out a previous study of the provided observed data in those areas for ensuring that the quality of those data is good enough for subsequent studies and conclusions – that's what a Data Quality Control process involves.

Subjecting a time series of records to quality control consists on developing a set of tests over that series that ensure data consistency within the series analysed. Since the most important climatic variables identified are precipitation and temperature, this report focuses on them. Results for the other variables are similar.

It is important to highlight that the tests must be designed to be able to present different results for different series, as each series represents the local climatology of the observed area. Therefore, although theoretical criteria in the tests must be the same for every observatory, the valid range must depend on the observatory. For instance, if we were studying the average temperature of a series (a possible theoretical criterion), a daily maximum temperature of 40°C would lead to different decisions if that value belongs to a series of average temperatures of 35°C (it would be an acceptable value in this case) or if that value belongs to a series of a maximum average of 20°C (in this case, it would be a remarkable value). In addition, pointing out a remarkable value *does not* mean necessarily to reject it, just the necessity of studying carefully the origin of that value to determine if it is correct.

The two main automatic controls to carry out a quality control are:

1. Basic consistency. Direct rejection of self-evident wrong values: for example, negative values for precipitation.
2. Atypical values or '*outliers*'. Unusual values within a data set: values that could come from different sources of data or values that could have been generated in a different way from the rest of the data. In this case, the theoretical difficulty of their recognition depends on our definition of "atypical". In practice, the recognition is generally referred to values whose absolute magnitude is unusually high.

#### 4.1.1.1 Temperature

*Basic consistency*

In the case of temperature, basic consistency has been made searching daily values where maximum temperature was lower than minimum temperature – a real example of some of those cases is shown in the table below (Table 13, based on real observed data). There are two typical situations where these cases happen:

1. Missing values are not recorded as missing (depending of the source, missing values can be recorded as "NA" (Not Available) or "-9999"), but they are recorded as a 0. In these cases, maximum temperature values are directly rejected provided that we can check that 0°C is not a possible value after analysing the series.
2. The value of the temperature is consistent by itself but it is not consistent when it is compared with the other value of daily temperature. An example of this case is

shown in the last two lines of the table below: either of the two values could be wrong, consequently both values must be rejected.

**Table 13**.Examples of real daily temperature data observed where maximum temperature is lower than minimum temperature. These values are given as an example of possible detected situations and they come from several different meteorological stations.

| Year | Month | Day | Maximum temperature (°C) | Minimum temperature (°C) |
|---|---|---|---|---|
| 1977 | 11 | 13 | 0 | 15 |
| 1978 | 1 | 11 | 0 | 13 |
| 2009 | 5 | 27 | 7 | 16.6 |
| 2009 | 5 | 28 | 9 | 17.3 |
| 2000 | 10 | 25 | 20.7 | 22.7 |
| 2009 | 12 | 2 | 22.5 | 23.5 |

*Outliers*

As it was said before, the problem of the recognition of an atypical value depends of the theoretical definition of the word “atypical”. Let’s look at the example shown in the figure below (Figure 20, corresponding to real data for a real meteorology station – showed for illustrative purposes, it is not a station provided for this study): it seems self-evident that the value of maximum temperature which reaches 94°C is an outlier (not only in this observatory, but worldwide), but we can ask ourselves some questions: Why is that value self-evident for us? Would it be self-evident if the value were 50°C? And 40°C? From a theoretical perspective, the way to assess if a value is atypical is analysing how far it is from the typical values of our series. The formal way to do this test consists of establishing how far the value is from the mean of the observed series, and the unit that fits how far the value is from the mean will be the standard deviation of the series.

Therefore, our tests have to determine the following:

1. Mean and standard deviation of each station.
2. A threshold value of the number of units of standard deviation (plus the mean) above which a daily value can be considered as atypical.
3. An exhaustive analysis of the values considered as outliers by the previous step in order to establish if they are true and consequently to decide if they must be rejected or if a new threshold value must be assigned and repeat the analysis.

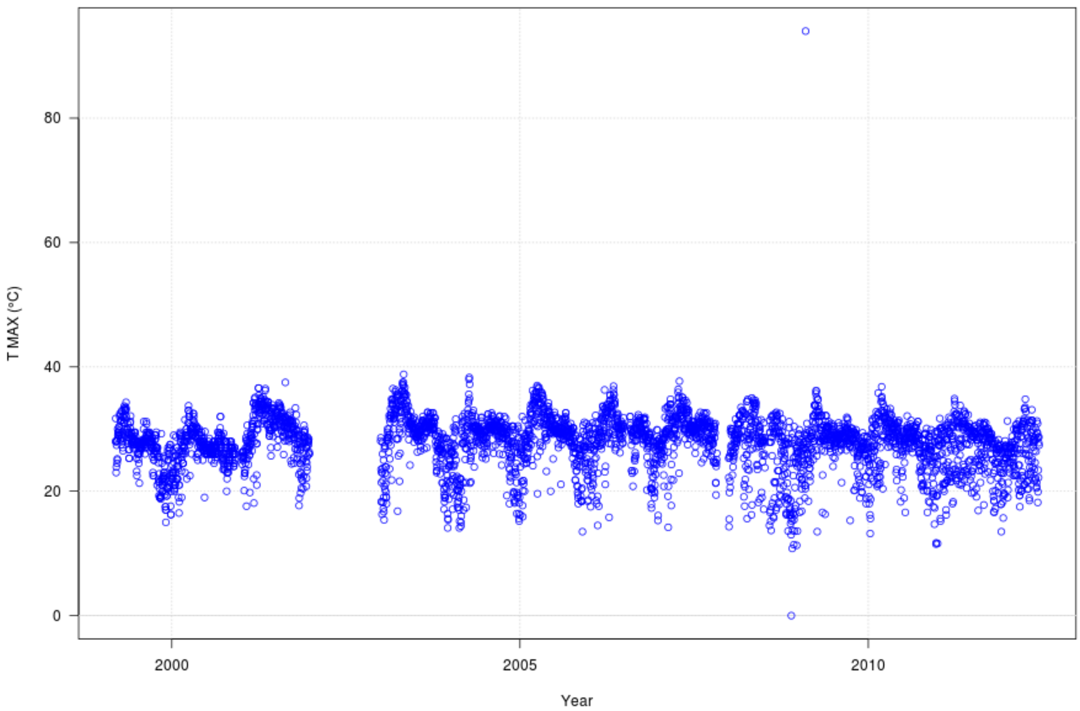


**Figure 20**. Observed series of maximum temperature for a real weather station (showed for illustrative purposes – not a station provided for this study).

#### 4.1.1.2 Precipitation

*Basic consistency*

In the case of precipitation, basic consistency tests are associated to the search of negative daily records - some real examples of these cases (based on real data from real weather stations) are shown in the table below (Table 14).

**Table 14**. Samples of real data where daily observed precipitation is negative (showed for illustrative purposes – not stations provided for this study).

| Year | Month | Day | Precipitation |
|---|---|---|---|
| 1986 | 8 | 31 | -1.0 |
| 2003 | 9 | 21 | -8.0 |

Due to the self-evident error of these values, every detected case is directly marked as wrong and immediately rejected.

*Outliers*

In the case of precipitation, as it was previously said in the case of temperature, an anomalous value is also detected when it exceeds a number of times the series mean. However, given the nature of this meteorological variable, the detection of an outlier does not involve its direct rejection because an event of extreme precipitation can be unusual but it is not necessarily impossible and a very careful analysis of the climatology of the area is needed. For example, daily records of precipitation in areas affected by hurricanes could seem anomalous although they are correct.

## 4.1.2 Homogenisation

### 4.1.2.1 Homogenisation: Theoretical approach

Homogenisation of a time series is related to quality control of the data matched to a time series. In other words, homogenisation analyses consistency of the data exactly in the order that they are presented. Previous tests could be used to analyse the same series, but they do not inform us about the data time variability, something that is normally related to annual cycle.

It must be said that the homogenisation process of a series can be also seen as a part of the general process of the quality control of a series. It is introduced here as a separated point just to highlight the importance of that process and its results.

Let's look at the figure below (Figure 21) of maximum temperature which belongs to a real station.

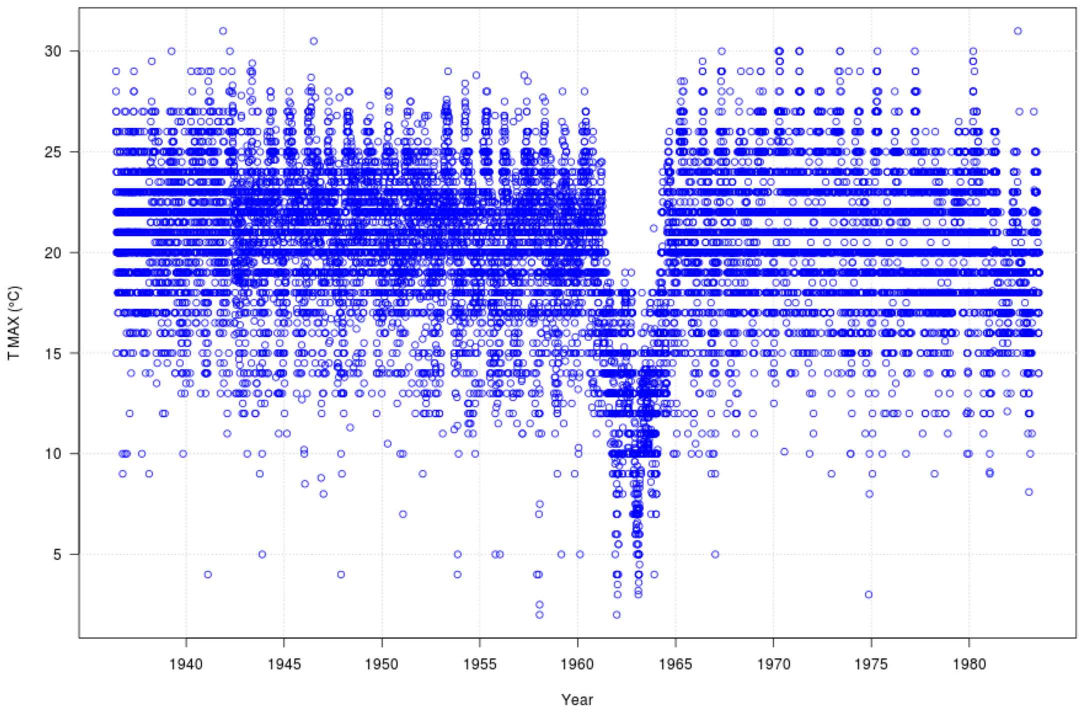


**Figure 21**. Another observed series of maximum temperature for a real weather station (showed for illustrative purposes – not a station provided for this study).

We can see clearly that the maximum temperature of this station presents an erratic behaviour between 1961 and 1964. It is erratic comparing with the previous and subsequent temperature behaviour, but these values are not erratic by themselves as they are not irrational by themselves. With this real example is easier to understand what the homogenisation tests try to find: time fragments of the series where data do not fit with the rest of the series – in fact, the series here showed as an example has actually been found thanks to these tests. The difficulty related to the formal implementation of a homogenisation test depends of the definition of *similarity* between a fragment of our series and the rest of the series.

The way to proceed of the homogeneity test that we have used is based on the method developed by Monjo *et al.*(2013):

1. If we have to measure how similar is data belonging to one year to data belonging to another year, it is used a distribution comparison test based on the Kolmogorov-Smirnov (KS) test. The KS test is a non-parametric statistical test (it does not presuppose distributions of the studied variable) which provides a p-value that can be used as a measurement of the similarity between two years. In the Figure 22it is shown the graph “Control analysis” generated by comparing the p-value of each year with the p-value of the following year (its logarithm, being strict) for the same example (maximum temperature of the studied station). Values which are close to 0 show that two years have a value distribution very similar and we can infer that there is not an inhomogeneity between them. The lower value for Log(KS), the greater is the probability of inhomogeneity between two consecutive values. Note that this first part only shows similarities between consecutive years. This is just a previous condition about the posibility of the existence of an inhomogeneity.
2. If one year has been selected as possible indicator of inhomogeneity, then it is subjected to another test (“Similarity between years”, in the Figure 22). Once we select the year that possibly presents an inhomogeneity and the following one, we figure out the p-value of every year of the series respect those two years (lines red and blue in the graph). If a jump or a break shows up between all those p-values in the years that we are considering, then we can infer that there is a true inhomogeneity for all the series.

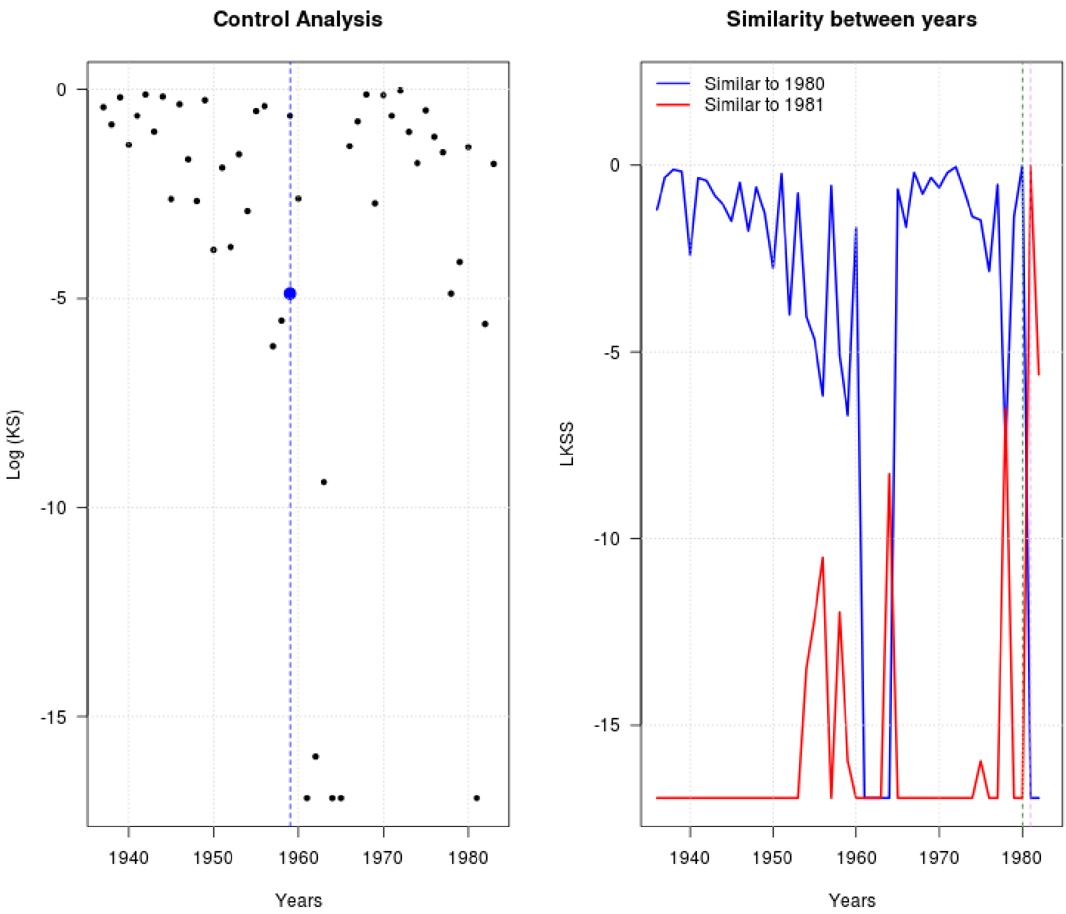


**Figure 22**. Logarithm of KS test p-value used in the homogenisation process for daily data. The case selected belongs to the maximum temperature of a real meteorological station whose daily data are represented in the **Figure 23**.

This process lets us know which years present an inhomogeneity in a series. Given that establishing how small a p-value is to categorize a possible inhomogeneity depends of our criteria, the same test has been launched several times with different threshold p-values (from very negative values to close to zero) in order to make the criterion more objective. If an inhomogeneity truly exists, it should show up when most of the tests are run.

It is important to highlight that it does not exist any automatic process that ensure what action must be carried out over a series (removal or adjustment). As these actions are necessary when a large group of observatories are studied, it is always needed a visual check after running the tests to ensure that final series are correct.

# 4.2 Barcelona

## 4.2.1 Temperature

### 4.2.1.1 Quality Control

Before starting the study of values too far of the mean, values that can be over historical thresholds will be identified, that is, the historical maximum and minimum temperatures ever registered. Thanks to the public information of the ServeiMeteorològic de Catalunya (SMC 2016d), the extreme values of temperature that must be marked as wrong when working with automatic temperature stations can be selected. Therefore, any daily value that exceeds these values is a wrong value and it must be discarded. No observed data of temperature exceeds these values.

After this study of wrong values (based in extremes), the possible outliers in the series must be found using the standard deviation criteria. After some tests, it was found that if a value is greater than 5 times the standard deviation above the average then it is an outlier (or 5 times less). Figure 23 shows us an example of this kind of work: note there are two values (indicated with a vertical red line) that are far enough from the mean to be marked as outliers.

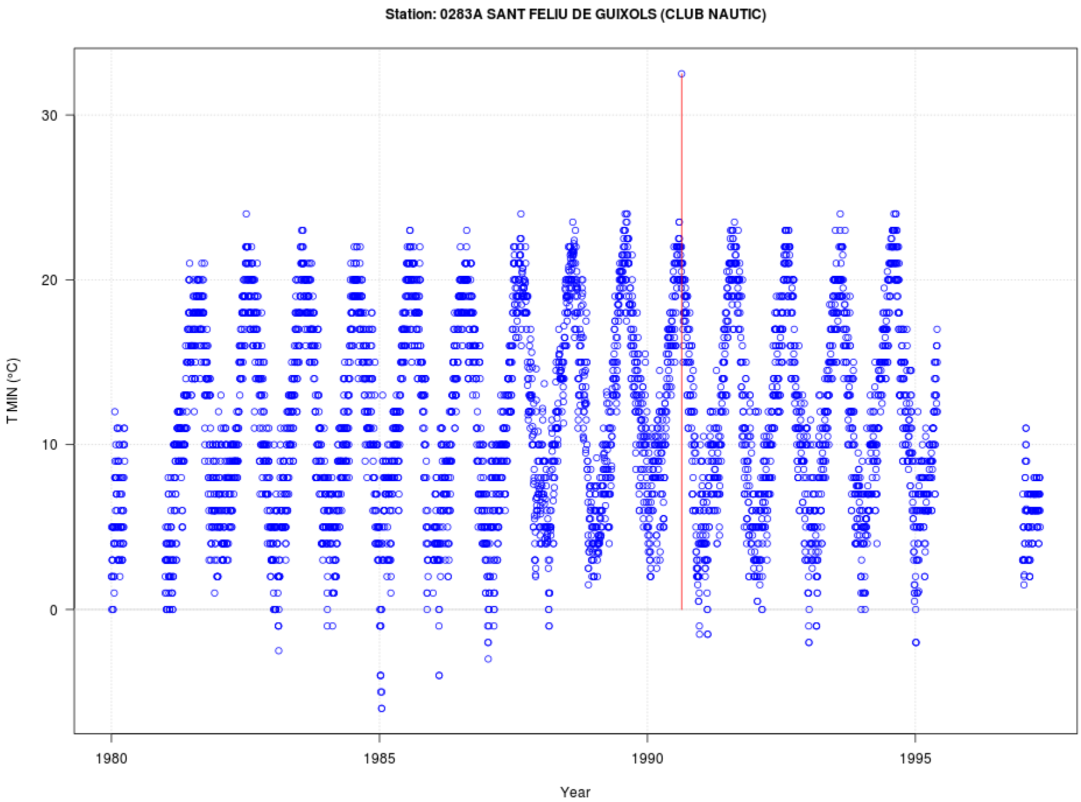


**Figure 23**. Daily data of minimum temperature for the SantFeliu de Guixols station (AEMET station code: 0283A).

### 4.2.1.2 Homogenisation

For one of the temperature stations of the Barcelona studied area, Figure 24 shows the daily minimum temperature and the point where the homogeneity test has detected one inhomogeneity (vertical red line – the horizontal black dashed lines show the mean of the period and the red lines show the moving averages when possible). Note the 1974-1982 period shows a clear discordance within the time series, but not for their values for themselves, but in the temporal way they appear. This period was finally discarded (their data were deleted).

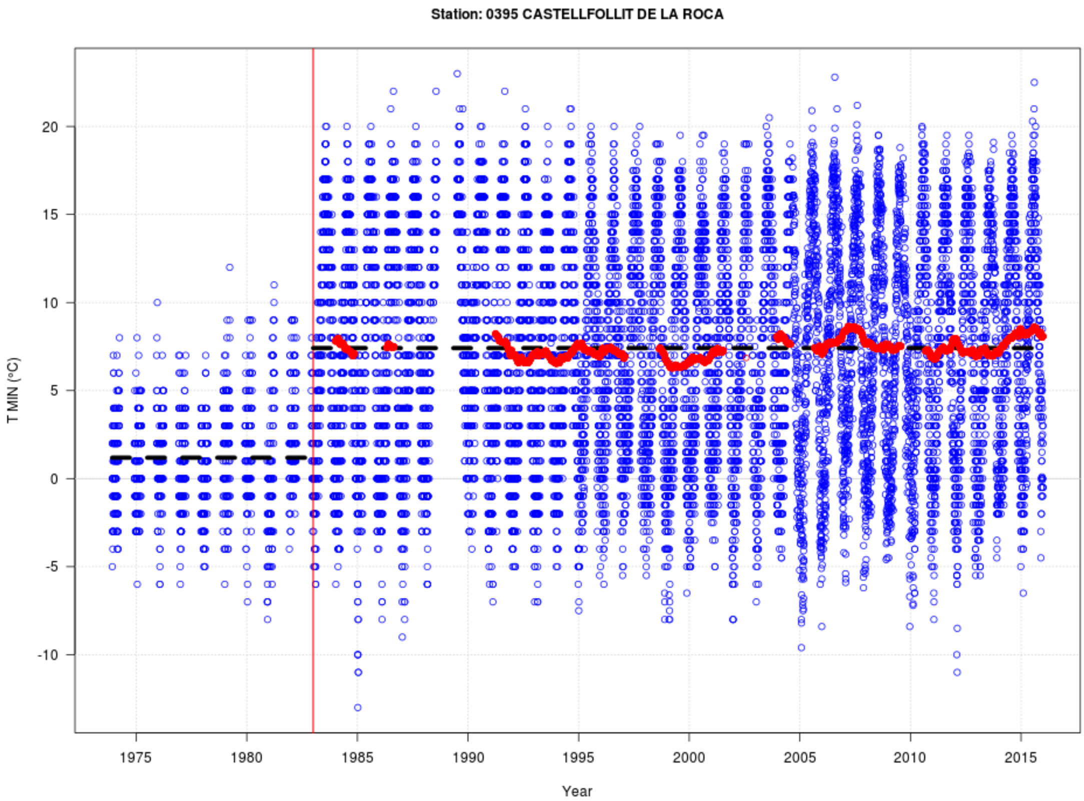


**Figure 24**. Daily data of minimum temperature for the Castellfollit de la Roca station (AEMET station code: 0395).

## 4.2.2 Precipitation

### 4.2.2.1 Quality Control

As for temperature, the values that can be over historical thresholds wil be identified, that is, the historical precipitations ever registered. There are three possible sources of these highest precipitations:

1. The maximum daily precipitation ever registered in Spain (817 mm), a measure provided by AEMET.
2. The one-day probable maximum precipitation of rainfall for the Ebre Observatory (415 mm), at the south of Barcelona. It has been calculated thanks to the Pérez-Zanón*et al.* (2016) work.

3. The one-day probable maximum precipitation of rainfall in Barcelona (371 mm). It has been calculated thanks to the Casas *et al.* (2011) work.

It must be noted that the second and the third values are theoretical values; if they are going to be usedas thresholds it is because there is any historical reference of the study area that could come from an official source (for example, as happens for the Bristol area, where the MetOffice provides maximum precipitation records). It is worth noting that this area (the Mediterranean coast of the Iberian Peninsula) has great precipitations due to convective storms (in fact, the maximum daily precipitation ever registered in Spain is in that area) and any possible conclusion about extreme values must be carefully studied.

After studying the provided observed data with these possible three thresholds it was not found any daily data that can be marked as an outlier.

#### 4.2.2.2 Homogenisation

For one of the precipitation stations of Barcelona, Figure 25 shows the daily precipitation and the points where the homogeneity test has detected inhomogeneities (vertical red lines). Note the 2000-2010 period shows a clear discordance with the time series, but not for their values for themselves (it can exist a daily precipitation of 0 mm), but in the temporal way they appear (maybe “0 mm” was trying to be used instead of “Not Available”?), so this period was finally discarded (their data were deleted). The year 1996 has also been marked as inhomogeneous, but this happens because this was an exceptionally rainy year, a situation that can be observed in several precipitation stations, so it has not been marked as inhomogeneous.

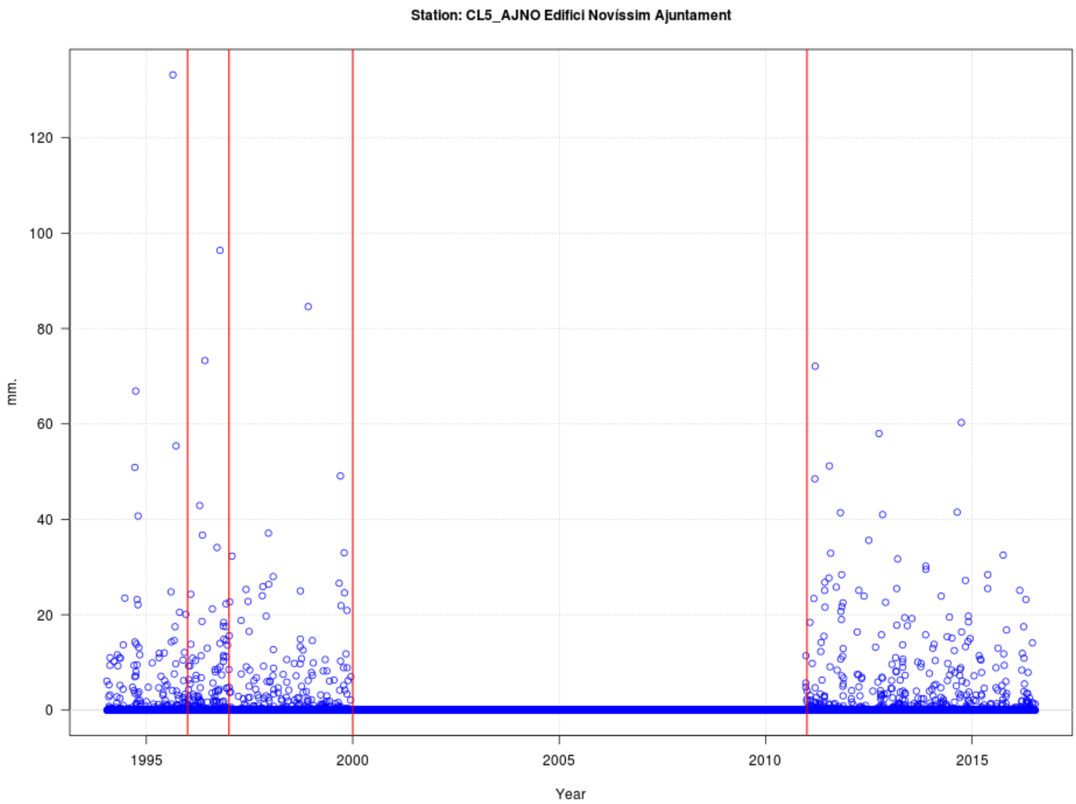


**Figure 25**. Daily data of precipitation for EdificiNovíssimAjuntament station (BCASA code: CL5_AJNO)

# 4.3 Bristol

## 4.3.1 Temperature

### 4.3.1.1 Quality Control

As the Barcelona case, before starting our study of values too far of the mean, the values that can be over historical thresholds will be identified using the historical maximum and minimum temperatures ever registered. Thanks to the public information of the Metoffice (2016e), the UK Meteorological Agency, the highest and lowest daily minimum and maximum temperatures ever registered in England and Wales can be known. Therefore, any daily value that exceeds those historical values is a wrong value and it must be discarded. Figure 26 shows one of these detected values, for the Bristol meteorological station: one daily record of minimum temperature exceeds the highest minimum temperature record (23.9 °C) and it has been discarded.

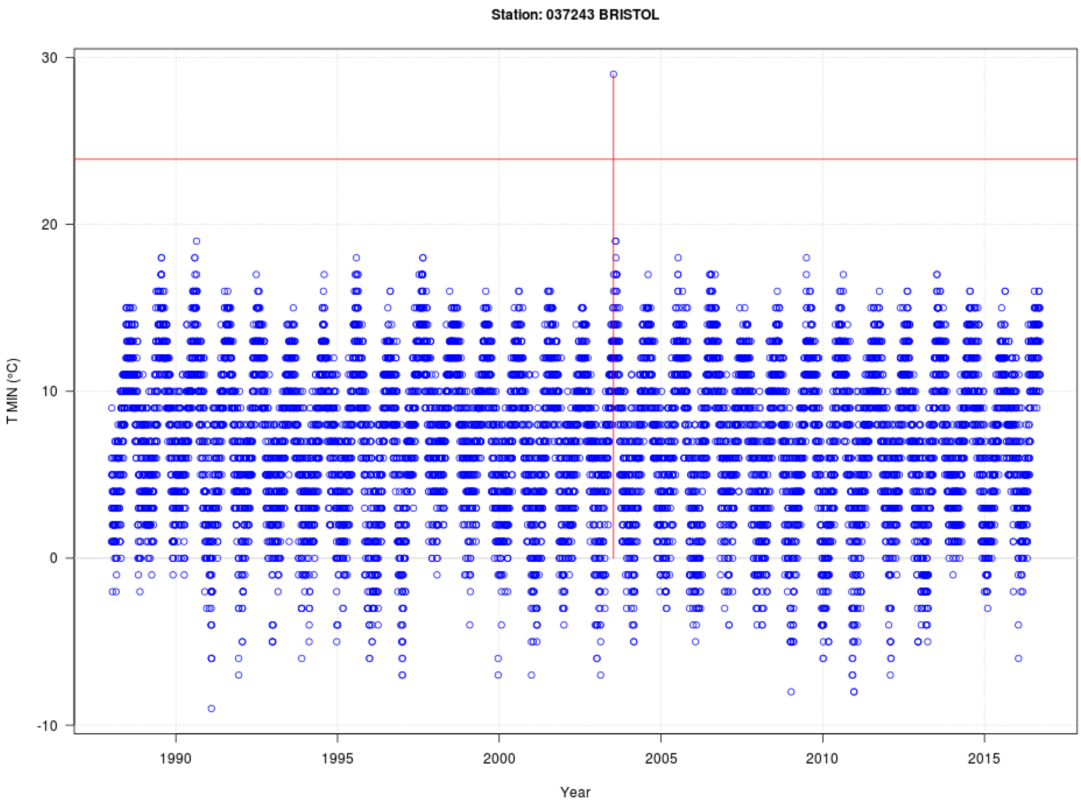


**Figure 26**. Daily data of minimum temperature for the Bristol station (NOAA-GSOD station code: 037243).

Once this study of extremes is finished, the possible outliers in the series must be found using the standard deviation criteria. After some tests, it was found that if a value is greater than 6 times the standard deviation above the average then it is an outlier (or 6 times less). This value (6 times the standard deviation) depends of the characteristics of the series, that is, the climatic characteristics of the temperature (the range of its natural variability) in the study area. Figure 27 shows an example of this kind of work: note there is a value (indicated with a vertical red line) that is far enough from the mean to be marked as an outlier.

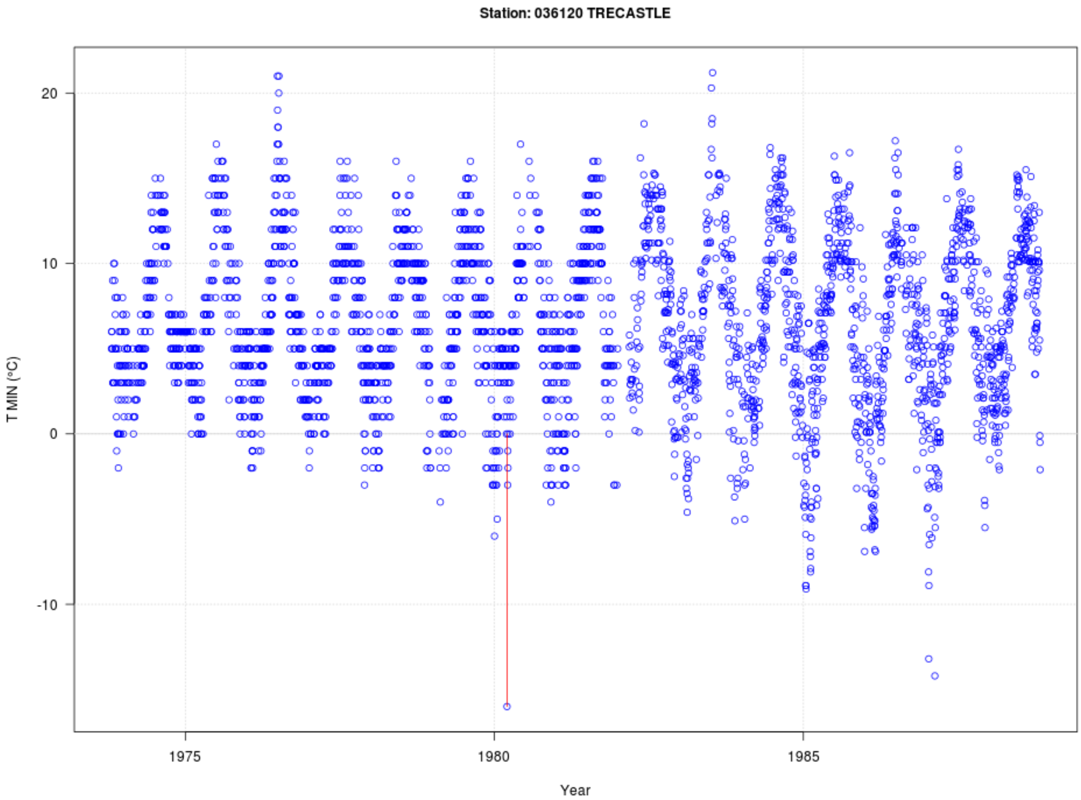


**Figure 27**. Daily data of minimum temperature for the Trecastle station (NOAA-GSOD station code: 036120).

### 4.3.1.2 Homogenisation

For one of the temperature stations of the Bristol studied area, Figure 28 shows the daily minimum temperature and the points where the homogeneity test has detected inhomogeneities (vertical red lines – the horizontal black dashed lines show the mean of the period and the red lines show the moving averages when possible). Note that 2002-2004 and 2007-2009 periods show a clear discordance with the time series, but not for their values for themselves, but in the temporal way they appear – the kind of behavior that an homogeneity test searches. Note the excessive number of 0 °C data (maybe “0 °C” was trying to be used instead of “Not Available”?) and the negative increase of the lower temperatures in the periods marked as inhomogeneous, periods which were finally discarded (their data were deleted).

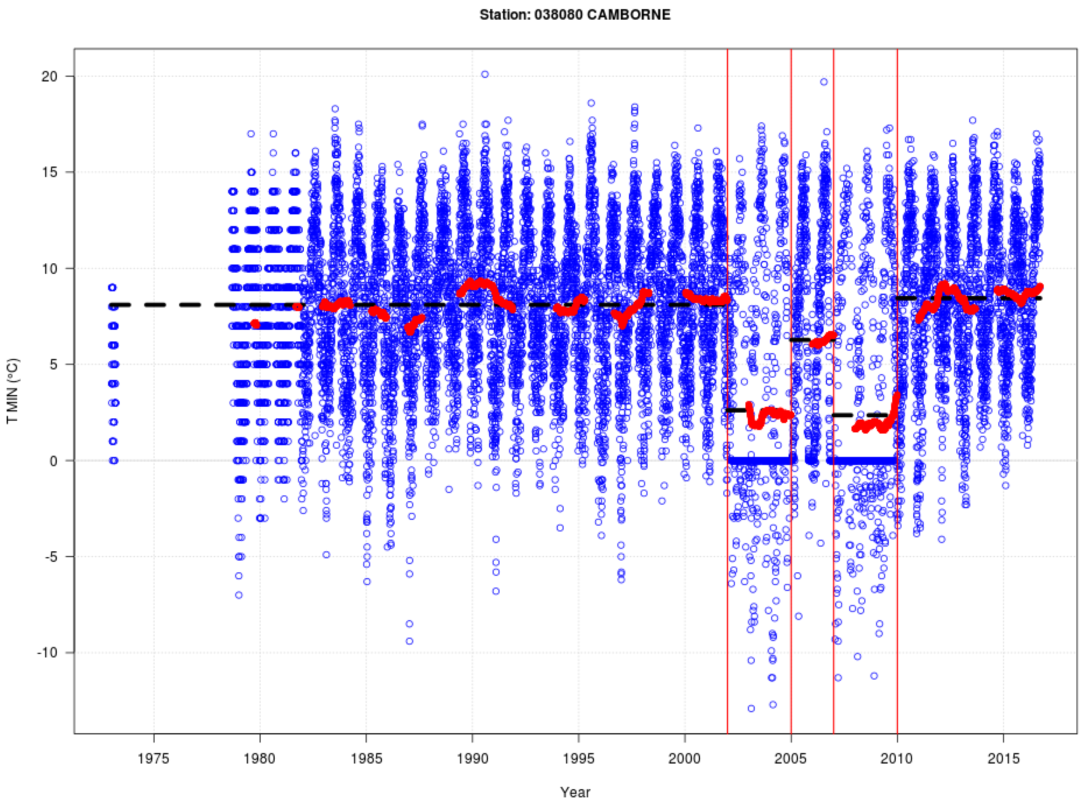


**Figure 28**. Daily data of minimum temperature for the Camborne station (NOAA-GSOD station code: 038080).

## 4.3.2 Precipitation

### 4.3.2.1 Quality Control

As for temperature, the values that can be over historical thresholds will be identified, that is, the highest precipitations ever registered. Again, thanks to the public information of theMetoffice (2016e), the highest *monthly* accumulated precipitation ever registered in South West England and Wales can be obtained. Therefore, any *daily* value that exceeds those monthly historical values is a wrong value and it must be discarded. Figure 29 shows one of these detected values as outliers (the horizontal red line shows the threshold), for the Aberporth meteorological station: one daily record of precipitation exceeds the highest monthly accumulated precipitation and it is removed.

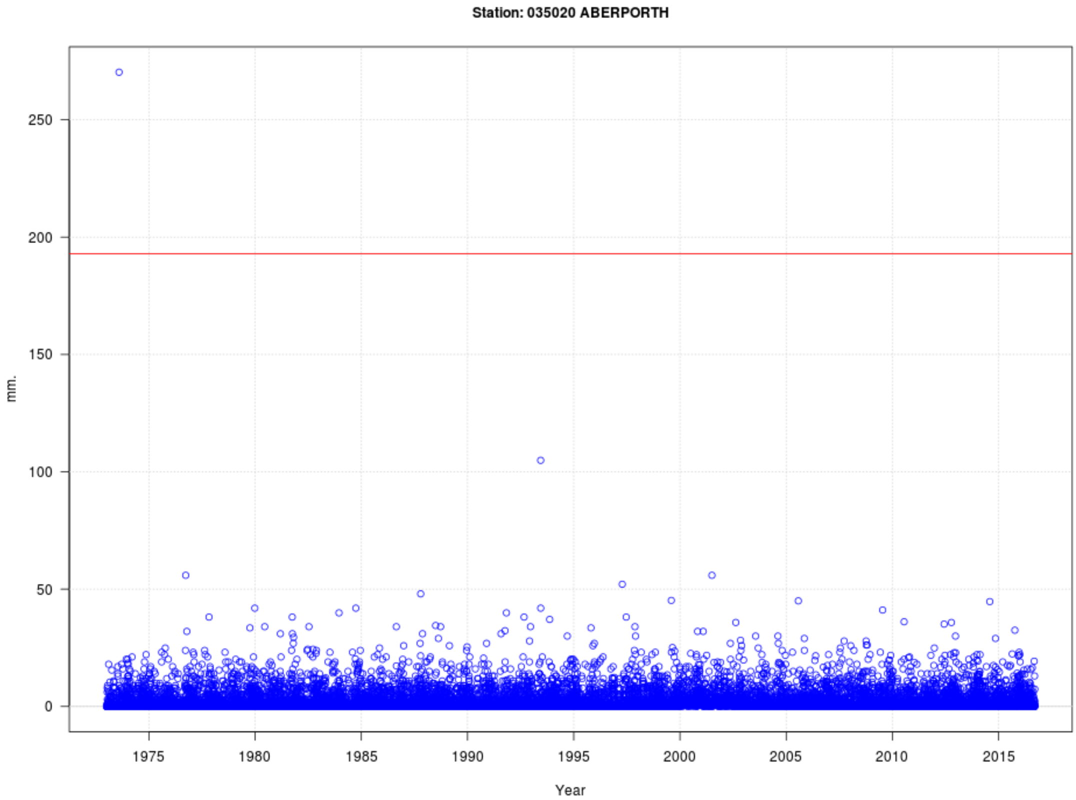


**Figure 29**. Daily data of precipitation for the Aberporth station (NOAA-GSOD station code: 035020).

Thanks to the public information of the Metoffice (2016e), a second test to identify outliers can be done, using the highest monthly accumulated precipitation per year (note that the test mentioned before uses the highest historical data, but not per year). Figure 30 shows one of the detected values as outliers (the horizontal red line shows the threshold), for the Aberporthweather station: one *daily* record of precipitation exceeds the highest *monthly* accumulated precipitation per that year and it is discarded. Note this station is the same presented in the previous quality control, but the value now marked as outlier (for its year) was not an historical outlier in the first control.

These two quality control tests have found outliers in daily data, but no study based on values over the mean plus standard deviations have found any outlier.

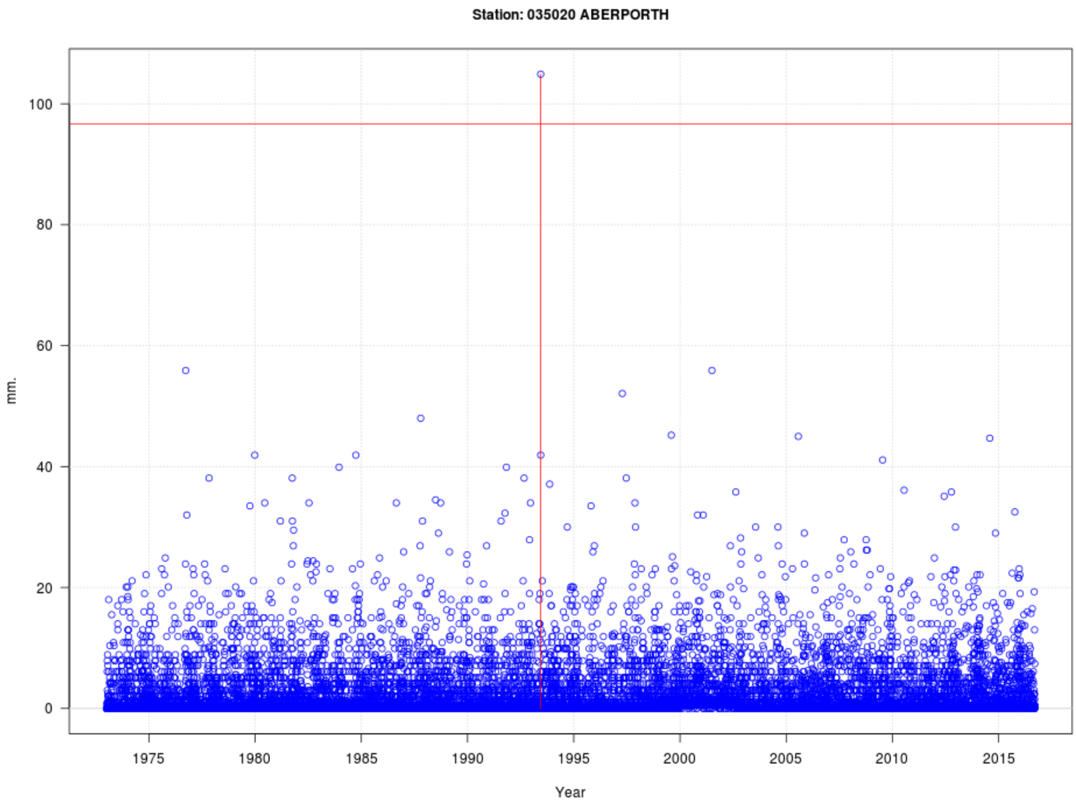


**Figure 30**. Daily data of precipitation for the Aberporth station (NOAA-GSOD station code: 035020). The data marked as outlier in the first quality control was deleted.

### 4.3.2.2 Homogenisation

For one of the precipitation stations of the Bristol studied area, Figure 31 shows the daily precipitation and the points where the homogeneity test has detected inhomogeneities (vertical red lines). Note that 1998 shows a clear discordance with the time series, but not for their values for themselves (it can exist a daily precipitation of 0 mm), but in the temporal way they appear (maybe “0 mm” was trying to be used instead of “Not Available”?), so this period was finally discarded (their data were deleted).

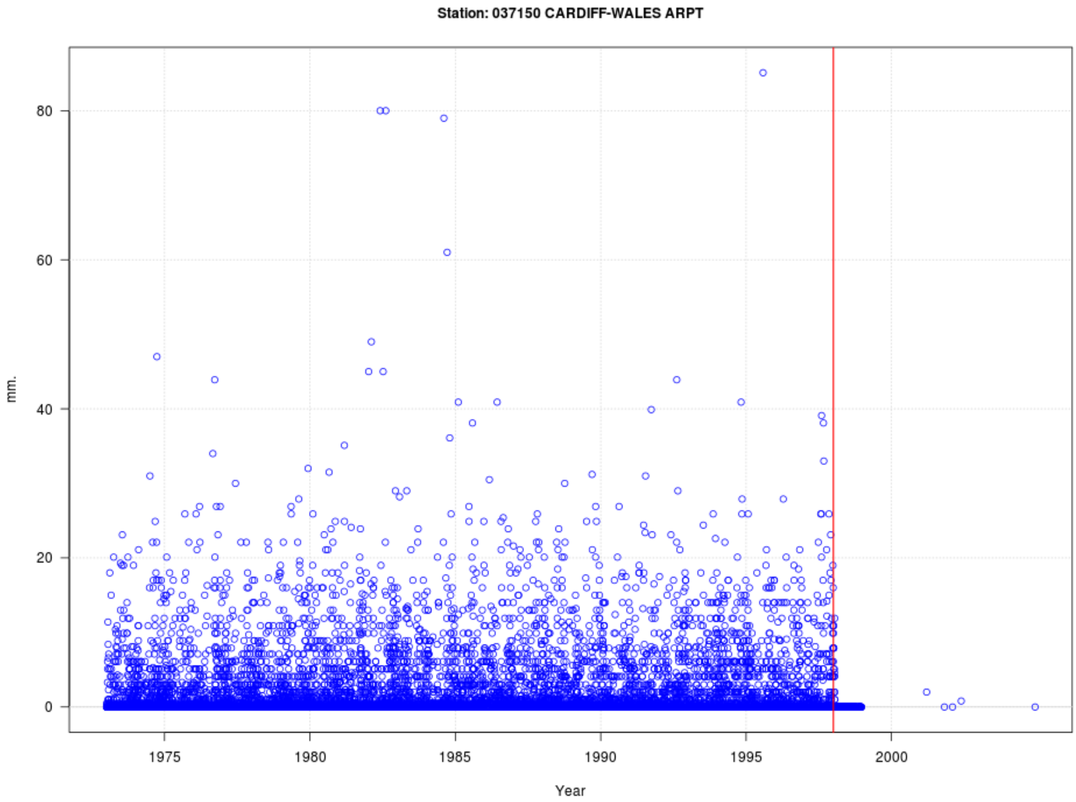


**Figure 31**. Daily data of precipitation for the Cardiff-Wales airport station (NOAA-GSOD station code: 037150).

# 4.4 Lisbon

## 4.4.1 Temperature

### 4.4.1.1 Quality Control

Before starting the study of values too farfrom the mean, the values that can be over historical thresholds can be identified, that is, the highest maximum and minimum temperatures ever registered. Thanks to the public information of the IPMA (https://www.ipma.pt/en/oclima/extremos.clima/), the Portuguese Meteorological Agency, the highest and lowest daily temperatures ever registered in Lisbon are known. Therefore, any daily value that exceeds those historical values is a wrong value and it must be removed. Figure 32 shows one of those detected values, for the Lisbon / Gago Coutinho weather station: one daily record of minimum temperature exceeds the lowest minimum temperature record (-1°C) and it is removed.

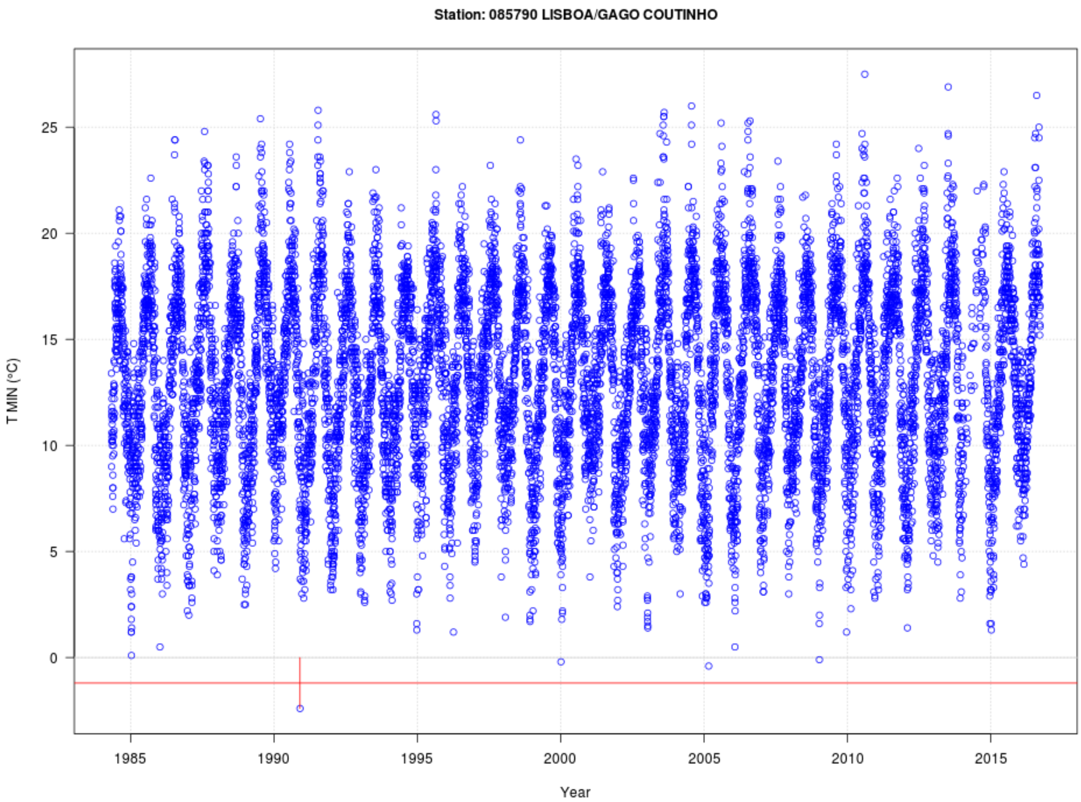


**Figure 32**. Daily data of minimum temperatures for the Lisbon / GagoCoutinho station (NOAA-GSOD station code: 085790).

Once this study of extremes is finished, the possible outliers in the series are identified using the standard deviation criteria. After some tests, if a value is greater than 5 times the standard deviation above the average then it is an outlier (or 5 times less). Note the difference with the value found for South England (6 times): again, it is worth noting that this value (5 times the standard deviation) depends of the characteristics of the series, that is, the climatic characteristics of the temperature (the range of its natural variability) in the study area. Figure 33 shows an example of this kind of work: note there are two values (indicated with a vertical red line) that are far enough from the mean to be considered outliers.

However, some candidates to outliers could be real extreme values. For instance, foehn phenomenon is recorded in some places of Iberian Peninsula coasts. This consists in a relatively very warm and down-slope wind that occurs in the downwind side of a mountain range (due to air drying after condensing moisture on the windward side). Therefore, the relief can condition the appearance of outliers, as the case of Sintra station (Figure 33), with an orographic barrier to maritime airstreams.

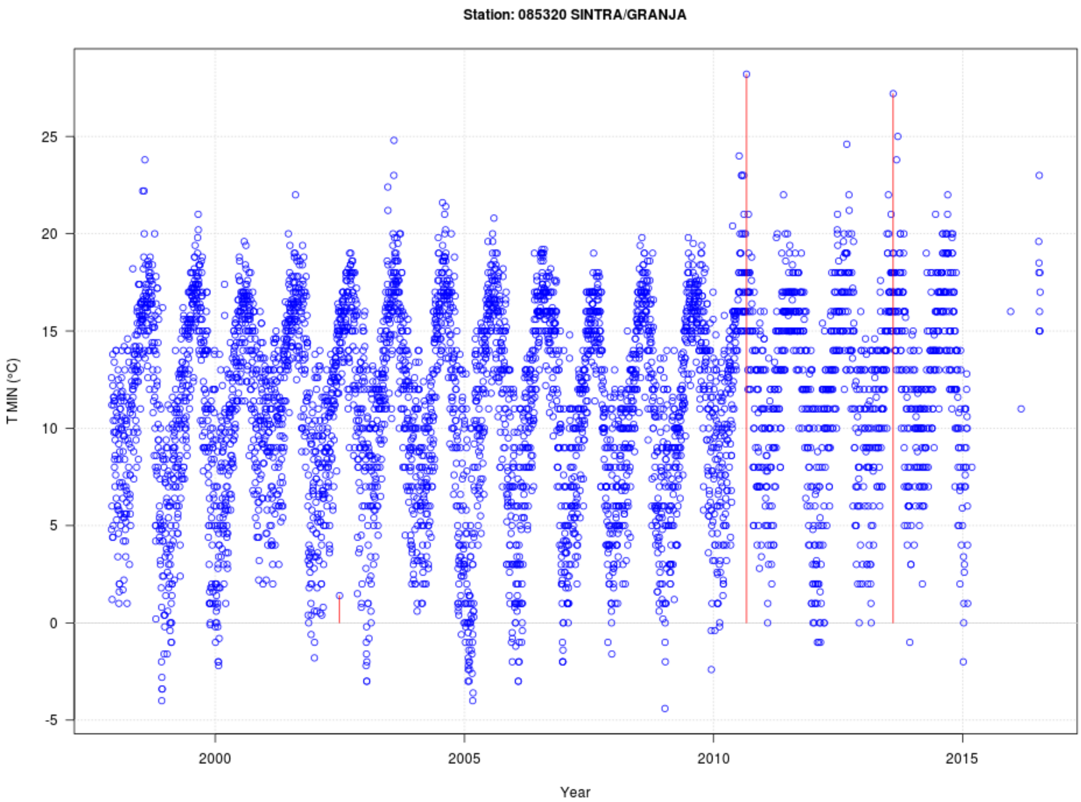


**Figure 33**. Daily data of minimum temperatures for the **Sintra** /Granja station (NOAA-GSOD station code: 085320).

#### 4.4.1.2 Homogenisation

No temperature station has showed inhomogeneities when doing the homogeneity tests.

### 4.4.2 Precipitation

#### 4.4.2.1 Quality Control

As for temperature, the values that can be over historical thresholds will be identidied, that is, the highest precipitations ever registered. Thanks to the work of Fragoso *et al.* (2010), the maximum daily precipitation over Lisbon for the 20th century are known, so any value higher than that will be a wrong one and it must be deleted –thanks to Trigo*et al.* (2012) it is known that in the 19th century there were observed precipitations even greater, but there is no observed data for that century. Figure 34 shows four of these detected values as outliers (the horizontal red line shows the historical threshold), for the Lisbon / Portelaweather station: four daily records of precipitation exceed the highest daily precipitation for the XXth century and they are removed.

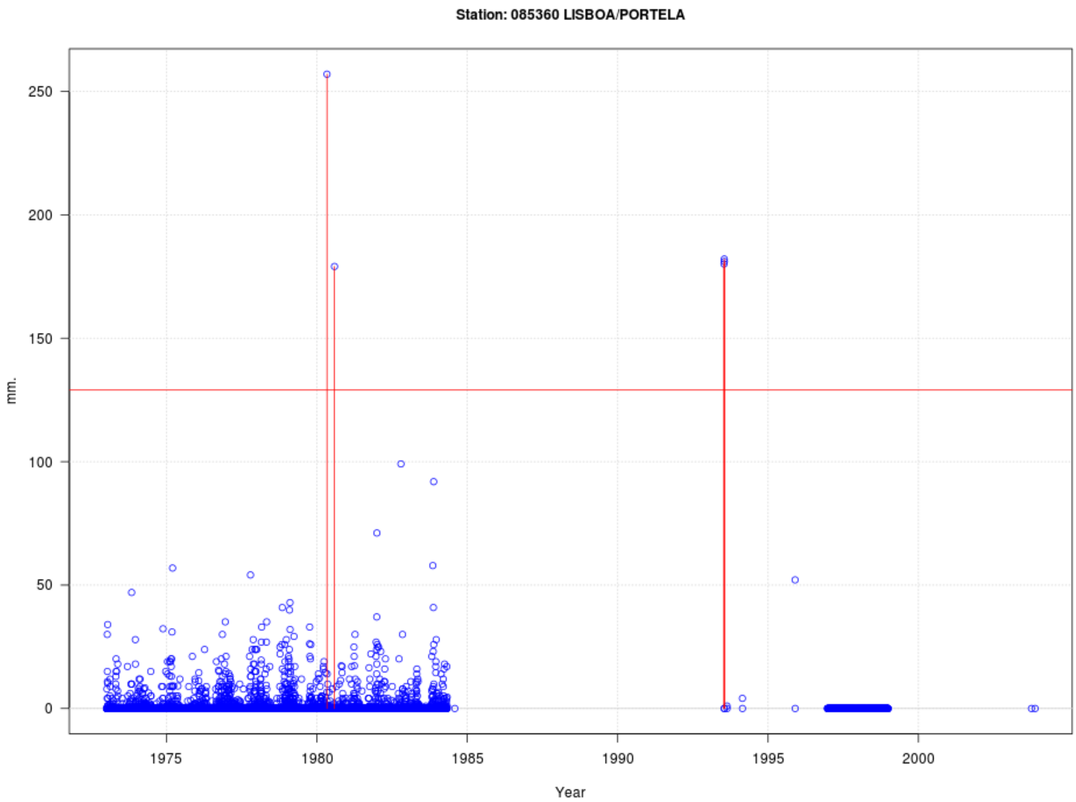


**Figure 34**. Daily data of precipitation for the Lisbon / Portela station (NOAA-GSOD station code: 085360).

### 4.4.2.2 Homogenisation

For one of the precipitation stations of Lisbon, Figure 35 shows the daily precipitation and the points where the homogeneity test has detected inhomogeneities (vertical red lines). Note the 1996-1999 periodis completely different to the rest of the time series, but not for their values for themselves (it can exist a daily precipitation of 0 mm), but in the temporal way they appear (maybe "0 mm" was trying to be use instead of "Not Available"?), so this period was finally discarded (their data were deleted). It is worth noting that the inhomogeneity was not marked those years, but some years before: that is because the homogeneity test for precipitation, anticipating possible years of droughts, works looking for finding differences between periods of enough years to discard possible droughts.

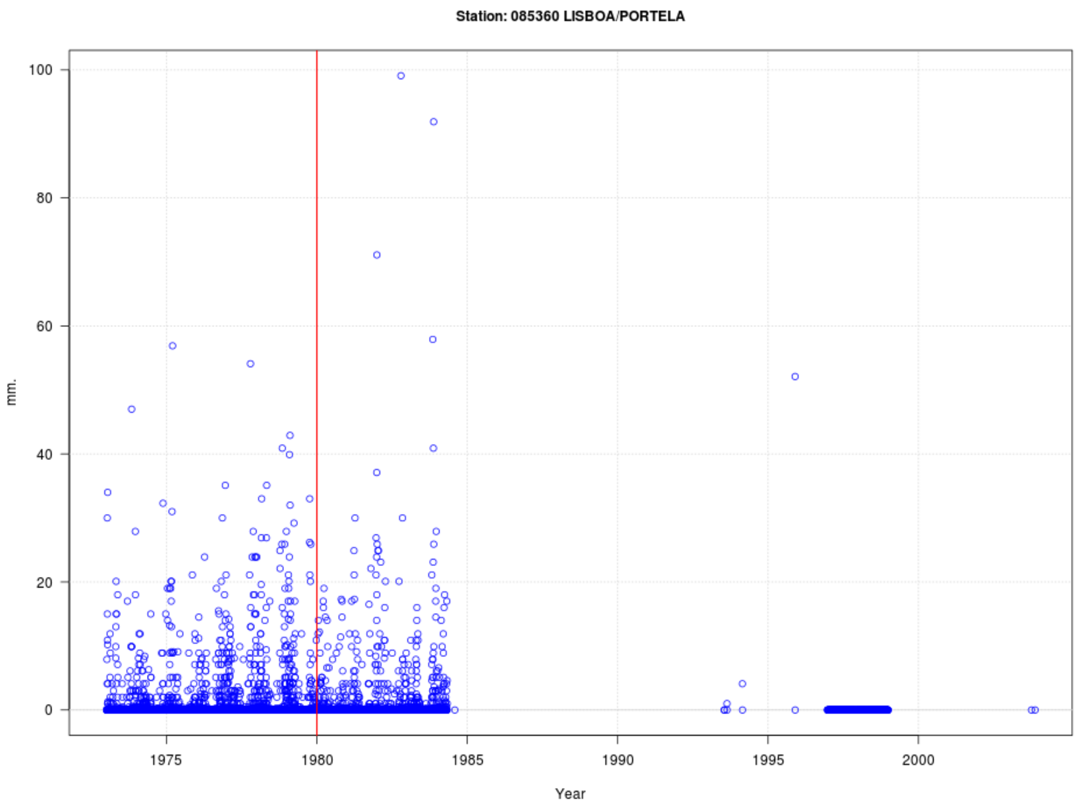


**Figure 35**. Daily data of precipitation for the Lisbon / Portela station (NOAA-GSOD station code: 085360). The data marked as outliers in the quality control were deleted.

## 4.5 Final summary

### 4.5.1 Temperature

The table below (Table 15) summarizes the work done for the provided temperature stations of every studied city (and its studied area of influence).

**Table 15.** Summary of the works of Quality Control done for the provided temperature stations of every studied city (and its area of influence).

| **Barcelona** | | | **Notes** |
|---|---|---|---|
| Stations provided | Original | 366 | |
| | With enough data | 196 | |
| Quality control | Deleted stations | - | |
| | Corrected stations | 47 | Threshold: 5 times the standard deviation |
| | Corrected values from data | 94 | |
| Homogeneity tests | Deleted stations | 5 | |
| | Corrected stations | 19 | |
| **Final number of useful stations** | | 191 | |
| **Lisbon** | | | **Notes** |
| Stations provided | Original | 6 | |
| | With enough data | 6 | |
| Quality control | Deleted stations | - | |
| | Corrected stations | 5 | Threshold: 5 times the standard deviation |
| | Corrected values from data | 8 | 1 value over registered historical values |
| Homogeneity tests | Deleted stations | - | |
| | Corrected stations | - | |
| **Final number of useful stations** | | 6 | |
| **Bristol** | | | **Notes** |
| Stations provided | Original | 112 | |
| | With enough data | 86 | |
| Quality control | Deleted stations | - | |
| | Corrected stations | 37 | Threshold: 6 times the standard deviation |
| | Corrected values from data | 86 | 42 values over registered historical values |
| Homogeneity tests | Deleted stations | - | |
| | Corrected stations | 16 | |
| **Final number of useful stations** | | 86 | |

## 4.5.2 Precipitation

The table below (Table 16) summarizes the work done for the provided precipitation stations of every studied city (and its studied area of influence).

**Table 16.** Summary of the works of Quality Control done for the provided precipitation stations of every studied city (and its area of influence).

| **Barcelona** | | | **Notes** |
|---|---|---|---|
| Stations provided | Original | 658 | |
| | With enough data | 326 | 300 stations from AEMET; 26 from BCASA |
| Quality control | Deleted stations | - | Due to its precipitation regime, especially difficult in the Mediterranean area |
| | Corrected stations | - | |
| | Corrected values from data | - | |
| Homogeneity tests | Deleted stations | - | |
| | Corrected stations | 9 | |
| **Final number of useful stations** | | 326 | |
| **Lisbon** | | | **Notes** |
| Stations provided | Original | 5 | |
| | With enough data | 5 | |
| Quality control | Deleted stations | - | |
| | Corrected stations | 3 | |
| | Corrected values from data | 7 | 7 values over registered historical values |
| Homogeneity tests | Deleted stations | - | |
| | Corrected stations | 1 | |
| **Final number of useful stations** | | 5 | |
| **Bristol** | | | **Notes** |
| Stations provided | Original | 64 | |
| | With enough data | 54 | |
| Quality control | Deleted stations | 1 | |
| | Corrected stations | 30 | |
| | Corrected values from data | 42 | 15 values over registered historical values |
| Homogeneity tests | Deleted stations | - | |
| | Corrected stations | 17 | |
| **Final number of useful stations** | | 53 | |

# 5 Accomplishments and conclusions

## 5.1 Changes with respect to the DoA

The main change of the deliverable is an extension of title to reflect more accurately all the contents of the document. Particularly, the addition of "Summary of studies on climate variables at the research cities" to the previous title "Data collection and quality control" is required to include the state of the art of climate change impacts on the three cities. These previous studies are essential to contextualize and identify climate hazards, and then climate drivers can be defined to properly conduct the data collection.

No other significant changes have been carried out in this deliverable respect to the Description of the Action (DoA). However, some difficulties appeared in the collaboration with public meteorological institutions (Spanish AEMET, Portuguese IPMA and British MetOffice). They requests for meteorological data are normally done very slowly and inefficiently. This was initially foreseen in the DoA, and according with this, most of observed data was collected from the open database of the U.S. National Oceanic and Atmospheric Administration (NOAA). Thisglobal databaseis freely available for climate research, but in some cases may be insufficient, and therefore it has been necessary to make a great effort to supplement them with data from the regional meteorological institutions. Finally, some additional observed data were obtained from AEMET and Catalan Meteorological Service (SMC), being able to complete the database for the RESCCUE project.

## 5.2 Accomplishment summary

All subtasks and milestones of tasks 1.1 and 1.2 have been satisfied at first six months of the project. Climate change drivers were identifiedthroughout the state-of-art of historical climate trends, future projections and their potential impacts on the main urban services. Previous studies showed that, despite the coastal climate of Barcelona and Lisbon, heat and cold waves are relative climate hazards with a medium level of importance. Synoptic and local severe eventshave also been identified for the cities with at least medium level, mainly windstorm for Lisbon and Bristol, hydrometeorologicalhazards (drought and flash flood) for Barcelona and Lisbon, and river-basin flooding for Bristol.

According to the risk matrix of all considered climate hazards, a level importance was proposed for each climate variable. In this way, priorities and efforts are assigned for the climate module of the RESCCUE project.

After identifying all climate variables and their importance level, data collection was performed for the three cities. CMIP5 data and observed data were considered for both atmospheric and oceanic variables. Climate change simulations, decadal outputs and seasonal models have been collected for the project. For the observed variables, the greatest database achieved consists of temperature, precipitation, humidity, wind, pressure, wave height and tide.

Regarding the quality control, a set of tests were applied over all time series: general consistency, outliers and inhomogeneities. Results of the tests showed an acceptable quality for the most of datasets.

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