Booklets

Research & Development & Innovation

27

Canal de Isabel II

Climate Change Scenarios for severe rainfall events in Madrid Region

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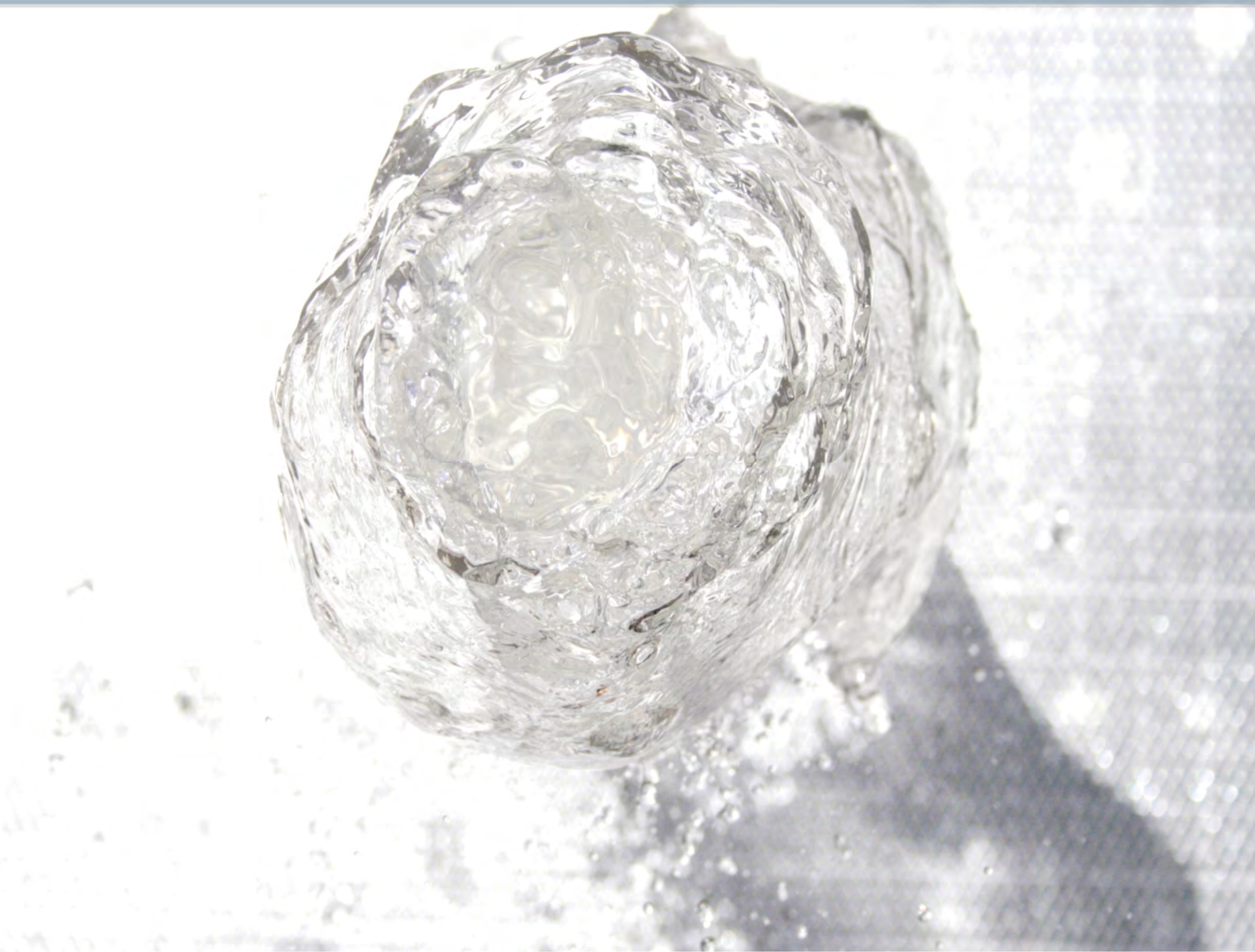
Climate change scenarios for severe rainfall events in Madrid Region



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Presentation

The collection Booklets of Research, Development & Innovation of Canal de Isabel II are part of the vision of the company's knowledge management, the development of its 2017-2020 R&D&I Strategy, and of the 2018- 2030 Strategic Plan of Canal de Isabel II.

The Booklets represent an element for diffusion of projects and initiatives developed and promoted by the company and aim at innovation in areas related to the water services in an urban environment.

They deal with the problems tackled by each project as well as the results obtained. The aim of publishing these Booklets is to share experience and knowledge with the entire water industry sector, with the scientific community and with all those who work in the fields of research and innovation. With these publication, what it is hoped is contribute the improvement and efficiency in water management and, as a result, make it possible to offer a better service to the citizens.

The titles published in the series to date are shown in the following table.

TITLES IN THE COLLECTION OF R&D&I BOOKLETS

Collection Number	***Research, Development and Innovation Booklets published***
1	Transferences of Water Rights between Urban and Agrarian Demands. The case of the Comunidad de Madrid
2	Identification of Hydrometeorological Runs and Tendencies within the scope of the Canal de Isabel II system
3	Contribution of Canal de Isabel II to the International Demand Management Project (IDMF)
4	Microcomponents and Explanatory Factors on Domestic Water Consumption in the Comunidad de Madrid
5	Virtual Water and Hydrological footprint in the Comunidad de Madrid
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid
7	Potentials of efficiency in using dishwashers in the Comunidad de Madrid
8	Accuracy in the measurement of individual water consumption in the Madrid Region
9	Research project to define and assess the applicability of a Bioassay Test to determine the toxicity of water using Zebra Fish embryos
10	Water Use Efficiency in Gardening in the Region of Comunidad de Madrid
11	Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid
12	Cyanotoxin Dynamics Study in two of the Canal de Isabel II supply reservoirs in the autonomous region of the Comunidad de Madrid
13	Development of a validation, estimation and prediction of hourly consumption by sector, for the distribution network of Canal de Isabel II
14	Monitoring of the consolidation urban development in the Comunidad de Madrid using remote sensing techniques
15	Experiences in the recovery of phosphorus from wastewater, in the form of Struvite, at Canal de Isabel II
16	Integration of weather forecasting in the management modules supply system of Canal de Isabel II, via daily contributions models
17	Improvement in forecast capacity of monthly and seasonal runoff in the scope of Canal de Isabel II
18	Inflow of nutrients from the basin to Pinilla reservoir. Effect on the eutrophication process
19	A new criterion for calculating urban sewage flows
20	Idea Management at Canal de Isabel II Gestión: The GENYAL Experience

Collection Number	***Research, Development and Innovation Booklets published***
21	Research on measuring techniques for subsidence related to groundwater exploitation
22	Precipitation patterns in the basins of the Lozoya and adjacent rivers
23	Observability study for hydraulic state estimation of the sectorised supply network
24	Study of failure causes and modes in pipes, service connections, and water meter assemblies in the Comunidad de Madrid
25	A Pattern Recognition System for the Identification of Residential End Uses of Water
26	Analysis of the influence of explanatory variables in the models of pipes failure

Document Structure

The objective of this booklet is to study and determine the coefficients of **climate change** that may affect future precipitation in Madrid Region, both extreme precipitation that may cause flooding and incorrect functioning of the urban drainage network, and the more common precipitation, which is the source of the primary water resource of the urban water supply system. Likewise, as a complementary work, the IDF curves applicable to Madrid Region have been recalculated.

At the beginning of the document, an **executive summary** has been developed that aims, in an abridged manner, to review the methodology, boundary conditions, data sources and, above all, results of the study carried out.

For a better understanding of the project carried out it has been included the first chapter, where the methodology to be used is reviewed, the concept of **radiative forcing** is explained, the different climate change scenarios on which researchers are going to work are exposed, and it is analysed how the correction of the potential methodology errors have been carried out.

In the second chapter, the methodology developed previously in Madrid Region is applied, with a detailed study being made of the available data sources. It also includes the development of climate change coefficients for Madrid. These coefficients are also displayed in the executive summary.

Lastly, the study is supplemented by various appendices to allow the document to be followed more easily, including a summary of the tables and figures used, a list of the acronyms used, and an extract of the references used.

Keywords

Climate change – Extreme rainfall – Floods – IDF curves - Resilience

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Executive Summary

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Project title	**Climate change scenarios for severe rainfall events in Madrid Region**
Research line	Environmental integration and sustainability
Areas involved at Canal de Isabel II	Subdirección de Investigación, Desarrollo e Innovación
External participation	Departamento de Astronomía y Meteorología de la Universidad de Barcelona, Dirección de Drenaje Urbano de Aqualogy, Departamento de Física e Ingeniería Nuclear de la Escuela Politécnica Superior de Ingeniería (UPC); Foundation for Climate Research.
Aim and justification of the Project	The latest report from the international organisation **IPCC** (Intergovernmental Panel on Climate Change) warns of changes that are taking place on a global scale in the water cycle, with an increase in extreme weather events (among others), caused by the warming of the atmosphere, the oceans and the increase in GHG (greenhouse gas) concentration. This research project aims to develop an adequate water resource and strategic infrastructure planning for Madrid Region (specially in drainage, since its dimensioning and behaviour depends mainly on the temporal and spatial distribution of the rains events) on the basis of the global scenarios proposed by the IPCC. So that, decision makers will be able to anticipate the influence that climate change and rainfall events will have on infrastructure design.
Contribution to the state of the art	This project has been one of the first international examples of application, in the field of urban drainage, of the new RCP scenarios proposed in the latest report of the Intergovernmental Panel on Climate Change.
Summary of the Project development and outstanding milestones	The international scientific community has defined a series of future scenarios of climate change under which simulations with global scope of the different existing climate models have been generated. In order to apply these global scenarios to the region of Madrid, a process of "regionalisation" has been carried out, which allows the application of the future simulations on the local level. The Foundation for Climate Research (FIC, for its Spanish acronym) has developed its own method of regionalisation, selected for this project, and it has been applied to three meteorological observatories in Madrid Region (Retiro, Getafe, and Torrejón) to generate, from global climate models, future scenarios of local climate change on precipitation in them. The advanced rainfall estimation study of extreme precipitation in the region of Madrid has been based on different General Circulation Models (GCM), a specific spatial downscaling technique called FICLIMA, developed and validated in Spain, and four radiative forcing scenarios (Representative Concentration Pathways, or RCP). The combination of the models used and the scenarios available for each one of them have provided a range of thirty-one possible evolutions for the future climate, extending to 2100. The possible effects of these scenarios have been quantified through the calculation of climate change coefficients that express the quotient between the rainfall intensity for a given return period and a certain duration, corresponding to a future climate scenario, and the equivalent rainfall intensity in the present climate for the same return period and the same duration.
Summary of the results obtained	Climate change coefficients have been obtained for the three pluviometric stations analysed, each time horizon, and each RCP scenario, for daily and hourly rainfall. Due to the high uncertainty of the results generated by the GCM and the other implicit hypotheses in the methodology used (statistical adjustments, use of the fractal technique, etc.) and in the absence of orographic aspects that explain significant climate changes in the three weather stations studied in Madrid, it was considered appropriate to average out the results of the GCM and the values of the coefficients of climate change, for the three stations analysed.
Research Lines open for continuing the work	Active monitoring of extreme precipitation phenomena in Madrid Region is necessary to be able to correctly monitor the results. Moreover, future projections are based on evolution models that must be periodically updated by the IPCC. Therefore, the results of this study have to be updated in the same way for a better approximation to the changes that occur.

Executive Summary

INTRODUCTION

In recent years, the international scientific community has expressed its concern for what has been called "Climate Change" whose effects have become evident in recent decades. According to the latest report of the IPCC (Intergovernmental Panel on Climate Change, 2013), it is extremely likely that climate change has an anthropogenic origin. Likewise, it is noted that the warming is unequivocal and since the 1950s many of the observed changes have been unprecedented. The abovementioned report makes clear the human influence on the climatic effect because the increase of the concentration of greenhouse gases (GHG) in the atmosphere has led to a warming of the atmosphere itself and the oceans, changes in the water cycle, reductions of snow and ice cover, a global rise in sea level and changes in extreme events.

As part of the fifth report of the Intergovernmental Panel on Climate Change (IPCC), the scientific community has defined a series of future scenarios of climate change under which global simulations of the different existing climate models created and developed by scientific institutions from all around the world have been generated. These simulations, of a global nature, must undergo a process of "regionalisation" for their results, to be used on a local scale; this is precisely the objective of a downscaling technique, which allows the local application of the results of future simulations, illustrated in Figure 1. The Foundation for Climate Research (FIC[1]) has developed its own regionalisation method, called FICLIMA, which has been selected for this research project and has been applied to a group of meteorological observatories of Madrid Region to generate, from global climate models, future scenarios of climate change on precipitation in these observatories.

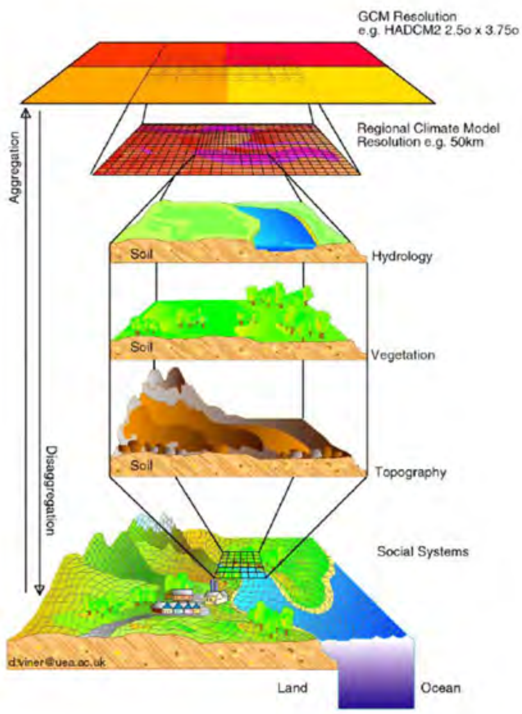
To bring about an adequate management of water resources, it is necessary to know how climate change will affect them, to develop a plan that minimises its effect and contributes to adapting management to potential changes. The latter particularly, affect urban drainage networks in that their sizing and behaviour depends especially on the temporal and spatial distribution of rain events. Therefore, the generation of different, and hypothetical future scenarios of climate change was carried out on a group of selected meteorological observatories of Madrid Region, in order to expand knowledge about possible variations in rainfall patterns.

Canal de Isabel II has developed an **Advanced Rainfall Study** to predict and estimate the possible effect of climate change on extreme precipitation, based on different General Circulation Models (GCM) and the regionalisation technique (Spatial Downscaling). The combination of the models used and the scenarios available for each of them have provided a range of thirty-one possible evolutions of the future climate, reaching the time horizon of 2100. The most important conclusions of this study are presented in this booklet.

[1] FIC, Foundation for Climate Research is a non-profit, private and totally independent entity, whose foundational objectives are focused on research in the field of climate change, as well as in the areas of climatology, meteorology, environment and development cooperation. It has a long experience in the generation of local climate change scenarios and its own prediction methodology, which is one of the most internationally robust (FICLIMA Methodology).

To carry out this work, Canal de Isabel II was assisted by the Directorate of Urban Drainage of Aqualogy, the Department of Astronomy and Meteorology of the University of Barcelona (UB), the Department of Physics and Nuclear Engineering (Polytechnic School of Engineering of Vilanova i la Geltrú, UPC), and the Foundation for Climate Research (FIC).

FIGURE 1. **REGIONALISATION OR "DOWNSCALING" MECHANISM**



Graphic representation of the regionalisation or Downscaling mechanism, adapting the outputs of global climate models to the physiographic characteristics of the region.

Source: David Viner, Climatic Research Unit, University of East Anglia, UK.

METHODOLOGY

The **Advanced Rainfall Study of Extreme Precipitation Estimation in Madrid Region**, which has provided the basis for this document, has been grounded on different General Circulation Models (GCM), a specific "regionalisation" technique (spatial downscaling) called FICLIMA[2], elaborated and validated in Spain, and four radiative forcing scenarios[3] (Representative Concentration Pathways or RCP[4]).

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[2] FICLIMA. Methodology of statistical climate prediction of the Foundation for Climate Research.

[3] Radiative Forcing. It is the change in the net flow of radiative energy towards the surface of the Earth, measured at the upper edge of the troposphere (at about 12,000 m above sea level), as a result of internal changes in the composition of the atmosphere, or changes in the external contribution of solar energy. It is expressed in W/m^2, units of watts per square metre of the Earth's surface. A positive radiative forcing contributes to heating the surface of the Earth, while a negative one favours its cooling. In the IPCC report, changes in radiative forcing are compared with the year 1750.
Source: http://www.ipcc.ch/publications_and_data/ar4/wg1/es/faq-2-1.html.

[4] RCP. Acronym of representative concentration pathways, RCP, are the new scenarios proposed by the IPCC in its fifth report. Throughout this R&D&I Booklet, the scenarios will be named using the English nomenclature since it is of international use and common knowledge. Thus, the scenarios used are RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (graphs may occasionally be found where the point does not appear). The origin of these codes comes from the calculation of radiative forcing thresholds measured in W/m^2, in accordance with these thresholds, work groups were established.

The combination of the models used and the scenarios available for each of them have provided a range of thirty-one possible future climate evolutions that extend to 2100.

Due to the high uncertainties associated with GCMs and spatial, and temporal downscaling techniques, and in accordance with the indications of the international scientific community, the possible influences of climate change have been estimated in terms of trend values (averaging out the results of the different GCMs and the different observatories, for each of the scenarios).

The potential effects of climate change in Madrid Region have been quantified through the calculation of climate change coefficients that express the quotient between rainfall intensity for a given return period and a certain duration, corresponding to a future climate scenario, and the equivalent rainfall intensity in the present climate for the same return period and the same duration.

A careful selection of meteorological observatories for the region of Madrid has been carried out to be able to guarantee the obtaining of the local future climate scenarios, in the best way possible in each point, with the requirements that are specified below:

- **Analysis of the observed data available**. Before they were used, the observed meteorological data available were studied to determine their validity and, therefore, if they could be fully used, if they need corrective actions, or even if they need to be discarded.
- **Verification of the FICLIMA methodology**. The results obtained by this methodology have been verified by simulating the climate of each observatory to determine their capacity to reflect the climate of each local point to study.
- **Validation of climate models**. It is of great importance to have as many climate models and future scenarios as possible so that a wide enough range of future climate changes can be considered; in this project researchers worked with nine climate models. Each model simulates the climate in a different way (colder/warmer, or drier/wetter) so before generating future climate scenarios, the behaviour of each model is evaluated at each point to be studied.
- **Generation of future climate scenarios at a local scale**. Based on the data provided by the global models for the new available scenarios (RCP), regionalisation techniques (downscaling) have been applied to obtain results in points of interest.

DATA SOURCES

In any process of regionalisation, which is intended to generate future climate scenarios, it is necessary to have several data sources. In the case of this project, the following data has been obtained:

- Series of observed daily meteorological data, with at least 2000 daily data available (a minimum number of observatory data that allow to categorise its climate), in the largest possible number of observatories located within the study region.
- A data bank consisting of low resolution fields (atmospheric fields) of a reanalysis. In this study ERA40 reanalysis[5] will be used.
- A data bank consisting of low resolution fields (atmospheric fields) of a set of general circulation climate models (GCM). In this study, nine climate models developed by different international research centres in Europe, Asia and America were used.

[5] ERA40 is a reanalysis of meteorological observations (september-1957 to august-2002) conducted by ECMWF (European Centre for Medium-Range Weather Forecasts), in collaboration with many institutions.

The reanalysis data are meteorological data that describe the state of the atmosphere in a regular mesh of different points, at different heights, and covering the entire Earth, in a past historical period. Given that the usage of global climate models requires a group of reference data, the use of the reanalysis data is absolutely necessary both so that their results can be compared, and to establish the initial model operating conditions. From the existing reanalysis data for this project, the "ERA40 European reanalysis" was chosen.

Both reanalysis and climate models can present certain problems when they are worked with (such as a lack of information, incomplete fields, etc.). These are relatively well-known problems and, therefore, correctable. On the other hand, the observed data from meteorological observatories can also have drawbacks (such as periods of time without any data, outliers[6], false data, and poor data length, among others). Therefore, before beginning to apply the regionalisation methodology, it is necessary to carry out a comprehensive study of the of the available data quality and discard all those observatories that do not meet minimum requirements that guarantee the optimal functioning of the downscaling methodology.

With respect to climate general circulation models, it is desirable to have the largest number of them to eliminate the potential trend errors of each one. For this study, researchers have had nine models whose characteristics are summarised in Table 1.

TABLE 1. CLIMATIC MODELS USED IN THE PROJECT

Climate Model	*Spatial resolution degrees*	*Temporal resolution*	*Calendar days/year*	*Research Centre*
MPI-ESM-MR	1.8 x 1.8	daily	Gregorian	Max Planck Institute for Meteorology (MPI-M), Germany
GFDL-ESM2M	2 x 2.5	daily	365	National Oceanic and Atmospheric Administration (NOAA), EE.UU.
CanESM2	2.8 x 2.8	daily	365	Canadian Centre for Climate Modelling and Analysis (CC-CMA), Canada
CNRM-CM5	1.4 x 1.4	daily	Gregorian	CNRM (Centre National de Recherches Meteorologiques), Meteo-France, France
BCC-CSM1-1	2.8 x 2.8	daily	365	Beijing Climate Center (BCC), China Meteorological Administration, China
HADGEM2-CC	1.25 x 1.8	daily	360	Met Office Hadley Centre, UK
MIROC-ESM-CHEM	2.8 x 2.8	daily	Gregorian	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan
NorESM1-M	1.8 x 2.5	daily	365	Norwegian Climate Centre, Norway
MRI-CGCM3	1.2 x 1.2	daily	Gregorian	MRI - Meteorological Research Institute, Tsukuba, Japan

[6] Outlier, in statistics an outlier is an observation that is numerically distant from the other data.

It should be acknowledged that the climate model data availability is in charge of the WCRP (World Climate Research Programme), it is a programme of the World Meteorological Organization (hereinafter **WMO**) which is responsible for the Coupled Model Intercomparison Project Phase 5 (CMIP5) initiative, while the development of the infrastructure necessary for its storage and downloading (hardware and software) is in charge of the US Department of Energy.

FUTURE "RCP" SCENARIOS

The emission scenarios are used in Climate Change as plausible descriptions of what future changes will be like within a wide range of variables: socioeconomic, technological, energy, land use, greenhouse gas (**GHG**) emissions, and air pollutants. To fulfil this function, sets of emission scenarios were developed, such as **IS92**[7], or more recently, **SRES**[8].

In the international scientific community, the need arose to have scenarios provided with more detailed information. In line with this need, the **IPCC** proposed, for the preparation of its fifth report, the definition of new scenarios that have been called Representative Concentration Pathways (**RCP**). Their definition is based on the following criteria:

- RCP must be based on existing emission scenarios, prepared by different centres and recorded in the literature. At the same time, each RCP must, by itself, be a plausible description that is internally consistent with the future.
- They must provide information on all the radiative forcings, necessary for climate modelling (land use, GHG emissions and air pollutants).
- They must be "harmonised", that is, the continuous transition between the historical period (the Historical experiment) and the future periods must be guaranteed.
- They must provide information until 2100 and be available to simulate further.

The name "**RCP**" contains two of its main characteristics:

Representative: refers to the idea that an RCP represents a set of existing emission scenarios. That is, the RCP must be compatible with both extreme scenarios and intermediate ones.

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[7] IS92. in 1992, the IPCC published emission scenarios that served as the basis for the global circulation models, to develop a context on climate change. the so-called "IS92 scenarios" (International Scenarios 1992), which constituted a great step forward.
Source*: HTTPS://WWW.IPCC.CH/PDF/SPECIAL-REPORTS/SPM/SRES-SP.PDF.*

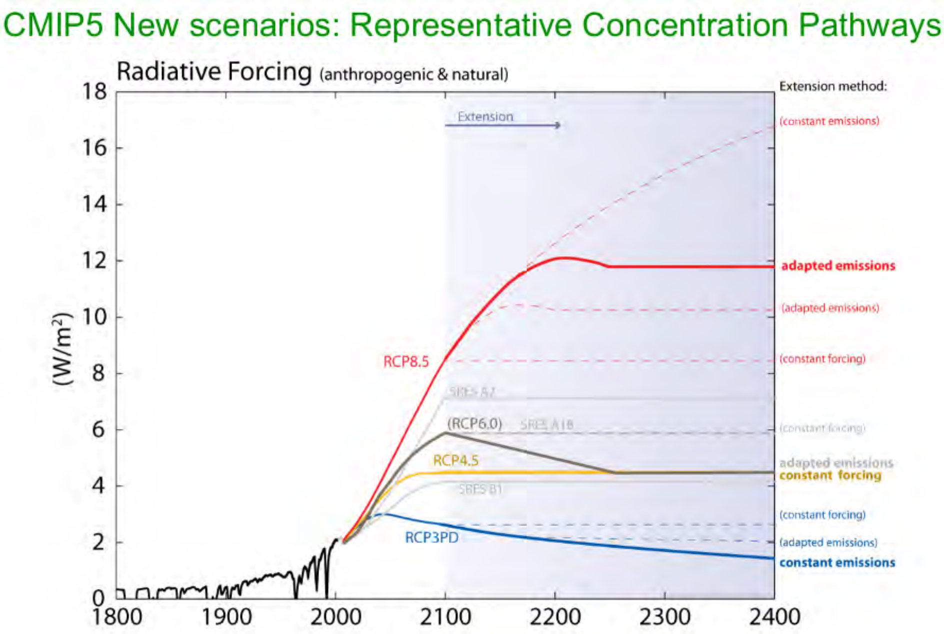
[9] SRES, in 2000, the IPCC published a new series of scenarios, which it called SRES (Special Report on Emissions Scenarios), for use in the third evaluation report. these respond to various driving forces on climate change, including population growth and socio-economic development. These driving forces generate several future scenarios that may have an influence on greenhouse gas sources and sinks, such as energy systems and the change in land use. The evolution of these driving forces, in relation to climate change, is uncertain, generating a wide range of possible paths for greenhouse gas emissions.
Source: WWW.LENNTECH.ES/EFECTO-INVERNADERO/ESCENARIOS-CAUSAS-IPCC-SRES.HTM#IXZZ3LTXEXXWS

Concentration Pathway: this term emphasises that RCP are not final products but are the tool (input) that assists the generation of emissions scenarios, hence the use of the term "concentrations" instead of "emissions". RCP are understood as a sufficiently consistent set of radiative forcing components, but they are not a complete set of climate, socioeconomic, and emission projections.

Figure 2 shows how the new RCP are related to the scenarios already existing in the previous IPCC reports.

The review of the existing literature (formed by the study of 324 scenarios from different research centres) found that the range of values of radiative forcing expected by 2100 ranged between 2.6W/m^2, as the lowest level and between 8-9W/m^2 at the highest level.

FIGURE 2. RADIATIVE FORCING DURING THE 21ST CENTURY ASSOCIATED WITH THE DIFFERENT RCP



Radiative forcing during the 21st century associated with the different RCP and the relationship to the scenarios of report nº. 4 of the IPCC (SRES). The RCP 2.6 scenario appears with its original name, RCP3PD. Source: Meinshausen, Smith, et al. (2011)

Since the RCP must cover the entire existing range and also provide interim information, a set of four RCP were chosen that included both the extreme values and two intermediate values, separated enough from each other, so that the results obtained from them also yielded different results (separated from each other by 2W/m^2).

The scientific community (consisting of more than 20 working groups from around the world) determined in September 2008, in Paris, that the new scenarios would be RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (the name refers to radiative forcing reached in 2100) and designated the four working groups that would be responsible for developing these scenarios. Table 2 reports the characteristics of these four RCP.

TABLE 2. **MAIN CHARACTERISTICS OF THE DIFFERENT RCP USED**

RCP	*Characteristics*
2.6	A peak of 3 W/m^2 is achieved before 2100 and then it decreases to 2.6 W/m^2
4.5	It stabilises without exceeding 4.5 W/m^2 (equivalent to around 650 ppm) in 2100
6.0	It stabilises without exceeding 6.0 W/m^2 (equivalent to around 850 ppm) in 2100
8.5	It reaches 8.5 W/m^2 (equivalent to around 1370 ppm of equivalent CO_2) in 2100, and the levels do not stabilise until 2050

The effects of climate change on rainfall are expressed through the climate change coefficients or factors (Arnbjerg-Nielsen, 2008).

The climate change coefficient, **C_f,** is the quotient between the intensity of rainfall in the return period T and duration t, corresponding to a future climate scenario, ($I(T,t)_{Future}$) and the equivalent rainfall intensity in the present climate ($I(T,t)_{Present}$):

$$c_f = \frac{I(T,t)_{Future}}{I(T,t)_{Present}} \tag{1}$$

These coefficients can be calculated for each return period from the simulated daily precipitation series and those corresponding to the historic control period (present climate).

CLIMATE CHANGE COEFFICIENTS FOR MADRID REGION

In the course of this project, in order to obtain coefficients of climate change for intensities with shorter than daily durations (sub-daily durations, up to one hour), the first step was to analyse the projections of the daily rainfall series, for each of the three stations of the AEMET[9] with the highest data quality in Madrid Region (Madrid Retiro, Madrid-Getafe and Madrid-Torrejón), corresponding to three future climate periods (2006-2036, 2037-2068, 2069-2100), in addition to the Historical control period (1951- 2005), analysing the results for the four seasons of the year (spring, summer, autumn and winter). In this way, a total of 1,530 series were analysed.

[9] The State Meteorology Agency (AEMET) has as its objective the development, implementation, and provision of meteorological services under State competence. It has the status of meteorological authority of the State, as well as the status of aeronautical meteorological authority.

Subsequently, spatial regionalisation techniques (**FICLIMA** statistical Downscaling) and temporal downscaling (using the fractal properties of rain) were applied to these time series, and climatic change factors were calculated for each return period, as a ratio between the sub-daily intensities for future series and those corresponding to the Historical control period (present climate).

In particular, based on the spatial regionalisation technique used and an analysis of extremes of the rainfall series projections, the values of the maximum daily rainfall intensity for the different climate scenarios were obtained in accordance with the return period.

Due to the high uncertainty of the results generated by the GCMs and other hypotheses implicit in the methodology used (statistical adjustments, use of the fractal technique, etc.) and, considering the absence of orographic aspects that explain significant climate changes in the three stations, it was considered appropriate to average out the hourly coefficients of climate change for the three stations analysed, as shown in the figures (3, 4 and 5).

The results were presented for three periods of time (2006- 2036, 2037-2068 and 2068-2100), different return periods and each of the RCP (Representative Concentration Pathways) 2.6, 4.5, 6.0 and 8.5, depending on the expected radiative forcing values.

CONCLUSIONS

Climate change coefficients have been obtained for each station, each time horizon and each RCP scenario, for daily and hourly rainfall.

Due to the high uncertainty of the results generated by the GCMs and other hypotheses implicit in the methodology used (statistical adjustments, use of the fractal technique, etc.) and in the absence of orographic aspects that explain significant climate changes in the three stations, it was considered appropriate to average out the results of the GCMs and the values of the coefficients of climate change, for the three stations analysed.

With respect to the resulting values, the following is observed:

- The RCP 8.5 scenario represents the most critical scenario in terms of radiative forcing.
- Although generally, the RCP 6.0 scenario provides higher climate change coefficient values, it is based on a smaller number of simulations, being statistically less significant with respect to the rest.
- Due to the significant uncertainties associated with the models, the statistical techniques used, and the general circulation models, it is recommended to use, for the hydrological and hydraulic calculations associated with the master plans of Madrid Region, the intermediate value of all the RCP scenarios for the intermediate time horizon and the corresponding design return period.

As figures 3, 4, and 5, show climate change coefficients (CC) are greater than one (1) in all studied scenarios and horizons. Thus, it is expected that hyetograph peaks are greater for the future rainfall events.

Lastly, it is worth noting that this work is one of the first examples at the national and international level of application in the field of urban drainage of the new RCP scenarios proposed in the last report of the Intergovernmental Panel on Climate Change (IPCC).

FIGURE 3. CLIMATE CHANGE COEFICIENTS FOR HORIZON 2006-2036

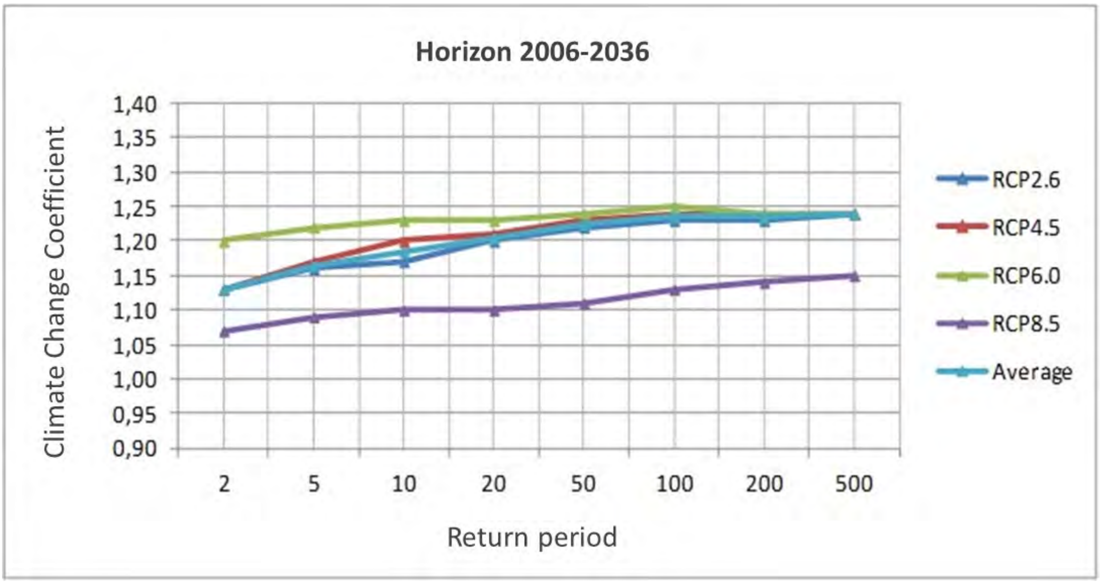


FIGURE 4. CLIMATE CHANGE COEFICIENTS FOR HORIZON 2037-2068, (NON-CUMULATIVE VALUES)

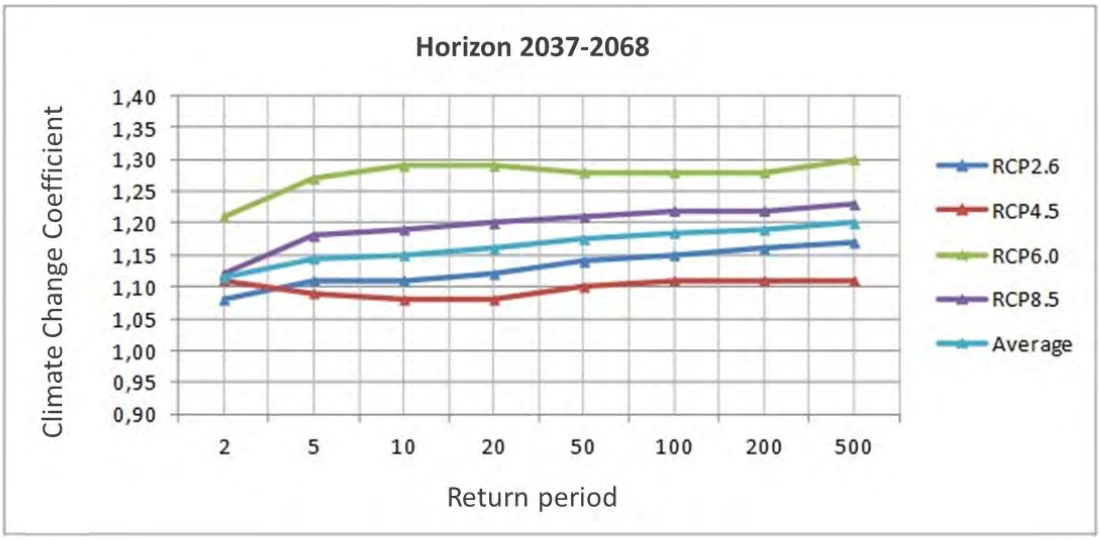


FIGURE 5. CLIMATE CHANGE COEFICIENTS FOR HORIZON 2069-2100, (NON-CUMULATIVE VALUES)

1. Generation and study of local precipitation on meteorological observatories of Madrid Region

1.1. INTRODUCTION TO THE GENERATION AND STUDY OF LOCAL SCENARIOS

This chapter, dedicated to the generation and study of local scenarios, is the basis for the establishment of the climate change coefficients and, therefore, the tool for the construction of IDF[10] curves that consider the influence of climate change.

As part of the fifth report of the Intergovernmental Panel on Climate Change (***IPCC***), the Scientific Community has defined a series of future scenarios of climate change under which global simulations of the different existing climate models, created and developed by institutions around the world, have been generated. These global simulations must undergo a process of regionalisation for their results to be used at a local scale: this is precisely the objective of a "**Downscaling**" technique, which allows the results of future simulations to be applied locally. The Foundation for Climate Research (***FIC***) has developed its own method of regionalisation, called the "***FICLIMA*** Methodology", which has been applied in this notebook, on a group of meteorological observatories selected to produce, from global climate models, future climate change scenarios on precipitation in these observatories.

To be able to guarantee the obtaining of the local future climate scenarios in the best possible way, a set of successive steps in each point has been carried out:

1. **Analysis of the observed available data**. Before using them, the observed meteorological, available data must be studied to determine their validity and, therefore, if they can be fully used or if they need corrective actions or should even be discarded.

2. **Verification of the *FICLIMA* methodology**. The results obtained by this methodology will be verified by simulating the climate of each observatory, in order to determine their capacity to reflect the climate of each local point to study.

3. **Validation of climate models**. It is of great importance to have as many climate models and future scenarios as possible so that a wide enough range of future climate changes can be considered; in this project, researchers have worked with nine climate models. Each model simulates the climate in a different way (colder/warmer, or drier/wetter) so before generating future climate scenarios, the behaviour of each model is evaluated at each point to be studied.

4. **Generation of future climate scenarios at a local scale**. Based on the available scenarios for each model, the results are regionalised into points of interest.

5. **Correction of the systematic error associated with future simulations**. The future scenarios as such show increases in the variable to be studied, but if what it is wanted are the initial and final values that determine those increases, as it is part of the objective of this project, it must be corrected the simulated values to determine their values

These activities are expanded on below.

[10] IDF. An IDF (Intensity-Duration-Frequency) curve is a mathematical relationship, generally empirical, between the intensity of precipitation, its duration and the frequency with which it is observed; they result from joining the representative points of the average intensity in intervals of different duration, all corresponding to the same frequency or return period.

1.2. OBJECTIVES IN THE GENERATION AND STUDY OF LOCAL SCENARIOS

To achieve the objectives set, the analysis of possible future changes in the precipitation regimes of three meteorological observatories of Madrid Region (Getafe, Torrejón, and Madrid Retiro) has been carried out in this work.

For the study of these future changes, nine global climate models, generated by other international research organisations, were used, which provide possible future climate scenarios on a global scale. These possible future scenarios have been established as part of the fifth report of the Intergovernmental Panel on Climate Change and are common to the different simulations of each climate model.

These global representations of climate - these climate models - given their global nature, must undergo a process of regionalisation, in order to use their results on the local points under study, such as the meteorological observatories chosen: this is precisely the objective of the downscaling technique, the application, on a local scale, of the results of future simulations.

This methodology allows the scientists to obtain, in the study points, a wide group of simulations on the future precipitation conditions. But the results obtained by using a climate model are always incremental and not absolute (there is a difference between what a model considers to be the past and the true past); however, its future scenarios are consistent and continuous projections of that past that the climate model itself has simulated, so the possible increases between its past and a certain future should be interpreted as correct, but this is not the case for the exact and absolute values provided by future scenarios.

Therefore, if it is necessary that the data “regionalised” in a point, from a certain climate model can be interpreted in their absolute values and not only in terms of relative increases, the possible errors liable to introduce biases in the regionalisation must be corrected, in order to obtain values that can be studied in their absolute magnitude. This correction is what is called **systematic error correction**.

It is not always necessary to perform this last step; carrying it out or not will depend on the type of study being carried out. In this paper, since extreme values of a certain meteorological variable such as precipitation are being studied, this correction is necessary as the specific absolute values of the precipitation determine the conclusions about its values and its evolution or change (such as the return period of specific, extreme or not, precipitation values).

1.3. FICLIMA, A REGIONALISATION METHODOLOGY

1.3.1. Regionalisation or “Downscaling”

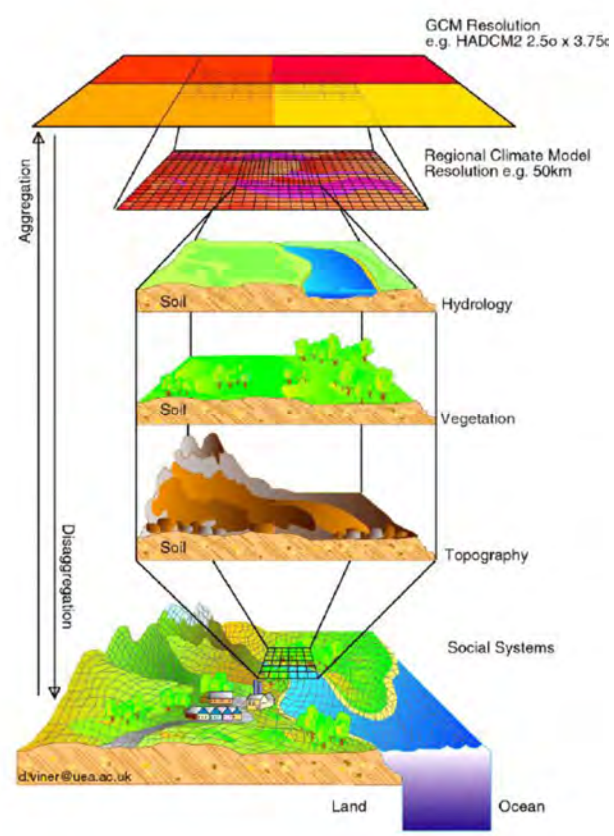
Global climate models show a remarkable ability to reproduce the main characteristics of the general atmospheric circulation; the problem arises when the results are evaluated on a smaller scale (that is, a few points of the work grid are selected) where the variables, especially on the surface, do not approach the values observed in the real world.

These limitations can have several explanations, generally related to the insufficient spatial resolution of the models that, today, is about 2 to 3 degrees of latitude/longitude:

- The topography (mountain ranges, coastlines, etc.) are described in little detail, which means some forcings related to it, of extraordinary importance at the local level, are omitted and, therefore, not taken into account by the model.
- Some of the atmospheric processes that are presented at a scale lower than that of the work grid of the models (which therefore tend not to be reflected by them) are collected through direct parameterisations, that is, they are represented by a direct adjustment of the parameters in the model. These parametrisations are statistically adjusted all over the planet and may be inefficient in specific regions.
- The parameterisation of the energy flow, from the synoptic scales (10^6 km^2), to those of a scale lower than the work grid, affects the reliability of the lower resolved scales.

Given that most impact evaluation studies require the presence of climate scenarios with local resolution of variables close to the earth's surface (temperature at 2 m, precipitation, etc.), the need arises to adapt the information provided by global climate models (of low spatial resolution) to the information required by the impact models (of greater spatial-local surface resolution). This regionalisation process is known as "Downscaling". The process is illustrated in Figure 6.

FIGURE 6. REGIONALISATION OR "DOWNSCALING" MECHANISM



Graphic representation of the regionalisation or Downscaling mechanism, adapting the outputs of global climate models to the physiographic characteristics of the region.

Source: David Viner, Climatic Research Unit, University of East Anglia, UK.

1.3.2. Regionalisation strategies

There are two main ways to deal with the problem of regionalisation; the characteristics of both are summarised in Table 3 and are described below:

a) Statistical approaches ("**Statistical Downscaling**"). With them, empirical relationships are obtained between large scale variables from global climate models and high-resolution variables (surface).

b) Approaches by dynamic modelling ("**Dynamic Downscaling**"). These models increase their resolution in the region of interest. It can be carried out in two ways, either with a zoom technique of the own grid of the model, or by the nesting of a limited area model (**LAM**[11]) in the boundary conditions provided by the climate model. These are the so-called ***Regional Climate Models*** (**RCM**[12]).

Statistical approaches have a much lower computational cost (which allows them to be applied to a multitude of climate models and emission scenarios) but there is an implicit uncertainty as a consequence of accepting the hypothesis that the high-resolution surface effects fields are the exclusive function of the dynamic and thermodynamic conditions on a large scale in the atmosphere, considering the characteristics of the fixed topography. It appears doubtful that in a climate change framework no mesoscale forcing (albedo, soil moisture, atmospheric fields at low resolution, etc.) will change. In addition, the statistical relationships between low-resolution atmospheric fields and surface variables at the local scale are always imperfect, and may turn out to be **non-stationary**, which means that, although these relationships are verified in the current climate, they do not have any reason to do so in a future climate (known as the problem of stationarity).

Dynamic approaches have a stronger physical basis (however, they also use statistical relationships in the parameterisations). Currently, the resolution of **RCMs** is approximately 25 kilometres, which is insufficient to correctly simulate surface variables on a local scale, especially in areas of complex topography. On the other hand, they have the disadvantage of a very high computational cost that is not always possible to bear.

It should be mentioned that there is a third approach, much less used, that integrates the previous two and that is called the **statistical-dynamic approach**.

[11] LAM, Limited Area Model
[12] RCM, Regional Climate Model

TABLE 3. DIFFERENCES BETWEEN STATISTICAL AND DYNAMIC DOWNSCALING

	For	*Against*	*Applications*
Dynamic Downscaling	It simulates climate mechanisms	Very costly, both in terms of IT needs and staff training	Geographic areas with few initial starting data
	It does not make *a priori* assumptions about how the present and future climate are related	The results are sensitive to the initial parameterisations	Studies associated with climatic extremes and non-linear variability, such as health studies
	Permanently updated scientific tools	The potential bias existing in the *GCMs* can be disseminated at a local scale	It relates the results to climate processes
	The continuous advances in computers mean that they are generated more quickly and are cheaper to run	The models' output format may not be useful to other disciplines of scientific analysis, and subsequent data processing is necessary	It allows the inclusion of land use impacts on the results
	It stimulates collaboration between climate scientists and those of other study disciplines		
	For	*Against*	*Applications*
Statistical Downscaling	Very cheap (it works very quickly in personal computers with free software)	It assumes that the relationships between the local climate and the large-scale climate remain constant	Climate averages, and certain variability ranges
	Take advantage of statistical experience among researchers	It does not incorporate climate mechanisms	Regions rich in meteorological data, such as the mid-latitudes of the northern hemisphere
	It can correct GCM biases	It is not adjusted to capture variances or extreme events	It allows consistent comparison between the present and future climate
	It allows climate results to be evaluated on a group of GCMs and on various scenarios		It can perform tests on various predictors
			It allows the measuring of variable scales to specific places

Source: J. A. Patz, D. Campbell-Lendrum, T. Holloway & J. A. Foley, Impact of regional climate change on human health, Nature, 2005. FIC translation (the specific references to health sciences have been generalised to "other disciplines").

1.3.3. *FICLIMA,* a regionalisation methodology

The regionalisation methodology FICLIMA is a “**Statistical Downscaling**” methodology. It therefore requires a prior selection of fields to be used as predictors, and once these are selected, it performs a treatment based on the analogue methodology. In the following paragraphs the foundations of the FICLIMA methodology are described in a certain degree of detail. If you wish to discover more of its content, please refer to Ribalaygua et al. (2013).

In general terms, the methodology is governed by the following scheme: a problem day “**X**” is selected, whose atmospheric fields (geopotentials, temperatures at different pressure levels ...) of low resolution are known (through the outputs of the global climate models for events for day X). From these known fields, what is pursued is to estimate the value of the meteorological variables on the surface (maximum and minimum temperatures, precipitation...) for day X at a specific point in the territory (observatory).

The method works in two steps, outlined in Figure 7.

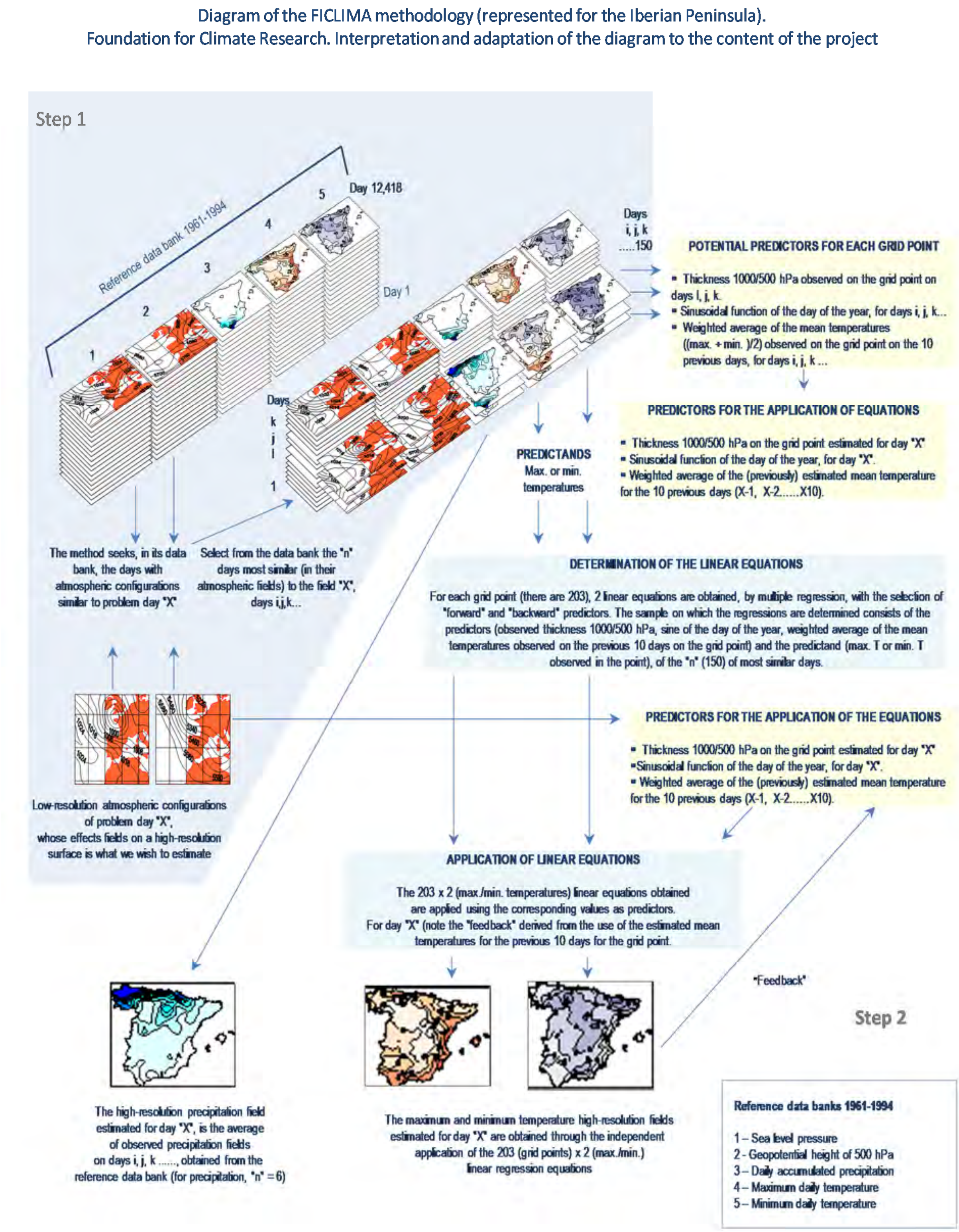
1. **The first step**, called “**analogical stratification**”, consists of selecting from a data bank those ***n*** days with the most similar atmospheric configurations to those of problem day X. The similarity measurement used compares the similarity between the variables used to characterise the atmospheric synoptic situations; these variables determine the synoptic forcing that causes the descents and ascents of air, generators of cloudiness and precipitation. It also seeks to provide information on the direction of surface wind, which allows the effects that the topography exerts on the spatial distribution of cloudiness and precipitation to be studied.

2. **The second step** applies different methods in accordance with the variable to be calculated.

- To estimate the minimum and maximum daily temperatures, a multiple linear regression with automatic selection of predictors is performed for each variable. The work population will consist of the *n* days selected in the previous step. As predictors there are, on the one hand, the values of the atmospheric variables in the vertical of the point for which to estimate the surface temperature is wanted and, on the other, potential predictors. These potential predictors are an indicator of the duration of the night on the day in question (it provides information on the potential of radiative heating/cooling), and a weighted average of the previous days temperatures (the effect of the floor thermal inertia is considered). Once the linear relationship between the selected predictors and the predictand (minimum, maximum temperature or precipitation) has been established, this relationship is applied to the values of the predictors of day X to estimate the value of the predictand on that day.

  The influence, strongly non-linear, that the cloudiness and precipitation exert on the surface temperature has been corrected in the analogical stratification. When selecting the days with the most similar atmospheric configurations, it is guaranteed that the conditions of precipitation and cloudiness are also similar and, therefore, also their influence on the predictand. In this manner, more robust linear relationships are obtained. An example of this is the relationship between the thickness of the low troposphere and the temperature at 2m, which is non-linear in nature. With regard to days with covered skies, the maximum temperature will strongly depend on the thickness; between both variables there will be a fairly linear relationship. However, on days with clear skies, dependence on the maximum temperature with the thickness is lower, depending, mainly, on hours of sunshine and the latter, in turn, on the time of year.

FIGURE 7. GENERAL DIAGRAM OF THE FICLIMA METHODOLOGY (FOR THE PENINSULA IBÉRICA)



- In the case of precipitation, several approaches have been tried. The simplest of all of them, represented in the diagram of Figure 7, contemplates the estimation by simple averaging of the analogue **k** days, most similar, to **X**. In addition to estimating the amount of rainfall, this method allows to obtain the probability of rain or dry weather. In the study of the series obtained it was detected that, although the behaviour of the prediction of average precipitation in a period was acceptable, the number of rainy days was clearly overestimated. This is due, to the fact that rain was being associated every day with a non-zero probability, even if it was very low. To correct this error, a statistical correction was introduced that drives to obtain the number of rainy days in a month from the rainfall probabilities of each of the days of the month. When the number of days of rain and the amount of rainfall is known, it is distributed between the days with the highest probability and expected amount of precipitation. In this manner improvements are obtained not only for the number of rainy days, but also for extreme rains and periods of drought.

1.3.4. Advantages of the methodology FICLIMA

Although some of the intrinsic weaknesses of the "**Statistical Downscaling**" method are insurmountable due to its very nature (dependence on a set of meteorological observatories with reliable data covering a long period of time), the need for successive tests of adaptation of the methodology to determine the fields that best record climate variability in the study area), the ***FICLIMA*** methodology has some advantages over other statistical methodologies:

1. The problem of stationarity will be minimised thanks to the predictor selection criteria, based on theoretical considerations that reflect the physical relationships between predictors and predictands, physical relationships that must not change over time.

2. When the ***analogue selection*** method is used, and since the final simulation will be based on the most analogous days, the value assigned to the meteorological variable studied will be limited by the observed value that it has in those analogous days, that is, its margin of variability will be given by the variability of the past itself (it would never be calculated higher or lower values). However, the second step introduced in the ***FICLIMA*** methodology allows to overcome this limitation: the daily linear relationships established for temperature and the redistribution of precipitation based on the distribution function allow to simulate values that may exceed the limitation of the initial values observed.

3. It considers absolutely all the available data: as there is no reduction in the dimensionality of the data supplied (using statistical techniques such as the main components), all the data are considered and, therefore, there is no loss of the information provided (the observations and atmospheric fields) or their variability.

1.4. ANALYSIS OF HISTORIC DATA

In every regionalisation process through which the aim is to generate future climate scenarios, it is necessary to have various data sources:

1. Series of meteorological data observed daily, with at least 2,000 daily data available (a minimum number of observatory data that allows to categorise its climate), in the largest possible number of observatories located within the study region.
2. A data bank consisting of low-resolution fields (atmospheric fields) of a reanalysis. In this study the ERA40 reanalysis will be used.
3. A data bank consisting of low-resolution fields (atmospheric fields) of a set of climate models. In this study, nine climate models were used that are explained below.

The reanalysis data are meteorological data that describe the state of the atmosphere in a regular mesh, from different points at different heights, and covering the entire earth in a past historical period. Given that the use of global climate models requires a group of reference data, the use of the reanalysis data is absolutely necessary, both so that their results can be compared, and to establish the initial operating conditions of the models. Among the existing reanalysis data, the researchers have chosen the European reanalysis ***ERA40*** for this project.

Both reanalysis and climate models can present certain problems when working with them (such as a lack of information, incomplete fields, etc.), but they are known problems if they have been worked with before. But the observed data from meteorological observatories can also present problems (such as periods of time without any type of data, outliers[13], false data, poor data length, etc.). Therefore, before beginning to apply the regionalisation methodology, it is necessary to carry out an exhaustive study of the quality of the available data and discard all those observatories that do not meet minimum requirements that guarantee the optimal functioning of the **downscaling** methodology.

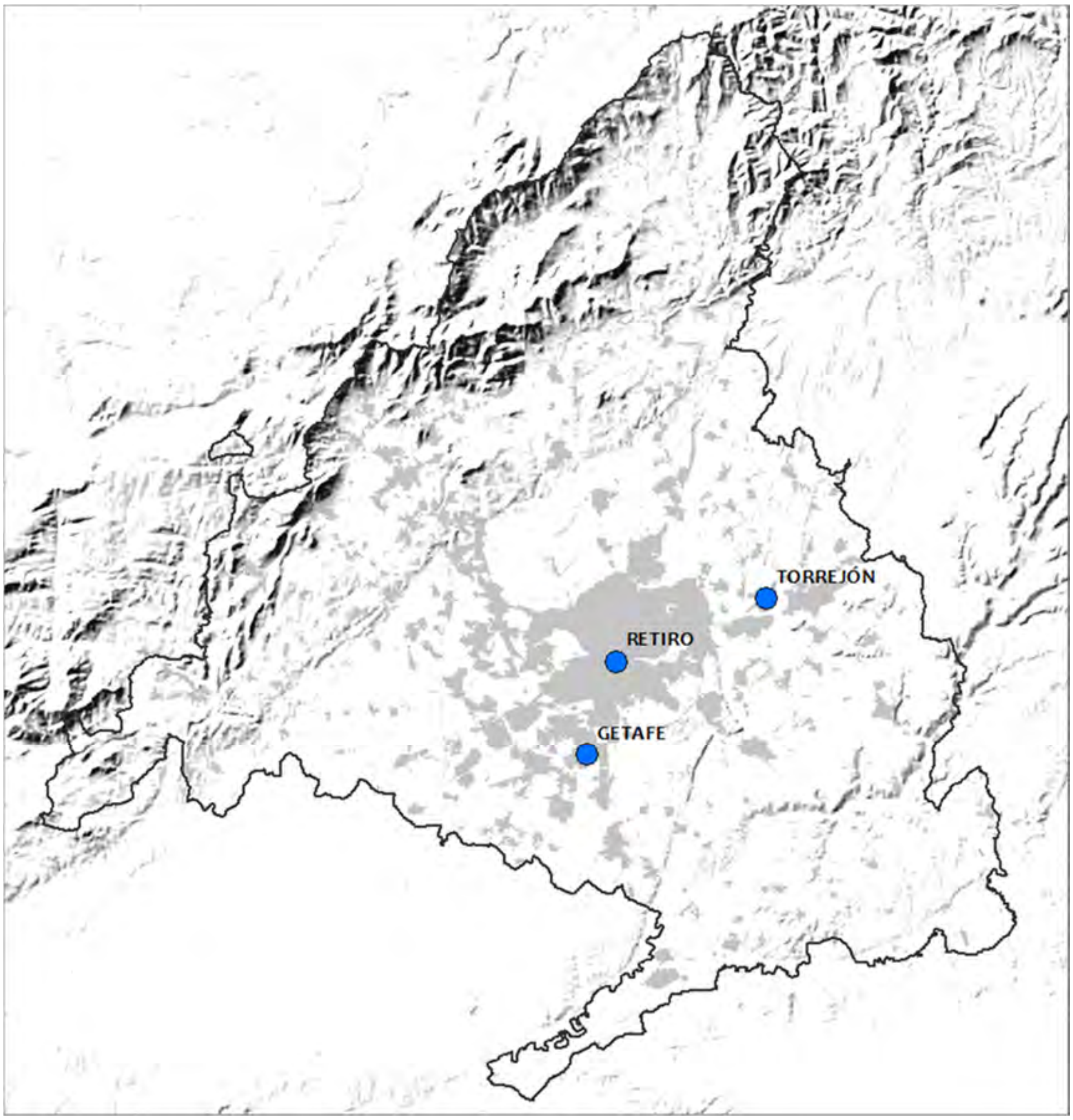
This section summarises the results obtained after studying the data, received from daily meteorological observations, necessary to carry out the climate change study in the defined points of Madrid Region.

1.4.1. Data supplied

The observed data provided belong to three observatories of the State Meteorological Agency (**AEMET**) located in Madrid Region (see Figure 8). For each one of them, the daily precipitation of a sufficient number of years has been provided to be used in this study.

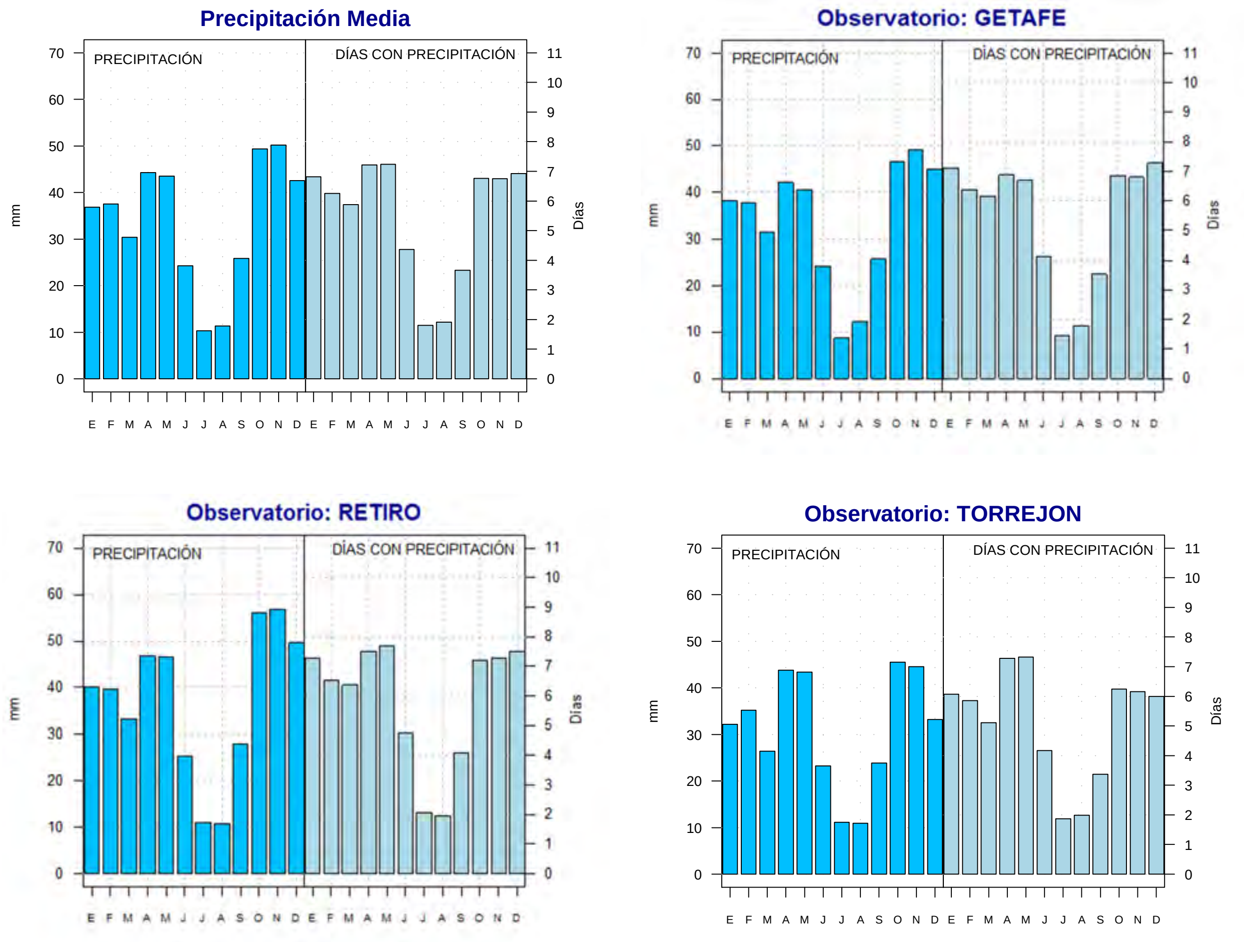
[13] Outlier: in statistics an outlier is an observation that is numerically distant from the other data.

FIGURE 8. **LOCATION OF THE THREE METEOROLOGICAL OBSERVATORIES SUPPLIED**



In Figure 9, four climographs are represented; the first one relates to the average monthly accumulated precipitation and the average monthly number of days with precipitation of the average of the three observatories. It can be observed that the observatories are characterised by having dry summers (June, July, August) and by distributing most of the precipitation over the rest of the seasons, with October and November being the months with the most precipitation. The three climographs refer to each of the observatories studied separately. As can be seen and given that the three belong to the same geographic and orographic area, their climographs are similar to each other, and are similar to the average climographs (dry summers and, on the other hand, October and November as months with the highest precipitation).

FIGURE 9. AVERAGE PRECIPITATION CLIMOGRAPH FROM THREE OBSERVATORIOS METEOROLOGICAL OBSERVATORIES



1.4.2. Quality Control

The quality control of a meteorological series of observed data consists in developing a set of tests on it that guarantees that the data are coherent within the study series itself.

It is important to emphasise that these tests must be designed in such a way that they are capable of presenting different results for different series, since each series includes the local climatology of the place observed and, therefore, although the theoretical criteria of the tests must be the same for all observatories, the validity ranges should be dependent on the observatories. If, for example, it were based on the study of the average of a series (a possible theoretical criterion), that a maximum daily temperature was 40ºC, it would cause different decisions, if this piece of data belonged to a 35ºC average series (in which it would be a more than acceptable value), or if this piece of data belonged to a 20ºC average series (in which it would be a value to indicate). Note also, and thanks to the previous example, that indicating a possible value does not necessarily imply its rejection, only the need to study this value more carefully to determine its meaning.

The two automatic main controls to be used in a quality control are the following:

1. **Basic coherence**. Direct rejection of manifestly erroneous values, such as negative precipitation.

   In the case of precipitation, basic coherence has addressed the search for negative daily values. In the specific case of the observatories supplied for this project, no case of this type has been detected.

2. **Outliers**. Unusually atypical values within a given set of data; that is, values that seem to come from different data sources, or that have been generated in a different way from the rest of the data. In this case, the theoretical difficulty of its detection will come from the definition that it is given to "atypical". In practice, detection generally refers to values of unusually high absolute magnitude.

   As it was said before, the problem of the detection of an atypical piece of data lies precisely in the theoretical definition of "atypical". From a theoretical point of view, the way to tell if a piece of data is atypical is to evaluate how far it is removed from the typical values of the series of the work: the formal way to perform such a test is to determine how many times a certain piece of data departs from the standard deviation of the total observed series in question.

   Therefore, what the tests will have to determine will be:

   - The standard deviation of each observatory.

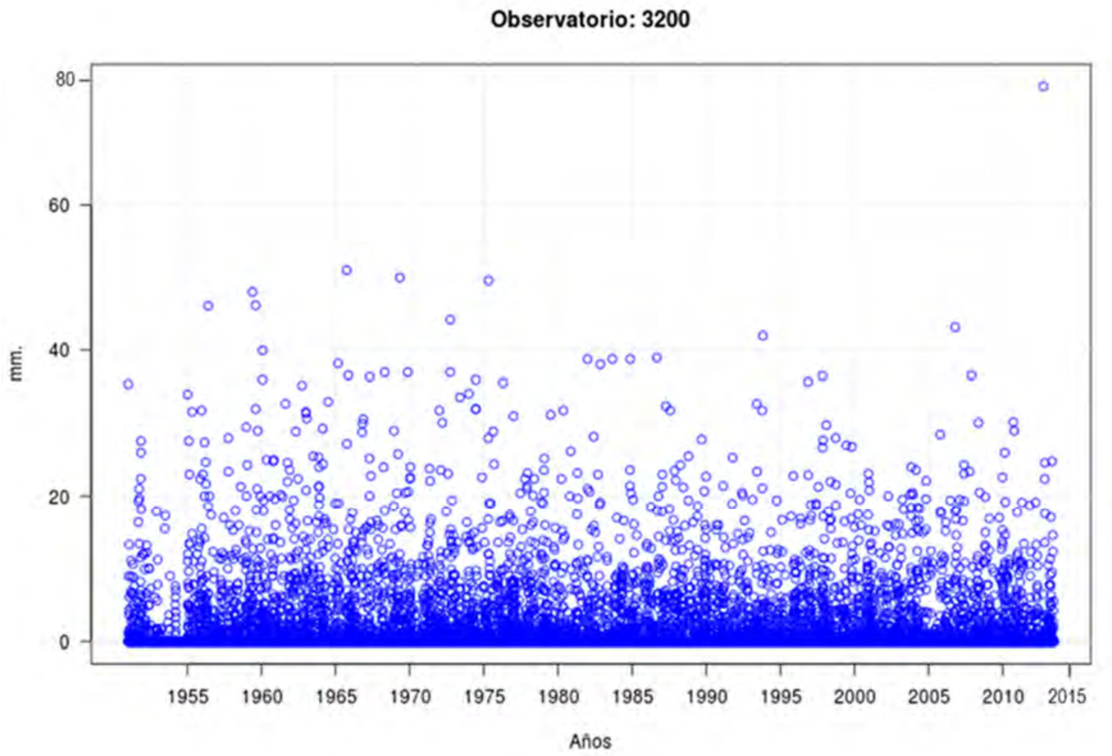
   - A threshold value of the number of units of standard deviation above which a certain daily value can be indicated as atypical.

   - A direct study of the data indicated as **outliers** by the previous step, to determine if they are true, and therefore should be discarded, or if a new threshold value should be reassigned and the study repeated.

   In the case of precipitation, an anomalous piece of data is detected by this data exceeding the standard deviation of the entire series a predetermined number of times. However, given the nature of this meteorological variable, its detection does not involve its elimination, in a way as defined as in temperature, since extreme precipitation is a phenomenon that, although unusual, does not have to be impossible, and therefore, it needs a careful examination that contrasts with the climatological values of the area. An obvious example would be the recording of daily precipitation in the passage of a hurricane (in areas where they occur), which will make these extreme values, even if true, may seem anomalous.

   The only situation that has presented a value that can be classified as being anomalous can be seen in Figure 10 and corresponds to a single value from the Getafe observatory (observatory identifier number 3200), that pertaining to 28/09/2012. This single value, in spite of being an unusually high value, cannot be marked it as erroneous, since it can enter within the margins of variability of this observatory, and as such this value has not been marked as erroneous.

FIGURE 10. **DAILY PRECIPITATION OBSERVED FROM OBSERVATORY 3200 (GETAFE YEAR 2012)**



1.4.3. Homogenisation

The homogenisation of the data of a time series refers to the quality control of the data, as elements of a time series, that is, it studies the possible coherence of the data exactly in the order in which they are presented. Note that the previous controls could be performed on the same series in a disorderly manner; however, they do not inform about the possible temporal variability of the data. This is something that is almost always linked, at least, to annual cycles.

It should be noted that the homogenisation process of a series can also be presented as part of the general process of quality control of the data of a series; if it is presented here as a separate point it is to highlight the importance of such a process and its results.

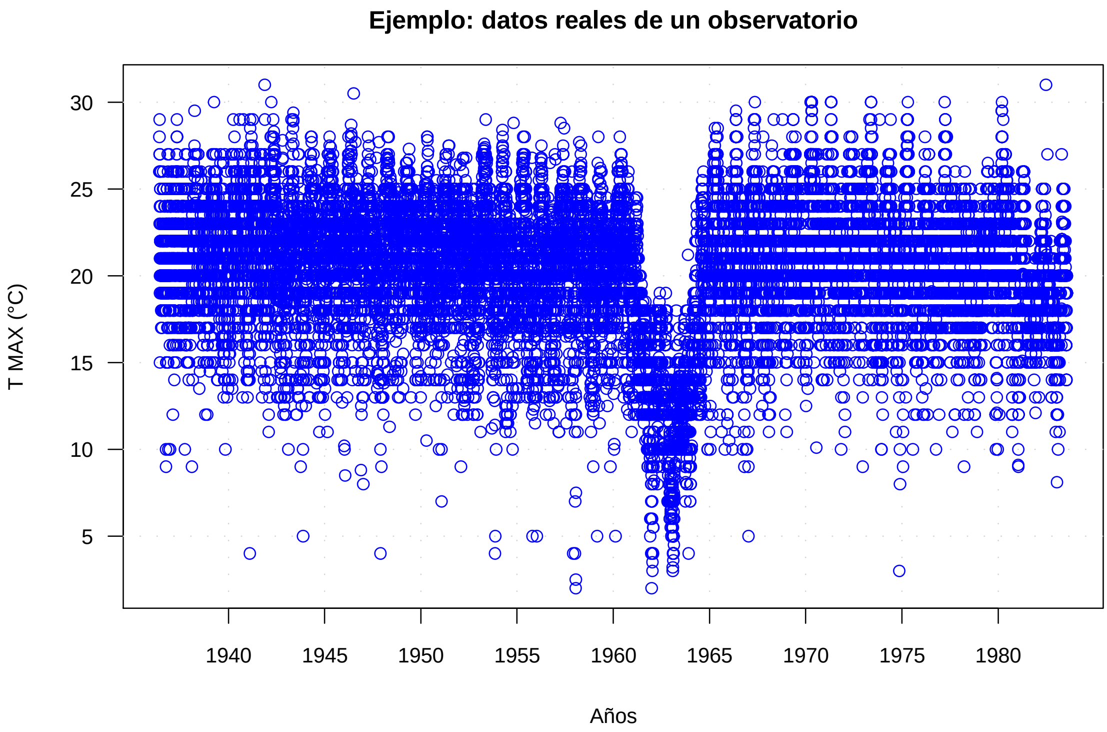
Homogenisation, theoretical basis

The theoretical basis of the homogenisation test used in this study is summarised below.

Figure 11 shows the real data of maximum daily temperature of a meteorological observatory that, although real, were not used in this project. It will only be taken as an example of the type of problem to be detected by the homogeneity tests.

It can clearly be seen that between 1961 and 1964 this observatory exhibited irregular behaviour, understanding as “irregular”, if it is compared with its previous and subsequent behaviour in time, but not by itself, since the values presented do not seem irrational in isolation. This is why this real example is illustrative of what the inhomogeneity detection tests can reveal, in the form of temporary fragments of the series that do not seem to fit the rest of the series and, in fact, the series provided as an example was found precisely thanks to these tests. The difficulty of formally implementing an inhomogeneity test will come through the definition researchers give to the similarity between a section of these series and the rest of it.

FIGURE 11. DAILY OBSERVED MAXIMUM TEMPERATURE SERIES CORRESPONDING TO A REAL OBSERVATORY USED AS AN EXAMPLE



The way of operating the homogeneity test used is described below:

1. To observe how similar one year is to another, a **Kolmogorov-Smirnov distribution comparison test** was used, a non-parametric statistical test (which does not presuppose distributions of the variable to be studied), therefore, it provides a **p**-value that can be used as a measure of the similarity between two years. Studying the logarithm of this **p**-value determines that values close to 0 indicate that two years have a similar distribution of values to each other, so it can be concluded that there is no inhomogeneity between them and, at a lower value, there is more probability of inhomogeneity between two consecutive values. Note that this first part only points out similarities between consecutive years and it is no more than a prior mark on the possibility of existence of inhomogeneity.

2. If a certain year has been marked as a possible indicator of inhomogeneity, then it will be subjected to a more generic test. Once the cut year is marked and the next one is known with a different distribution, and assuming that they mark different periods, the p-value of each of the years of the whole series with respect to those two years is determined. If there is a jump, or a break, between all those p-values, in the years considered, then it is considered that there is a **true** inhomogeneity for the whole series.

This way of working allows to indicate in which years a certain inhomogeneity appears in a series. Given that establishing how small a p-value is in order to indicate possible inhomogeneity is a matter of criterion, the same test has been launched several times, with different p-cut-off values (from very negative, to closer to 0) to eliminate the subjectivity of the opinion, since inhomogeneity, if true, should appear in most of the test executions.

Final situation

Once the criteria of homogeneity on the possible meteorological values of these series have been established, a consistent work is carried out in the following steps:

a) Execute the homogeneity tests several times, with different criteria (varying the rigour with which a period is declared to be inhomogeneous) until there is a list of possible observatories with possible cut-off years that indicate inhomogeneity in the majority of the executions.

b) The series thus marked are inspected manually and the action to be taken is decided on: elimination of the whole series, correction (marking certain sections as erroneous), or marking the series as of average reliability (but without intervention on it).

c) If the series has been corrected, the inhomogeneity tests are re-launched to verify that it has disappeared, once the correction has been made.

Table 4 shows the observatories that presented inhomogeneity, according to the automatic tests and actions executed.

TABLE 4. ACTIONS TAKEN FOR EACH METEOROLOGICAL OBSERVATORY. THE ACTIONS WERE TAKEN AFTER EXECUTING THE HOMOGENEITY TESTS

Precipitation	
ID	*Action*
3200 (GETAFE)	Deletion of all data before 1955

Figure 10 above shows the graph representation of the daily precipitation data of the only observatory on which an action has been carried out, the 3200 observatory (Getafe). The homogeneity test marked an inhomogeneity in 1955 (even a mere visual inspection of the figure seems to suggest that the data prior to that year show anomalous behaviour) so they were eliminated from the series before it was used in the study.

1.5. VERIFICATION OF THE RESULTS

Before beginning the generation of future climate scenarios, it is necessary to verify the accuracy of the methodology when simulating the present climate in the observatories to be studied, the process is called **verification**. For this purpose, fields supplied for a reanalysis are used as predictors, and the precipitation itself to be simulated in the observatories are used as predictands.

The verification process consists in the comparison of the observed data (from the different meteorological stations), with the simulated data obtained through the application of the downscaling methodology (FICLIMA) on the reanalysis (in this study, ERA40). By comparing the two sets of data, observed and simulated, it can be evaluated whether the methodology is able to correctly simulate the current climate (and that of the recent past), or otherwise it tends to simulate a cooler/warmer and wet/dry climate. The resulting information is very important and has to be taken into account when working with future climate scenarios.

Thus, the methodology will be applied to the European reanalysis **ERA40** of the **ECMWF** (European Center for Medium-Range Weather Forecasts) for the period 1958-2000.

The ERA40 reanalysis provides “observations” of the predictors and covers with a grid of 1,125 x 1,125 the entire land surface, with six-hour resolution (4 pieces of data per day). However, this information of *relatively high resolution* (spatial and temporal), should be relaxed to that of the General Circulation Models (GCM) that will be used at a later stage (grids of 2 to 3 degrees of resolution, and in general, with a single piece of data per day), since this verification is intended to evaluate the error of the downscaling methodology applied in the same conditions that will be applied later to the GCMs. This is important, since some downscaling methodologies, and that of FIC among them, improve their regionalisation capacity when the spatial and temporal resolution of the input information (the predictors) is greater. Therefore, if the spatial and temporal resolution of the ERA40 is not relaxed to that of the GCMs that will be regionalised, verification errors obtained would be lower than what should, actually, be considered (and corrected).

The first thing to do is to obtain the values of the predictors, based on the information provided by the ERA40. The next step is to obtain situations that are synoptically analogous to those that occurred during the common period between observations and reanalysis, in this case 1958-2000. This part of the process has a high computational cost, since for each day of the verification period (1958-2000), the most similar situations of the reference period (1958-2000) are determined, except for the 5 previous days, the 5 following days and the problem day itself to avoid the phenomenon known as **overfitting**.

Once the situations analogous to a certain problem day X have been determined, the simulated value of precipitation and temperature for that day X is obtained. Carrying out this process for each of the days of the verification period, a simulated series is obtained by ERA40 regionalisation for each one of the observatories.

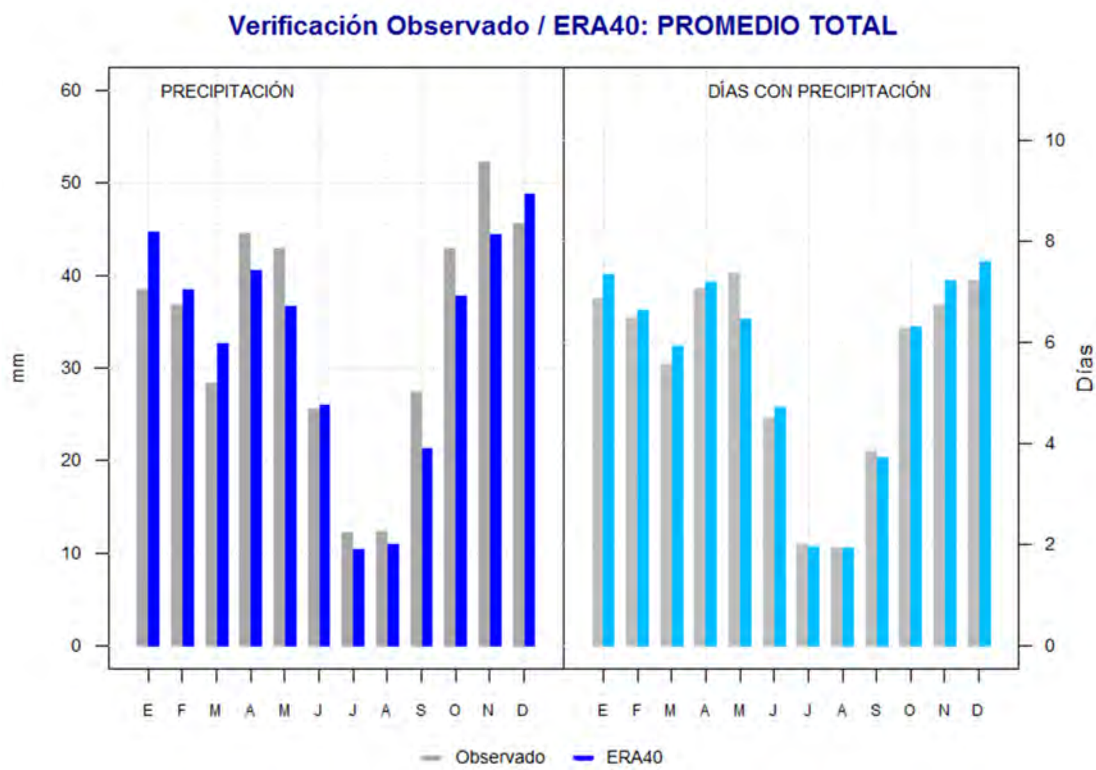
It is important to highlight that it is not necessary for there to be observations of the predictands of all the days of the verification period (which very rarely happens), since in the series simulated by regionalisation of ERA40 each day corresponds to a real date. Therefore, the comparisons between the observations and the series simulated by regionalisation of the ERA40 are carried out day by day (with the days of observation). This aspect is essential since, if a regionalisation methodology is able to reproduce the day by day observations, this suggests that the physical relationships between predictors and predictands are being captured, and therefore the problem of stationarity, the main disadvantage of the statistical methodologies, is reduced.

Figure 12 shows the average monthly accumulated precipitation, and the average monthly number of days with precipitation, both of the observations provided and of the simulations performed with the downscaling process on the ERA40 reanalysis, for the common data period 1958-2000, and where that which is represented is the average of the three observatories (it should be remembered that the three observatories have a similar climate).

Figure 12 shows that the methodology used reflects very well the annual variation of precipitation (its annual cycle): low rainfall in the summer months, a strong increase in the autumn months (autumn: September, October, and November), high precipitation in winter (winter: December, January, and February), and a recovery in spring (spring: March, April, and May). It is extremely important that the methodology records the annual cycle because it guarantees that the **predictor/predictand** relationships established by the methodology include the climate variability of the points to be studied.

On the negative side, the extremes of the months of October and November are not properly recorded, a situation caused by the fact that the rainfall in those months is especially determined by convective phenomena (types of weather related to the vertical movement of the masses of air, such as storms), phenomena of a small or medium size, that are not able to be completely recorded by the models since their large grid sizes do not allow to correctly specify those phenomena. Note also the high degree of precision shown in the graph of days with precipitation, which says that the methodology is very good at determining if at a certain point, and for a certain day, it will rain or not.

FIGURE 12. RESULTS OF THE VERIFICATION FOR THE AVERAGE OF ALL OBSERVATORIES

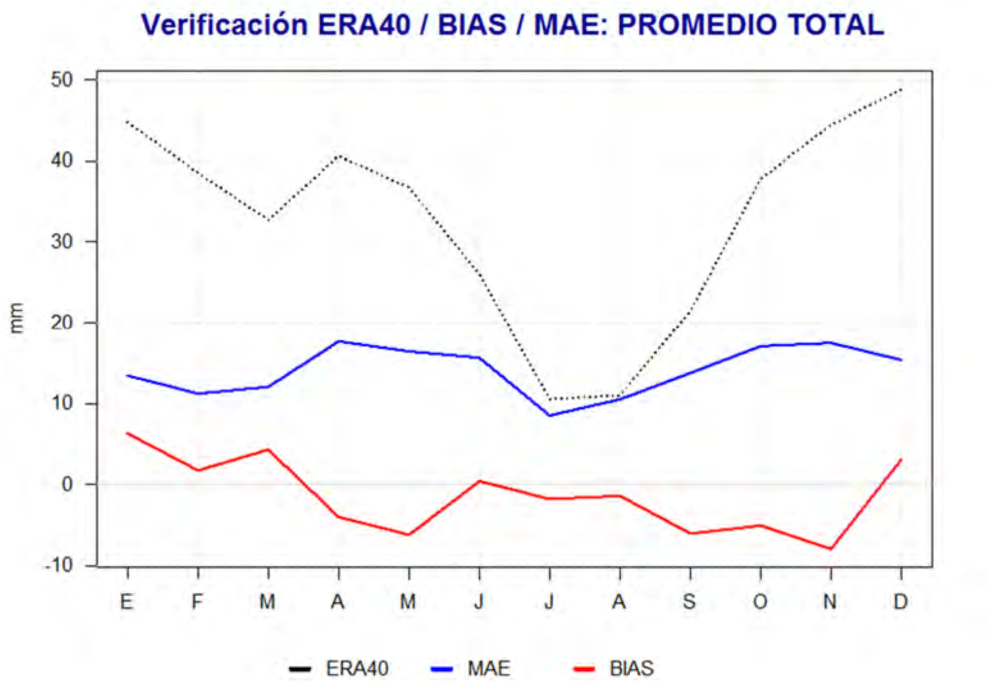


Monthly mean of accumulated precipitation (left) and of the days with precipitation (right), for the observed data (grey) and the regionalised data of the ERA40 *reanalysis (blue). Common period 1958 – 2000*

Figure 13 shows in detail two statistics obtained by comparing the observed and simulated series. That the BIAS (the average of the differences) oscillates around **0** expresses that, in general, the methodology does not introduce any bias in the simulations carried out (at least not in climate terms). Note that the greater bias introduced corresponds to October and November, as could be expected, as reflected in the previous figure and due to the predominantly convective nature of the rainfall.

Note that the MAE (the average of the absolute value of the differences) shows that the range of variability of the simulation is not able to adjust exactly to the range of variability of the observation, a phenomenon common to the processes of statistical downscaling. In the specific case of these observatories studied, the high MAE corresponding to the summer indicates that the results that are going to be obtained for that season of the year must be treated with extreme caution.

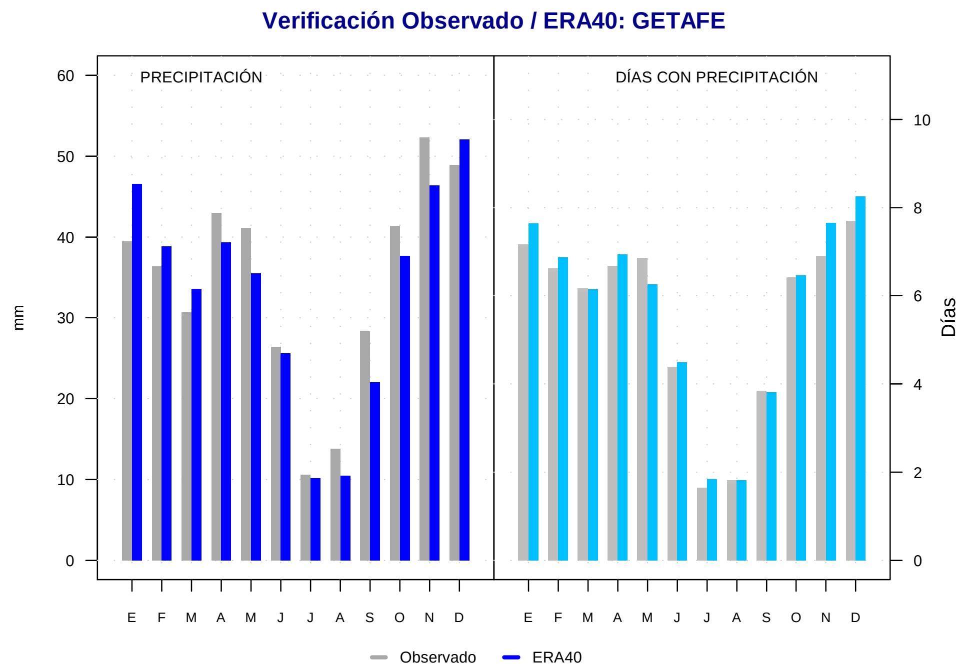
FIGURE 13. **RESULTS OF THE VERIFICATION PROCESS FOR THE AVERAGE OF ALL THE OBSERVATORIES**



Monthly average accumulated precipitation simulated by ERA40 (broken black line), BIAS (red line) and MAE (blue), monthly average of the simulated data, against the observed data. Common period 1958 – 2000

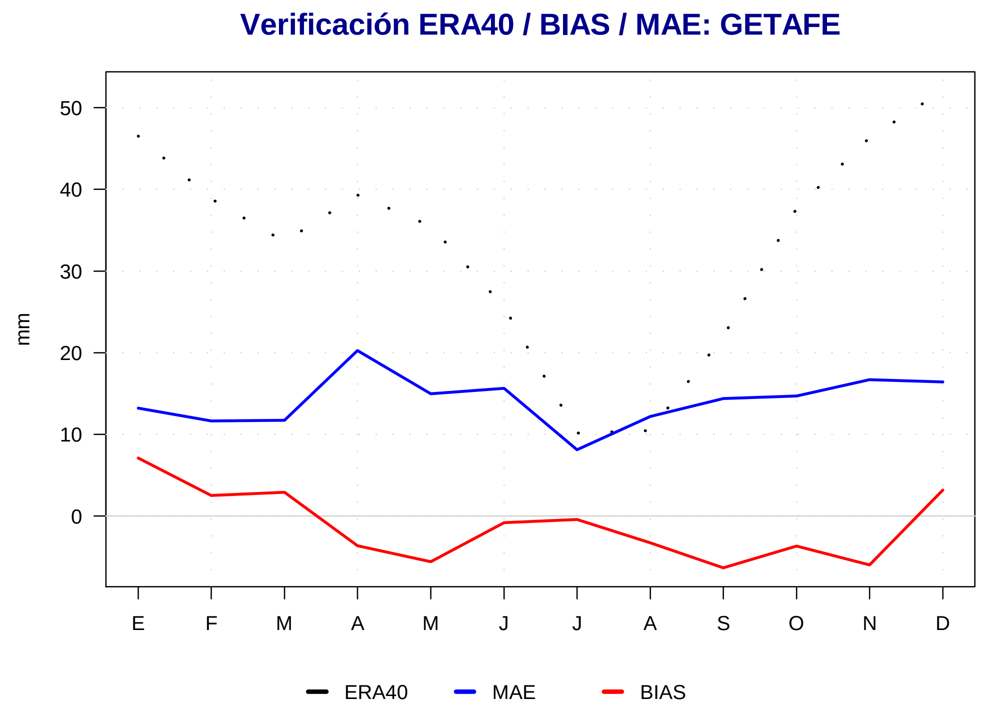
The following figures (14 to 19) show the results of the verification, for each of the observatories studied.

FIGURE 14. **RESULTS OF THE VERIFICATION PROCESS FOR THE GETAFE OBSERVATORY. OBSERVED DATA/CALCULATED DATA**



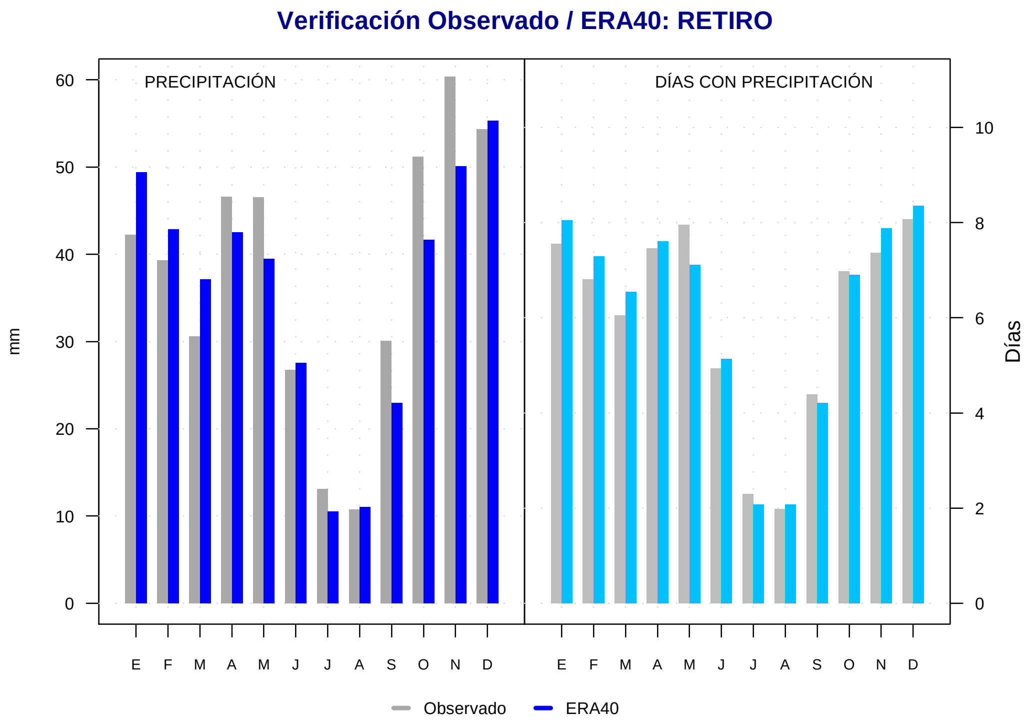
Monthly average accumulated precipitation (left), and of the days with precipitation (right), for the observed data (grey) and the regionalised ERA40 reanalysis data (blue). Common period 1958 – 2000

FIGURE 15. **RESULTS OF THE VERIFICATION PROCESS FOR THE GETAFE OBSERVATORY**



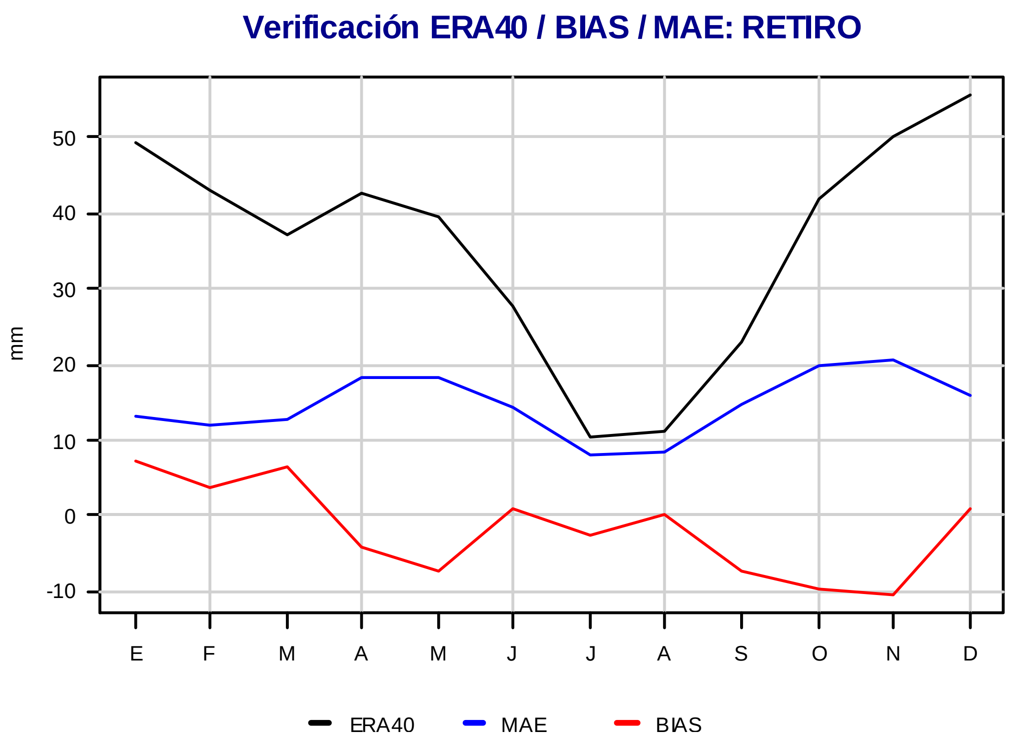
Monthly average accumulated precipitation simulated by ERA40 (broken black line), BIAS (red line) and MAE (blue), monthly average of the simulated data versus the observed data. Common period 1958 – 2000

FIGURE 16. **RESULTS OF THE VERIFICATION PROCESS FOR THE RETIRO OBSERVATORY. OBSERVED DATA/CALCULATED DATA**



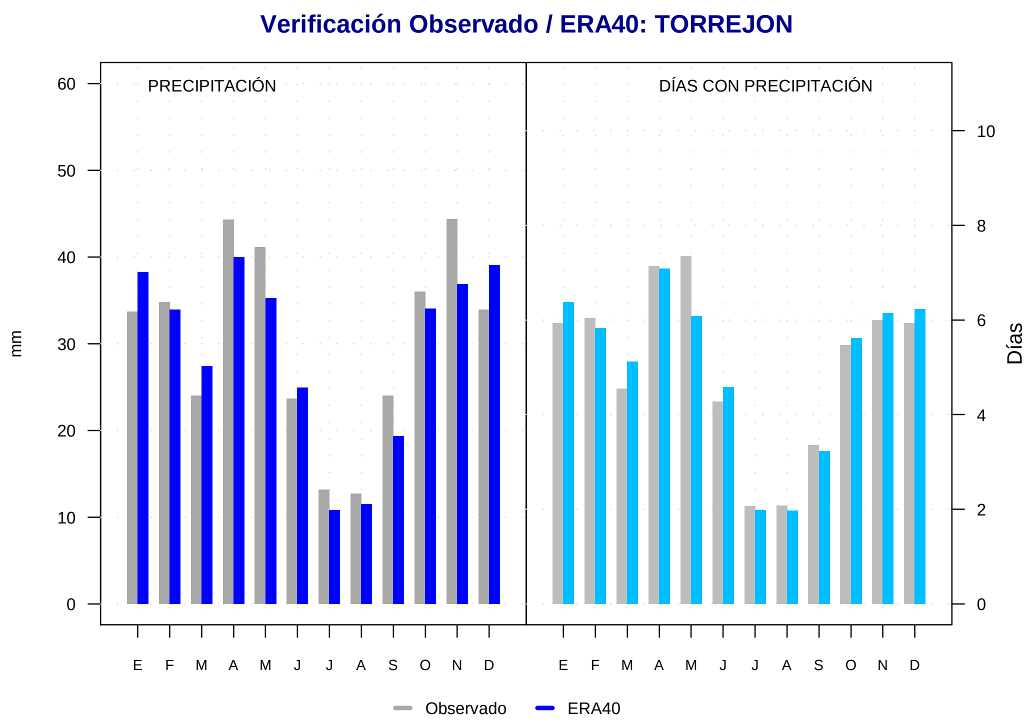
Monthly average accumulated precipitation (left), and of the days with precipitation (right), for the observed data (grey) and the regionalised ERA40 reanalysis data (blue). Common period 1958 – 2000

FIGURE 17. **RESULTS OF THE VERIFICATION PROCESS FOR THE RETIRO OBSERVATORY**



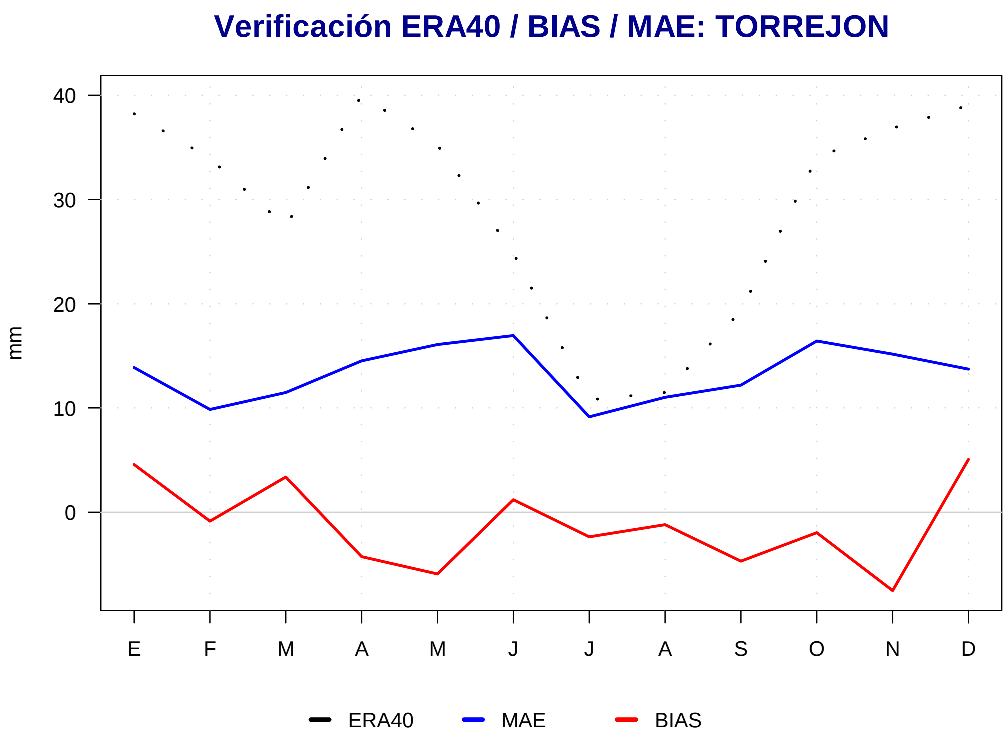
Monthly average accumulated precipitation simulated by ERA40 (broken black line), BIAS (red line) and MAE (blue), monthly average of the simulated data against the observed data. Common period 1958 – 2000

FIGURE 18. **RESULTS OF THE VERIFICATION PROCESS FOR THE TORREJÓN OBSERVATORY. OBSERVED DATA/CALCULATED DATA**



Monthly average accumulated precipitation (left), and of the days with precipitation (right), for the observed data (grey) and the regionalised ERA40 reanalysis data (blue). Common period 1958 – 2000

FIGURE 19. **RESULTS OF THE VERIFICATION PROCESS FOR THE TORREJÓN OBSERVATORY**



Monthly average accumulated precipitation simulated by ERA40 *(broken black line), BIAS (red line) and MAE (blue), monthly average of the simulated data against the observed data. Common period 1958 – 2000*

The conclusions for each one of these are similar to those presented for the average of all of them: the methodology employed reflects very well the annual variation of precipitation (low precipitation in the summer months, a strong increase in the autumn months, high precipitation in winter, and recovery in spring); the extremes of October and November (due to convective phenomena), precision in the graph of days with precipitation, BIAS oscillating around 0, and high MAE in summer are not adequately recorded.

1.6. VALIDATION OF THE CLIMATE MODELS

The statistical regionalisation methodologies generate future climate scenarios at local scale, from the outputs provided by the different climate models and emission scenarios available, so that the atmospheric field data provided by the models (predictor fields) will be the inputs of these processes, while the series of the variable to be simulated at the local scale (in this case, temperature and precipitation) will be the outputs of the statistical regionalisation methodologies.

Each climate model has characteristics, both spatial and temporal, of their own, as well as an internal functioning of each model (parametrisations, resolution of atmospheric equations, etc.) that will determine the way in which each model simulates the climate of a certain region. Table 5 summarises the spatial and temporal characteristics of each of the climate models used in this study.

TABLE 5. GENERAL CHARACTERISTICS OF THE CLIMATE MODELS USED

Climate Model	*Spatial resolution degrees*	*Temporal resolution*	*Calendar days/year*	*Research centre*
MPI- ESM- MR	1.8 x 1.8	daily	Gregorian	Max Planck Institute for Meteorology (MPI-M), Germany
GFDL-ESM2M	2 x 2.5	daily	365	National Oceanic and Atmospheric Administration (NOAA), E.E.U.U.
CanESM2	2.8 x 2.8	daily	365	Canadian Centre for Climate Modelling and Analysis (CC-CMA), Canada
CNRM-CM5	1.4 x 1.4	daily	Gregorian	CNRM (Centre National de Recherches Meteorologiques), Meteo-France, France
BCC-CSM1-1	2.8 x 2.8	daily	365	Beijing Climate Center (BCC), China Meteorological Administration, China
HADGEM2-CC	1.25 x 1.8	daily	360	Met Office Hadley Centre, UK
MIROC- ESM- CHEM	2.8 x 2.8	daily	Gregorian	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan
NorESM1-M	1.8 x 2.5	daily	365	Norwegian Climate Centre, Norway
MRI-CGCM3	1.2 x 1.2	daily	Gregoriano	MRI - Meteorological Research Institute, Tsukuba, Japan

It should be mentioned that the WCRP (World Climate Research Programme) should be thanked for the availability of climate model data; it is a programme of the World Meteorological Organization that is responsible for the Coupled Model Intercomparison Project 5 (CMIP5) initiative, and the development of the infrastructure necessary for its storage and downloading (hardware and software) is down to the US Department of Energy. Each of the working groups of the models employed should be thanked for the work carried out in their modelling and in execution.

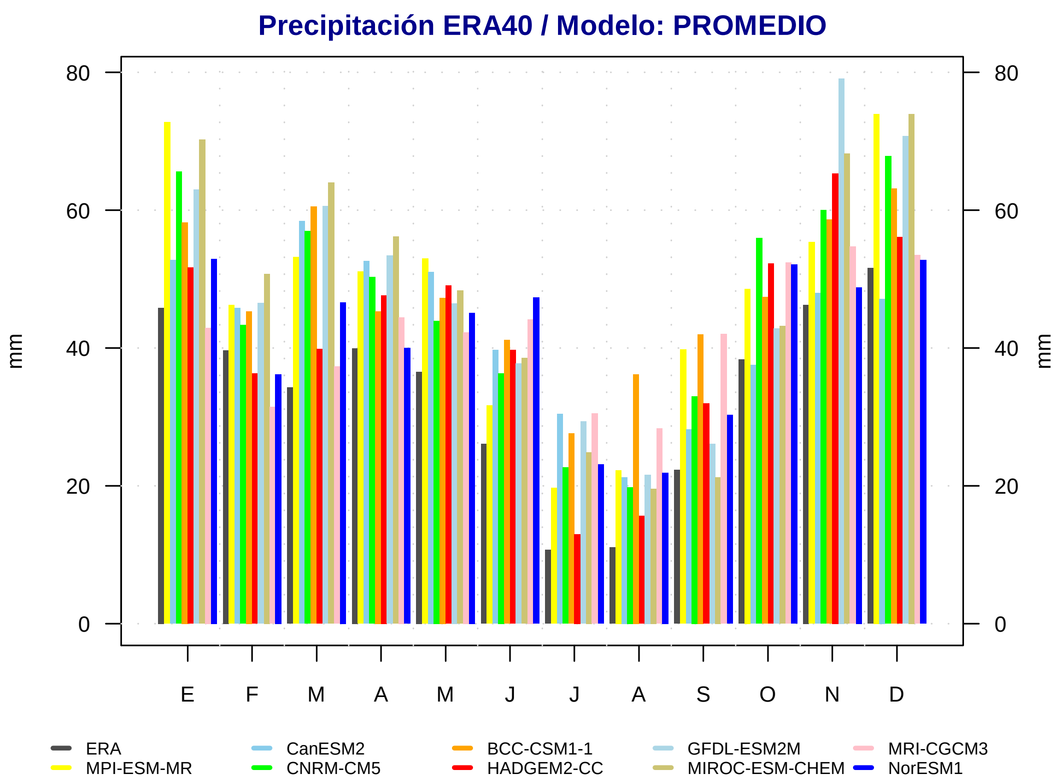
In general, climate models tend to simulate a present climate that is warmer/colder or wetter/drier than it is, in real life, and the magnitude with which they move away from reality varies depending on the specific region in which they are working since the simulation of the models is carried out on a global scale. Since each model works differently in climate simulation, the need to evaluate the behaviour of all the models in the specific study area arises, in order to determine the precision of the model simulating the present climate of the region, and if its use is adequate and, if not, it should not be worked with.

The process whereby the behaviour of a climate model is evaluated is what is known as **validation**. This process consists of comparing the simulated series obtained through regionalisation of the reanalysis (ERA40 in this case), with the simulated series obtained by regionalising the **Historical** scenario of each model (its control simulation) for a common period, in this case 1958-2000.

Historical corresponds to the execution of a specific experiment related to data from the past and is not, therefore, a future scenario of climate change. Its mission is to provide an experiment that shows if the climate model to be used is capable of reflecting natural climate variability, and that is why it covers a period of the past, between 1951 and 2005, (however, some models make this period start further back). Figure 20 shows the accumulated average monthly precipitation of the Historical period, of each of the nine models used, as well as that determined by the ERA40 reanalysis; the statistics were calculated for the 1958-2000 period (the common period of the data shown) and show the average of the three observatories used in this project (it should be remembered that the three observatories have a similar climate).

Note that the models used do include climatic variability in the annual precipitation cycle, which *indicates* that they are well constructed, in the sense that they are capable of establishing the specific characteristics of the region. What they fail to do is to correctly reproduce the amounts of precipitation associated with the cycle (in general, they tend to overestimate them). Their correct reproduction of precipitation is precisely the characteristic that makes trust in their capacity to correctly reproduce the climate of the local points to study; if they do not do it with the quantities, this is what makes, when talking about the data obtained for future scenarios of a certain model, always emphasise that the increases with respect to the past (a Historical) should be analysed in a relative and not absolute manner, and that the study of the absolute increases requires a correction of the systematic error (of the absolute difference between simulated by the reanalysis and simulated by the model).

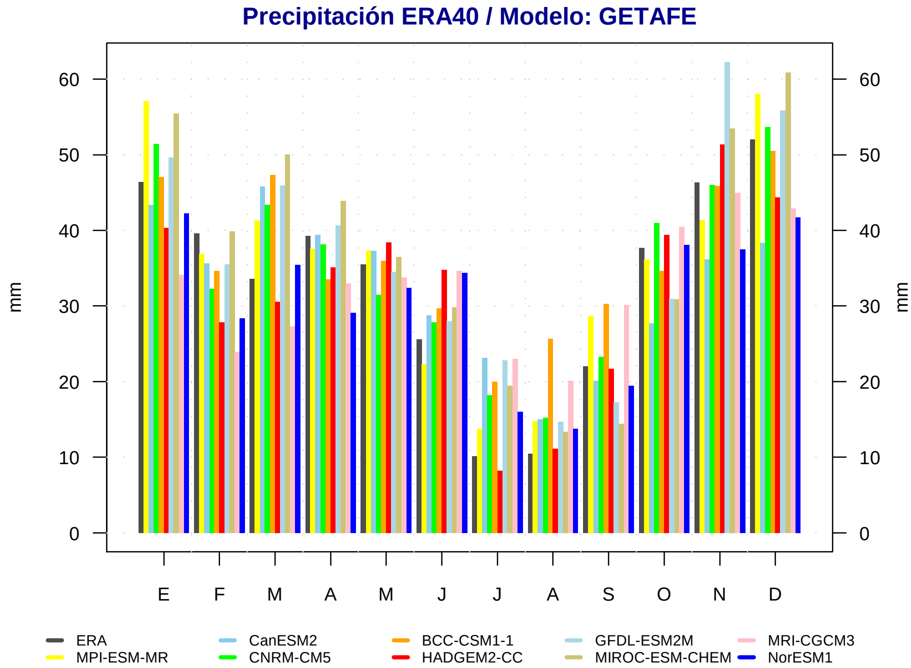
FIGURE 20. CLIMATE MODELS. MONTHLY AVERAGE PRECIPITATION, HISTORICAL SCENARIO VERSUS THE ERA40 REANALYSIS VALUE



Graph comparing different climate models. Monthly average precipitation of the Historical scenario versus the ERA40 *reanalysis value. Common comparison period: 1958 – 2000. Average of the three observatories used in this study.*

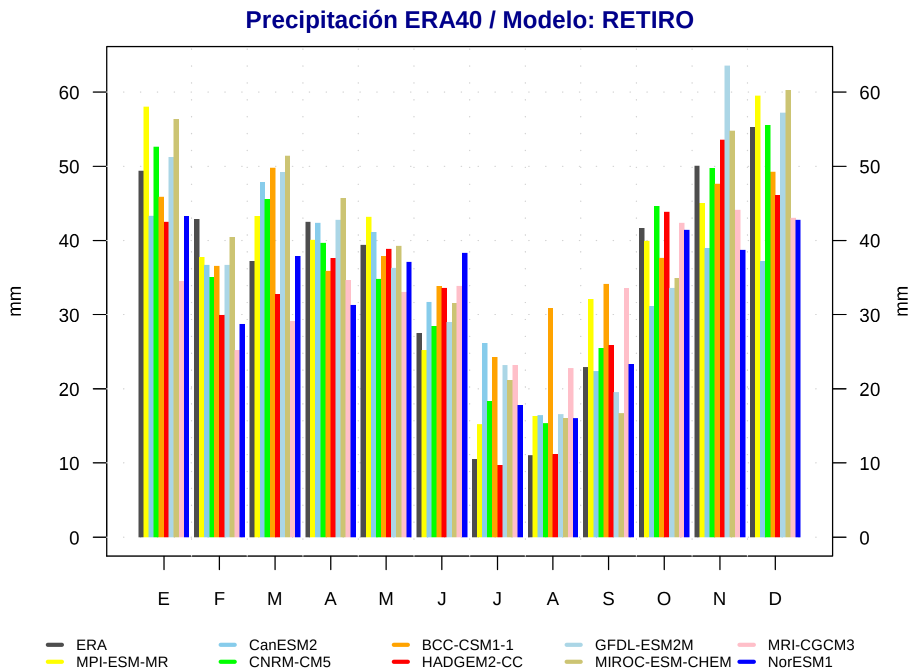
The following figures (21 to 23) show the validation results broken down for each of the observatories studied in Madrid Region (Getafe, Retiro and Torrejón).

FIGURE 21. CLIMATE MODELS. MONTHLY AVERAGE PRECIPITATION, HISTORICAL SCENARIO VERSUS THE ERA40 REANALYSIS VALUE. GETAFE OBSERVATORY



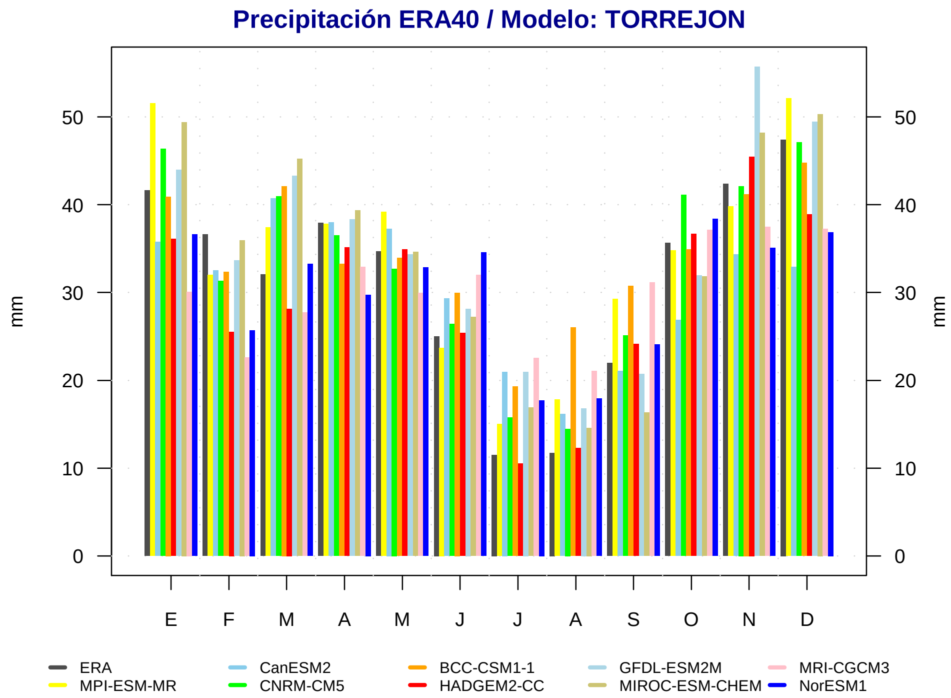
Graph comparing different climate models. Monthly average precipitation of the Historical scenario versus the ERA40 *reanalysis value. Common comparison period: 1958 – 2000. Getafe observatory*

FIGURE 22. CLIMATE MODELS. MONTHLY AVERAGE PRECIPITATION, HISTORICAL SCENARIO VERSUS THE ERA40 REANALYSIS VALUE. RETIRO OBSERVATORY



Graph comparing different climate models. Monthly average precipitation of the Historical scenario versus the ERA40 *reanalysis value. Common comparison period: 1958 – 2000. Retiro observatory*

FIGURE 23. **CLIMATE MODELS. MONTHLY AVERAGE PRECIPITATION, HISTORICAL SCENARIO VERSUS THE ERA40 REANALYSIS VALUE. TORREJÓN OBSERVATORY**



Graph comparing different climate models. Monthly average precipitation of the Historical scenario versus the ERA40 *reanalysis value. Common comparison period: 1958 – 2000. Torrejón observatory*

As can be seen, the results are similar to the one described above for the average of the observatories: the models used do record climate variability, in the annual precipitation cycle, and are capable of establishing the climate characteristics of the region. What they do not achieve is to correctly reproduce the amounts of precipitation associated with the cycle (they tend to overestimate them). Their correct reproduction of the cycle is precisely the characteristic that leads to trust their ability to correctly represent the climate of the observatories; if they do not do it with the quantities, this is what makes the researchers emphasise that the increases with respect to the past (a Historical) should be analysed in a relative and not absolute manner, and that the study of the absolute increases requires a correction of the systematic error.

1.7. GENERATION OF FUTURE CLIMATE SCENARIOS ON A LOCAL SCALE

Emissions scenarios are used in climate change as plausible descriptions of how future changes will be in a wide range of variables: socioeconomic, technological, energy, land use, greenhouse gas emissions (***GHGs***), and air pollutants.

To fulfil this function, sets of emission scenarios were developed, such as ***IS92***[14], or more recently, ***SRES***[15] But in the scientific community there arose the need for scenarios provided with more detailed information.

In response to this need, the IPCC (Intergovernmental Panel on Climate Change) proposed defining new scenarios. In this case, the proposal consisted of the scientific community defining these scenarios through the joint collaboration of those responsible for the different centres that generate **climate models** and those responsible for the **integrated evaluation model** centres. The idea of combining them resides in the fact that the latter provide additional information on socio-economic aspects that complete the information generated by the models.

The new future scenarios to be used, associated with the fifth IPCC report, have been called Representative Concentration Pathways (hereinafter, **RCP**) and their definition is based on the following criteria:

1. RCP should be based on existing emission scenarios, developed by different centres and recorded in the literature. At the same time, each RCP must, by itself, be a plausible description and internally consistent with the future.
2. They must provide information on all the radiative forcings necessary for climate modelling (land use, GHG emissions and air pollutants).
3. They must be "harmonised", that is, the continuous transition between the historical period (the **Historical** experiment) and the future periods must be guaranteed.
4. They must offer information until 2100 and be available to simulate further.

The name "RCP**"** reflects two of its main characteristics:

- *Representative*: it refers to the idea that an RCP represents a set of existing emission scenarios. That is, the RCP must be compatible with both extreme and average scenarios.

- *Concentration Pathway*: this term emphasises that the RCP are not final products but are the tool (the input) towards the generation of emission scenarios, hence the use of concentrations instead of emissions. RCP are understood as a sufficiently consistent set of radiative forcing components, but they are not a complete set of climate, socioeconomic, and emission projections.

[14] IS92, in 1992, the IPCC published emission scenarios that served as the basis for the global circulation models, in order to develop a context on climate change. The so-called "IS92 SCENARIOS" (*International Scenarios 1992*) constituted a great step forward.
Source: https://www.ipcc.ch/pdf/special-reports/spm/sres-sp.pdf.

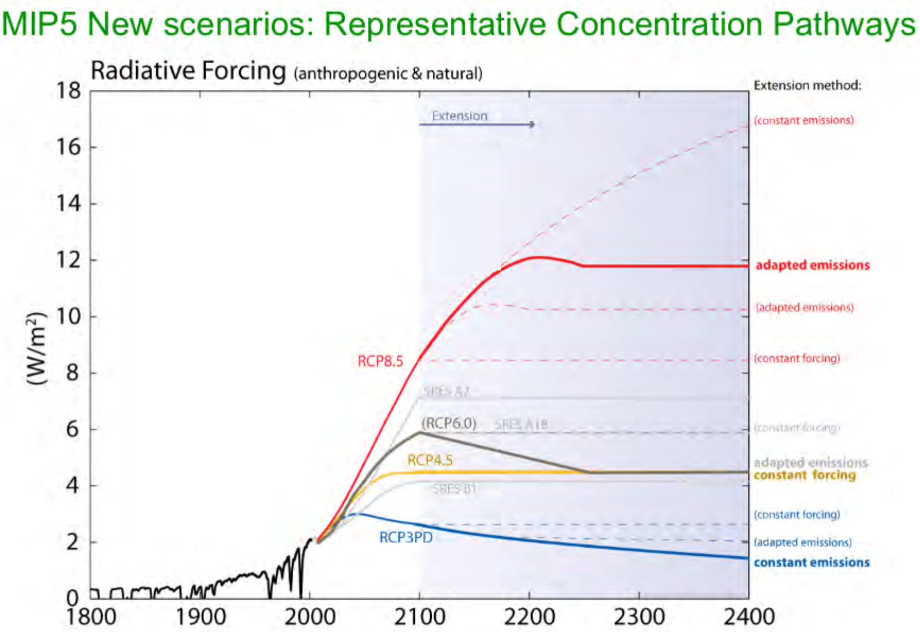
[15] SRES, in 2000, the IPCC published a new series of scenarios, which it called SRES (Special Report on Emissions Scenarios), for use in the third evaluation report. These respond to several motivating forces on climate change, including population growth and socio-economic development. These motivating forces generate several future scenarios that may have an influence on the sources and sinks of greenhouse gases (GHG), such as energy systems and the change in land use. The evolution of these motivating forces in relation to climate change is uncertain, generating a wide range of possible routes for greenhouse gas emissions.
Source: www.lenntech.es/efecto-invernadero/escenarios-causas-ipcc-sres.htm#ixzz3ltxexxws

Figure 24 shows how the new RCP relate to the scenarios already existing in previous IPCC reports. Reviewing the existing literature (formed by the study of 324 scenarios from different research centres) it was found that the range of expected radiative forcing[16] values in 2100 ranged between 2.6 W/m^2 as the lowest level; and between 8 and 9 W/m^2 at the highest level.

Since the RCP must cover the entire existing range and also provide intermediate information, a set of four RCP covering both the extreme values and two intermediate values were chosen and separated enough so that the results obtained from them would also result in different results (separated by 2W/m^2, between each other).

The scientific community (consisting of more than 20 working groups from around the world) determined, in September 2008 in Paris, that the new scenarios would be **RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5** (the name refers to the radiative forcing reached in 2100), and the four groups that would be responsible for developing these scenarios were designated (see Table 6).

FIGURE 24. **RADIATIVE FORCING, FORECAST OF 21ST CENTURY SCENARIOS ASSOCIATED WITH RCP**



Radiative forcing during the 21st century, associated with the different RCP and their relationship with the scenarios of IPCC (SRES) report no. 4. The RCP2.6 scenario appears with its original name, RCP3PD. Source: Meinshausen, Smith, et al. (2011).

[16] Radiative forcing, is the change in the net flow of radiative energy towards the surface of the Earth measured at the upper edge of the troposphere (about 12,000m above sea level) as a result of internal changes in the composition of the atmosphere, or changes in the external contribution of solar energy. It is expressed in Wm^{-2}, units of watts per square meter of the earth's surface. A positive radiative forcing contributes to heat the surface of the Earth, while a negative one favours its cooling. In the IPCC report, changes in radiative forcing are compared to the year 1750. Source: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-2-1.html.

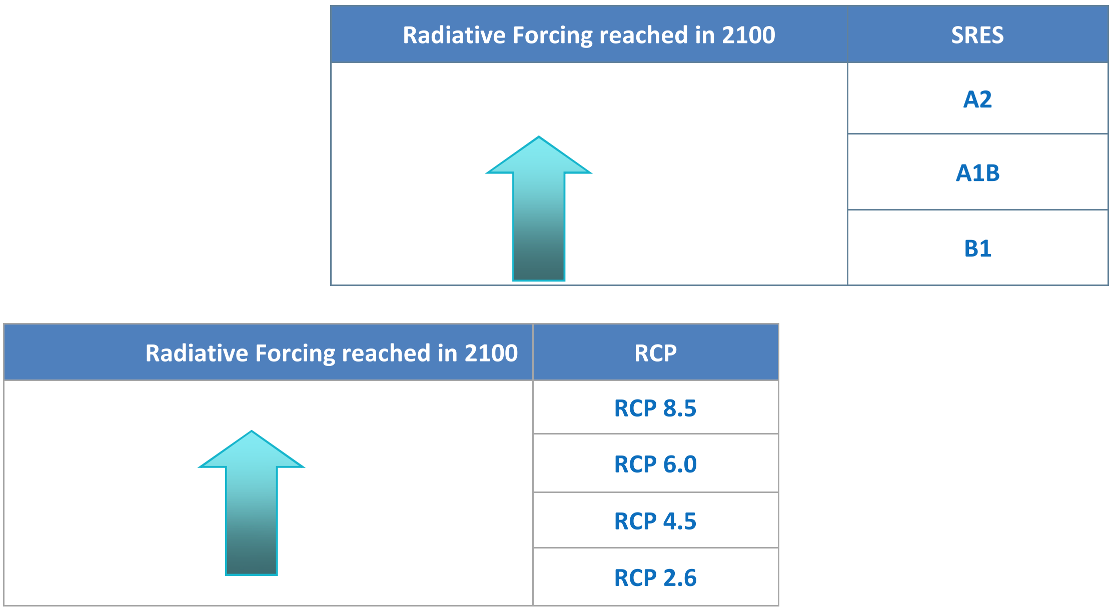
Radiative Forcing was defined by V. Ramaswamy (2001) as "the change in net irradiance in the Tropopause after allowing the stratospheric temperatures to readjust to the radiative balance, but the surface and tropospheric temperatures remaining fixed at their undisturbed values".

TABLE 6. MAIN CHARACTERISTICS OF THE DIFFERENT RCP

RCP	*Characteristics*	*Reference*
2.6	A peak of 3 W/m^2 is achieved before 2100 and then it decreases to 2.6 W/m^2	Van Vuuren et al. (2011)
4.5	It stabilises without exceeding 4.5 W/m^2 (equivalent to around 650 ppm) in 2100	Thomson et al. (2011)
6.0	It stabilises without exceeding 6.0 W/m^2 (equivalent to around 850 ppm) in 2100	Fujino et al. (2006)
8.5	It reaches 8.5 W/m^2 (equivalent to around 1370 ppm of equivalent CO_2) in 2100, and the levels do not stabilise until 2050	Riahi et al. (2011)

Given the different way in which they have been defined, there is no direct relationship between the future scenarios associated with the 4th IPCC report (SRES) and those associated with the IPCC 5th report (RCP), nor an explicit relationship between their different characteristics. However, as shown in Figure 25, a category can be established within each of the two scenario families, according to the impact that each one of them has on the current climate conditions. Thus, in the same way that for the SRES family, the scenarios of greatest impact were those associated with "group A", and those with the least impact on "group B" (from highest to lowest impact they were A2, A1B and B1), for the RCP family, greater impact on the climate is associated with those with the highest radiative forcing (from highest to lowest, they would be RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6) reached in 2100.

FIGURE 25. RADIATIVE FORCING REACHED IN 2100, ACCORDING TO THE RCP AND SRES SCENARIOS



Radiative forcing for the family of future RCP scenarios (associated with the 5th IPCC report) and for the family of SRES (associated with the 4th IPCC report), order of the different defined scenarios (the most commonly used, in the case of the SRES) according to the radiative forcing reached in 2100 (derived from its definitions), from lowest to highest, as a suggestion of the possible impact of each possible scenario on the climate.

Along with the new RCP, the CMIP5 (**Climate Model Intercomparison Project 5**) was formed with the objective of creating a work base where all the information is available to the scientific community, in order to be used in the next IPCC report.

Due to the enormous amount of information generated by the different research centres, the CMIP5 has divided the information into different levels, with the aim of all the centres providing a minimum of common information that allows comparison between them. Thus, the first level called "**Core**", which must be provided by all the members, is made up of RCP 4.5 and RCP 8.5.

In a second level called "**Tier 1**" are RCP 2.6 and 6.0, and more detailed experiments.

The last level, called "**Tier 2**", includes more complex emissions scenarios, for example, the **Extended Concentration Pathways**, extensions of the RCP up to 2300.

In this project researchers have worked with 9 climate models that had between 2 and 4 RCP each. It must be said that their choice has not been determined by any specific scientific criteria since, given the recentness of the models associated with the CMIP5, there is still not enough scientific literature regarding the behaviour of all existing models and, as such, for now it is completely impossible to establish a (better/worse) classification of the existing models.

For the selection of the nine models chosen (a sufficient number to show the variability between the existing ones), those that met the following criteria were chosen:

- Showing good behaviour in the past IPCC report, or at least, having been generated by the same scientific bodies, seeking a certain degree of confidence in the capacity of the teams involved when generating a model and,

- Giving preference to models of the type "**Earth System Model**" (**ESM**) type, considering them to be more advanced.

These models are a set of equations that describe the processes that take place within and between the atmosphere, the ocean, the cryosphere and the marine and terrestrial biosphere. These equations record the physical, chemical and biological mechanisms that govern the elements of the terrestrial system and, also include, volcanic eruptions and variations of incoming solar radiation. Their main advancement versus the traditional **General Circulation Models** is that they allow the interaction of the system with the carbon cycle and they take into account marine biogeology and biochemistry.

The models finally used and the scenarios available for each of them are listed in Table 7.

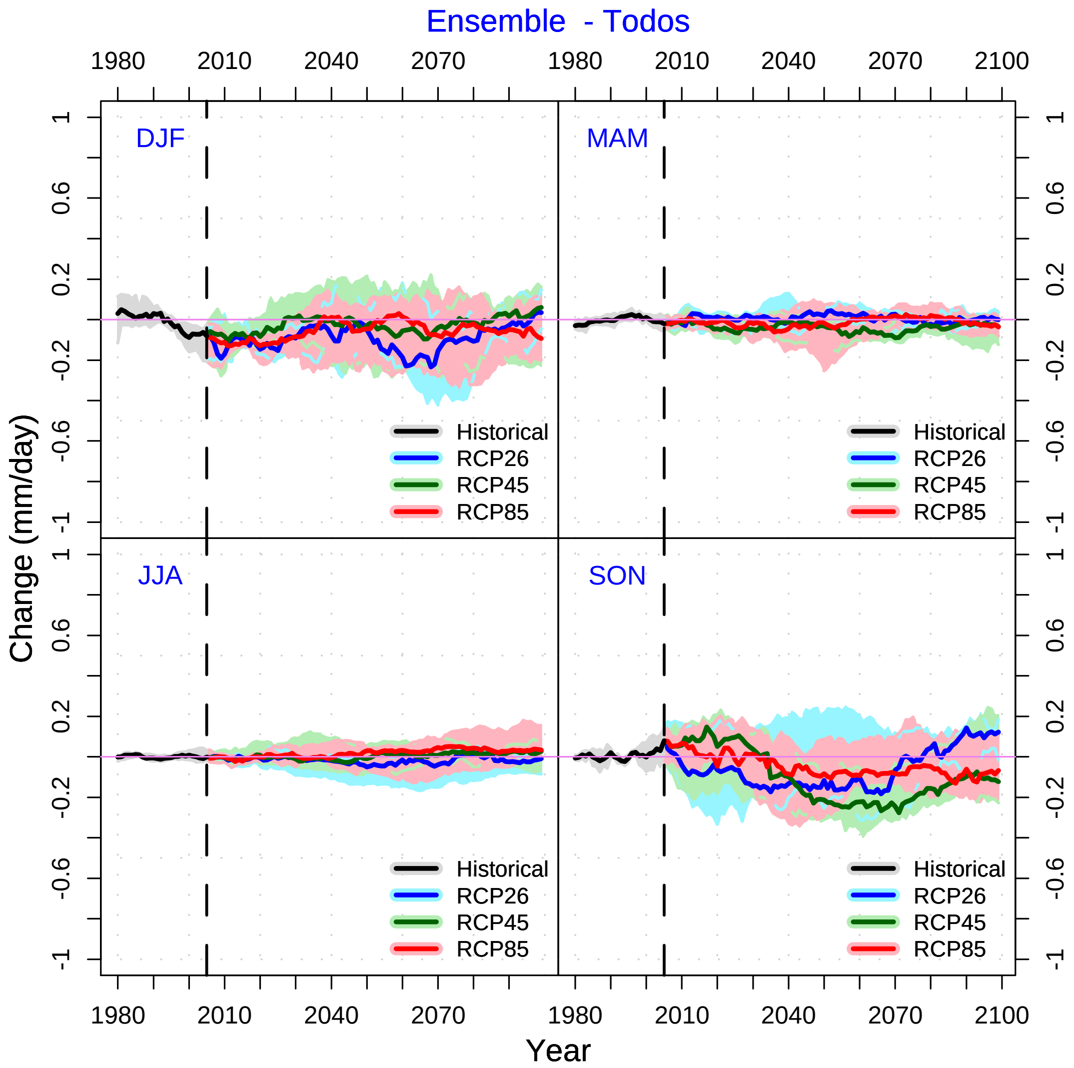
The combination of models used and available scenarios, for each one of them, shows that for this project a range of possibilities was available composed of 31 possible future climate evolutions. The period in which the different scenarios work is, for the *Historical Scenario* (the control period of each model), 1951- 2005; and for each of the **RCP** considered, 2006-2100.

Figure 26 statistically summarises the future change in precipitation provided by simulations of the models for the average of all the observatories, separated by seasons of the year.

TABLE 7. **SCENARIOS PROVIDED FOR EACH OF THE CLIMATE MODELS USED**

Climate Model	*Available Scenarios*	*Research Centre*
MPI-ESM-MR	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5	Max Planck Institute for Meteorology (MPI-M), Germany
GFDL-ESM2M	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5 RCP 6.0	National Oceanic and Atmospheric Administration (NOAA), E.E.U.U.
CanESM2	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5	Canadian Centre for Climate Modelling and Analysis (CC-CMA), Canada
CNRM-CM5	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5	CNRM (Centre National de Recherches Meteorologiques), Meteo-France, France
BCC-CSM1-1	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5 RCP 6.0	Beijing Climate Center (BCC), China Meteorological Administration, China
HADGEM2-CC	*"Historical"* RCP 4.5 RCP 8.5	Met Office Hadley Centre, UK
MIROC-ESM-CHEM	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5 RCP 6.0	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan
NorESM1-M	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5 RCP 6.0	Norwegian Climate Centre, Norway
MRI-CGCM3	*"Historical"* RCP 2.6 RCP 4.5 RCP 8.5 RCP 6.0	MRI (Meteorological Research Institute, Tsukuba), Japan

FIGURE 26. ABSOLUTE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY. RCP 2.6; RCP 4.5; RCP 8.5



Absolute expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on all observatories. The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

Before studying the implications represented in Figure 26, it must be described in detail how it has been constructed to understand what it means. What is shown is the seasonal evolution of the variable for each **RCP** as the median of all the results obtained for each Climate Model (for example, that corresponding to **RCP** 8.5 is built with all available **RCP 8.5** scenarios, one for each model that provides this scenario) and for each observatory; these medians are the thick lines drawn. The shaded areas represent, for each **RCP**, the dispersion of the data for all the models and all the observatories, where the upper limit is the 90th percentile and the lower limit is the 10th percentile of all the data. Each specific value is calculated as the 30-year moving average: a specific value associated with 2050 corresponds to the moving average of the period 2020 - 2050, that is, the 30 years prior to the year referenced.

The calculations are shown against the average obtained versus the 1971-2000 period, that is to say that the 0 value in the graphs corresponds to the average of that average and, as such, any change is referenced against that value. The vertical broken line represents the year in which the *Historical* experiment ends (year 2005) and the RCP scenarios begin.

Each season of the year is identified by the initials of the months that comprise it (**DJF** - December, January, February; **MAM** -March, April, May; **JJA** -June, July, August; **SON** -September, October, November). Although researchers could work on annual statistics (that is, a single graph with annual data could be represented), in the case of variables so strongly dependent on the season of the year, such as precipitation, it is much more appropriate to study seasonal rather than annual conclusions; note that a single annual graph would mask the different behaviour on the graph of, for example, summer and winter.

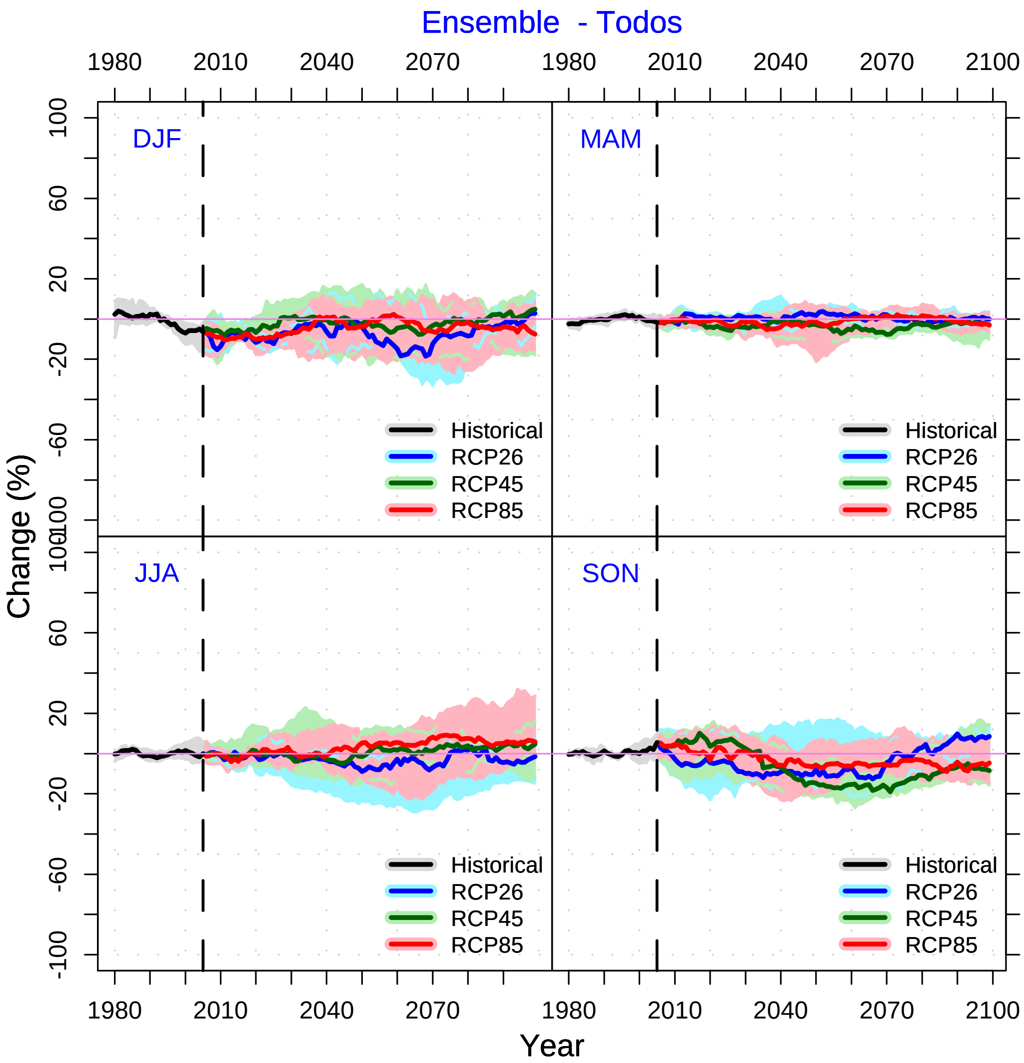
The inclusion of shaded areas is due to the need to include some variability criterion that reports the variation margin that can be expected from the simulations, even though the median (a robust statistical centralisation measure) informs of what is considered to be the central value among the most likely. Note that the graphs do not show the RCP 6.0 scenario, because only 5 of the models used provide it, and their statistical values are not, therefore, comparable to the statistics obtained for the rest of the RCP (which does not mean that the data themselves should be discarded versus the other RCP). What the previous figure shows is that the absolute increases of precipitation in the spring and summer seasons are practically zero, and climate change that particularly varies the precipitation regime with respect to that of the past should not be expected.

Winter, after a first decrease stage, shows a continuous evolution, except for the case of the RCP 2.6 scenario, which shows a certain decrease: a succession of changes like this one (the oscillation recorded here) seem to suggest that the changes are more due to the climatic variability of precipitation itself than the climate response to the radiative forcing of the RCP.

Autumn, and after a start of different orders according to the RCP considered (positive increase, negative, or no increase), is the only season that shows a continuous decline for the remaining period of the century, with a slight recovery at the end of it (especially for RCP 2.6), although it must be said that not all models show the same behaviour (shaded areas are not located in a single positive or negative sign).

Figure 27 shows the same results seen in Figure 26 (with the same criteria used in the graphical representation of the statistics) but reflecting the increases in relative quantities. Note that what is shown in this figure coincides with what was shown in the previous figure for absolute increases; the main difference is that the increases expected in summer show a greater variation, an effect caused by the fact that, since the summer has such low precipitation, small absolute increases reflect greater relative increases.

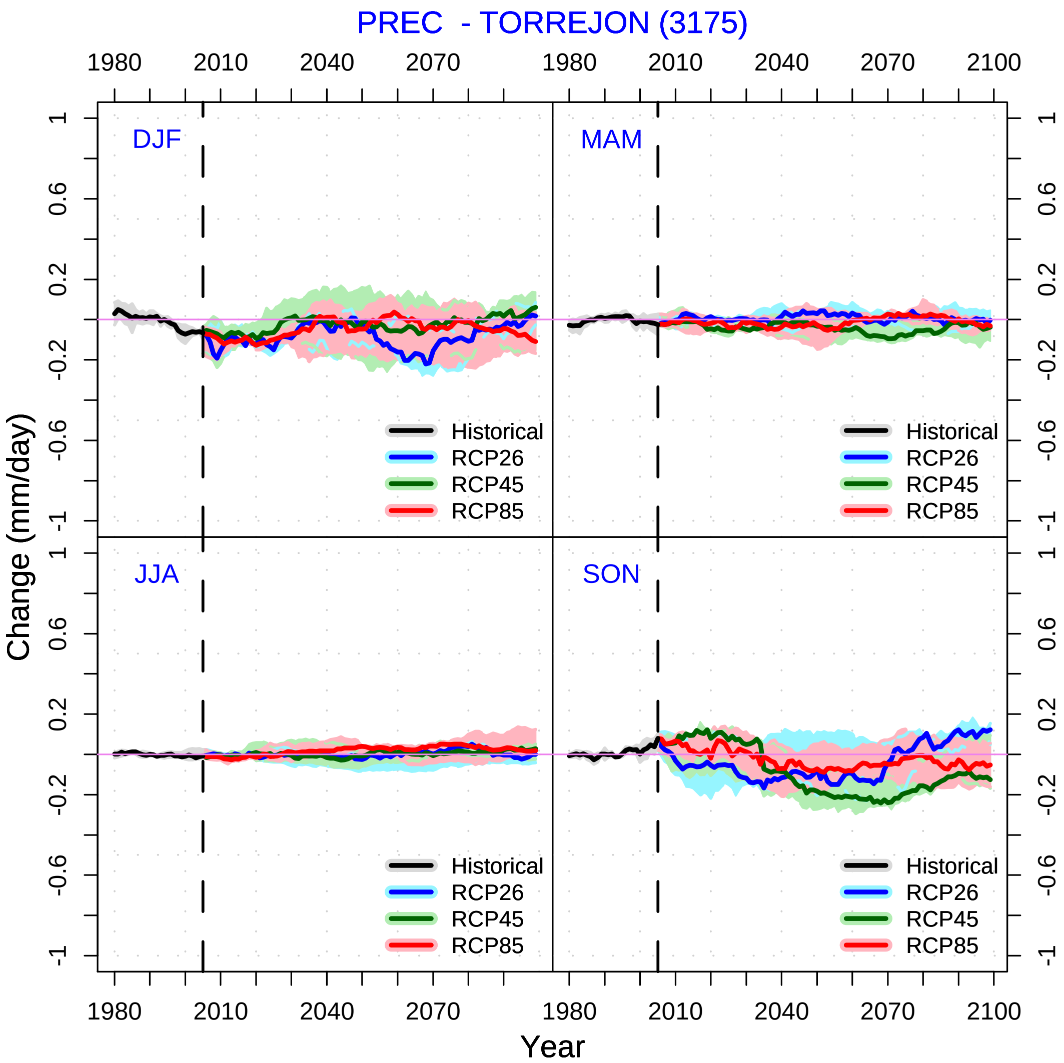
FIGURE 27. **RELATIVE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES**



Relative expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on all observatories. The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

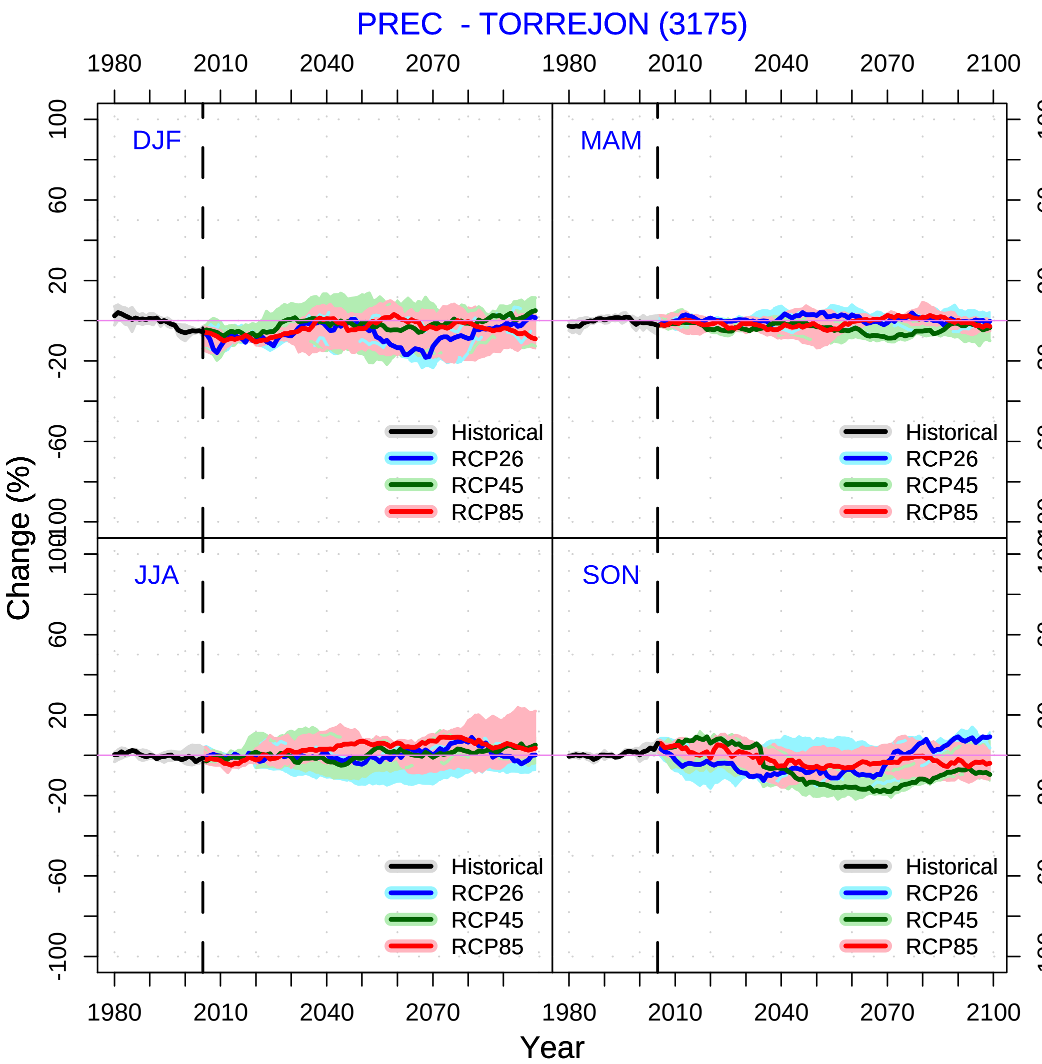
Figures 28 to 33 show the same results of expected increases, both absolute and relative, but broken down for each of the observatories studied; as can be seen, the conclusions are similar to those obtained for the average of all the observatories.

FIGURE 28. **ABSOLUTE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. TORREJÓN OBSERVATORY**



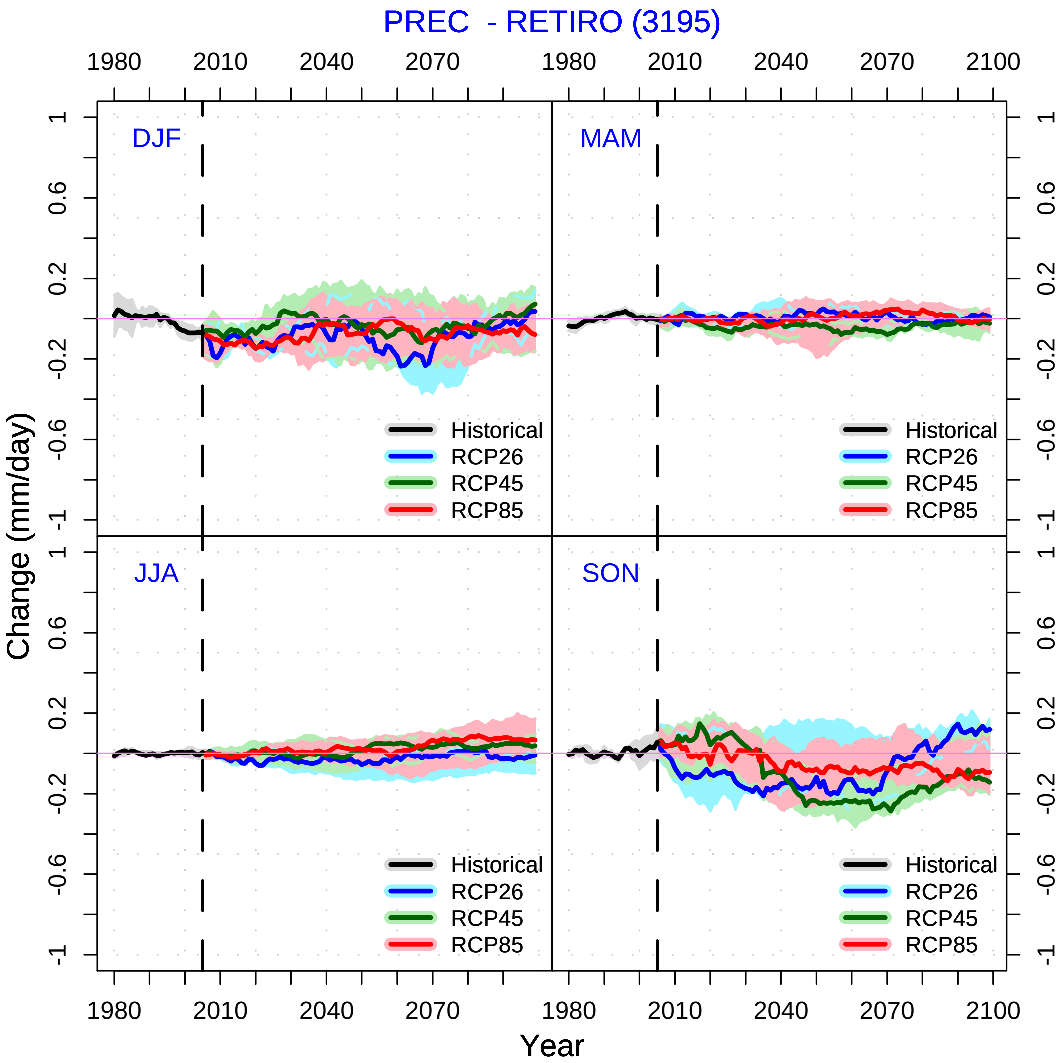
Absolute expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Torrejón observatory (meteorological observatory 3175). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 29. **RELATIVE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. TORREJÓN OBSERVATORY**



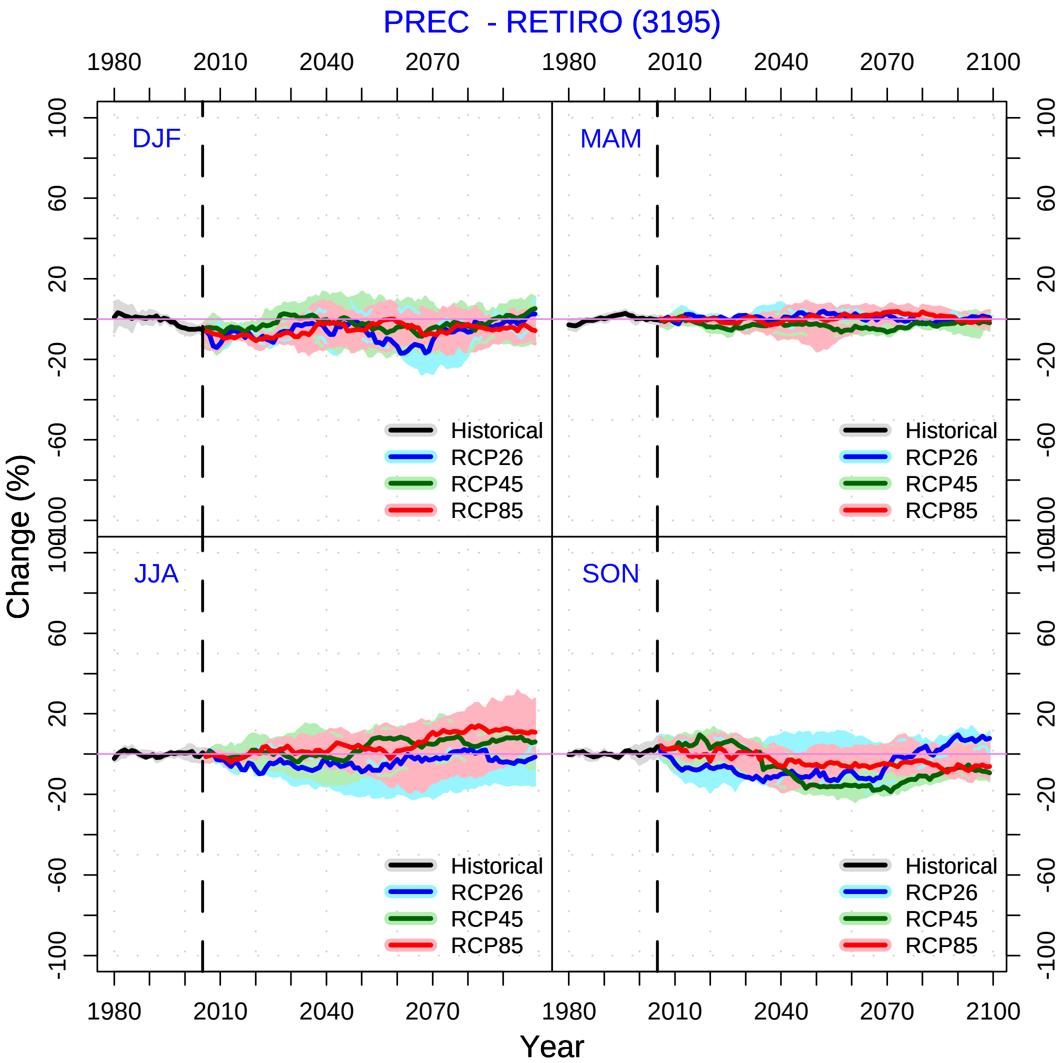
Relative expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Torrejón observatory (meteorological observatory 3175). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 30. ABSOLUTE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY. MADRID RETIRO OBSERVATORY



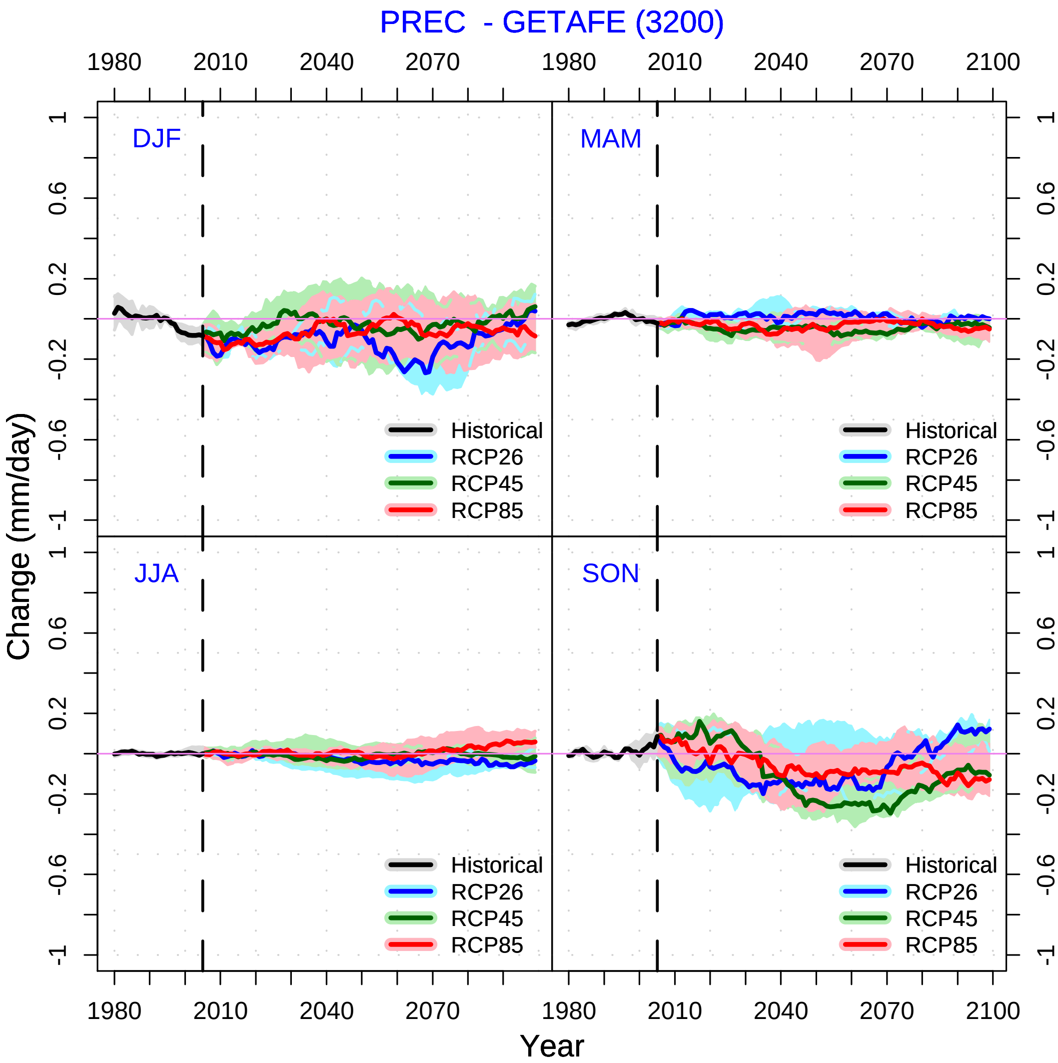
Absolute expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Madrid Retiro observatory (meteorological identifier 3195). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 31. **RELATIVE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY. MADRID RETIRO OBSERVATORY**



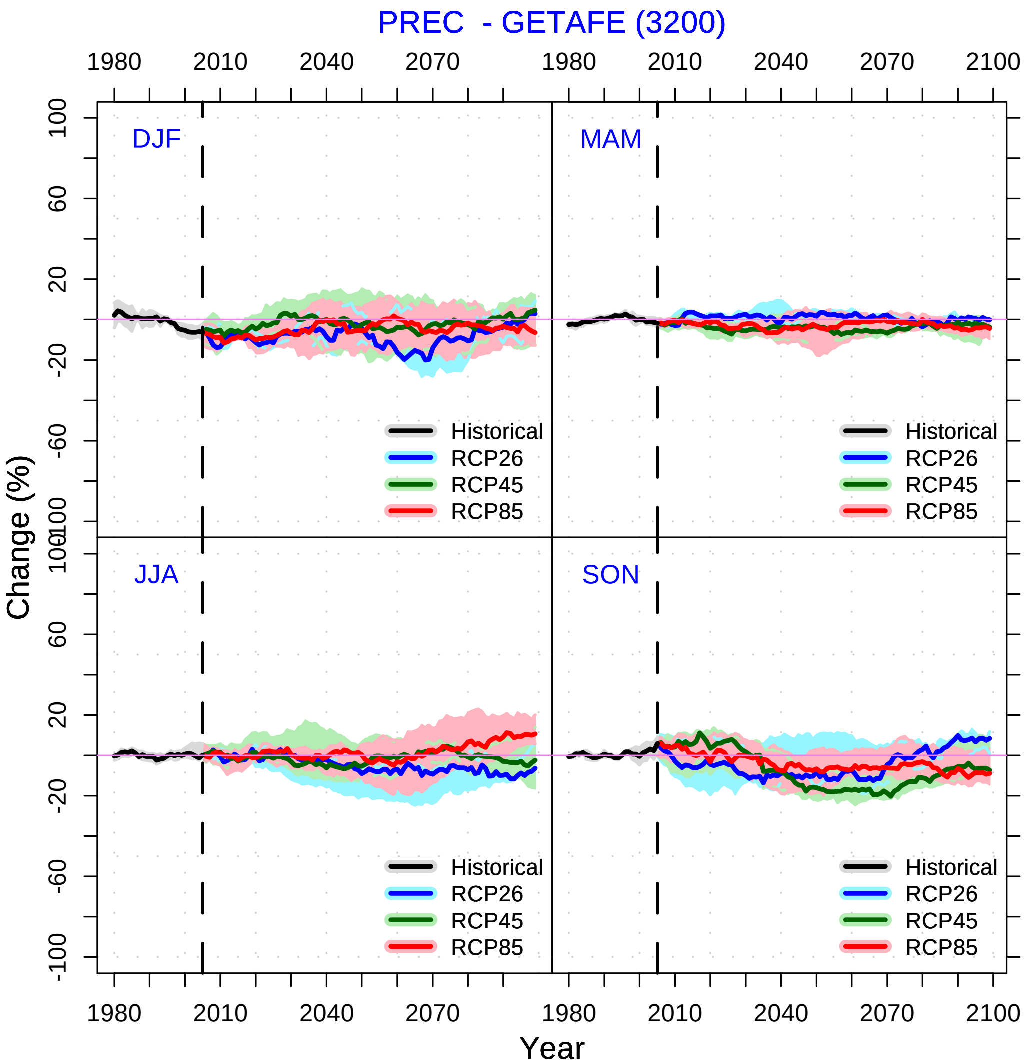
Relative expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Madrid Retiro observatory (meteorological identifier 3195). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 32. ABSOLUTE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY. GETAFE OBSERVATORY



Absolute expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Getafe observatory (meteorological identifier 3200). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 33. RELATIVE EXPECTED SEASONAL PRECIPITATION INCREASES FOR THE 21ST CENTURY. GETAFE OBSERVATORY



Relative expected seasonal precipitation increases for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5) with respect to the average of the 1971-2000 period (taken as a reference). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Getafe observatory (meteorological identifier 3200). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

1.8. ON THE USE OF THE CLIMATE SCENARIO DATA

When simulated data on future climate change scenarios are available, before working with them, their processing should be considered with extreme caution and the exact nature of the data should be clearly understood, especially if, as is the case, the data has been produced on a daily scale. There are two main considerations that must be taken into account:

1. The data are climatic and ***not*** meteorological. Although the simulation is performed on a daily scale, it should never be interpreted that a certain climate model states that the weather will be, on the day of the simulation, exactly the one given by the simulation, precisely due to the climatic and not meteorological nature of the model. The variables processed by the model and the simulations carried out, of course, refer to atmospheric variables, but the conclusions must refer to the climate of the point on which researchers have made a regionalisation. In the same way that a day does not describe the climate of a point (or, for example, a month, or a year of data), a simulated day does not describe climate changes.

   Thus, for the conclusions to be ***climatic***, **the climate at the point** must be studied, that is, very long series that, added in accordance with the statistic of interest, describe the climate at the point. The description, for example, of the average temperature of a point needs more data than a year of data may have. A sufficiently large set of data should be taken whose average allows to conclude what its average temperature is. This fact is even more visible in studies related to precipitation: if only a few years of data are considered, data from a period of drought (or rainfall) can be included, leading to the conclusion that precipitation at this point is due to regimes of drought, when in reality this is not the case.

   The choice of the statistic to be used becomes, therefore, extremely important when approaching a climate study. If you want to talk about the ***average climate*** at one point, choosing the mean of a set of values seems to be the clearest option; however, the median may be a better option, since it is a much more robust measure. In addition, another statistic should be studied to report the variability of the variable, not simply its average, such as the deviation of the values considered to calculate the average or two percentiles (for example, the 10^{th} and 90^{th} percentiles), of all the data considered. In any case, whatever the statistic to be used (return periods of precipitation, drought rates, frequency of heat waves, etc.) the choice must be made always taking into account the climatic nature of the data.

   Dealing with the climatic nature of the data implies defining long periods of time that allow to draw statistical conclusions (and that do not appear distorted with the data of certain possible anomalous years). A long period of time must include at least 30 years of data, to be able to draw climatic conclusions (hence 30-year data are included in these median studies), and in the case of precipitation (whatever the statistic derived, and not only the quantity, such as days with precipitation, return periods, etc.) it may be advisable to use up to 50 years of data, if what you want is to compare two different periods with one another.

   It should not be forget that statistical conclusions can refer to annual periods (something that seems natural since the cycles of variables are usually annual), or even seasonal (if you can clearly associate a certain period of the year with a season), but managing statistics related to very small periods can be dangerous: a fortnight is a very short period in which to draw conclusions, and even more so, a week.

2. The data must be interpreted incrementally and not absolutely. As it has been seen throughout the work carried out, there is a difference between what a model considers to be the past (its **Historical** scenario) and the true past. However, their future scenarios are consistent and continuous projections of that past that the climate model itself has simulated and, as such, the possible increases between its past and a certain future ***should*** be interpreted as correct, but not the exact and absolute values provided by future scenarios.

   Once again, and as recalled in the previous point, the notion of increase must be carried out carefully, and must refer to the choice of a certain statistic that allows to measure, in a rigorous way, the meteorological variable to be studied (or a certain property of that variable); likewise, the increase between two statistics must also be defined with a criterion that differentiates between absolute and relative increases (if the relative ones make sense, as for example, is not the case for temperature).

   Studying these possible increases will involve being able to compare the ***baseline climate*** of a certain point with the future scenario to be studied and thus obtain conclusions. The work to be carried out will depend on the definition of "***baseline climate***" that researchers make; since a meteorological station may have few observed data, the baseline climate can be taken as the regionalisation of the reanalysis at that point, and then taking the possible increase as the difference between the regionalisation of the reanalysis and the regionalisation of the scenario - which, in addition, allows to reduce the problems derived from the difference between the past of the model and the point (what in this work has been called the ***validation of the model***).

   If the observatory has enough data, then the work can be extended like the increase between the observed data and the regionalised data of the reanalysis, but previously determining if the observed data allow this work (for example, there can be data associated with many years, but if for each of those years there are no data for a certain month, then the conclusions will be defective); the existence of some gaps in the observed data does not have to be decisive since the regionalisation of the reanalysis does provide continuous data in the period to be considered. Thus, if one is able to determine increases between *observed/reanalyses* and between *reanalyses/model*, working with both increases (relating them, in accordance with the chosen statistic), it will provide the most rigorous estimate of the change to be expected at a given point.

1.9. THE CORRECTION OF THE SYSTEMATIC ERROR

As mentioned above, it is necessary that the regionalised data at a point of a certain climate model can be interpreted in their absolute values and not only in terms of relative increases; as a result, the possible errors that have led to the introduction of biases in regionalisation must be corrected in order to obtain values that can be studied in their absolute magnitude. This correction is what is called ***systematic error correction***.

1.9.1. Theoretical foundations

In any future climate simulation there is an uncertainty that is the joint result of several uncertainties of different origin and nature, which constitute what is called a ***cascade of uncertainties***. In a first approach, these uncertainties could be grouped into two groups:

1. Uncertainties **prior** to **downscaling**: what will be the low resolution atmospheric situation in the future (not for a specific day in the future, but the frequency of appearance of each configuration)? These uncertainties are revealed through the different simulations of low resolution atmospheric configurations that may be available, obtained with different "**General Circulation Models**" (**GCM**), different executions of the same **GCM**, different future scenarios of greenhouse gas emissions, etc.

2. Uncertainties **relating** to **downscaling**: given a low resolution atmospheric configuration, for a certain day, in a certain area, what will be its surface effects with high resolution? These uncertainties are evident through the different regionalisations of the same low resolution atmospheric situation, made with different **downscaling** methodologies (statistical and dynamic), and through their comparison with the real observations of the surface effects associated with that atmospheric configuration, if available.

When carrying out the regionalisation of a certain ***General Circulation Model***, there are three types of errors that must be considered:

- **Error 1**, or **Verification** Error (corresponds to group B above). It is an error associated with the downscaling method that is being used (whichever it is), that is to say, that which is produced by applying this method to the "observations" of the predictors (in this case atmospheric analysis is used). It is estimated by comparing that which is simulated by downscaling of an atmospheric reanalysis, with the observations of the predictands.

- **Error 2**, or **Validation** Error (corresponds to group A above). It is an error of the **GCM** that is being used. It is estimated by comparing that which is simulated by downscaling the output of the **GCM** for the present climate, with that simulated by the downscaling of an atmospheric reanalysis ("observations" of the predictors).

- **Error 3**, or **Unpredictability** Error. Apart from the previous errors, when carrying out simulations in the future regionalising **GCMs**, there will always remain uncertainties that are impossible to determine with accuracy. For example, establishing whether the fact that a certain **GCM** reflects the past well means, or not, that it will reflect the future well, is out of reach. This type of error, which is not quantifiable (and in any case, it can only be estimated), will not be addressed in this study.

Therefore, the quantification and correction of the systematic error to be analysed in this section will seek:

a. To quantify error 1, that is, quantify the magnitude of the bias introduced by the downscaling method used, using the comparison between the regionalised **ERA40** reanalysis and the observed data.

b. To quantify error 2, that is, quantify the magnitude of the bias introduced by each climate model used, using the comparison between the control period of the regionalised model to be studied and the regionalised **ERA40** reanalysis.

c. Lastly, to apply correction factors for these errors proportionally to the errors found and the magnitudes to be corrected.

Whatever the correction method used, not to correct all the data in the same way (not to add or multiply this data by the same amount) should be tried, but proportionally, so that major corrections will be applied to the values that contain the greater errors, and minor corrections will be applied to the values that incorporate lesser errors.

To determine, which values have greater or lesser error, the distribution function of the observed values will be compared with those of regionalised **ERA40**; and that of regionalised **ERA40** values will be compared with those of regionalised models. Specifically, the Empirical Cumulative Distribution Function (**ECDF**) will be used, which allows, when comparing two values to each other, to compare the difference between the same magnitudes (strictly speaking, among the same quantiles, since researchers are working with distribution functions) and establish relations of proportionality between the magnitudes, which will depend on the magnitudes themselves. This method provides a non-linear way (as was sought) to establish the differences between two different data groups; the measurement of these differences will allow correction of the error between both groups of data.

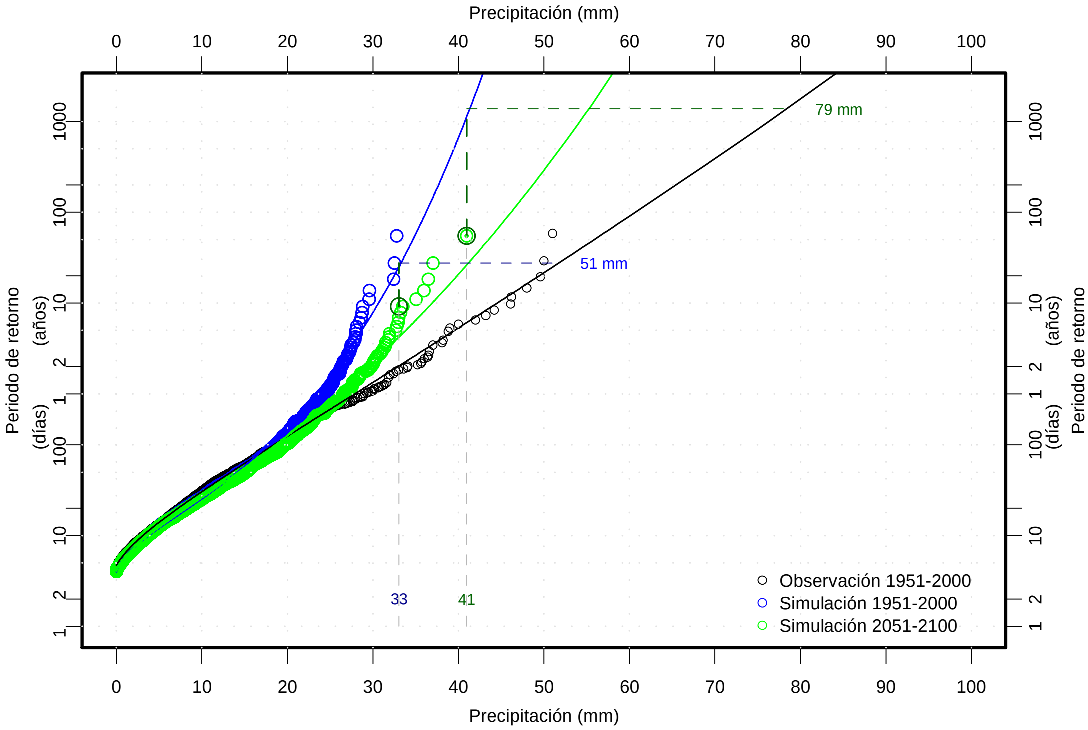
The way to apply this method is illustrated in Figure 34. Although the method is based on the use of the **ECDF**, here researchers have represented the return period of each amount of precipitation, understood as the inverse of its probability, given that visually it is much more illustrative, and also, it is a way of representing its distribution function. What it will be seen is an example of how correction works, where black circles represent observed values; blue circles, simulated values of the control period (this would correspond to the Historical experiment of a climate model); and the green ones, the simulated values of a future scenario. Below, an example explains what the method consists of:

1. Starting with the data themselves, the theoretical distribution of each of the data groups is calculated; with these theoretical distributions corresponding to the continuous lines represented (each with the colour of the group to which it corresponds).

2. A daily rainfall of 33 millimetres in the control group corresponds to one of 51 millimetres in those observed; this is the case, because the order imposed, based on return periods (in probability, or in ECDF), associates that the same return period of precipitation of 33 millimetres corresponds to that of 51 millimetres, in the group of those observed.

3. The correction of the future scenario must necessarily pass through the previous comparison with its own control group, since only the control group can be compared with the group of observed values. In this way, assuming there is precipitation of 41 millimetres in the future scenario group, that same precipitation has a different return period (a probability) in the control group, and that is the one that must be taken and brought to the group of observation, assigning the value of 79 millimetres.

FIGURE 34. ILLUSTRATED EXAMPLE OF THE CORRECTION OF THE SYSTEMATIC ERROR



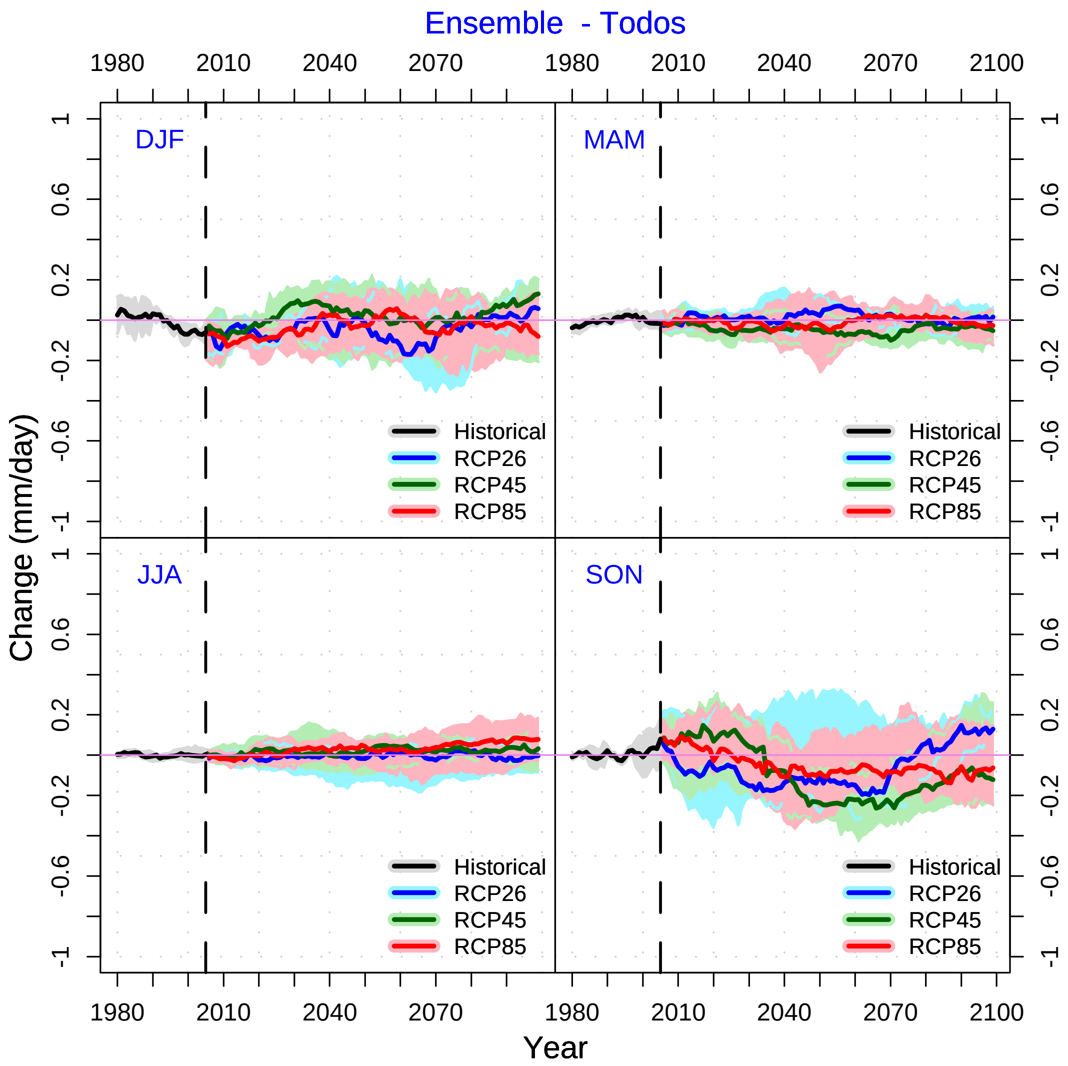
Visualisation, with examples, of the correction of the systematic error. The black points correspond to observed values, the blue ones to simulations for a control period, and the green ones to simulations of future periods. The solid lines are the theoretical distributions of each group. The use of the return period (as inverse of the probability) shows the relations between the groups, exemplified in the cases of 33 and 41 millimetres.

1.9.2. Corrected future scenarios

The correction of future scenarios leads to a new group of data for each simulation carried out that, again, can be analysed statistically to draw conclusions about the future evolution of the precipitation variable. This information is illustrated graphically in Figures 35 and 36, elaborated with the same criteria as detailed above.

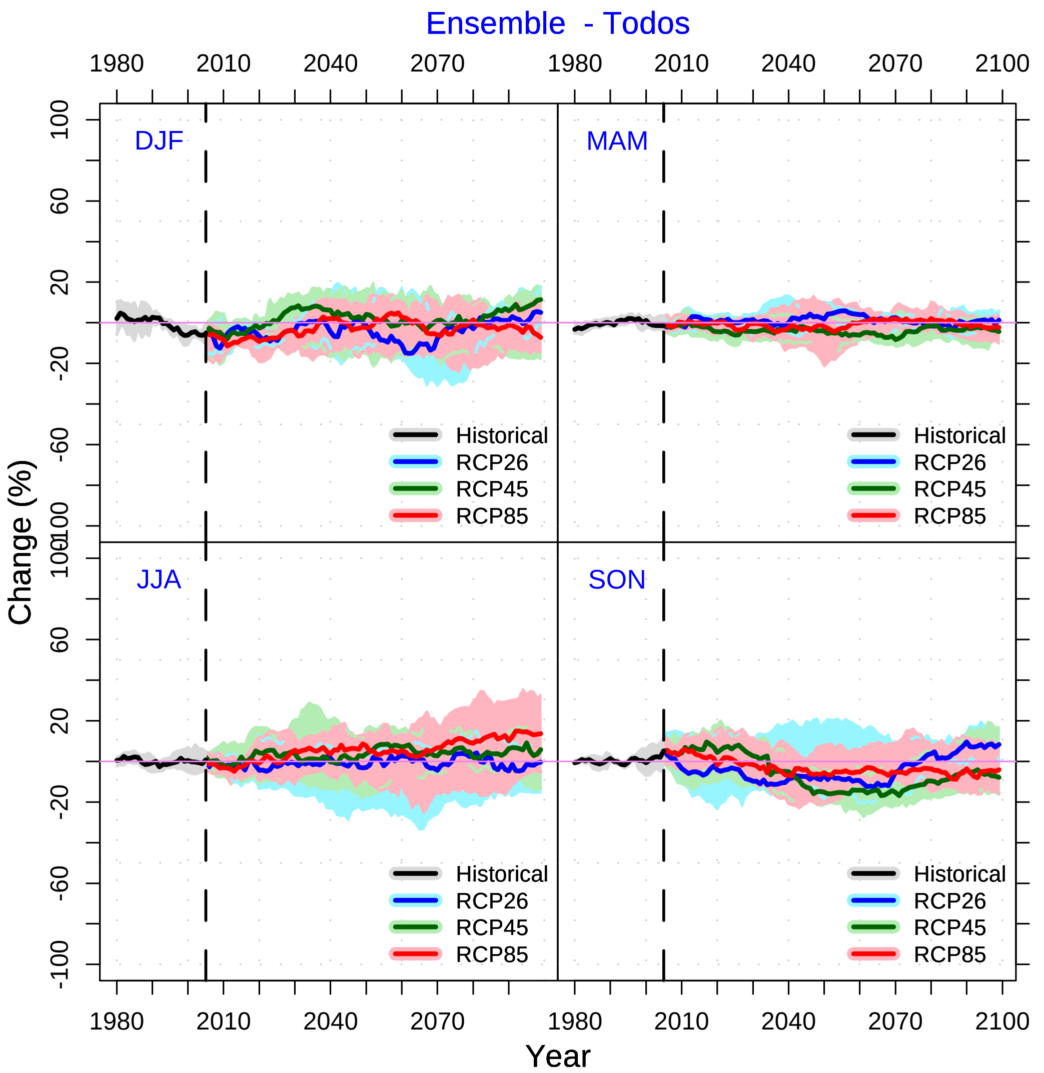
As can be seen in both, the future behaviour of these two measures (absolute increase in precipitation, and relative increase in precipitation) is similar to that described for them before correcting the data, as was to be expected, since the correction of the systematic error should not change the data so much that the climatic conclusions are different, since then the nature of the characteristics of the models would change. The only slight appreciable difference appears, and only at certain points, in the extension of the shadows associated with the simulations, that is, their variability margin (percentiles 90 and 10), and it makes sense that this is the case since some of the corrections of the extremes have been able to change a specific variability margin (the percentiles).

FIGURE 35. **ABSOLUTE SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY**



Absolute seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on all observatories. The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 36. **RELATIVE EXPECTED SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY**

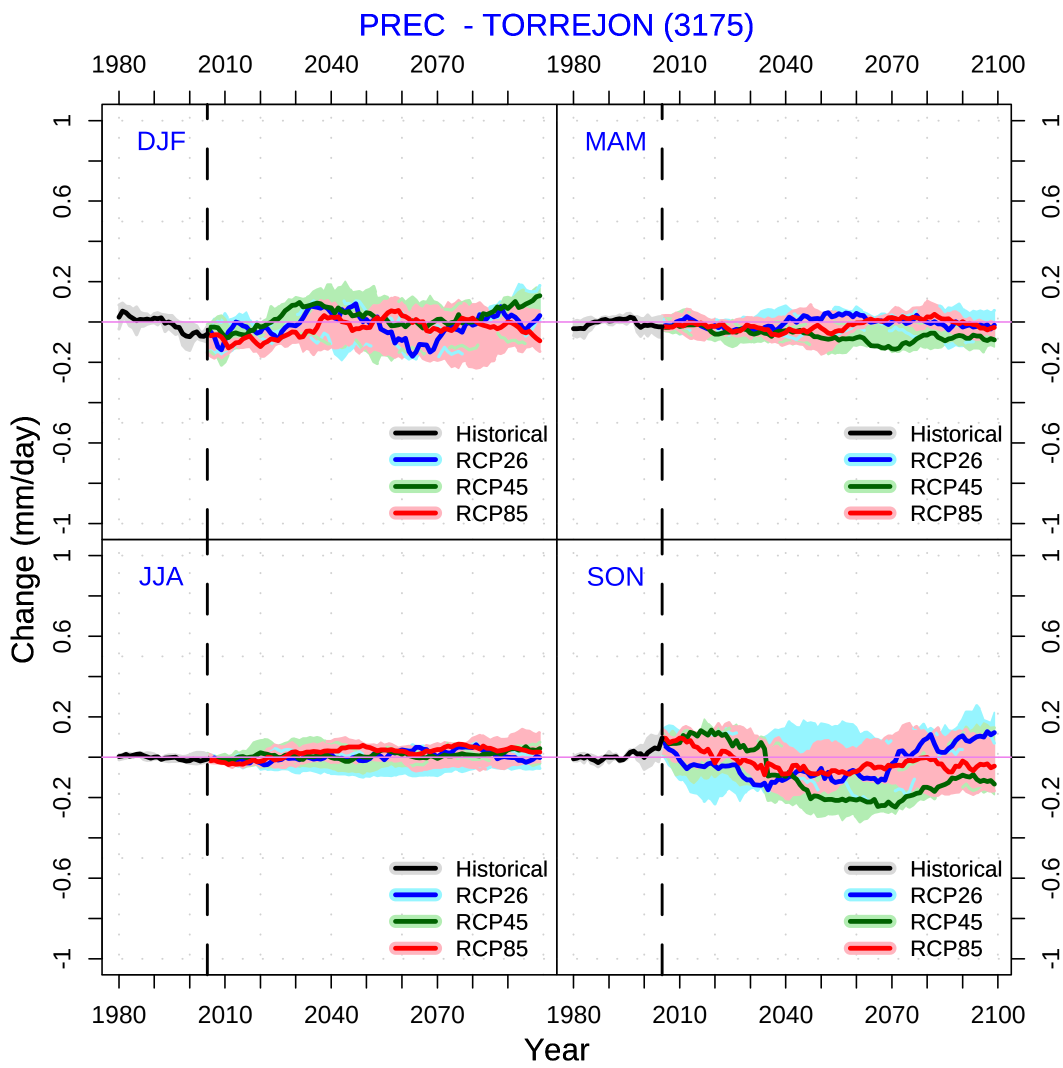


Relative expected seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on all observatories. The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

Figures 37 to 42 show the same results of expected increases, both absolute and relative, with the systematic error corrected, but disaggregated for each of the observatories studied. As can be seen, the conclusions are similar to those obtained for the average of all the observatories.

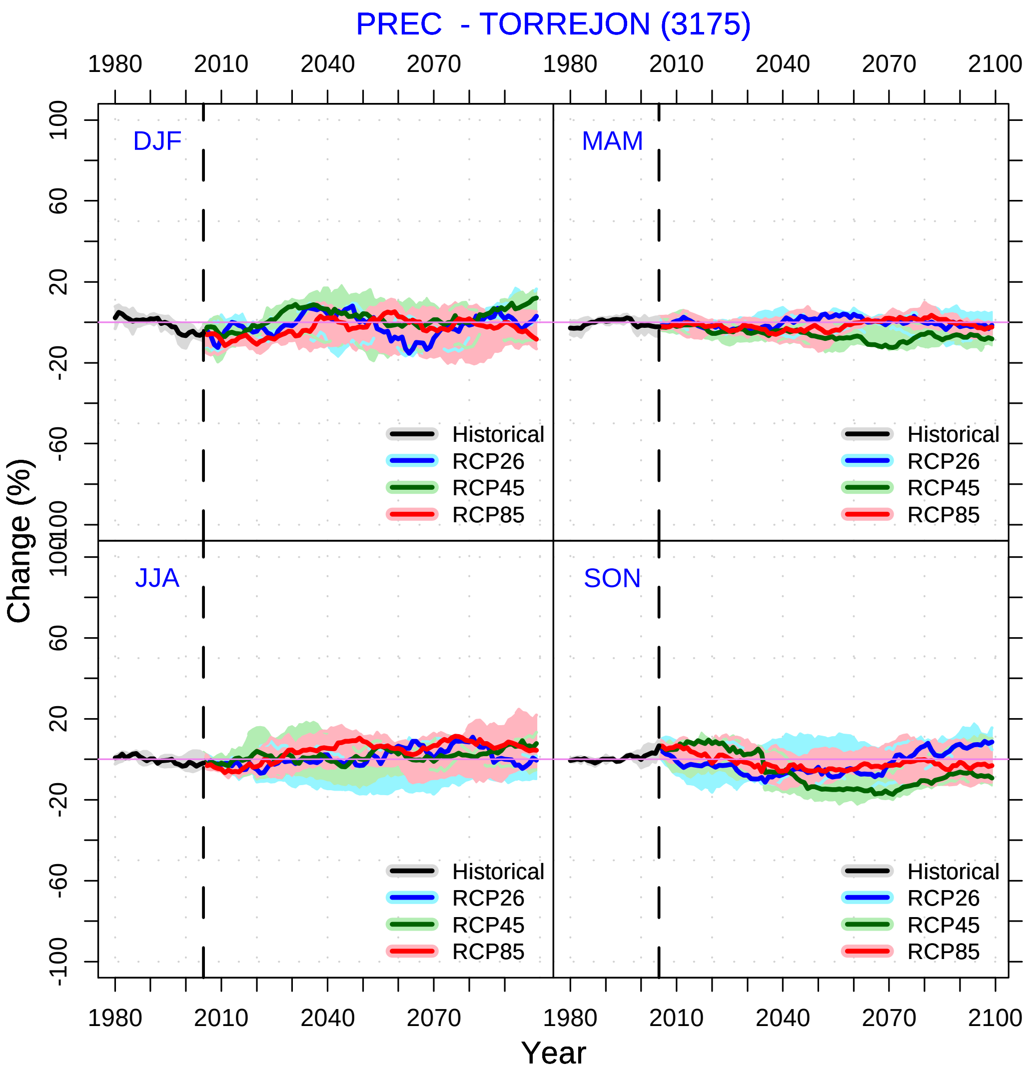
For a better understanding of the results obtained, for each of the observatories, the absolute and relative increases for three periods, 2001-2030, 2041-2070, and 2071-2100, understood as the beginning, middle, and end of the century, were numerically broken down, with respect to reference period 1970-2000, understood as a period of the past (see tables 8 to 10).

FIGURE 37. **ABSOLUTE SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. TORREJÓN OBSERVATORY (3175)**



Absolute seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Torrejón observatory (Identifier 3175). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 38. **RELATIVE EXPECTED SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. TORREJÓN OBSERVATORY (3175)**



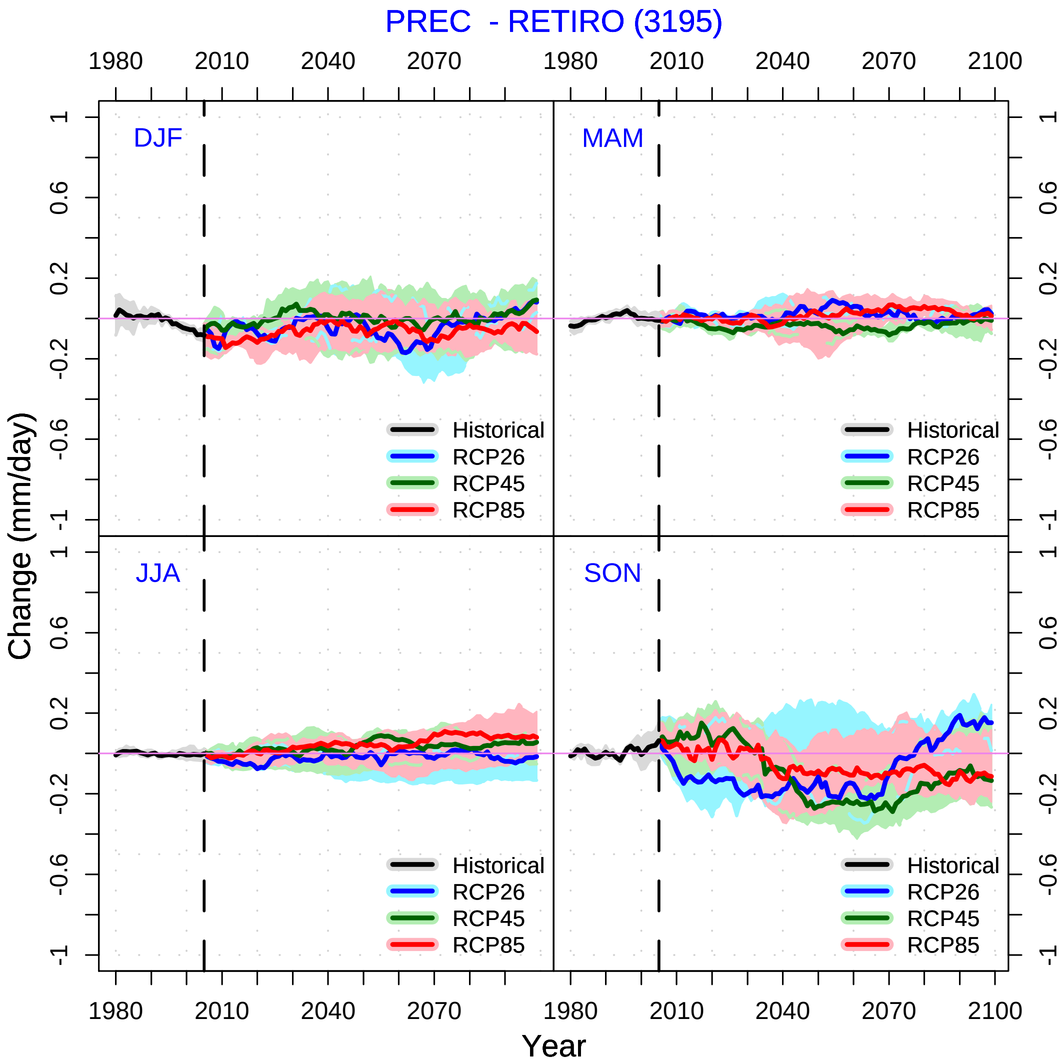
Relative expected seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Torrejón observatory (identifier 3175). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

TABLE 8. TORREJÓN OBSERVATORY

Absolute precipitation increases (milimetres/day) - Torrejón				
Season	***Scenario***	***2001-2030***	***2041-2070***	***2071-2100***
DJF	***RCP 2.6***	0.12	0.07	0.6
	RCP 4.5	0.1	0.07	0.13
	RCP 6.0	0.16	0.18	-0.1
	RCP 8.5	0.1	0.15	0.05
MAM	***RCP 2.6***	-0.04	0	0.04
	RCP 4.5	-0.01	-0.01	-0.06
	RCP 6.0	-0.07	-0.08	-0.12
	RCP 8.5	-0.04	-0.02	-0.08
JJA	***RCP 2.6***	0.03	0.01	0.01
	RCP 4.5	0.02	-0.01	0.01
	RCP 6.0	0.02	0.02	0
	RCP 8.5	0.01	0.03	0.04
SON	***RCP 2.6***	-0.04	-0.03	0
	RCP 4.5	0	-0.06	0.01
	RCP 6.0	-0.03	-0.07	0.06
	RCP 8.5	0.03	-0.04	-0.04
Relative precipitation increases (%) - Torrejón				
Season	***Scenario***	***2001-2030***	***2041-2070***	***2071-2100***
DJF	***RCP 2.6***	10	6	13
	RCP 4.5	8	6	11
	RCP 6.0	13	14	-8
	RCP 8.5	8	13	4
MAM	***RCP 2.6***	-4	0	4
	RCP 4.5	-1	-1	-5
	RCP 6.0	-6	-7	-11
	RCP 8.5	-3	-2	-7
JJA	***RCP 2.6***	6	3	2
	RCP 4.5	4	-1	1
	RCP 6.0	4	3	1
	RCP 8.5	3	6	7
SON	***RCP 2.6***	-3	-2	0
	RCP 4.5	0	-5	0
	RCP 6.0	-3	-6	4
	RCP 8.5	3	-3	-4

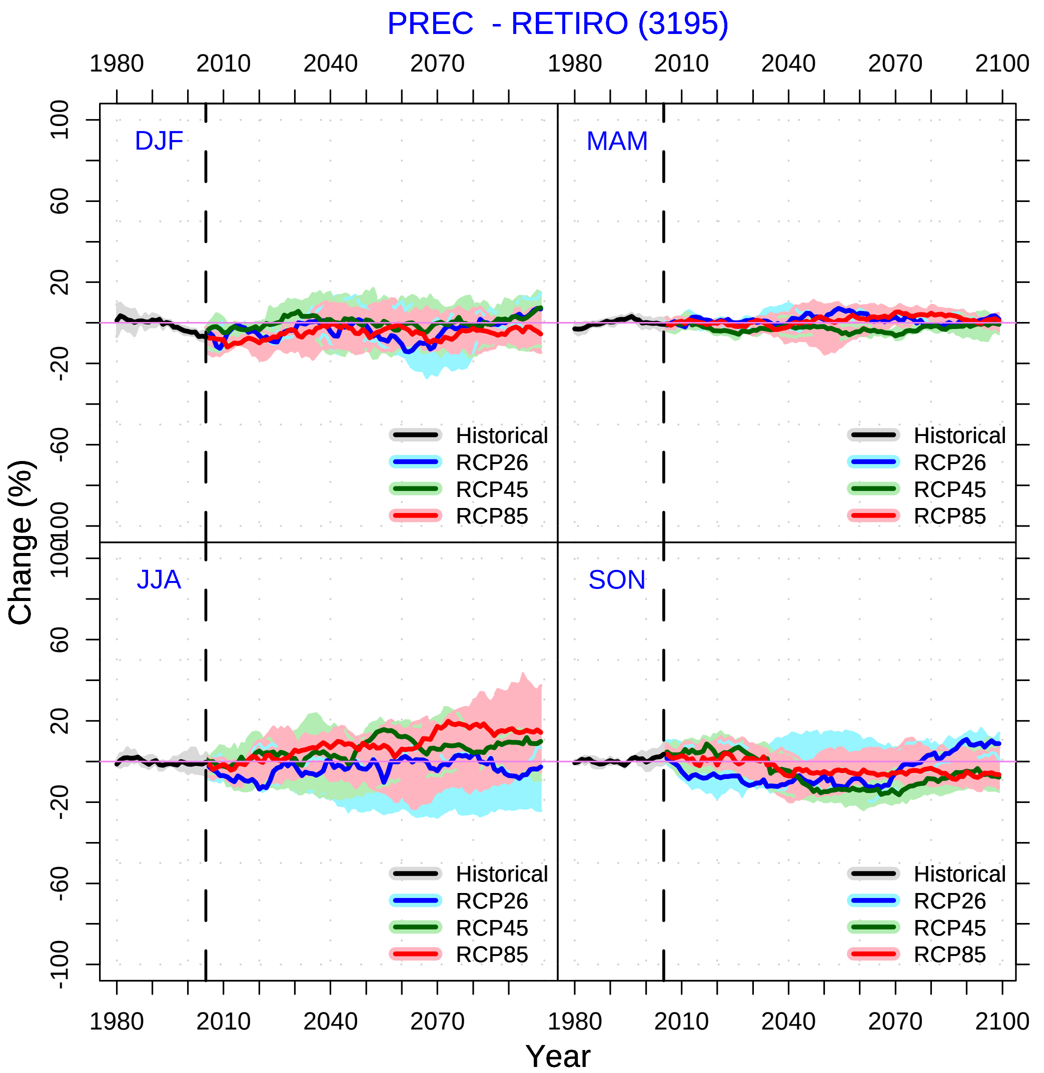
Absolute and relative expected precipitation increases for the Torrejón observatory, in the periods 2001-2030, 2041- 2070, and 2071-2100 (understood as beginning, middle, and end of the century), with respect to the 1970-2000 period (understood as the past). Average results of all models, for each of the seasons of the year and for each of the future scenarios considered.

FIGURE 39. **ABSOLUTE SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. MADRID RETIRO OBSERVATORY (3195)**



Absolute expected seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Madrid Retiro observatory (identifier 3195). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 40. **RELATIVE EXPECTED SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. MADRID RETIRO OBSERVATORY (3195)**



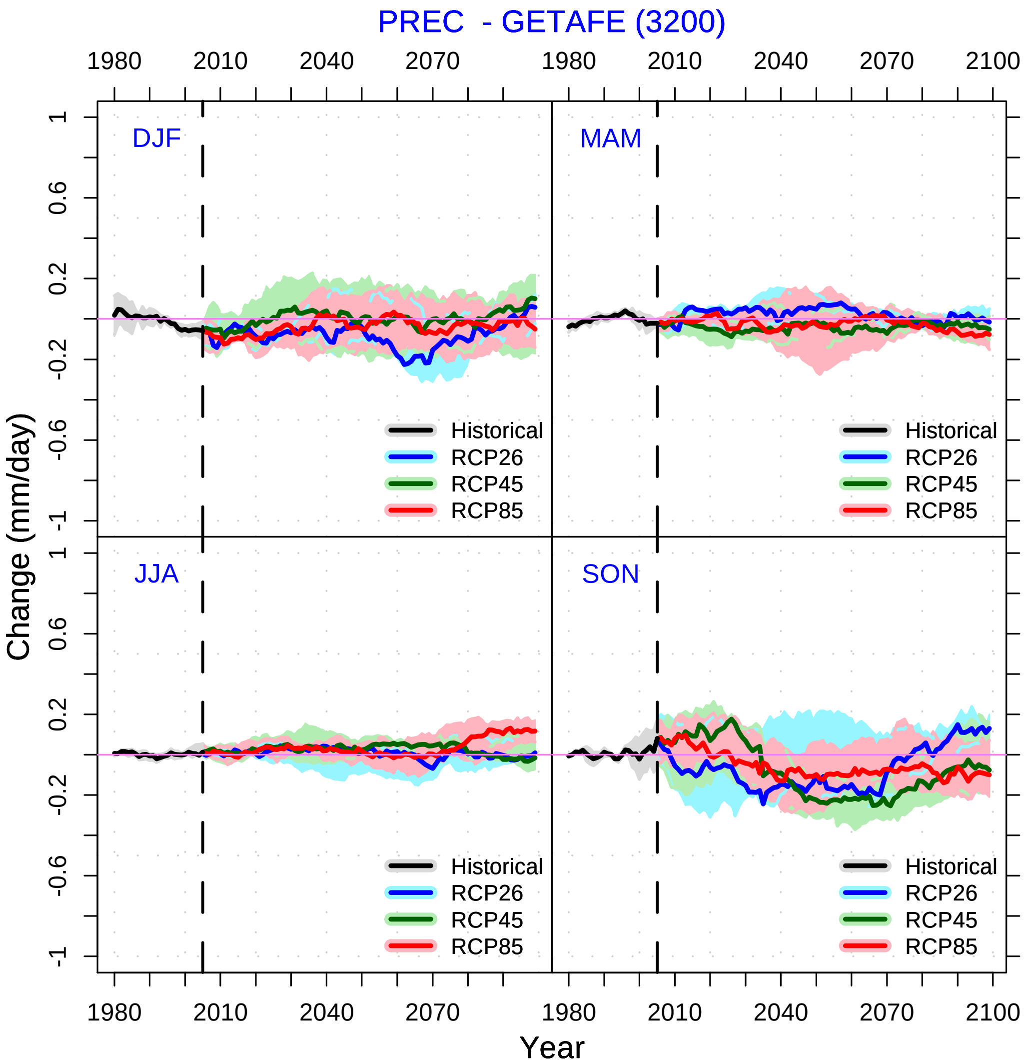
Relative expected seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Madrid Retiro observatory (identifier 3195). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

TABLE 9. **MADRID – RETIRO OBSERVATORY**

Absolute precipitation increases (millimetres/day) – Madrid Retiro				
Season	***Season***	***2001-2030***	***2041-2070***	***2071-2100***
DEF	***RCP 2.6***	0.08	0.07	0.13
	RCP 4.5	0.1	0.11	0.1
	RCP 6.0	0.07	0.09	-0.04
	RCP 8.5	0.08	0.12	0.09
MAM	***RCP 2.6***	-0.05	-0.02	0.05
	RCP 4.5	-0.01	0.01	-0.04
	RCP 6.0	-0.02	-0.04	-0.05
	RCP 8.5	0.02	0.03	-0.09
JJA	***RCP 2.6***	0.04	0.06	0.03
	RCP 4.5	0.05	0.05	0.09
	RCP 6.0	0.08	0.15	0.06
	RCP 8.5	0.08	0.11	0.16
SON	***RCP 2.6***	-0.02	-0.08	-0.02
	RCP 4.5	0.01	-0.07	-0.01
	RCP 6.0	0.03	-0.05	-0.18
	RCP 8.5	0.01	-0.09	-0.12
Relative precipitation increases (%) - Madrid Retiro				
Estación	***Escenario***	***2001-2030***	***2041-2070***	***2071-2100***
DEF	***RCP 2.6***	6	5	9
	RCP 4.5	7	8	7
	RCP 6.0	5	7	-3
	RCP 8.5	5	8	6
MAM	***RCP 2.6***	-4	-2	3
	RCP 4.5	-1	0	-3
	RCP 6.0	-2	-3	-4
	RCP 8.5	1	2	-7
JJA	***RCP 2.6***	7	10	5
	RCP 4.5	9	8	15
	RCP 6.0	14	26	10
	RCP 8.5	14	20	28
SON	***RCP 2.6***	-1	-5	-1
	RCP 4.5	1	-5	-1
	RCP 6.0	2	-3	-12
	RCP 8.5	1	-6	-8

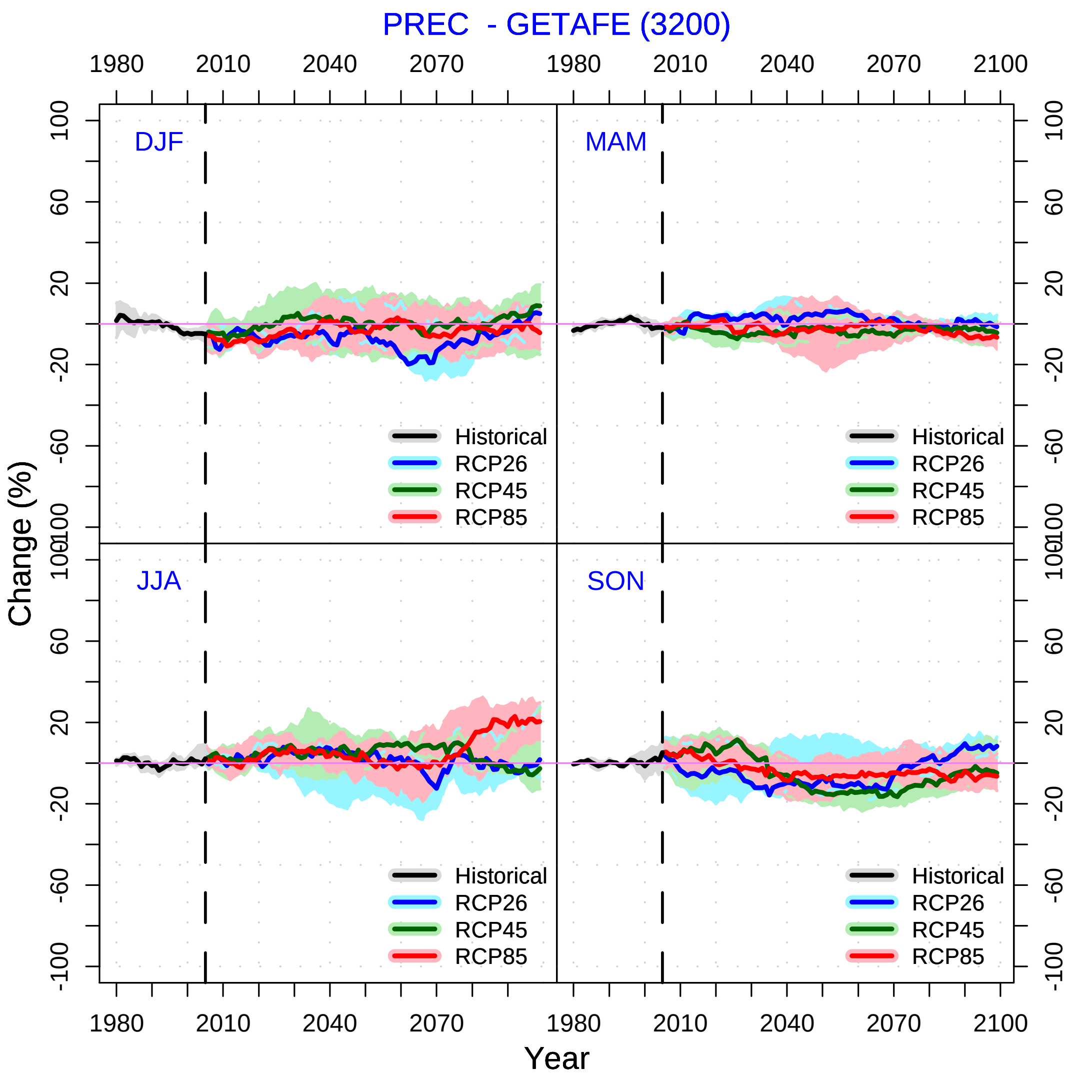
Absolute and relative expected precipitation increases for the Madrid Retiro observatory, in the periods 2001-2030, 2041-2070, and 2071-2100 (understood as beginning, middle, and end of the century), with respect to the 1970-2000 period (understood as the past). Average results of all models, for each of the seasons of the year and for each of the future scenarios considered.

FIGURE 41. ABSOLUTE SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. GETAFE OBSERVATORY (3200)



Absolute seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Getafe observatory (identifier 3200). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

FIGURE 42. RELATIVE EXPECTED SEASONAL INCREASES OF THE DATA, WITH CORRECTED SYSTEMATIC ERROR, OF PRECIPITATION FOR THE 21ST CENTURY, REPRESENTED AS 30-YEAR MOVING AVERAGES. GETAFE OBSERVATORY (3200)



Relative expected seasonal increases of the data, with corrected systematic error, of the precipitation for the 21st century, represented as 30-year moving averages, according to the RCP represented (2.6, 4.5, and 8.5), with respect to the average of the period taken as a reference (1971-2000). The broken line marks the end of the Historical experiment and the beginning of the RCP. Simulations of all models on the Getafe observatory (identifier 3200). The lines show the median of all the values; the shaded areas cover from the 10th to the 90th percentile.

TABLE 10. GETAFE OBSERVATORY

Absolute precipitation increases (millimetres/day) – Getafe				
Season	***Scenario***	***2001-2030***	***2041-2070***	***2071-2100***
DJF	***RCP 2.6***	0.07	0.07	0.14
	RCP 4.5	0.13	0.14	0.14
	RCP 6.0	0.07	0.07	-0.11
	RCP 8.5	0.08	0.12	0.12
MAM	***RCP 2.6***	-0.02	0	0.05
	RCP 4.5	-0.01	-0.02	-0.02
	RCP 6.0	0.1	-0.03	-0.06
	RCP 8.5	0.05	0	-0.07
JJA	***RCP 2.6***	-0.02	-0.01	0.02
	RCP 4.5	0	0.01	-0.02
	RCP 6.0	0	0.03	-0.01
	RCP 8.5	0.02	0.02	0.08
SON	***RCP 2.6***	-0.01	-0.06	0.04
	RCP 4.5	-0.02	-0.06	-0.04
	RCP 6.0	0.05	0	0.12
	RCP 8.5	-0.03	-0.07	-0.05
Relative precipitation increases (%) - Getafe				
Season	***Scenario***	***2001-2030***	***2041-2070***	***2071-2100***
DJF	***RCP 2.6***	5	5	11
	RCP 4.5	10	11	11
	RCP 6.0	5	5	-9
	RCP 8.5	6	10	9
MAM	***RCP 2.6***	-1	0	4
	RCP 4.5	-1	-2	-2
	RCP 6.0	8	-3	-5
	RCP 8.5	4	0	-6
JJA	***RCP 2.6***	-3	-2	3
	RCP 4.5	0	1	-3
	RCP 6.0	1	5	-1
	RCP 8.5	4	4	14
SON	***RCP 2.6***	-1	-5	3
	RCP 4.5	-2	-4	-3
	RCP 6.0	4	0	9
	RCP 8.5	-2	-5	-4

Absolute and relative expected precipitation increases for the Getafe observatory, in the periods 2001-2030, 2041-2070, and 2071-2100 (understood as the beginning, middle, and end of the century), with respect to the 1970-2000 period (understood as the past). Average results of all models, for each of the seasons of the year and for each of the future scenarios considered.

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1.10. CONCLUSIONS

1.10.1. On the "*Downscaling*" methodology

The methodology used to carry out the regionalisation records very well the climatic variation of precipitation (its annual cycle): low precipitation in the summer months, a strong increase in the autumn months (September, October, and November), high precipitation in winter (December, January, and February), and a recovery in spring (March, April, and May). On the downside, the extremes of October and November are not recorded adequately, a situation caused by the fact that the rainfall in those months is particularly determined by convective phenomena (such as storms), a few small or medium-sized phenomena that are not able to be completely recorded by the models since their large grid sizes do not allow correct specification of those phenomena.

To clarify the good features of the methodology, two statistics were evaluated. In the first place, the **BIAS** (average of the differences), which when oscillating around 0, in general, expresses that the methodology does not introduce any bias in the simulations carried out (at least not in climatic terms). The greatest bias introduced corresponds to the months of October and November due to the predominantly convective nature of the rainfall in those months.

Secondly, the **MAE** (mean of the absolute value of the differences), shows that the range of variability of the simulation is not able to adjust exactly to the range of variability of the observation, a phenomenon common to the statistical downscaling processes. In the specific case of these observatories studied, the high **MAE**, corresponding to summer, indicates that the results that can be obtained for that season of the year must be treated with extreme caution.

1.10.2. On future scenarios

The results obtained for the observatories studied show that the absolute increases of precipitation in the spring and summer are practically non-existent and climate change that particularly varies the precipitation regime with respect to the past is not expected. Winter, after a first stage of descent, shows a continuous evolution except for the **RCP** 2.6 scenario, which shows a certain decrease with a succession of changes such as the oscillation recorded here, it seems to suggest that the changes are more due to the climatic variability of the precipitation than to the climatic response associated with the radiative forcing of the different RCP. Autumn, after a start of different orders in accordance with the RCP considered (positive, negative increase, or no increase), is the only season that shows a continued decline for the remaining period of the century, with a slight recovery at the end of it (especially for **RCP** 2.6). It should be note that it is speaking of average precipitation and not of the intensity peaks in the extreme rainfall events that will be discussed in the next chapter.

If the relative increases obtained are studied, similar conclusions are obtained; the main difference is that the increases expected in summer show a greater variation, an effect caused by the fact that, with summer being a season with such low precipitation, small absolute increases will reflect higher relative increases.

2. Calculation of climate change coefficients for different horizons and scenarios, from daily precipitation projections

2.1. INFLUENCE OF CLIMATE CHANGE ON THE PRECIPITATION OF THE PENINSULA IBÉRICA

In the recent research on the climate of the Peninsula Ibérica and the repercussions of climate change on the precipitation regime, most authors (Pérez and Boscolo, 2010) agree that the annual rainfall in the Peninsula Ibérica, **PI**, in the last three decades has decreased significantly compared to the 60's and 70's, especially in late winter. In particular, the last decade has recorded the lowest values of annual precipitation since 1950. However, the strong year-to-year variability and the lack of series that date back to the beginning of the century prevents research from stating that rainfall has fallen in a generalised manner to historic lows. Overall, the anthropogenic signal in precipitation has not emerged clearly above the natural "background noise".

The global increase in the temperature of the planet will undoubtedly lead to permanent alterations in the hydrological cycle, so changes in the spatial distribution of precipitation can be expected, with increases in some areas and decreases in others. Even if the total amount of precipitation does not change, the frequency of rainy days or the intensity of precipitation could undergo strong variations in response to an increase in atmospheric concentration of water vapour, which complicates the detection of a possible anthropogenic signal. It is also important to bear in mind that even a small movement in the mean precipitation value could lead to major changes in the distribution of extreme values, so it is also necessary to examine possible variations in the frequency of extreme precipitation events. It is also argued that global warming could lead to an increase in extreme precipitation events. In accordance with these theoretical predictions, 21st century simulations with climate models predict significant decreases in precipitation in the Peninsula Ibérica, especially in summer, where the decline could reach 50% by the end of the 21st century.

With regard to the regional projections of future climate on the Peninsula Ibérica, the main conclusions of the reports and work carried out point to a general decrease in precipitation in summer, and in winter there is a north-south structure, with slight increases in the northern half and decreases in the southern part. However, the discrepancies between the results of the different models are greater than those obtained when comparing temperatures. A decrease in the total number of rainy days in all seasons and for the entire region is also obtained. Other authors find that the functions of probability distribution of annual precipitation changes indicate a decrease of between 18% and 0.4% for percentiles 1 and 99. The daily precipitation distribution function points towards a decrease in light precipitation values.

Some authors (Buonomo et al., 2007) have found that changes in extreme amounts of rainfall are greater the greater the rainfall return period is and the lesser the duration considered is. Thus, for the European region, on average, rainfall in 24 hours of 20-year return period will increase by 18% by the end of the 21st century, while, for a 2-year return period, the average increase will be 13%. The increases are smaller when durations greater than 24 hours are considered.

In general, there is an increase in extreme rainfall as opposed to a decrease in average annual precipitation, which indicates a change in the climate of the future with a substantial reduction in the occurrence of weak and moderate rainfall and an increase in episodes of intense rainfall.

2.2. ANALYSIS OF THE DAILY PRECIPITATION SERIES 2006-2100

This section presents the results of the analysis of the daily precipitation series, simulated by the Foundation for Climate Research (hereinafter **FIC**) for the period 2006-2100, based on the information provided by different general circulation models.

The series correspond to three thermopluviometric (hereinafter, **TP**) stations that the State Meteorological Agency (**AEMET**) installed in the metropolitan area of Madrid, (Madrid-Retiro, observatory 3195, Madrid- Torrejón, observatory 3175 and Getafe, observatory 3200). Nine General Circulation Models (GCM) and four future climate scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) were used.

The daily rainfall series were considered for each of the three TP stations corresponding to three future climate periods (2006-2036, 2037-2068, 2069-2100), and to the historical control period (1951-2005), with them being subdivided into the four seasons of the year (spring, summer, autumn and winter). In this manner, a total of 1,530 series have been analysed. The corresponding series of maximum daily rainfall were obtained from them (see Figure 43).

In order to calculate the maximum daily rainfall corresponding to different return periods, the series have been adjusted to the distribution function of extreme values **SQRT-ETmax**, proposed by Etoh et al. (1987) and Zorraquino (2004).

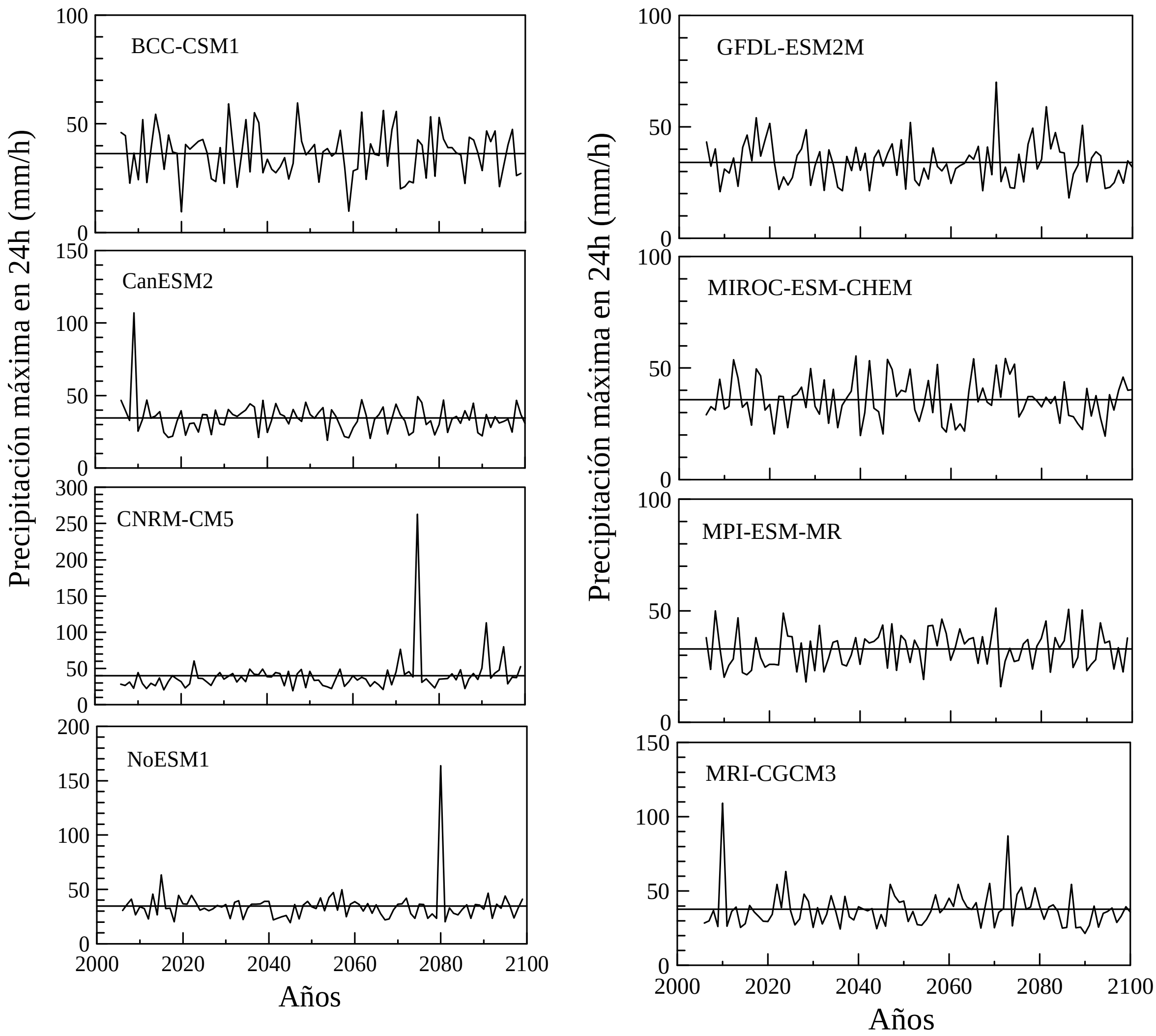
The chosen return periods were 2, 5, 10, 20, 50, 100, 200 and 500 years. In all cases, the chosen distribution function correctly adjusts the data. Figure 44 shows some of these adjustments.

The climate change factor, ***CF***, (Arnbjerg-Nielsen, 2008) is the quotient between the rainfall intensity of the return period ***T*** and the duration ***d*** corresponding to a future climate scenario, $I(T,d)_{Future}$ and the equivalent rainfall intensity in the present climate $I(T,d)_{Present}$, this is:

$$FC = \frac{I(T,d)_{Futuro}}{I(T,d)_{Presente}} \quad (2)$$

These climate change factors can be calculated, for each return period, from the simulated daily precipitation series and those corresponding to the historical control period (present climate).

FIGURE 43. **SERIES OF ANNUAL MAXIMUM PRECIPITATION IN 24 HOURS, CORRESPONDING TO THE GETAFE TP STATION AND SCENARIO RCP 2.6**



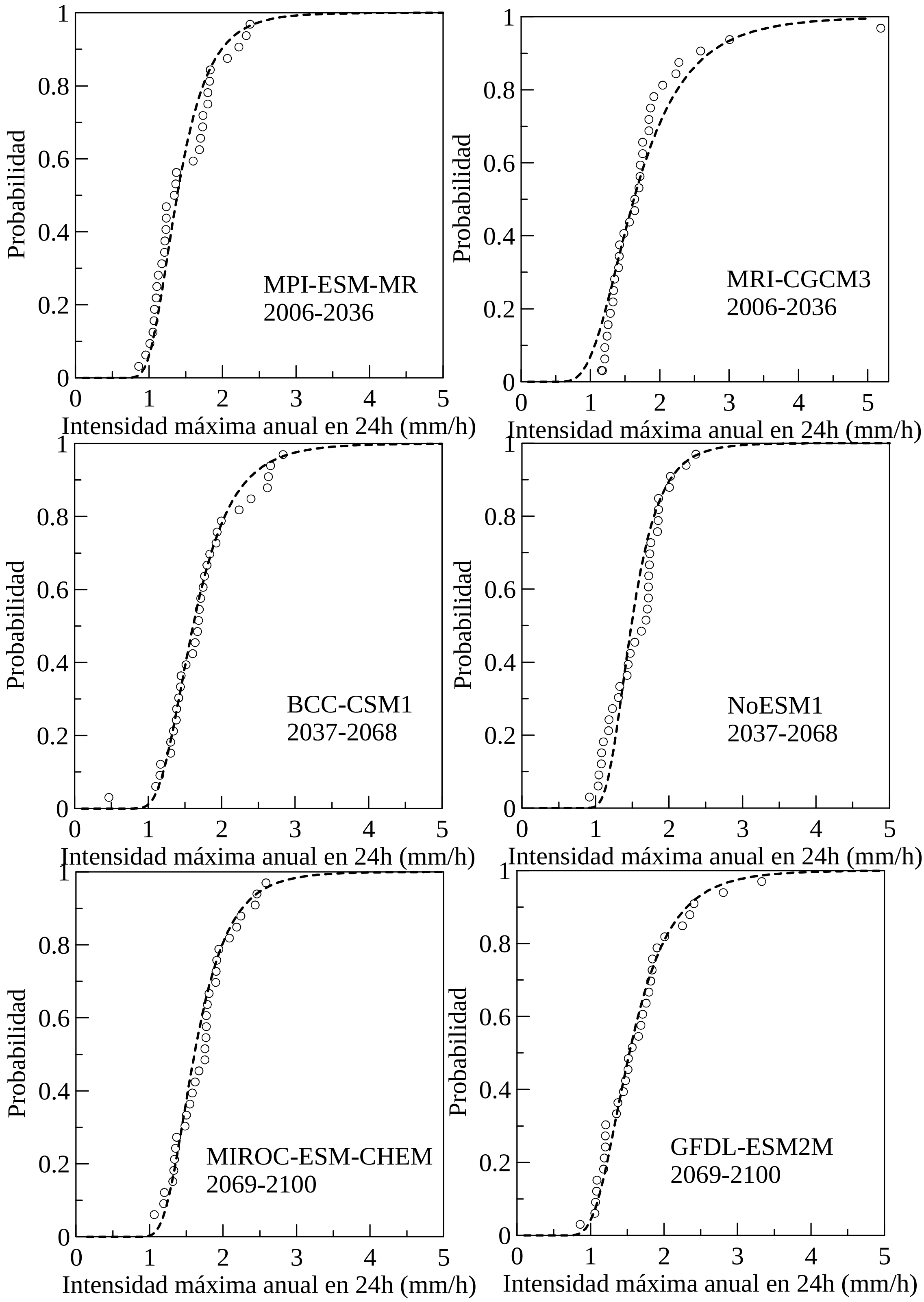
The **CF** were calculated, corresponding to the maximum rainfall in 24 hours for each of the three TP stations, and for each climate change scenario and general circulation model (24 cases correspond to the **RCP 2.6** scenario, 27 cases to **RCP 4.5**; 15 cases to **RCP 6.0** and 27 cases to the **RCP 8.5** scenario).

Figure 45 shows the results obtained for one of the scenarios contemplated.

To understand the limitation of the results, it is appropriate to carry out a prior verification on the uncertainty associated with the climate change factors, comparing the observations of the current IDF curves with those obtained from the simulations of the historical control periods of the models (Willems and Vrac, 2011).

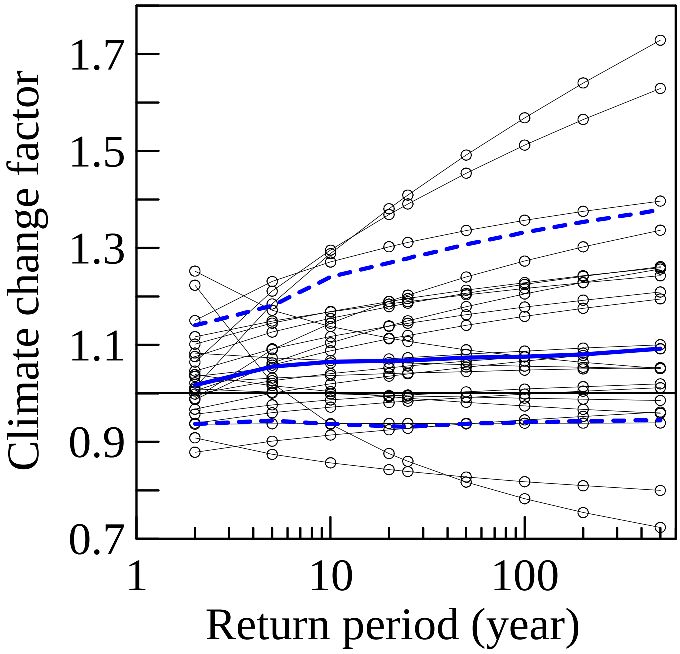
Figure 46 shows the comparison between the intensity values for different return periods corresponding to 24 hours, based on historical rainfall observations of the three TP stations in Madrid Region and the intensity- frequency values obtained from the climatic models for the historical control period, averaged for the three TP stations.

FIGURE 44. **ADJUSTMENTS OF SOME ANNUAL MAXIMUMS SERIES IN GETAFE TP STATION**



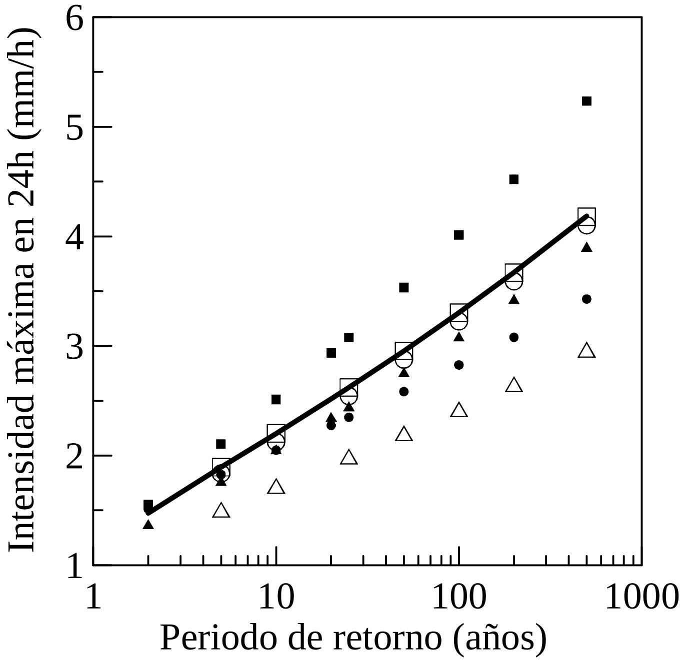
Adjustments of some annual maximums series under the RCP 2.6 scenario to the SQRT-ETmax function in Getafe TP Station.

FIGURE 45. **CLIMATE FACTORS (CF) OBTAINED IN 24 CASES OF THE RCP 2.6 SCENARIO IN ACCORDANCE WITH THE RETURN PERIOD**



Climate factors (CF) obtained in the 24 cases of the RCP 2.6 scenario in accordance with the return period. The continuous blue line represents the median of the set of cases corresponding to all the models and all the TP stations, and the broken lines represent the percentiles: upper, P90, and lower, P10.

FIGURE 46. **CURRENT VALUES OF MAXIMUM INTENSITY IN 24 HOURS, FOR DIFFERENT RETURN PERIODS BETWEEN 2 YEARS AND 500 YEARS**



Current values of maximum intensity in 24 hours, for different return periods between 2 years and 500 years, obtained from the annual maximums series of the stations 3195 Retiro (square), 3200 Getafe (circle) and 3175 Torrejón (triangle), compared to the average intensity values obtained for the historical control periods of the nine GCMS models considered for each TP station, 3195 Retiro (black square), 3200 Getafe (black circle) and 3175 Torrejón (black triangle). The solid line shows the average of the three TP stations).

2.3. CALCULATION OF THE MAXIMUM HOURLY INTENSITY FOR DIFFERENT CLIMATE CHANGE SCENARIOS AND THE OBTAINING OF THE CLIMATE CHANGE FACTOR (CF)

From the precipitation series simulated by the FIC, for the three TP stations (Madrid-Retiro, Madrid- Getafe and Madrid-Torrejón), the maximum daily rainfall intensity values were obtained for the different climate scenarios, in accordance with the return period, for the Madrid area. When it is wanted to calculate the ***Intensity, Duration and Frequency*** curves for the different climate scenarios from them it is necessary to apply some scale reduction technique or hypothesis that allows research to estimating rainfall intensities for shorter durations than those decided by the climate simulation models, which do not go beyond 24 hours of temporary resolution.

This method of obtaining IDF curves has been applied by different authors (Benjoudi et al., 1997, De Michele et al., 2002, Pao-Shan et al., 2004, Desramaut, 2008, Rodríguez et al., 2013) as a downscaling technique for the intensity of rainfall from low to high resolution and, in essence, consists of applying the invariance of scale that is characteristic of fractal processes.

Many atmospheric processes, among which are the generation of rainfall, are produced by complex dynamic processes that act over a wide time range, the repetition of the dynamics of the phenomenon, at different time scales, means that the phenomenon has the same aspect, independently of the scale on which it was contemplated (*self-similarity*). It can be considered to be a fractal-type process, and its properties obey potential laws of the scale parameter, the so-called **scale laws**. The potential laws are free of any characteristic scale and no other type of function possesses this property. The scale parameter **λ** is defined as the ratio between the work scale (any scale from the resolution, to the length of the series) and the resolution scale of the phenomenon (in this case, 1 day). The properties of this type of process can obey a simple scale, with a single constant exponent that governs them and that is related to the fractal dimension (monofractal behaviour) or follow a multiscale (multifractal) behaviour in which the exponent is a function.

The *self-similarity* of natural fractal processes, such as rainfall generation, is statistical, as opposed to mathematical fractals in which the parts are an exact copy of the whole. Therefore, the scale properties of phenomena such as rainfall are expressed by certain statistical relationships that describe their fractal behaviour (Schertzer and Lovejoy, 1987). The precipitation intensity probability distribution, and also the distribution of the maximum precipitation intensities, fulfil scale relationships (Koutsoyiannis and Foufoula-Georgiu, 1993, Burlando and Rosso, 1996, Menabde et al., 1999), which means that the probability distribution (**Id**) of the annual maximum daily intensity series (duration **d0** = 1 day) will be related with the corresponding (**Id0**) to another scale (duration d = **λ d0**), by a factor that is a potential function of the scale parameter **λ**:

$$I_d \overset{dist}{=} \lambda^{\beta} \cdot I_{d_0} \tag{3}$$

This equality must be understood as an equality between probability distribution functions.

The scale invariance of statistical distributions is evident in the equality of its statistical moments of order **q**.

$$\langle I_d^q \rangle = \lambda^{K(q)} \cdot \langle I_{d_0}^q \rangle$$

(4)

If the scale function **K(q)** is linear **(K(q) = βq)**, the process is of a simple or monofractal scale and, if not, the process is multiscale or multifractal.

The adjustments obtained between the scale function **K(q)** and the order **q** of the moments in the series determine the **β** exponent of the potential function that expresses the dependence with the duration of the maximum rainfall intensity.

$$I(T,d) = \frac{f(T)}{d^{\beta}}$$

(5)

From equation (5), and making use of the calculated **β** exponent values, the maximum intensities can be obtained for a duration of 1 hour and for the different selected return periods, according to the following relationship:

$$I(T,d) = I(T,24) \times \left(\frac{24}{d}\right)^{\beta}$$

$$\mathrm{I(T,d)} = \frac{\mathrm{f(T)}}{\mathrm{d}^{\beta}}$$

(6)

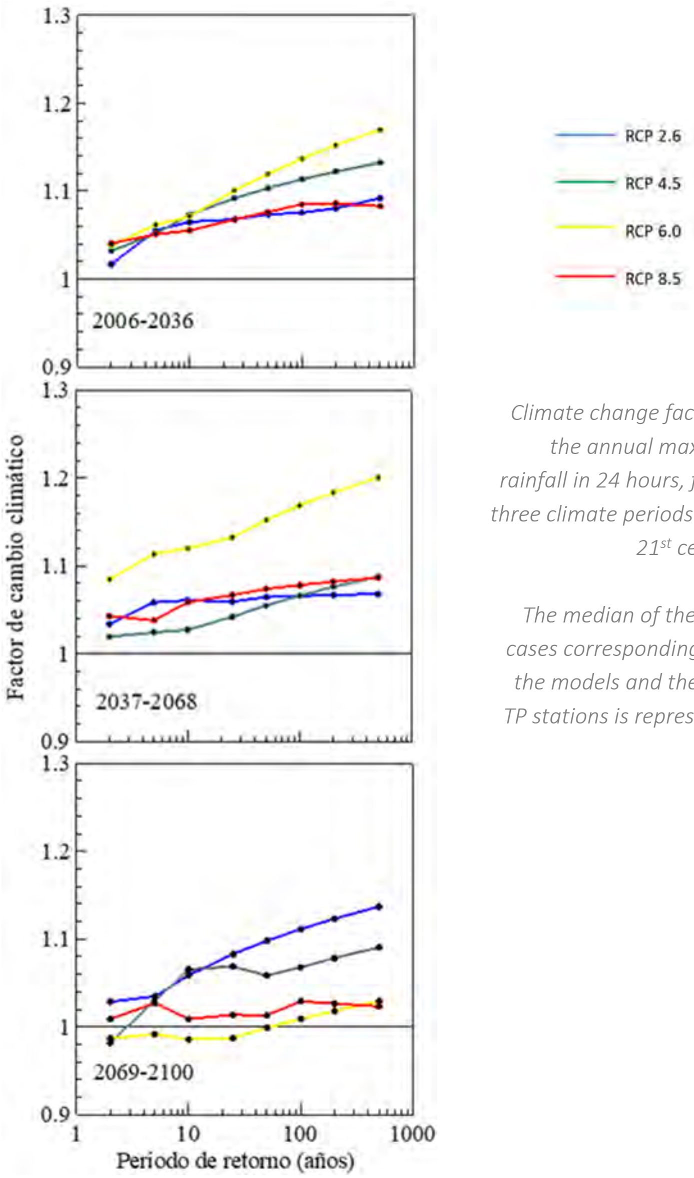
Once the maximum hourly intensity has been calculated for the return periods and the scenarios that have been considered, including the control period, the climatic factor for a duration of 1 hour has been calculated, using equation (2), for all cases studied.

2.4. AVERAGE ANNUAL CLIMATE ELEMENTS OF THE THREE THERMOPLUVIOMETRIC (TP) STATIONS

In this section, the annual climatic factors have been calculated by averaging the results of the three **TP** stations. For this purpose, the annual **CF** corresponding to the maximum rain in 24 hours, for each of the three TP stations, and for each climate change scenario and general circulation model was firstly obtained. Then, for each scenario, the median of the cases corresponding to all the models and to the three TP stations was calculated. The dispersion of the results was quantified from the 90th and 10th percentiles of the set of cases.

Figure 47 shows the medians of the annual climate change factors (CF) for the four climate change scenarios that were contemplated in the study, grouped into the periods 2006-2036, 2037-2068 and 2069- 2100. Table 11 shows the results obtained for the four climate change scenarios considered and the climate periods analysed.

FIGURE 47. CLIMATE CHANGE FACTOR FOR THE ANNUAL MAXIMUM RAINFALL IN 24 HOURS, FOR THE THREE CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for the annual maximum rainfall in 24 hours, for the three climate periods of the 21st century.

The median of the set of cases corresponding to all the models and the three TP stations is represented.

TABLE 11. ANNUAL CLIMATE FACTOR AND PERCENTILES 10 & 90, FOR MAXIMUM RAINFALL IN 24 H.

Annual		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
	T (years)	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	2	1.02	0.94	1.14	1.03	0.94	1.17	1.04	0.95	1.14	1.04	0.96	1.11
	5	1.06	0.94	1.18	1.05	0.93	1.23	1.06	0.96	1.18	1.05	0.94	1.17
	10	1.07	0.94	1.24	1.07	0.91	1.32	1.07	0.93	1.22	1.06	0.93	1.21
	20	1.07	0.93	1.28	1.09	0.85	1.41	1.10	0.91	1.27	1.07	0.92	1.24
	50	1.07	0.94	1.31	1.10	0.82	1.44	1.12	0.89	1.31	1.08	0.92	1.25
	100	1.08	0.94	1.33	1.11	0.81	1.46	1.14	0.88	1.34	1.09	0.92	1.26
	200	1.08	0.94	1.35	1.12	0.79	1.48	1.15	0.87	1.37	1.09	0.92	1.28
	500	1.09	0.94	1.38	1.13	0.78	1.51	1.17	0.86	1.40	1.08	0.92	1.29
2037 - 2068	2	1.03	0.99	1.12	1.02	0.91	1.10	1.08	0.94	1.14	1.04	0.94	1.12
	5	1.06	0.96	1.11	1.02	0.92	1.12	1.11	0.90	1.31	1.04	0.92	1.18
	10	1.06	0.92	1.14	1.03	0.93	1.14	1.12	0.88	1.41	1.06	0.91	1.21
	20	1.06	0.87	1.17	1.04	0.91	1.16	1.13	0.86	1.53	1.07	0.89	1.24
	50	1.06	0.85	1.20	1.05	0.90	1.17	1.15	0.85	1.61	1.07	0.88	1.26
	100	1.07	0.83	1.22	1.07	0.89	1.18	1.17	0.83	1.69	1.08	0.87	1.28
	200	1.07	0.82	1.24	1.08	0.88	1.20	1.18	0.82	1.75	1.08	0.86	1.30
	500	1.07	0.80	1.26	1.09	0.88	1.21	1.20	0.81	1.84	1.09	0.84	1.33
2069- 2100	2	1.03	0.95	1.18	0.98	0.92	1.12	0.99	0.89	1.13	1.01	0.91	1.12
	5	1.03	0.95	1.36	1.03	0.90	1.23	0.99	0.89	1.19	1.03	0.91	1.17
	10	1.06	0.89	1.44	1.07	0.90	1.29	0.99	0.87	1.27	1.01	0.89	1.20
	20	1.08	0.85	1.54	1.07	0.90	1.39	0.99	0.84	1.32	1.01	0.86	1.22
	50	1.10	0.83	1.60	1.06	0.89	1.46	1.00	0.82	1.36	1.01	0.85	1.24
	100	1.11	0.82	1.65	1.07	0.88	1.53	1.01	0.80	1.39	1.03	0.83	1.26
	200	1.12	0.80	1.70	1.08	0.87	1.58	1.02	0.79	1.41	1.03	0.82	1.28
	500	1.14	0.79	1.76	1.09	0.87	1.64	1.03	0.78	1.45	1.02	0.80	1.31

Annual climate factor and percentiles 10 and 90, for maximum rainfall in 24 hours

Going into further detail, the method to obtain the IDF curves from the historical records of daily rainfall consists in applying the scale invariance characteristic of the fractal processes to determine the **β**-scale exponent of the potential function that expresses the dependence with regard to the duration of maximum rainfall intensity.

Table 12 shows the values of the mean exponent **β**, for all the scenarios and periods considered.

TABLE 12. MEAN EXPONENT (β) FOR ALL PERIODS AND SCENARIOS

Annual		*RCP 2.6*	*RCP 4.5*	*RCP 6.0*	*RCP 8.5*
Historical	0.754				
2006-2036		0.780	0.777	0.784	0.768
2037-2068		0.777	0.782	0.792	0.774
2069-2100		0.796	0.780	0.781	0.782

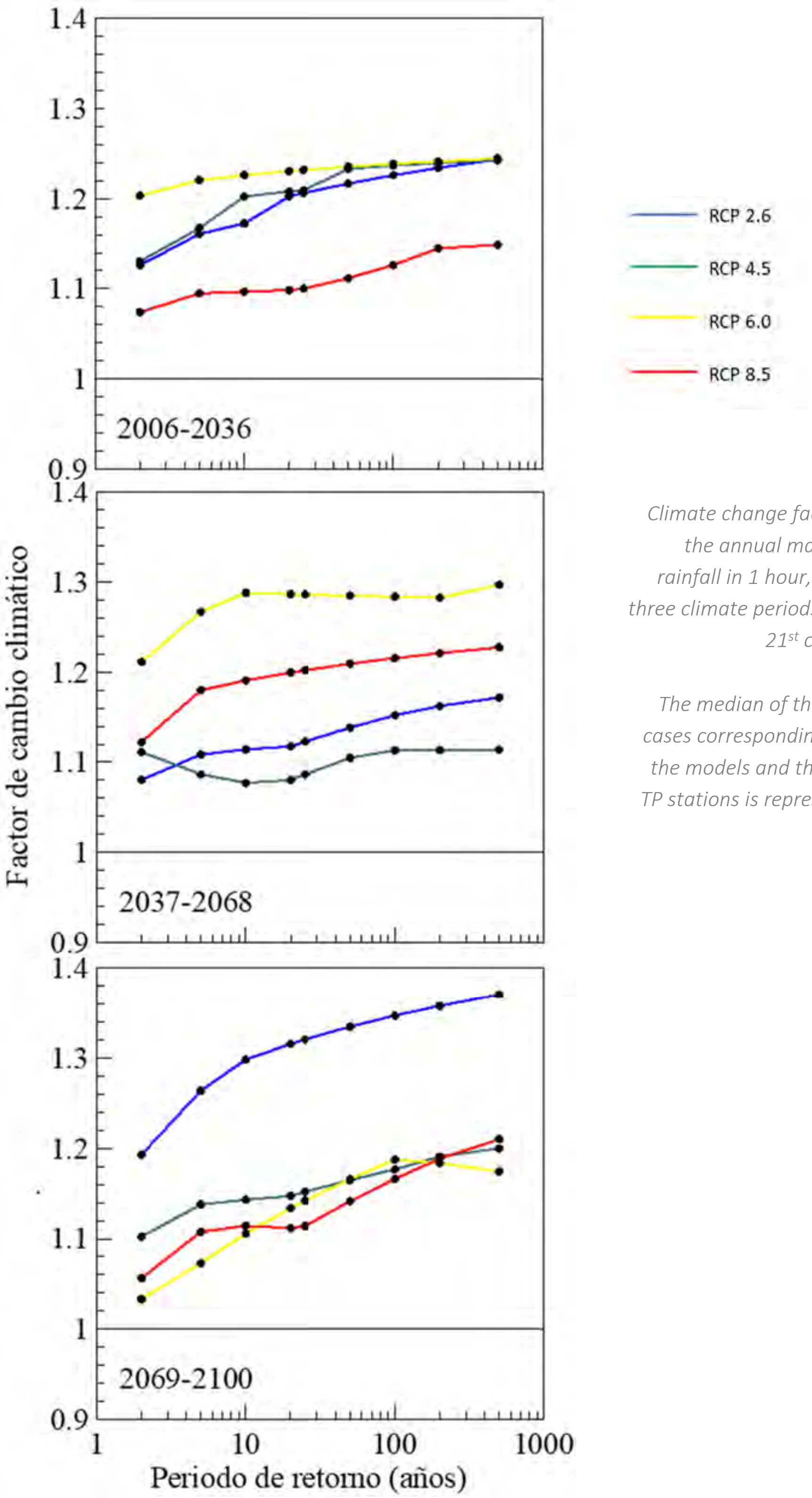
Mean exponent (β) for all periods and scenarios

Using the calculated **β**-exponent values, the maximum intensities were obtained for a duration of 1 hour, and for the different selected return periods.

Once the maximum hourly intensity has been calculated for the return periods and the scenarios that have been considered, including the control period, the climatic factor for a duration of 1 hour for all cases studied has been calculated.

The results for all the scenarios and climatic periods considered are shown in Figure 48 and Table 13.

FIGURE 48. CLIMATE CHANGE FACTOR FOR THE ANNUAL MAXIMUM RAINFALL IN 1 HOUR FOR THE THREE CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for the annual maximum rainfall in 1 hour, for the three climate periods of the 21st century.

The median of the set of cases corresponding to all the models and the three TP stations is represented.

TABLE 13. ANNUAL CLIMATE CHANGE FACTOR (CF) FOR A DURATION OF 1 HOUR

Annual		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	T (years)	median	P10	P90	median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.13	0.94	1.34	1.13	0.88	1.50	1.20	0.85	1.35	1.07	0.90	1.33
	5	1.16	0.96	1.42	1.17	0.78	1.65	1.22	0.80	1.43	1.09	0.91	1.35
	10	1.17	0.97	1.46	1.20	0.76	1.71	1.23	0.78	1.49	1.10	0.91	1.37
	20	1.20	0.98	1.49	1.21	0.75	1.79	1.23	0.76	1.54	1.10	0.91	1.38
	50	1.22	0.99	1.54	1.23	0.71	1.87	1.24	0.74	1.59	1.11	0.91	1.41
	100	1.23	0.99	1.59	1.24	0.69	1.94	1.24	0.73	1.63	1.13	0.90	1.43
	200	1.23	0.99	1.65	1.24	0.67	2.00	1.24	0.72	1.66	1.14	0.89	1.45
	500	1.24	0.99	1.71	1.24	0.65	2.08	1.24	0.71	1.70	1.15	0.88	1.47
2037 - 2068	2	1.08	0.91	1.41	1.11	0.92	1.28	1.21	0.90	1.65	1.12	0.85	1.40
	5	1.11	0.85	1.48	1.09	0.92	1.41	1.27	0.89	1.85	1.18	0.83	1.44
	10	1.11	0.81	1.53	1.08	0.91	1.46	1.29	0.88	1.99	1.19	0.81	1.46
	20	1.12	0.79	1.58	1.08	0.91	1.48	1.29	0.87	2.11	1.20	0.79	1.48
	50	1.14	0.76	1.64	1.10	0.90	1.52	1.28	0.85	2.26	1.21	0.77	1.50
	100	1.15	0.75	1.67	1.11	0.89	1.55	1.28	0.84	2.35	1.22	0.76	1.51
	200	1.16	0.74	1.68	1.11	0.89	1.58	1.28	0.83	2.44	1.22	0.75	1.52
	500	1.17	0.72	1.70	1.11	0.88	1.61	1.30	0.82	2.55	1.23	0.73	1.54
2069- 2100	2	1.19	0.90	1.66	1.10	0.81	1.45	1.03	0.80	1.52	1.06	0.87	1.39
	5	1.26	0.77	1.84	1.14	0.81	1.60	1.07	0.76	1.71	1.11	0.84	1.48
	10	1.30	0.70	1.95	1.14	0.82	1.67	1.11	0.74	1.83	1.11	0.82	1.52
	20	1.32	0.68	2.05	1.15	0.82	1.73	1.13	0.72	1.94	1.11	0.80	1.55
	50	1.33	0.67	2.16	1.16	0.82	1.84	1.17	0.70	2.06	1.14	0.78	1.58
	100	1.35	0.66	2.23	1.18	0.82	1.93	1.19	0.69	2.13	1.17	0.76	1.61
	200	1.36	0.65	2.30	1.19	0.82	2.01	1.18	0.68	2.18	1.19	0.75	1.64
	500	1.37	0.65	2.38	1.20	0.82	2.11	1.17	0.67	2.23	1.21	0.74	1.67

Annual climate change factor (CF) for a duration of 1 hour

2.5. CLIMATE FACTORS FOR EACH THERMOPLUVIOMETRIC STATION (TP)

This section presents the annual climate factors of each of the three TP stations. The annual CF were calculated, corresponding to the maximum rainfall in 24 hours, for each of the three TP stations and each climate change scenario and general circulation models.

For each scenario, the median of the cases corresponding to all the models was obtained. The dispersion of the results was quantified from the 90th and 10th percentiles of the set of cases. Tables 14, 15 and 16 present the results obtained for the climate change scenarios considered and the climate periods analysed.

When analysing TP stations separately, only the following are averaged:

- 8 cases corresponding to the RCP 2.6 scenario
- 9 cases to the RCP 4.5 scenario
- 5 cases to the RCP 6.0 scenario
- 9 cases to the RCP 8.5 scenario.

The results corresponding to the RCP 6.0 scenario have not been considered here since the limited numbers of cases means that the result is not representative.

Figures 49, 50 and 51 show the medians of the climate change factors (CF) for maximum annual rainfall in 24 hours, from each of the TP stations, for the four climate change scenarios that have been considered in the study, in the periods 2006-2036, 2037-2068 and 2069-2100.

TABLE 14. ANNUAL CLIMATE FACTOR AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. GETAFE

Getafe		*RCP 2.6*			*RCP 4.5*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	2	1.04	0.94	1.09	1.06	0.98	1.08	1.01	0.97	1.19
	5	1.09	0.97	1.19	1.06	1.01	1.16	1.05	0.98	1.18
	10	1.11	0.98	1.29	1.05	1.01	1.19	1.06	0.99	1.17
	20	1.12	0.97	1.37	1.06	1.01	1.22	1.07	0.99	1.16
	50	1.14	0.97	1.47	1.07	1.00	1.26	1.08	1.00	1.15
	100	1.15	0.97	1.53	1.08	1.00	1.29	1.09	1.00	1.15
	200	1.16	0.96	1.59	1.09	0.99	1.32	1.09	1.01	1.16
	500	1.17	0.96	1.66	1.09	0.99	1.36	1.10	1.01	1.17
2037 - 2068	2	1.05	0.99	1.10	1.01	0.92	1.09	1.04	0.92	1.10
	5	1.08	0.96	1.11	1.03	0.95	1.11	1.06	0.93	1.13
	10	1.08	0.95	1.12	1.04	0.95	1.11	1.06	0.95	1.14
	20	1.08	0.94	1.13	1.05	0.95	1.12	1.07	0.93	1.16
	50	1.09	0.93	1.15	1.07	0.94	1.15	1.07	0.92	1.17
	100	1.10	0.92	1.16	1.07	0.94	1.16	1.08	0.91	1.18
	200	1.11	0.92	1.17	1.07	0.94	1.18	1.08	0.91	1.19
	500	1.12	0.91	1.18	1.07	0.93	1.19	1.09	0.90	1.20
2069- 2100	2	1.01	0.95	1.05	0.98	0.94	1.14	1.03	0.93	1.06
	5	1.03	0.98	1.13	1.03	0.96	1.13	1.04	0.92	1.09
	10	1.05	0.99	1.18	1.07	0.96	1.19	1.04	0.94	1.13
	20	1.07	0.99	1.22	1.07	0.96	1.20	1.04	0.96	1.16
	50	1.10	0.99	1.27	1.06	0.94	1.24	1.04	0.96	1.19
	100	1.12	0.99	1.30	1.05	0.93	1.26	1.04	0.95	1.21
	200	1.14	0.99	1.33	1.04	0.92	1.29	1.04	0.94	1.23
	500	1.16	1.00	1.36	1.03	0.91	1.32	1.04	0.92	1.26

Annual climate factor and percentiles 10 and 90 for maximum rainfall in 24 hours. Station: Getafe.

TABLE 15. ANNUAL CLIMATE FACTOR AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. RETIRO

Retiro		RCP 2.6			RCP 4.5			RCP 8.5		
	T (years)	median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.00	0.93	1.21	1.00	0.95	1.18	1.05	0.97	1.10
	5	1.04	0.92	1.20	1.06	0.91	1.22	1.02	0.94	1.20
	10	1.06	0.91	1.18	1.08	0.89	1.32	1.02	0.93	1.27
	20	1.08	0.91	1.19	1.11	0.85	1.39	1.03	0.92	1.34
	50	1.08	0.90	1.22	1.13	0.82	1.46	1.04	0.92	1.40
	100	1.08	0.90	1.23	1.15	0.80	1.50	1.05	0.91	1.45
	200	1.07	0.90	1.25	1.17	0.79	1.54	1.06	0.91	1.49
	500	1.07	0.90	1.27	1.18	0.78	1.59	1.07	0.91	1.54
2037 - 2068	2	1.02	0.98	1.08	1.07	0.90	1.12	1.01	0.95	1.11
	5	0.99	0.95	1.13	1.11	0.91	1.13	1.03	0.92	1.12
	10	0.99	0.92	1.17	1.12	0.92	1.16	1.05	0.88	1.15
	20	0.99	0.90	1.21	1.11	0.91	1.20	1.06	0.85	1.17
	50	0.99	0.87	1.25	1.10	0.90	1.24	1.08	0.82	1.19
	100	0.99	0.86	1.28	1.10	0.89	1.27	1.08	0.80	1.20
	200	0.99	0.84	1.30	1.10	0.89	1.30	1.09	0.79	1.23
	500	0.99	0.83	1.33	1.10	0.88	1.33	1.10	0.77	1.25
2069- 2100	2	1.02	0.92	1.22	0.99	0.87	1.07	0.99	0.89	1.11
	5	1.00	0.93	1.25	1.00	0.87	1.24	0.94	0.89	1.20
	10	0.99	0.89	1.31	1.00	0.88	1.34	0.93	0.89	1.24
	20	1.00	0.86	1.36	1.00	0.88	1.41	0.94	0.88	1.28
	50	1.01	0.84	1.42	1.00	0.88	1.49	0.96	0.85	1.32
	100	1.01	0.83	1.46	1.00	0.87	1.54	0.96	0.84	1.34
	200	1.02	0.82	1.50	1.01	0.87	1.58	0.97	0.82	1.36
	500	1.02	0.81	1.54	1.01	0.86	1.63	0.98	0.81	1.39

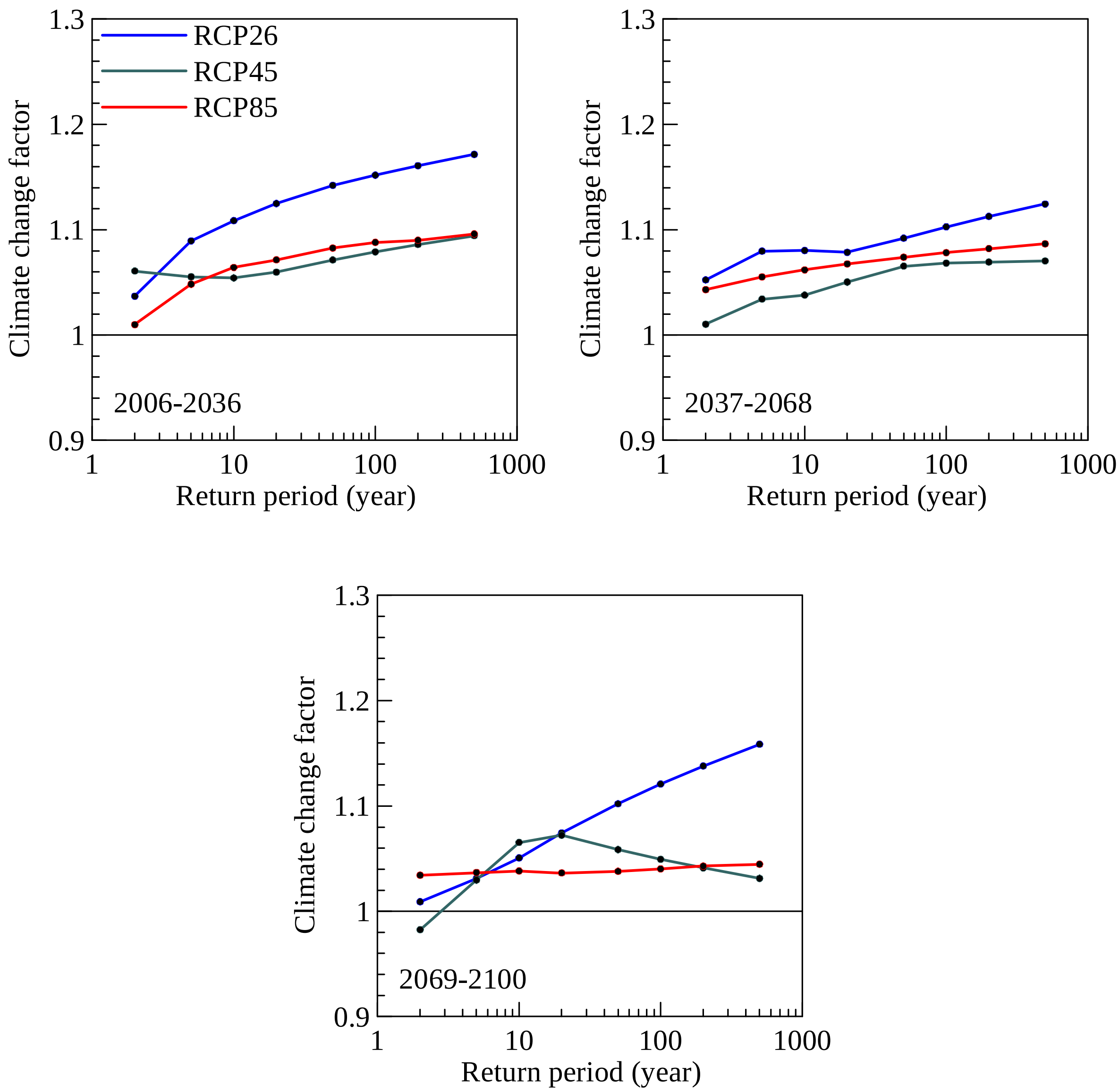
Annual climate factor and percentiles 10 and 90 for maximum rainfall in 24 hours. Station: Retiro.

TABLE 16. **ANNUAL CLIMATE FACTOR AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. TORREJÓN**

Torrejón		*RCP 2.6*			*RCP 4.5*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	2	1.02	0.98	1.12	1.00	0.94	1.16	1.02	0.99	1.09
	5	1.07	0.99	1.17	1.04	0.93	1.17	1.05	1.00	1.09
	10	1.09	1.00	1.20	1.07	0.91	1.20	1.06	1.02	1.10
	20	1.10	1.00	1.22	1.09	0.90	1.23	1.06	1.03	1.12
	50	1.12	1.00	1.27	1.10	0.89	1.27	1.07	1.02	1.15
	100	1.13	1.00	1.30	1.11	0.88	1.29	1.07	1.02	1.17
	200	1.14	1.01	1.32	1.12	0.88	1.31	1.07	1.02	1.18
	500	1.15	1.01	1.35	1.13	0.87	1.33	1.07	1.02	1.20
2037 - 2068	2	1.05	1.00	1.11	1.03	0.95	1.10	1.05	0.95	1.24
	5	1.07	0.98	1.14	1.00	0.97	1.11	1.05	0.99	1.28
	10	1.08	0.97	1.17	1.02	0.96	1.12	1.09	0.97	1.30
	20	1.09	0.96	1.20	1.01	0.95	1.13	1.09	0.95	1.32
	50	1.10	0.96	1.22	1.00	0.93	1.13	1.09	0.92	1.34
	100	1.11	0.95	1.24	1.00	0.92	1.14	1.09	0.90	1.35
	200	1.11	0.95	1.26	0.99	0.92	1.16	1.09	0.89	1.36
	500	1.12	0.95	1.27	0.99	0.91	1.19	1.09	0.89	1.38
2069- 2100	2	1.04	1.00	1.11	0.98	0.92	1.12	0.98	0.93	1.15
	5	1.11	1.00	1.18	1.04	0.94	1.16	0.97	0.93	1.18
	10	1.15	0.98	1.21	1.08	0.95	1.18	1.00	0.92	1.20
	20	1.18	0.97	1.24	1.11	0.93	1.20	1.02	0.91	1.20
	50	1.21	0.96	1.28	1.14	0.91	1.22	1.01	0.90	1.24
	100	1.23	0.96	1.31	1.15	0.90	1.24	1.01	0.89	1.26
	200	1.24	0.95	1.34	1.16	0.89	1.26	1.00	0.88	1.27
	500	1.26	0.94	1.37	1.17	0.88	1.28	1.00	0.88	1.29

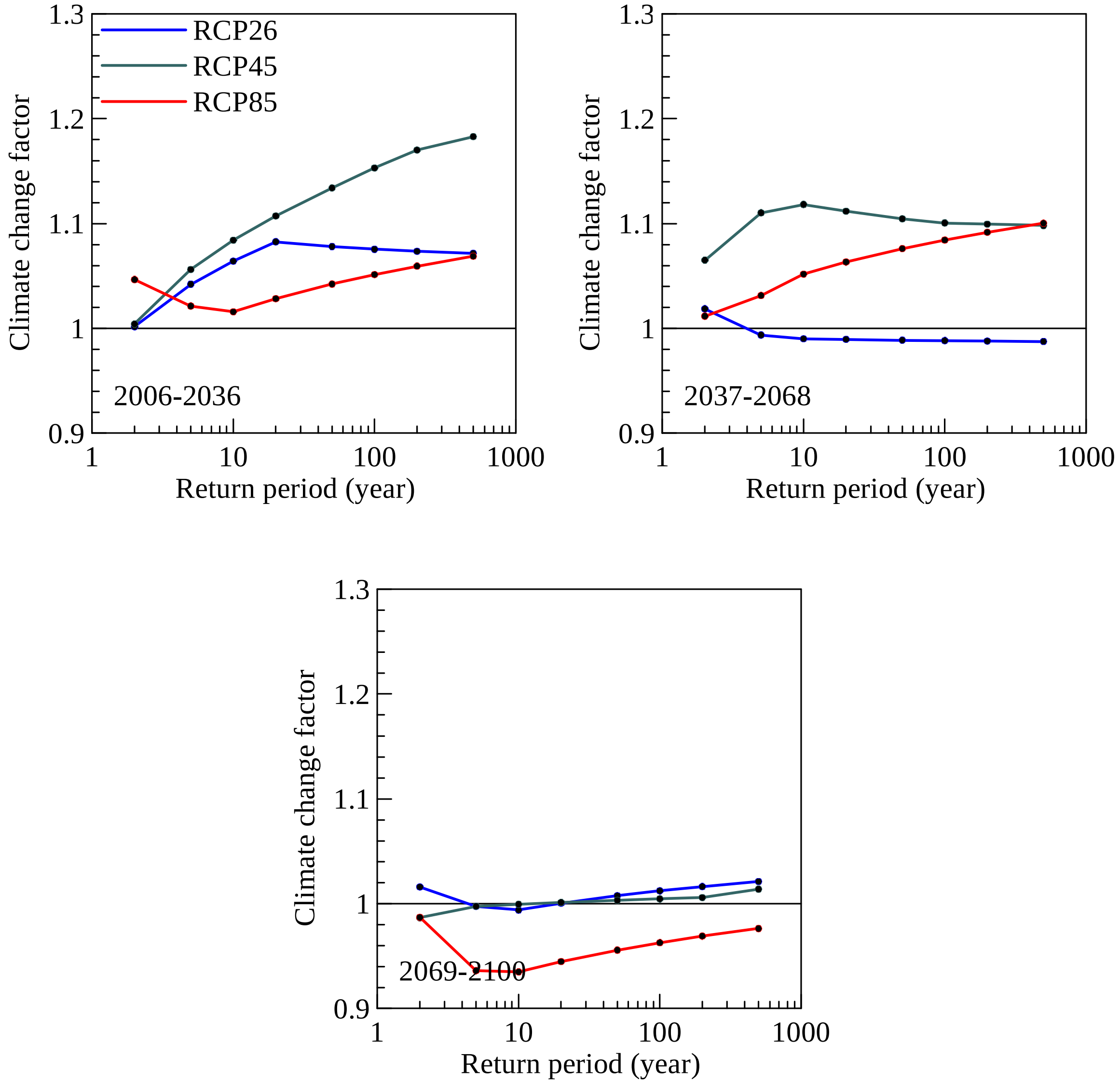
Annual climate factor and percentiles 10 and 90 for maximum rainfall in 24 hours. Station: Torrejón.

FIGURE 49. CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM RAINFALL IN 24 HOURS. GETAFE TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



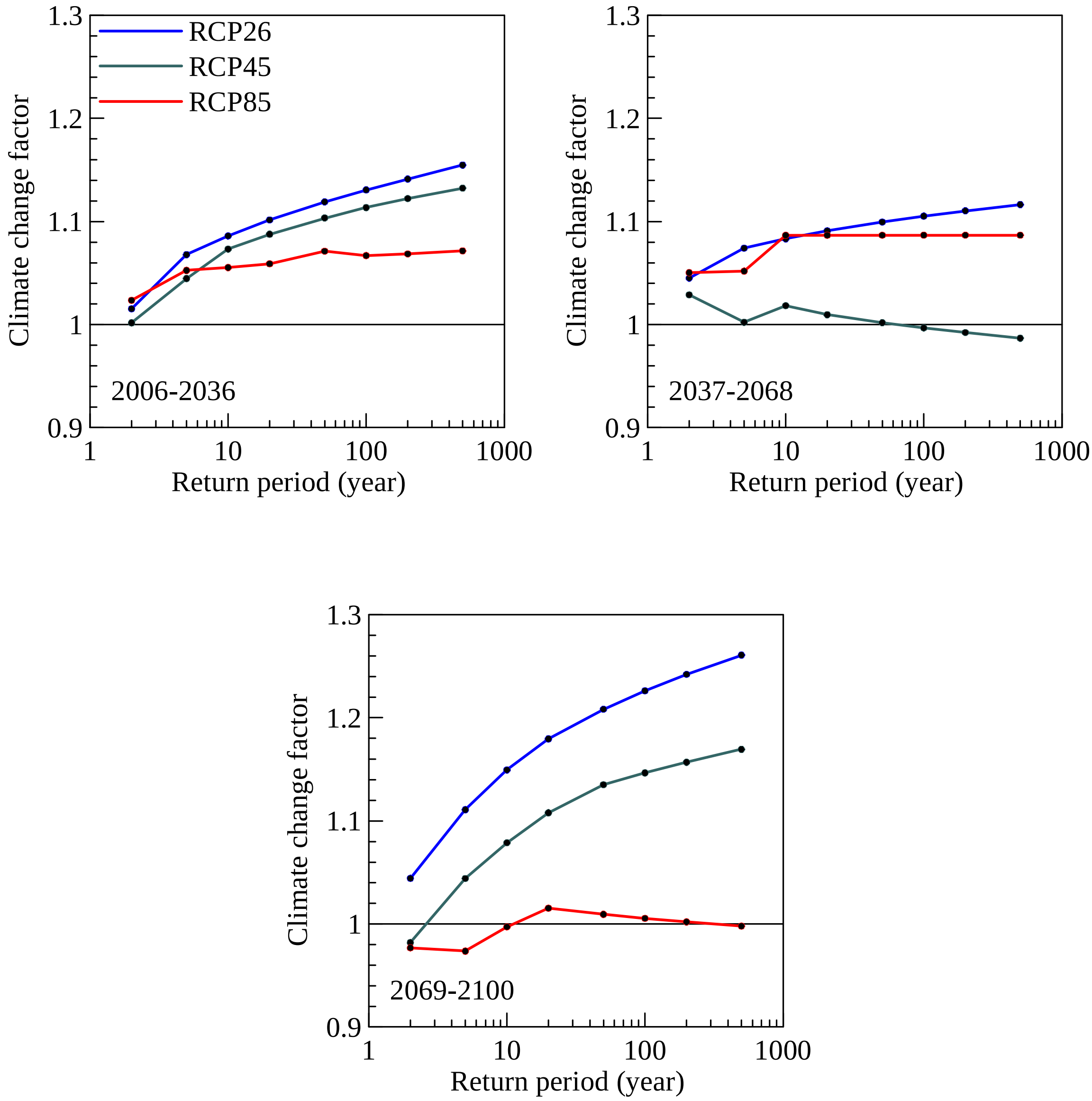
Climate change factor for annual maximum rainfall in 24 hours, Getafe TP station for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented.

FIGURE 50. CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM RAINFALL IN 24 HOURS. RETIRO TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for annual maximum rainfall in 24 hours, Retiro TP station for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented.

FIGURE 51. CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM RAINFALL IN 24 HOURS. TORREJÓN TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for annual maximum rainfall in 24 hours, Torrejón TP station for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented.

The method used to obtain the maximum annual rainfall values corresponding to 1 hour of duration and for subsequently calculating the corresponding climate factors consists of applying the invariance of scale characteristic of the fractal processes to determine the **β** scale exponent of the potential function that expresses the dependence with regard to the duration of the maximum rainfall intensity.

Table 17 shows the values of the mean **β** exponent for all the scenarios and periods considered.

TABLE 17. MEAN EXPONENT (β) FOR ALL PERIODS AND SCENARIOS

Getafe	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 8.5*
Historical	0.727			
2006-2036		0.757	0.763	0.747
2037-2068		0.766	0.773	0.758
2069-2100		0.824	0.754	0.733
Retiro	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 8.5*
Historical	0.773			
2006-2036		0.781	0.775	0.778
2037-2068		0.77	0.787	0.764
2069-2100		0.767	0.792	0.778
Torrejón	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 8.5*
Historical	0.762			
2006-2036		0.801	0.792	0.781
2037-2068		0.795	0.786	0.802
2069-2100		0.797	0.793	0.836

Using the calculated **β**-exponent values, the maximum intensities have been obtained, for a duration of 1 hour, for each of the return periods selected.

Once the maximum annual hourly intensity has been calculated for the return periods and the scenarios that have been considered, including the control period, the climate factor was calculated, for a duration of one hour, for all cases studied.

The results for all scenarios and climate periods are presented in Tables 18, 19 and 20, as well as in Figures 52, 53 and 54 below.

TABLE 18. CLIMATE CHANGE FACTOR (CF) I FOR A DURATION OF 1 HOUR. GETAFE TP STATION

Getafe		RCP 2.6			RCP 4.5			RCP 8.5		
T (años)		mediana	P10	P90	mediana	P10	P90	mediana	P10	P90
2006 - 2036	2	1.10	0.95	1.36	1.17	0.92	1.32	1.06	0.91	1.36
	5	1.16	0.98	1.43	1.22	0.91	1.40	1.10	0.92	1.34
	10	1.22	1.00	1.49	1.24	0.91	1.44	1.12	0.93	1.32
	20	1.27	1.01	1.54	1.26	0.91	1.47	1.14	0.94	1.31
	50	1.30	1.03	1.59	1.27	0.91	1.52	1.17	0.94	1.33
	100	1.31	1.03	1.65	1.28	0.90	1.54	1.18	0.95	1.33
	200	1.32	1.03	1.72	1.29	0.90	1.57	1.20	0.95	1.34
	500	1.34	1.02	1.81	1.30	0.90	1.60	1.21	0.96	1.34
2037 - 2068	2	1.14	0.97	1.47	1.12	0.95	1.52	1.14	0.92	1.33
	5	1.13	0.99	1.45	1.12	0.96	1.27	1.19	0.93	1.36
	10	1.13	1.00	1.47	1.11	0.95	1.28	1.22	0.93	1.37
	20	1.13	1.01	1.49	1.12	0.95	1.29	1.25	0.93	1.38
	50	1.15	1.02	1.52	1.14	0.95	1.31	1.28	0.94	1.40
	100	1.15	1.03	1.54	1.15	0.94	1.33	1.29	0.94	1.41
	200	1.16	1.02	1.55	1.16	0.94	1.35	1.30	0.94	1.41
	500	1.17	1.01	1.57	1.16	0.94	1.36	1.30	0.94	1.42
2069- 2100	2	1.25	1.03	1.40	1.13	0.95	1.36	1.16	0.97	1.42
	5	1.35	1.05	1.44	1.14	0.97	1.39	1.18	1.00	1.49
	10	1.40	1.06	1.47	1.14	0.95	1.47	1.20	0.99	1.51
	20	1.43	1.07	1.52	1.15	0.94	1.48	1.21	0.98	1.53
	50	1.45	1.08	1.57	1.15	0.92	1.50	1.22	0.96	1.55
	100	1.47	1.08	1.61	1.17	0.91	1.51	1.23	0.96	1.56
	200	1.49	1.09	1.65	1.19	0.90	1.51	1.24	0.95	1.58
	500	1.50	1.10	1.69	1.22	0.89	1.53	1.25	0.94	1.60

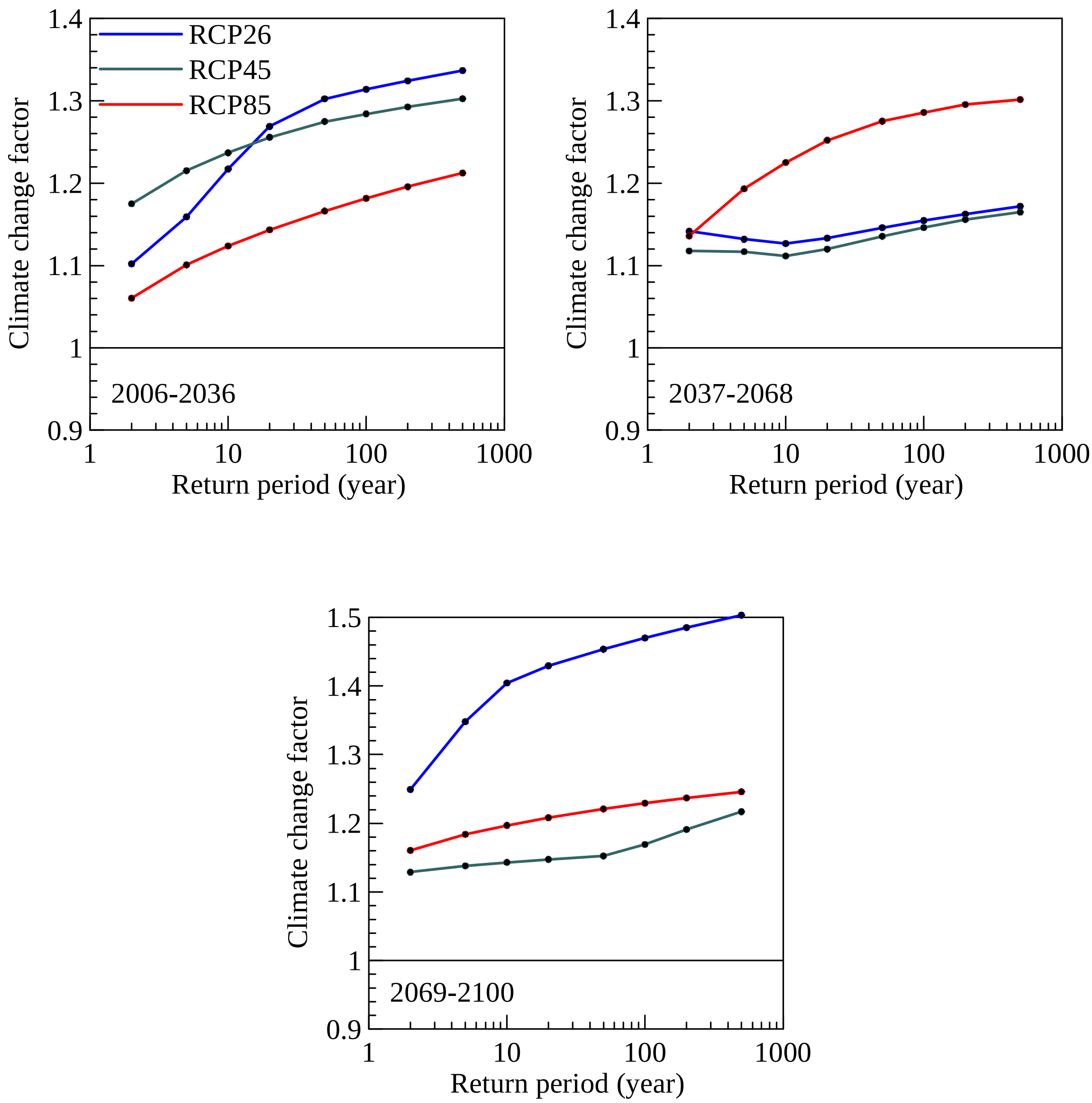
TABLE 19. CLIMATE CHANGE FACTOR (CF) I FOR A DURATION OF 1 HOUR. RETIRO TP STATION

Retiro		RCP 2.6			RCP 4.5			RCP 8.5		
T (years)		median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.18	0.92	1.25	1.10	0.82	1.42	1.07	0.92	1.34
	5	1.18	0.91	1.30	1.17	0.71	1.60	1.09	0.90	1.52
	10	1.19	0.90	1.33	1.20	0.66	1.73	1.09	0.89	1.61
	20	1.20	0.90	1.36	1.23	0.63	1.85	1.08	0.88	1.69
	50	1.22	0.90	1.39	1.26	0.60	1.97	1.10	0.87	1.77
	100	1.23	0.90	1.41	1.29	0.58	2.06	1.11	0.87	1.83
	200	1.23	0.89	1.43	1.30	0.56	2.13	1.12	0.86	1.88
	500	1.24	0.89	1.45	1.33	0.55	2.22	1.13	0.86	1.94
2037 - 2068	2	1.04	0.92	1.24	1.16	0.93	1.25	1.07	0.83	1.18
	5	1.05	0.85	1.31	1.20	0.95	1.41	1.09	0.76	1.23
	10	1.06	0.83	1.36	1.20	0.93	1.45	1.10	0.73	1.27
	20	1.07	0.81	1.40	1.20	0.93	1.48	1.11	0.70	1.31
	50	1.07	0.79	1.44	1.20	0.92	1.52	1.12	0.68	1.35
	100	1.08	0.77	1.47	1.19	0.91	1.54	1.13	0.66	1.38
	200	1.08	0.76	1.50	1.19	0.90	1.57	1.13	0.65	1.40
	500	1.09	0.75	1.53	1.19	0.90	1.59	1.14	0.64	1.43
2069- 2100	2	1.04	0.86	1.44	1.01	0.75	1.36	1.00	0.90	1.39
	5	1.05	0.72	1.53	1.01	0.73	1.63	1.04	0.85	1.49
	10	1.06	0.67	1.57	1.01	0.72	1.74	1.06	0.83	1.54
	20	1.06	0.64	1.61	1.01	0.71	1.84	1.08	0.81	1.58
	50	1.07	0.63	1.65	1.01	0.70	1.94	1.10	0.78	1.62
	100	1.07	0.62	1.69	1.01	0.69	2.01	1.12	0.77	1.65
	200	1.08	0.61	1.74	1.01	0.69	2.07	1.13	0.76	1.67
	500	1.08	0.60	1.79	1.02	0.68	2.14	1.14	0.74	1.70

TABLE 20. CLIMATE CHANGE FACTOR (CF) I FOR A DURATION OF 1 HOUR. TORREJÓN TP STATION

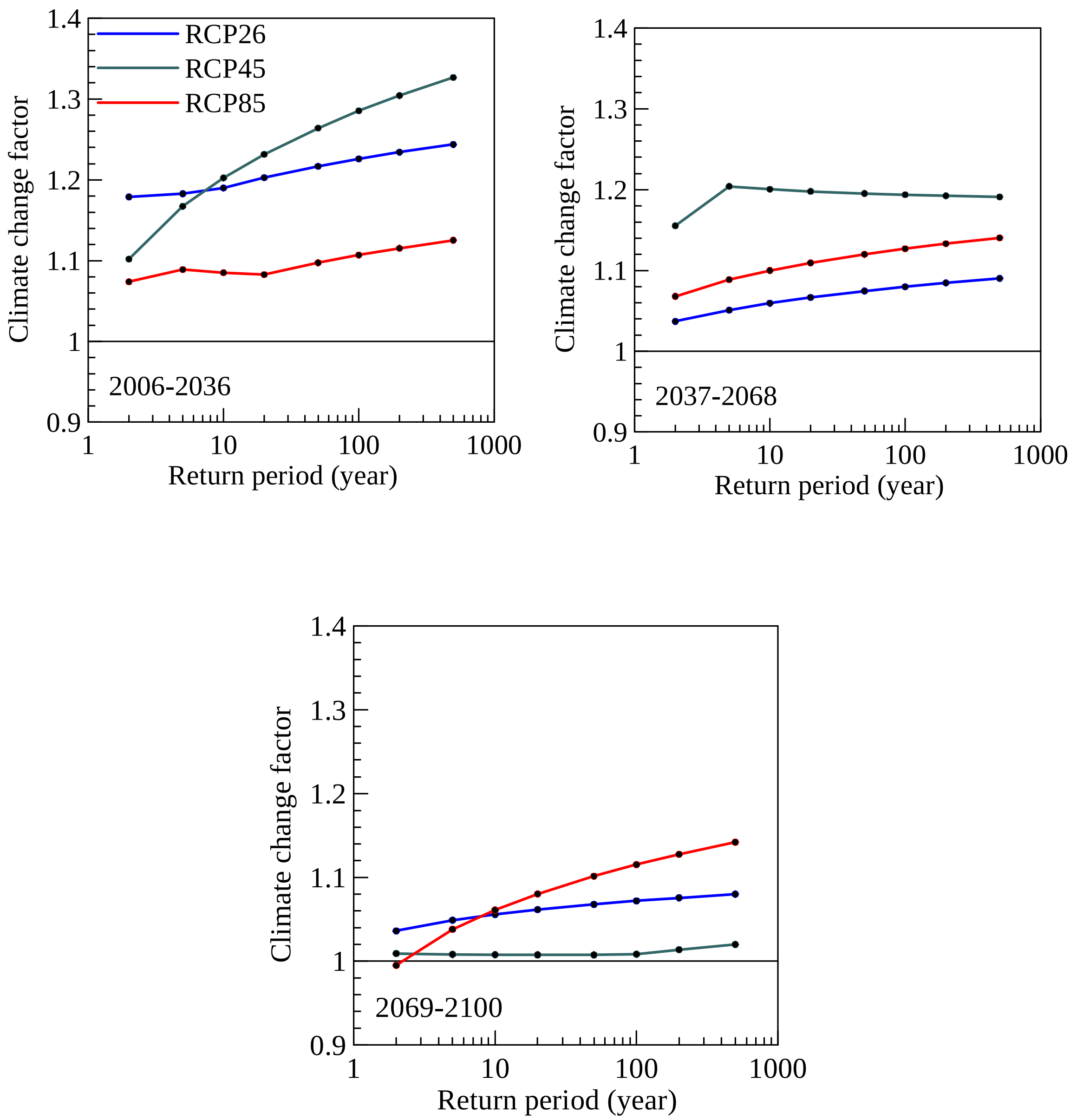
Torrejón		*RCP 2.6*			*RCP 4.5*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	*2*	1.15	1.00	1.35	1.13	0.95	1.35	1.09	1.00	1.23
	5	1.19	1.06	1.42	1.16	0.87	1.43	1.09	1.03	1.23
	10	1.21	1.06	1.45	1.17	0.83	1.47	1.10	1.04	1.23
	20	1.24	1.06	1.48	1.20	0.80	1.51	1.10	1.07	1.23
	50	1.27	1.06	1.51	1.21	0.78	1.55	1.11	1.06	1.23
	100	1.28	1.06	1.53	1.22	0.77	1.58	1.13	1.06	1.23
	200	1.30	1.06	1.55	1.22	0.77	1.60	1.14	1.05	1.24
	500	1.32	1.06	1.57	1.23	0.76	1.63	1.15	1.05	1.27
2037 - 2068	*2*	1.15	0.92	1.45	1.11	1.00	1.20	1.11	0.97	1.68
	5	1.17	0.91	1.53	1.06	1.03	1.23	1.22	0.91	1.75
	10	1.18	0.91	1.56	1.05	1.01	1.24	1.29	0.88	1.78
	20	1.18	0.90	1.60	1.06	1.02	1.26	1.33	0.85	1.80
	50	1.19	0.90	1.63	1.07	1.00	1.27	1.33	0.84	1.83
	100	1.20	0.89	1.66	1.08	0.99	1.28	1.33	0.83	1.85
	200	1.20	0.89	1.68	1.07	0.98	1.29	1.33	0.83	1.86
	500	1.21	0.89	1.70	1.07	0.97	1.30	1.33	0.82	1.88
2069- 2100	*2*	1.22	0.97	1.30	1.08	0.96	1.37	1.12	0.88	1.36
	5	1.27	0.98	1.39	1.11	0.96	1.43	1.12	0.88	1.37
	10	1.30	0.99	1.45	1.13	0.94	1.45	1.13	0.87	1.38
	20	1.33	1.00	1.50	1.15	0.92	1.48	1.16	0.87	1.39
	50	1.36	1.01	1.55	1.16	0.91	1.50	1.18	0.87	1.40
	100	1.38	1.02	1.59	1.18	0.89	1.52	1.19	0.86	1.40
	200	1.40	1.02	1.62	1.19	0.88	1.54	1.21	0.85	1.41
	500	1.42	1.02	1.66	1.20	0.87	1.56	1.21	0.85	1.43

FIGURE 52 CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM HOURLY RAINFALL. GETAFE TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



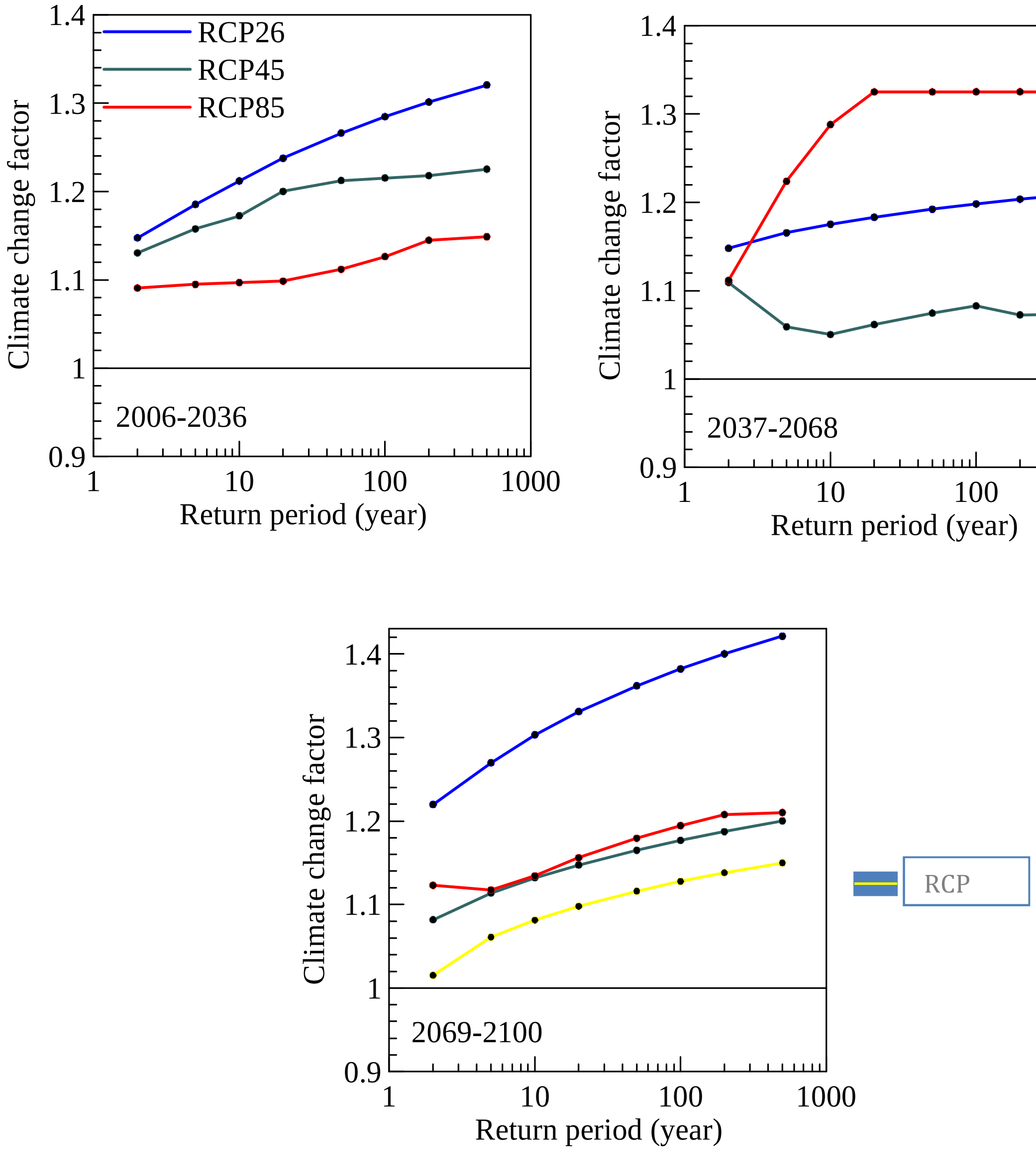
Climate change factor for the maximum annual hourly rainfall corresponding to Getafe TP station, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented.

FIGURE 53. CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM HOURLY RAINFALL. RETIRO TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for the maximum annual hourly rainfall corresponding to Retiro TP station, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented.

FIGURE 54. CLIMATE CHANGE FACTOR FOR ANNUAL MAXIMUM HOURLY RAINFALL. TORREJÓN TP STATION. CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for the maximum annual hourly rainfall corresponding to Torrejón TP station, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models is represented. The bottom graph also contains an additional value (yellow line) corresponding to RCP 6.0.

2.6. CLIMATE FACTORS IN ACCORDANCE WITH THE SEASON OF THE YEAR

In this section, the value of the CF obtained for each of the four seasons of the year (spring, summer, autumn and winter) is presented. For each scenario, the median of the cases corresponding to all the models and the three TP stations has been calculated. The dispersion of the results has been quantified from the 90th and 10th percentiles of the set of cases. Tables 21 to 24 show, for the four seasons of the year, the results obtained for the four climate change scenarios considered and the climatic periods analysed.

TABLE 21. CLIMATE FACTORS AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. SPRING

Spring		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
T (years)		median	P10	P90	median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.00	0.88	1.08	1.01	0.92	1.12	1.05	0.94	1.13	0.99	0.93	1.12
	5	0.95	0.82	1.19	1.02	0.83	1.20	1.06	0.90	1.17	1.03	0.92	1.28
	10	0.94	0.81	1.24	1.03	0.79	1.26	1.06	0.85	1.26	1.07	0.91	1.37
	20	0.96	0.75	1.29	1.00	0.74	1.32	1.06	0.80	1.35	1.08	0.87	1.47
	50	0.98	0.71	1.33	0.98	0.72	1.37	1.07	0.78	1.41	1.08	0.85	1.53
	100	1.00	0.68	1.36	0.98	0.69	1.41	1.06	0.75	1.47	1.09	0.83	1.58
	200	1.00	0.66	1.38	0.99	0.67	1.44	1.06	0.74	1.52	1.09	0.81	1.63
	500	1.00	0.63	1.42	1.03	0.65	1.48	1.06	0.71	1.58	1.10	0.79	1.68
2037 - 2068	2	1.04	0.89	1.13	1.02	0.86	1.10	1.04	0.95	1.10	1.02	0.94	1.11
	5	1.02	0.82	1.17	1.04	0.92	1.18	1.10	0.87	1.21	1.02	0.91	1.19
	10	1.03	0.79	1.22	1.06	0.88	1.23	1.09	0.82	1.29	1.02	0.87	1.24
	20	1.02	0.73	1.30	1.07	0.88	1.32	1.09	0.78	1.38	1.03	0.86	1.28
	50	1.04	0.70	1.36	1.07	0.86	1.37	1.09	0.76	1.44	1.04	0.84	1.30
	100	1.04	0.68	1.40	1.06	0.84	1.42	1.09	0.74	1.49	1.04	0.83	1.32
	200	1.05	0.65	1.43	1.06	0.82	1.47	1.09	0.73	1.54	1.05	0.81	1.33
	500	1.06	0.63	1.49	1.07	0.81	1.51	1.09	0.71	1.59	1.05	0.79	1.35
2069- 2100	2	0.98	0.90	1.12	0.98	0.88	1.11	0.98	0.89	1.11	0.96	0.86	1.06
	5	1.01	0.89	1.19	0.96	0.81	1.13	0.96	0.82	1.10	0.99	0.84	1.07
	10	1.02	0.85	1.24	0.98	0.74	1.16	0.98	0.79	1.12	0.99	0.83	1.17
	20	1.02	0.83	1.30	0.97	0.72	1.20	0.99	0.75	1.16	0.99	0.80	1.23
	50	1.02	0.81	1.35	0.96	0.72	1.22	0.98	0.73	1.19	0.98	0.77	1.27
	100	1.02	0.79	1.42	0.95	0.72	1.25	0.97	0.72	1.21	0.98	0.75	1.30
	200	1.02	0.78	1.47	0.94	0.72	1.28	0.98	0.70	1.23	0.98	0.74	1.32
	500	1.02	0.76	1.53	0.94	0.70	1.30	0.98	0.68	1.26	0.98	0.72	1.36

TABLE 22. **CLIMATE FACTORS AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS SUMMER**

Summer		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	2	0.98	0.85	1.16	0.98	0.83	1.18	1.01	0.89	1.13	1.00	0.83	1.14
	5	1.00	0.79	1.20	0.97	0.77	1.20	1.00	0.89	1.07	0.99	0.83	1.12
	10	1.02	0.77	1.22	0.96	0.73	1.21	0.98	0.90	1.04	1.01	0.79	1.14
	20	1.04	0.77	1.26	0.95	0.70	1.22	0.95	0.89	1.07	1.02	0.77	1.17
	50	1.04	0.77	1.30	0.94	0.69	1.23	0.95	0.89	1.09	1.02	0.75	1.19
	100	1.04	0.75	1.33	0.94	0.69	1.23	0.95	0.89	1.10	1.01	0.73	1.20
	200	1.03	0.74	1.36	0.94	0.68	1.24	0.94	0.88	1.12	1.01	0.71	1.21
	500	1.03	0.73	1.38	0.93	0.67	1.25	0.93	0.86	1.13	1.01	0.69	1.23
2037 - 2068	2	1.00	0.85	1.08	0.98	0.78	1.12	1.07	0.95	1.27	1.03	0.79	1.21
	5	0.99	0.84	1.10	0.98	0.83	1.16	1.10	0.88	1.30	1.01	0.83	1.24
	10	0.99	0.86	1.11	0.99	0.79	1.17	1.10	0.85	1.30	1.02	0.92	1.26
	20	0.98	0.87	1.13	1.02	0.76	1.20	1.05	0.82	1.32	1.05	0.91	1.29
	50	0.97	0.87	1.14	1.02	0.74	1.22	1.05	0.81	1.34	1.05	0.88	1.30
	100	0.97	0.86	1.15	1.02	0.73	1.23	1.06	0.80	1.36	1.05	0.85	1.32
	200	0.97	0.85	1.17	1.02	0.71	1.24	1.07	0.79	1.37	1.05	0.83	1.33
	500	0.97	0.85	1.18	1.01	0.70	1.26	1.08	0.77	1.39	1.05	0.83	1.34
2069- 2100	2	0.99	0.84	1.15	1.01	0.89	1.25	0.99	0.87	1.14	1.09	0.92	1.33
	5	0.99	0.82	1.19	0.98	0.89	1.26	0.99	0.80	1.19	1.05	0.90	1.28
	10	0.95	0.82	1.29	1.00	0.86	1.27	1.02	0.75	1.23	1.07	0.88	1.26
	20	0.95	0.81	1.30	1.00	0.83	1.28	1.04	0.70	1.33	1.06	0.85	1.26
	50	0.95	0.80	1.31	1.00	0.83	1.28	1.05	0.68	1.37	1.06	0.83	1.25
	100	0.95	0.80	1.33	1.01	0.81	1.28	1.07	0.66	1.39	1.06	0.80	1.24
	200	0.95	0.79	1.35	1.01	0.80	1.27	1.08	0.64	1.41	1.06	0.78	1.26
	500	0.94	0.78	1.38	0.99	0.78	1.27	1.09	0.62	1.43	1.04	0.75	1.27

TABLE 23. CLIMATE FACTORS AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. AUTUMN

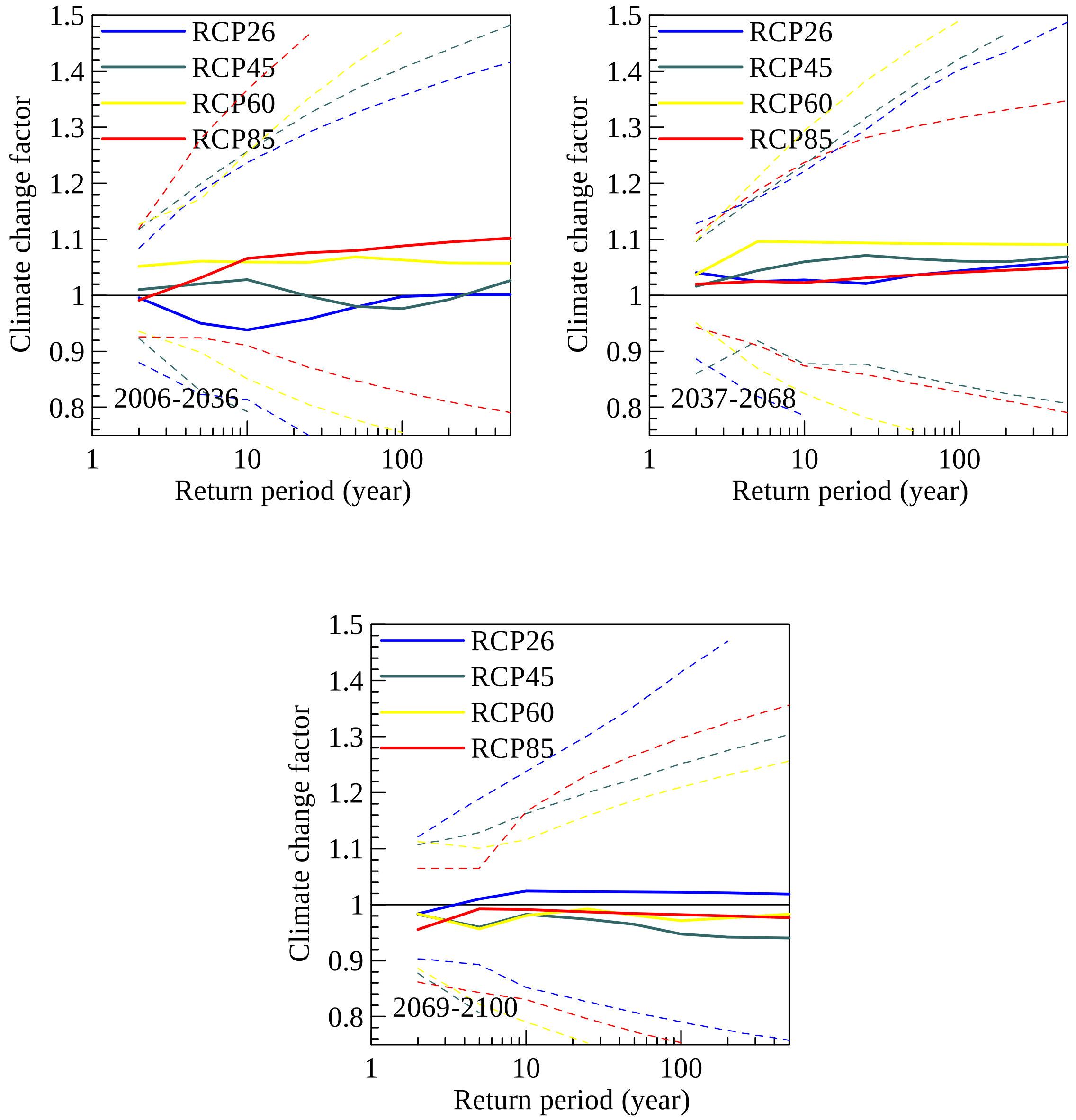
Autumn		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	**2**	0.95	0.89	1.07	0.97	0.91	1.04	1.01	0.86	1.06	0.99	0.91	1.05
	5	0.99	0.87	1.07	1.00	0.91	1.11	1.02	0.94	1.08	0.99	0.91	1.13
	10	1.00	0.85	1.07	1.00	0.92	1.15	1.01	0.95	1.13	0.99	0.90	1.19
	20	1.02	0.83	1.10	1.01	0.91	1.23	1.04	0.95	1.20	1.01	0.89	1.23
	50	1.04	0.82	1.12	1.01	0.91	1.28	1.06	0.94	1.22	1.00	0.88	1.25
	100	1.04	0.81	1.14	1.02	0.90	1.32	1.06	0.94	1.24	1.00	0.87	1.27
	200	1.04	0.80	1.16	1.02	0.89	1.36	1.07	0.94	1.26	1.00	0.86	1.29
	500	1.04	0.79	1.18	1.03	0.88	1.40	1.08	0.93	1.29	1.00	0.85	1.32
2037 - 2068	**2**	1.01	0.93	1.05	0.97	0.87	1.06	0.97	0.87	1.10	0.95	0.90	1.08
	5	1.01	0.93	1.07	0.98	0.90	1.11	1.02	0.82	1.13	0.97	0.90	1.10
	10	1.01	0.91	1.09	1.00	0.89	1.14	1.04	0.79	1.15	0.98	0.90	1.11
	20	1.02	0.89	1.12	1.02	0.87	1.17	1.06	0.76	1.17	0.99	0.89	1.13
	50	1.03	0.88	1.14	1.04	0.86	1.19	1.07	0.75	1.18	0.99	0.89	1.16
	100	1.03	0.87	1.15	1.05	0.86	1.21	1.09	0.73	1.20	0.99	0.88	1.18
	200	1.03	0.86	1.17	1.06	0.85	1.23	1.10	0.72	1.21	0.99	0.88	1.19
	500	1.04	0.85	1.18	1.06	0.84	1.25	1.11	0.70	1.23	0.99	0.87	1.21
2069- 2100	**2**	1.00	0.87	1.12	0.99	0.90	1.08	0.98	0.88	1.08	0.96	0.82	1.04
	5	1.04	0.89	1.12	1.02	0.91	1.11	1.00	0.89	1.13	0.96	0.81	1.08
	10	1.06	0.92	1.16	1.03	0.92	1.13	1.01	0.90	1.14	0.96	0.85	1.12
	20	1.06	0.94	1.22	1.04	0.92	1.18	1.02	0.90	1.17	0.96	0.85	1.14
	50	1.07	0.94	1.25	1.05	0.92	1.21	1.03	0.90	1.18	0.99	0.85	1.16
	100	1.08	0.93	1.28	1.05	0.91	1.23	1.03	0.90	1.20	0.99	0.84	1.18
	200	1.09	0.92	1.31	1.06	0.90	1.24	1.03	0.90	1.21	0.99	0.84	1.19
	500	1.09	0.92	1.35	1.07	0.89	1.26	1.03	0.90	1.23	0.98	0.83	1.21

TABLE 24. CLIMATE FACTORS AND PERCENTILES 10 AND 90 FOR MAXIMUM RAINFALL IN 24 HOURS. WINTER

Winter		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	**2**	1.02	0.88	1.25	1.02	0.95	1.35	1.00	0.87	1.13	1.02	0.89	1.16
	5	1.01	0.89	1.28	1.01	0.89	1.34	1.04	0.86	1.25	1.02	0.86	1.18
	10	1.03	0.82	1.31	1.02	0.86	1.38	1.04	0.81	1.32	1.07	0.79	1.22
	20	1.03	0.76	1.36	1.03	0.80	1.42	1.05	0.76	1.39	1.05	0.76	1.25
	50	1.02	0.74	1.39	1.03	0.77	1.42	1.05	0.73	1.44	1.06	0.73	1.30
	100	1.02	0.73	1.41	1.01	0.74	1.43	1.05	0.71	1.49	1.07	0.71	1.34
	200	1.02	0.72	1.45	1.01	0.72	1.43	1.05	0.70	1.54	1.08	0.69	1.36
	500	1.03	0.70	1.50	1.01	0.70	1.45	1.05	0.69	1.60	1.08	0.67	1.39
2037 - 2068	**2**	1.00	0.90	1.27	1.05	0.85	1.16	1.00	0.94	1.19	1.03	0.91	1.32
	5	0.98	0.88	1.24	1.01	0.80	1.13	1.07	0.85	1.22	1.05	0.89	1.18
	10	0.97	0.84	1.26	1.01	0.83	1.14	1.07	0.80	1.26	1.04	0.85	1.24
	20	0.97	0.80	1.31	1.02	0.79	1.19	1.05	0.76	1.34	1.03	0.80	1.30
	50	0.97	0.78	1.36	1.02	0.76	1.22	1.05	0.74	1.39	1.02	0.76	1.33
	100	0.97	0.77	1.39	1.01	0.73	1.24	1.04	0.72	1.44	1.01	0.73	1.36
	200	0.97	0.76	1.41	1.00	0.70	1.26	1.04	0.71	1.49	1.00	0.70	1.39
	500	0.97	0.75	1.44	0.99	0.68	1.28	1.03	0.69	1.54	1.00	0.68	1.43
2069- 2100	**2**	1.05	0.93	1.21	1.02	0.90	1.19	0.97	0.85	1.12	1.02	0.89	1.26
	5	1.04	0.88	1.24	1.03	0.85	1.17	0.99	0.85	1.10	1.01	0.83	1.22
	10	1.01	0.85	1.31	1.01	0.82	1.23	1.02	0.83	1.14	1.03	0.81	1.21
	20	1.00	0.79	1.37	1.00	0.79	1.27	1.00	0.80	1.19	1.03	0.75	1.22
	50	1.00	0.76	1.40	1.00	0.75	1.30	0.98	0.79	1.24	1.03	0.72	1.23
	100	1.00	0.74	1.44	0.99	0.73	1.32	0.97	0.78	1.30	1.05	0.69	1.25
	200	1.00	0.72	1.47	0.99	0.70	1.34	0.98	0.77	1.35	1.05	0.66	1.28
	500	1.00	0.71	1.51	0.99	0.68	1.36	0.99	0.75	1.42	1.06	0.63	1.32

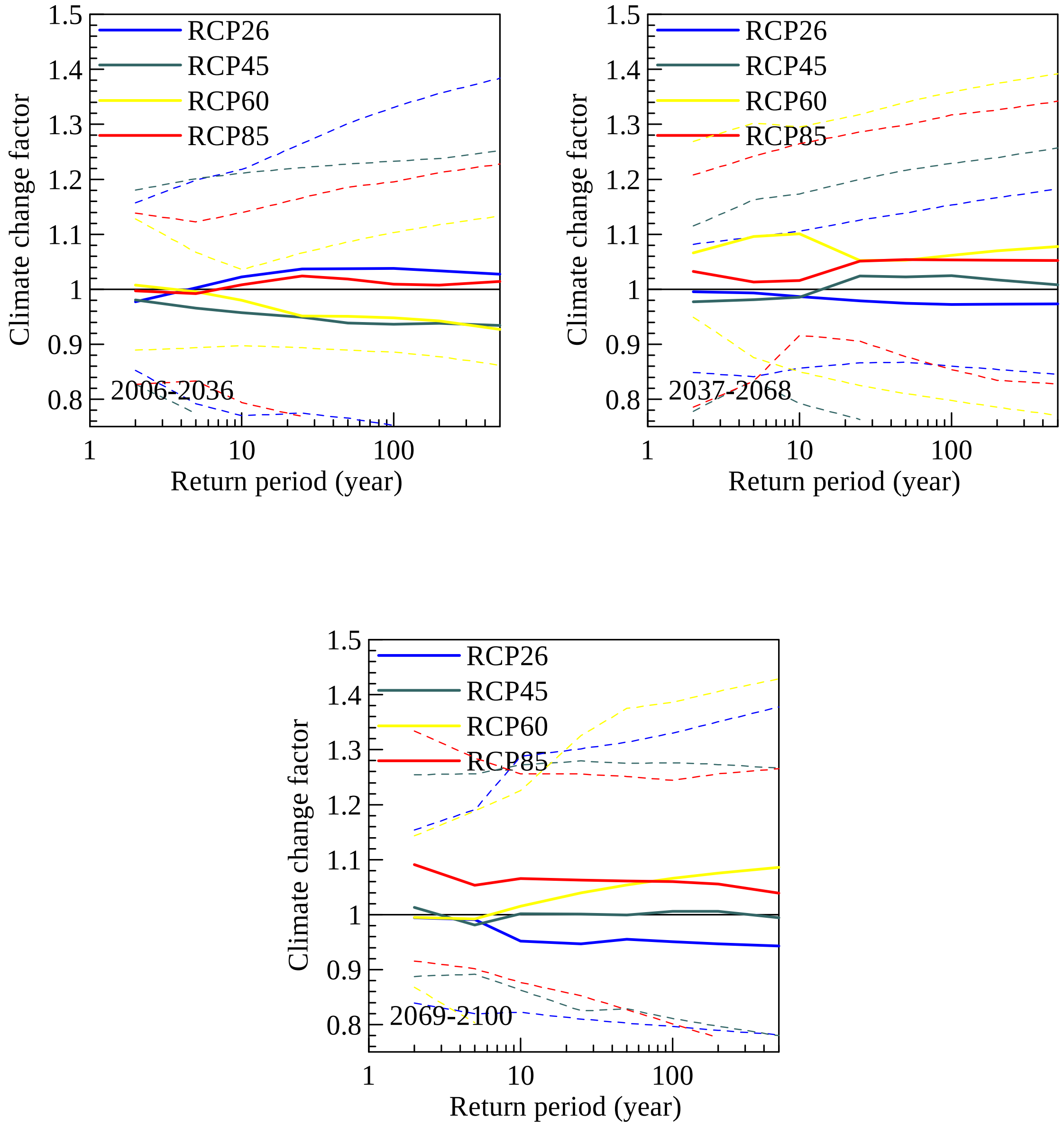
Figures 55 to 58 graphically represent the medians and the upper percentile P90, and lower percentile P10, of the climate change factors (CF), for the four climate change scenarios that have been considered in the study, grouped into the periods 2006-2036, 2037-2068 and 2069-2100, as well as for the four seasons of the year.

FIGURE 55. CLIMATE CHANGE FACTOR FOR MAXIMUM RAINFALL IN 24 HOURS. SPRING, THREE CLIMATE PERIODS OF THE 21ST CENTURY



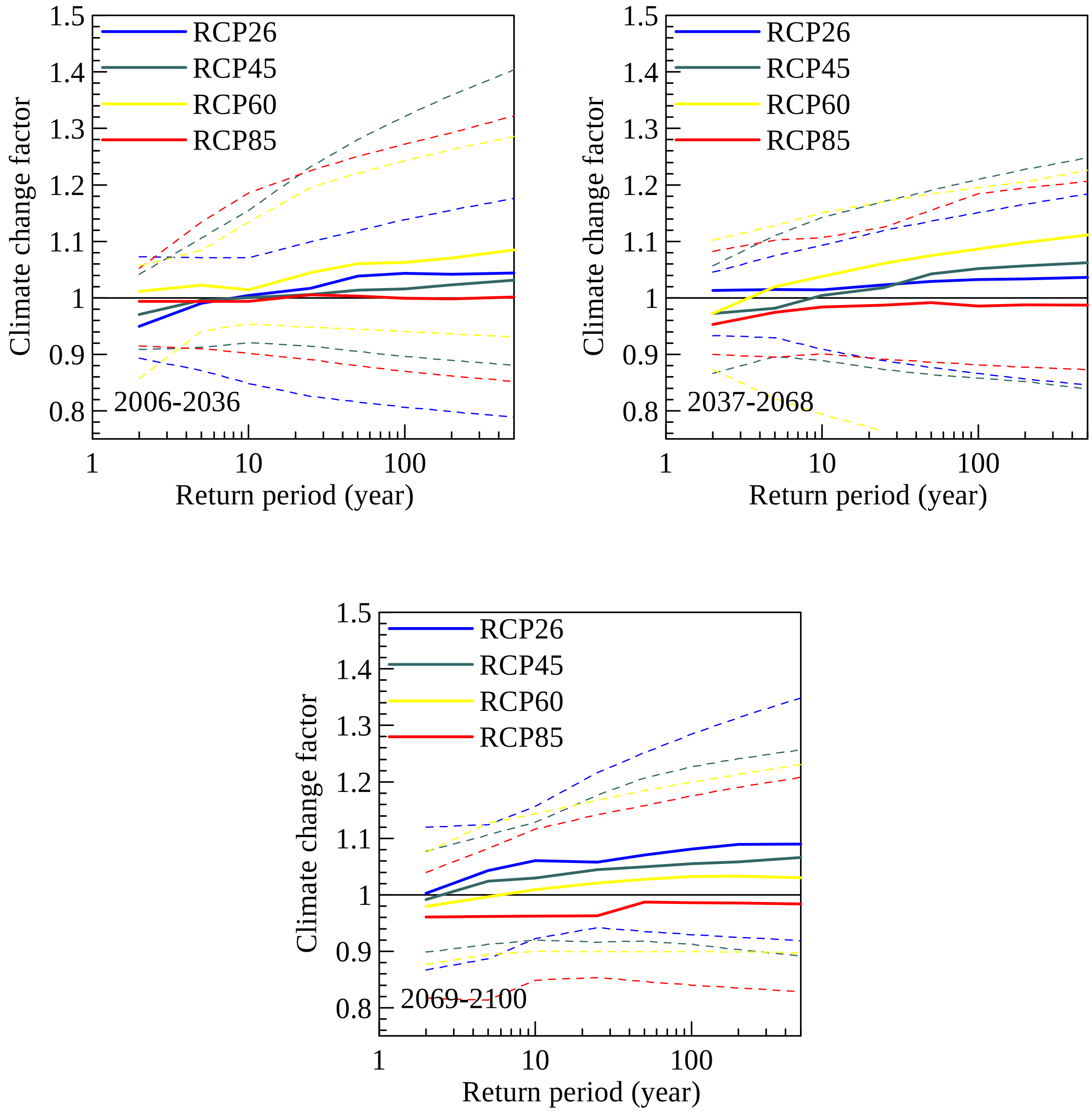
Climate change factor for maximum rainfall in 24 hours, corresponding to Spring, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 56. CLIMATE CHANGE FACTOR FOR MAXIMUM RAINFALL IN 24 HOURS. SUMMER, THREE CLIMATE PERIODS OF THE 21ST CENTURY



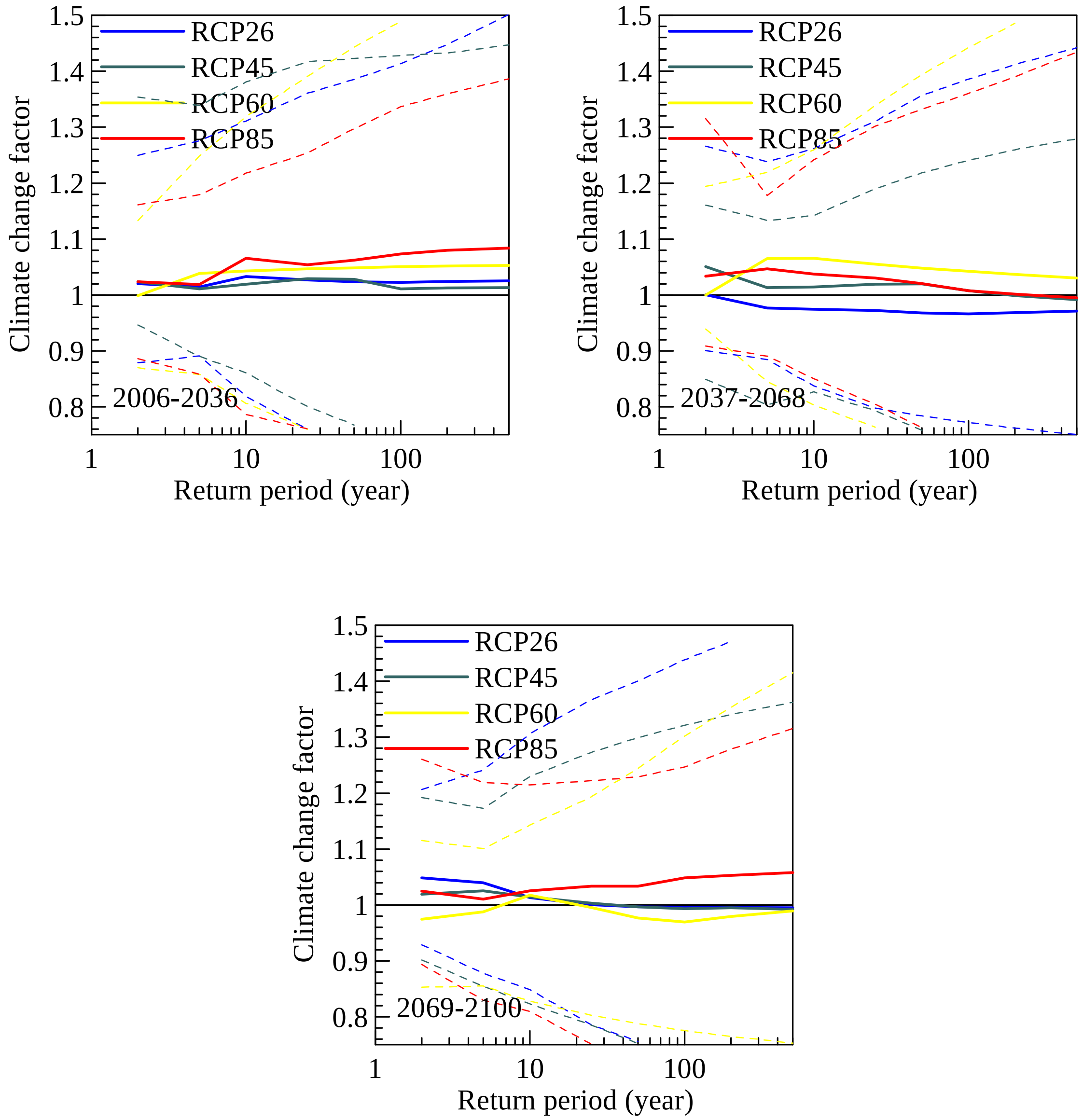
Climate change factor for maximum rainfall in 24 hours, corresponding to Summer, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 57. CLIMATE CHANGE FACTOR FOR MAXIMUM RAINFALL IN 24 HOURS. AUTUMN, THREE CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for maximum rainfall in 24 hours, corresponding to Autumn, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 58. CLIMATE CHANGE FACTOR FOR MAXIMUM RAINFALL IN 24 HOURS. WINTER, THREE CLIMATE PERIODS OF THE 21ST CENTURY



Climate change factor for maximum rainfall in 24 hours, corresponding to Winter, for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

The method used to obtain the hourly intensities, based on the daily rainfall data, consists of applying the scale invariance characteristic of the fractal processes to determine the **β**-scale exponent of the potential function that expresses the dependence with regard to the duration of the maximum rainfall intensity.

Table 25 shows the values of the mean **β** exponent for all the scenarios and periods considered.

TABLE 25. MEAN EXPONENT (β) FOR ALL PERIODS AND SCENARIOS

SPRING	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 6.0*	*RCP 8.5*
Historical	0.776				
2006-2036		0.791	0.779	0.792	0.801
2037-2068		0.796	0.807	0.799	0.794
2069-2100		0.796	0.793	0.797	0.803
VERANO	*Historical a*	*RCP 2.6*	*RCP 4.5*	*RCP 6.0*	*RCP 8.5*
Historical	0.856				
2006-2036		0.878	0.843	0.847	0.847
2037-2068		0.888	0.859	0.869	0.847
2069-2100		0.881	0.869	0.875	0.869
OTOÑO	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 6.0*	*RCP 8.5*
Historical	0.7				
2006-2036		0.714	0.724	0.732	0.71
2037-2068		0.721	0.727	0.726	0.715
2069-2100		0.726	0.719	0.732	0.729
INVIERNO	*Historical*	*RCP 2.6*	*RCP 4.5*	*RCP 6.0*	*RCP 8.5*
Historical	0.74				
2006-2036		0.743	0.746	0.737	0.722
2037-2068		0.738	0.725	0.739	0.745
2069-2100		0.753	0.737	0.747	0.734

From the equation (4) and making use of the values of calculated exponent **β**, the maximum intensities were obtained, for a duration of 1 hour and for the different return periods selected.

Once the maximum hourly intensity has been calculated for the return periods and the scenarios that have been considered, including the control period, the climatic factor for a duration of 1 hour has been calculated, using equation (1), for all cases studied.

Tables 26 to 29 present the results for all the scenarios and climate periods considered.

TABLE 26. CLIMATE CHANGE FACTOR (CF) FOR A DURATION OF 1 HOUR. SPRING

Spring		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006-2036	2	0.99	0.79	1.34	1.04	0.75	1.29	1.13	0.87	1.39	1.10	0.90	1.29
	5	0.94	0.75	1.47	1.04	0.75	1.33	1.12	0.80	1.59	1.16	0.87	1.51
	10	0.98	0.74	1.53	1.04	0.70	1.39	1.11	0.76	1.71	1.19	0.85	1.67
	20	0.98	0.70	1.59	1.03	0.67	1.45	1.11	0.73	1.82	1.21	0.82	1.76
	50	1.01	0.65	1.65	1.04	0.63	1.52	1.10	0.69	1.93	1.22	0.80	1.86
	100	1.03	0.62	1.68	1.03	0.60	1.56	1.10	0.67	2.01	1.23	0.78	1.92
	200	1.02	0.60	1.72	1.05	0.58	1.60	1.09	0.66	2.08	1.24	0.77	1.98
	500	1.02	0.58	1.76	1.06	0.56	1.64	1.09	0.64	2.16	1.25	0.75	2.05
22037-2068	2	1.09	0.80	1.38	1.09	0.84	1.41	1.09	0.86	1.34	1.05	0.95	1.27
	5	1.05	0.74	1.50	1.09	0.82	1.55	1.17	0.78	1.54	1.05	0.91	1.32
	10	1.10	0.69	1.59	1.09	0.80	1.64	1.17	0.73	1.65	1.07	0.88	1.38
	20	1.11	0.65	1.66	1.09	0.78	1.72	1.17	0.70	1.74	1.09	0.85	1.42
	25	1.12	0.64	1.68	1.09	0.77	1.74	1.17	0.69	1.76	1.08	0.84	1.44
	50	1.13	0.62	1.75	1.12	0.76	1.81	1.17	0.66	1.84	1.06	0.81	1.47
	100	1.13	0.59	1.80	1.15	0.75	1.86	1.16	0.64	1.91	1.07	0.79	1.51
	200	1.13	0.58	1.85	1.16	0.74	1.91	1.16	0.62	1.97	1.07	0.78	1.54
	500	1.13	0.55	1.91	1.16	0.73	1.97	1.16	0.60	2.04	1.08	0.76	1.57
2069-2100	2	1.03	0.82	1.36	1.05	0.85	1.25	1.00	0.88	1.23	1.03	0.87	1.26
	5	1.04	0.78	1.51	1.05	0.73	1.38	1.01	0.76	1.18	1.07	0.78	1.35
	10	1.04	0.75	1.61	1.05	0.71	1.40	1.02	0.72	1.19	1.06	0.76	1.39
	20	1.08	0.73	1.61	1.04	0.71	1.46	1.03	0.70	1.22	1.07	0.72	1.43
	25	1.09	0.72	1.61	1.04	0.71	1.47	1.04	0.69	1.23	1.07	0.72	1.45
	50	1.10	0.69	1.62	1.04	0.71	1.51	1.04	0.67	1.26	1.08	0.70	1.50
	100	1.10	0.67	1.63	1.03	0.70	1.55	1.05	0.65	1.28	1.08	0.69	1.54
	200	1.10	0.66	1.63	1.03	0.68	1.58	1.06	0.64	1.31	1.08	0.68	1.58
	500	1.11	0.64	1.64	1.02	0.67	1.61	1.06	0.63	1.33	1.08	0.67	1.62

TABLE 27. CLIMATE CHANGE FACTOR (CF) FOR A DURATION OF 1 HOUR. SUMMER

Summer		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
T (years)		median	P10	P90	median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.07	0.72	1.51	0.94	0.63	1.45	0.96	0.82	1.39	0.99	0.64	1.35
	5	1.11	0.65	1.56	0.92	0.61	1.43	1.06	0.82	1.35	1.01	0.63	1.38
	10	1.10	0.61	1.58	0.91	0.59	1.42	1.04	0.78	1.34	0.97	0.58	1.37
	20	1.11	0.61	1.60	0.90	0.57	1.43	1.02	0.76	1.33	1.01	0.55	1.39
	50	1.10	0.60	1.64	0.88	0.56	1.43	1.01	0.73	1.32	1.03	0.53	1.41
	100	1.10	0.60	1.66	0.87	0.57	1.43	0.99	0.72	1.31	1.01	0.51	1.42
	200	1.10	0.60	1.68	0.87	0.56	1.43	0.98	0.71	1.31	1.00	0.50	1.42
	500	1.11	0.60	1.72	0.86	0.55	1.43	0.97	0.69	1.30	0.98	0.48	1.43
2037 - 2068	2	1.12	0.85	1.34	1.01	0.68	1.31	1.16	0.90	1.74	0.97	0.73	1.28
	5	1.11	0.80	1.38	1.02	0.67	1.38	1.11	0.87	1.73	0.95	0.80	1.31
	10	1.11	0.84	1.40	0.98	0.68	1.41	1.10	0.84	1.88	0.94	0.79	1.33
	20	1.12	0.87	1.43	0.96	0.66	1.44	1.09	0.82	1.91	0.95	0.79	1.34
	50	1.12	0.88	1.46	0.94	0.64	1.46	1.11	0.80	1.93	0.96	0.78	1.35
	100	1.13	0.89	1.48	0.94	0.63	1.48	1.10	0.79	1.95	0.97	0.77	1.35
	200	1.13	0.89	1.50	0.93	0.62	1.49	1.10	0.77	1.97	0.98	0.77	1.36
	500	1.13	0.89	1.53	0.94	0.61	1.51	1.09	0.75	1.99	0.99	0.75	1.36
2069- 2100	2	1.07	0.80	1.31	1.07	0.77	1.59	1.05	0.82	1.64	1.21	0.80	1.51
	5	1.08	0.79	1.46	1.07	0.76	1.61	1.11	0.77	1.70	1.10	0.78	1.51
	10	1.06	0.82	1.90	1.03	0.75	1.60	1.14	0.74	1.73	1.06	0.75	1.52
	20	1.05	0.81	1.98	1.01	0.73	1.62	1.16	0.71	1.76	1.06	0.71	1.55
	50	1.03	0.80	1.99	1.01	0.71	1.63	1.18	0.67	1.83	1.05	0.67	1.57
	100	1.02	0.79	2.00	0.99	0.70	1.63	1.20	0.65	1.85	1.08	0.65	1.56
	200	1.01	0.78	2.01	0.97	0.69	1.63	1.21	0.63	1.85	1.11	0.63	1.55
	500	1.01	0.77	2.02	0.98	0.69	1.63	1.22	0.60	1.85	1.15	0.60	1.54

TABLE 28. CLIMATE CHANGE FACTOR (CF) FOR A DURATION OF 1 HOUR. AUTUMN

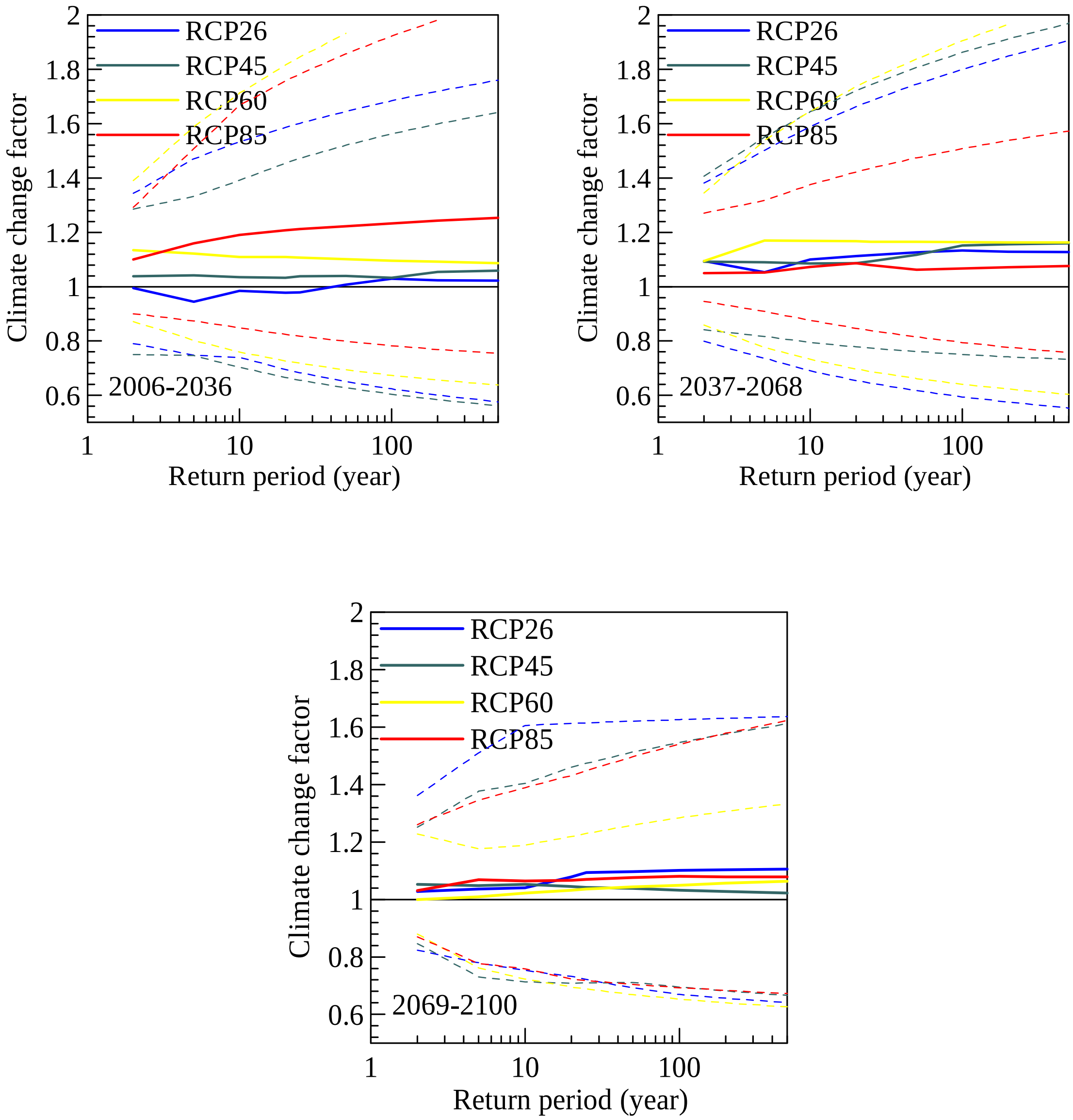
Autumn		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
T (years)		median	P10	P90	median	P10	P90	median	P10	P90	median	P10	P90
2006 - 2036	2	1.01	0.84	1.27	1.02	0.88	1.33	1.09	0.86	1.25	1.00	0.87	1.22
	5	1.05	0.83	1.29	1.05	0.88	1.33	1.10	0.89	1.35	1.01	0.85	1.25
	10	1.06	0.84	1.30	1.08	0.87	1.34	1.10	0.89	1.41	1.00	0.84	1.30
	20	1.06	0.84	1.30	1.08	0.86	1.38	1.11	0.88	1.46	1.01	0.83	1.33
	50	1.07	0.85	1.31	1.09	0.86	1.42	1.11	0.87	1.53	1.02	0.82	1.36
	100	1.08	0.85	1.31	1.10	0.87	1.45	1.11	0.86	1.57	1.02	0.81	1.38
	200	1.08	0.86	1.32	1.11	0.87	1.47	1.12	0.87	1.61	1.02	0.80	1.41
	500	1.09	0.85	1.33	1.11	0.87	1.51	1.12	0.87	1.65	1.02	0.80	1.43
2037 - 2068	2	1.03	0.94	1.26	1.07	0.91	1.21	1.00	0.85	1.34	1.04	0.83	1.17
	5	1.08	0.93	1.25	1.07	0.97	1.27	1.06	0.84	1.40	1.04	0.83	1.24
	10	1.10	0.92	1.27	1.08	0.99	1.28	1.09	0.82	1.43	1.05	0.83	1.27
	20	1.11	0.90	1.30	1.09	0.98	1.30	1.12	0.80	1.45	1.04	0.83	1.30
	50	1.12	0.89	1.32	1.09	0.96	1.34	1.14	0.78	1.47	1.04	0.83	1.33
	100	1.13	0.88	1.34	1.09	0.94	1.37	1.15	0.76	1.49	1.05	0.83	1.36
	200	1.12	0.87	1.36	1.11	0.93	1.39	1.16	0.74	1.50	1.05	0.83	1.37
	500	1.11	0.86	1.40	1.12	0.91	1.41	1.18	0.73	1.52	1.05	0.83	1.40
2069- 2100	2	1.11	0.86	1.32	1.06	0.87	1.24	1.03	0.90	1.31	1.03	0.84	1.18
	5	1.15	0.87	1.37	1.10	0.88	1.31	1.06	0.90	1.32	1.06	0.87	1.22
	10	1.16	0.88	1.39	1.11	0.88	1.36	1.07	0.90	1.34	1.09	0.87	1.26
	20	1.19	0.88	1.42	1.11	0.88	1.40	1.08	0.89	1.36	1.09	0.86	1.28
	50	1.20	0.88	1.44	1.13	0.87	1.44	1.08	0.89	1.38	1.09	0.86	1.29
	100	1.20	0.88	1.45	1.14	0.87	1.47	1.09	0.89	1.40	1.09	0.86	1.32
	200	1.20	0.88	1.47	1.15	0.86	1.49	1.09	0.89	1.41	1.09	0.86	1.35
	500	1.20	0.88	1.51	1.17	0.85	1.51	1.10	0.89	1.42	1.09	0.85	1.37

TABLE 29. CLIMATE CHANGE FACTOR (CF) FOR A DURATION OF 1 HOUR. WINTER

Winter		*RCP 2.6*			*RCP 4.5*			*RCP 6.0*			*RCP 8.5*		
T (years)		*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*	*median*	*P10*	*P90*
2006 - 2036	**2**	1.07	0.79	1.49	1.12	0.83	1.46	0.94	0.72	1.31	1.03	0.70	1.28
	5	1.13	0.74	1.51	1.08	0.75	1.56	1.06	0.65	1.45	1.08	0.60	1.31
	10	1.13	0.71	1.54	1.01	0.72	1.60	1.13	0.63	1.51	1.08	0.56	1.36
	20	1.13	0.69	1.59	0.98	0.69	1.64	1.16	0.61	1.56	1.08	0.54	1.40
	50	1.13	0.66	1.61	1.02	0.67	1.69	1.16	0.59	1.62	1.08	0.51	1.44
	100	1.13	0.65	1.64	1.05	0.65	1.72	1.16	0.57	1.66	1.08	0.49	1.47
	200	1.13	0.64	1.68	1.07	0.64	1.74	1.16	0.56	1.69	1.07	0.48	1.50
	500	1.13	0.62	1.74	1.09	0.62	1.77	1.16	0.55	1.73	1.07	0.47	1.53
2037 - 2068	**2**	1.04	0.77	1.39	1.02	0.70	1.33	1.13	0.69	1.41	1.05	0.87	1.40
	5	1.04	0.75	1.49	1.00	0.63	1.26	1.15	0.62	1.54	1.06	0.75	1.62
	10	1.03	0.75	1.59	1.01	0.59	1.26	1.17	0.60	1.64	1.07	0.68	1.73
	20	1.02	0.74	1.67	1.00	0.57	1.26	1.17	0.58	1.72	1.09	0.65	1.82
	50	1.00	0.73	1.72	1.01	0.54	1.30	1.18	0.56	1.82	1.10	0.61	1.92
	100	0.99	0.73	1.75	1.01	0.52	1.35	1.19	0.54	1.89	1.11	0.59	1.99
	200	0.99	0.72	1.78	1.02	0.51	1.38	1.20	0.53	1.95	1.12	0.58	2.04
	500	0.99	0.71	1.81	1.02	0.49	1.41	1.20	0.52	2.02	1.13	0.56	2.11
2069- 2100	**2**	1.04	0.83	1.34	1.02	0.77	1.26	1.02	0.82	1.28	1.05	0.75	1.34
	5	1.12	0.72	1.38	1.03	0.68	1.51	1.07	0.78	1.38	1.05	0.71	1.36
	10	1.14	0.68	1.47	1.04	0.63	1.54	1.10	0.74	1.42	1.07	0.68	1.39
	20	1.15	0.65	1.58	1.03	0.60	1.56	1.12	0.72	1.49	1.07	0.64	1.44
	50	1.15	0.62	1.71	1.04	0.57	1.58	1.14	0.69	1.59	1.07	0.61	1.49
	100	1.14	0.60	1.80	1.05	0.55	1.59	1.15	0.68	1.67	1.09	0.58	1.52
	200	1.14	0.59	1.86	1.04	0.54	1.60	1.16	0.66	1.74	1.10	0.56	1.54
	500	1.13	0.57	1.91	1.03	0.52	1.61	1.17	0.65	1.82	1.10	0.54	1.56

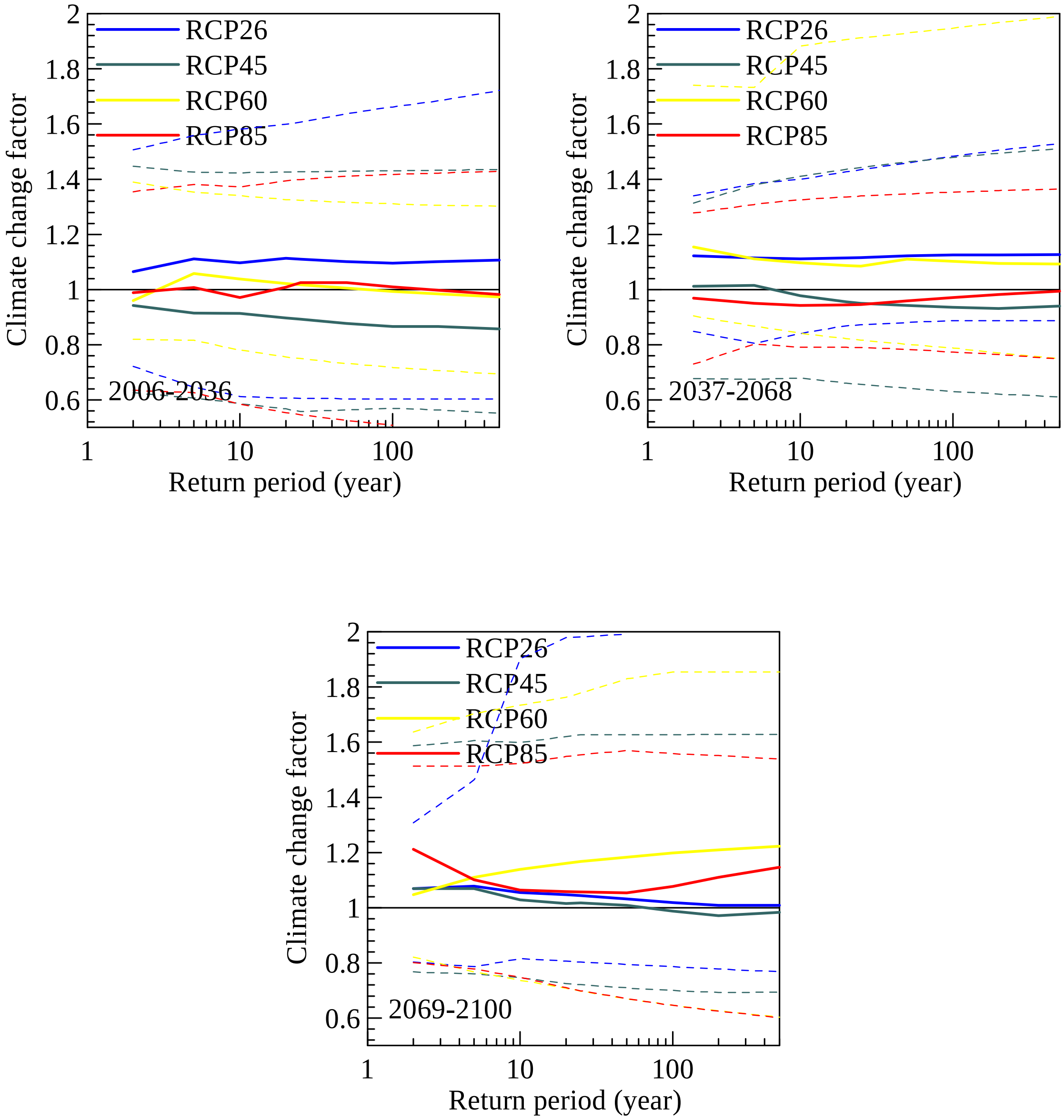
Figures 59 to 62 show, for each season of the year, the median of the climate factor for the duration of 1 hour and the upper percentile P90, and lower percentile P10, for the four climate change scenarios contemplated (RCP 2.6 - RCP 4.5 - RCP 6.0 - RCP 8.5), grouped into the climate periods 2006-2036, 2037- 2068 and 2069-2100.

FIGURE 59. CLIMATE CHANGE FACTOR FOR A DURATION OF 1 HOUR. SPRING



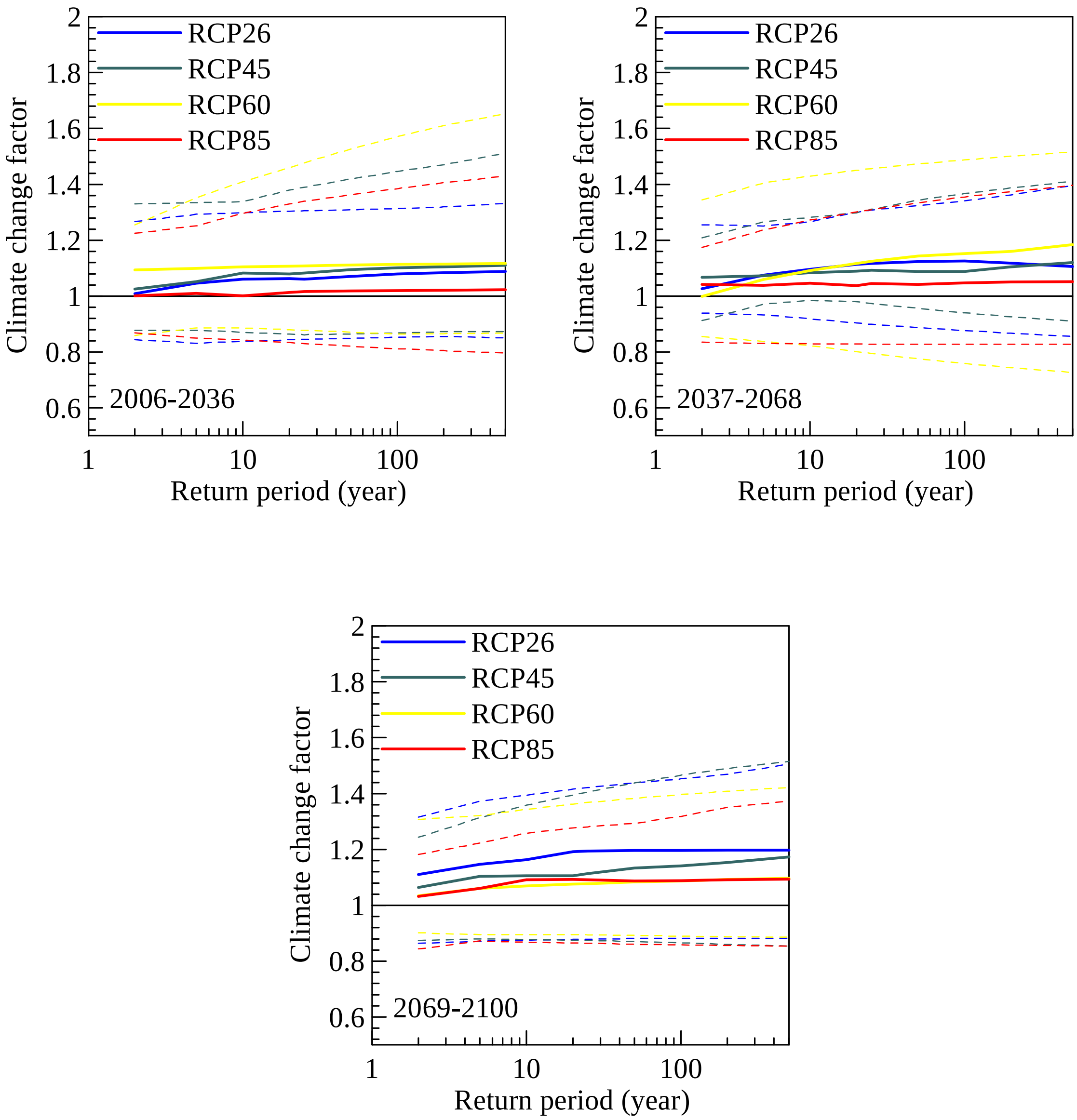
Climate change factor for a duration of 1 hour, in spring, obtained for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 60. CLIMATE CHANGE FACTOR FOR A DURATION OF 1 HOUR. SUMMER



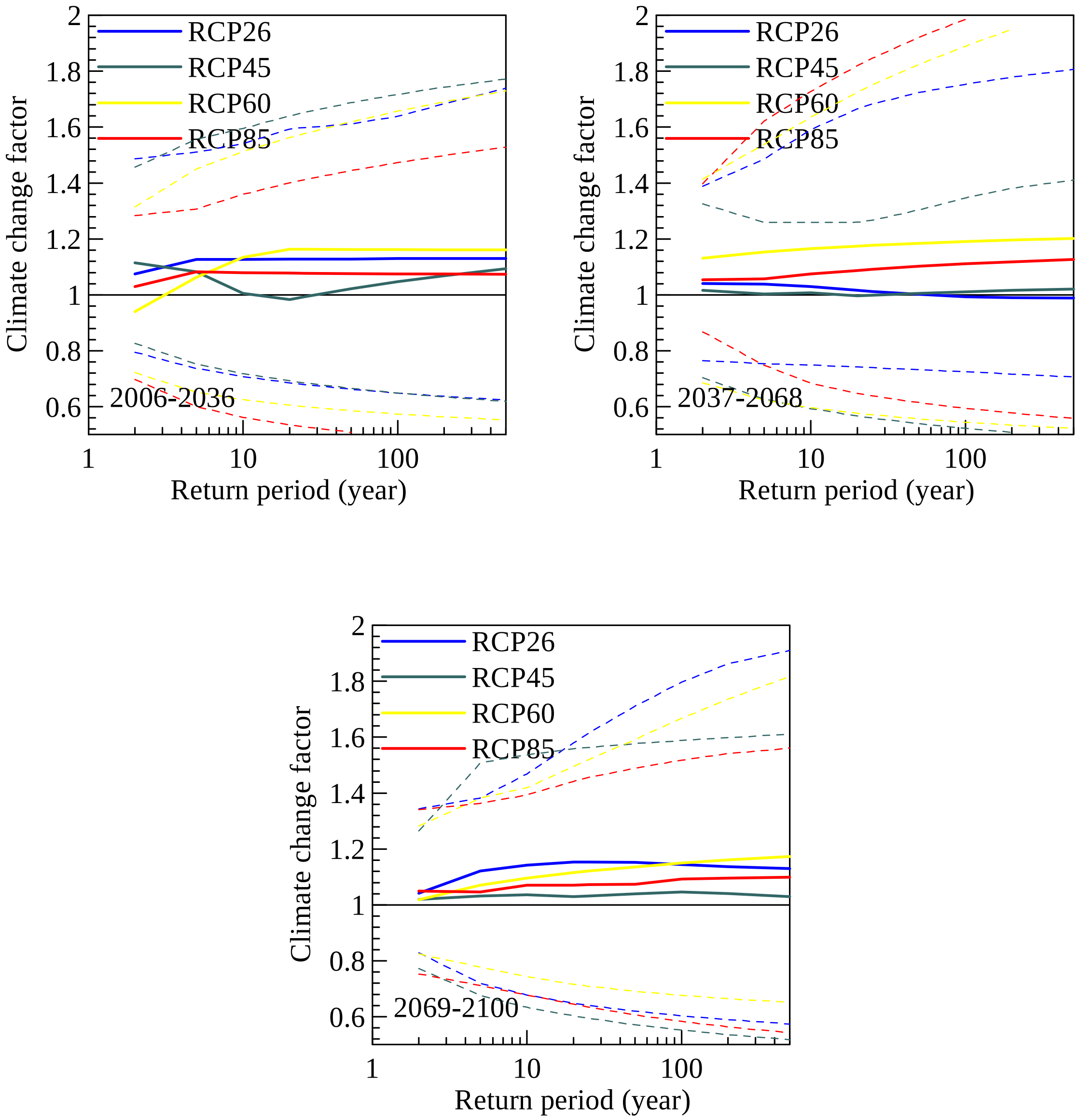
Climate change factor for a duration of 1 hour, in summer, obtained for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 61. **CLIMATE CHANGE FACTOR FOR A DURATION OF 1 HOUR. AUTUMN**



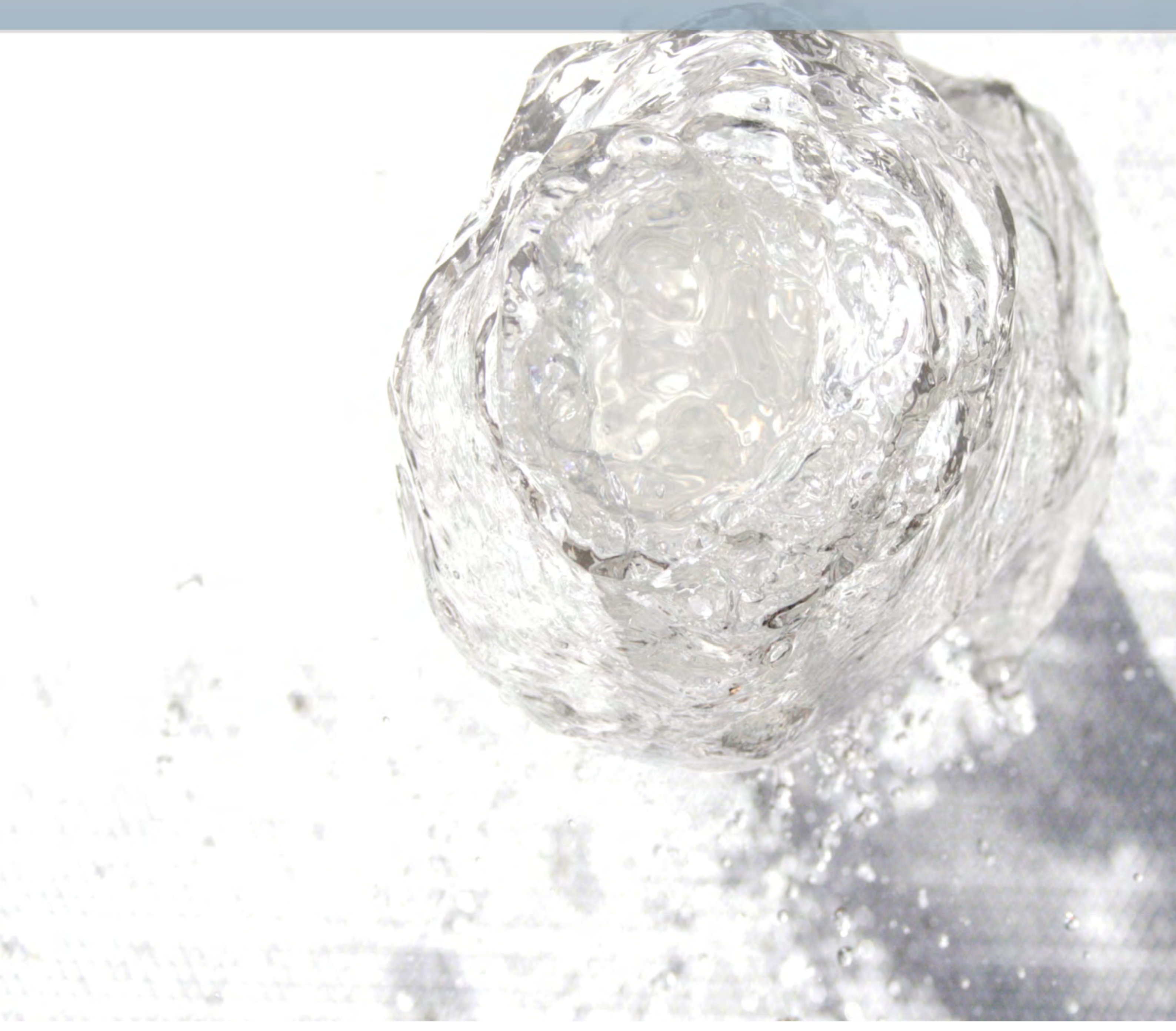
Climate change factor for a duration of 1 hour, in autumn, obtained for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

FIGURE 62. **CLIMATE CHANGE FACTOR FOR A DURATION OF 1 HOUR. WINTER**



Climate change factor for a duration of 1 hour, in winter, obtained for the three climate periods of the 21st century. The median of the set of cases corresponding to all the models and the three TP stations (unbroken lines) is represented, as well as the percentiles: upper P90, and lower P10 (broken lines).

3. Conclusions



From the study carried out on the climate change scenarios applicable to the region of Madrid, the conclusions summarised in this chapter are extracted.

1. From the analysis of the annual maximum daily rainfall series obtained from the daily rainfall series simulated by the FIC, it should firstly highlight the great variability that they present in accordance with general circulation model used and the reference TP station.

Figure 63 shows the variability of the cases corresponding to the **RCP 2.6** scenario for a return period of 10 years; variations ranging from an 18% decrease to a 21% increase in daily precipitation intensity are found. While, for a return period of 50 years, the variations go from a decrease of 24%, to an increase of 38%.

It has been found that 33% of the series have points that can be considered "**outliers**" at a distance from the average greater than 3**σ**.

There are 5 cases in which a point has appeared that is more than 5**σ** of the mean; these series have been discarded so that they do not distort the expected values of extreme intensity.

Table 30 displays the "**outliers**" detected.

TABLE 30. OBSERVATORIES AND OUTLIERS DETECTED

Observatory Code	*Observatory*	*Model*	*Scenario*	*Period*
3200	Getafe	CNRM-CM5	RCP 2.6	2075
23200	Getafe	NorESM1	RCP 2.6	2080
3195	Retiro	MPI-ESM-MR	RCP 4.5	2074
3200	Getafe	HADGEM2-CC	RCP 4.5	2007
3200	Getafe	MIROC-ESM-CHEM	RCP 4.5	2043

2. Taking into account the great variability observed, it is appropriate to average out the maximum number of cases to reduce the uncertainty of the results.

When the three TP stations are averaged out:

- 24 cases correspond to the RCP 2.6 scenario
- 27 to the RCP 4.5 scenario
- 15 to the RCP 6.0 scenario and
- 27 cases to the RCP 8.5 scenario.

When the TP stations are analysed separately:

- there is only an average of 8 cases that correspond to the RCP 2.6 scenario.
- 9 to the RCP 4.5 scenario
- 5 to the RCP 6.0 scenario
- 9 cases to the RCP 8.5 scenario.

The results obtained in the RCP 6.0 scenario, when analysing TP thermopluviometric stations separately, are very unreliable, so they are not considered in this study.

3. The climate factor, calculated for the maximum rainfall in 24 hours, is greater than 1 in 66% of the cases studied, for a return period of 10 years, and greater than 1.05 in 51% of cases.

4. When analysing the calculated CF for the hourly precipitation from the **downscaling** performed through the fractal analysis, it should be noted that the climatic factor is greater than 1 in 75% of the cases studied, for the same 10-year return period and exceeds 1.1 in 57% of total cases.

5. For T = 10 years, the average 24-hour CF of the three TP stations has a value of 1.06 - 1.07 for most scenarios and climate periods, with the following exceptions: RCP scenario 4.5 (1.03); and RCP scenario 8.5 (1.01), (the second and last third of the 21st century, respectively, see Table 31).

TABLE 31. VALUE OF CF IN 24 HOURS, AVERAGE OF THE THREE STATIONS (T=10 YEARS)

Period observed	*RCP 2.6*	*RCP 4.5*	*RCP 8.5*
2006-2036	1.07	1.07	1.06
2037-2068	1.06	1.03	1.06
2069-2100	1.06	1.07	1.01

6. For T = 10 years, the 1-hour CF has an average value of 1.15 in the first third of the 21st century; 1.13 in the second third and 1.18 in the last third, see Table 32.

TABLE 32. VALUE OF CF IN 1 HOUR, AVERAGE OF THE THREE STATIONS (T=10 YEARS)

Period observed	*RCP 2.6*	*RCP 4.5*	*RCP 8.5*
2006-2036	1.17	1.20	1.10
2037-2068	1.11	1.08	1.19
2069-2100	1.30	1.14	1.11

APPENDICES

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APPENDIX 3. ACRONIMS AND TERMS

Acronym	*Description*
AEMET	STATE METEOROLOGY AGENCY (AEMET)
BIAS	AVERAGE OF THE DIFFERENCES
CF	CLIMATE CHANGE FACTOR
CLABSA	CLAVEGUERAM BARCELONA S.A.
CMIP5	COUPLED MODEL INTERCOMPARISON PROJECT 5
ECDF	EMPIRICAL CUMULATIVE DISTRIBUTION FUNTION
ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
EOGCM	ATMOSPHERE-OCEAN COUPLED GENARAL CIRCULATION MODEL
ESM	EARTH SYSTEM MODEL
FIC	FOUNDATION FOR CLIMATE RESEARCH
FICLIMA	DOWNSCALING METHODOLOGY
GCM	GENERAL CIRCULATION MODELS
GHG	GREENHOUSE GAS EMISSIONS (GHGS)
GFDL	GEOPHYSICAL DYNAMICS LABORATORY
GPA	DISTRIBUCIÓN GENERALIZADA DE PROMOTION
IDF	INTENSITY-DURATION-FREQUENCY) CURVES
IPCC	INTERNATIONAL PANEL ON CLIMATE CHANGE
LAM	LIMITED AREA MODEL
MAE	AVERAGE OF THE ABSOLUTE VALUE OF THE DIFFERENCES
NCAR	NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
PCMDI	PROGRAMME FOR THE COMPARISON AND THE DIAGNOSIS OF THE CLIMATE RESEARCH
PI	PENÍNSULA IBÉRICA
RCM	REGIONAL CLIMATE MODELS
RCP	REPRESENTATIVE CONCENTRATION PATHWAYS
TP	THERMOPLUVIOMETRIC STATIONS
UB	UNIVERSIDAD DE BARCELONA
UPC	UNIVERSIDAD POLITÈCNICA DE CATALUNYA
WCRP	WORLD CLIMATE RESEARCH PROGRAMME
WMO	WORLD METEOROLOGICAL ORGANIZATION

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