VINEYARDS INTEGRATED SMART CLIMATE APPLICATION

Deliverable 2.5: Decadal projection performance report

WP	2	Climatic & Agricultural Data		
Task	2.5	Decadal Climatic Data		
Dissemination level[1]		PU	**Due delivery date**	30-04-19
Nature[2]		R	**Actual delivery date**	06-03-19

Lead beneficiary	METEOSIM
Contributing beneficiaries	-

Version	1.0
Total number of pages	44

[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium, **CO** = Confidential, only for members of the consortium

[2] Nature of the deliverable: **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

Version history

Document Version	Date	Author	Comments[3]
0.1	01/2019	Josep Maria Solé (MET)	Main structure
0.2	02/2019	Josep Maria Solé (MET)	Development of contents
1.0	03/2020	Josep Maria Solé (MET)	Final Review

[3] Creation, modification, final version for evaluation, revised version following evaluation, final.

Deliverable abstract

This deliverable D2.5 “Decadal Projection Performance Report” consists of an analysis of climate projections at European scale and particularly at demosite of the project in order to provide critical climate information of the most important variables for vineyard management. Mean climate about precipitation and temperature is analysed, specific agriculture indexes are provided such as Winkler classification and climate extremes affecting the vine growth are studied. This document is intended to provide useful information in order to empower the wine industry to make strategic decision to adapt their businesses to new climate conditions in the coming decades.

List of acronyms and abbreviations

DoW	Document of Work
VISCA	Vineyards Integrated Smart Climate Application
WP	Work Package
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
RCP	Representative Concentration Pathway

Applicable and reference documents

REF.	SUBJECT
RD01	Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., **123**. doi:10.1029/2017JD028200
RD02	Klok, L., and A. M. G. Klein Tank (2008), Updated and extended European dataset of daily observations, Accepted by International Journal of Climatology.

Contents

1. Introduction

1.1 Motivation

The extension and the quality of wine production is strongly related to the environmental condi tions of the grape growing season. Grapevine growing factors are determined within a narrow c limatic range in which the adequate heat accumulation, the availability of enough water and the low risk of extreme temperature episodes is required. As example, in 2017 a historically low production (8% less in comparison with 2016) was registered due to climate conditions.

While climate patterns can differ radically from on year to another (climate variability), climate change is more concerning, because a significant shift in the long-term climatology would make the wine business unsustainable. Adaptation measures are most probably needed to adapt the current grape varieties to warmer climate conditions and the presence of more frequent and more intense extreme events such as heat waves, heavy rainy or long dry spells.

Future suitability of a certain viticulture regions highly depends on the change on the mean patterns on temperature and precipitation in the coming decades, but also on the impact of extreme temperature and precipitation. For that reason, estimation regional changes in temperature and precipitation and the derived impacts on the suitability of vine cultivation is of paramount importance for the business of gives critical information for making strategic decisions and investments in the near future, which will make the industry more resilient and adapted to climate change.

1.2 Purpose of the Document

This document reports the outcomes of the activities performed in Task 2.5 "Decadal Climatic Data", within the frame of the Work Package 2 "Climatic & Agricultural Data" of the VISCA project (RD01).

The purpose of this document is to show the change of climate variables which are impacting the most in the viticulture, namely mean precipitation and temperature, but also temperature and precipitation extreme events for the coming decades until 2100. Specific agronomic indices such as Winkler will be used specifically to assess vine suitability.

The analysis will be performed at European scale, but also specific results will be provided by the 3 demosites provided by the end-users of the project:

- Cordorniu, located in Raimat (Spain).
- Symingtn, located in Quinta do Ataíde (Portugal).
- Mastroberardino, located in Atripalda (Italy).

Figure 1: Location of end-users demosites

1.3 Structure of the Document

This document is structured into five chapters:

- Chapter 1 is this introduction and description of the document itself;
- Chapter 0 summarises the used data
- Chapter 3 introduces the methodology
- Chapter 4 provides the main results and discussion. Results regarding mean climate, Winkler index and extreme climate is provided.
- Chapter 5 concludes the document summarizing the main findings and discussion

2. Data

This chapter presents the climate datasets, which have been used to perform the climate analyiss

2.1 Observations

E-OBS[4] version 17 (RD01) has been used as observational dataset. This is a gridded observational dataset derived through interpolation of the ECA&D (European Climate Assessment and Data) station data described collected at European scale (RD02. The station dataset comprises a network of 2316 stations, with the highest station density in Ireland, the Netherlands and Switzerland, and lowest density in Spain, Northern Africa, the Balkans and Northern Scandinavia. The number of stations used for the interpolation differs through time and by variable.

The E-OBS dataset is derived through a three-stage process:

- Monthly means of temperature and precipitation are first interpolated to a 0.1-degree latitude by longitude grid using three-dimensional (latitude, longitude, elevation) thin plate splines.
- Daily anomalies, defined as the departure from the monthly mean temperature or precipitation, are interpolated to the same 0.1-degree grid, and combined with the monthly mean grid. For temperature, daily anomalies are interpolated using kriging with elevation as an external variable. For precipitation kriging is first used o interpolate the the state (wet/dry); after that the magnitude at 'wet' 0.1 degree grid points is interpolated using universal kriging.
- Finally, the 0.1-degree points are used to compute area-average values at the four E-OBS grid resolutions (0.25- and 0.5-degree regular latitude-longitude grid and 0.22 and 0.44 degree lat-long rotated-pole grids).

[4] We acknowledge the E-OBS dataset from the EU-FP6 project UERRA (http://www.uerra.eu) and the Copernicus Climate Change Service, and the data providers in the ECA&D project (https://www.ecad.eu)

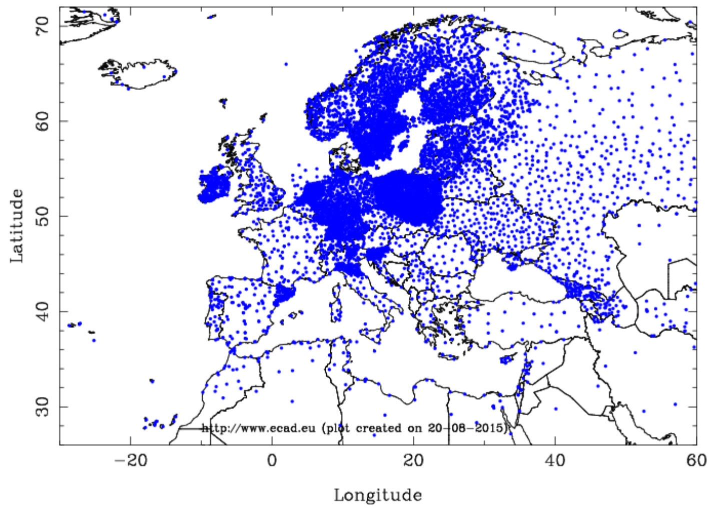

Figure 2. ECA&D station network map.
Source: https://climatedataguide.ucar.edu/climate-data/e-obs-high-resolution-gridded-meanmaxmin-temperature-precipitation-and-sea-level

In the present study the 0.22-degree lat-long rotated-pole grid has been used, because it coincide with the grid of EURO-CORDEX grid (see chapter below). The full dataset covers the period from 1950 to 2017 (both included).

2.2 EURO-CORDEX

EURO-CORDEX is the European branch of the international CORDEX initiative, which is a program sponsored by the World Climate Research Program (WRCP) to organize an internationally coordinated framework to produce improved regional climate change projections for all land regions world-wide. The CORDEX-results are being used world-wide to assess for climate change impact and to feed adaptation studies within the timeline of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and beyond.

EURO-CORDEX consists of a set of simulations provided by the participating groups. Nowadays, mainly dynamical downscaling simulations are available, namely the output of a regional climate model (RCM) coupled to a Global Climate Model (GCM) or a Reanalysis. The outputs of these simulations are available on rotated-pole regular grids at 0.11 degrees of horizontal resolution (~12 km, depending on the latitude). They are free to download from Earth System Grid Federation (ESGF) nodes like https://esgf-data.dkrz.de/projects/esgf-dkrz/. In order to be able to be compared with E-OBS database, EURO-CORDEX was regridded to 0.22 rotated-grid pole resolution.

From all the CORDEX simulations are available, the following are selected for the purpose of the following study:

- **Historical simulations**: Different RCM are coupled to different GCM from Coupled Model Intercomparison Project (Phase 5). They are useful as a historical basis to compare the future climate as well as to validate the skill of GCM-RCM to reproduce the regional historical climate.
- **Future simulations**: Different RCMs are coupled to different GCM and different Representative Concentration Pathways (RCPs). The available RCPs are **RCP4.5 and RCP8.5**, which are emissions scenarios projecting a radiative forcing of 4.5 W/m^2 and 8.5 W/m^2 at 2100, as shown in Figure 3.

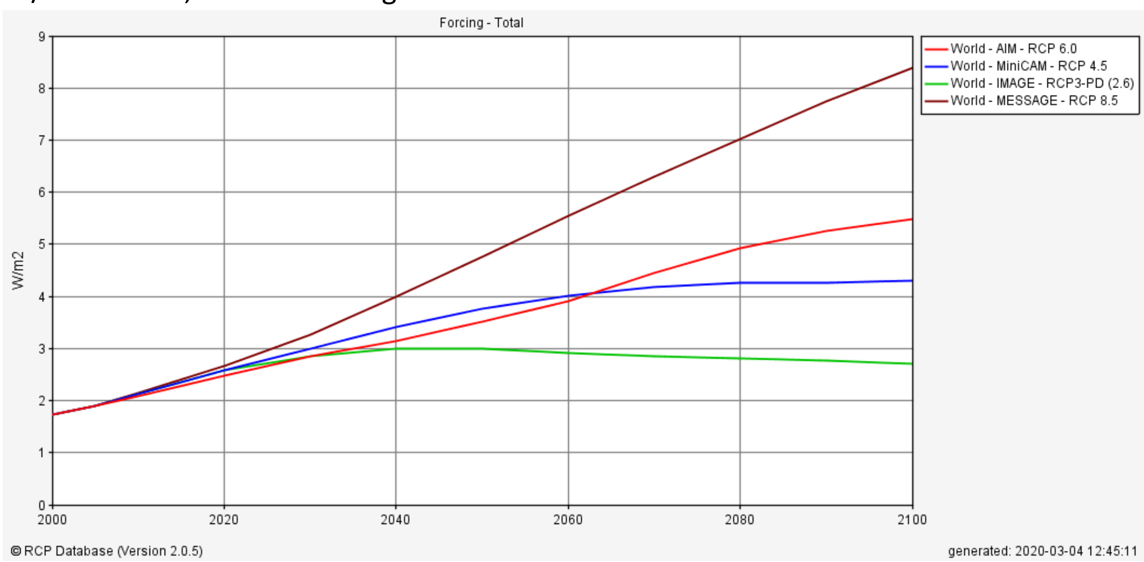

Figure 3. Radiative forcing according to Representative Concentration Pathways (RCPs)

From all simulations available[5], the 17 shown in Table 1 were selected, because they meet the following requirements:

- They are available at **daily time resolution**.
- The variables of interest are available: **precipitation, daily mean temperature, daily maximum temperature and daily minimum temperature**.
- The simulations cover the required period:
  - **Historical period**: 1976-2005.
  - **Future period**: 2010-2100.

[5] A detailed description of the abovementioned models and their simulations available at EURO-CORDEX can be found at: https://euro-cordex.net/imperia/md/content/csc/cordex/20180130-eurocordex-simulations.pdf

As shown in Table 1, each GCM is run under different initial conditions, also known as GCM ensemble members. This GCM simulations are used as initial and boundary conditions of different RCMs.

Simulations group	**GCM**	**GCM ensemble member**	**RCM**
Historical and RCP simulations	CNRM-CERFACS-CNRM-CM5	r1i1p1	SMHI-RCA4
		r1i1p1	CLMcom-CCLM4-8-17
	ICHEC-EC-EARTH	r12i1p1	SMHI-RCA4
		r1i1p1	KNMI-RACMO22E
		r12i1p1	KNMI-RACMO22E
		r3i1p1	DMI-HIRHAM5
		r12i1p1	CLMcom-CCLM4-8-17
	IPSL-IPSL-CM5A-MR	r1i1p1	IPSL-INERIS-WRF331F
		r1i1p1	SMHI-RCA4
	MOHC-HadGEM2-ES	r1i1p1	CLMcom-CCLM4-8-17
		r1i1p1	KNMI-RACMO22E
		r1i1p1	SMHI-RCA4
	MPI-M-MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17
		r1i1p1	SMHI-RCA4
		r1i1p1	MPI-CSC-REMO2009
		r2i1p1	MPI-CSC-REMO2009
	NCC-NorESM1-M	r1i1p1	DMI-HIRHAM5

Table 1: EURO-CORDEX simulations list. Simulations are classified according to the group (historical, RCP or evaluation), the GCM and the RCM

3. Methodology

This chapter presents the methods used to evaluate the data presented in Section 0.

First of all, s set of climate indices are defined giving key information about the impact on the wine sector. They are the following:

- **Seasonal temperature climatology:** Defined as the mean temperature over a period of a 3-monthly season.
- **Seasonal daily precipitation climatology:** Defined as the mean of maximum daily precipitation over a period of a 3-monthly season[6].
- **Winkler index:** Winker classifies a location according to the range of the growing degree-days (GDD). GDD is an annual value defined as the accumulation of temperature above a base temperature (defined as 10ºC) from 1st April to 31st of September. The climatology of GDD over a defined period can be classified according to A. Winkler into 5 categories, as shown in Table 2.

Regions	GDD (ºC)	Wine regions examples	Grape varieties examples
Region I	<1390	Tasmania, Champagne, Burgundy Friuli, Chablis	Chardonnay, Pinot noir, Sauvignon blanc, Riesling
Region II	1391 – 1670	Yarra Valley, Alsace, Boredeaux, Napa	Cabernet sauvignon, Merlot, Semillion, Syrah, Chardonnay
Region III	1671 – 1950	Rioja, Piemonte, Clare Valley, Capetown, Barossa valley	Tempranillo, Grenache, Barbera, Syrah
Region IV	1951 – 2220	Langhore Creek, Montpellier, Florence, McLaren Vale	Tempranillo, Mourvedre, Carignan, Cinsault

The 3-monthly seasons are defined as follows:

- **DJF**: December-February,
- **MAM**: March-May,
- **JJA**: June-August,
- **SON**: September-November.

Region V	>2220	Sicily, Sardinia, Jerez, Swan Valley	Fiano, Primit

Table 2: Winkler classification

- **Frequency of summer days**: Climatology of the number of days per year where mean temperature is above 25ºC.
- **Length of the heat waves:** Climatology of maximum number of consecutive days per year where maximum temperature > 90th percentile of daily maximum temperature record.
- **Frequency of frost days in boreal spring months:** Climatology of the number of days when daily minimum temperature < 0°C per year during MAM (March-May).
- **Climatology of maximum length of dry spell:** Climatology mean of Maximum number of consecutive days where daily precipitation < 1mm per year.

Secondly, the validation EURO-CORDEX simulations against E-OBS has been performed. This has consisted in the following:

- A comparison between climatological maps at European scale of E-OBS against EURO-CORDEX, which allows to assess how EURO-CORDEX is able to reproduce the **spatial distribution** of the precipitation and temperature throughout Europe. See the results in Chapter 4.1.1.
- A comparison of mean the annual cycle of temperature and precipitation, which allows to assess the ability of CORDEX to reproduce the **intraanual variability**. For this, mean regional mean values[7] were calculated for the validation of the regions of interest of the project. A square box of 3.0 degrees centered on the demosites were used to calculate the mean regional values. The results of this analysis are shown in Chapter 4.1.2.

Finally, an analysis of the projected changed over the period 2070-2099 in comparison to a historical climate period 1976-2005 is done. Also, two other periods have been analysed: 2010-2039 and 2040-2069, although similar results are found, but with less intensity. So, only the results for 2070-2099 are finally shown in this report, which suppose a conservative scenario for planning adaptation measures in the wine sector.

Firstly, maps at European scale are analysed, so the expected change for mean precipitation and temperature, Winkler index and climate extremes (dryspell, frost days and heatwave length) are shown according to RCP4.5 and RCP85. After that, an specific analysis for each demosite is

[7] Regional values were calculated as an area average of values weighted by the cosine of the latitudes, given that the projection of the data is lat-long.

provided, analysing how mean and extreme parameters are expected to change in the 2070-2100 in comparison with 1976-2005.

In the regional analysis, an estimation of the uncertainty of climate projections is given by means of an histogram of projected changes across the considered simulations. An example of the histogram is shown in Figure 4. The horizontal axis refers to the variable of interest, in this case, the change of mean temperature between 2070-2100 and 1976-2005. The bars express the percentage of the models lying in each bin and the shaded area represents the percentage of models in which the project change is significative. Significance is evaluated using a Mann-Whitney test[8]. Each row of points displays the individual values each GCM (with different RCMs), giving an idea of the uncertainty of each group of GCM simulations.

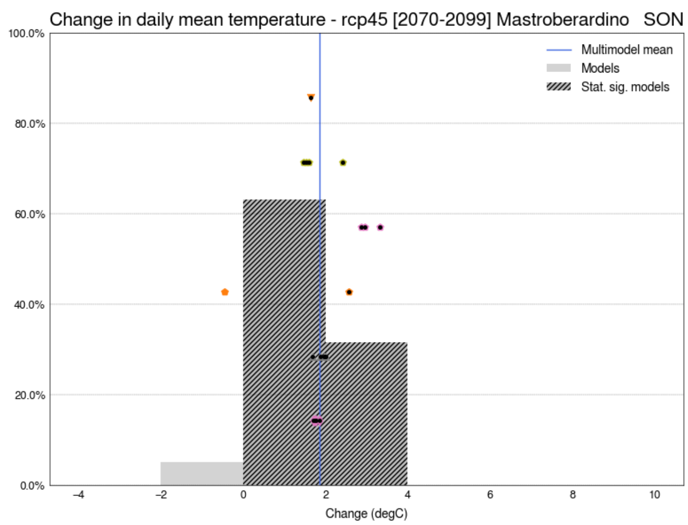

Figure 4: Example of histogram of changes provided in the results chapter

[8] Kruskal WH (1957) Historical notes on the Wilcoxon unpaired two-sample test. J Am Stat Assoc 52:356–360

4. Results and discussion

This chapter presents the results and discussion obtained from the application of the methods detailed in Section 0.

4.1 EURO-CORDEX validation against E-OBS

4.1.1 Validation at European scale

The validation of EURO-CORDEX simulations against E-OBS at European scale consists of evaluating their capability of representing the spatial distribution. For this purpose, in Figure 5 and Figure 6 the seasonal climatology of daily precipitation and mean temperature are shown.

In terms of precipitation, EURO-CORDEX describes correctly the main spatial features in Europe in comparison to E-OBS. The following results can be derived:

- EURO-CORDEX slightly overestimates the mean daily precipitation in central Europe and Iberia, especially in DJF, MAM and JJA, except in Iberia in JJA, where is not overestimated. In general, northern Europe is underestimated in DJF and MAM and SON, although it is slightly overestimated during JJA.
- EURO-CORDEX clearly overestimates the magnitude of precipitation in the most wet areas such mountainous areas such as the Pyrenees and the Alps.
- EURO-CORDEX shows a spatial distribution similar to the observed in E-OBS, so in DJF and SON regions close to the Atlantic Ocean show much higher precipitation than continental regions (e.g., the north-western Iberia, northern Great Britain and western Norway).

In terms of daily temperature, EURO-CORDEX describes correctly the main spatial features in Europe in comparison to E-OBS. The following results can be derived:

- EURO-CORDES shows a positive gradient North-South, which is also identified in E-OBS.
- The effect of the elevation if well captures in EURO-CORDEX, so mountainous regions such as Pyrenees and Alps show lower temperatures, which are slightly underestimated in DJF and SON.

In Figure 7, E-OBS and EURO-CORDEX are compared in terms of extreme climate, so the ability of representing maximum annual dry spell, the spring frosts and the summer days is confirmed. From this figure it is possible to conclude qualitatively that EURO-CORDEX is capable to reproduce the spatial variability of these variables as well as their magnitude across Europe.

In Figure 8, the Winkler index is shown. E-OBS represents correctly the main wine regions in Spain, France, Germany, Portugal, Italy and eastern countries like Greece, where Region I and II are located in central Europe, whereas Regions III, IV and V are located in southern Europe. EURO-CORDEX also reproduces quite well this distribution, although cold regions are poorly represented, due there is an underestimation of temperatures in some areas, as shown before.

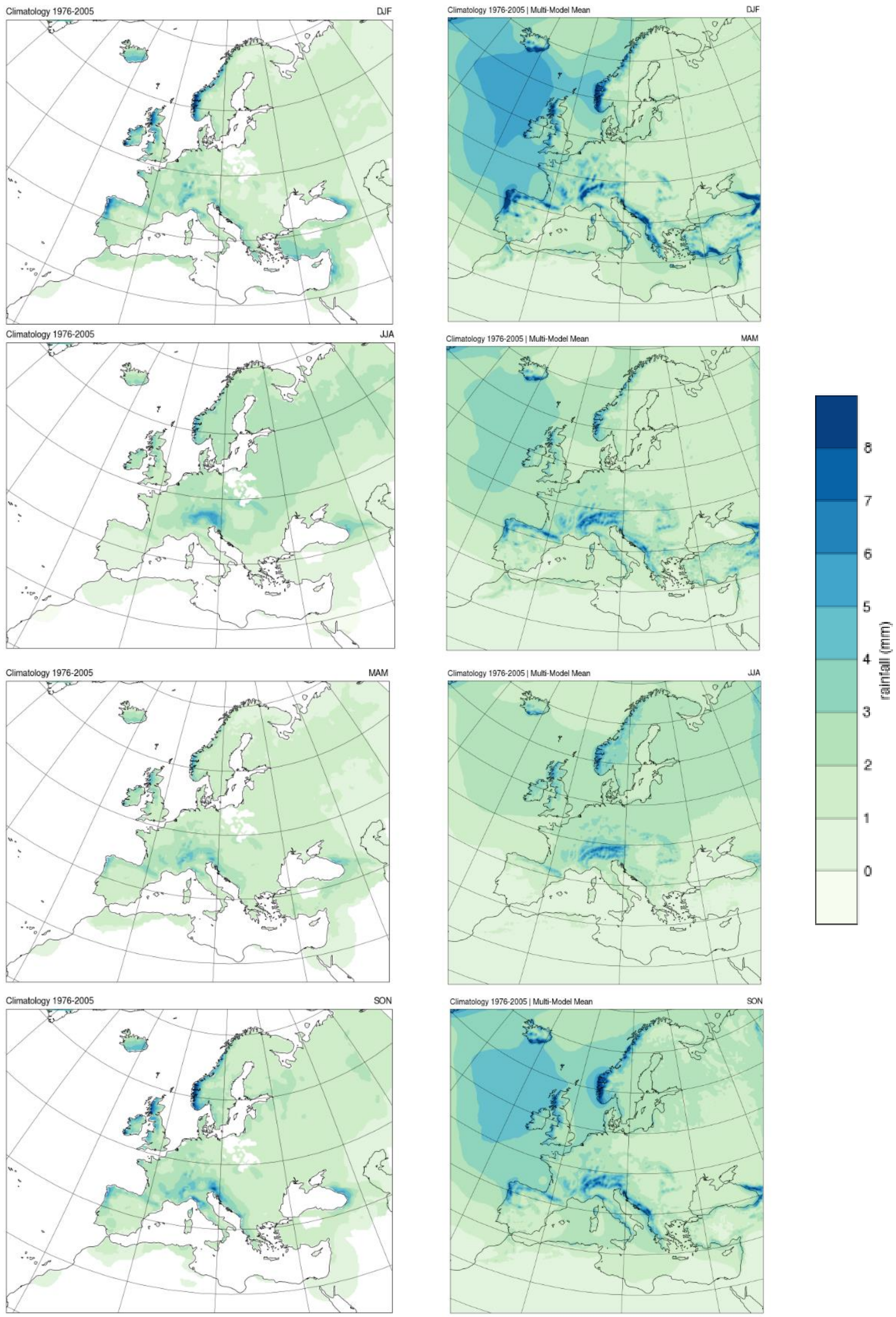

Figure 5: Seasonal daily precipitation climatology over the period 1976-2005. E-OBS (left). EURO-CORDEX (right).

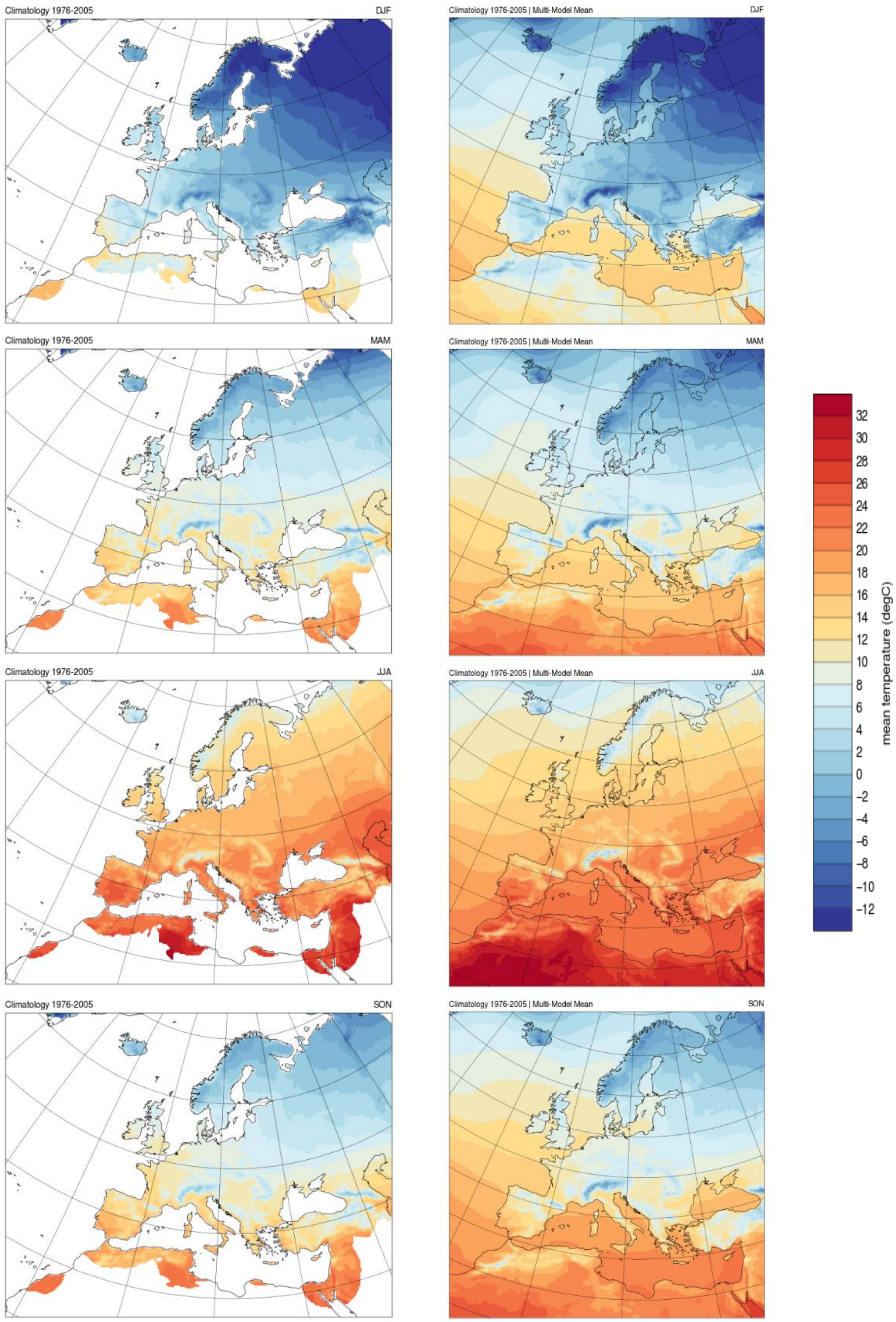

Figure 6: Seasonal mean temperature over the period 1976-2005. E-OBS (left). EURO-CORDEX (right).

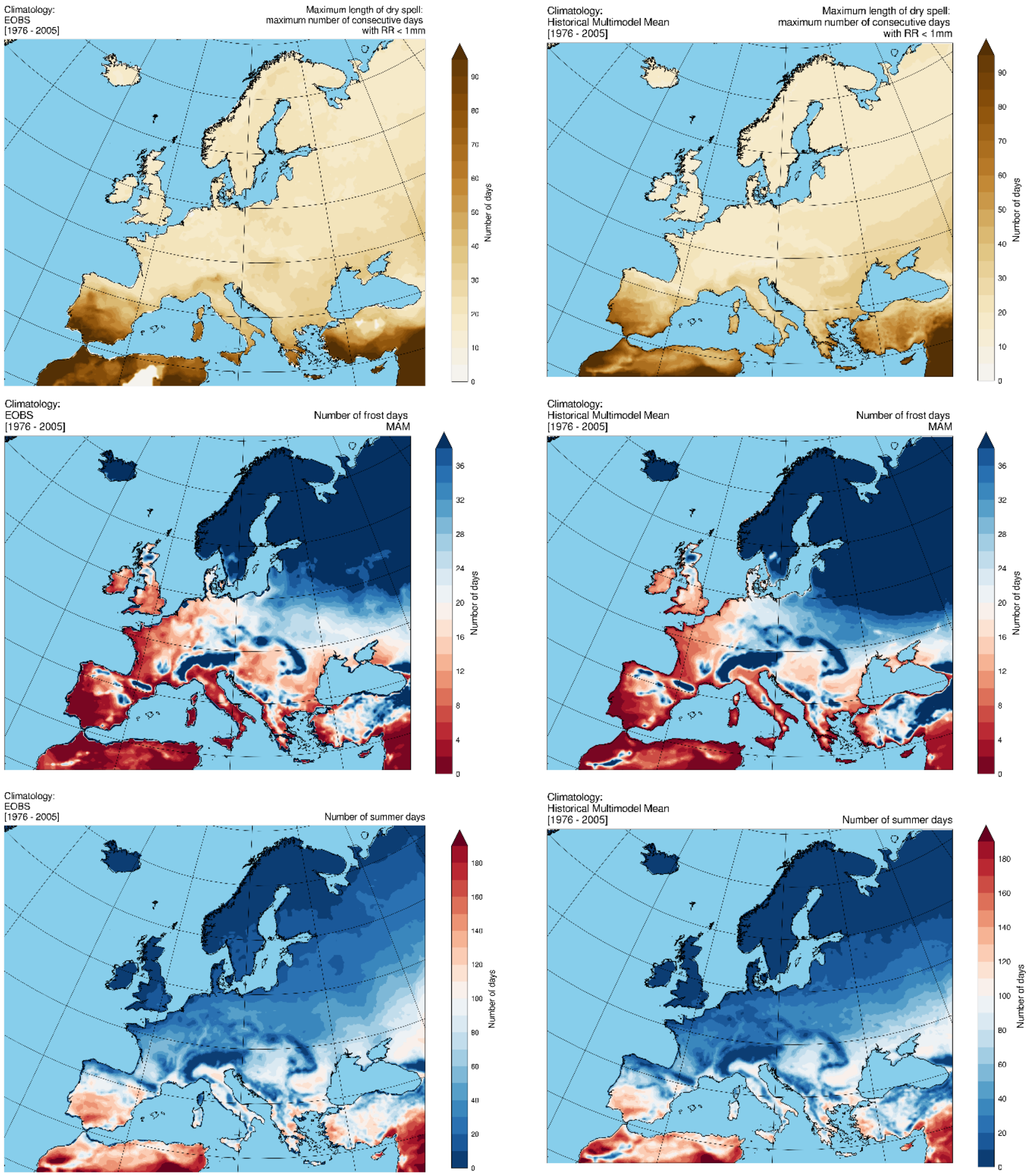

Figure 7: Climatology of extremes according to EOBS (left) and EURO-CORDEX (right). Annual Maximum length (top), Number of frost days (middle), Number of summer days (bottom)

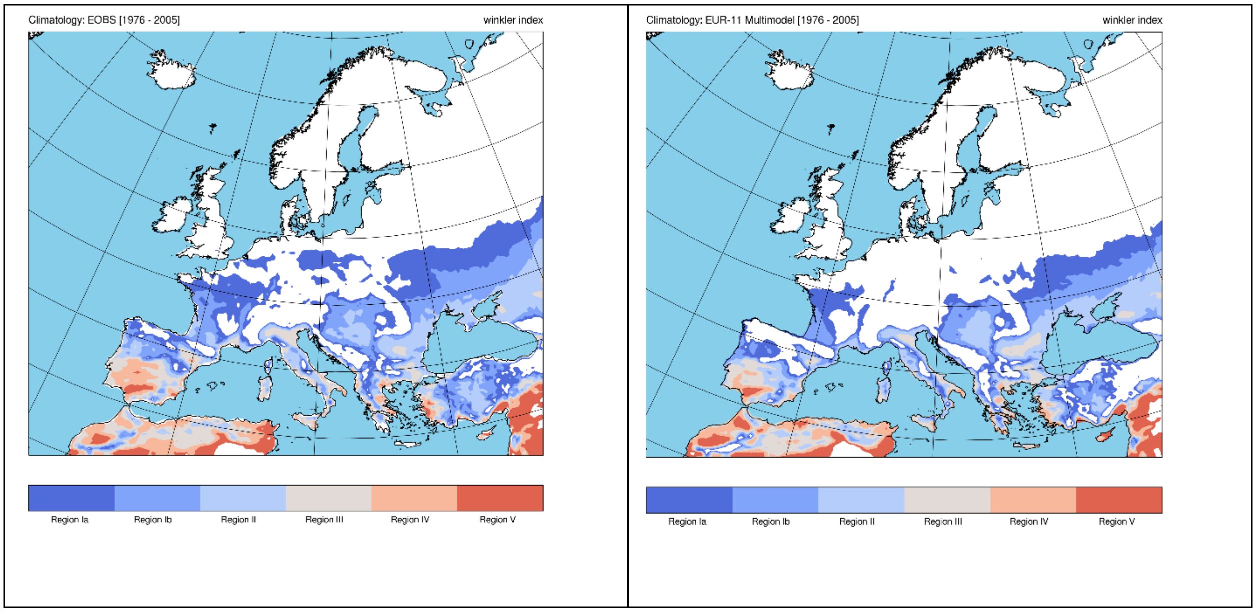

Figure 8: Climatology of Winkler index according to EOBS (left) and EURO-CORDEX (right).

4.1.2 Validation at demosites

In this chaper, the analysis is focused in the three demosites: Atripalda (Napoli), Raïmat (Catalunya) and Quinta do Ataíde (Porto). The annual cycle of daily precipitation and mean temperature is analysed by comparing E-OBS data with EURO-CORDEX.

In Figure 9, the yearly cycle of daily precipitation and mean temperature is shown for the three demosites. The red line shows the observed values, the grey lines show all the simulations under EURO-CORDEX, while the black line is the computed Multi-model mean of EURO-CORDEX. From this figure, the following conclusions are extracted:

- The yearly cycle of mean temperature shows a peak in July and August reaching values greater than 20ºC for any demosite, while the minimum values are in January ranging from 5 to 10ºC depending on the demosite.
- EURO-CORDEX shows a good performance of the yearly cycle of mean temperature, so it is well correlated in the three demosites, although the multi-model mean is underestimating the mean temperature between 2 and 3ºC depending on the month and the demosite.
- EURO-CORDEX simulations show a range around 5ºC of uncertainty constantly throughout the year.
- In Catalonia, there is a yearly cycle of daily precipitation with two peaks in May and October with a dry period from June to August. EURO-CORDEX performs properly the two bimodal cycle, although it is clearly overestimated in comparison to E-OBS around 50%
- In Napoli, E-OBS shows a yearly cycle of daily precipitation with a peak in November, which is quite good correlated with EUROCORDEX, although it is clear overestimated in winter months from January to May.
- In Porto, E-OBS show a yearly cycle of daily precipitation with a peak between December and January and a minimum in July and August. EURO-CORDEX is well correlated with E-OBS. Overestimation is identified in the winter months, whereas there is almost no overestimation during the summer months.

Despite the overestimation found in the places of interest, this issue is not perturbing the analysis of future climate, since the biases are found in both the historical and future simulation, so they are correctly balanced. The most important is that spatial distribution as well as yearly cycle are well represented and correlated.

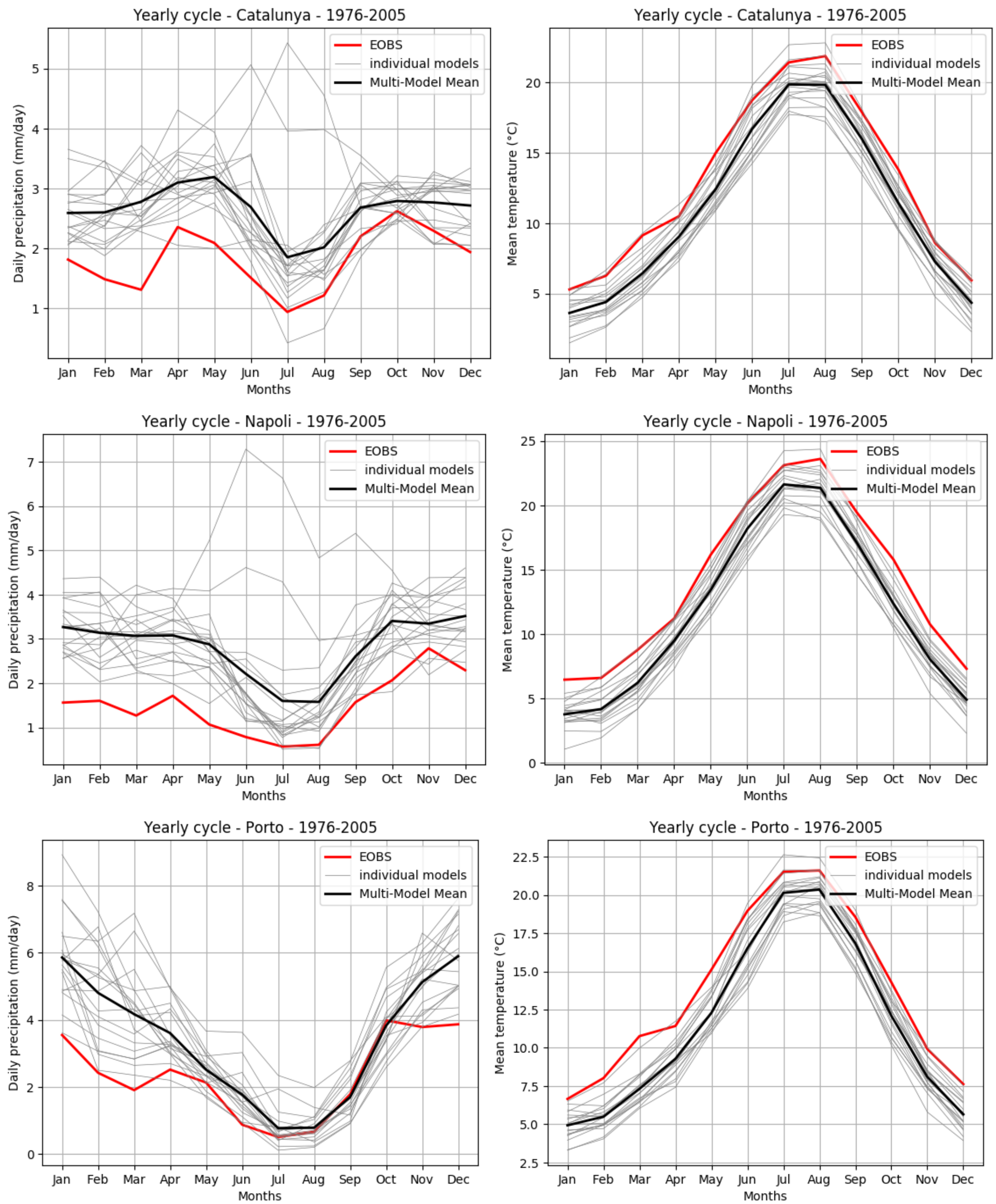

Figure 9: Annual cycle of daily precipitation (left) and mean daily temperature (right) over the period 1976-2005 over EOBS and EURO-CORDEX. Regional values are displayed over Catalonia

4.2 Regional climate projections

4.2.1 Regional climate projections at European scale

In this chapter, the projected changes in the period 2070-2100 compared to the period 1976-2005 are exposed through the analysis of maps of precipitation and temperature mean climates, maps of the Winkler index and maps of climate extremes.

In Figure 10 and Figure 11 the projected changes for daily precipitation and mean temperature at European scale according to the multi-model mean of EURO-CORDEX under RCP4.5 and RCP8.5 are shown. The following results are extracted:

- There is a decrease of precipitation in the Iberian Peninsula, Italy, Greence and Turkey, while an increase in the rest of central and northern European countries for all seasons.
- The decrease of precipitation is more intense in JJA, when it is extended also to France and UK.
- The decrease is clearly more intense under RCP8.5 than in RCP4.5.
- There is an increase of temperature overall in Europe and under RCP4.5 and RCP8.5
- Increases of temperature are greater under RCP8.5 than RCP4.5, as expected.
- Increase of temperature are larger in southern countries like Spain, Portugal, Italy, Greece and North Africa during JJA, while these increases are milder in central Europe countries like France, Germany and UK.
- In DJF, there is a clear gradient south-north, so the southern countries have a mild increase of temperature, while the northern countries like Sweden or Finland have a much larger increase reaching values around +8ºC under RCP8.5.

In Figure 12, the projected changes for the Winkler index are shown. The following results are extracted:

- A shift of the suitable regions for vine growing[9] to norther latitudes is clearly projected under RCP4.5 and RCP8.5 due to an increase of temperatures at European scale. While in period 1976-2005, the suitability of grape growing is mainly located in southern Europe countries like Spain, Portugal, south France, southern Germany, Italy, Greece and Northern Africa, in 2070-2099 the suitable areas are extended to central Europe and even northern Europe under RCP8.5. South UK, north Germany, Denmark are expected to be new suitable areas if the climate projections under RCP4.5 become true. Under RCP8.5,

[9] A region is defined as suitable to grow is its within the Winkler regions according to GGD.

south Ireland, south Sweden and even south Finland could be suitable under Regions I and II of Winkler classification

- South Europe (Spain, south France, Italy, Portugal and Greece) and most places in North Africa are shifted to higher Winkler regions under RCP4.5, while south Spain and north Europe can be non-suitable for vine growing under RCP8.5. Given that suitability is a very complex concept depending on very local climate conditions, the homogeneity of all cited regions is not assured, so there can exist suitable regions with the classified non-suitable regions and vice versa.
- All regions in south, central and north Europe shift the Winkler classification due to an increase of temperatures of 2070-2099 in comparison to 1976-2005.
- High altitude regions such as the Pyrenees and Alps can be suitable areas in the future, so they will have a softer climate in the future.

However, the suitability of a certain regions does not only depend on the Winkler index, but also on the frequency and intensity of extreme events. So, changes in the historical patterns of extreme events can counter the suitability of those remaining and emerging regions in the future. In order to assess the changes in the extreme climate, the Figure 13 shows the changes in the dryspell length, the number of frost days during spring and the number of summer days per year (as an indicator of presence of higher temperatures). The following conclusions can be extracted:

- Longer dryspells are expected in the southern European countries like Spain, Portugal and in Turkey and North Africa.
- A decrease of the number of frost days in MAM is expected under RCP4.5 and RCP8.5 (more intense). The more intense decreases are focused in the Norther countries and the mountainous areas like the Pyrenees and the Alps.
- The number of summer days is expected to increase significantly across Europe. Southern countries are more prone to have an more intense increase, while mountainous areas and norther countries the increase of summer days is less intense.

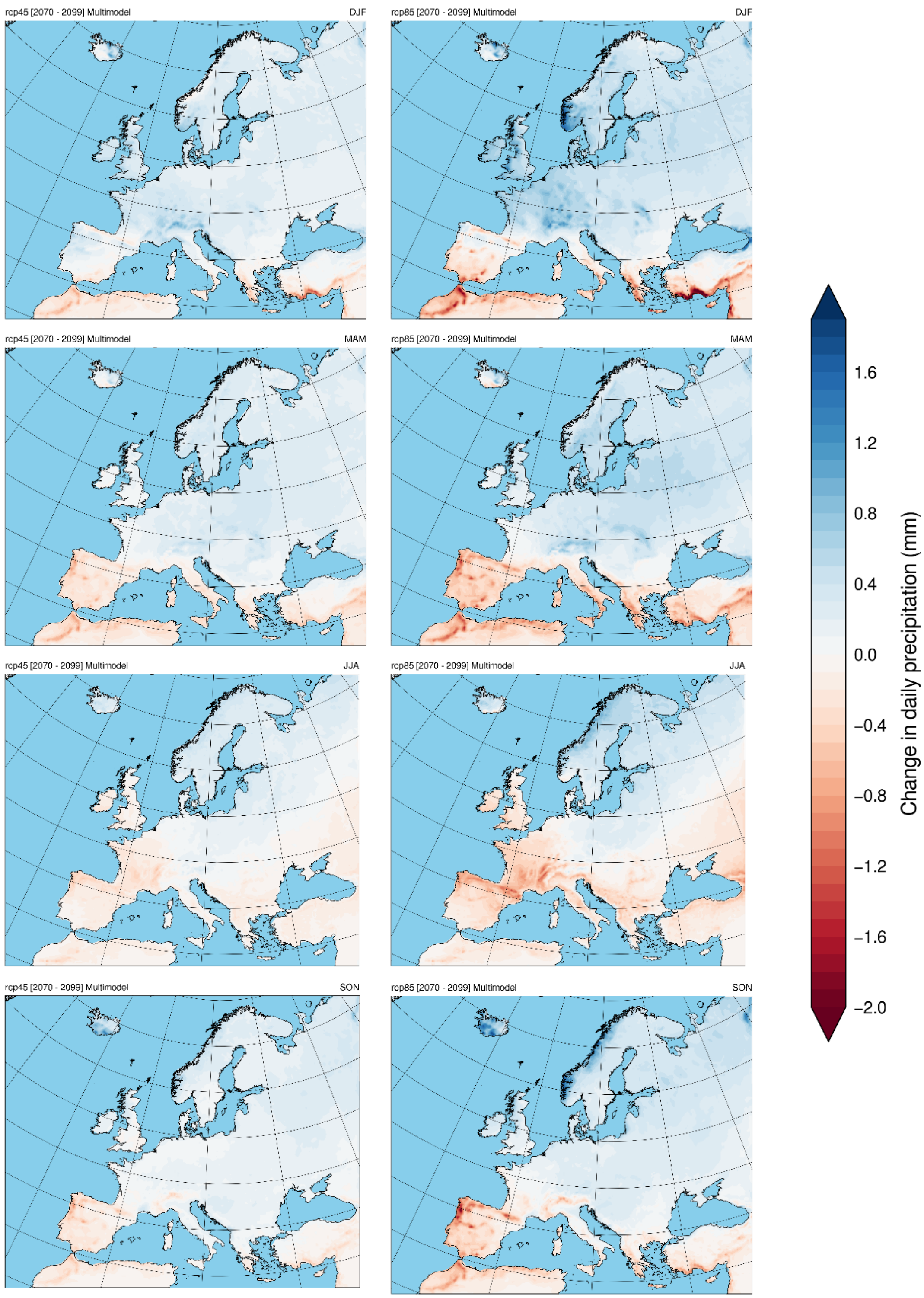

Figure 10: EURO-CORDEX Multi-model mean of the change in the climatology of daily precipitation between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right).

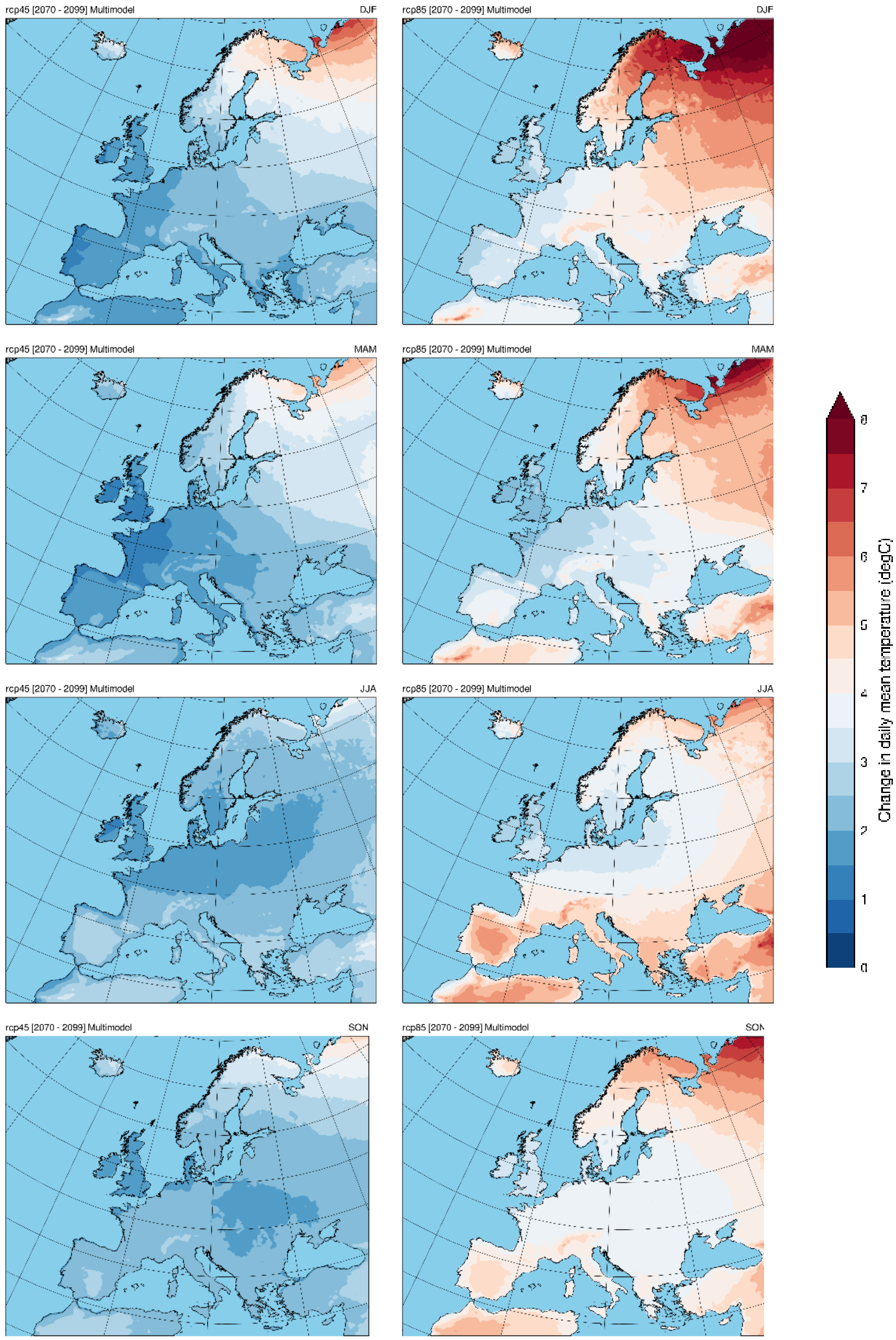

Figure 11: EURO-CORDEX Multi-model mean of the change in the climatology of mean temperature between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right).

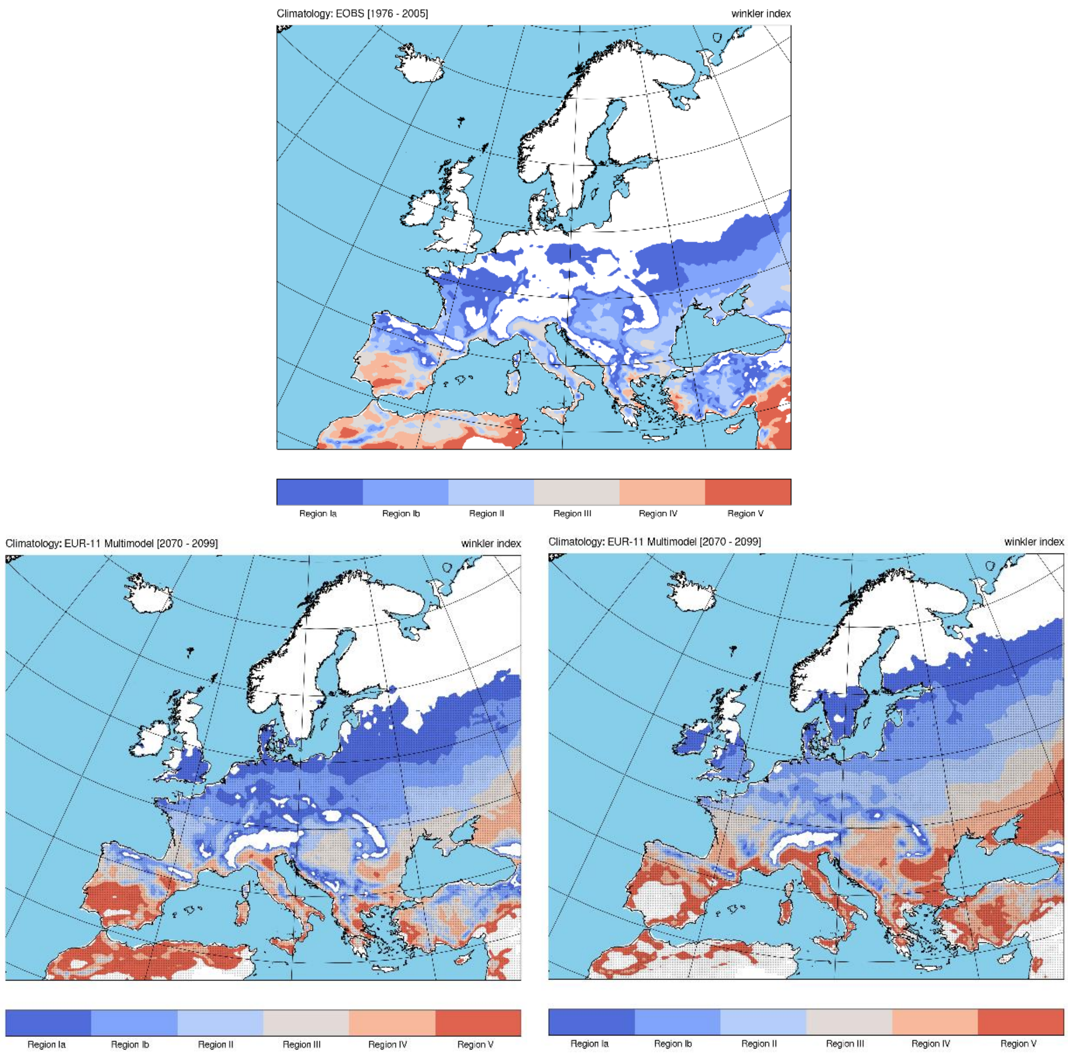

Figure 12: EURO-CORDEX Multi-model mean of the climatology of Winkler index of period 1976-2005 (above) and 2070-2099 under RCP4.5 (bottom left) and RCP8.5 (bottom right). The dots in the bottom maps indicates the regions where a change in the Winkler region has happened.

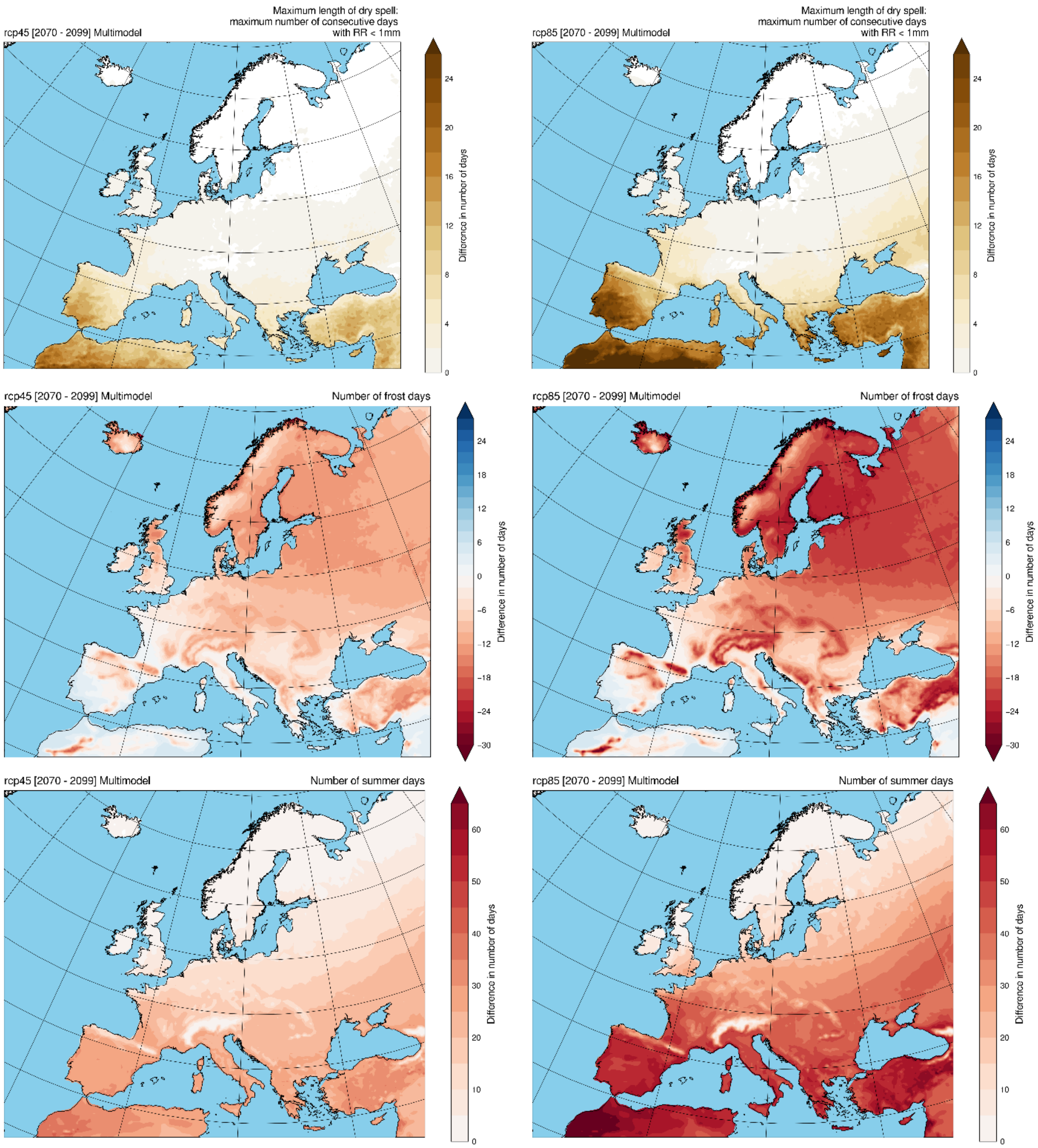

Figure 13: EURO-CORDEX Multi-model mean of the Winkler index the climatology of dryspell (top), frost days in spring (middle) and summer days (bottom) between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right).

4.2.2. Regional climate projections at demosites

In this chapter, climate projections at each demosite are analysed. The projected changes in mean precipitation and temperature as well as climate extremes given by EURO-CORDEX are shown. Also, an estimation of a range of uncertainty across all the models.

Mastroberardino

Climate projections from EURO-CORDEX in Mastroberardino are shown in Figure 14, Figure 15 and Figure 16 for mean precipitation, mean temperature and climate extremes respectively. Results are described in Table 3.

Climate indicator	Results
Mean Precipitation	- No significant change in DJF and SON - Significant decrease in MAM and JJA when looking at RCP8.5. - EURO-CORDEX models do not converge (models show a wide range of projections), so the projected changes are not conclusive.
Mean Temperature	- Clear increase of temperatures in all seasons. - In DJF and SON, temperature is expected to increase around 2ºC (from 1ºC to 3ºC according to the histograms) under RCP4.5, while under RCP8.5 the increase is around 4ºC (from 3ºC to 6ºC). - In MAM and JJA, the projected increases in temperature are clearly greater, so in MAM it is expected an increase greater than 4ºC (some models project an increase around 8ºC).
Length of dryspell (droughts)	- An **increase** of the annual maximum length of dryspell is expected. Under RCP4.5 it is not significant (less than 5 days), whereas it is greater than 10 days under RCP8.5.
Frost days in spring (MAM)	- No significant change in frost days in MAM under RCP4.5 and RCP8.5 - Large dispersion (uncertainty) across EURO-CORDEX models.
Number of heat waves days	- Significant increase of the length of heatwaves under RCP4.5 (13 days) and under RCP8.5 (almost 40 days) - Large dispersion (uncertainty) across EURO-CORDEX models

Table 3: Main climate projections for mean and extreme climate for Mastroberdino

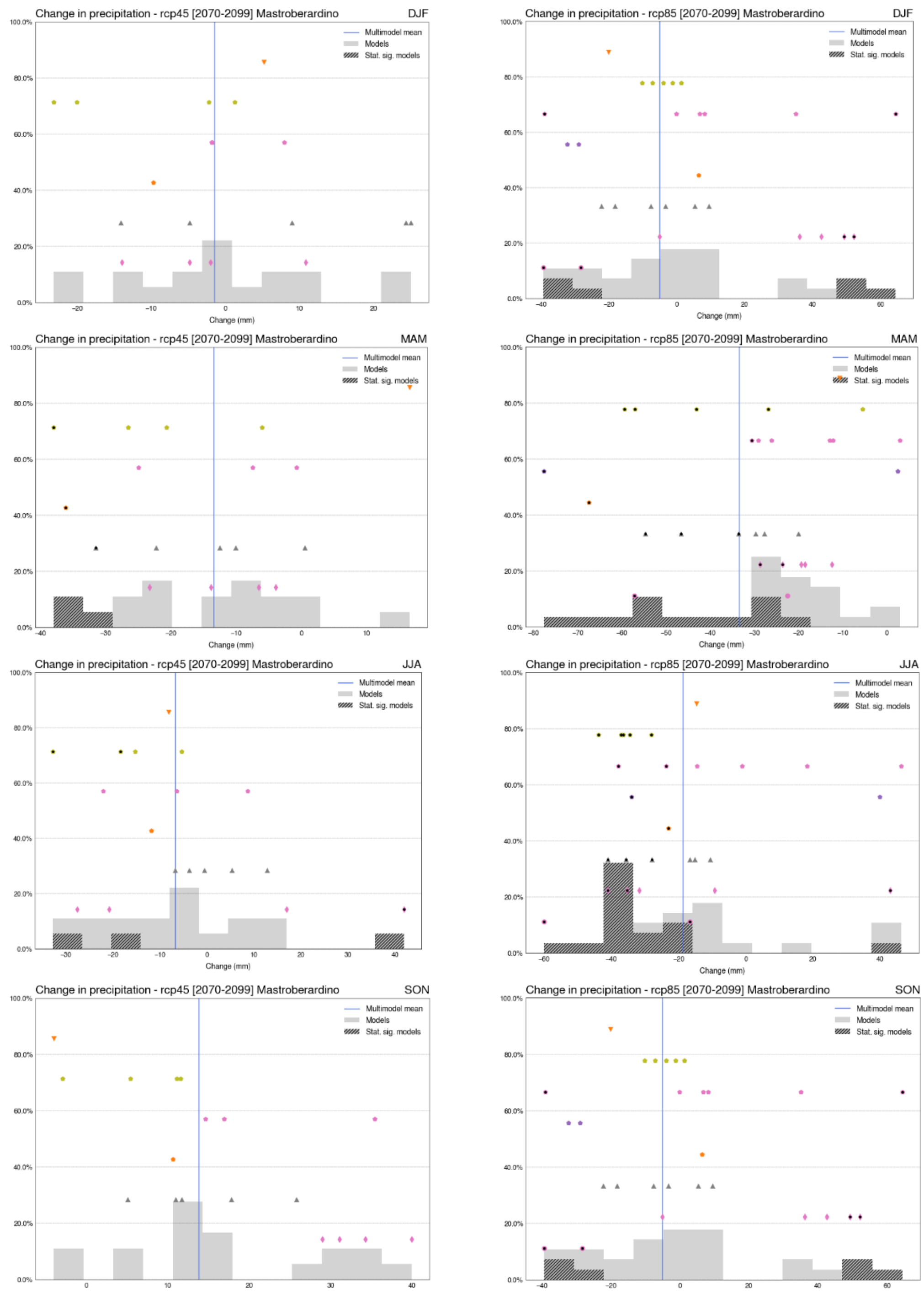

Figure 14: Distribution of EURO-CORDEX seasonal precipitation (mm/season) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Mastroberardino location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

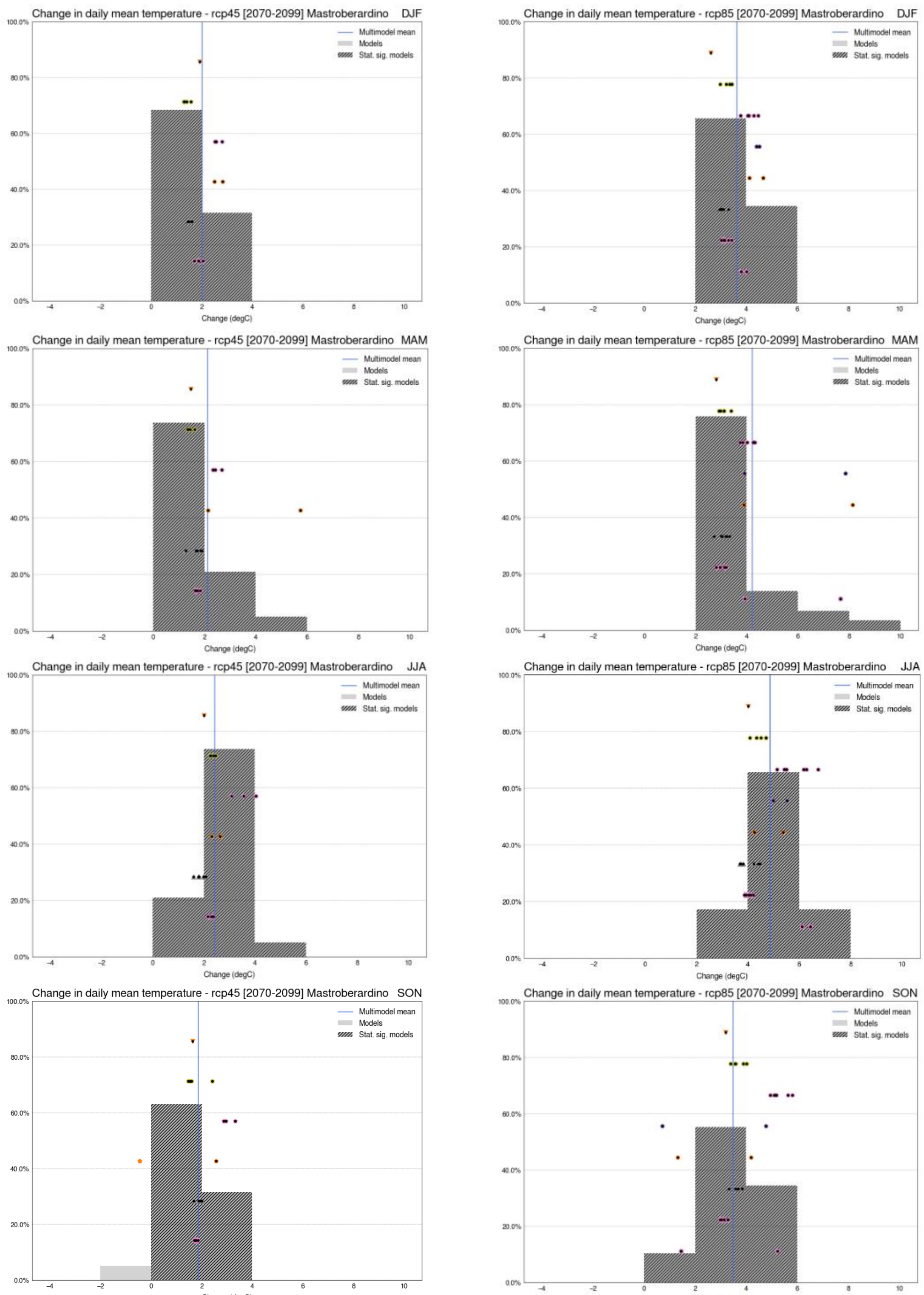

Figure 15: Distribution of EURO-CORDEX mean temperature (ºC) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Mastroberardino location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

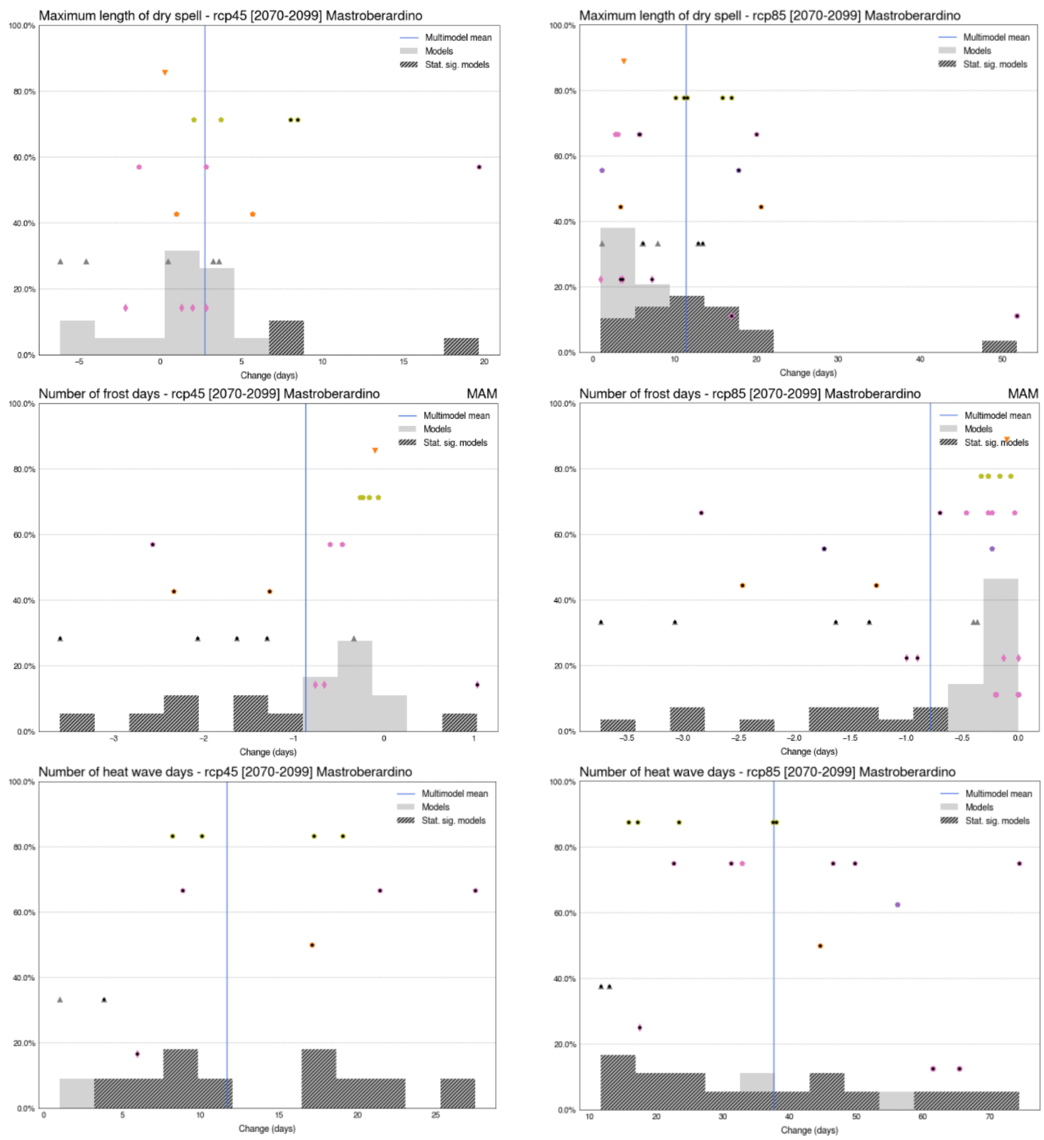

Figure 16: Distribution of EURO-CORDEX climate extremes change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Mastroberardino location. Length of dryspell (top), Number of frost days in spring (second row), number of heat wave days (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

Raimat

Climate projections from EURO-CORDEX in Raïmat are shown in Figure 17, Figure 18 and Figure 19 for mean precipitation, mean temperature and climate extremes respectively. Results are described in Table 4.

Climate indicator	Results
Mean Precipitation	- No significant change in DJF under RCP4.5 and RCP8.5 - Significant decrease in SON, MAM and JJA when looking at RCP8.5. - EURO-CORDEX models do not converge (models show a wide range of projections).
Mean Temperature	- Clear increase of temperatures in all seasons. - In DJF temperature is expected to increase around 2ºC (from 1ºC to 3ºC according to the histograms) under RCP4.5, while under RCP8.5 the increase is around 4ºC (from 3ºC to 6ºC). - In MAM and JJA, the projected increases in temperature are clearly greater, so in MAM it is expected an increase greater than 4ºC (some models project an increase around 10ºC). - In SON temperature is expected to increase around 2ºC (from 1ºC to 3ºC) under RCP4.5, while under RCP8.5 the increase if slightly greater than 4ºC with a large uncertainty (from 1ºC to 8ºC)
Length of dryspell (droughts)	- An non-significant **increase** of the annual maximum length of dryspell is expected. Under RCP4.5 it is not significant (less than 5 days), whereas it is below than 10 days under RCP8.5.
Frost days in spring (MAM)	- No significant change in frost days in MAM under RCP4.5 and RCP8.5 - Large dispersion (uncertainty) across EURO-CORDEX models.
Number heat waves days	- Significant increase of the length of heatwaves under RCP4.5 (6 days) and under RCP8.5 (almost 13 days) - Large dispersion (uncertainty) across EURO-CORDEX models

Table 4: Main climate projections for mean and extreme climate for Raïmat

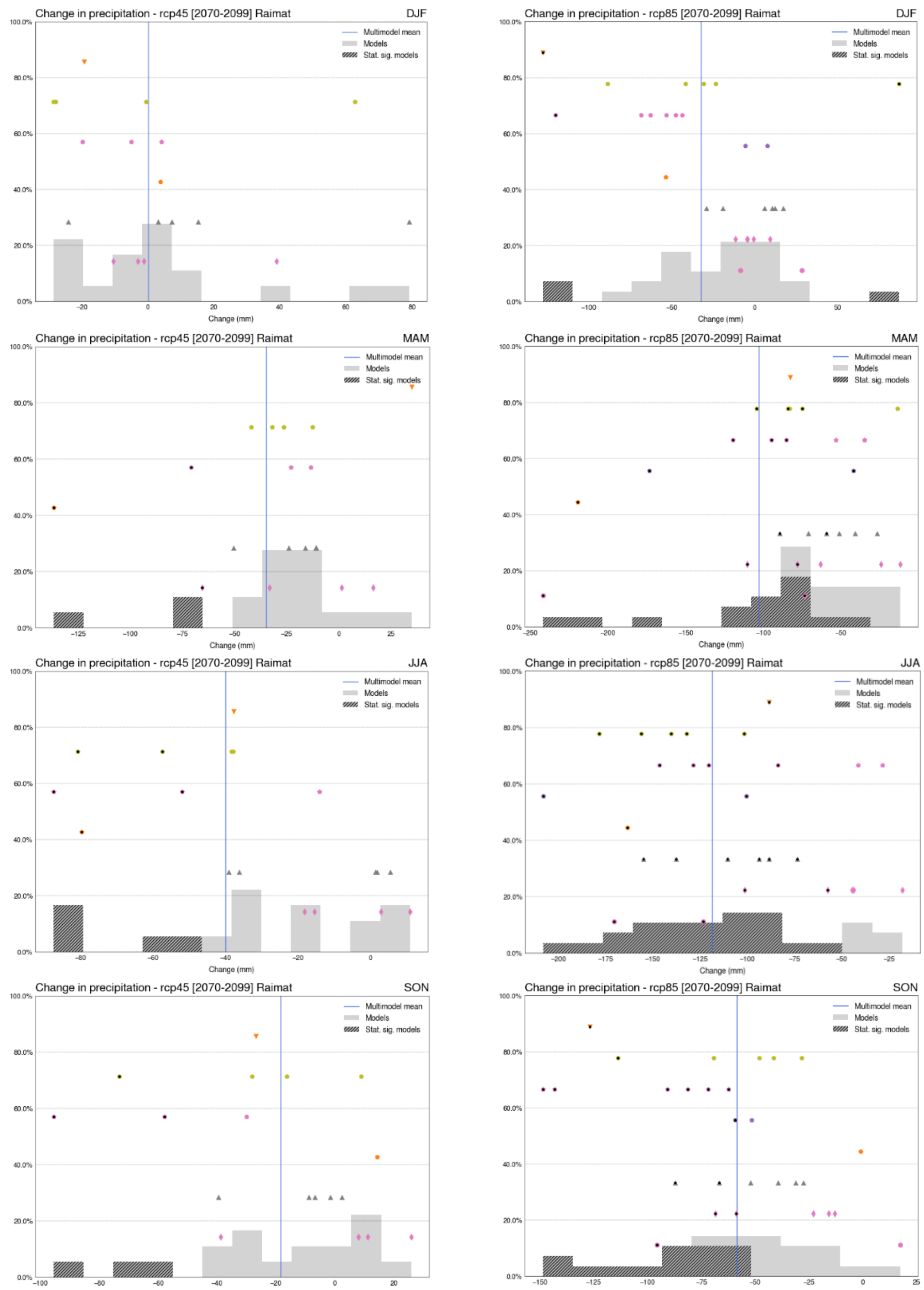

Figure 17: Distribution of EURO-CORDEX seasonal precipitation (mm/season) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Raïmat location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

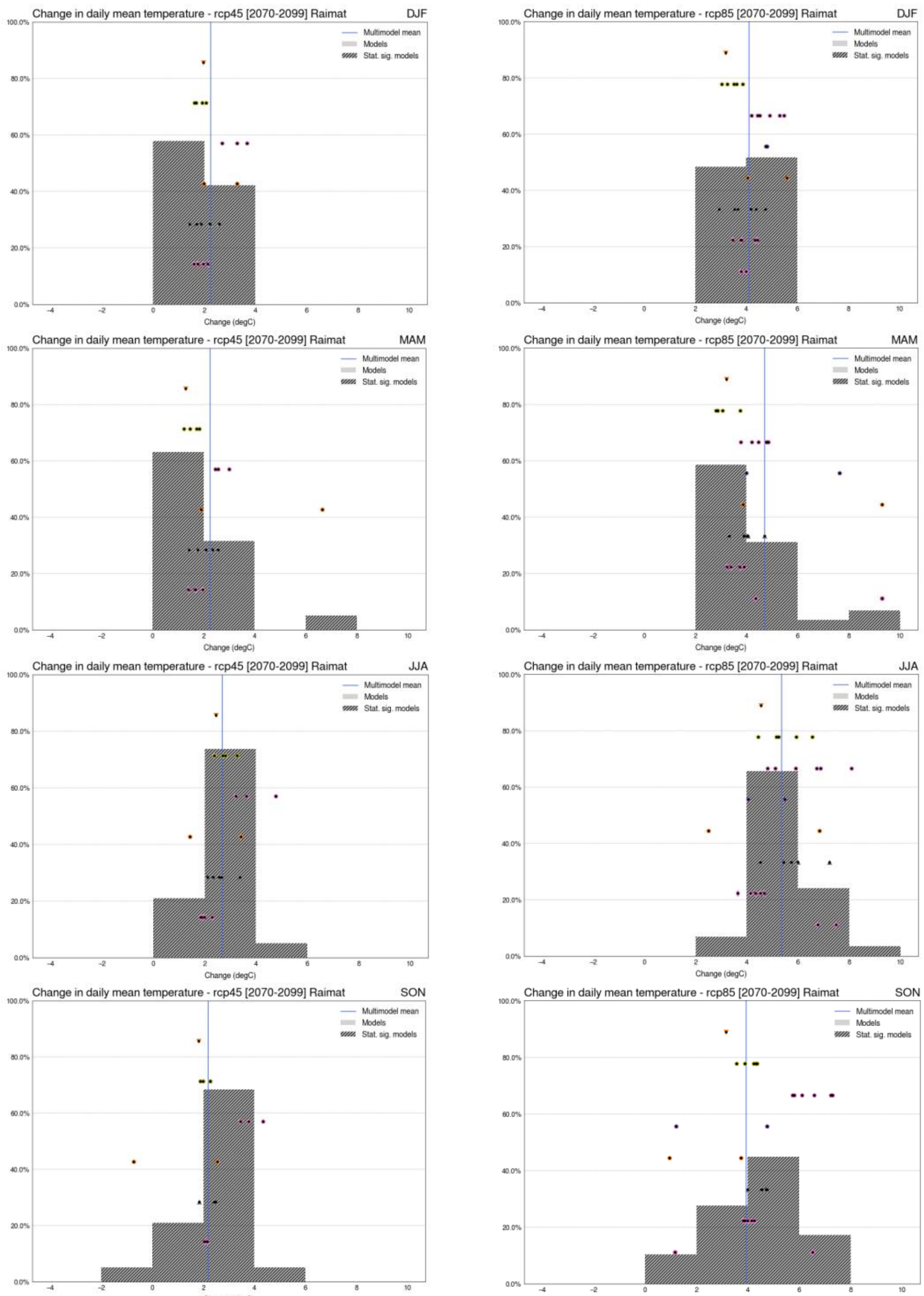

Figure 18: Distribution of EURO-CORDEX mean temperature (ºC) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Raïmat location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

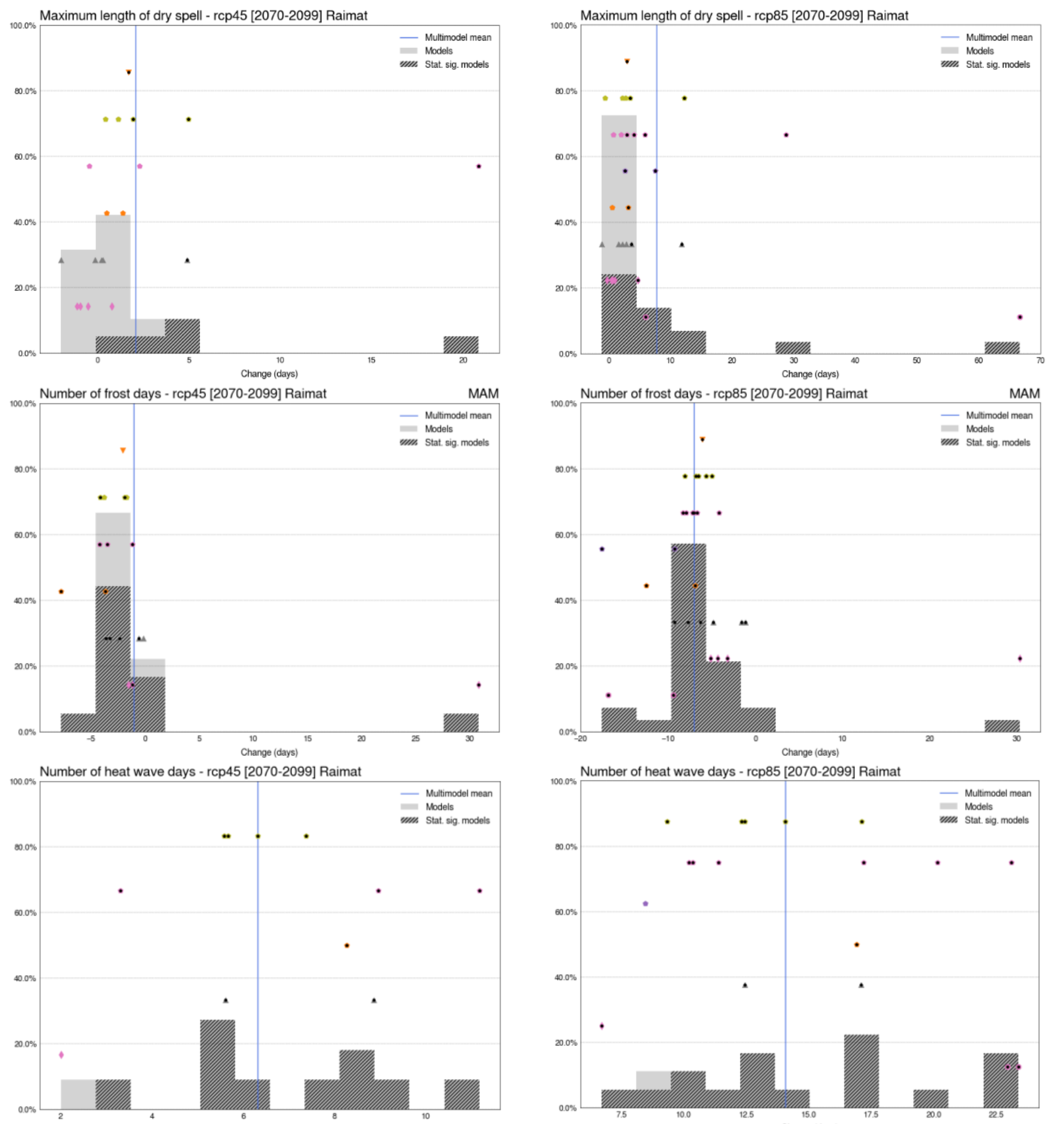

Figure 19: Distribution of EURO-CORDEX climate extremes change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Raïmat location. Length of dryspell (top), Number of frost days in spring (second row), number of heat wave days (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

Symington

Climate projections from EURO-CORDEX in Symington are shown in Figure 20, Figure 21 and Figure 22 for mean precipitation, mean temperature and climate extremes respectively. Results are described in Table 5.

Climate indicator	Results
Mean Precipitation	- A decrease in precipitation is projected in all seasons under RCP4.5, which become more intense under RCP8.5. - The most significant changes are found in MAM under RCP8.5, in JJA under RCP4.5 and RCP8.5 and in SON under RCP8.5. - Large dispersion of EURO-CORDEX simulations, so the projected decreases vary within a wide range of values.
Mean Temperature	- Clear increase of temperatures in all seasons. - JJA is the season with a more intense increase reaching almost 3ºC under RCP4.5 and more than 5ºC under RCP8.5. - JJA and DFC show a narrow dispersion of the models, while MAM and SON have a greater dispersion, which means more uncertainty. In MAM under RCP8.5 mean temperature can increase from 2 to 8ºC .
Length of dryspell (droughts)	- An **increase** of the annual maximum length of dryspell is expected. Under RCP4.5 it is not significant (less than 10 days), whereas it is greater than 20 days under RCP8.5.
Frost days in spring (MAM)	- Significant change in frost days in MAM under RCP4.5 and RCP8.5 - Large dispersion (uncertainty) across EURO-CORDEX models.
Number of days with heat waves	- Significant increase of the length of heatwaves under RCP4.5 (7 days) and under RCP8.5 (almost 20 days) - Large dispersion (uncertainty) across EURO-CORDEX models

Table 5: Main climate projections for mean and extreme climate for Symington

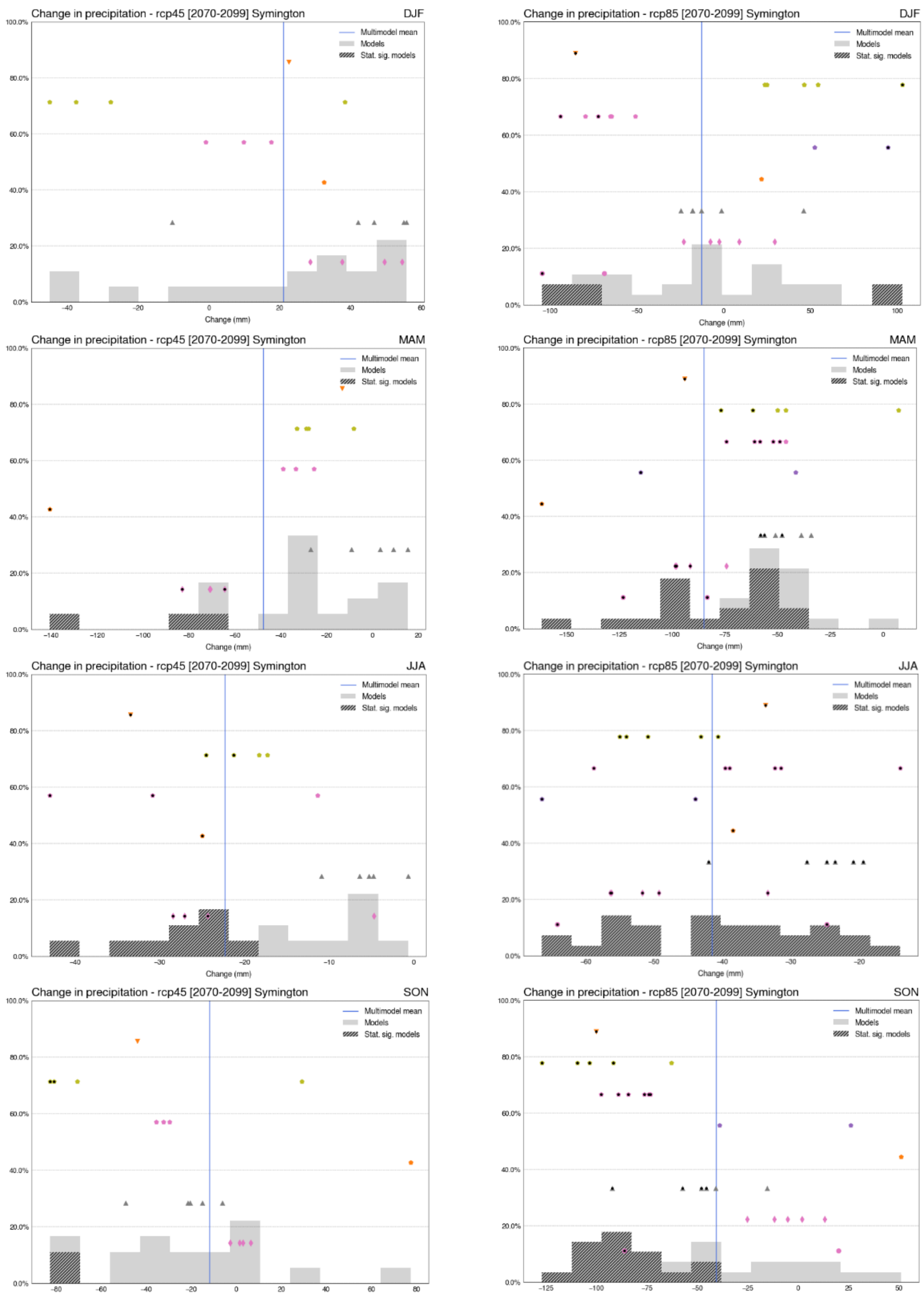

Figure 20: Distribution of EURO-CORDEX seasonal precipitation (mm/season) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Raïmat location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

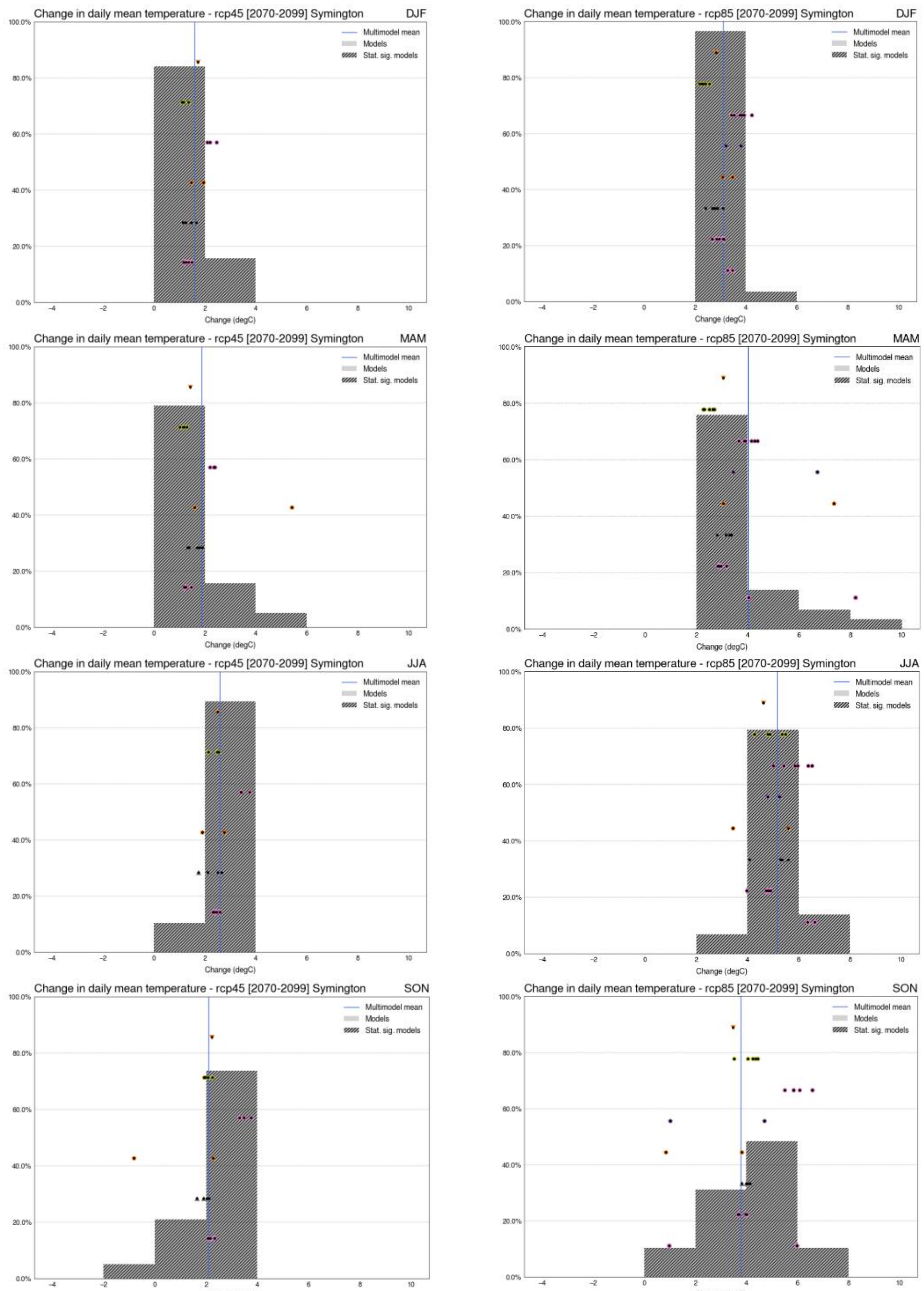

Figure 21: Distribution of EURO-CORDEX mean temperature (ºC) change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Symington location. DJF (top), MAM (second row), JJA (third row) and SON (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

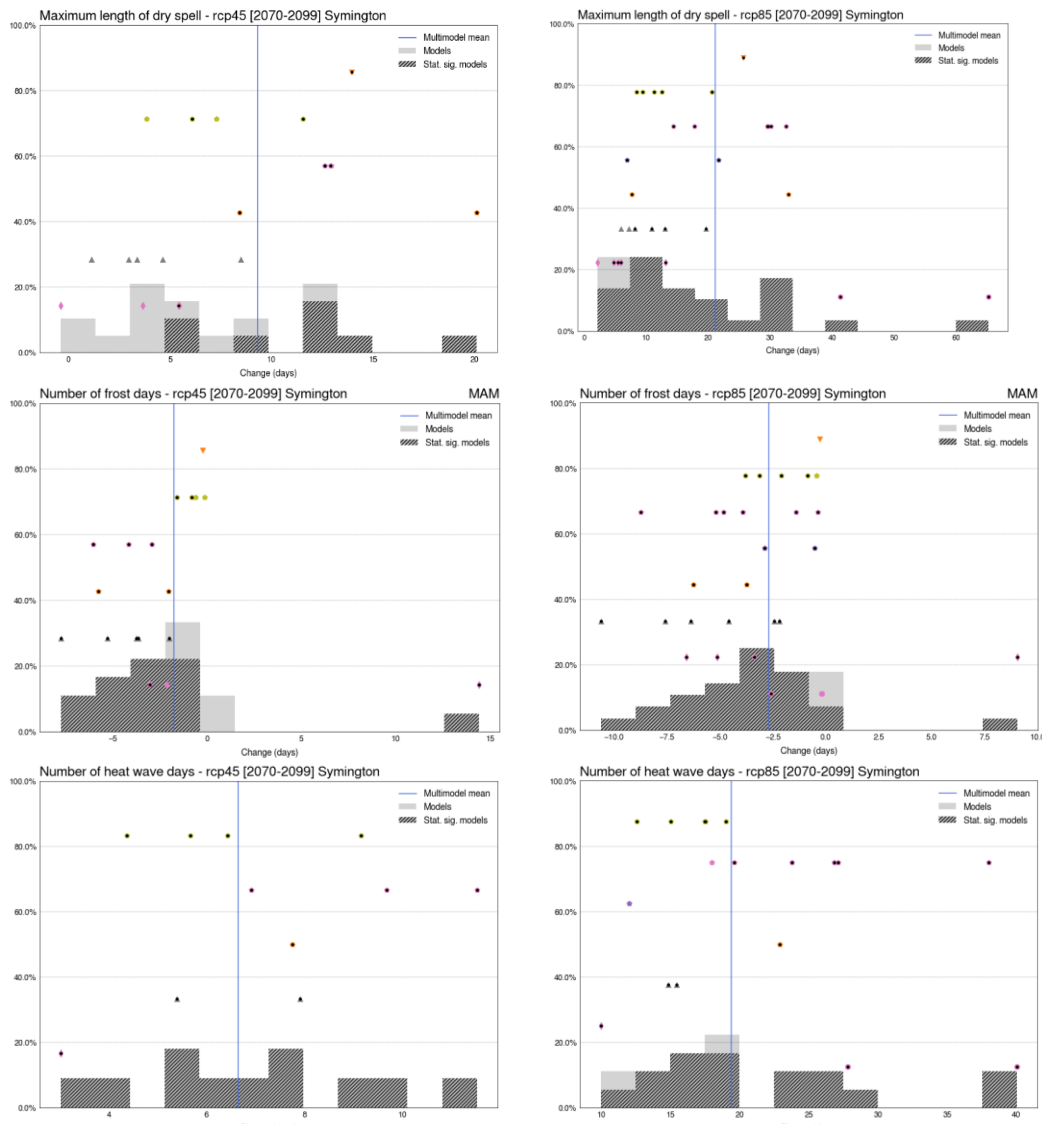

Figure 22: Distribution of EURO-CORDEX climate extremes change between period 2070-2100 and 1976-2005 under RCP4.5 (left) and RCP8.5 (right) for Symington location. Length of dryspell (top), Number of frost days in spring (second row), number of heat wave days (bottom). The histogram shows the distribution of all projected changes from all the simulations. Each row of dots corresponds to a different model with its different ensemble members.

5. Conclusions

Facing climate change and climate variability is one of the main challenges in viticulture. Developing strategic actions to adapt viticulture to the impacts of a warmer climate is one of the main interests of the sector, which has been suffering for changes in the quality and yield of the

The present document has provided a set of regional climate projections at European scale and at demosites of the project, so that, the wine industry is able to plan long-term adaptation strategies to face climate change and a new climate variability in the coming decades.

First of all, EURO-CORDEX climate projections have been analysed in terms of their ability to reproduce the historical climate. As a result, it has been confirmed that EURO-CORDEX is representing correctly the temporal and spatial correlation of the main interesting variables such as mean temperature and precipitation, climate extremes such as droughts, spring frosts and heatwaves and, finally, specific agronomical parameters such the Winkler index.

After that, the analysis of climate projections at European scale and at demosites is providing by comparing the climatology off the period 2070-2099 against the historical period 1976-2005. In terms of precipitation, a decrease in the southern European countries, which is more intense in the summer months. In terms of temperature, there is an clear increase throughout Europe, although it is more intense in southern countries like Spain, Portugal, Italy, Greece and also in norther countries like Sweden and Finland. Regarding extremes, there is an increase of the length of droughts, specially in the Iberian Peninsula, a decrease of frost days in spring months and an increase of heatwaves, specially in the southern European countries.

When looking at Winkler index, a shift of the suitable regions for vine growing to norther latitudes is clearly identified due to an increase of temperatures. While in period 1976-2005, the suitability of grape growing is mainly located in southern Europe countries like Spain, Portugal, south France, southern Germany, Italy, Greece and Northern Africa, in 2070-2099 the suitable areas are extended to central Europe and even northern Europe under RCP8.5. South UK, north Germany, Denmark are expected to be new suitable areas if the climate projections under RCP4.5 become true. Under RCP8.5, south Ireland, south Sweden and even south Finland could be suitable under Regions I and II of Winkler classification. Also, high altitude regions such as the Pyrenees and Alps can be suitable areas in the future, so they will have a softer climate in the future.

When looking at demosites, Mastroberardino, Raïmat and Symington show a decrease of precipitation an increase of temperatures more intense during summer than in winter months.

In terms of extremes, they show an increase of the length of droughts and heatwaves, while a decrease of frost days in spring months.

- There is a decrease of precipitation in the Iberian Peninsula, Italy, Greece and Turkey, while an increase in the rest of central and northern European countries for all seasons.
- The decrease of precipitation is more intense in JJA, when it is extended also to France and UK.
- The decrease is clearly more intense under RCP8.5 than in RCP4.5.
- There is an increase of temperature overall in Europe and under RCP4.5 and RCP8.5
- Increases of temperature are greater under RCP8.5 than RCP4.5, as expected.
- Increase of temperature are larger in southern countries like Spain, Portugal, Italy, Greece and North Africa during JJA, while these increases are milder in central Europe countries like France, Germany and UK.
- In DJF, there is a clear gradient south-north, so the southern countries have a mild increase of temperature, while the northern countries like Sweden or Finland have a much larger increase reaching values around +8ºC under RCP8.5.