MASTER ADAPT

MAinSTreaming Experiences
at Regional and local level
for ADAPTation to climate change

REPORT ON CLIMATE ANALYSIS AND VULNERABILITY ASSESSMENT RESULTS IN THE PILOT REGION (SARDINIA REGION) AND IN THE AREAS TARGETED IN ACTION C3

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AUTHORS

REPORT COORDINATION:

F. Giordano (ISPRA), V. Lucia (ISPRA), I. Marinosci (ISPRA), T. Freixo Santos (Ambiente Italia), L. Bono (Ambiente Italia), M. Lapi (FLA), S. Marras (UNISS), D. Maragno (IUAV), F. Magni (IUAV), F. Musco (IUAV), G. Satta (Regione Sardegna)

AUTHORS AND CONTRIBUTORS BY CHAPTER/SECTION

CHAPTER 1: PREFACE

F. Giordano (ISPRA), partnership of the Action A1

CHAPTER 2: CLIMATE ANALYSIS

G. Fioravanti (ISPRA), E. Piervitali (ISPRA), F. Desiato (ISPRA)

CHAPTER 3: VULNERABILITY ASSESSMENT

Section 3.4: Regional level - Sardinia

S. Marras (UNISS), M. Salis (UNISS), V. Mereu (UNISS), V. Bacciu (UNISS), F. Arras (Regione Sardegna), A. Congiu (Regione Sardegna), G. Satta (Regione Sardegna)

Section 3.5: Target areas

***Area of Venice**:* D. Maragno (IUAV), F. Magni (IUAV), F. Musco (IUAV)

***Northern Milan**:* S. Oliveri (Ecometrics), M. Pregnolato (Ecometrics), M. Lapi (FLA), L. Cozzi (FLA)

***Cagliari and Sassari**:* S. Marras (UNISS), M. Salis (UNISS), V. Mereu (UNISS), V. Bacciu (UNISS), F. Arras (Regione Sardegna), A. Congiu (Regione Sardegna), G. Satta (Regione Sardegna)

***Northern Salento**:* F. Baiocco (ISPRA), F. Giordano (ISPRA), V. Lucia (ISPRA), I. Marinosci (ISPRA), C. Vicini (ISPRA)

CHAPTER 4: CONCLUSIONS

F. Giordano (ISPRA), partnership of the Action A1

CONTENTS

1 PREFACE

The "*Report on climate analysis and vulnerability assessment results in the pilot Region (Sardinia Region) and in the areas targeted in Action C3*" represents the first of two deliverables of the preparatory Action A1 – *Climate analysis and vulnerability assessment at Regional level* of the LIFE MASTER-Adapt Project and aims at summarizing the activities carried out within the first action of the project.

Among the main objectives of the LIFE MASTER-Adapt Project, the identification and test of innovative tools of multi-level governance is addressed to support Regions and local authorities (cities and groups of towns) in defining and developing adaptation strategies and policies. In particular, the project builds on existing developments in Lombardy and aims at creating a scalable methodology with the purpose to optimise and facilitate the targeting and the integration of Regional policies in different sectors with respect to climate change adaptation (mainstreaming of adaptation).

The structure of the Report reflects the operational approach of the Action, which is mainly based on two sub-tasks implemented both at Regional and target areas level (Figure 1.1):

- Climate analysis (see Chapter 2 for further details);
- Vulnerability assessment (see Chapter 3 for further details).

The main objective of the first deliverable of Action A1 is to provide the knowledge base in terms of climate-related threats, expected climate change impacts and the vulnerability to those impacts required as input information for the adaptation target setting at Regional and sub-Regional level (Action C.1, C2 and C3). The Report describes the procedure adopted and the results achieved by performing past and current climate trends analysis as well as climate projections and by assessing the Regional vulnerability of Sardinia as well as the vulnerability of the target areas.

Based on the experience acquired in performing such kind of analysis, the second deliverable of Action A1 (Guidelines, principles and standardized procedures for climate analysis and vulnerability assessment at Regional and local level) will provide guiding principles and standardized procedures in order to support Regions and local authorities in building a sound scientific knowledge base for the development of effective adaptation strategies.

The first sub-task of Action A1 has been performed by ISPRA with the aim to analyse both the trends and the future projections of climate variables over Sardinia Region and the target areas. For this purpose both mean and extreme data of temperature and precipitation have been processed.

The second sub-task, aiming at the vulnerability assessment of the Regional and target areas, is the result of an extensive collaboration among the MASTER-Adapt project partners involved in the Action: ISPRA (lead partner of the A1), Regione Autonoma della Sardegna, Ambiente Italia srl, Università di Sassari - DIPNet, Fondazione Lombardia per l'Ambiente and IUAV.

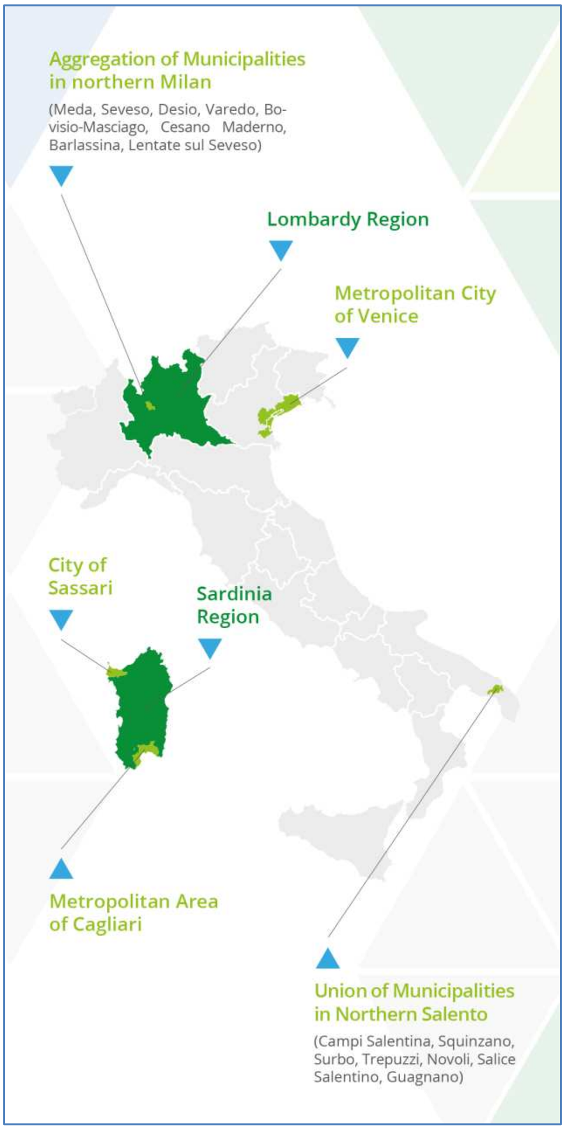


Figure 1.1 - Regional and target areas of the LIFE MASTER ADAPT Project

For a full and deep understanding of the approaches used and a right reading and interpretation of results and maps, it is recommended to read carefully the text of the Report. Figures and tables alone may be misunderstood and not correctly interpreted.

2 CLIMATE ANALYSIS

The assessment of climate change impacts and the development of adaptation strategy and implementation plans require information on both current climate trends and future climate. The analysis of long time series of climatic variables allows to evaluate ongoing variations and their significance, while climate change assessment for future period is based on climate model projections.

The study of climate variation involves both the mean and the extreme values of climatic variables, since climatic extremes are important indicators for the assessment of climatic changes, having a wide range of negative impacts on environment and human health.

Action A1 of Life MASTER Adapt Project provided climate analysis in the pilot area (Sardinia Region), with also a focus on the areas targeted by Action C3 (the metropolitan network of Sassari, the metropolitan area of Cagliari, the union of municipalities in northern Salento, the aggregation of municipalities in northern Milan, the area of Venice).

2.1 Regional level: Sardinia

Climate analysis was carried out at the regional level over Sardinia. Average variations respect to the 1971-2000 reference mean of temperature, precipitation and extreme climatic indices were computed. The first part of the study concerns the analysis of past and current climate trend from 1961 to 2015, while the second part refers to future climate projections over a time period useful to an adaptation strategy (i.e. 2030-2050) and was extended until 2100.

2.1.1 Past and current climate trends

Information on past and current climate is provided by the analysis of time series of meteorological observations representative of the locations under investigation, and by the application of statistical models for trend recognition and estimation. In order to get a reliable estimate of trends, time series must meet several requirements. They must be as long as possible (at least 50-60 years), quality checked, complete and continuous in time. In the Sardinia Region, very few time series satisfy these criteria and they are not representative of the whole area. Therefore, to analyse past and current climate variations from 1961-2015 the e-obs gridded dataset (Haylock et al., 2008) was employed. This dataset was realized after a spatial interpolation and kriging of spatially irregular temperature and precipitation daily station data, originating from European and circum-Mediterranean Countries. Before interpolation process, several quality control procedures were applied to raw data to identify and remove erroneous or suspicious data.

Data covering the domain of Sardinia, with 25 Km of resolution, were extracted and analysed, to assess temperature (minimum, maximum and mean) and precipitation trend evolution at the annual and seasonal level. Variability of extreme values was also estimated, using a subset of the indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI, Peterson et al., 2001), a joint group of World Meteorological Organization (WMO) Commission for Climatology (CCL)/Climate Variability and Predictability (CLIVAR)/Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM). For each variable and index a mean anomaly series was calculated as the arithmetic mean of the departures of each single cells from its respective 1971–2000 average.

Mean values

Sardinian annual anomaly time series of temperature (maximum, mean and minimum) with respect to 1971-2000 is shown in Figure 2.1. A warming tendency characterizes all the three temperature series since the early ‘80s, as found for the Italian series (Desiato et al., 2016). Over the last 30 years maximum temperature has always been greater than 1971-2000 mean, excluding 1986, 1991, 1996 and 2005, which show weak negative anomalies; minimum temperature reveal positive anomalies, with exception of 1991, 1993 and 1995. As result, the mean temperature series has assumed all values greater than the 1971-2000 average since 1986, except for 1991 and 1996; the anomaly values of +1.8°C of 2015 is the highest since 1961.

Similarly, the seasonal analysis highlights a prevalence of positive anomalies for the three variables in all seasons, as shown in Figure 2.2, Figure 2.3 and Figure 2.4, respectively for maximum, mean and minimum temperature.

Mean annual and seasonal trends (Table 2.1), evaluated using a linear regression model, are positive and statistically significant for all the three examined variables. The annual rate of variation of mean temperature is estimated of +0.35°C/decade; a stronger trend is found for minimum temperature (+0.43°C/decade) than for maximum temperature (+0.28°C/decade).

The seasonal analysis indicates the most marked trends in summer (+0.5°C/decade) for maximum temperature and in spring (+0.31°C/decade) and summer (+0.29°C/decade) for minimum temperature. Mean temperature shows the strongest increase in summer, with a statistically significant trend of (+0.40°C/decade).

The mean annual precipitation anomalies from 1961 to 2015 over Sardinia region, are shown in Figure 2.5, while Figure 2.6 illustrates the mean seasonal series. The anomaly values are expressed as percentage differences with respect to the 1971-2000 base period.

Precipitation patterns don’t reveal a clear signal of increase or reduction. The trend analysis was performed using two different approaches: a linear regression model and a non-parametric approach, involving the Mann-Kendall rank test (Mann 1945; Kendall 1976) and the Theil-Sen estimator (Sen 1968).

These two methods show similar results, estimating non significant trends for both the annual and the seasonal series.

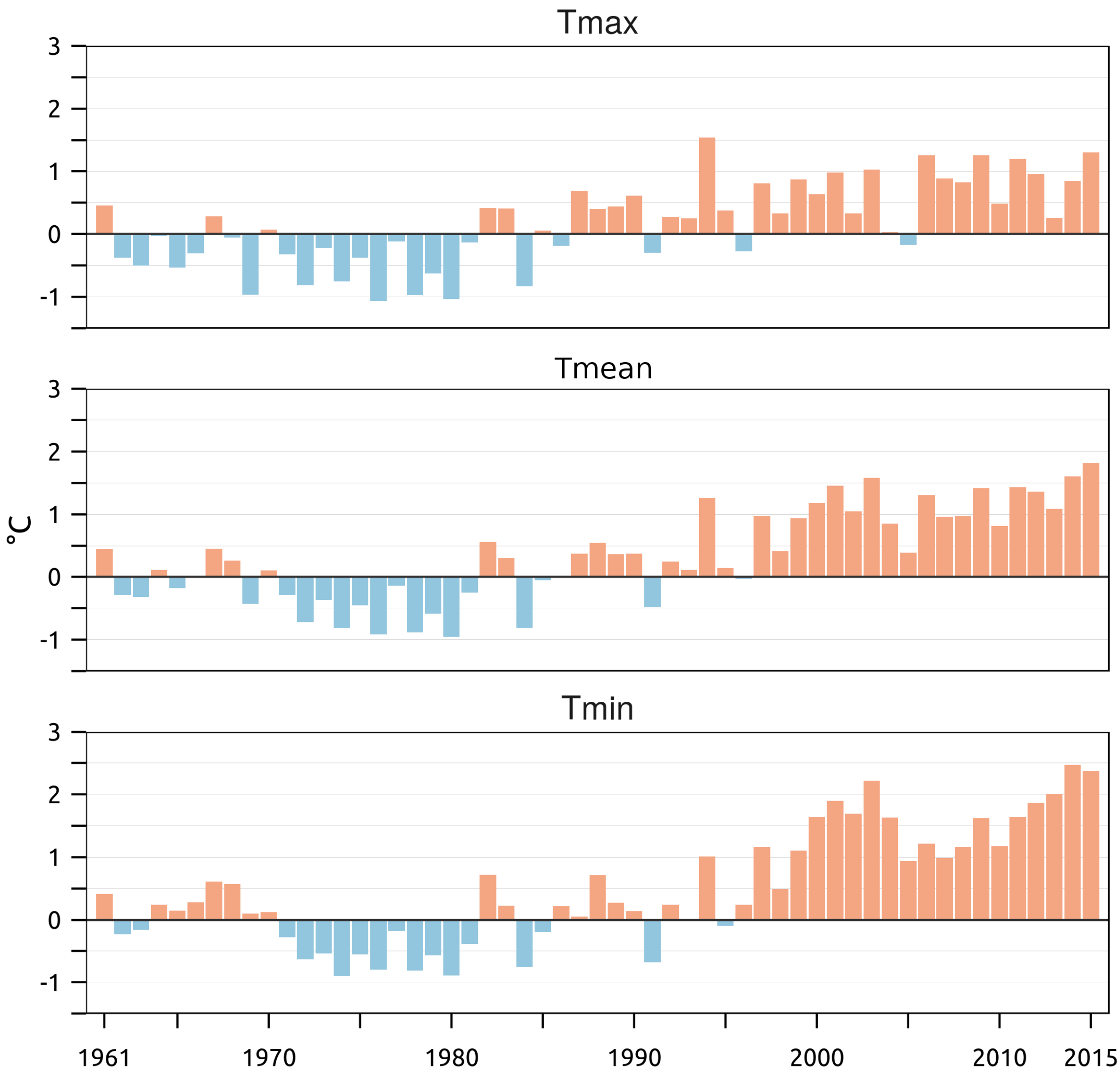


Figure 2.1 - Mean anomaly series (over Sardinia region) of annual temperature (maximum, mean and minimum) in the period 1961-2015 with respect to 1971-2000 base period

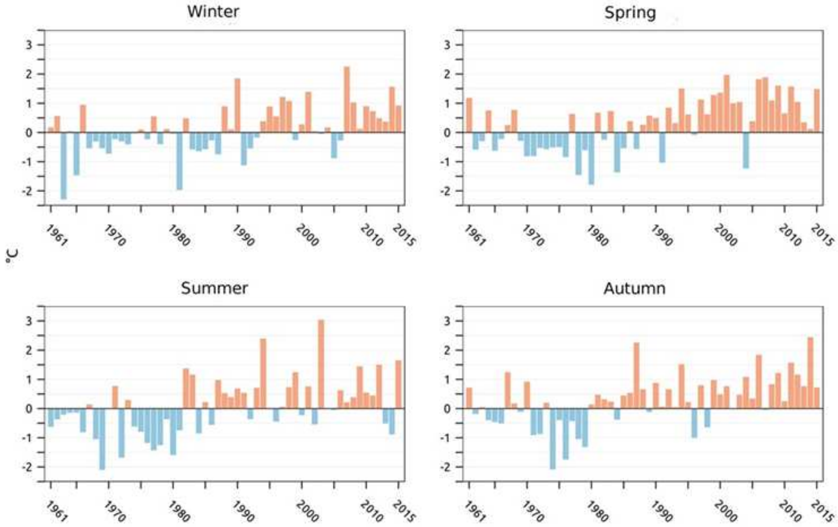


Figure 2.2 - Seasonal anomaly series of maximum temperature from 1961 to 2015, with respect to 1971-2000 base period, over Sardinia region

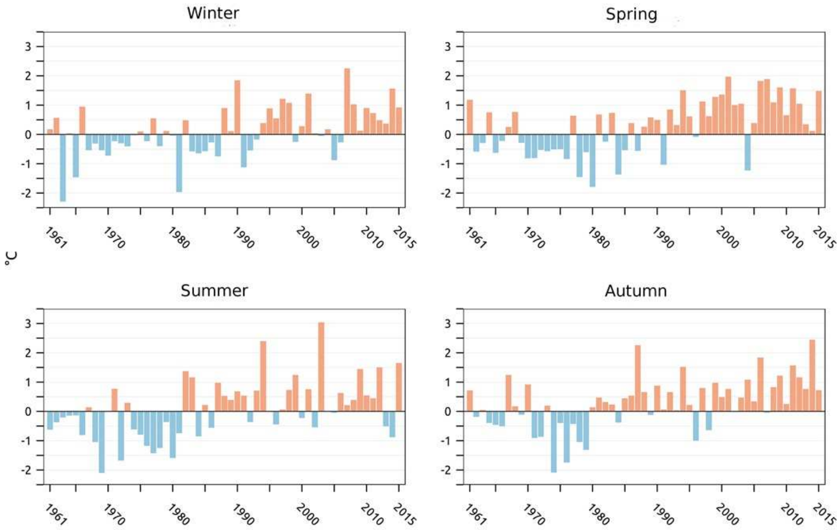


Figure 2.3 - As in figure 2.2, for mean temperature

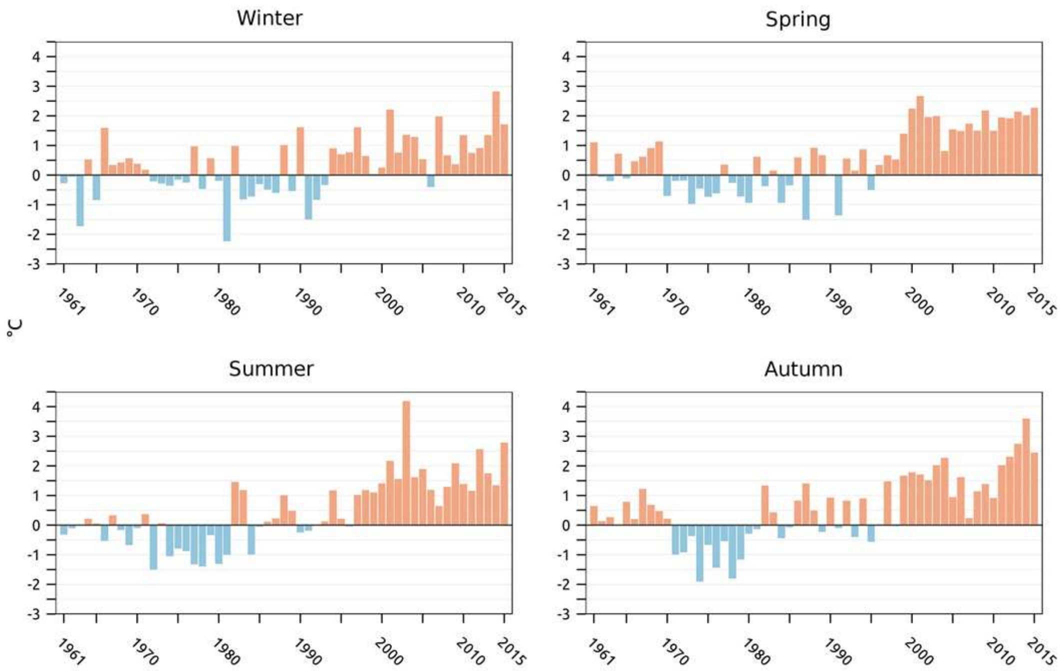


Figure 2.4 - As in figure 2.2, for minimum temperature

	Trend (°C/10 years)				
	Year	**Winter**	**Spring**	**Summer**	**Autumn**
Tmax	+0.28±0.04	+0.25±0.06	+0.31±0.07	+0.29±0.08	+0.27±0.07
Tmean	+0.35±0.04	+0.27±0.07	+0.36±0.06	+0.40±0.07	+0.36±0.06
Tmin	+0.43±0.05	+0.30±0.07	+0.42±0.07	+0.50±0.07	+0.45±0.07

Table 2.1 - Annual and seasonal trends (and relative standard deviations) of temperature (maximum, mean and minimum) from 1961 al 2015 (Sardinia region), evaluated using a linear regression model. All the estimated trends are statistically significant

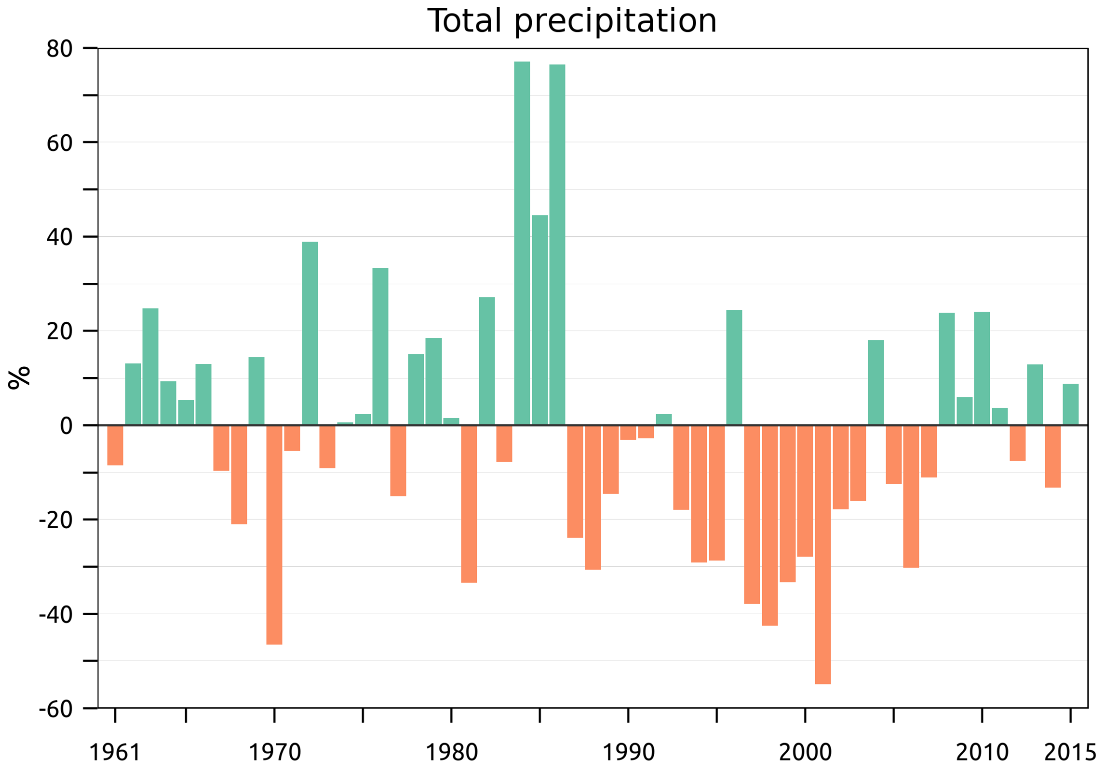


Figure 2.5 - Mean anomaly series (over Sardinia region) of annual precipitation (in percent values), with respect to the base period 1971-2000

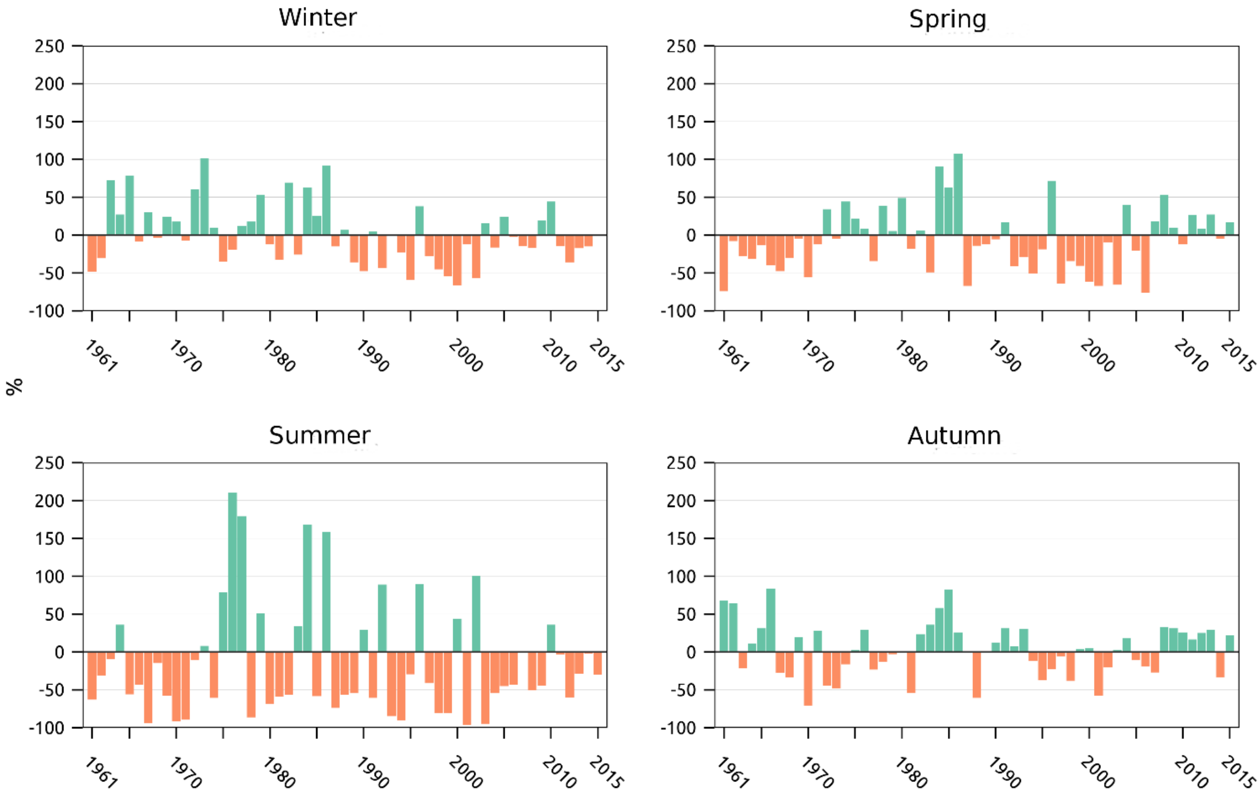


Figure 2.6 - Seasonal anomaly series of precipitation from 1961 to 2015, with respect to 1971-2000 base period, over Sardinia region

ETCCDI extreme indices

Temperature and precipitation extremes were analysed using the ETCCDI indices, widely employed to assess climate extremes in time series of observations (Klein Tank and Können, 2003; Alexander et al., 2006; Donat et al., 2013). A subset of 13 indices was selected to examine climatic extremes over Sardinia region, reported in Table 2.2 (temperature) and Table 2.3 (precipitation).

The anomaly series of temperature indices with respect to the 1971-2000 base period are shown in Figure 2.7 - Figure 2.14. Temperature extremes confirm the warming tendency observed for the mean values, with an increase of the indices describing extremes of heat and a reduction of extremes of cold. In general, warming is more clear and pronounced since the early ’80s, as found at the national level (Fioravanti et al., 2015).

The average number of frost days (FD0, Figure 2.7) has always been lower than the 1971-2000 average over the last 20 years, excluding 1999, 2005 and 2012.

Over the last 30 years, the number of summer days (SU25) has been characterized by a prevalence of anomaly values below the 1971-2000 average (Figure 2.8) and the mean number of tropical nights (TR20) has always been greater than the 1971-2000 average (Figure 2.9), with the exception of 1990, 1991 and 1996. The highest TR20 anomaly of 58 days was recorded in 2003, when many European Countries experienced one of their warmest summers. The Warm Day Duration Index (WSDI, Figure 2.10) has assumed the largest anomaly values of the time series after 2000, in 2003, 2006, 2007 and 2014. Warm nights (Figure 2.11) and days (Figure 2.12) show a prevalence of positive anomalies over the last 30 years, while cold nights (Figure 2.13) and days (Figure 2.14) highlight an opposite pattern, showing a prevalence of negative anomalies.

Statistical significant trends are estimated for all the examined temperature extreme indices, over 1961-2015 (Table 2.4). In particular, the mean number of tropical nights increases at the rate of +7.7 days/decade, summer days and warm nights increases are respectively estimated +4.2 days/decade and +4.8%/decade.

Unlike temperature extremes, precipitation indices do not highlight clear signals of changes in the frequency and intensity of precipitation during 1961-2015 (Figure 2.15 -Figure 2.19).

A weak decrease tendency is found for all indices (Table 2.5); all trends are statistically non significant except for the Consecutive Dry Day index, which shows a statistically significant trend of -3.4 days/decade.

Index	Definition	Units
FD0 (Frost Days)	Annual count of days when TN (daily minimum) < 0°C	days
SU25 (Summer days)	Annual count of days when TX (daily maximum) > 25°C	days
TR20 (Tropical nights)	Annual count of days when TN (daily minimum) > 20°C	days
WSDI (Warm Spell Duration Index)	Annual count of days with at least 6 consecutive days when TX > 90th percentile of the base period	days
TN10P (Cold nights)	Percentage of days when TN < 10th percentile of the base period	%
TX10P (Cold days)	Percentage of days when TX<10th percentile of the base period	%
TN90P (Warm nights)	Percentage of days when TN>90th percentile of the base period	%
TX90P (Warm days)	Percentage of days when TN>90th percentile of the base period	%

Table 2.2 - Extreme temperature and precipitation indices selected from ETCCDI core set, where TN = minimum temperature, TX = maximum temperature

Index	Definition	Units
RX1day (Max 1-day precipitation amount)	Maximum value of 1-day precipitation	mm
R95p (Very wet days)	Annual total precipitation when daily PRCP > 95th percentile of the base period	mm
SDII (Simple Daily Intensity Index)	Annual total precipitation divided by the number of wet days (defined as daily PRCP ≥ 1.0 mm) in the year	mm/day
CDD (Consecutive Dry Days)	Maximum number of consecutive days with daily PRCP < 1mm	days
R20 (Very heavy precipitation days)	Annual count of days when daily PRCP ≥ 20 mm	days

Table 2.3 - Extreme precipitation indices selected from ETCCDI core set, where PRCP = precipitation

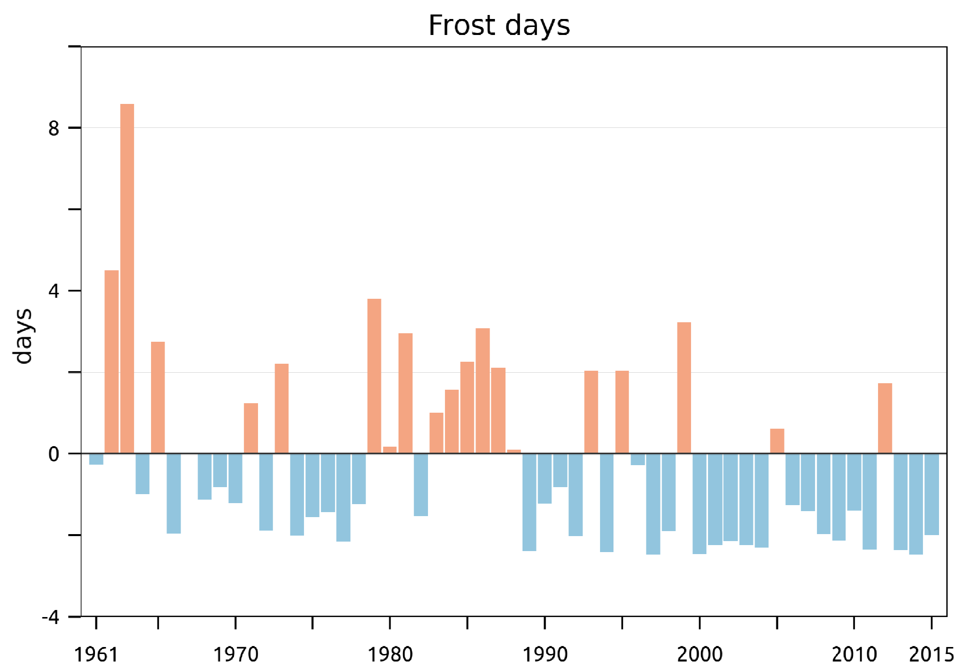


Figure 2.7 - Mean anomaly series (over Sardinia region) of frost days in the period 1961- 2015 with respect to 1971-2000 base period

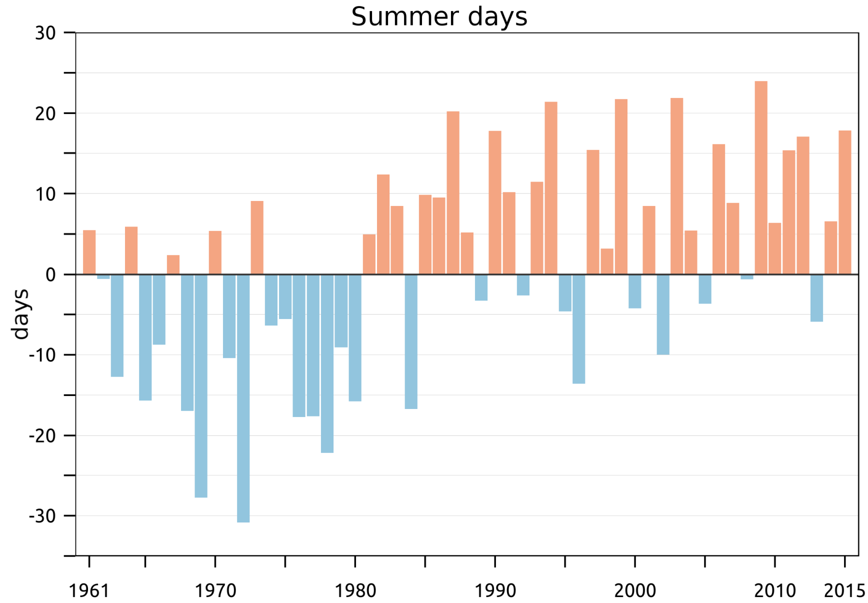


Figure 2.8 - As in figure 2.7, for summer days

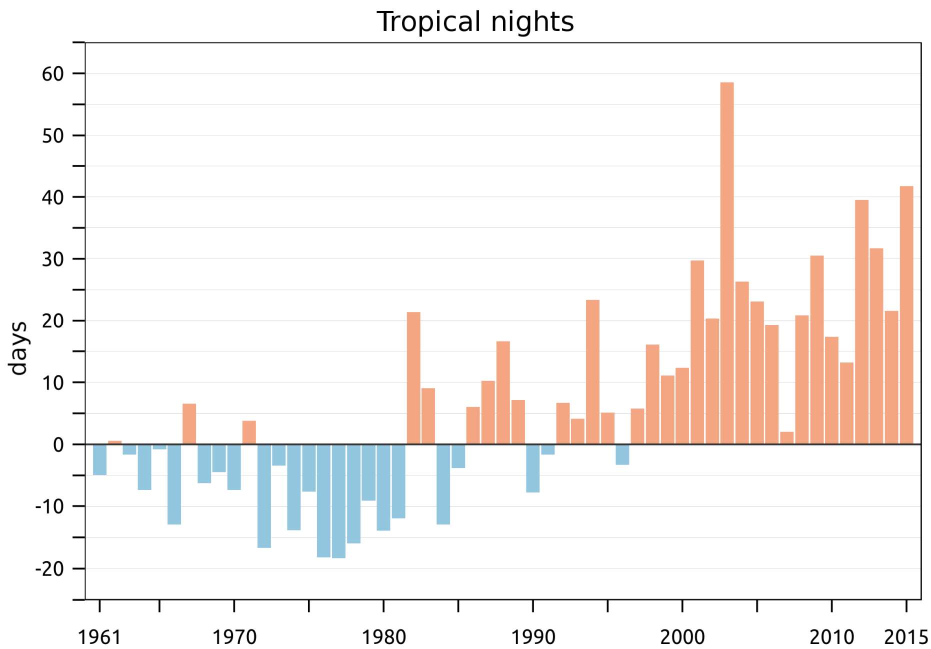


Figure 2.9 - Mean anomaly series (over Sardinia region) of tropical nights in the period 1961- 2015 with respect to 1971-2000 base period

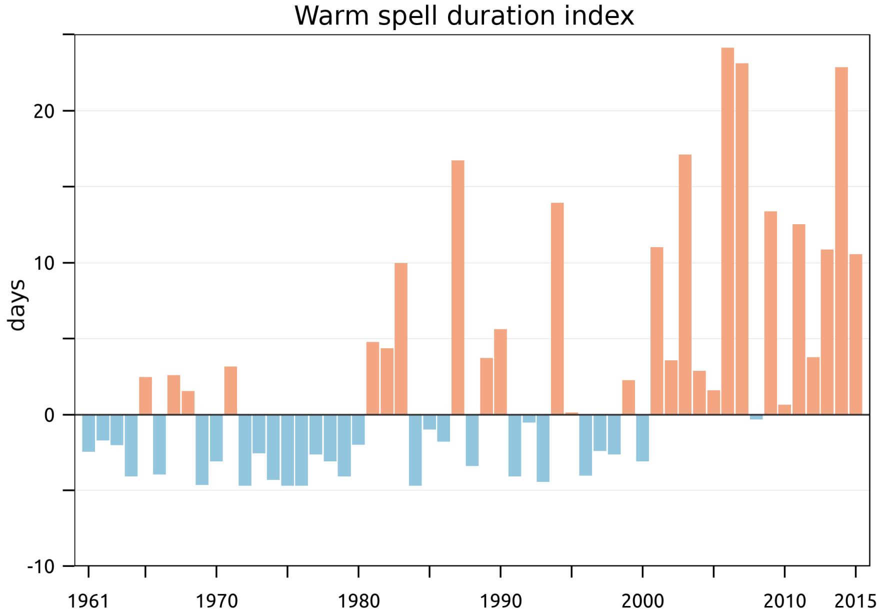


Figure 2.10 - As in figure 2.9, for warm spell duration index

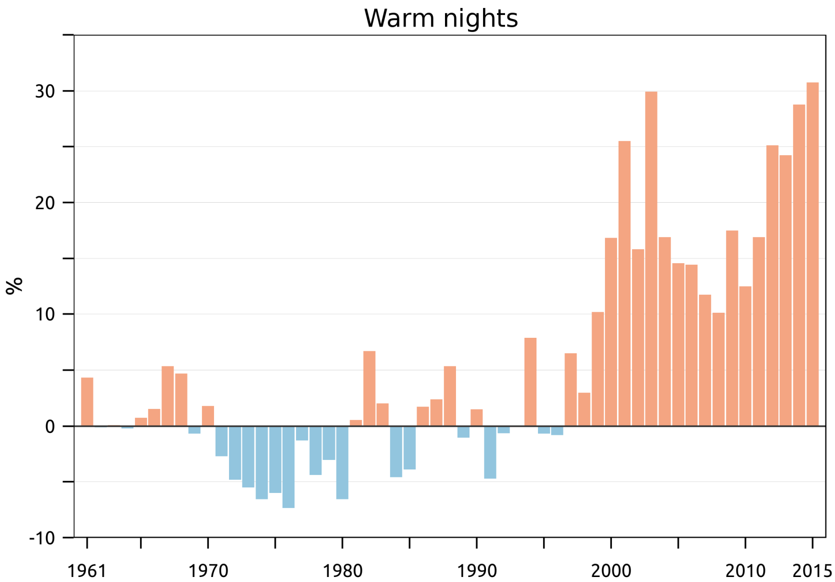


Figure 2.11 - Mean anomaly series (over Sardinia region) of warm nights, in the period 1961- 2015 with respect to 1971-2000 base period

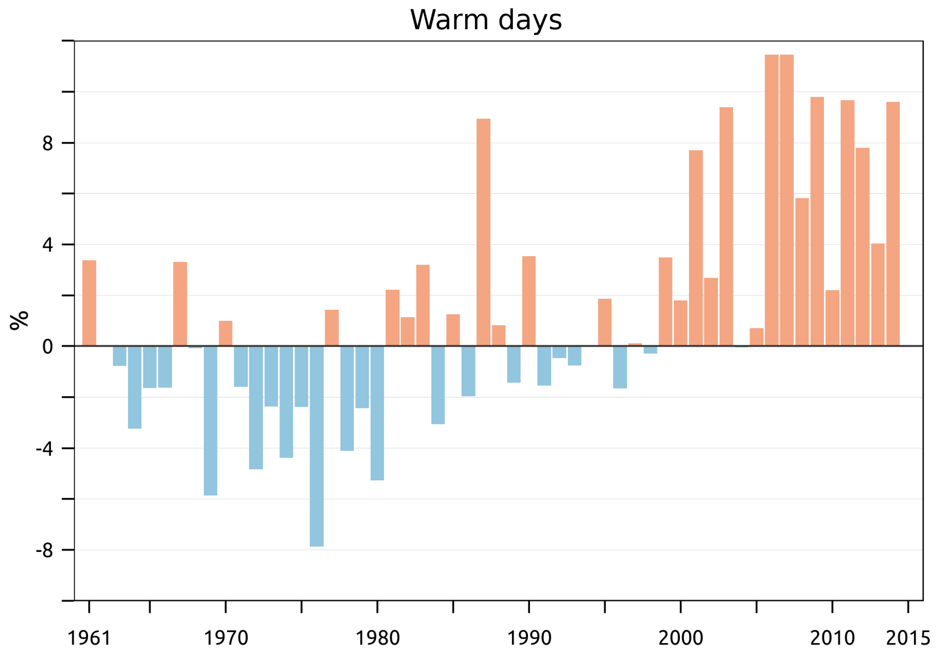


Figure 2.12 - As in figure 2.11, for warm days

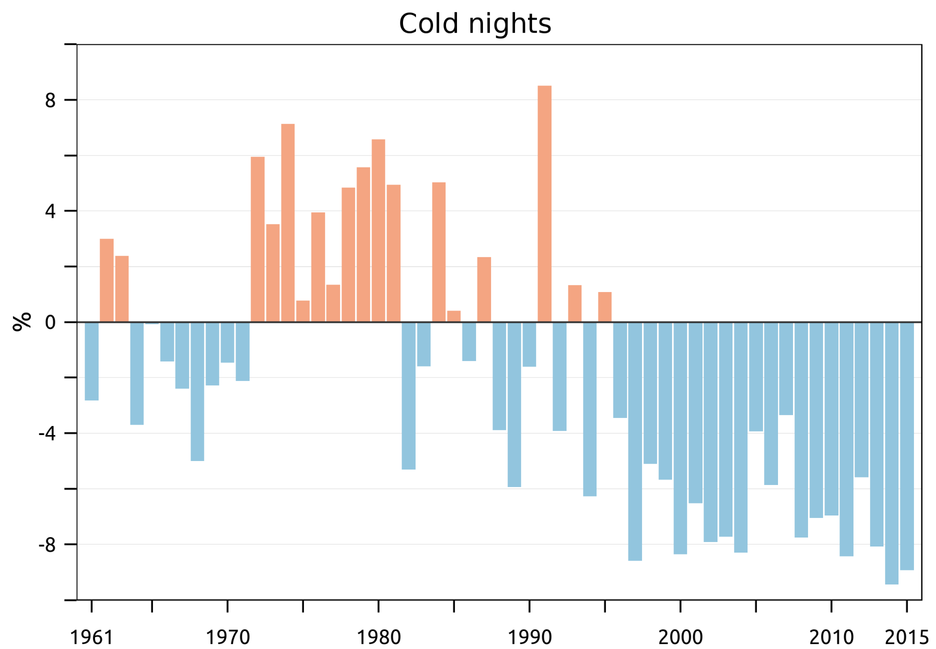


Figure 2.13 - Mean anomaly series (over Sardinia region) of cold nights, in the period 1961- 2015 with respect to 1971-2000 base period

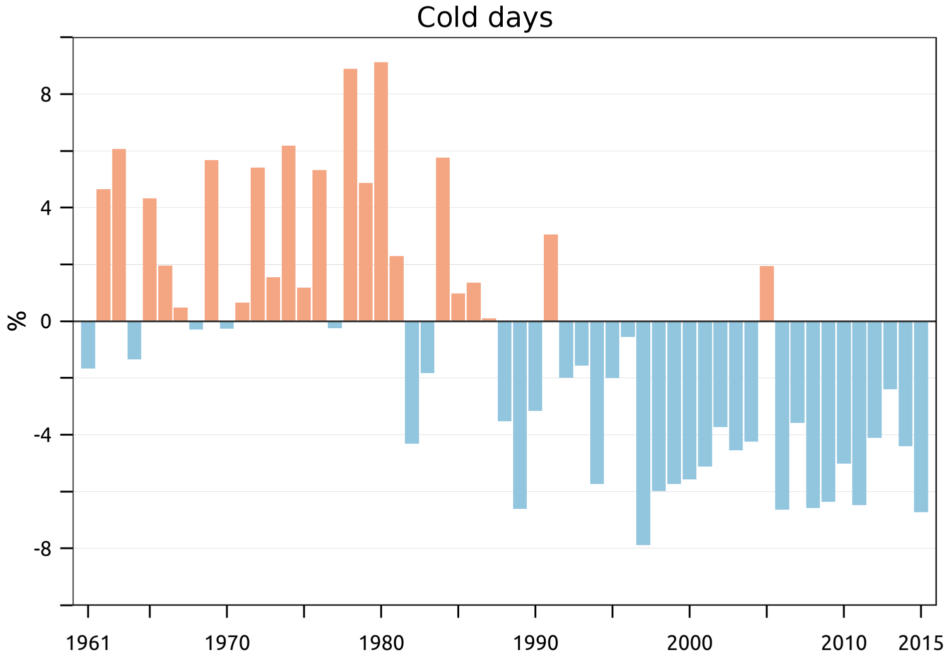


Figure 2.14 - As in figure 2.13, for cold days

Index	Unit	Trend per decade
FD0	days	-0.6±0.2
SU25	days	+4.2±1.0
TR20	days	+7.7±0.1
WSDI	days	+2.7±0.5
TN10P	%	-1.9±0.3
TX10P	%	-1.9±0.3
TN90P	%	+4.8±0.6
TX90P	%	+2.0±0.3

Table 2.4 - Annual trends per decade (evaluated using a linear regression model) of temperature extreme indices over 1961-2015 (Sardinia region)

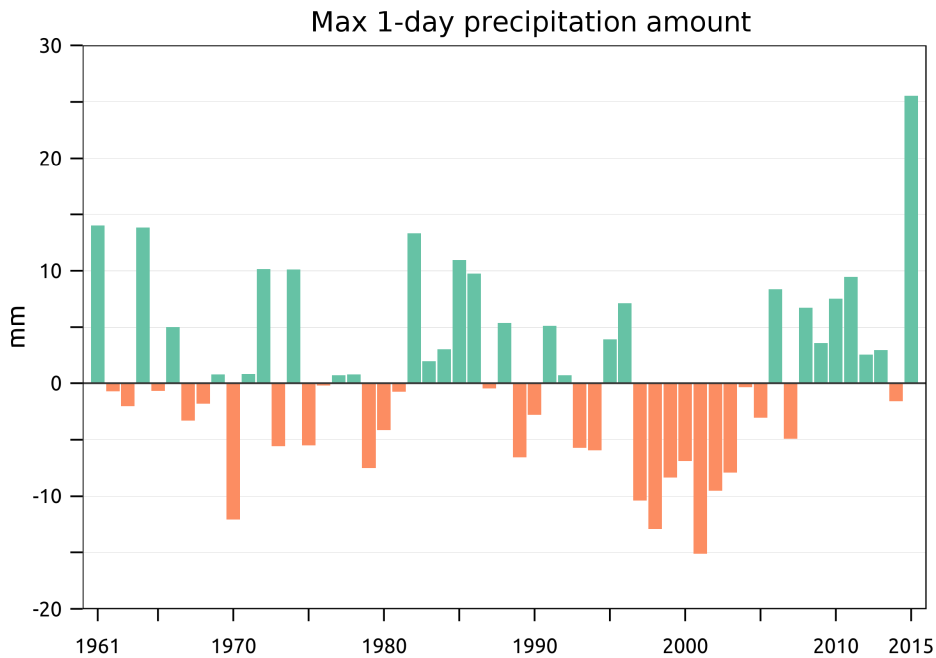


Figure 2.15 - Mean anomaly series (over Sardinia region) of max 1-day precipitation amount, in the period 1961- 2015 with respect to 1971-2000 base period

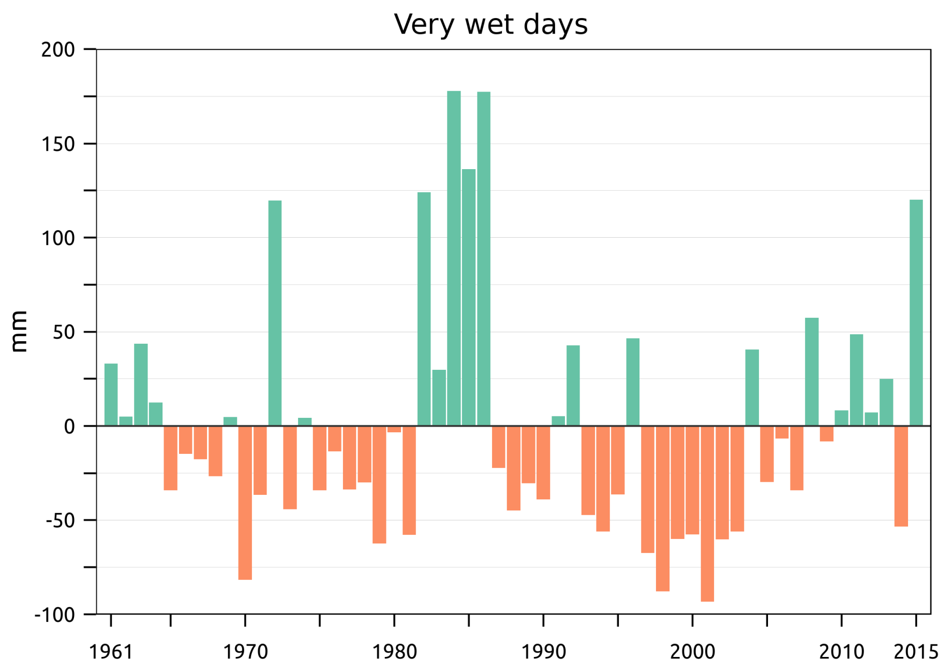


Figure 2.16 - Mean anomaly series (over Sardinia region) of very wet days , in the period 1961- 2015 with respect to 1971-2000 base period

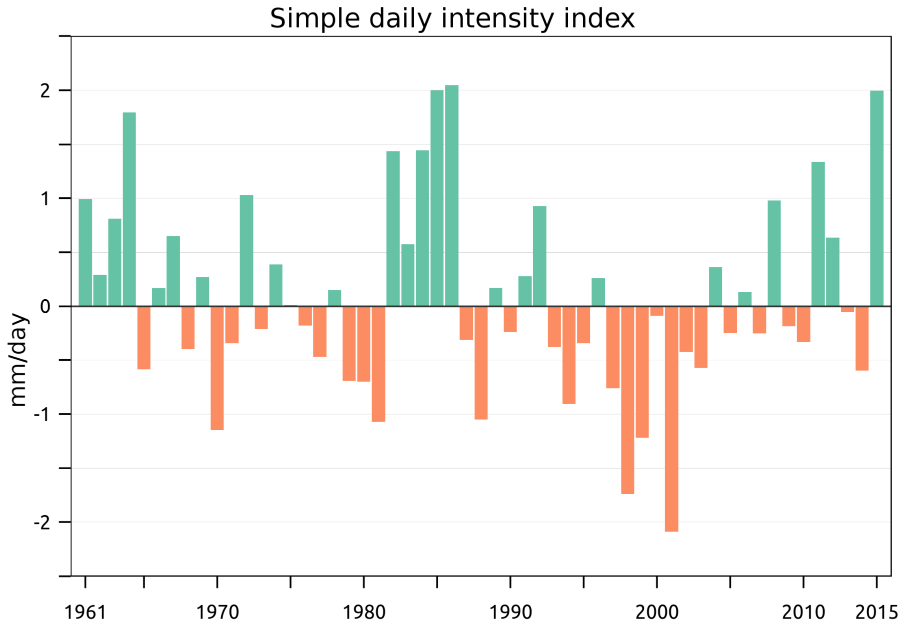


Figure 2.17 - As in figure 2.16, for simple daily intensity index

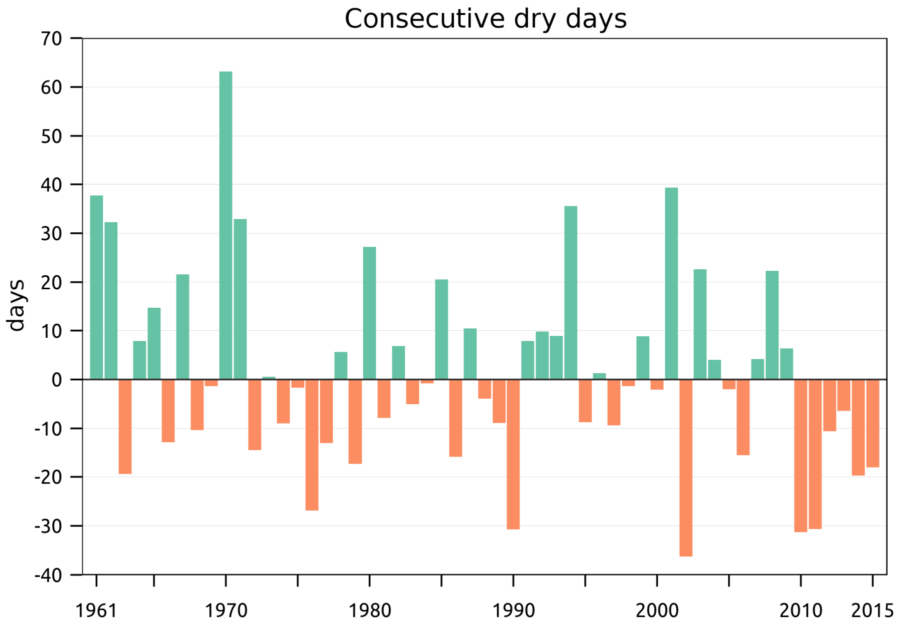


Figure 2.18 - Mean anomaly series (over Sardinia region) of consecutive dry days , in the period 1961- 2015 with respect to 1971-2000 base period

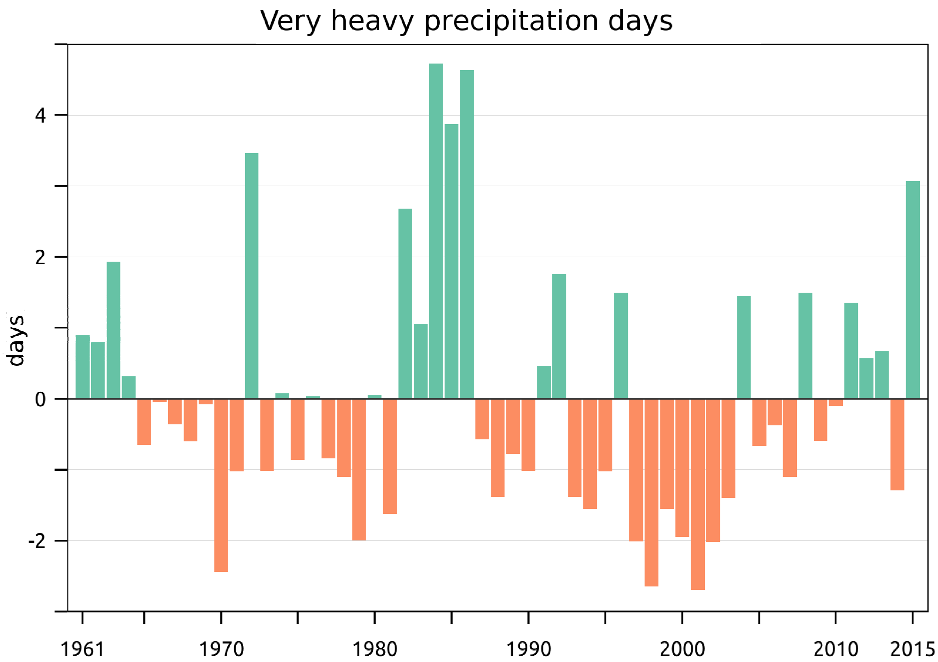


Figure 2.19 - As in figure 2.18, for very heavy precipitation days

Index	Unit	Trend per decade
RX1day	mm	(-0.1±0.7)
R95p	mm	(-1.1±5.4)
SDII	mm/day	(-0.06±0.07)
CDD	days	-3.4±1.6
R20	days	(-0.08±0.10)

Table 2.5 - Annual trends per decade (evaluated using a linear regression model) of extreme precipitation indices from 1961 to 2015 (Sardinia region)

2.1.2 Climate projections

The evolution of temperature (minimum, maximum and average) and precipitation over Sardinia region was examined, in the next decades of 21st century. Daily projections from 1971 to 2100 were selected and analysed, on the base of four regional climate models taking part in Med-CORDEX (www.medcordex.eu), an international research initiative focused on the Mediterranean region (Table 2.6). The model outputs follow two different socio-economic and greenhouse emissions scenarios (Representative Concentration Pathways - RCP), as defined by the IPCC, which respectively represent an intermediate (4.5 W/m^2, RCP4.5) and a high emission scenario (8.5 W/m^2, RCP8.5). The spatial resolution of each model is roughly 50 x 50 km (0.44° on a rotated grid). Each RCM is driven by a GCM, providing the required lateral boundary conditions. GCM-driven hindcast simulations (1971-2000) were used as base period to evaluate climate variations. Daily data covering the Sardinian domain were extracted from RCM outputs and aggregated to annual and seasonal averages. Several temperature and precipitation extreme indices were also estimated, using the same subset of ETCCDI indices, selected for the analysis of the past climate variations. ETCCDI indices are widely used to describe variability of climate extremes not only in time series of observations, but also in model projections (Jacob et al., 2014; Russo and Sterl, 2011; Sillmann et al., 2013; Zollo et al., 1015).

In addition, future projections of some other indices, useful for the analysis of vulnerability, were also considered: the total summer precipitation, the aridity index and the growing degree days.

Future climate changes were evaluated as differences between the projected value of a climatic variable or index and its corresponding mean of the base period 1971-2000; it allows to compare climatic signals from different models, independently by their ability to reproduce absolute values. The analysis was focused in particular on the following three time horizons: 2021-2050, 2041-2070 and 2061-2090.

Acronym	Institute	RCM	GCM
ALADIN	Centre National de Recherches Météorologiques	CNRM-ALADIN5.2	CNRM-CM5
GUF	Goethe University Frankfurt	GUF-CCLM4-8-18	MPI-ESM-LR
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici	CMCC-CCLM4-8-19	CMCC-CM
LMD	Laboratoire de Météorologie Dynamique	LMD-LMDZ4-NEMOMED8	IPSL-CM5A-MR

Table 2.6 - RCM models selected from med-CORDEX program

Mean values

With reference to temperature, future model projections indicate a general increase for 21st century.

The increase of mean temperature is estimated between 1.9 and 3.0 °C in a century, under RCP4.5 scenario and between 3.5 and 5.2 °C under RCP8.5 scenario (Figure 2.20). The ensemble mean (average of the four models) shows a positive trend of 0.2 °C / 10 years for RCP4.5 scenario and 0.5 °C / 10 years for RCP8.5.

Maximum temperature is expected to increase from 1.9 to 3.1°C in a century, under RCP4.5 scenario, and from 3.4 to 5.5°C in a century, under RCP8.5 scenario (Figure 2.21).

For the minimum temperature the increase is estimated between 1.8 and 2.9°C in a century under RCP4.5 and between 3.4 and 5.0°C under RCP8.5 scenario (Figure 2.22).

Positive temperature changes are expected in all seasons (Table 2.7). The strongest variation of mean temperature is projected in summer, ranging from 2.4 to 3.7 °C in a century for RCP4.5 scenario and from 4.1 in 6.8 °C for RCP8.5 (Figure 2.23), while the weakest change is expected in spring, with an increase from 1.4 and 2.6 °C for RCP4.5 scenario and from 2.8 e 4.4 °C for RCP8.5.

The expected climate change signal is less clear in case of precipitation than for temperature. Under RCP4.5 scenario (Figure 2.24), three out of four selected models forecast a reduction of annual precipitation in a century (from -9 to -58 mm); conversely, one model predicts an increase of 29 mm. As result, the ensemble mean shows a weak decrease of annual precipitation of -22 mm. Following the RCP8.5 scenario, all models predict a precipitation reduction, ranging from -15 to -129 mm in a century. Seasonal precipitation results indicate a weak reduction in spring, summer and autumn, whereas in winter wetter conditions are estimated compared to the 1971-2000 base period Figure 2.25 and Table 2.8).

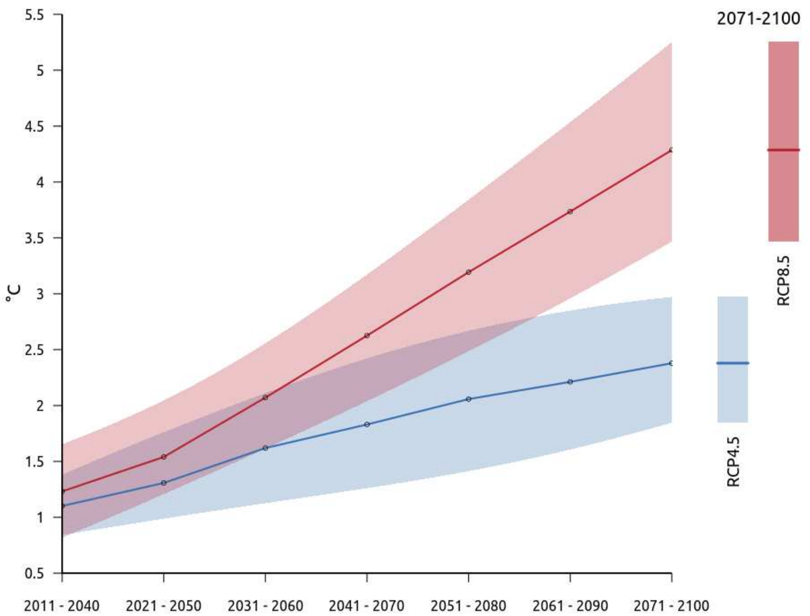


Figure 2.20 - Mean temperature. Variations of model projections (average over 30-years periods) with respect to 1971-2000 under RCP4.5 (blu) and RCP8.5 scenario (red). The line indicates the average of the model projections (ensemble mean), while the shaded area shows the difference between the minimum and the maximum value of model predicted variations (spread). The upper and lower limits of the area are "loess" interpolation (Cleveland, 1979)

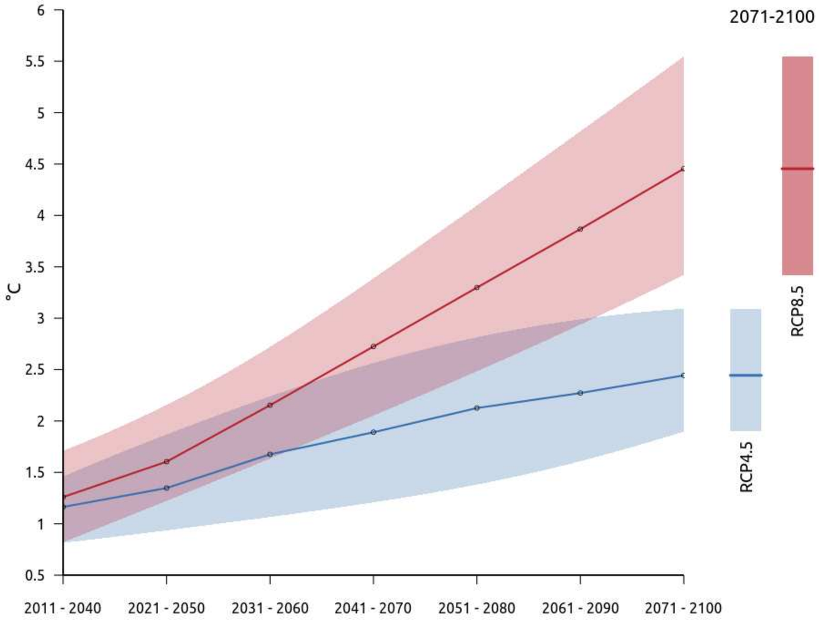


Figure 2.21 - As in figure 2.20, for maximum temperature

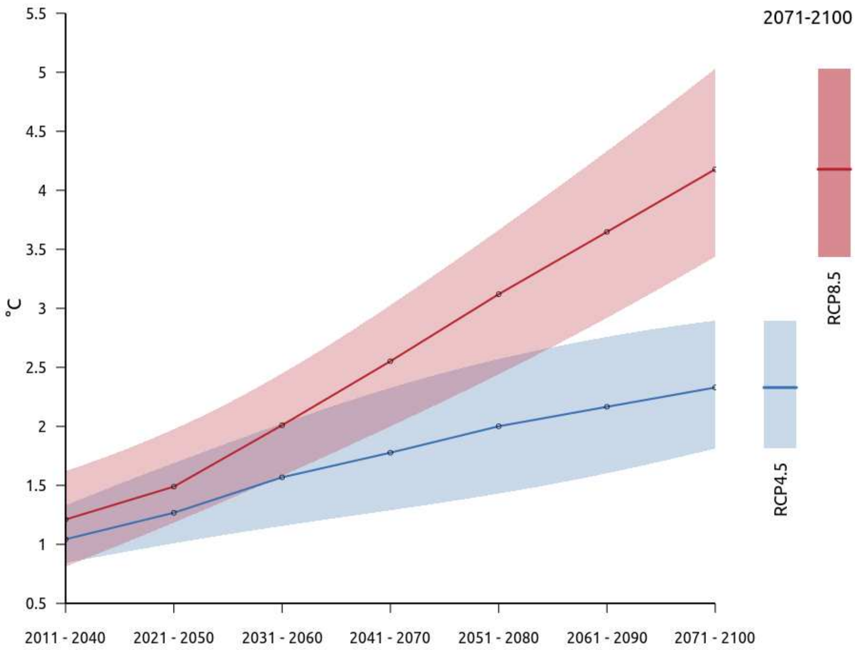


Figure 2.22 - As in figure 2.20, for minimum temperature

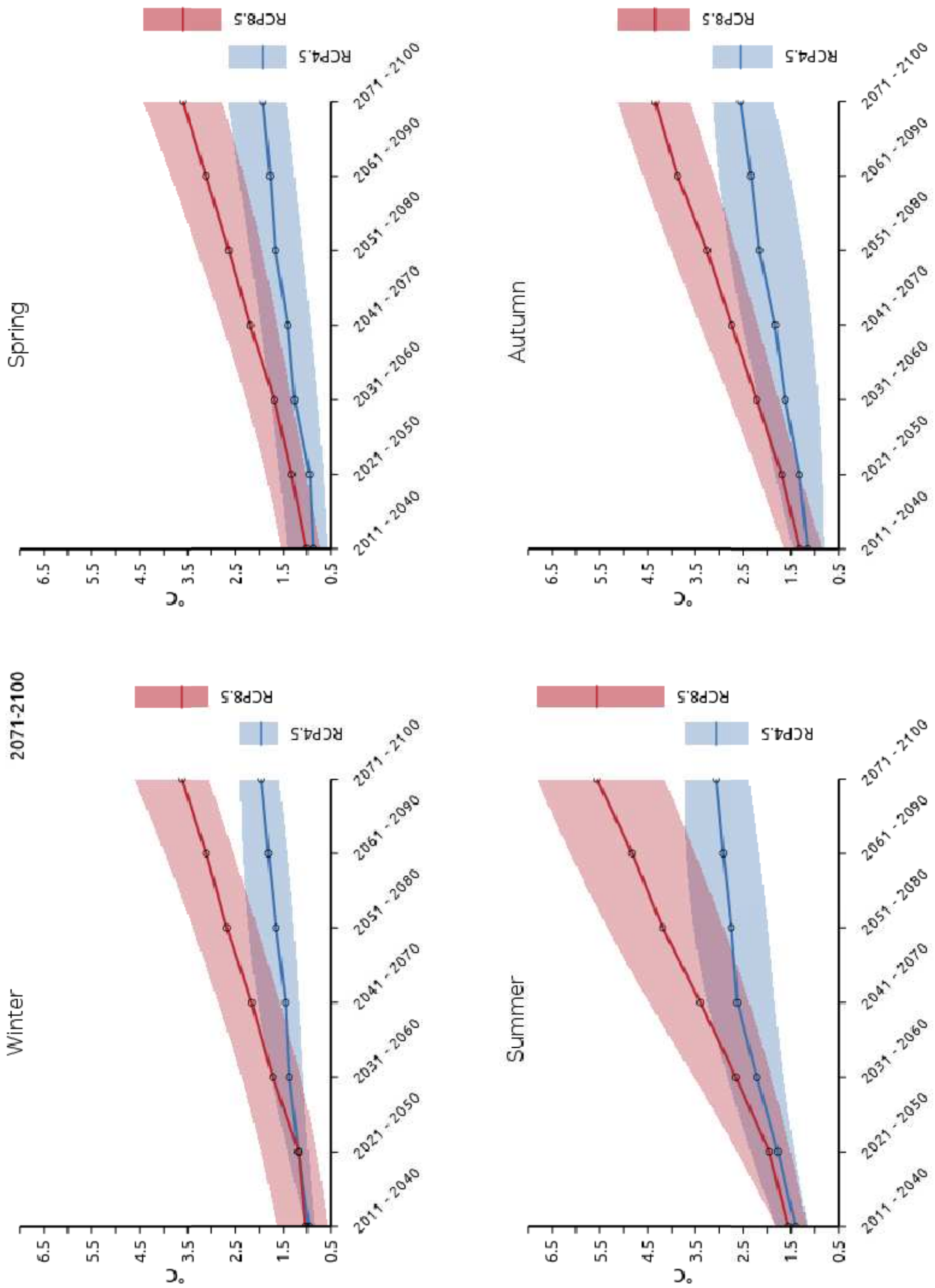


Figure 2.23 - As in figure 2.20, for seasonal mean temperature

	RCP4.5 scenario		RCP8.5 scenario	
	ΔT ensemble mean	Spread	ΔT ensemble mean	Spread
Annual	+2.4	1.1	+4.3	1.8
Winter	+2.0	0.8	+3.6	1.6
Spring	+1.9	1.2	+3.6	1.6
Summer	+3.1	1.3	+5.6	2.7
Autumn	+2.5	1.2	+4.3	1.5

Table 2.7 - Increase of annual and seasonal mean temperature (average over Sardinia region, °C) projected for 2071-2100 with respect to 1971-2000

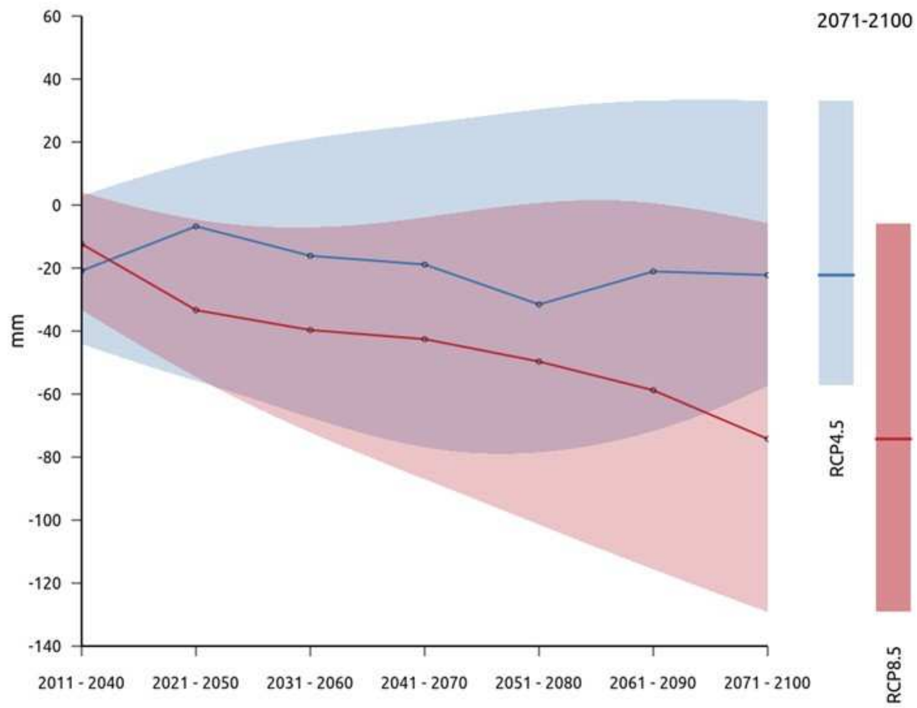


Figure 2.24 - Total precipitation. Variations of model projections (average over 30-years periods) with respect to 1971-2000 under RCP4.5 (blu) and RCP8.5 scenario (red). The line indicates the average of the model projections (ensemble mean), while the shaded area shows the difference between the minimum and the maximum value of model predicted variations (spread). The upper and lower limits of the area are "loess" interpolation (Cleveland, 1979)

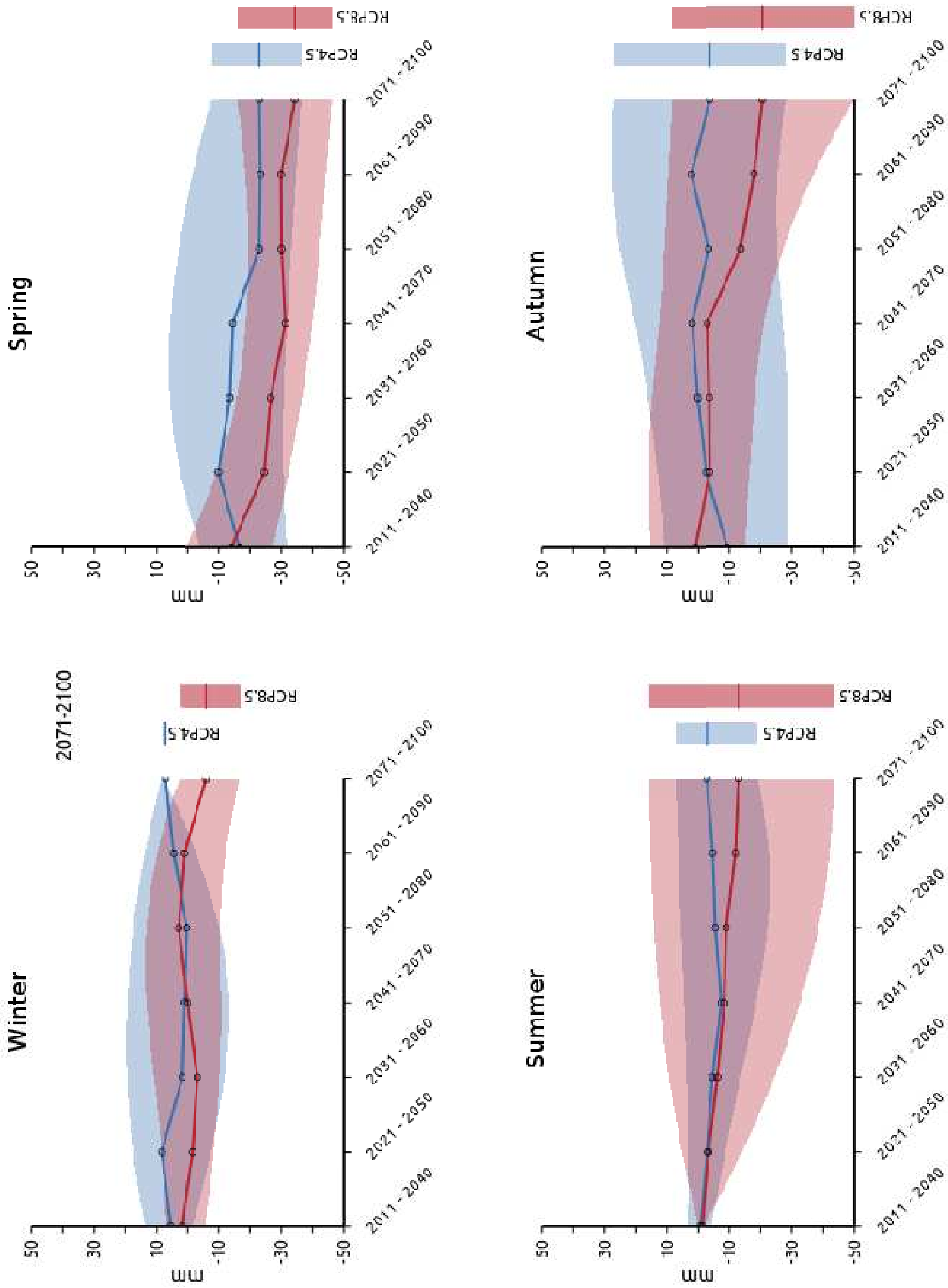


Figure 2.25 - As in figure 2.24, for seasonal precipitation

	Scenario RCP4.5		Scenario RCP8.5	
	ΔP ensemble mean	**Spread**	**ΔP ensemble mean**	**Spread**
Winter	+7.2	2.0	-6.0	23.6
Spring	-23.0	29.7	-34.4	31.3
Summer	-2.8	23.2	-13.1	59.8
Autumn	-3.8	52.9	-20.6	56.4
Annual	-22.2	86.6	-74.2	113.8

Table 2.8 - Variation of annual (AP) and seasonal precipitation (average over Sardinia region, mm) projected for 2071-2100, with respect to 1971-2000

ETCCDI extreme indices

Projections of the extreme temperature indices confirm the warming tendency predicted for the mean values, showing significant variations. All model agree to predict a future reduction of frost days and an increase of tropical nights, summer days and heat waves, however the expected changes are significantly different in magnitude, among models. For each index, the mean variations with respect to the 1971-2000 mean and the spatial distribution of the variations over Sardinia region are reported, at three time horizons (2021-2040, 2041-2070, 2061-2090).

A decrease of frost days is estimated for 2061-2090, with a mean decrease over Sardinia ranging from -1.9 to -14.8 days under RCP4.5 and from -2.4 to -22.4 days under RCP8.5 scenario (Figure 2.26). The reduction is stronger inland, since very few frost days normally occur on the coast (Figure 2.27 and Figure 2.28).

Climate projections by 2061–2090 highlight a mean increase of tropical nights over Sardinia from +18.5 to +39.8 days under RCP4.5 scenario and from +33.6 to +67.6 days under RCP8.5 (Figure 2.29). Figure 2.30 and Figure 2.32 show the spatial distribution of the predicted increases.

A decrease of cold nights (Figure 2.32 - Figure 2.34) and an increase of warm nights (Figure 2.35 - Figure 2.37) are expected. By 2061-2090 cold night mean reductions range from -7.0% to -9.2% under RCP4.5 scenario and from -9.1% to -9.8% under RCP8.5 scenario (Figure 2.32), while warm night increases range from +18.3% to +33.3% under RCP4.5 scenario (Figure 2.35) and from +36.2% to +55.7% under RCP8.5 scenario. Analyses of cold days and nights are respectively shown in Figure 2.38 – Figure 2.40 and in Figure 2.41 – Figure 2.43). Similarly to cold and warm nights, a decrease of cold days (from -5.6% to -8.5% under RCP4.5 and from -8.4% to -9.7% under RCP8.5, Figure 2.38) and an increase of warm days (from +13.9% to +32.0% under RCP4.5 and from 29.4% to 55.0% under RCP8.5, Figure 2.41) are projected.

Finally, consistent increases of summer days and heat waves are expected: the projected mean changes of summer days range between +22 and +39 days for RCP4.5 scenario and from +40 to +60 days for RCP8.5 (Figure 2.44), while the increases of heat waves range from +28 to +85 days for RCP4.5 scenario and from +72 to +172 days for RCP8.5 (Figure 2.47).

Spatial distributions of projected variations of summer days are shown in Figure 2.45 (RCP4.5) and Figure 2.46 (RCP8.5), while maps of future changes of heat waves are reported in Figure 2.48 (RCP4.5) and Figure 2.49 (RCP8.5). Projections of the extreme precipitation indices exhibit less clear results. A tendency to less frequent and more intense precipitation events seems to be expected, however, the projected changes are generally weak or moderate.

Future projections of the maximum value of 1-day precipitation for 2061-2090 indicate variations ranging between a reduction of -2.3 and an increase of +11.6 mm, under RCP4.5 and between a reduction of -2.6 and an increase of +9.6 mm, under RCP8.5 scenario Figure 2.50), with a light increase of the ensemble mean. Also the spatial distribution of the expected changes highlights differences among models (Figure 2.51, scenario RCP4.5 and Figure 2.52, scenario RCP8.5).

An increase of very wet days is showed by the ensemble mean under both the RCPs (Figure 2.53); with reference to the spatial distribution of the projected changes, one model indicates a prevalence of negative changes over Sardinia, while a general increase of R95p is projected by the others (Figure 2.54 for RCP4.5 and Figure 2.55 for RCP8.5).

Future projections of the Simple Daily Intensity Index (SDII) indicate an increase of the ensemble mean value; by 2061-2090 the expected increase is 0.3 mm/day under RCP4.5 scenario and 0.5 mm/day under RCP8.5 scenario (Figure 2.56), quite uniform over the area (Figure 2.57 for RCP4.5 and Figure 2.58 for RCP8.5). Considering that the ensemble mean show a decrease of the total precipitation, the increase of SDII indicate a probable concentration of precipitation in less frequent and more intense events in the future. The analysis of consecutive dry days (CDD) highlights a likely increase of dry spells (Figure 2.59). Three out of four models indicate future marked increases of CDD, while for one model the expected increase is weak (Figure 2.60 for RCP4.5 and Figure 2.61 for RCP8.5). The strongest increase is predicted under the assumption of RCP8.5 scenario: by 2061-2090 the projections range from +1.9 to +42.1 days with respect to 1971-2000 average.

Finally, future projections of very heavy precipitation days (Figure 2.62 - Figure 2.64) indicate slight variations at all the time frames. By 2061-2090 the expected changes range from -0.4 to +0.8 days under RCP4.5 and from -0.5 and +0.5 days under RCP8.5 scenario.

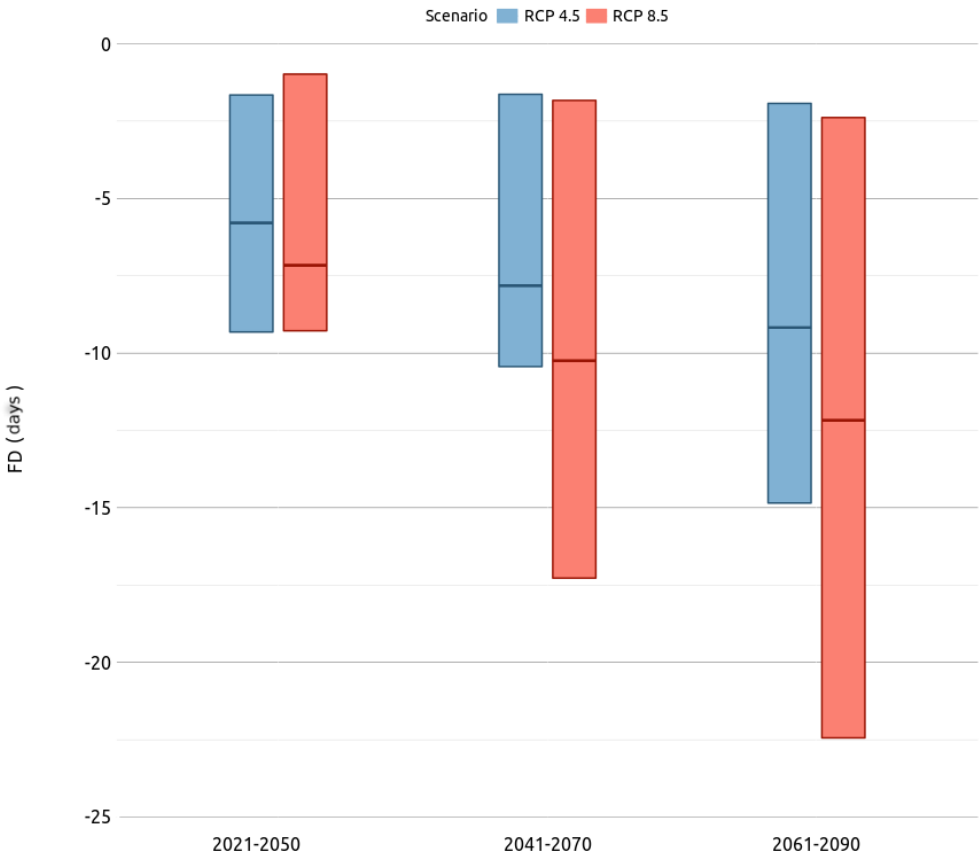


Figure 2.26 - Frost days (FD, days). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

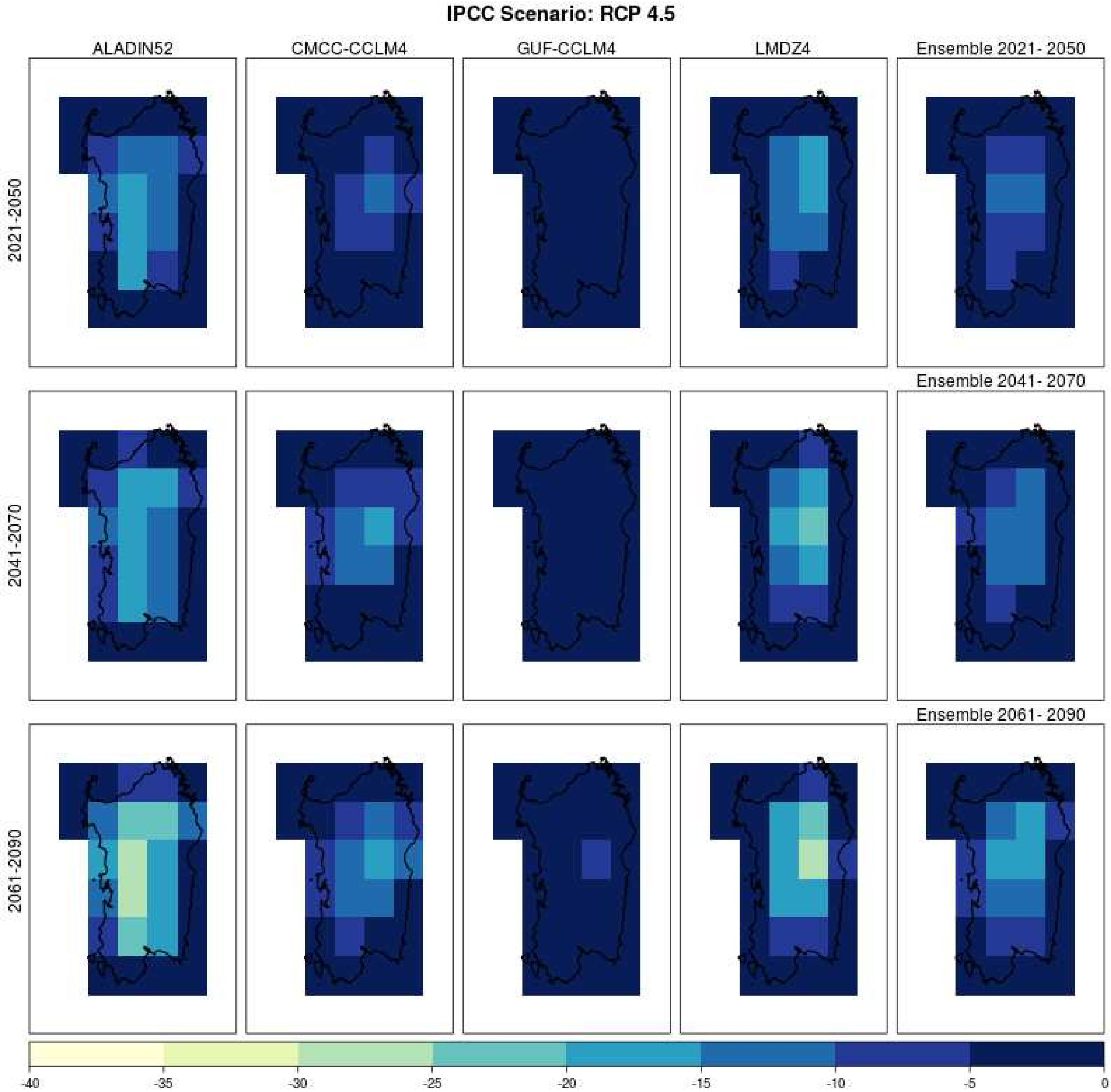


Figure 2.27 - Frost days (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

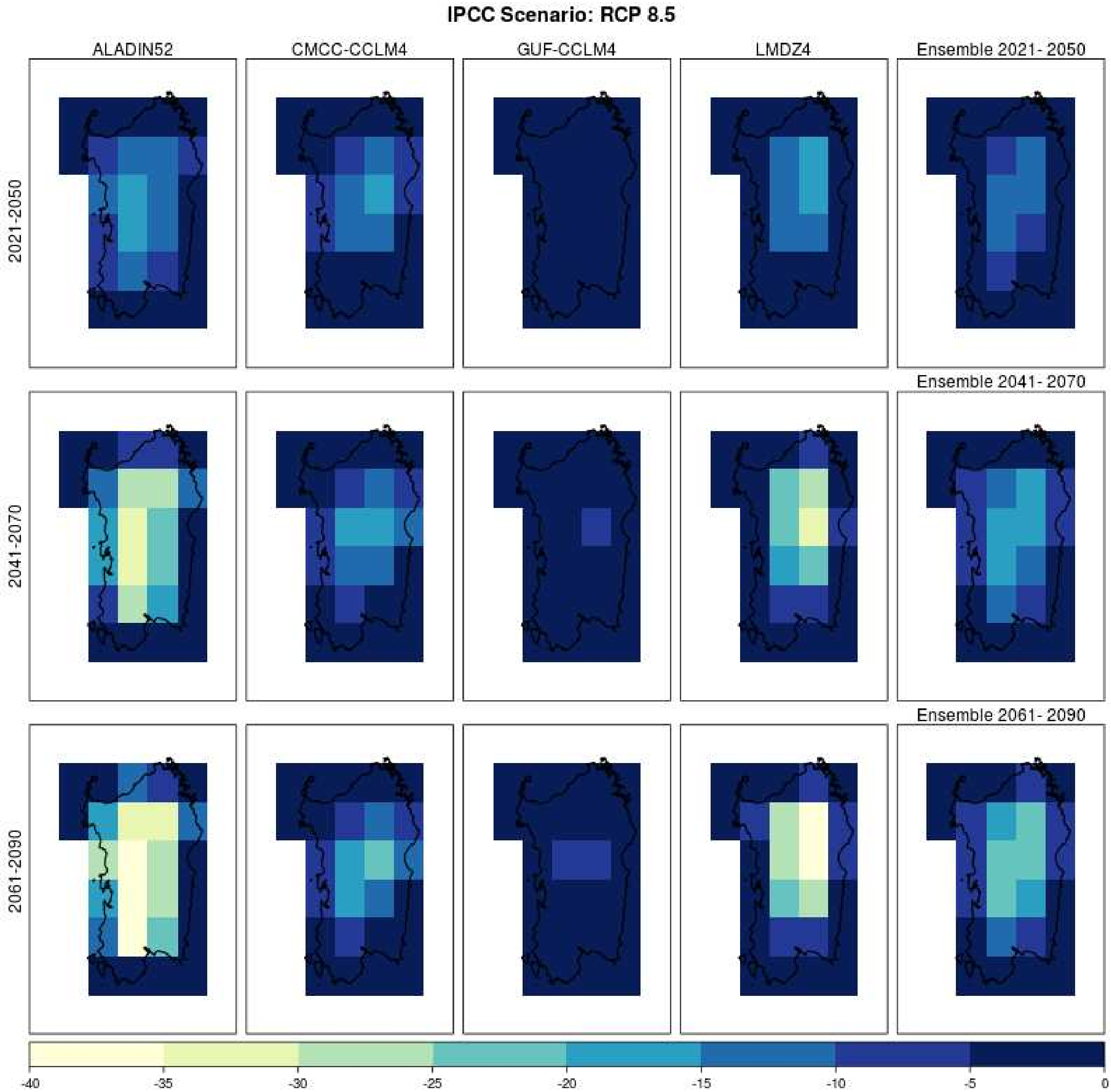


Figure 2.28 - As in figure 2.27, RCP8.5 scenario

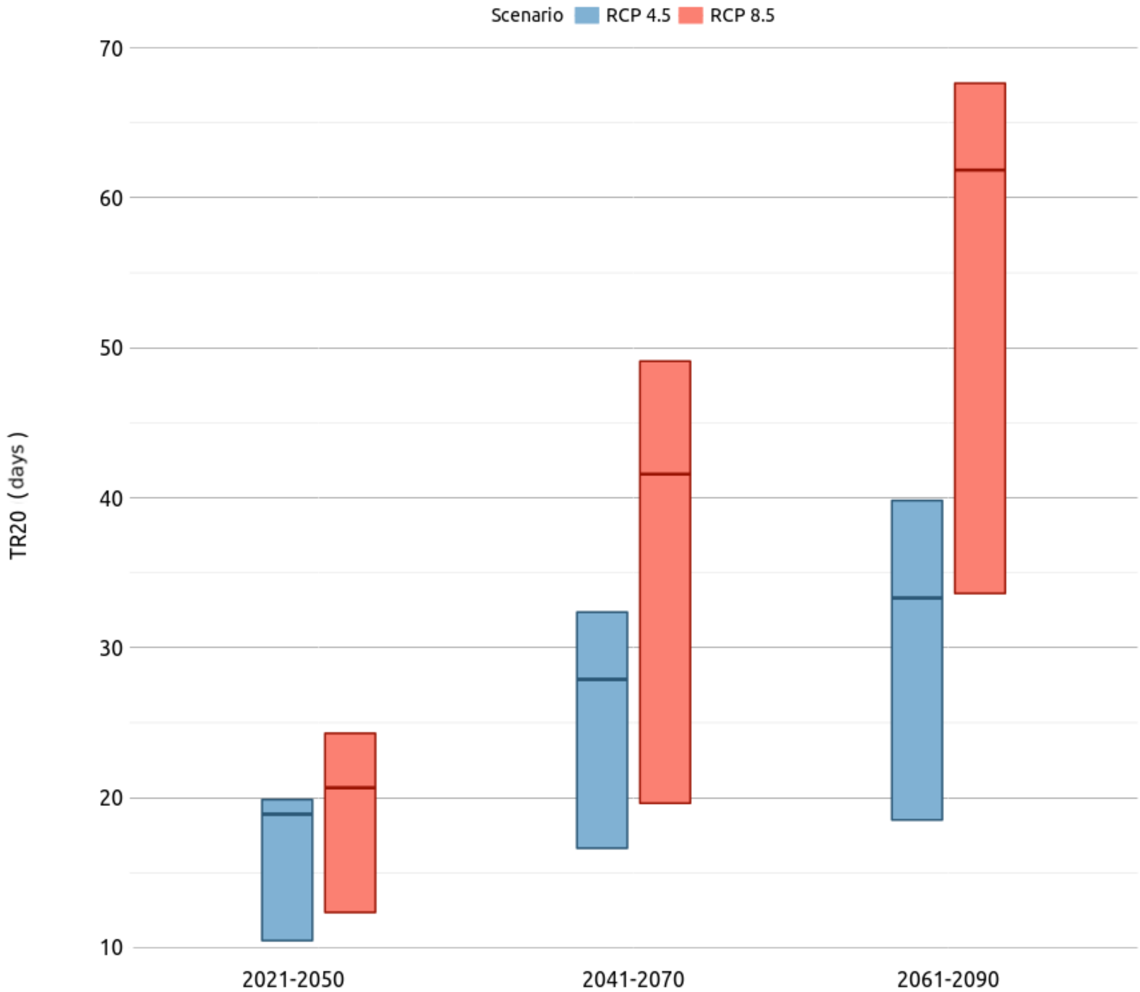


Figure 2.29 - Tropical nights (TR20, days). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

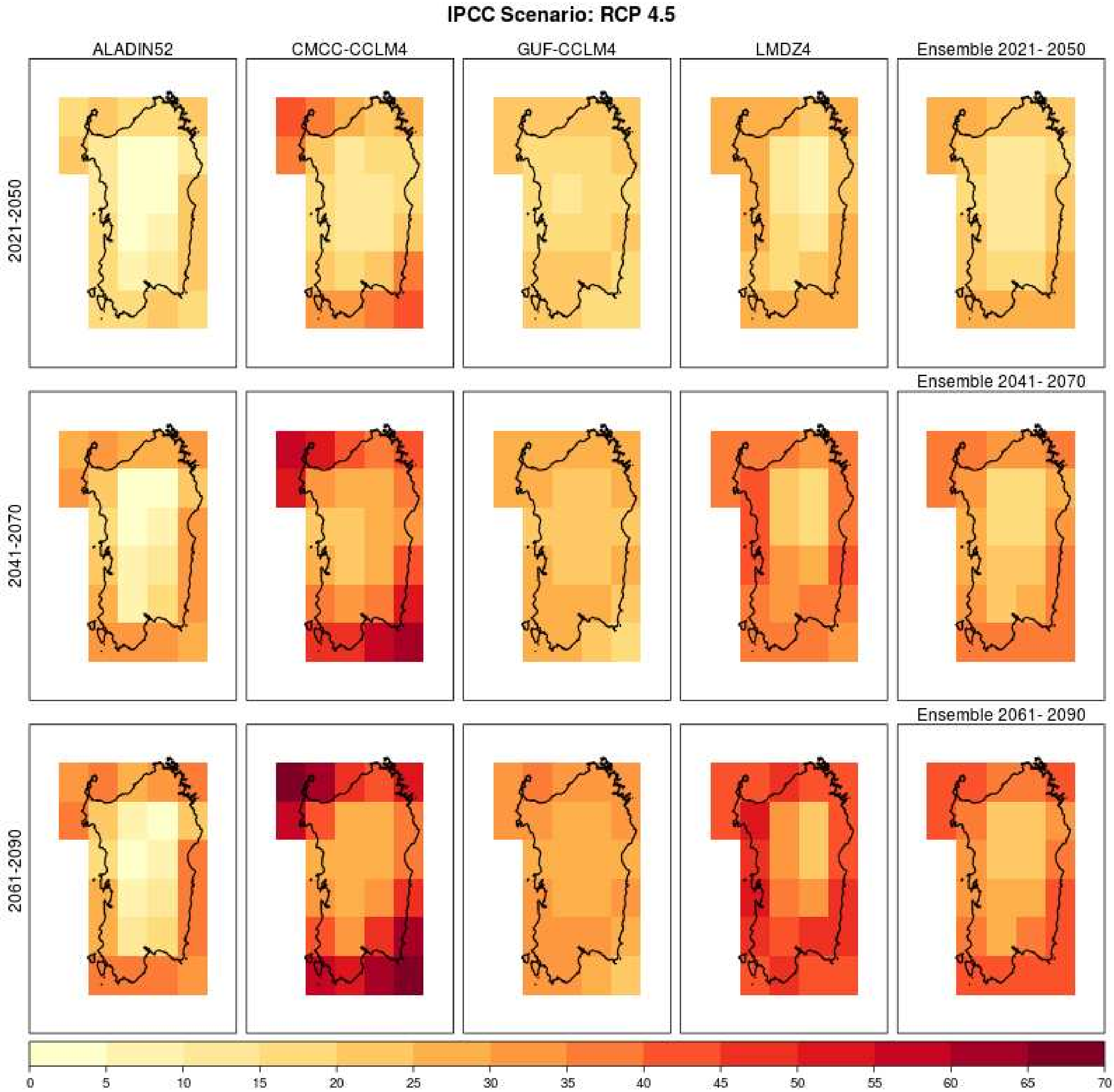


Figure 2.30 - Tropical nights (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

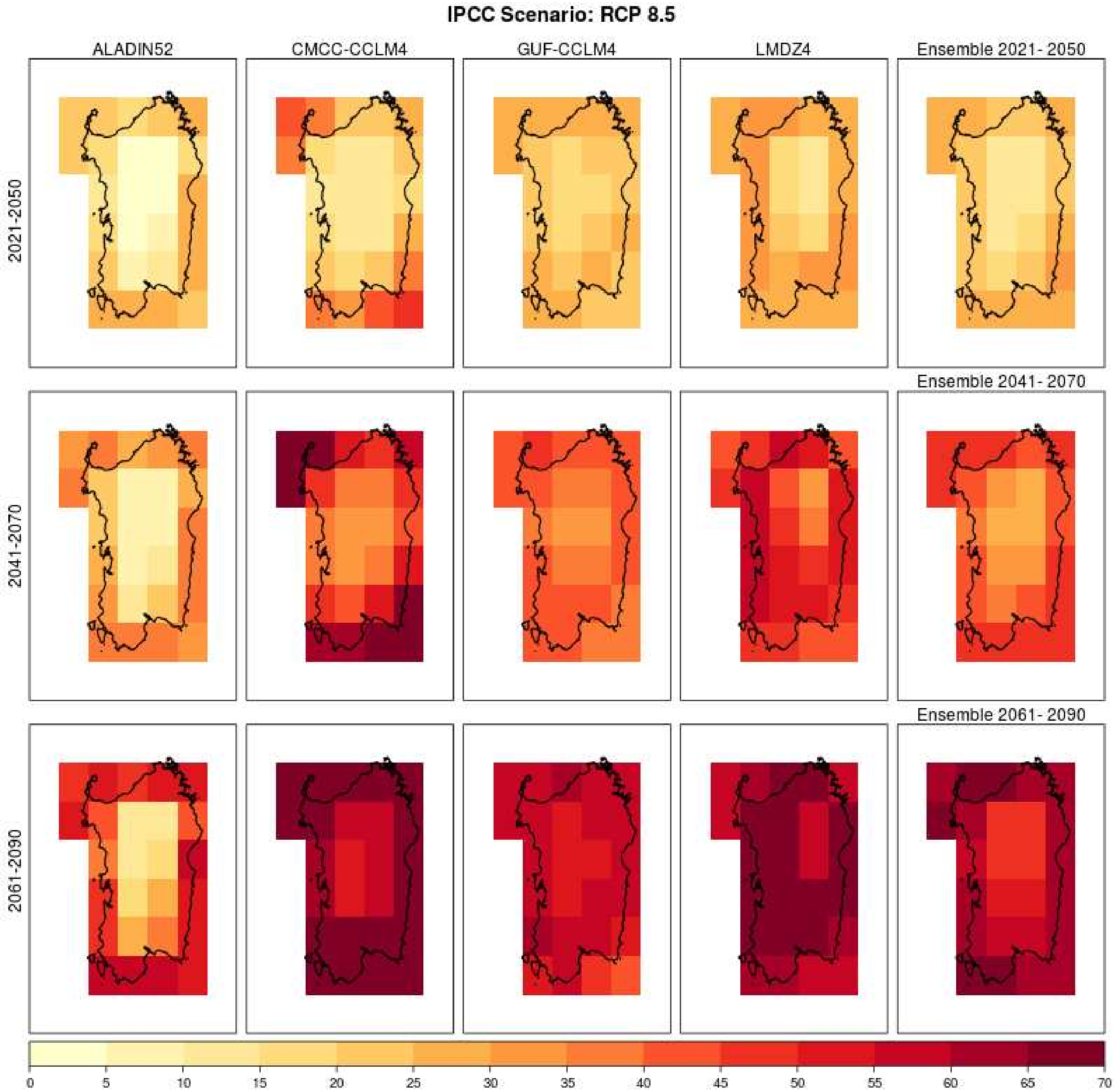


Figure 2.31 - As in Figure 2.30, PCP8.5 scenario

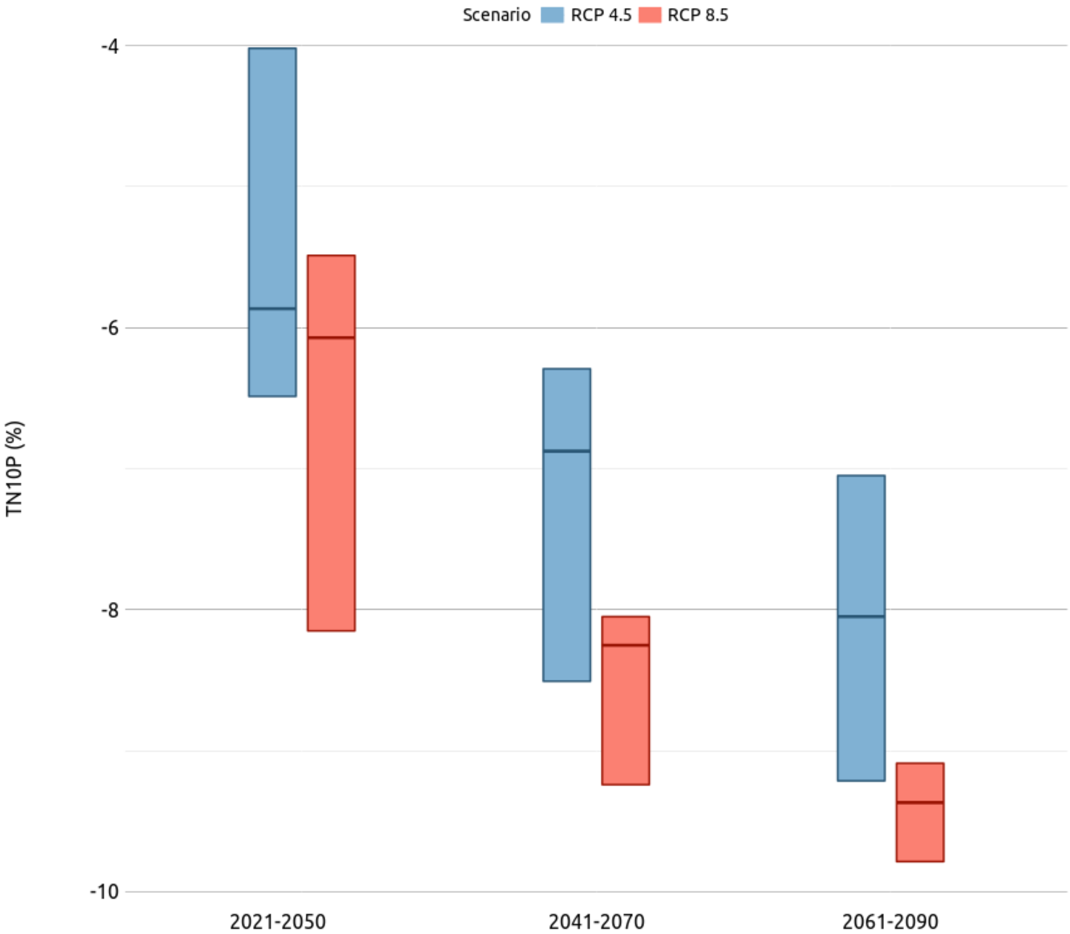


Figure 2.32 - Cold nights (TN10P, %). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

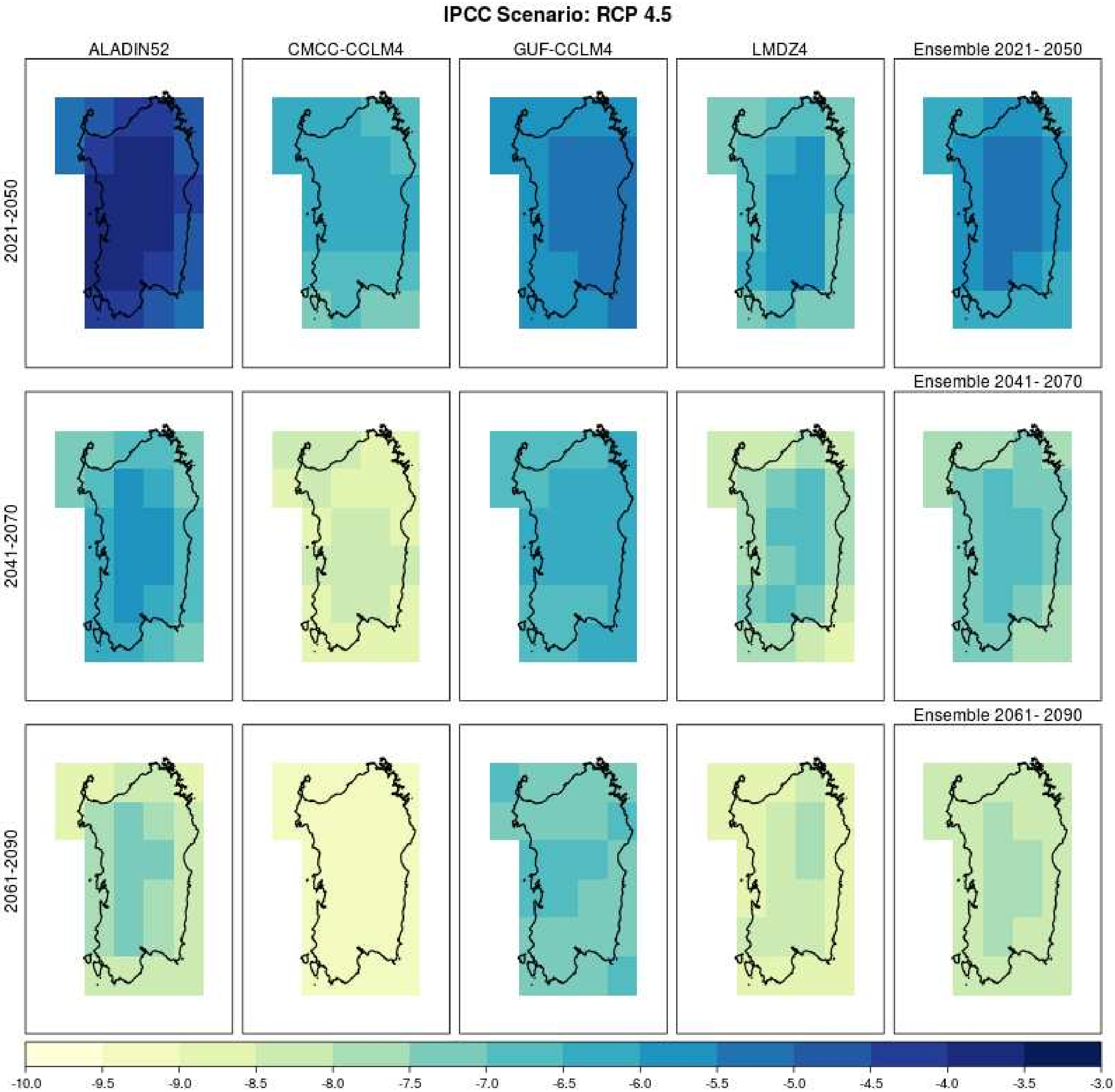


Figure 2.33 - Cold nights (%), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

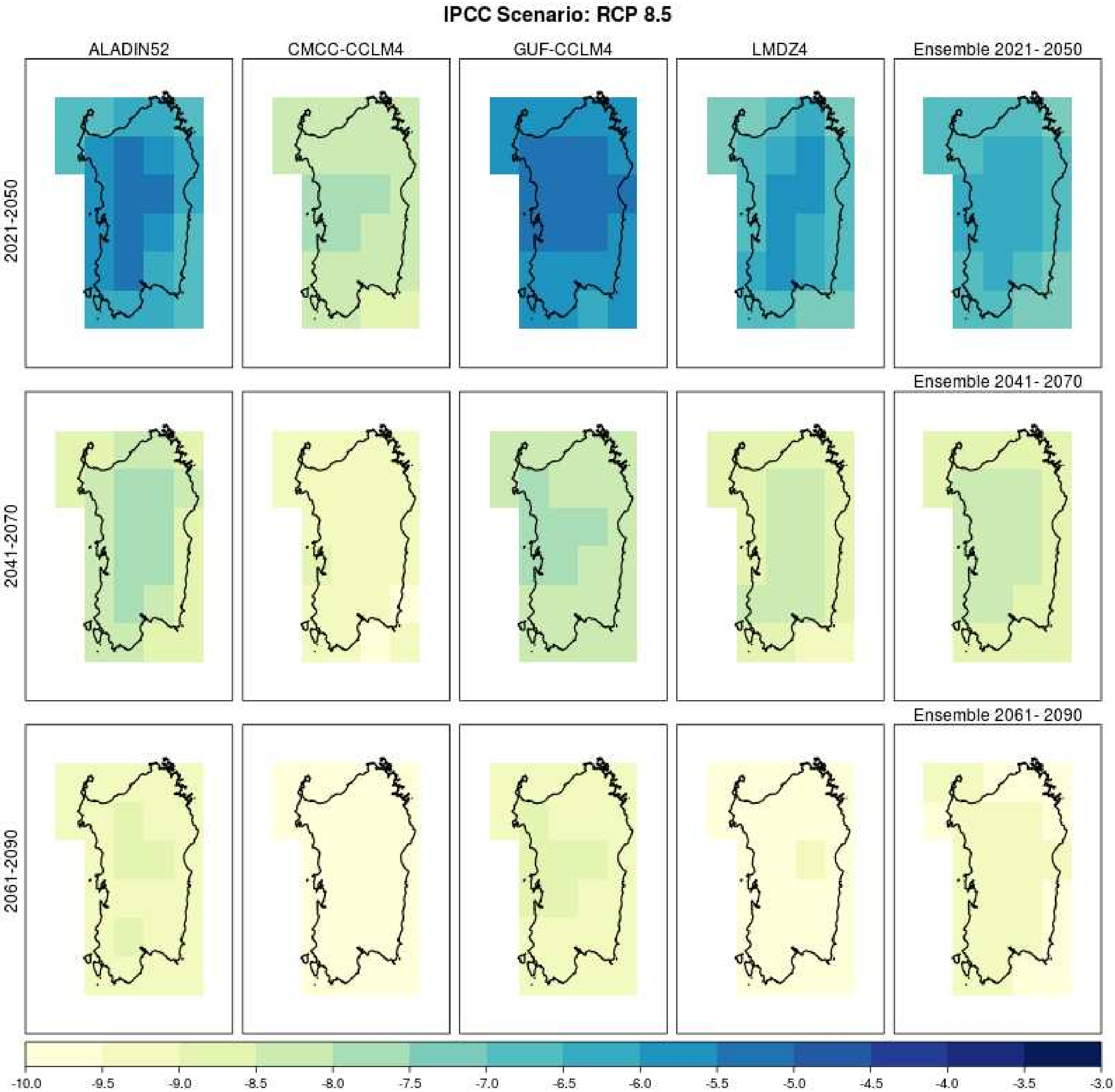


Figure 2.34 - As in figure 2.33, RCP8.5 scenario

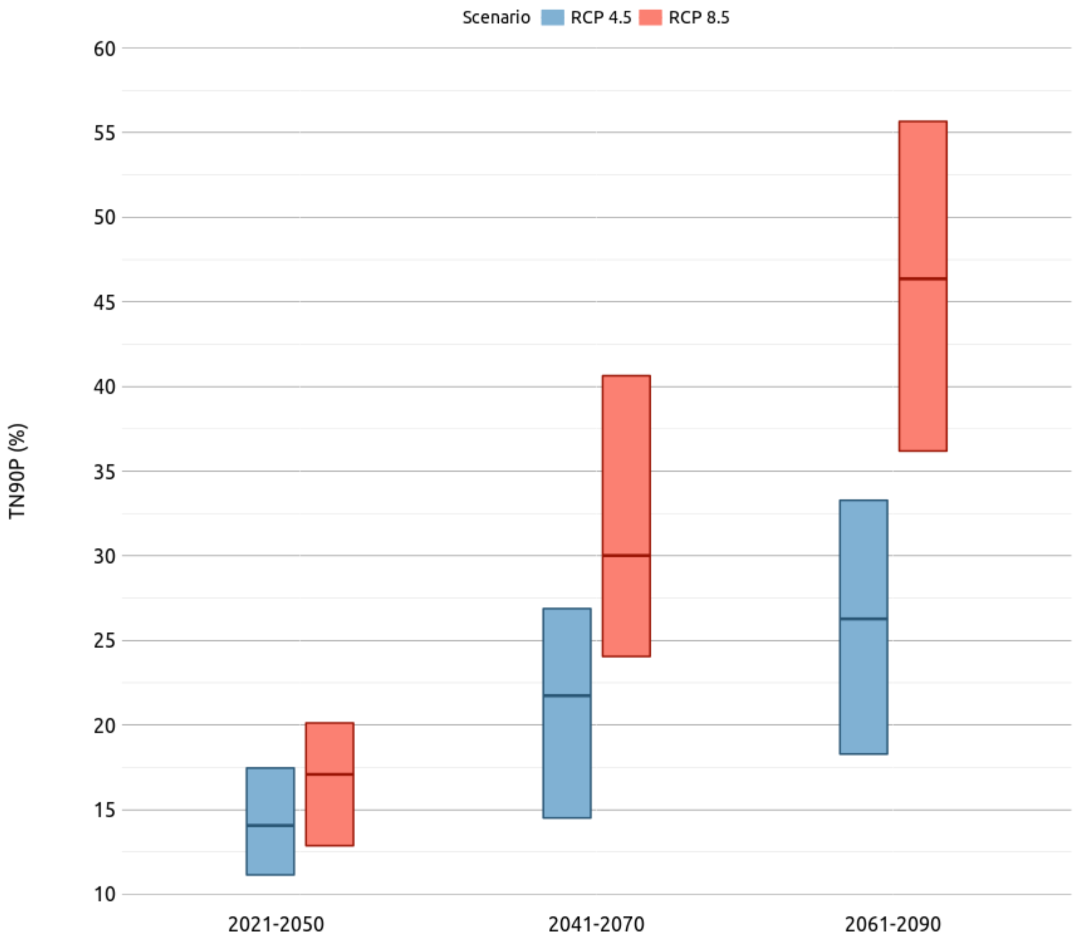


Figure 2.35 - Warm nights (TN90P, %). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

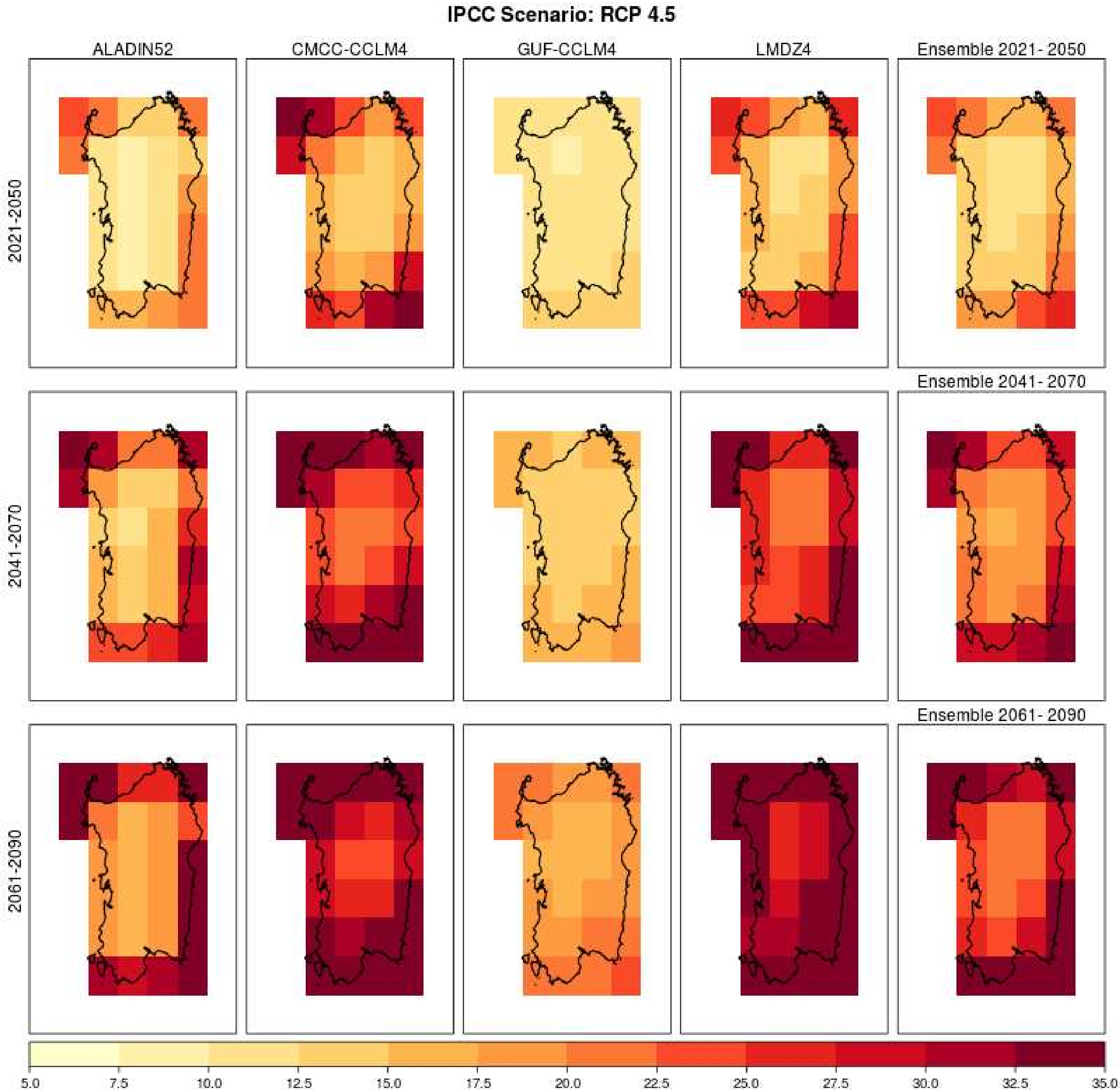


Figure 2.36 - Warm nights (%), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

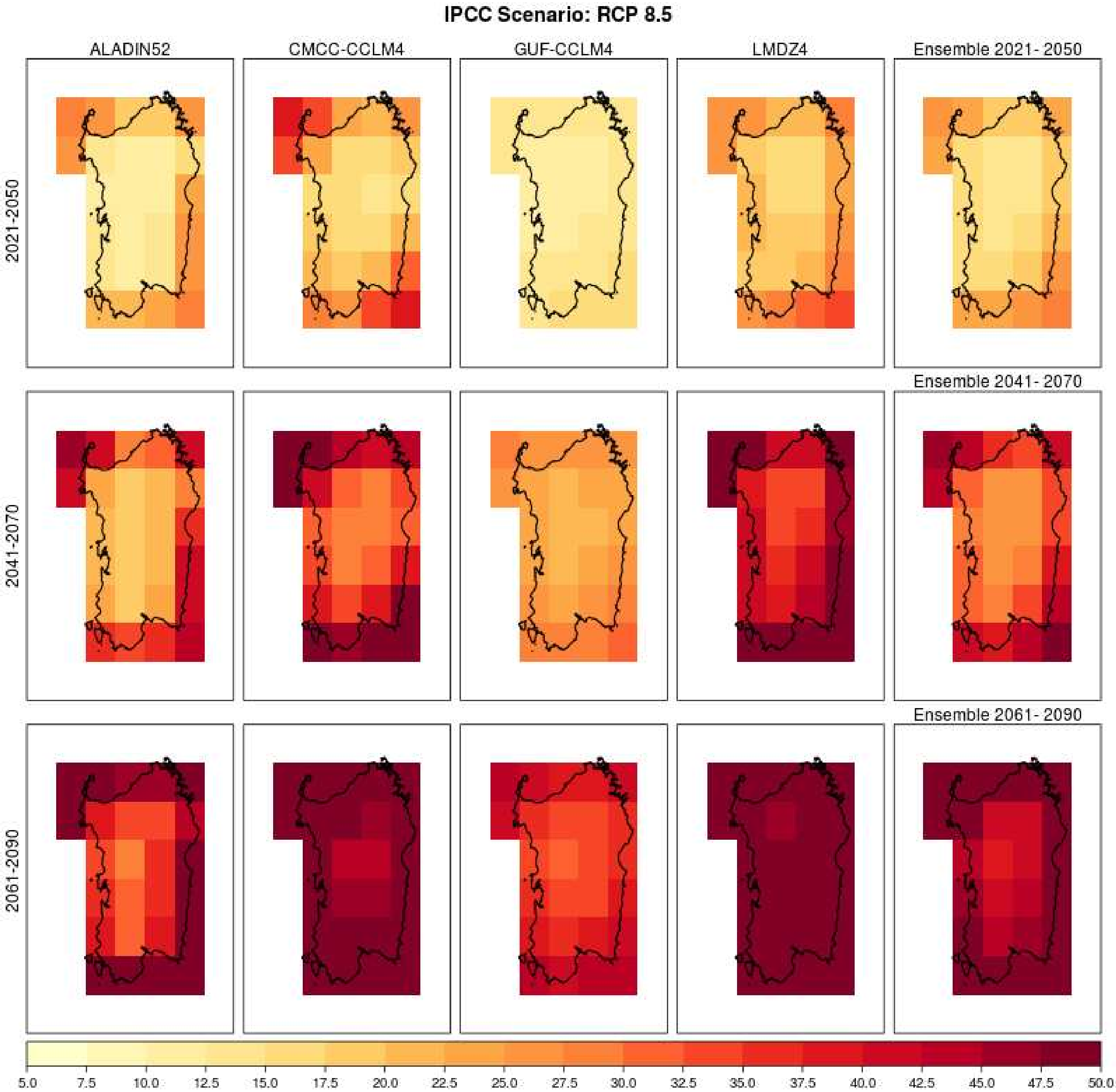


Figure 2.37 - As in figure 2.36, RCP8.5 scenario

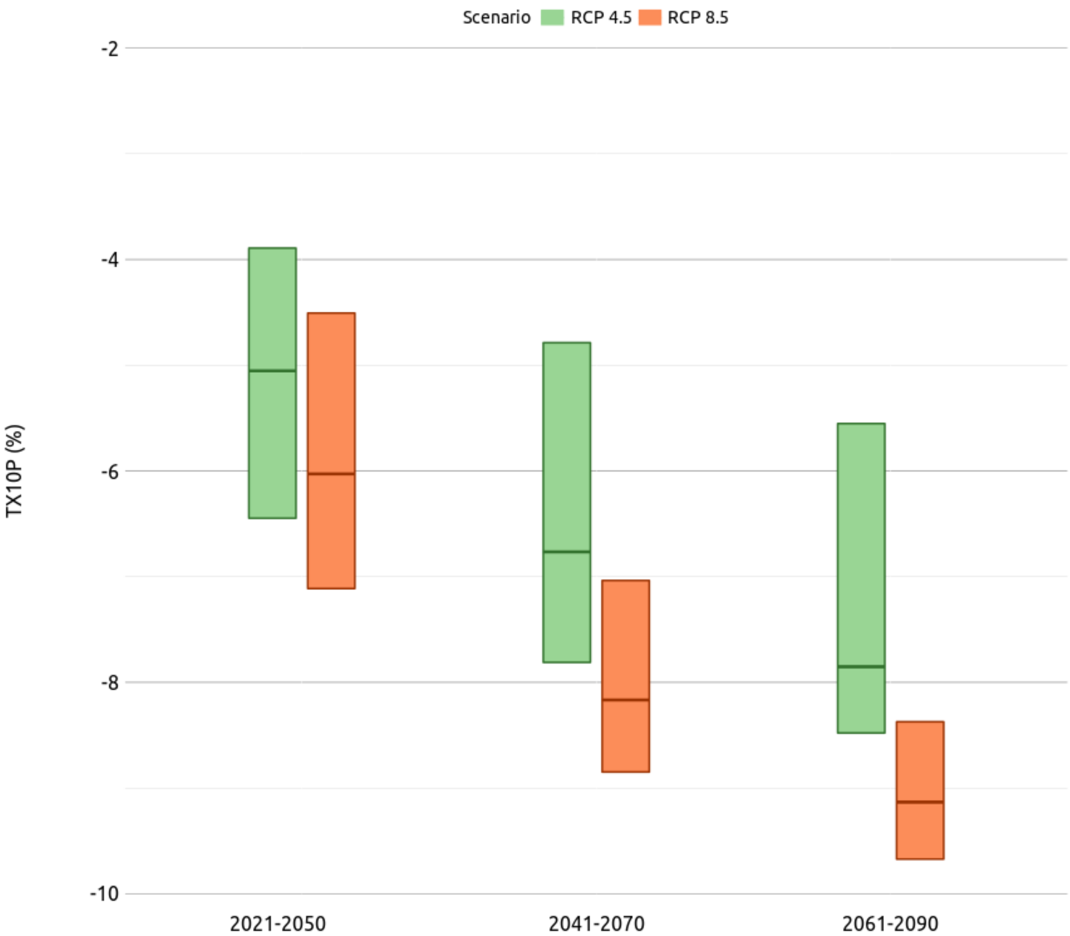


Figure 2.38 - Cold days (TX10P, days). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

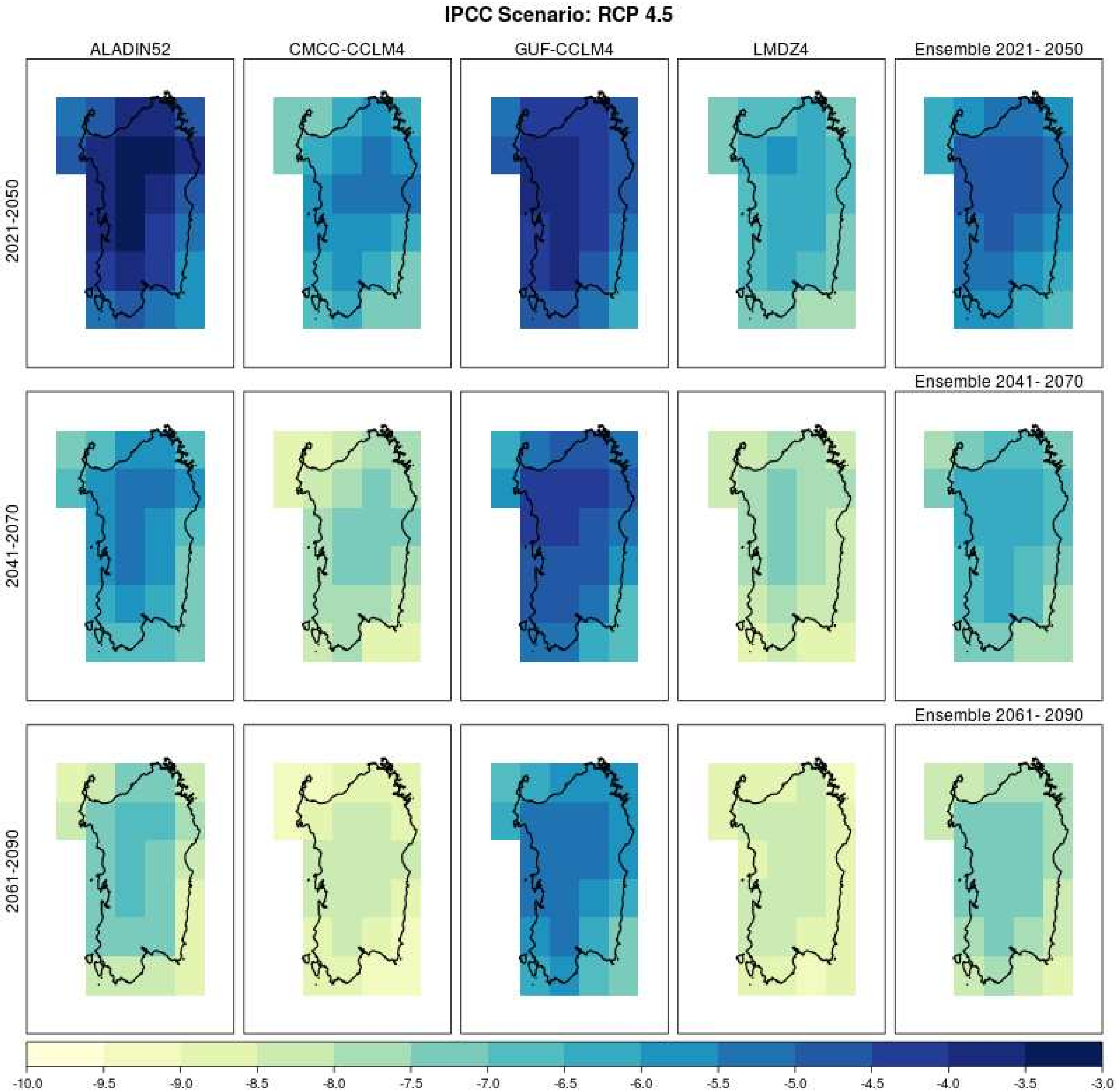


Figure 2.39 - Cold days (%),RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

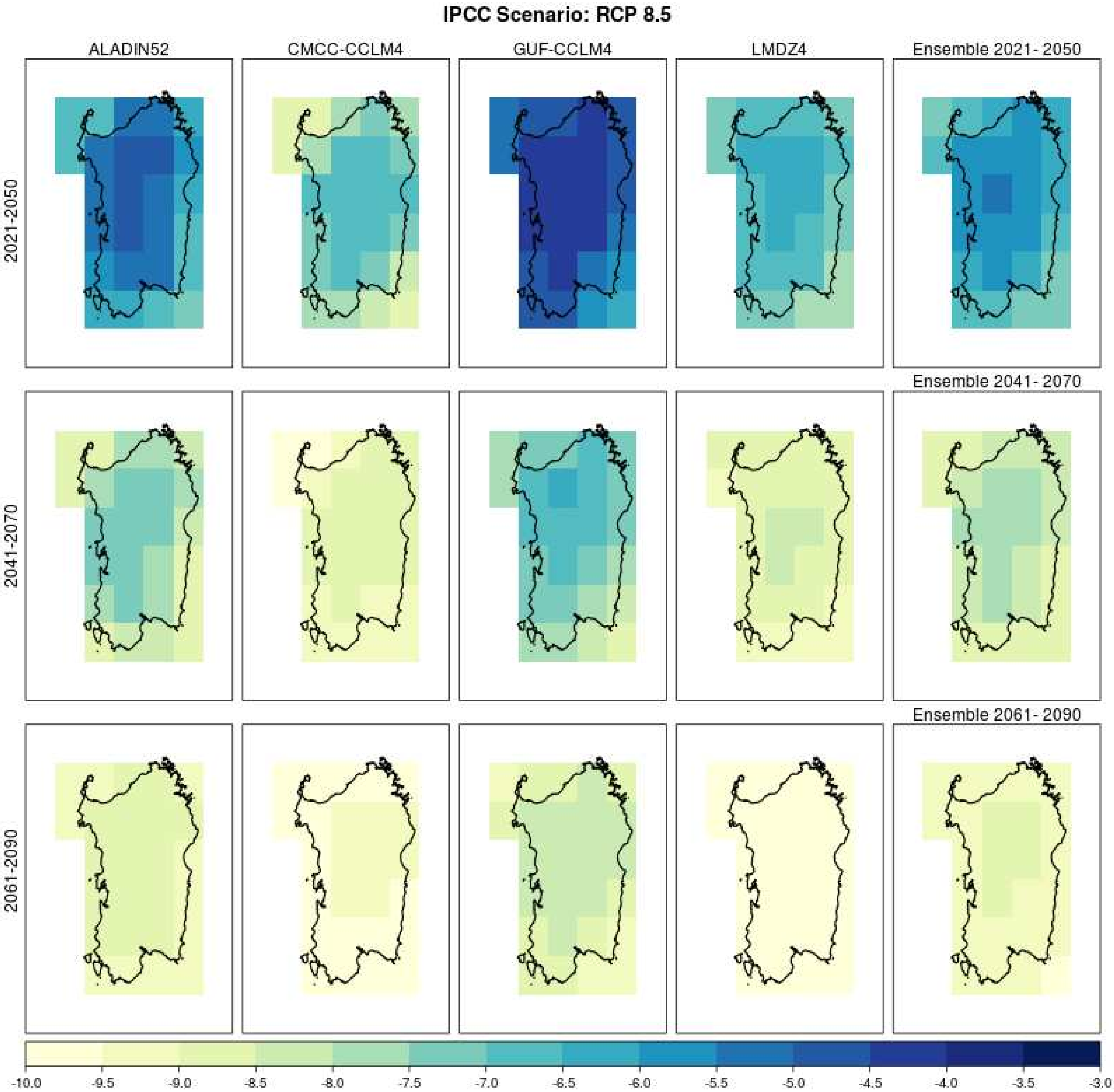


Figure 2.40 - As in figure 2.39, RCP8.5 scenario

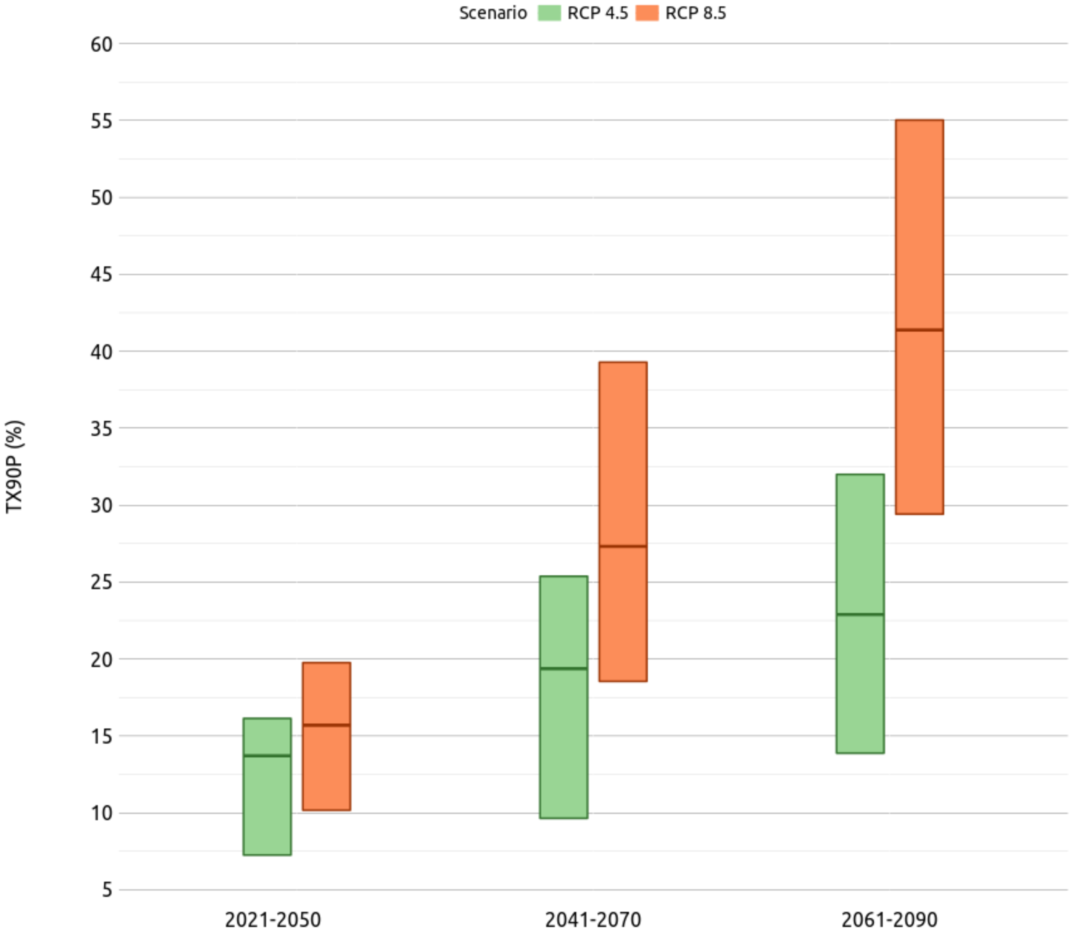


Figure 2.41 - Warm days (TX90P, %). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

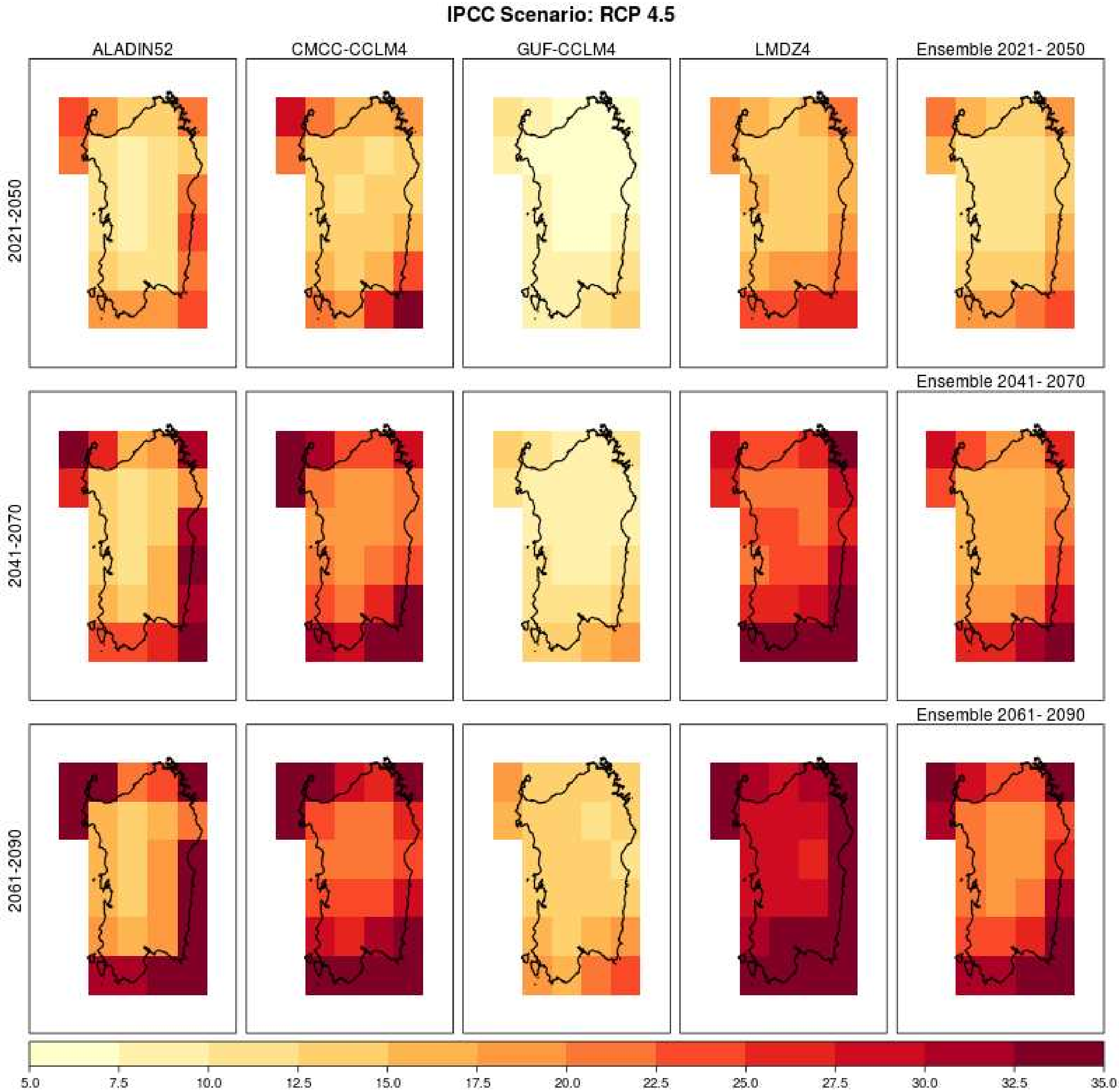


Figure 2.42 - Warm days (%), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

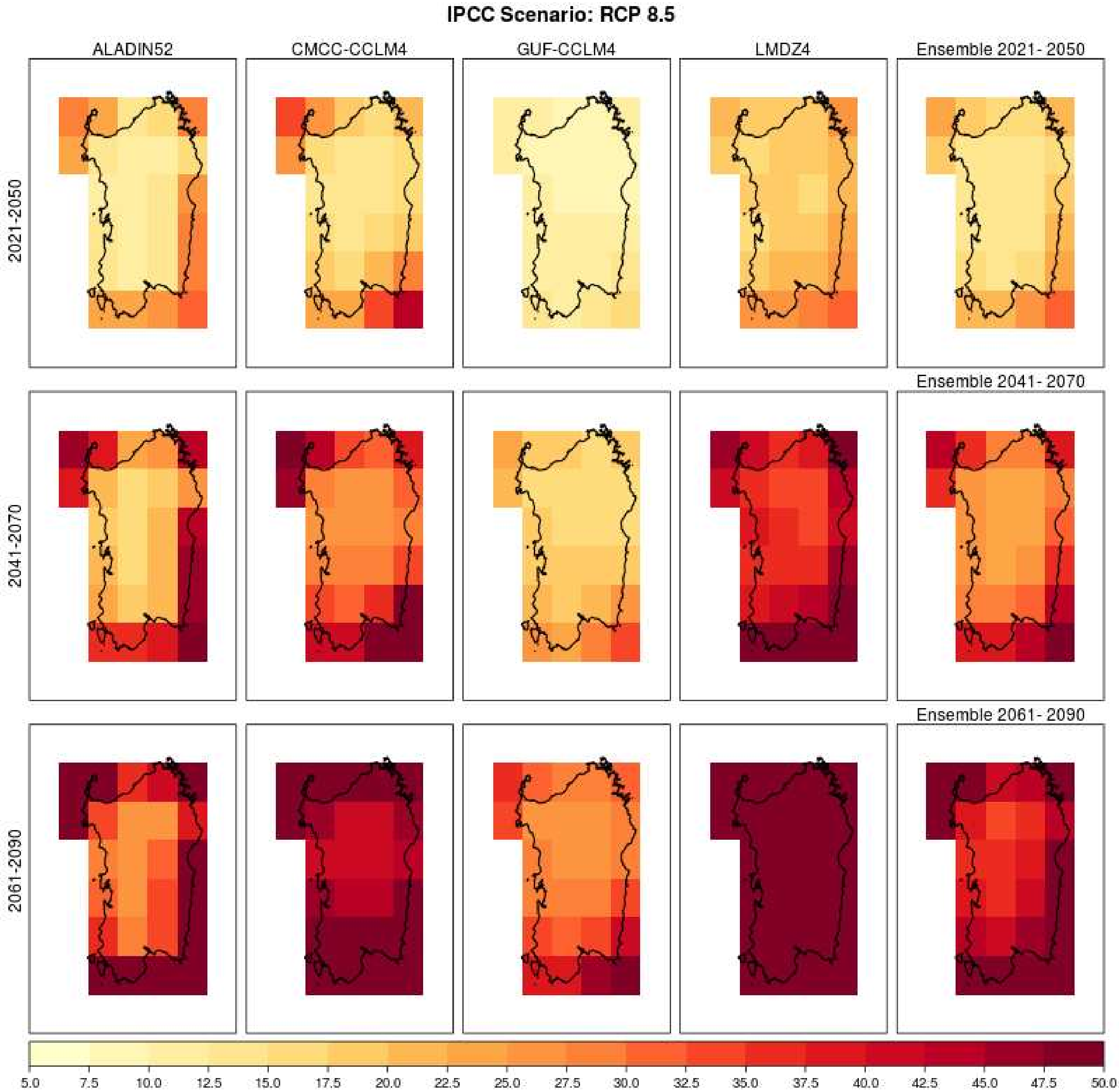


Figure 2.43 - As in figure 2.42, RCP8.5 scenario

Figure 2.44 - Summer days (SU25, days). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

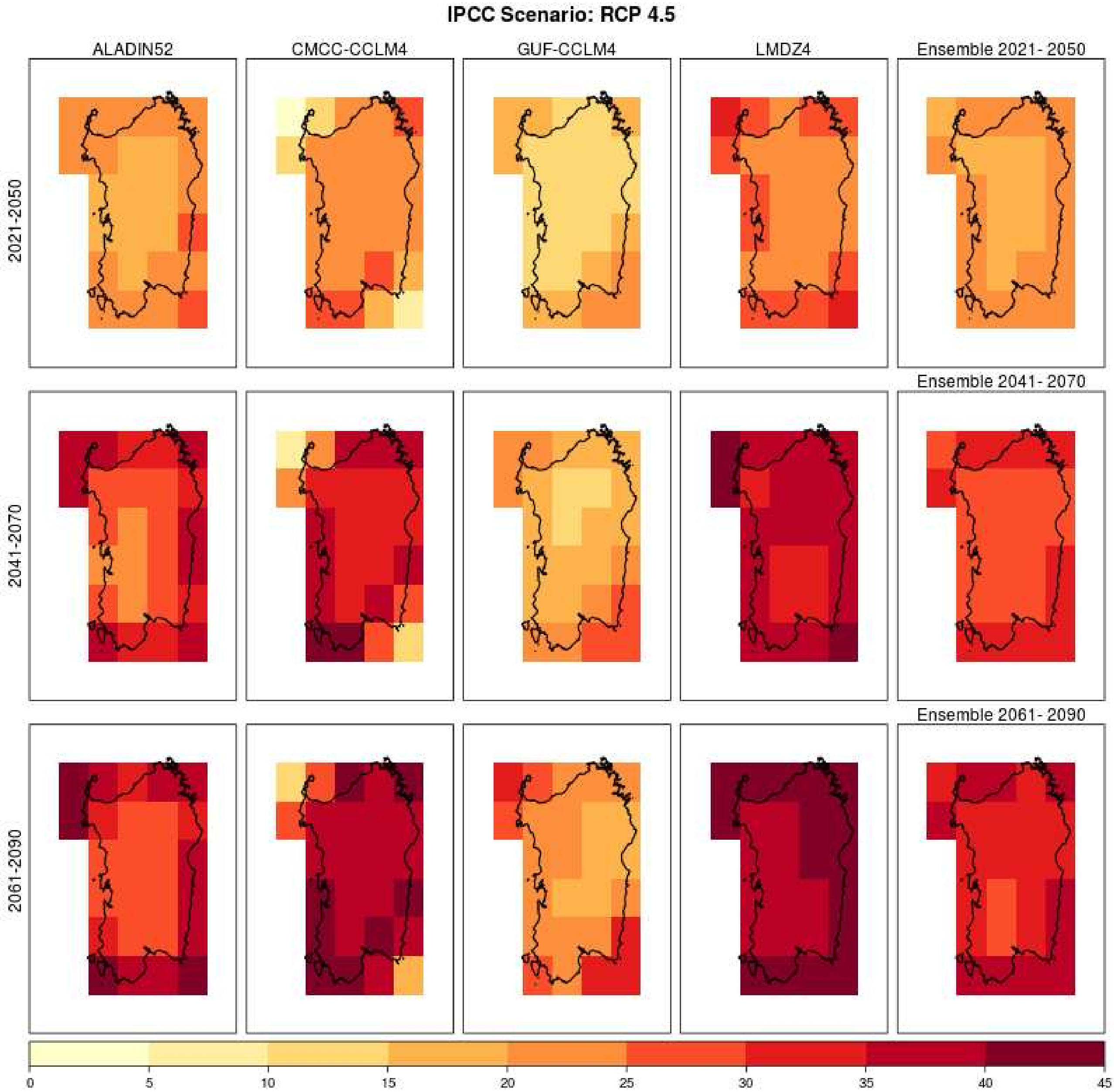


Figure 2.45 - Summer days (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

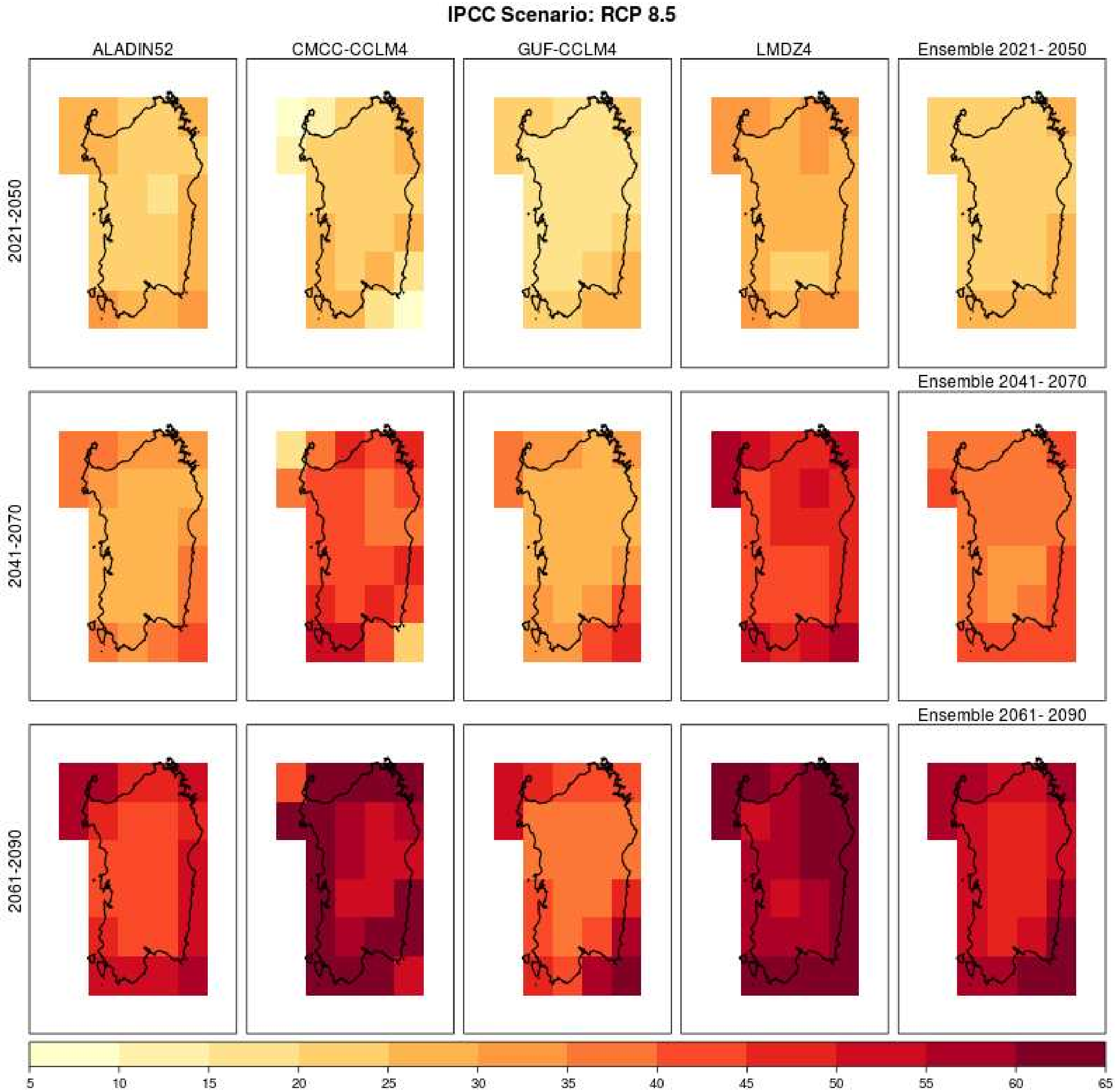


Figure 2.46 - As in figure 2.45, RCP8.5 scenario

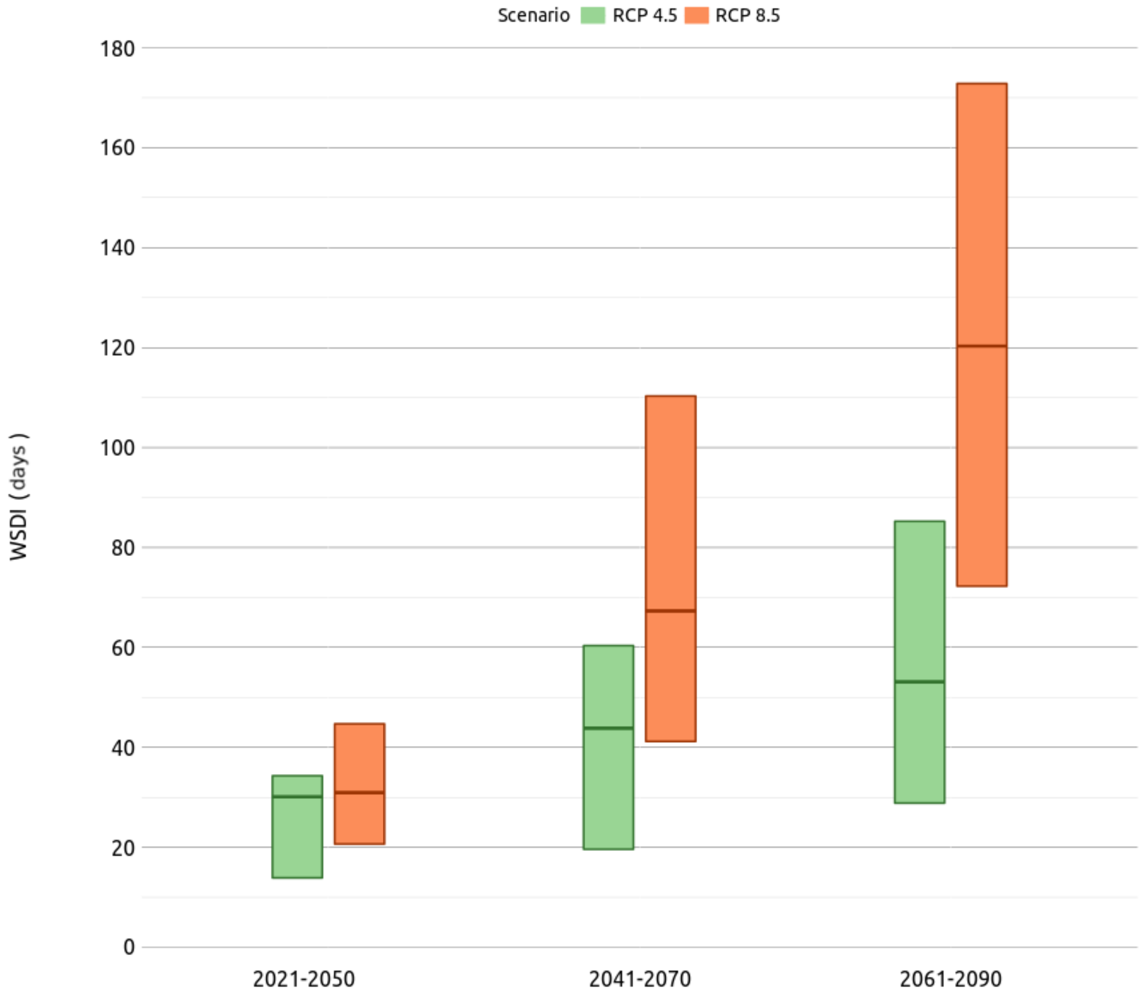


Figure 2.47 - Warm Spell Duration Index (WSDI, days). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenario

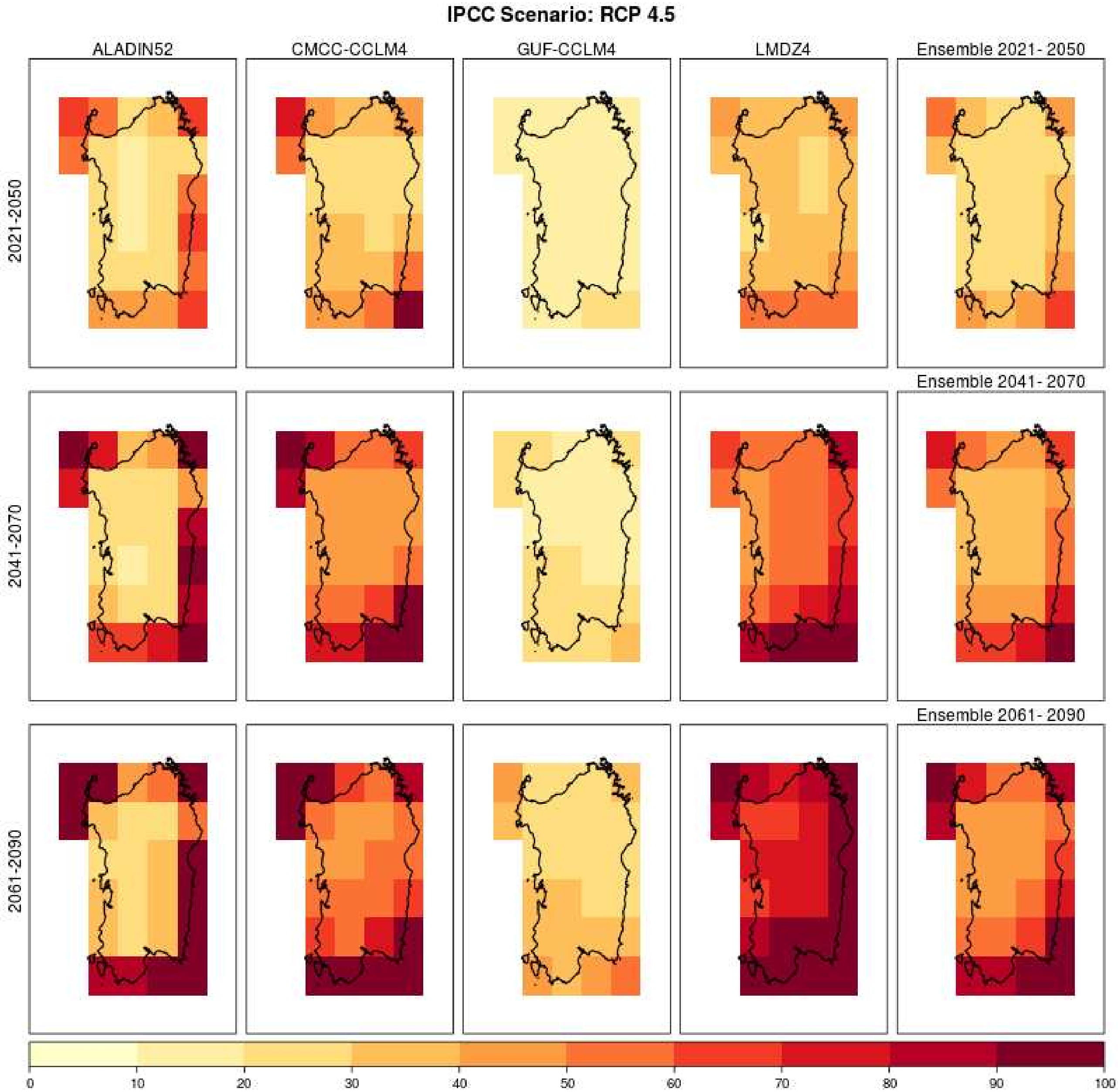


Figure 2.48 - Warm Spell Duration Index (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

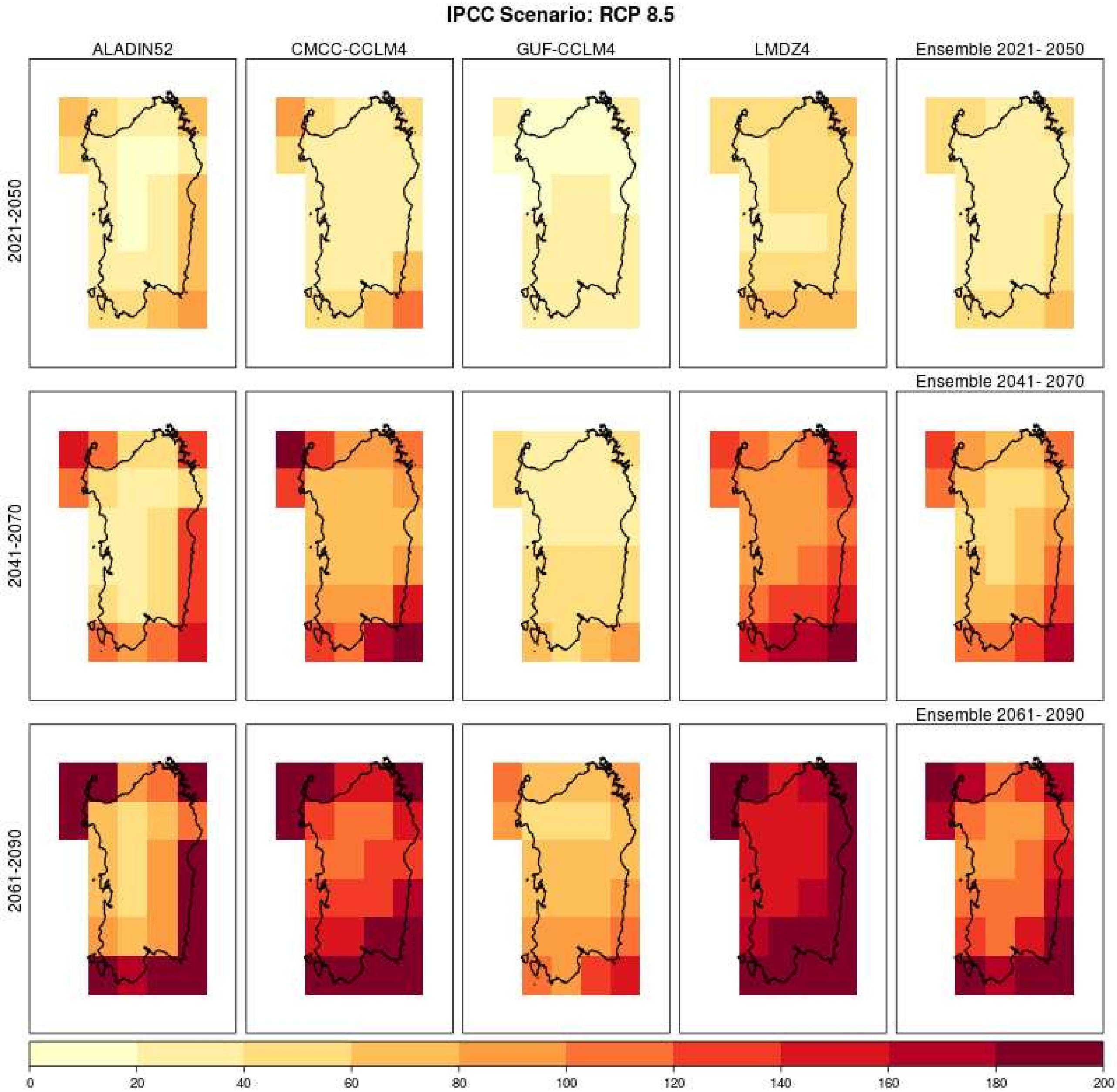


Figure 2.49 - As in figure 2.48, RCP8.5 scenario

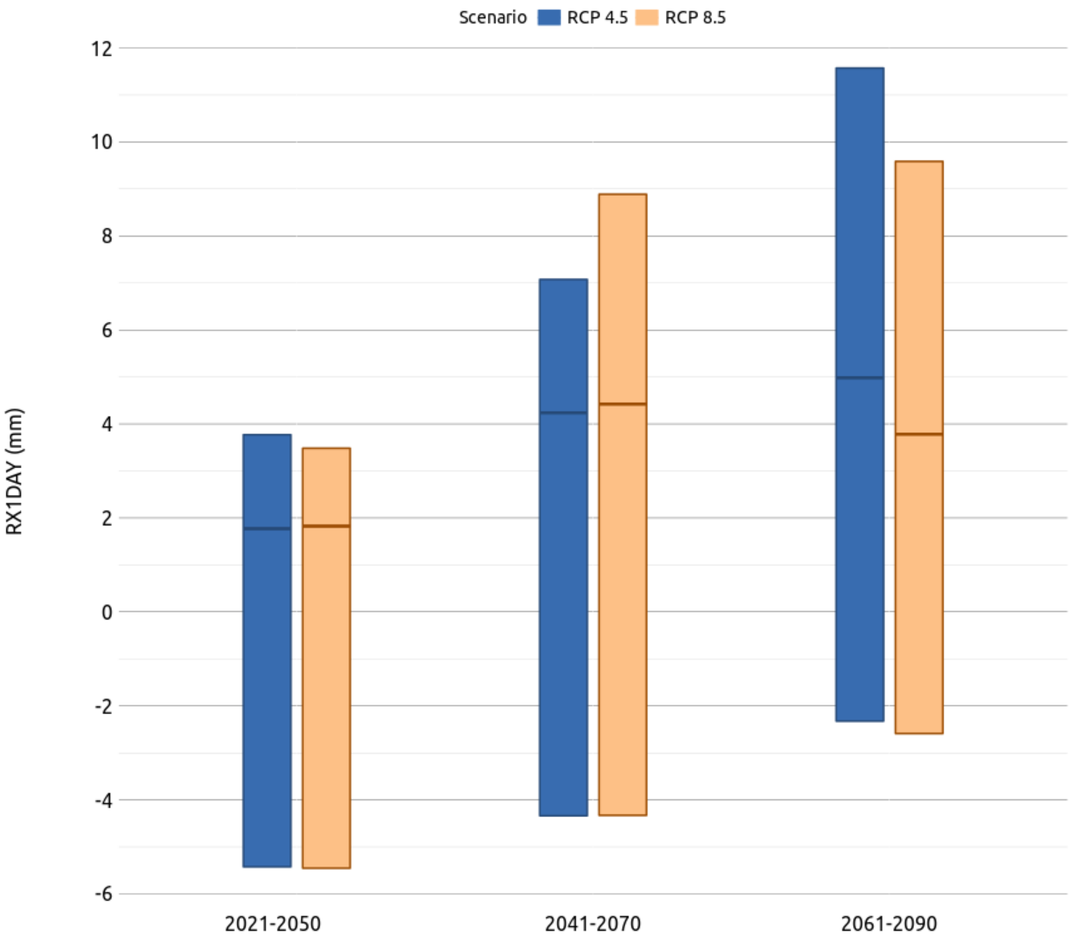


Figure 2.50 - Maximum value of 1-day precipitation (Rx1-day, mm). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

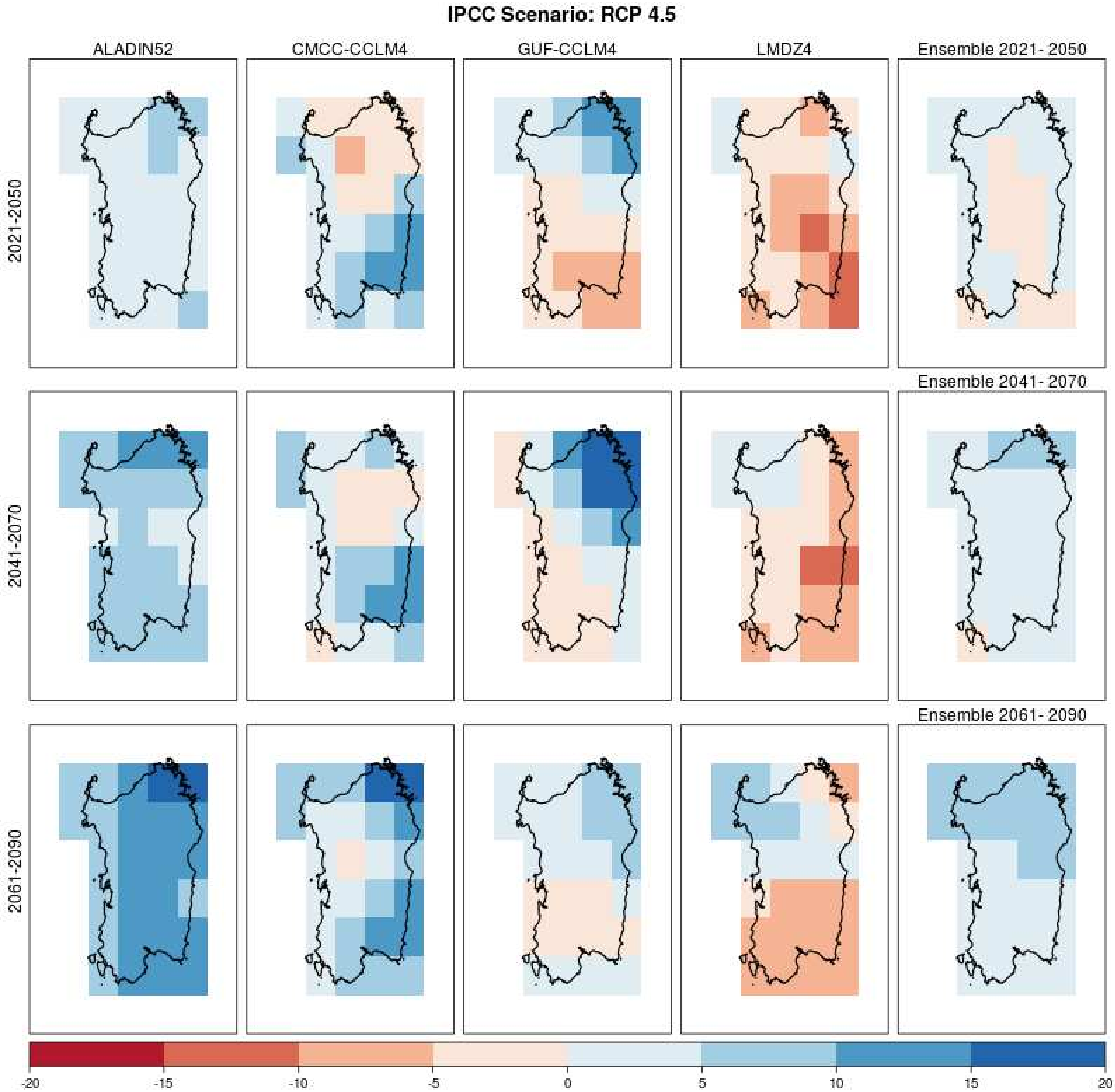


Figure 2.51 - Maximum value of 1-day precipitation (mm), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

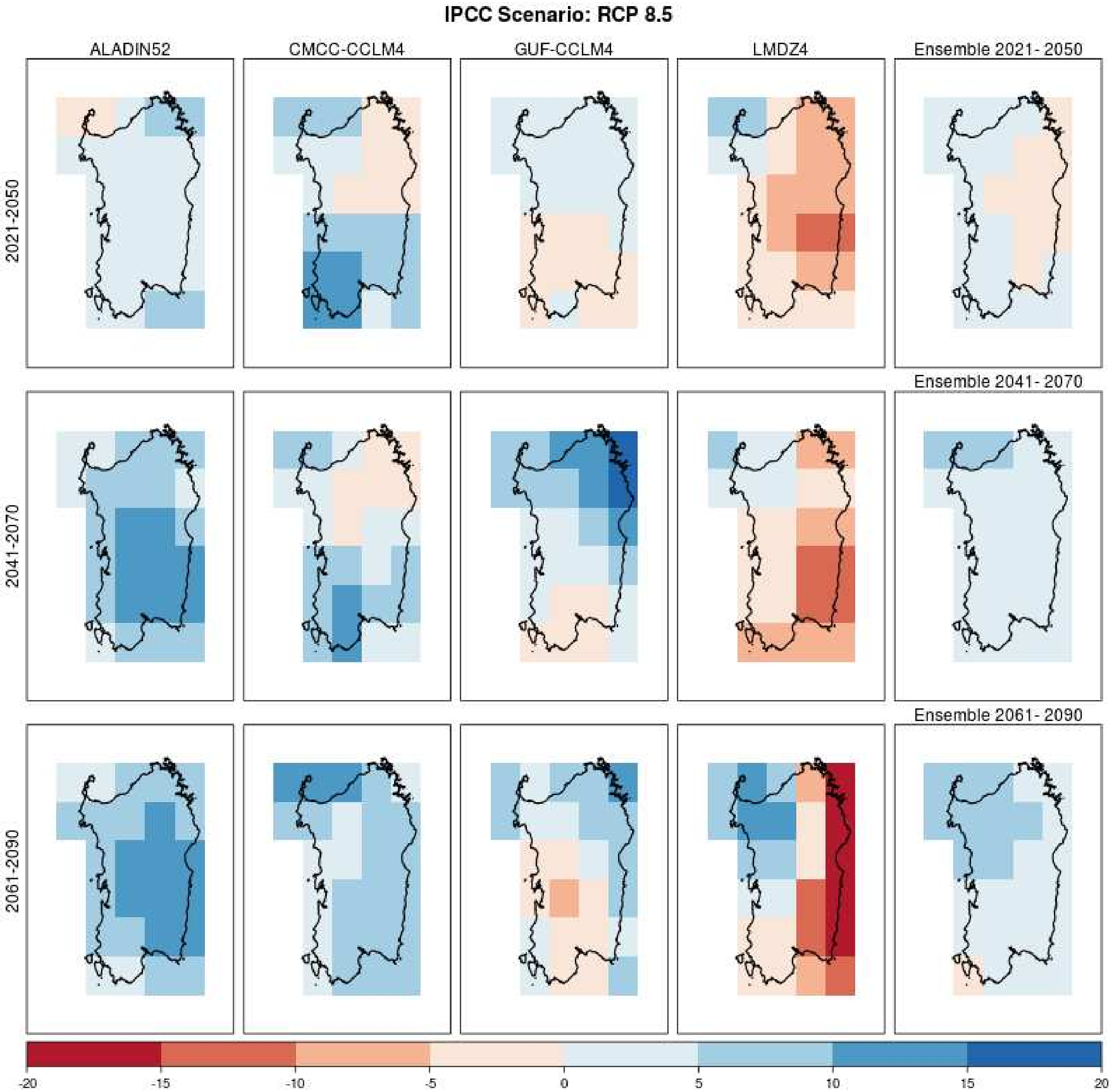


Figure 2.52 - As in figure 2.51, RCP8.5 scenario

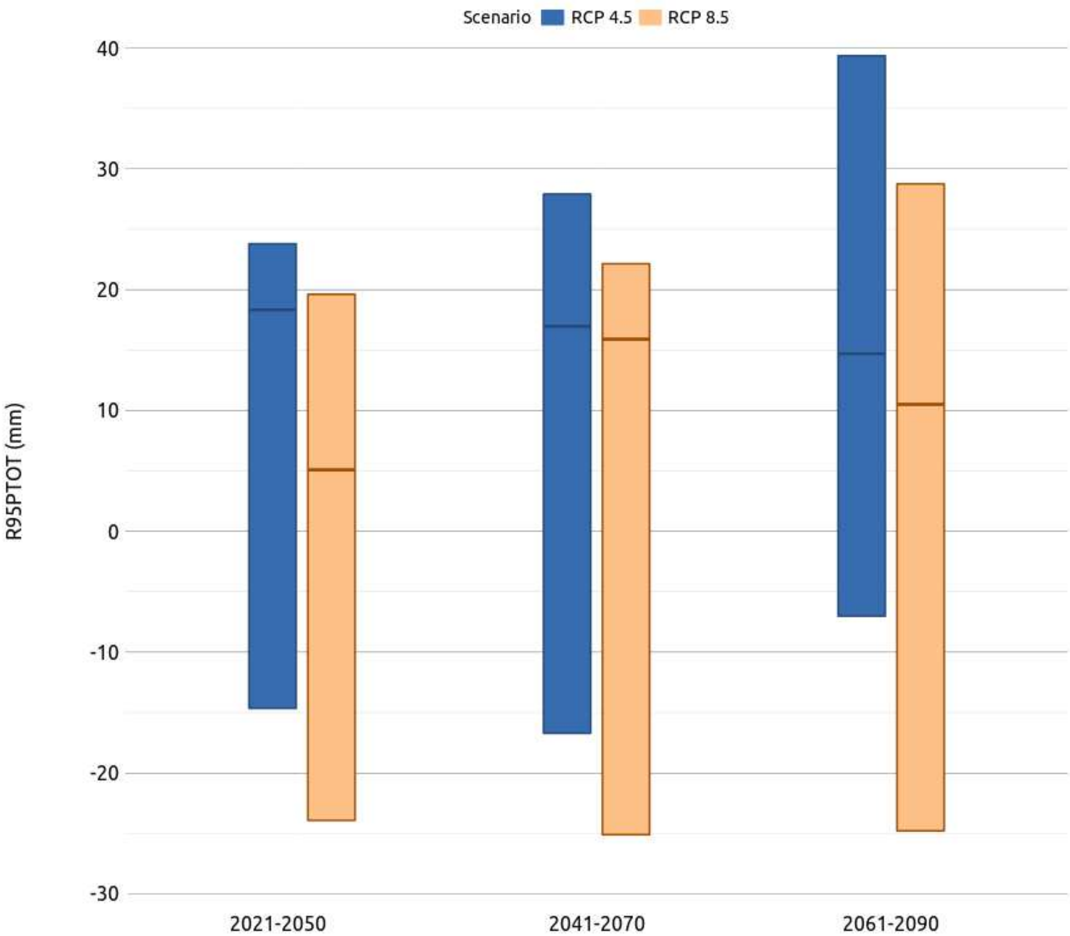


Figure 2.53 - Very wet days (R95P, mm). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

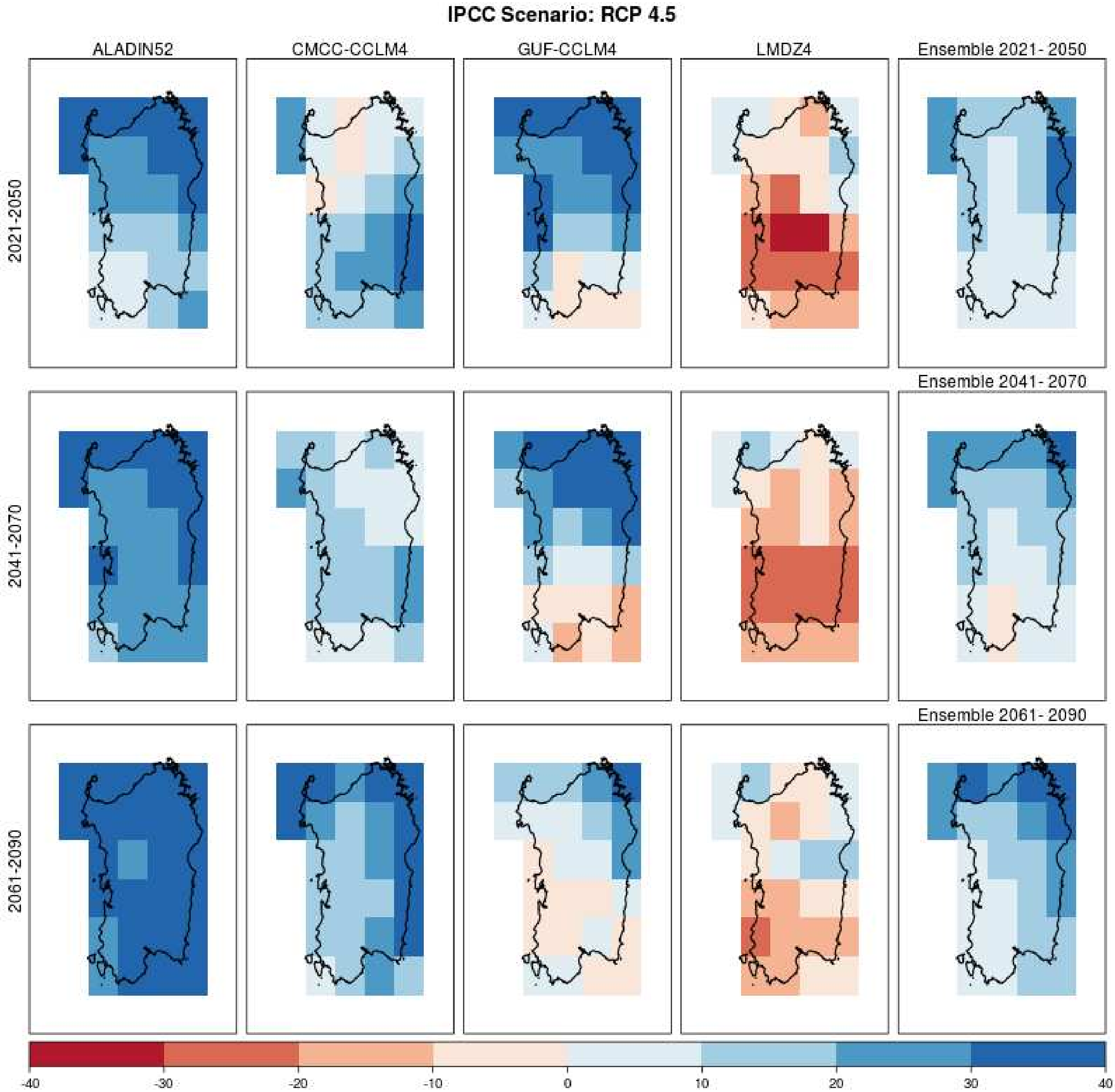


Figure 2.54 - Very wet days (mm), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

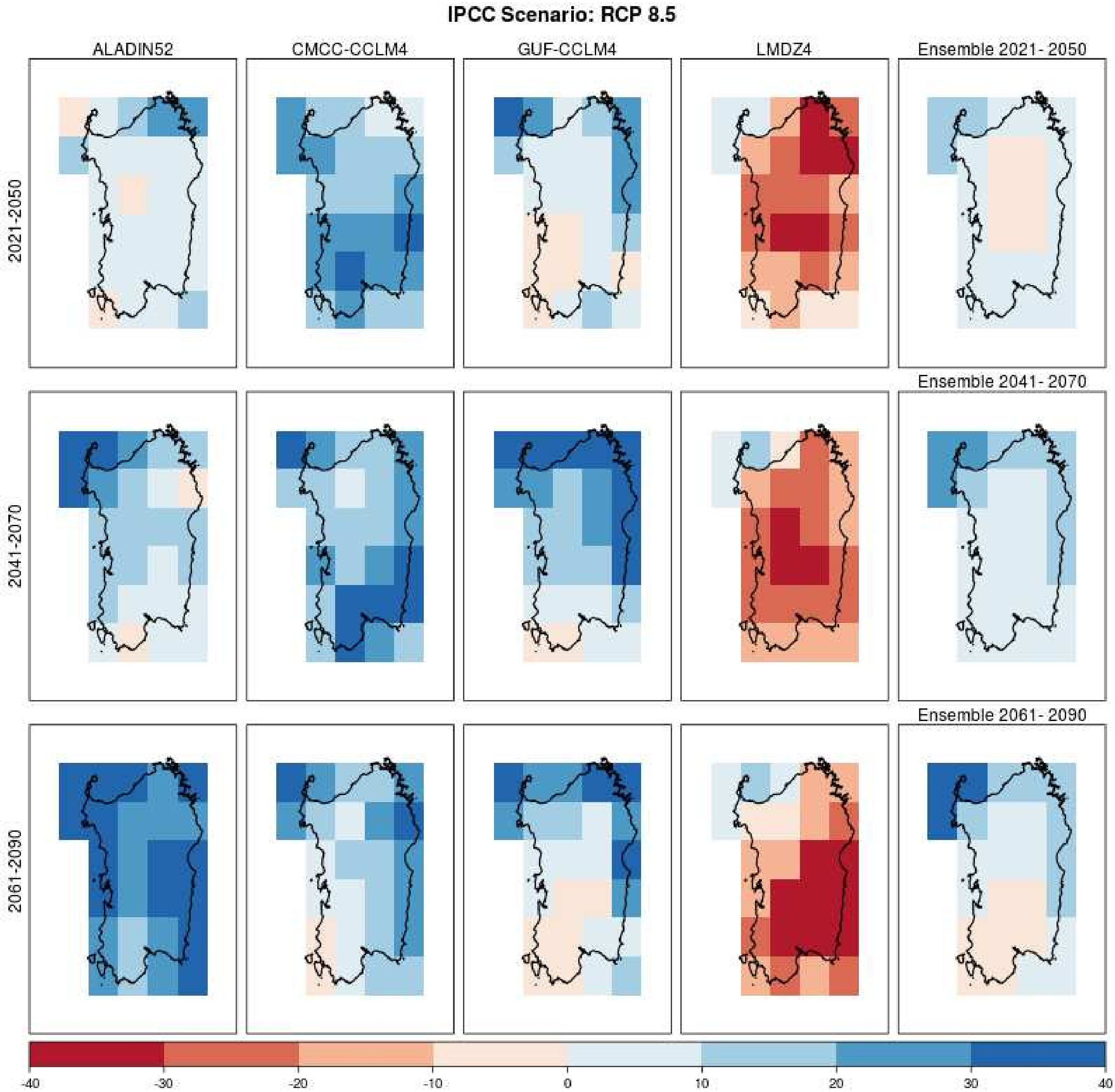


Figure 2.55 - As in figure 2.54, RCP8.5 scenario

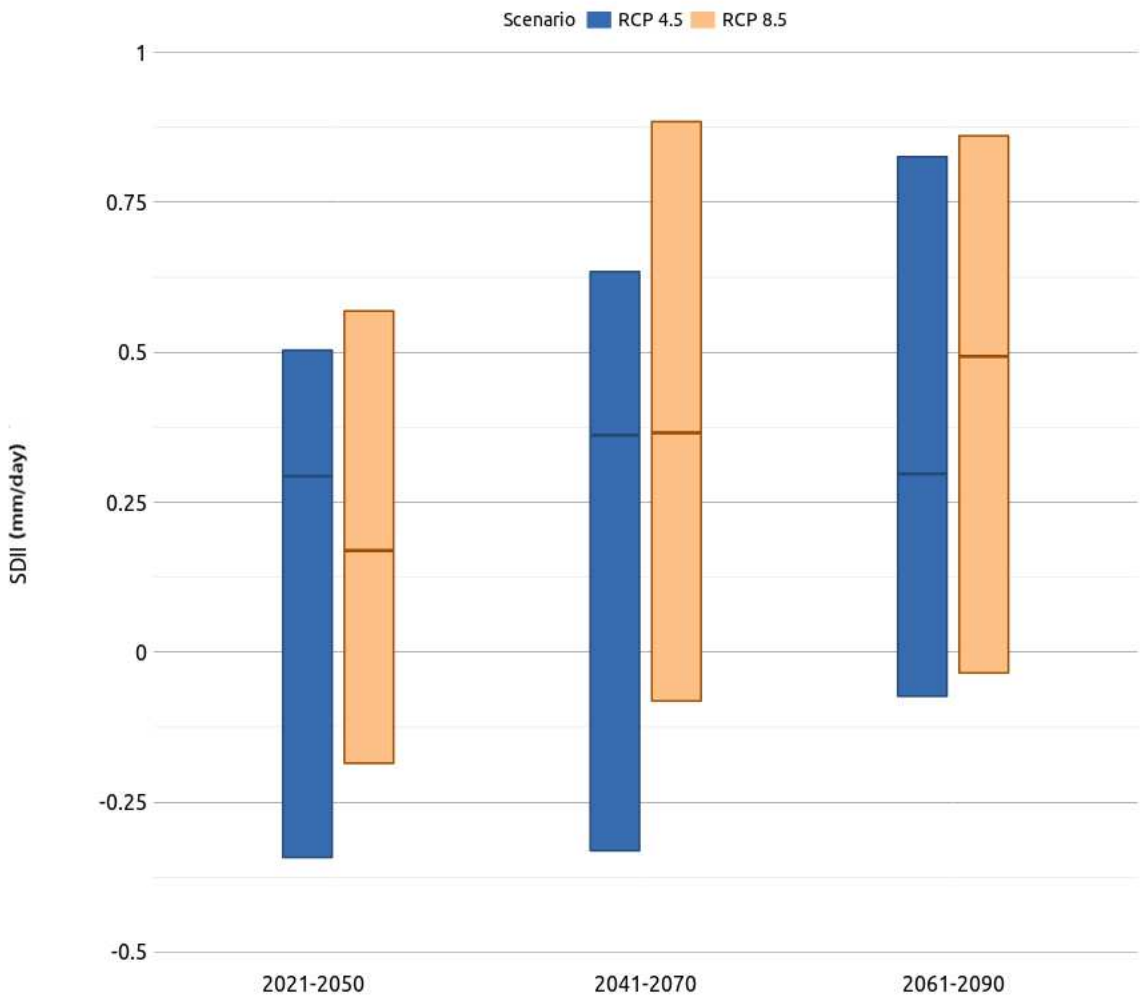


Figure 2.56 - Simple Daily Intensity Index (SDII, mm/day). Expected variations for 2021-2050, 2041-2070 e 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

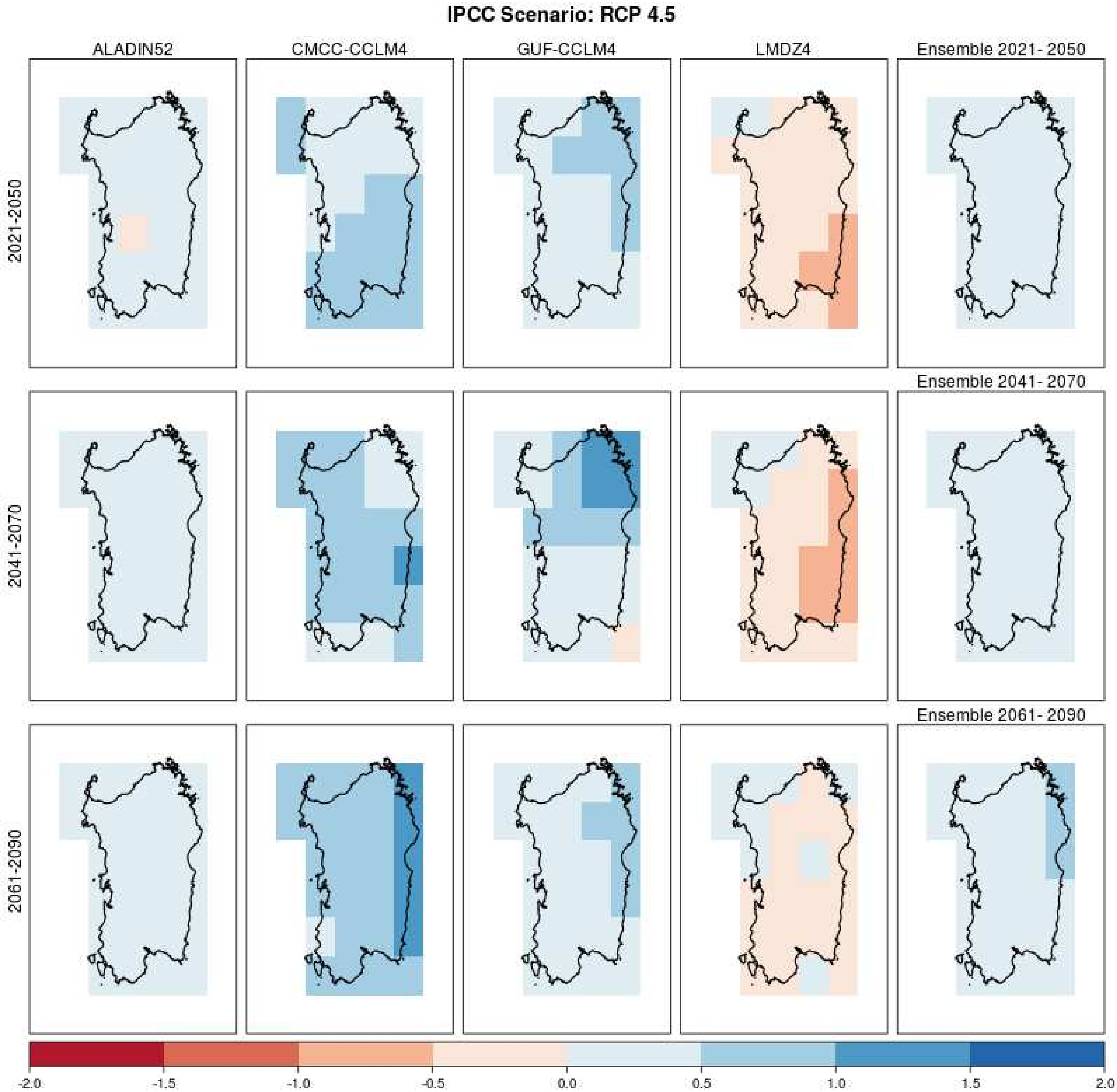


Figure 2.57 - Simple Daily Intensity Index (mm/day), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

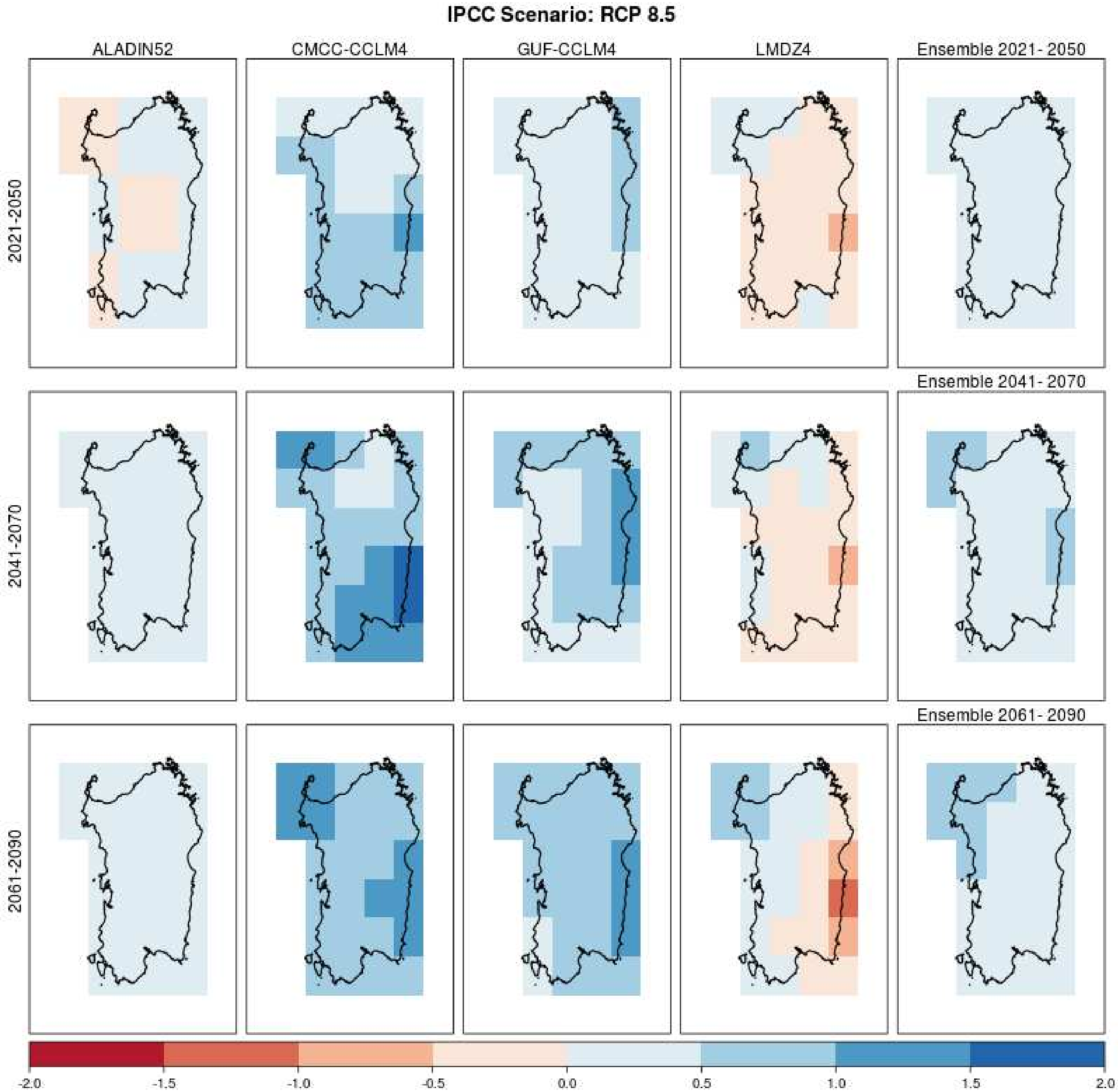


Figure 2.58 - As in figure 2.57, RCP8.5 scenario

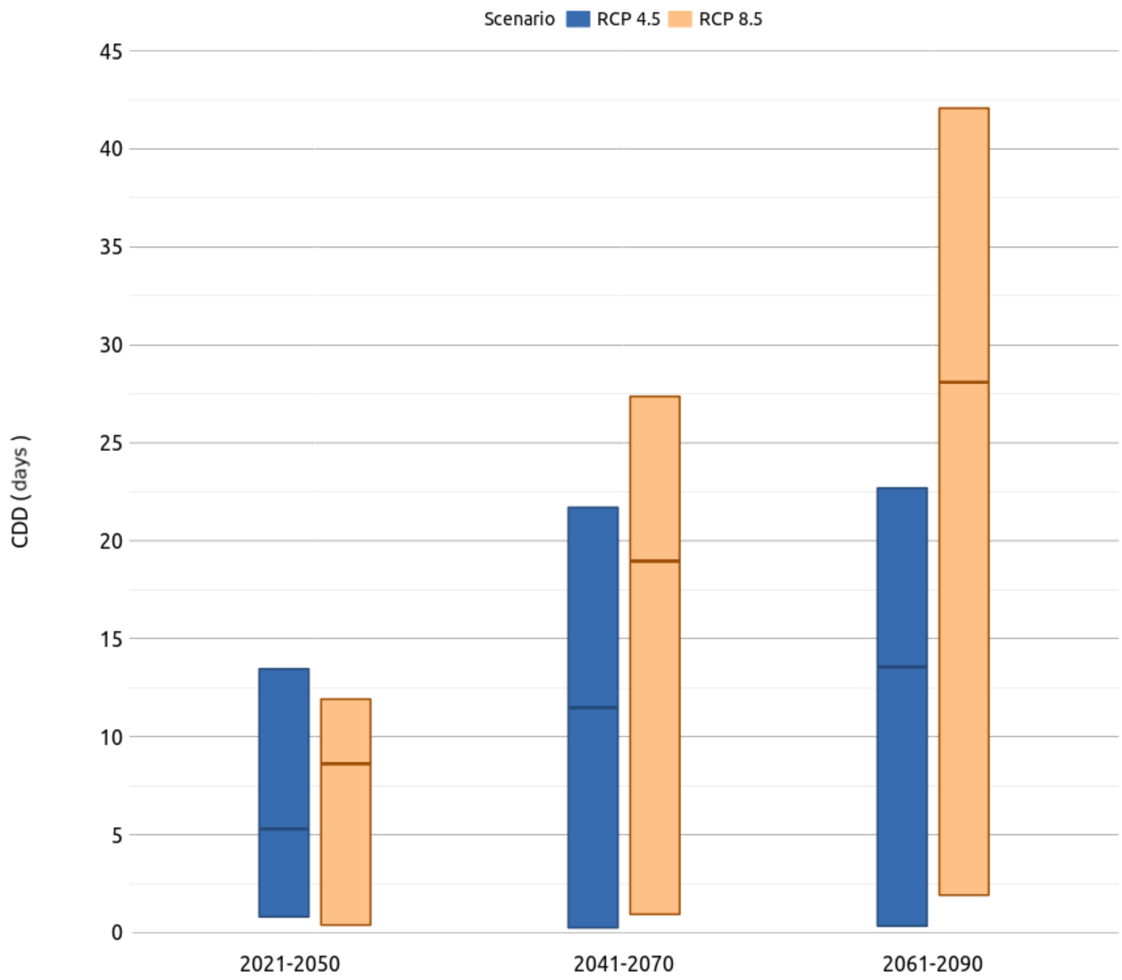


Figure 2.59 - Consecutive Dry Days (CDD, days). Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

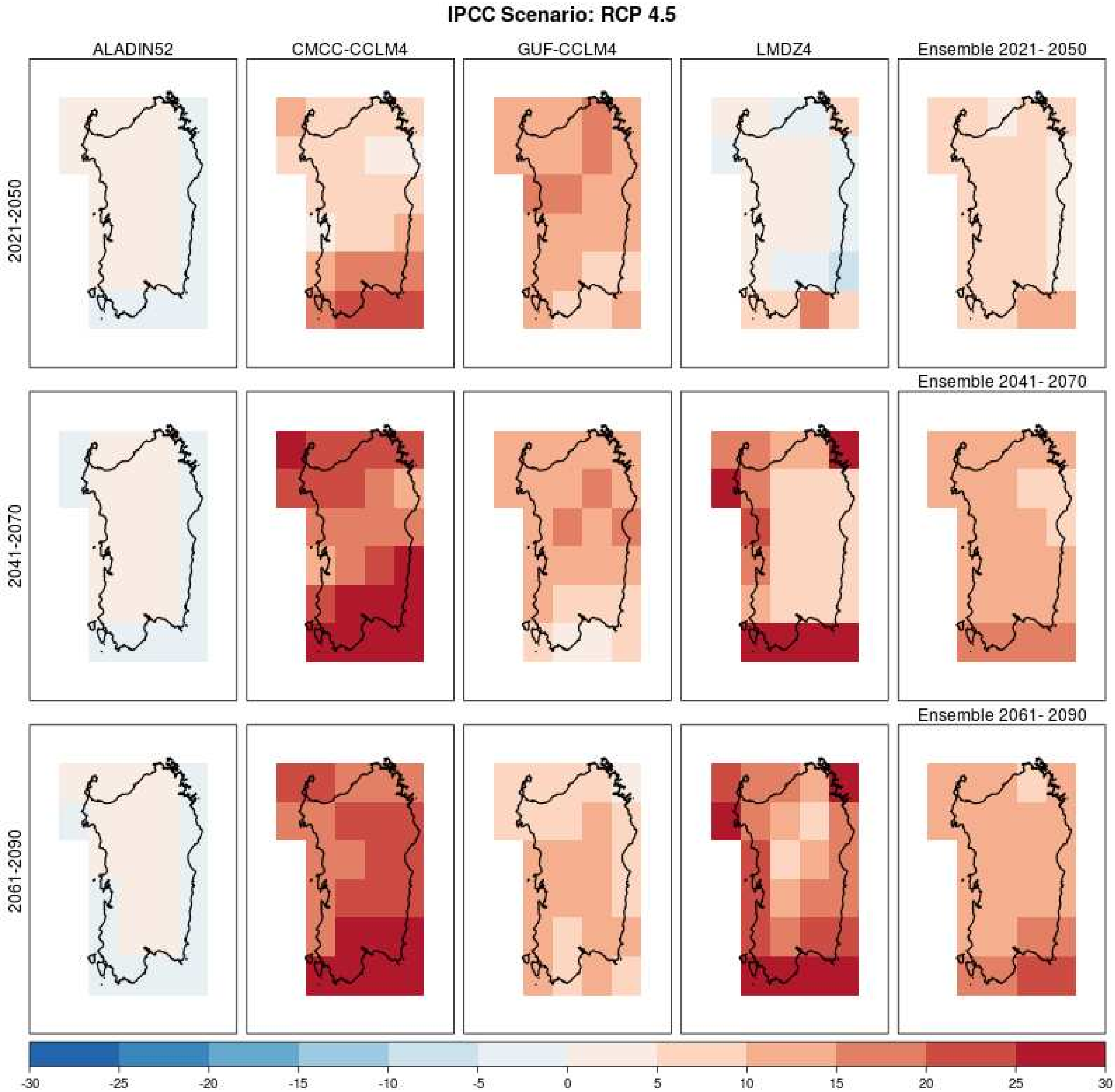


Figure 2.60 - Consecutive Dry Days (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

Figure 2.61 - As in figure 2.60, RCP8.5 scenario

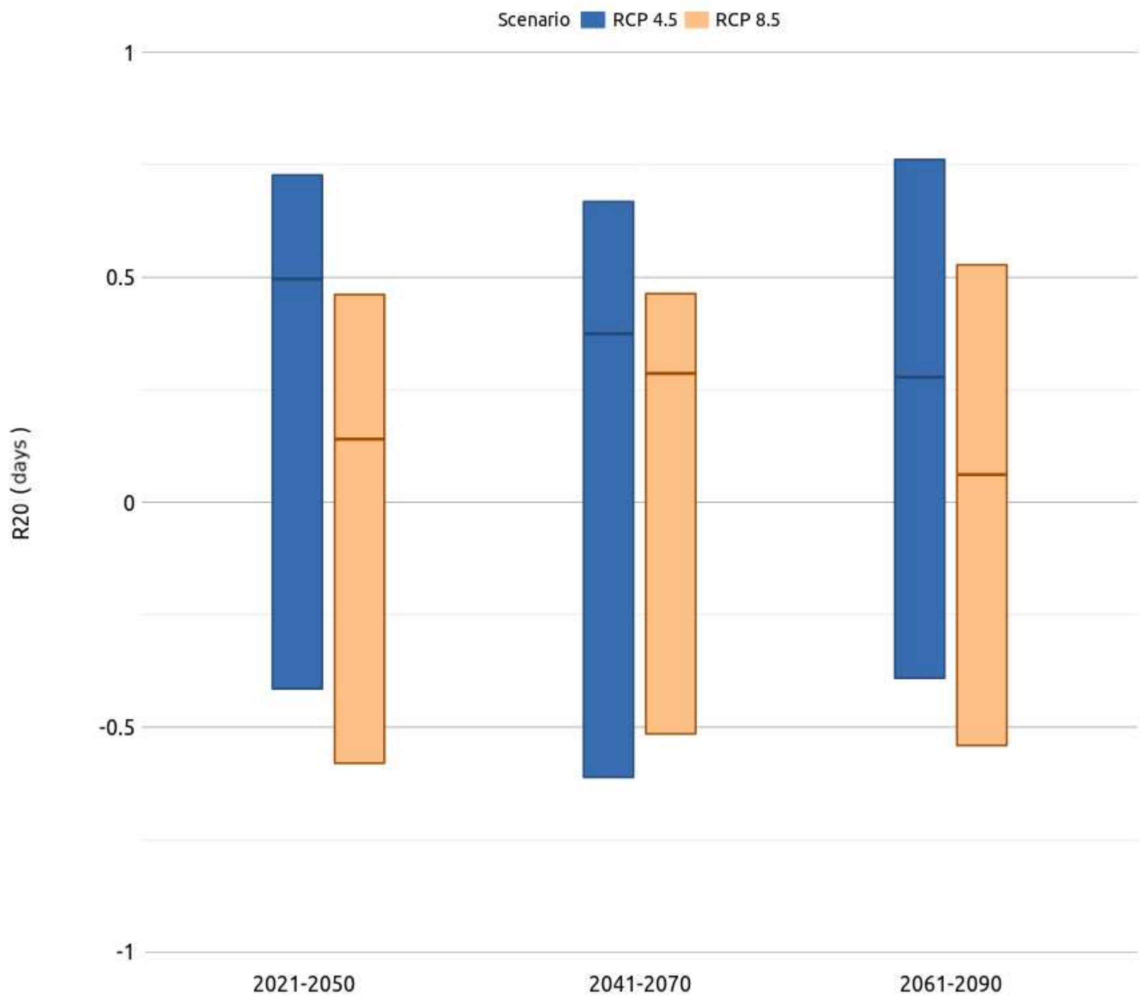


Figure 2.62 - Very heavy precipitation days (R20, days). Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

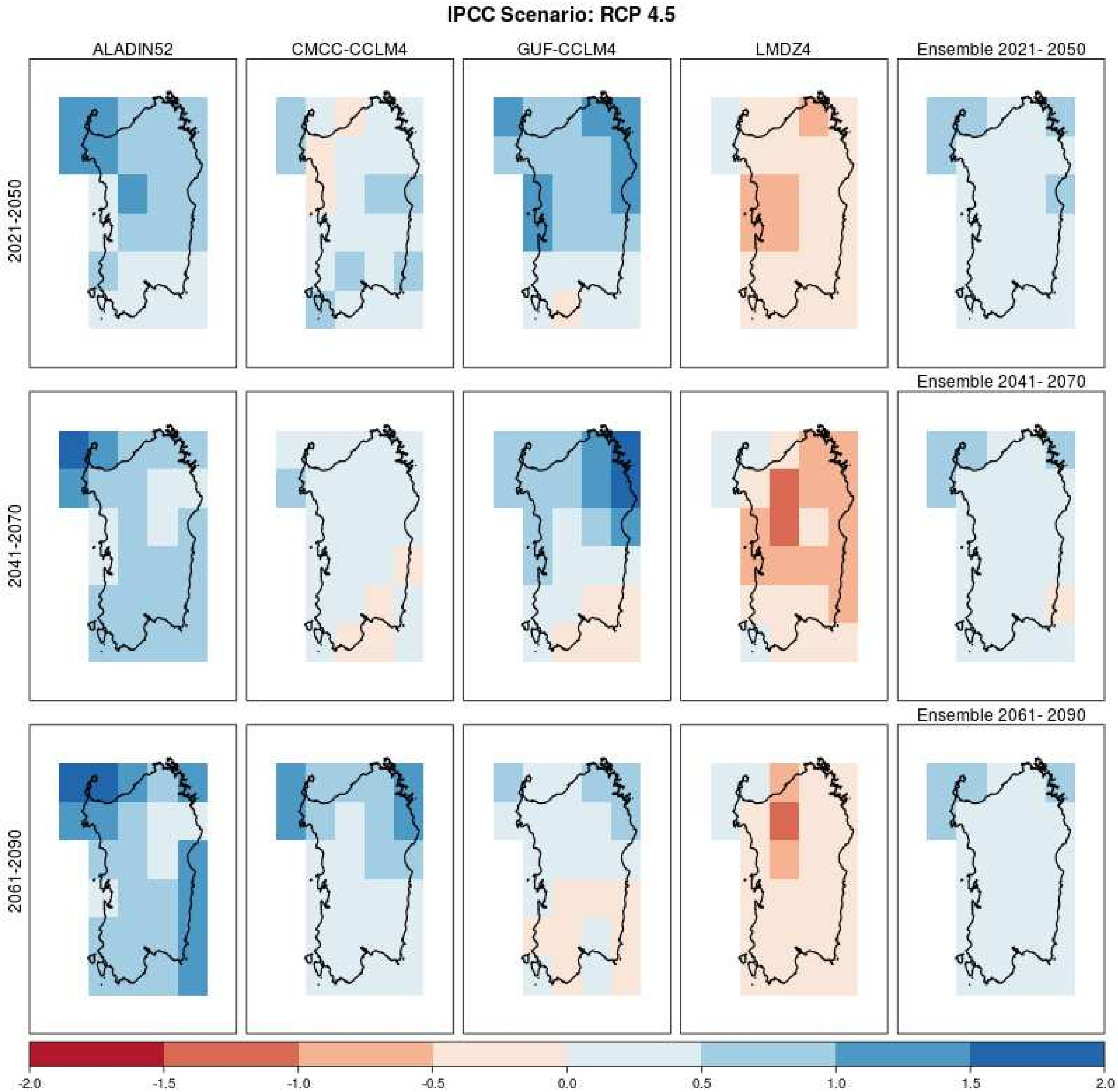


Figure 2.63 - Very heavy precipitation days (days), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

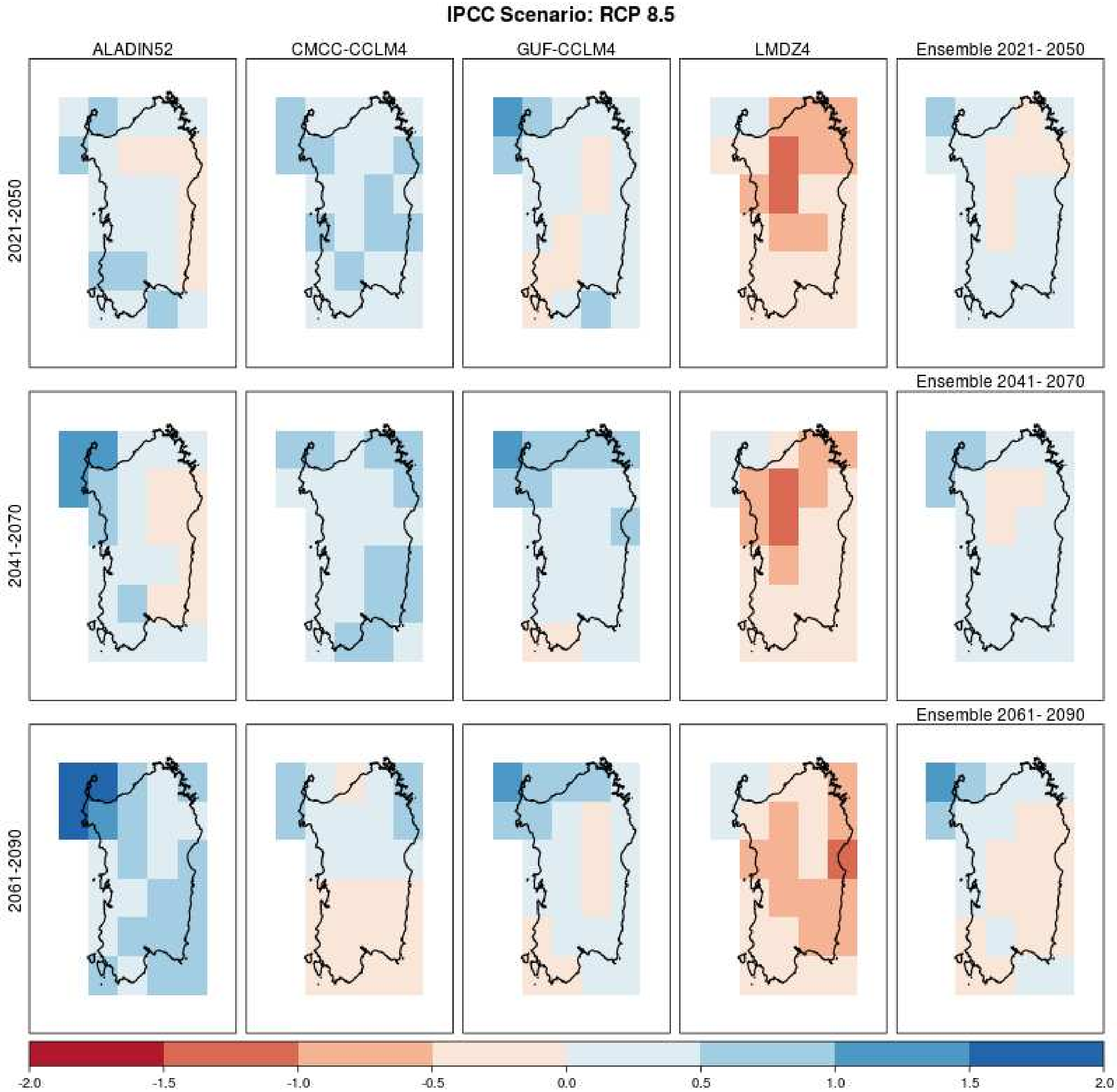


Figure 2.64 - As in figure 2.63, RCP8.5 scenario

Other indices

Future projections of some other indices, usefull for the analysis of vulnerability, were also examined (Table 2.9): the total summer precipitation (SP), the aridity index (AI) and the growing degree days (GDD). With reference to the aridity index, the potential evapotraspiration was estimated using the Hargreaves equation (Shahidian et al., 2012). The GDD index was evaluated for six different temperature base values: Tb= 0°C, Tb= 2°C, Tb= 4°C, Tb= 6°C, Tb= 8°C, Tb=10°C.

Index	Definition	Unit
SP (Summer Precipitation)	Summer precipitation amount (Jun, July, Aug)	mm
AI (Aridity Index)	AI=(P/ETp) P = mean annual precipitation ETp = potential evapotranspiration	dimensionless index
GDD* (Growing Degree Days)	Annual sum of TM - T_b (where TM= mean temperature and T_b is a user-defined location-specific base temperature and TM >T_b)	°C

Table 2.9 - Additional indices selected for the analysis of future climate

Future projections of these additional indices were computed for the three time frames 2021-2040, 2041-2070, 2061-2090, as performed for the extreme ETCCDI indices.

The mean variations of summer precipitation amount over Sardinia with respect to the 1971-2000 reference mean, is reported in Figure 2.65. The ensemble mean indicates a future reduction of summer precipitation at each time frame, however the model projected variations range from negative to positive values. For 2061-2090 the expected changes range between -25.7 and +7.3 mm under RCP4.5 and between -42.6 and +13.4 under RCP8.5 scenario. The spatial distribution of the projected variation is shown in Figure 2.66 and Figure 2.67, respectively for RCP4.5 and RCP8.5 scenarios.

The analysis of the aridity index is reported in Figure 2.68 - Figure 2.70. The maps of the historical simulations relative to 1971-2000 (Figure 2.68) indicate differences among models. The simulations range from a prevalence of “semi-arid” areas to a prevalence of “humid” zones. The ensemble mean characterizes almost all the Sardinia region as “semi-arid”, with the exception of some north-western and south-eastern areas, which are “dry sub-humid”. Future projections of the Aridity Index (Figure 2.69 for RCP4.5 and Figure 2.70 for RCP8.5) do not highlight clear evidence of variations, showing an “arid” index over the whole Sardinia region, under both the RCPs. One model predicts a small “hyper-arid” zone in the south, under both the RCPs. A larger “hyper-arid” area is projected by 2061-2090 under RCP8.5 scenario.

Finally the Growing Degree Days index, estimated for different temperature base values (T_b), show a general increase respect to the 1971-2000, under both the RCP scenarios. The obtained results are shown from Figure 2.71 to Figure 2.88 for Tb= 0°C, Tb= 2°C, Tb= 4°C, Tb= 6°C, Tb= 8°C, Tb=10°C.

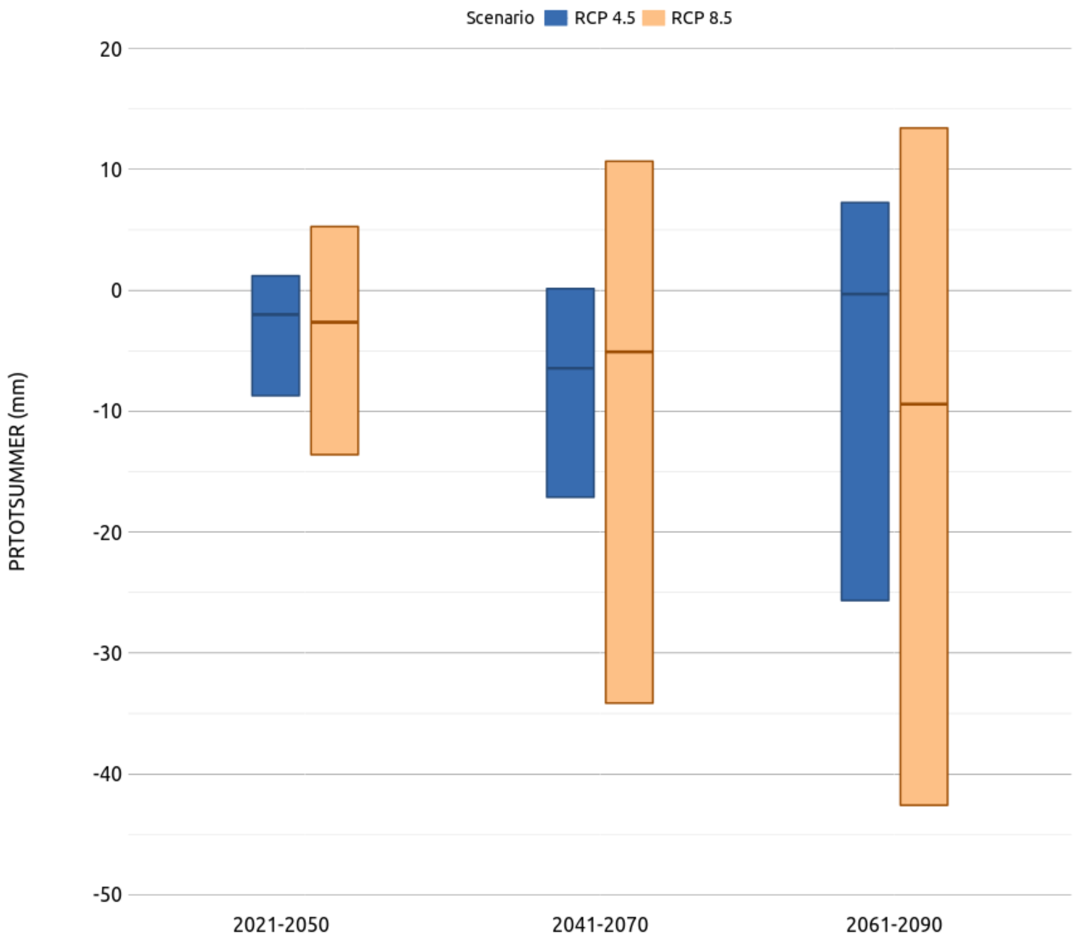


Figure 2.65 - Summer precipitation (SP, mm). Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

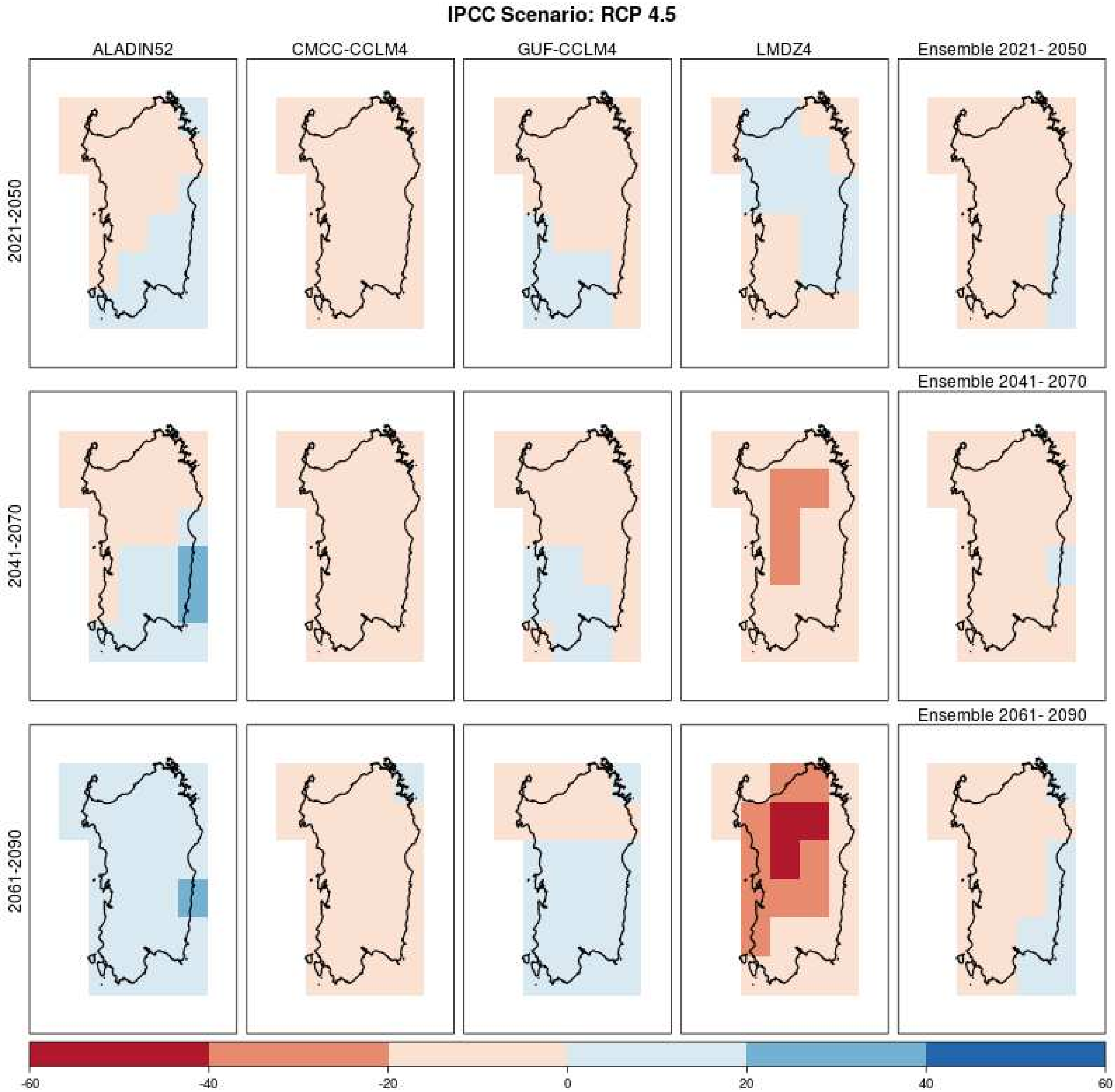


Figure 2.66 - Summer precipitation (mm), RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

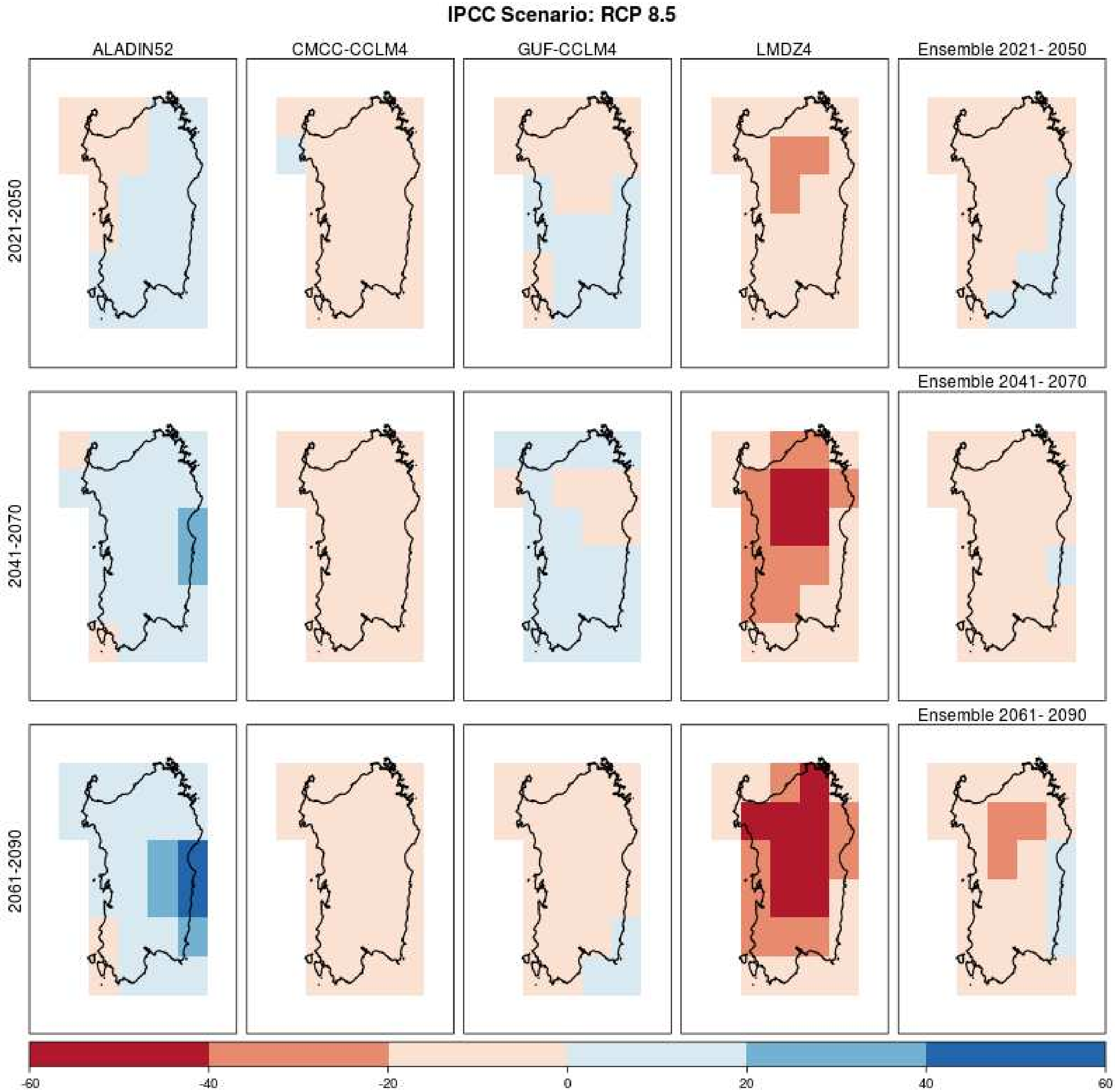
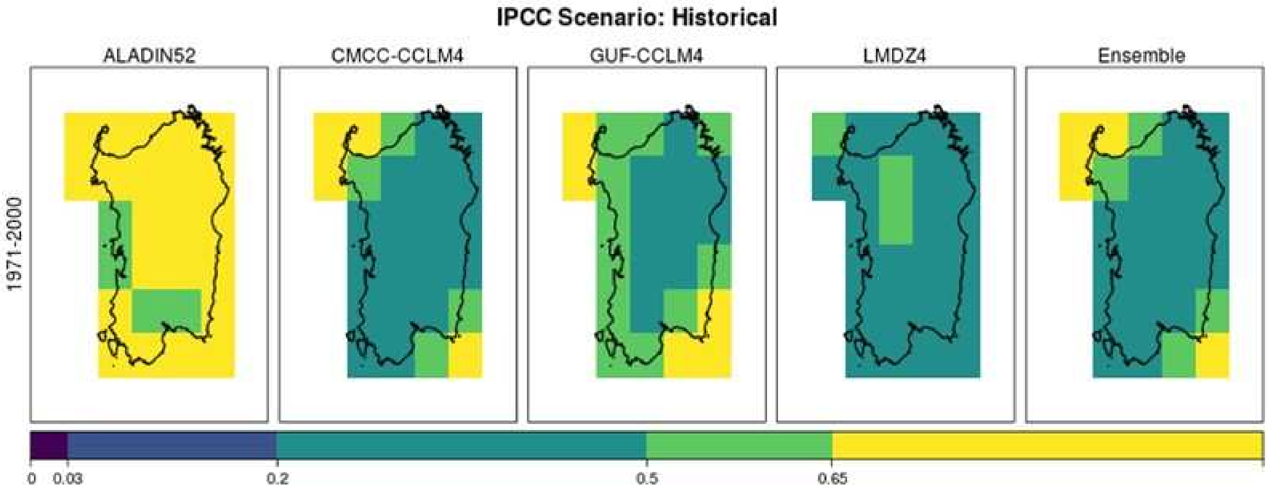
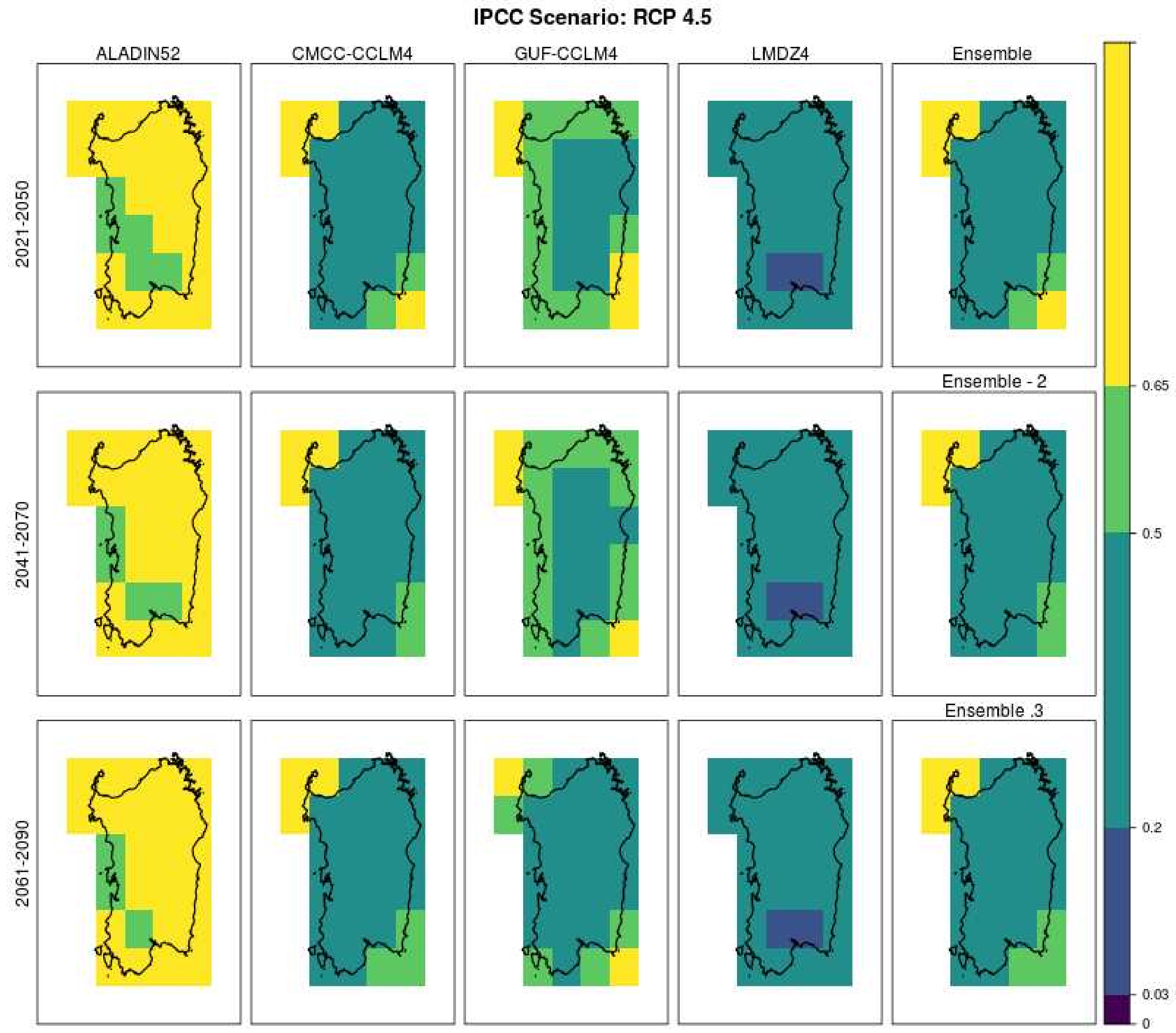


Figure 2.67 - As in figure 2.66, RCP8.5 scenario



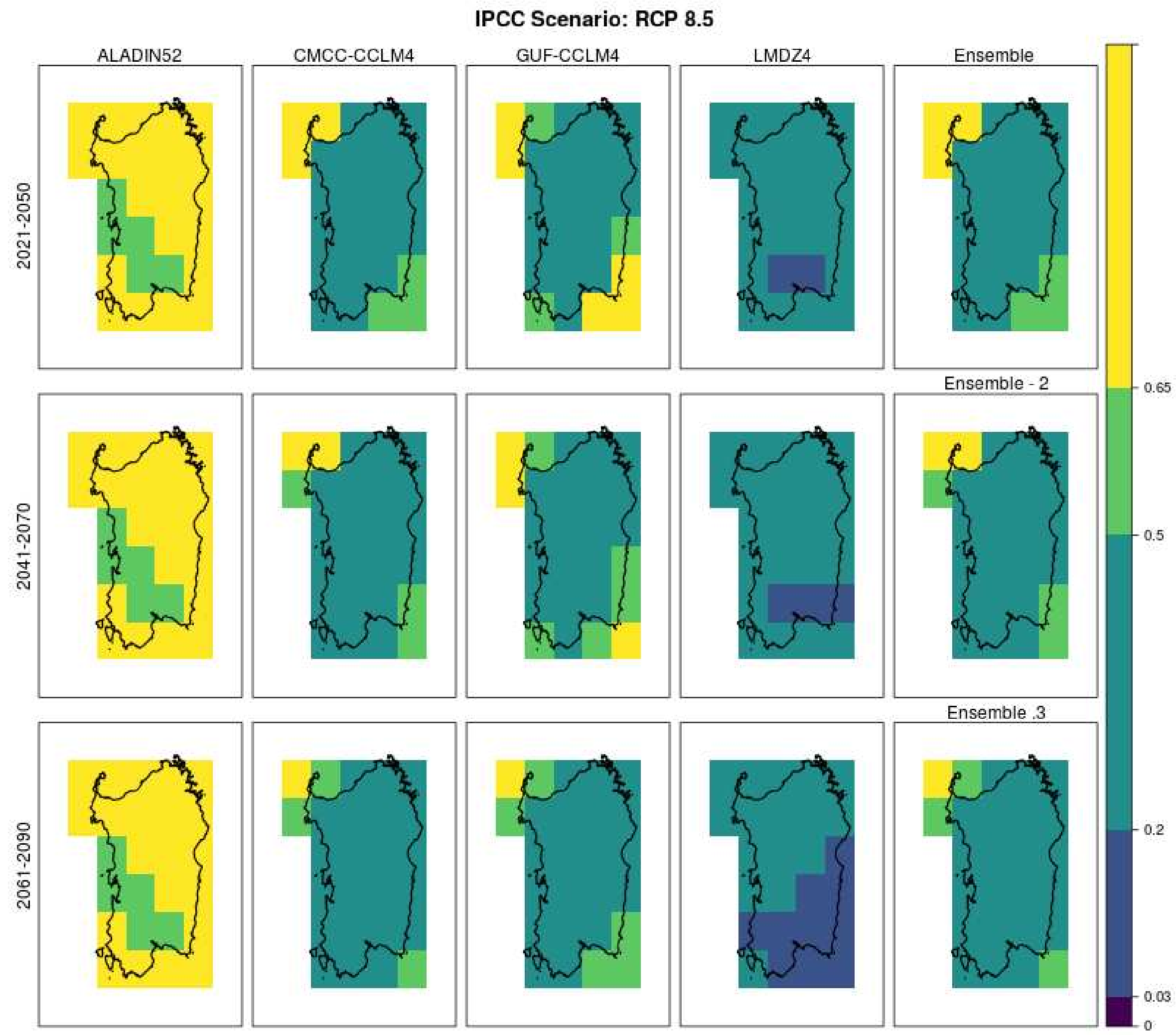
IA < 0.05	hyperarid
0.05 < IA < 0.20	arid
0.20 < IA < 0.50	semi-arid
0.50 < IA < 0.65	dry sub-humid
0.65 < IA	humid

Figure 2.68 - Aridity Index (AI). Maps of four model simulations and ensemble mean for 1971-2000



IA < 0.05	hyperarid
0.05 < IA < 0.20	arid
0.20 < IA < 0.50	semi-arid
0.50 < IA < 0.65	dry sub-humid
0.65 < IA	humid

Figure 2.69 - Aridity Index (AI) projections for 2021-2050, 2041-2070 e 2061-2090, under RCP4.5 scenario



IA < 0.05	hyperarid
0.05 < IA < 0.20	arid
0.20 < IA < 0.50	semi-arid
0.50 < IA < 0.65	dry sub-humid
0.65 < IA	humid

Figure 2.70 - As in figure 2.69, RCP8.5 scenario

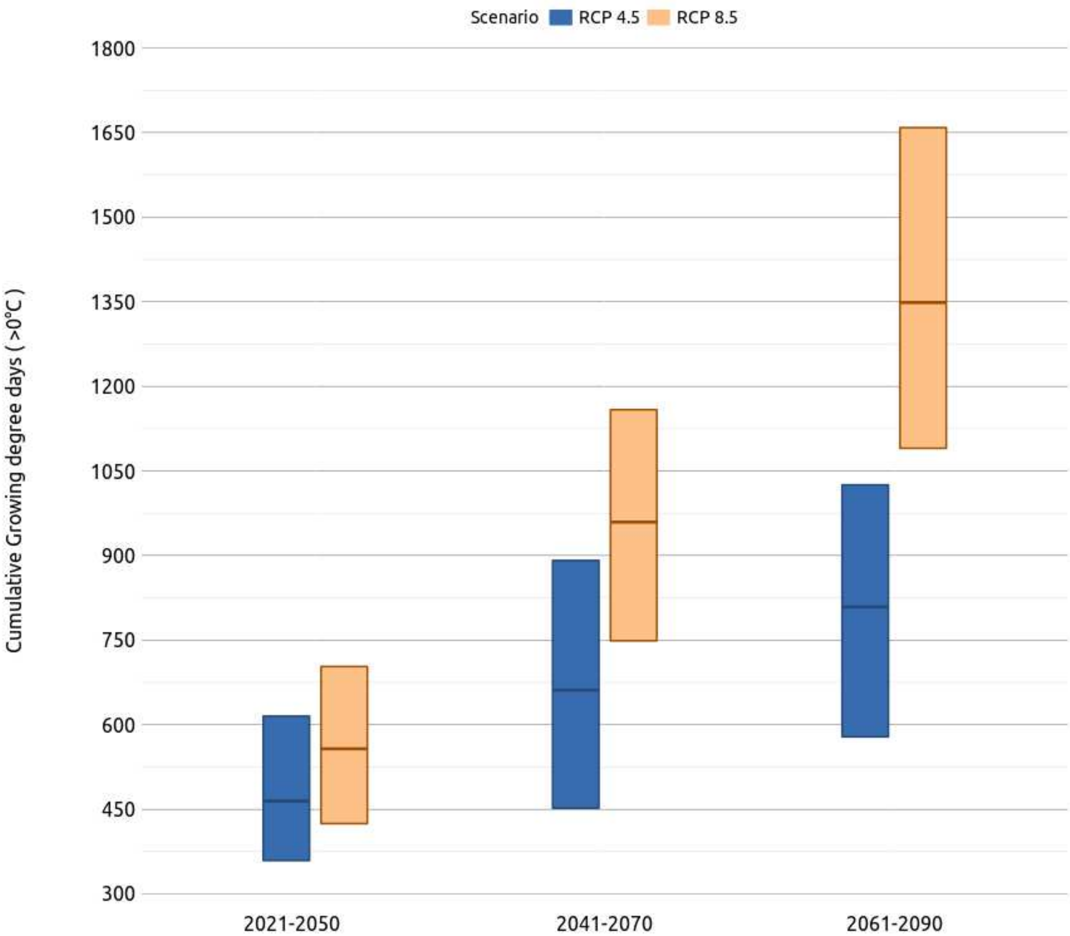


Figure 2.71 - Growing Degree Days, Tb = 0°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

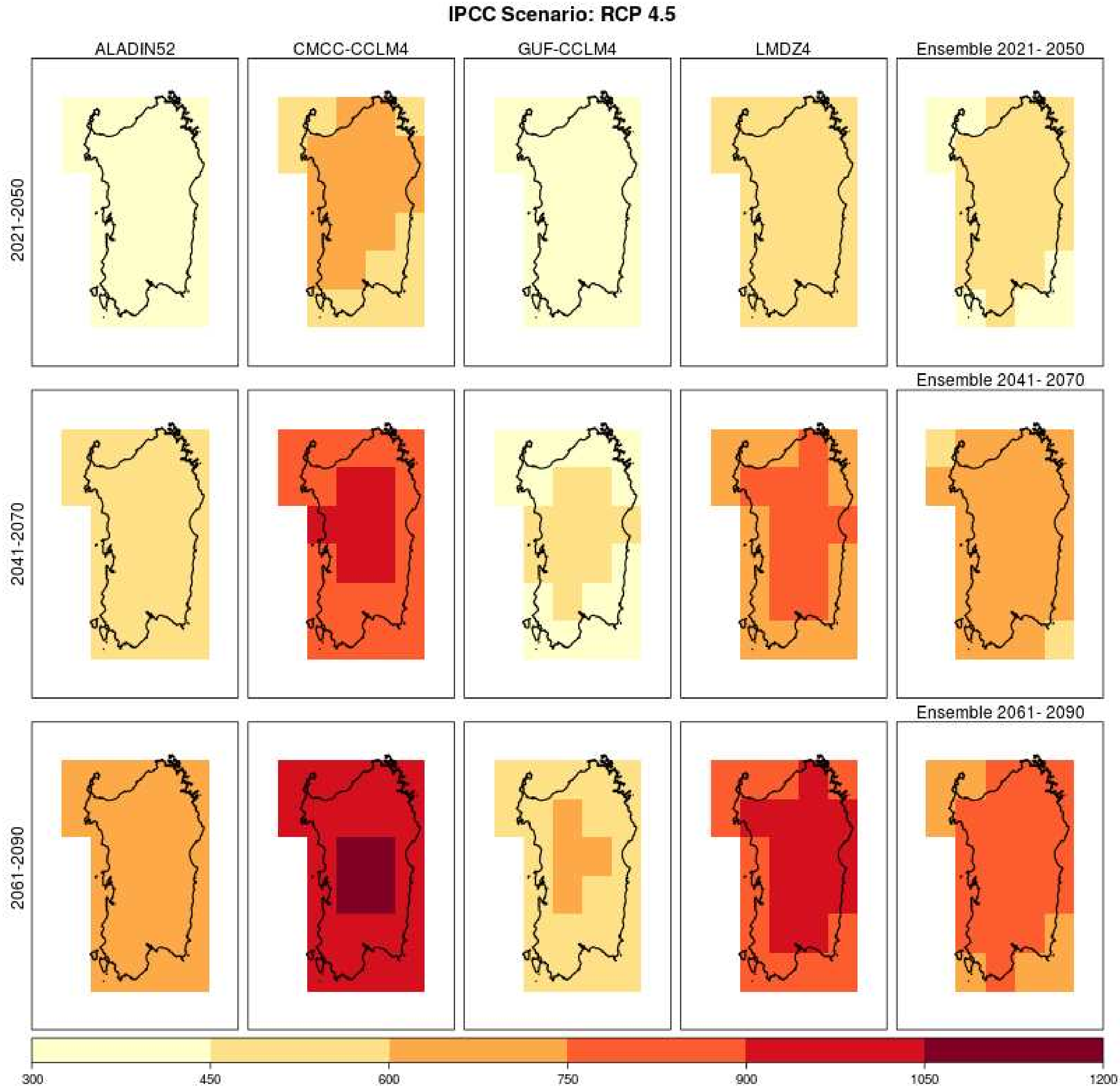


Figure 2.72 - Growing Degree Days (°C), Tb = 0°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

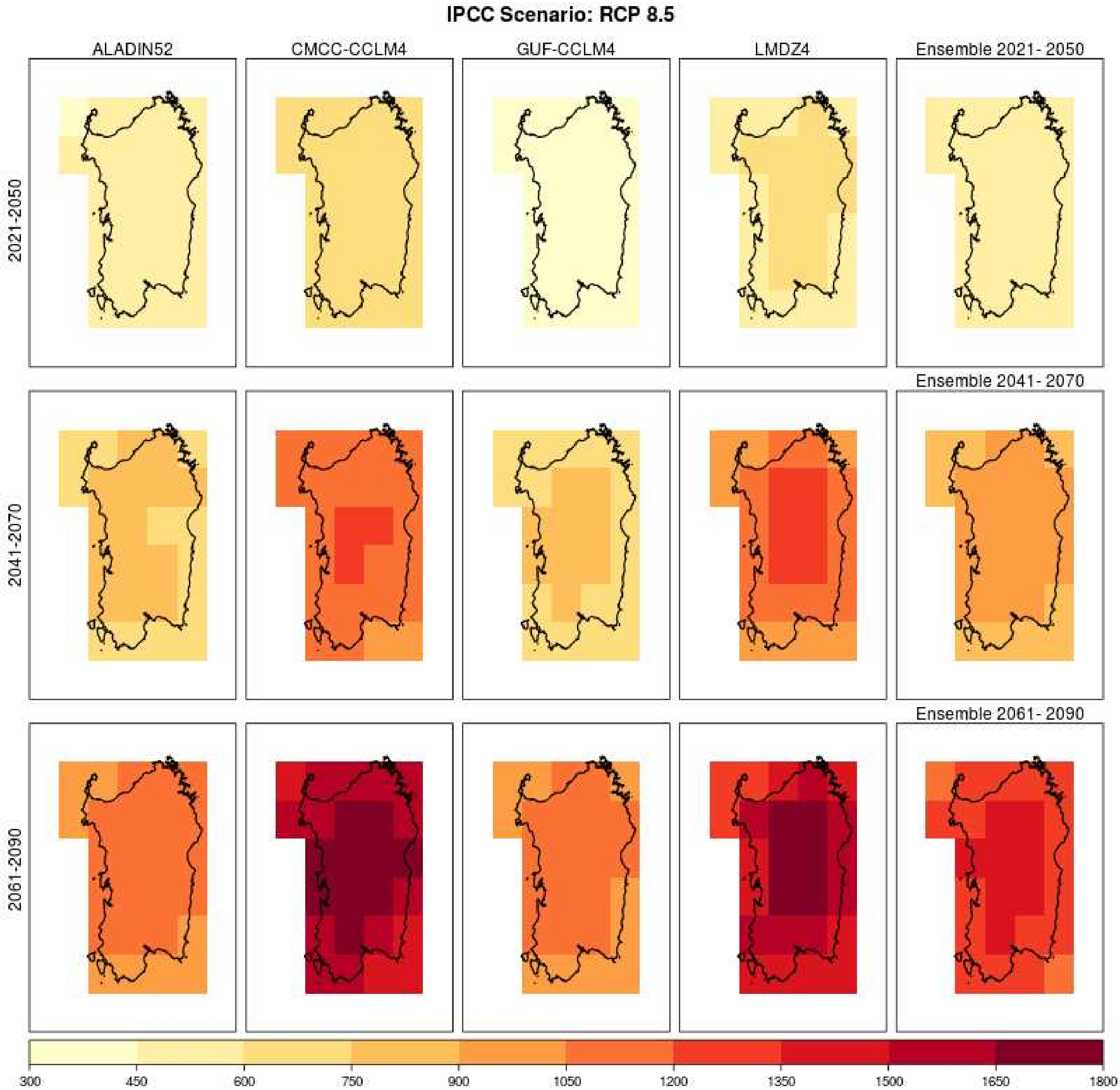


Figure 2.73 - As in figure 2.72, RCP8.5 scenario

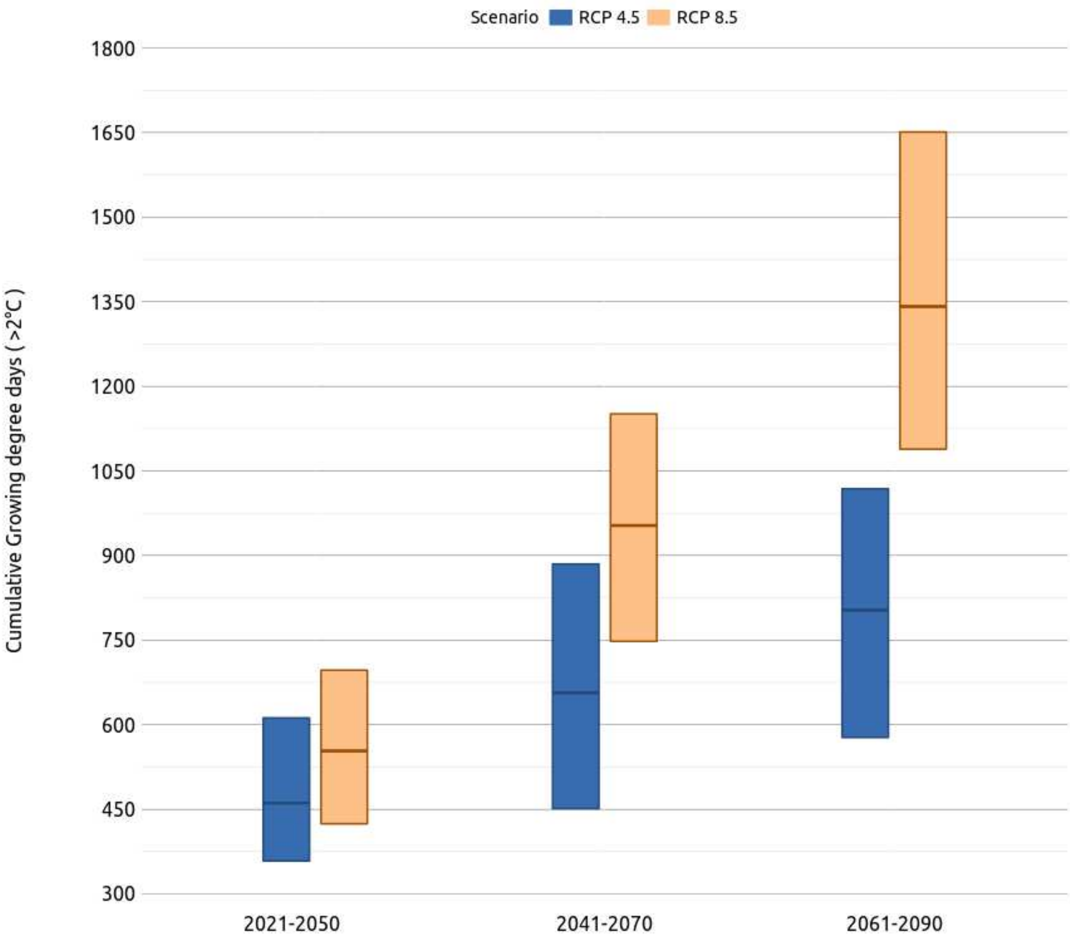


Figure 2.74 - Growing Degree Days, Tb = 2°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

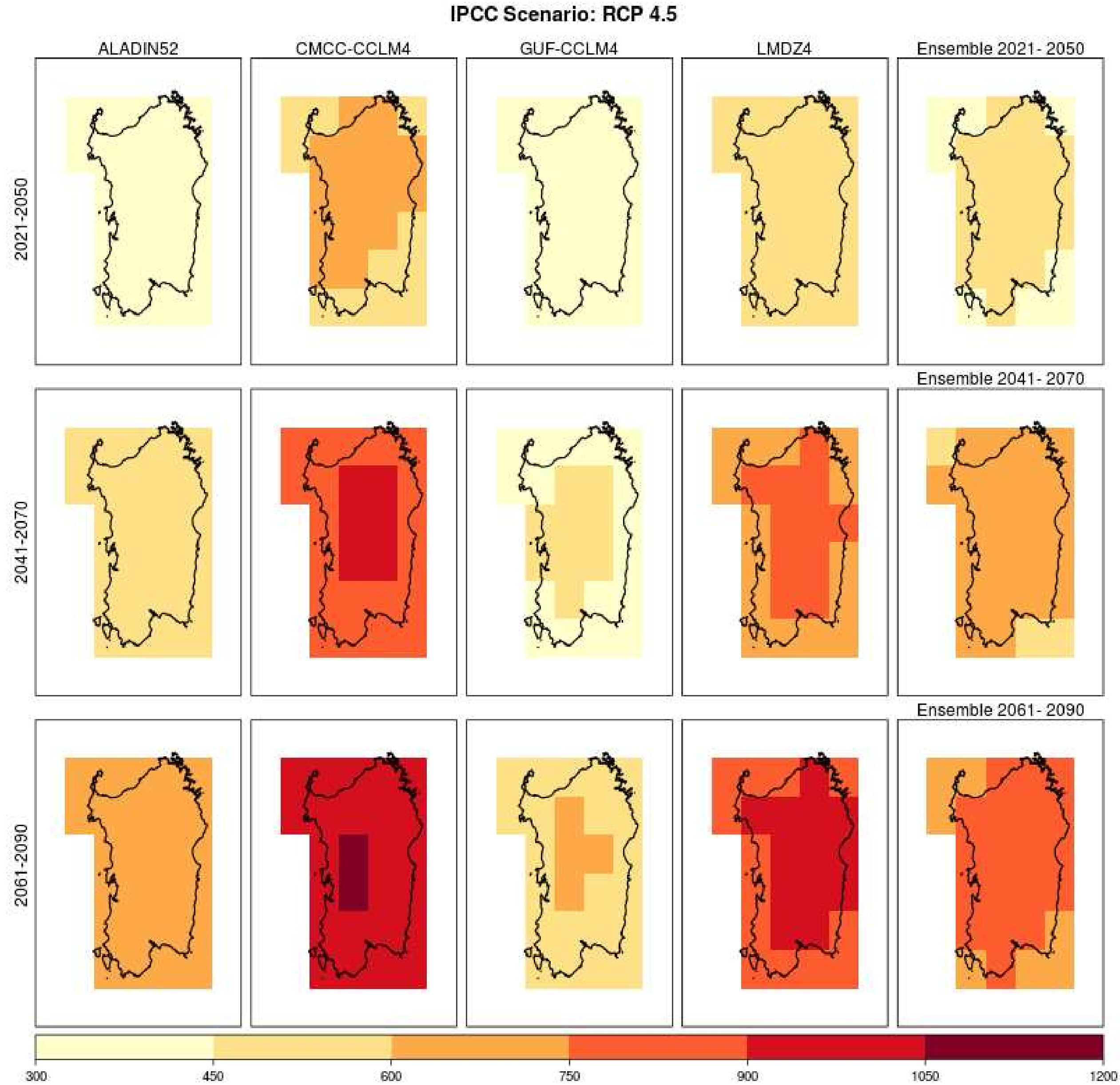


Figure 2.75 - Growing Degree Days (°C), Tb = 2°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

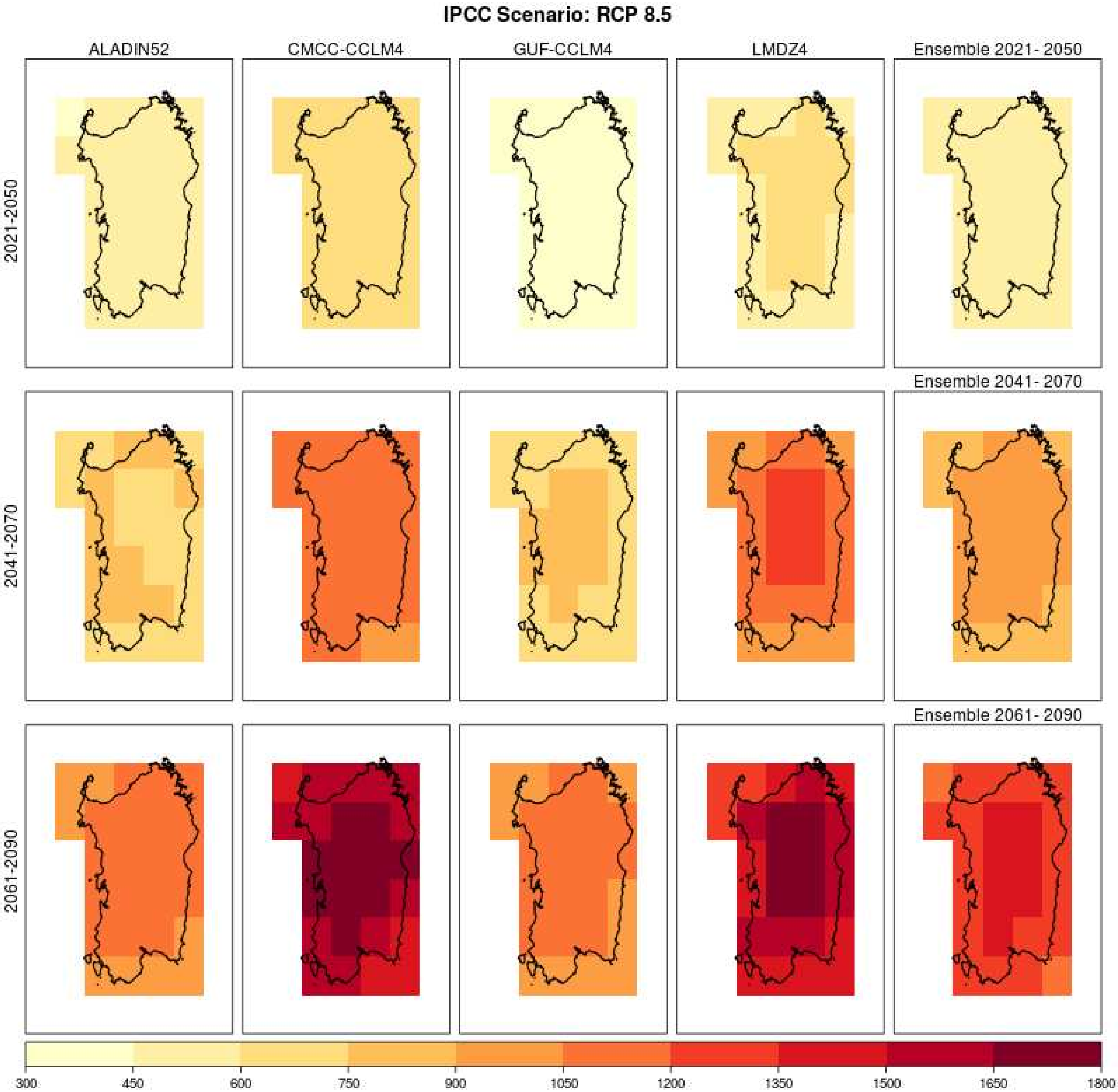


Figure 2.76 - As in figure 2.75, RCP8.5 scenario

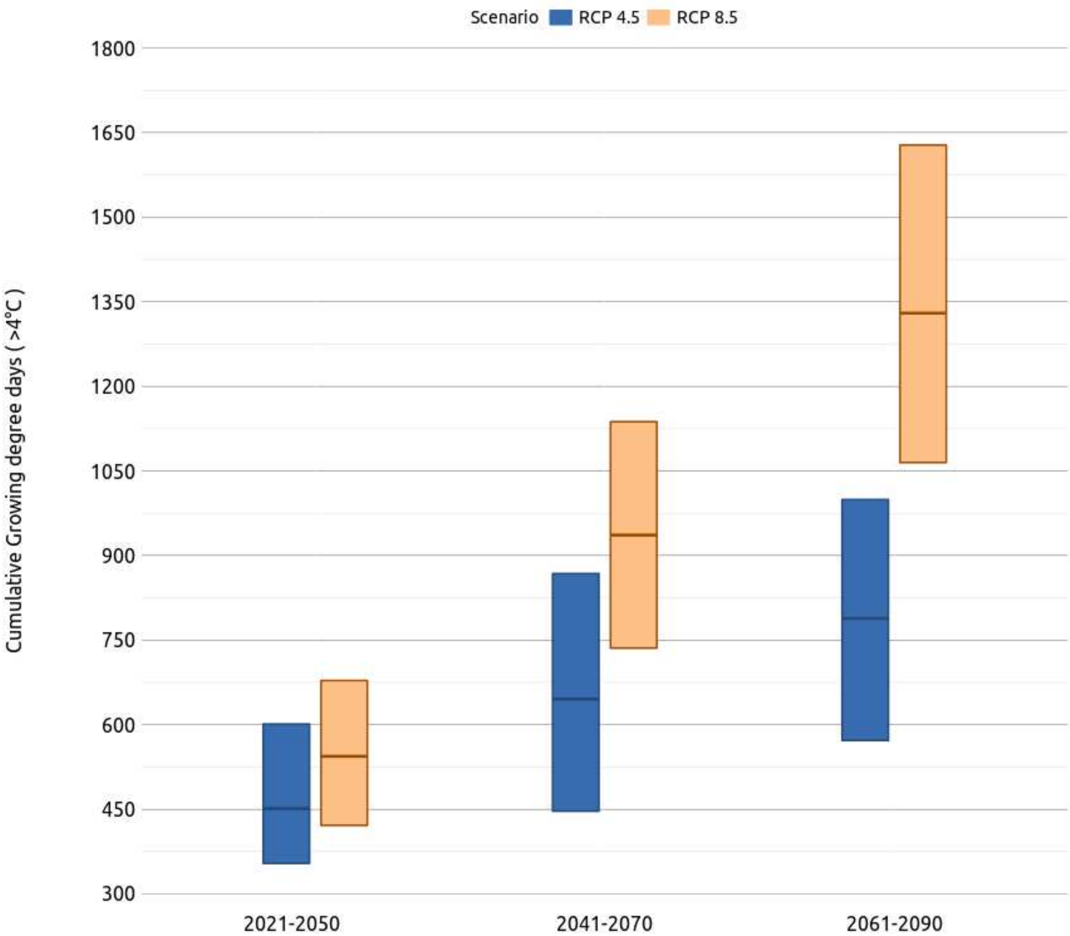


Figure 2.77 - Growing Degree Days, Tb = 4°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

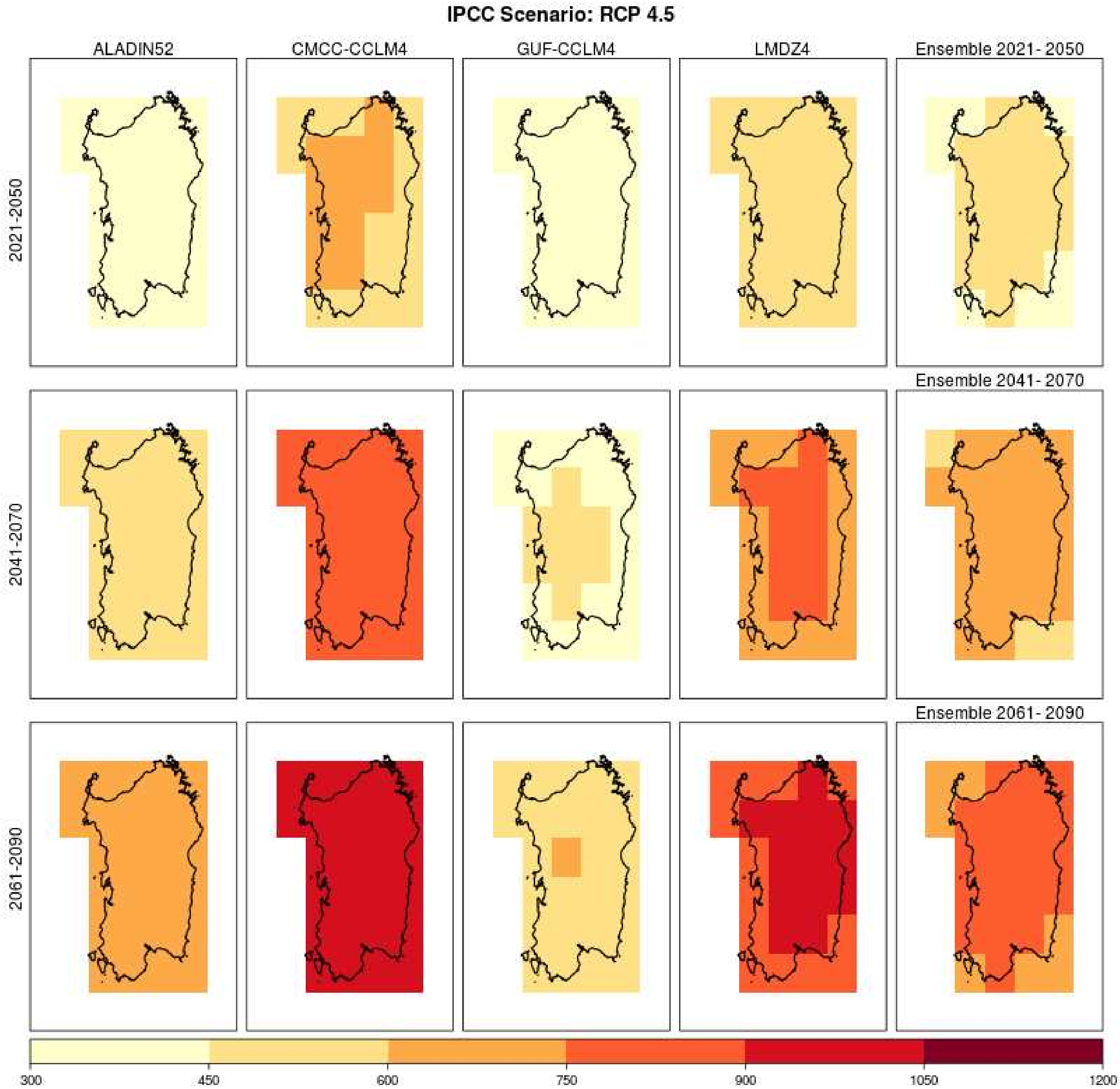


Figure 2.78 - Growing Degree Days (°C), Tb = 4°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

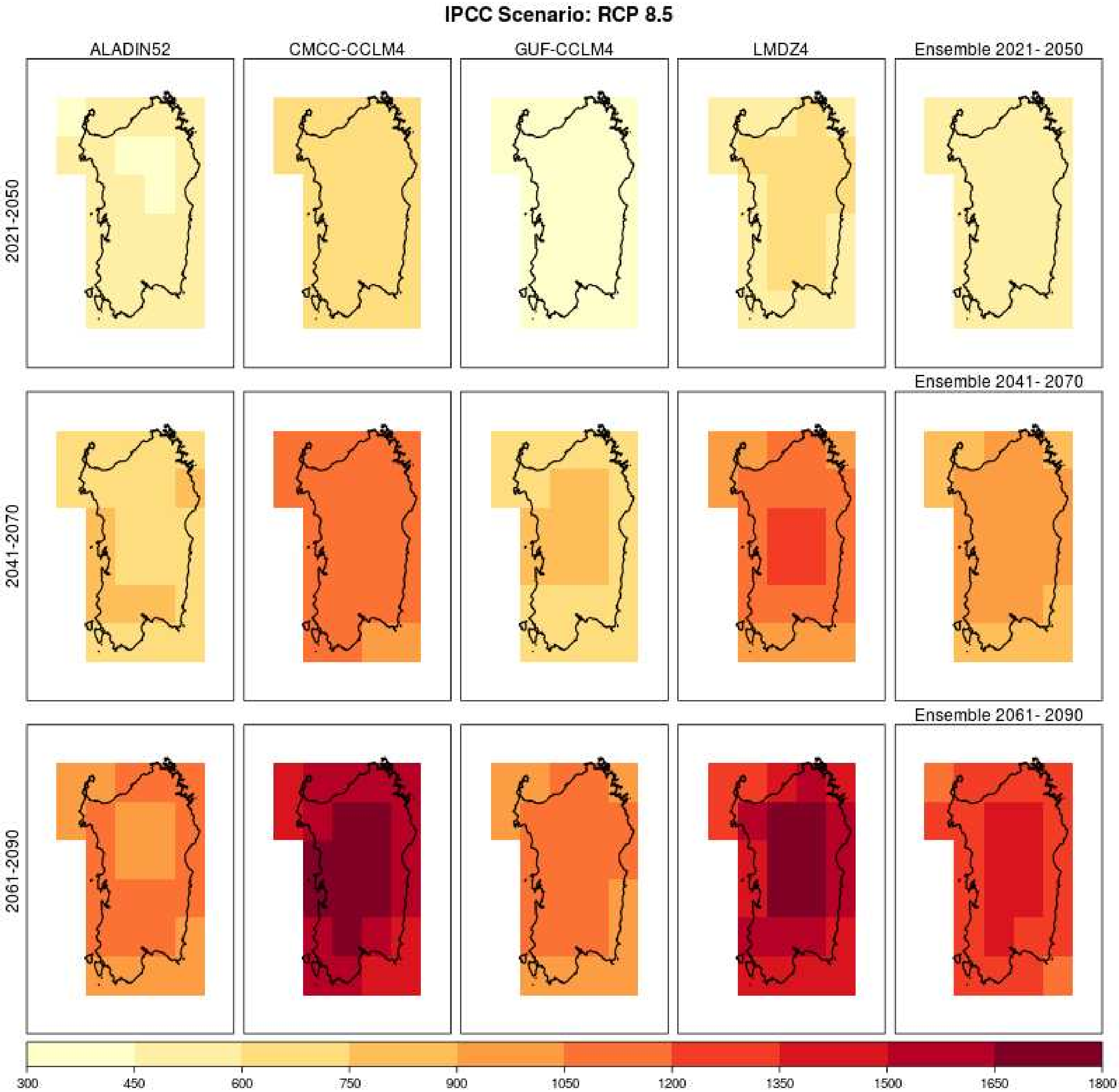


Figure 2.79 - As in figure 2.78, RCP8.5 scenario

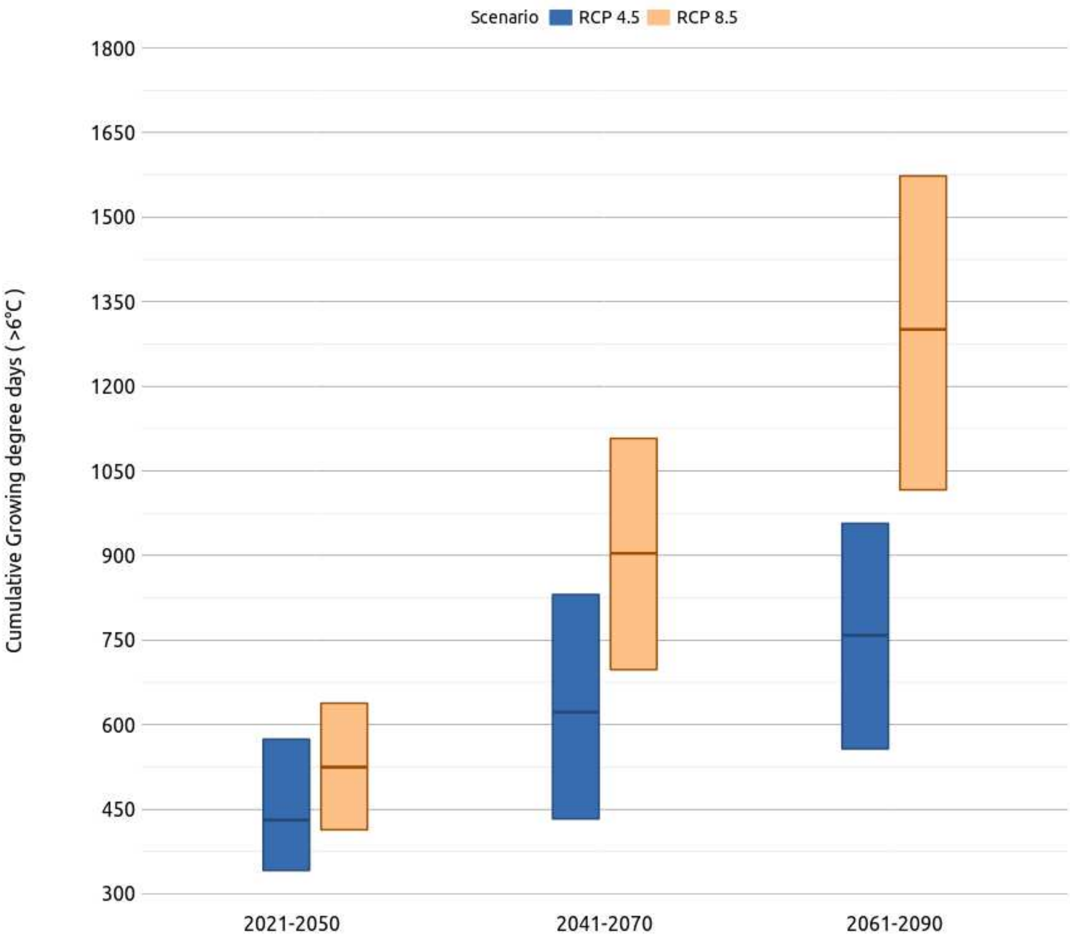


Figure 2.80 - Growing Degree Days, Tb = 6°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

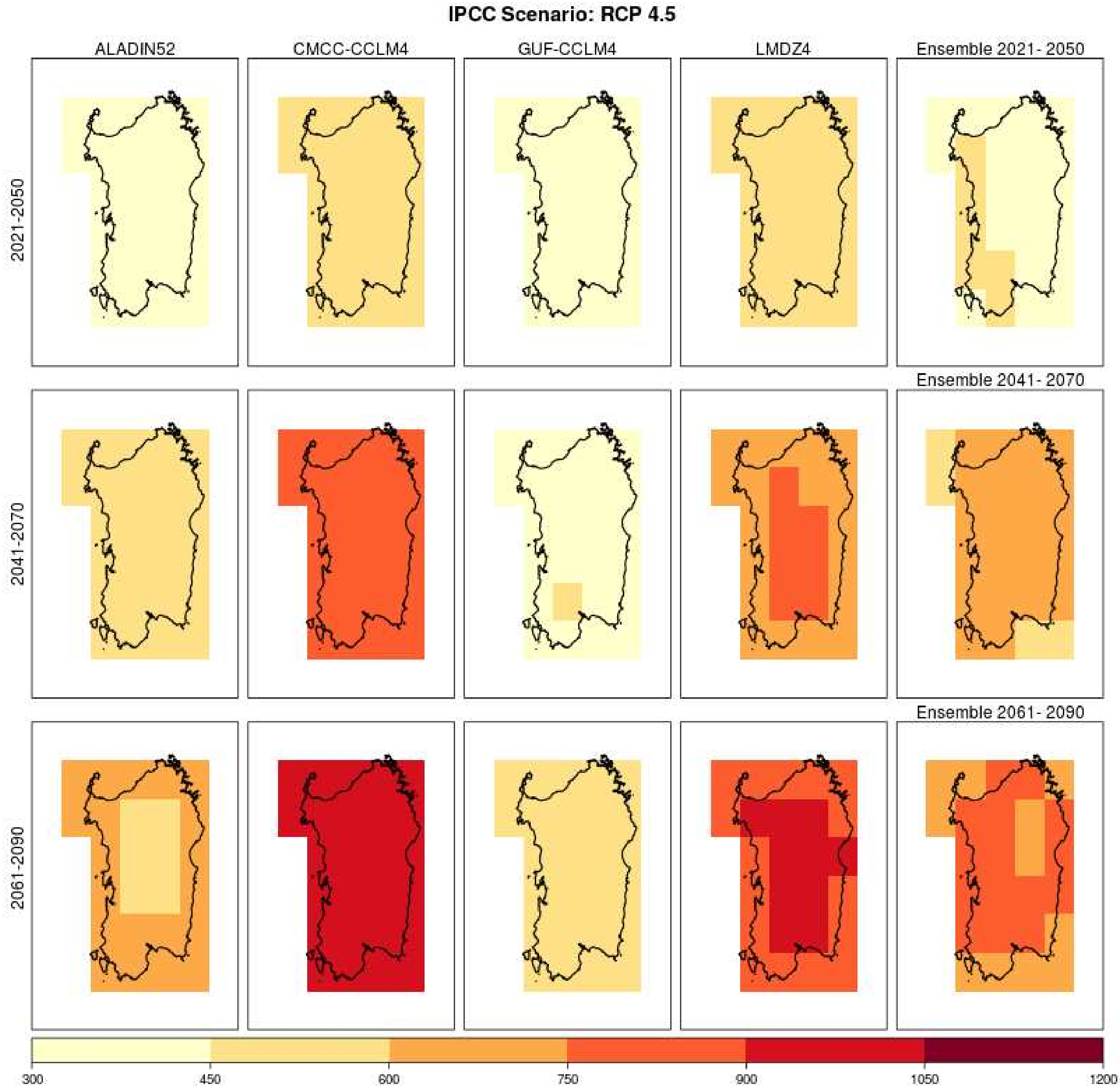


Figure 2.81 - Growing Degree Days (°C), Tb = 6°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

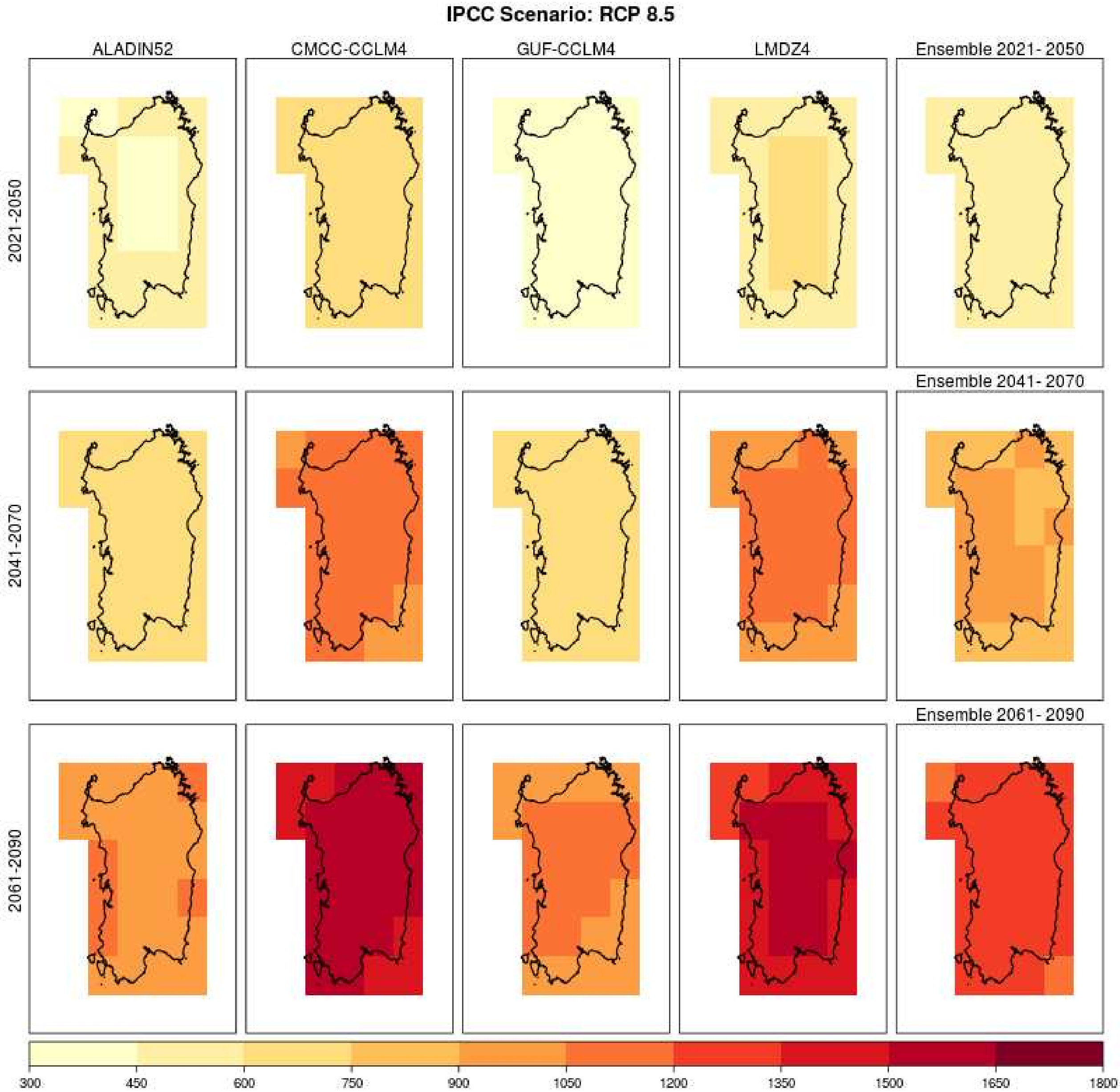


Figure 2.82 - As in figure 2.81, RCP8.5 scenario

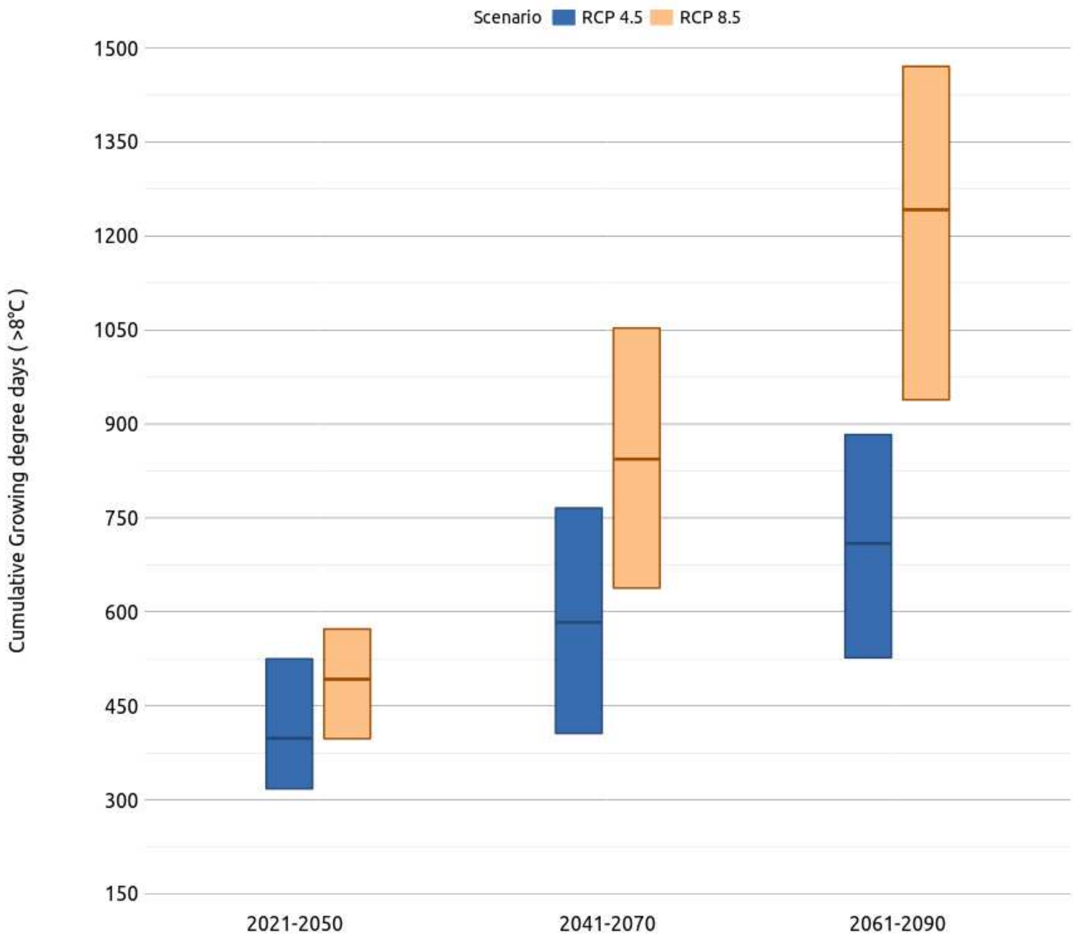


Figure 2.83 - Growing Degree Days, Tb = 8°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

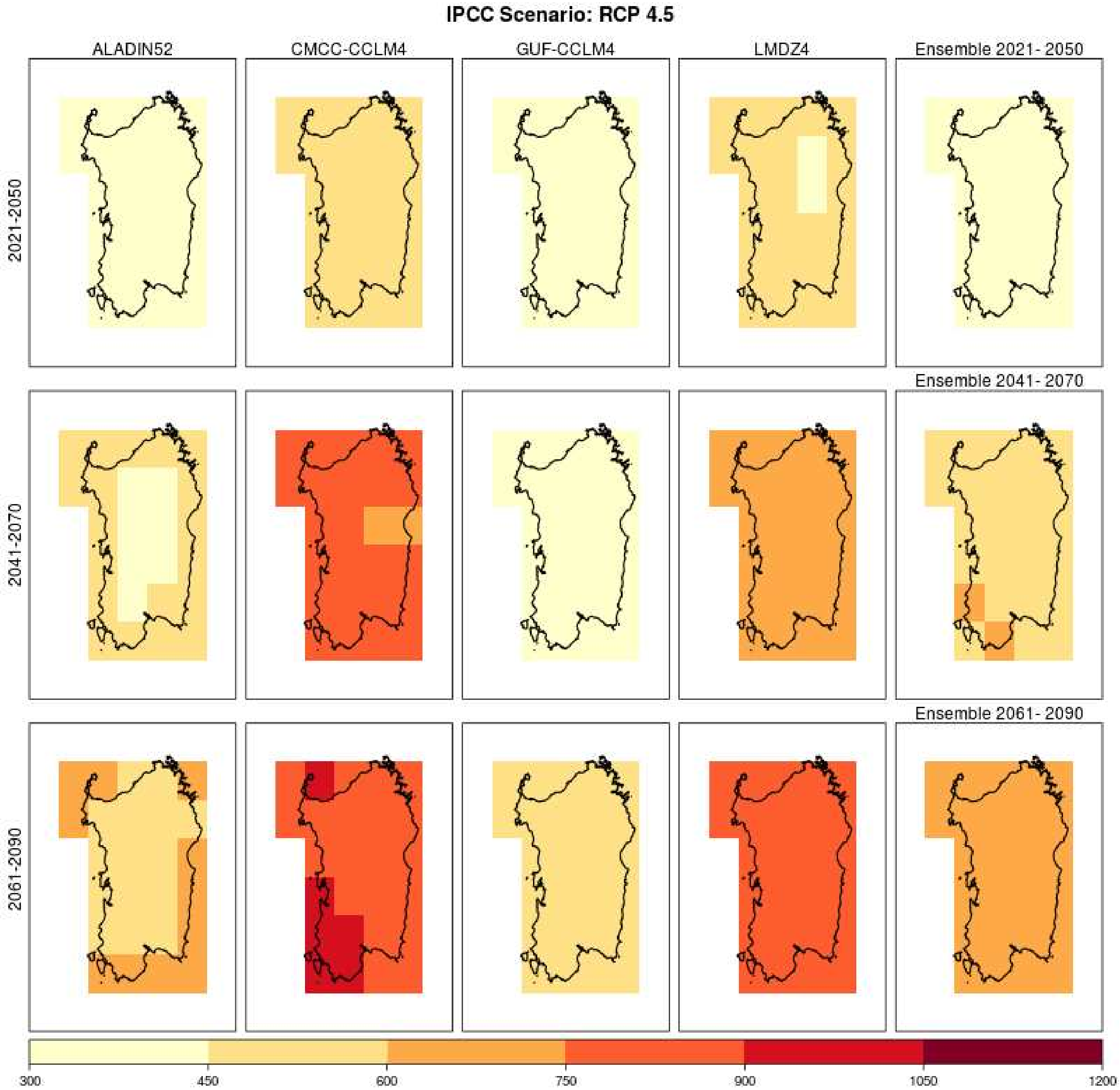


Figure 2.84 - Growing Degree Days (°C), Tb = 8°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

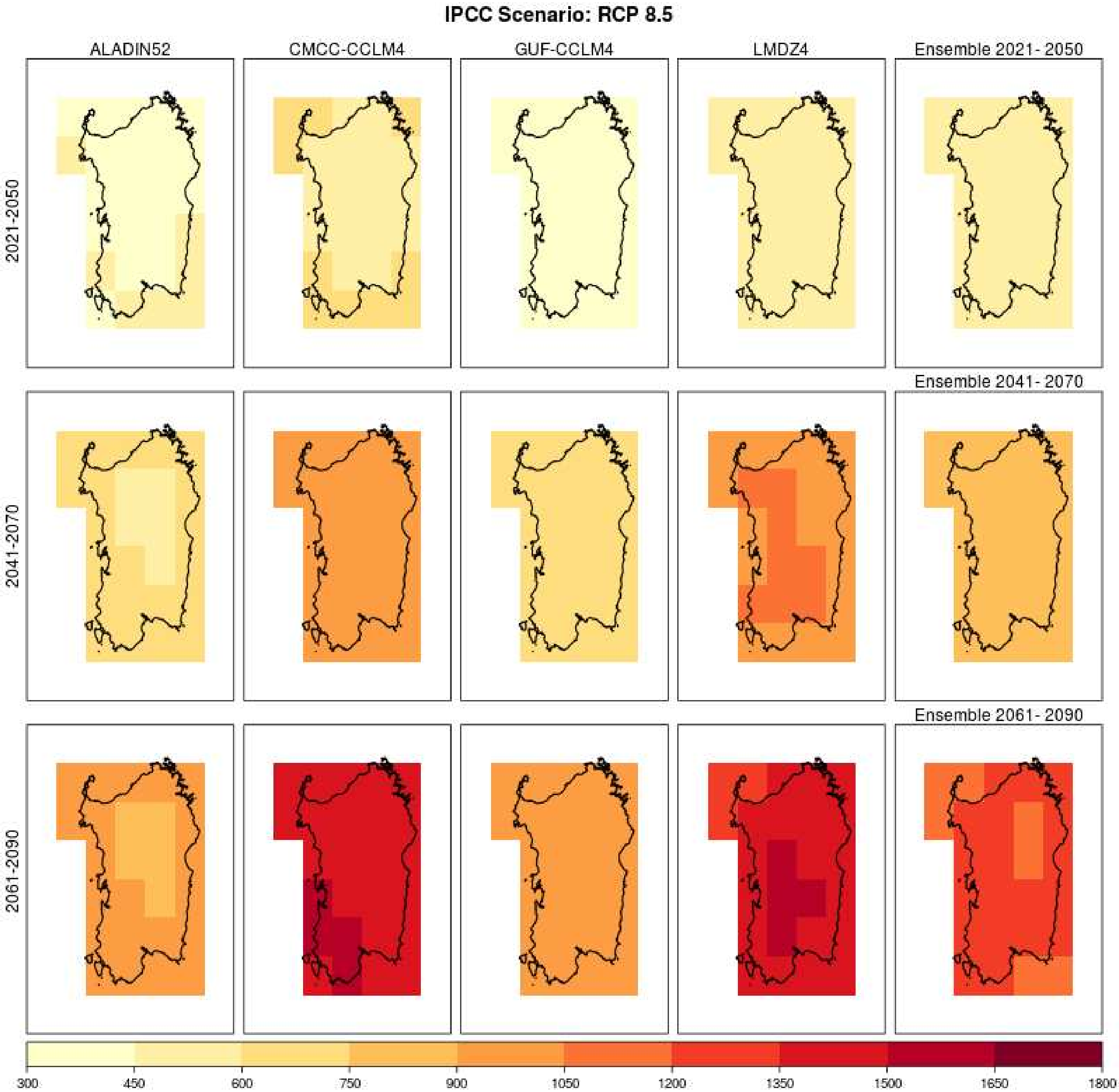


Figure 2.85 - As in figure 2.84, RCP8.5 scenario

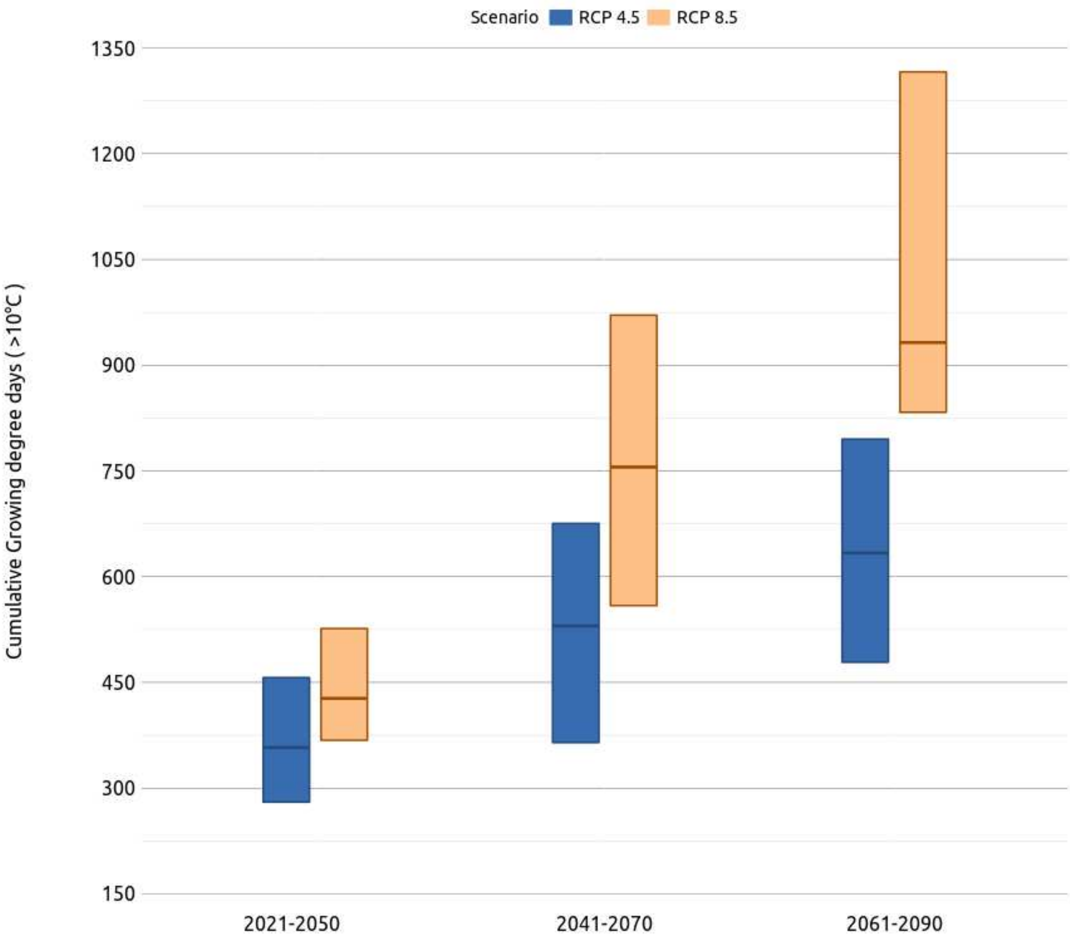


Figure 2.86 - Growing Degree Days, Tb = 10°C. Expected variations for 2021-2050, 2041-2070 and 2061-2090, with respect to 1971-2000, under RCP4.5 and RCP8.5 scenarios

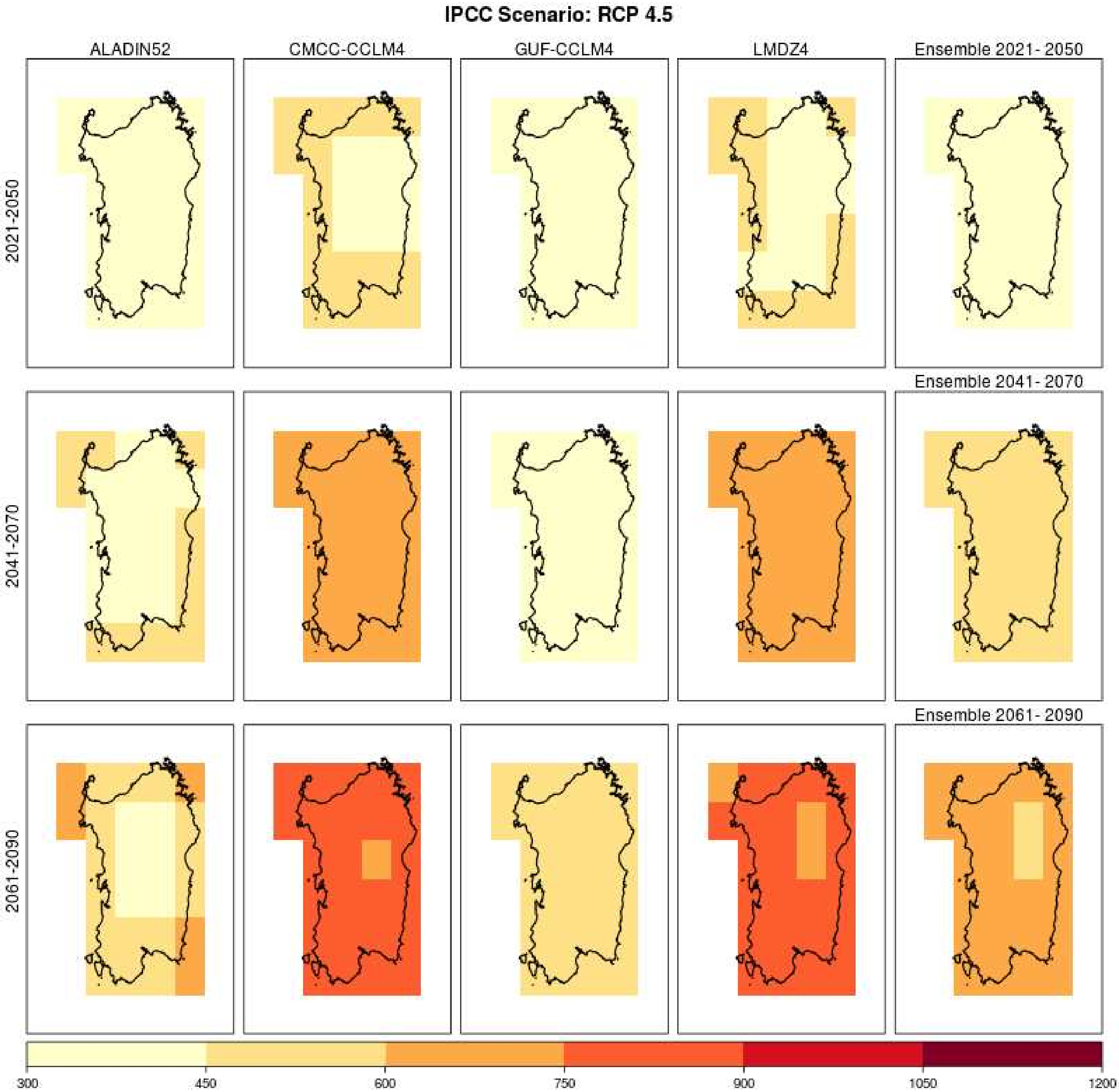


Figure 2.87 - Growing Degree Days (°C), Tb = 10°C, RCP4.5 scenario. Maps of model projected variations and ensemble mean, for 2021-2050 (first row), 2041-2070 (second row), 2061-2090 (third row)

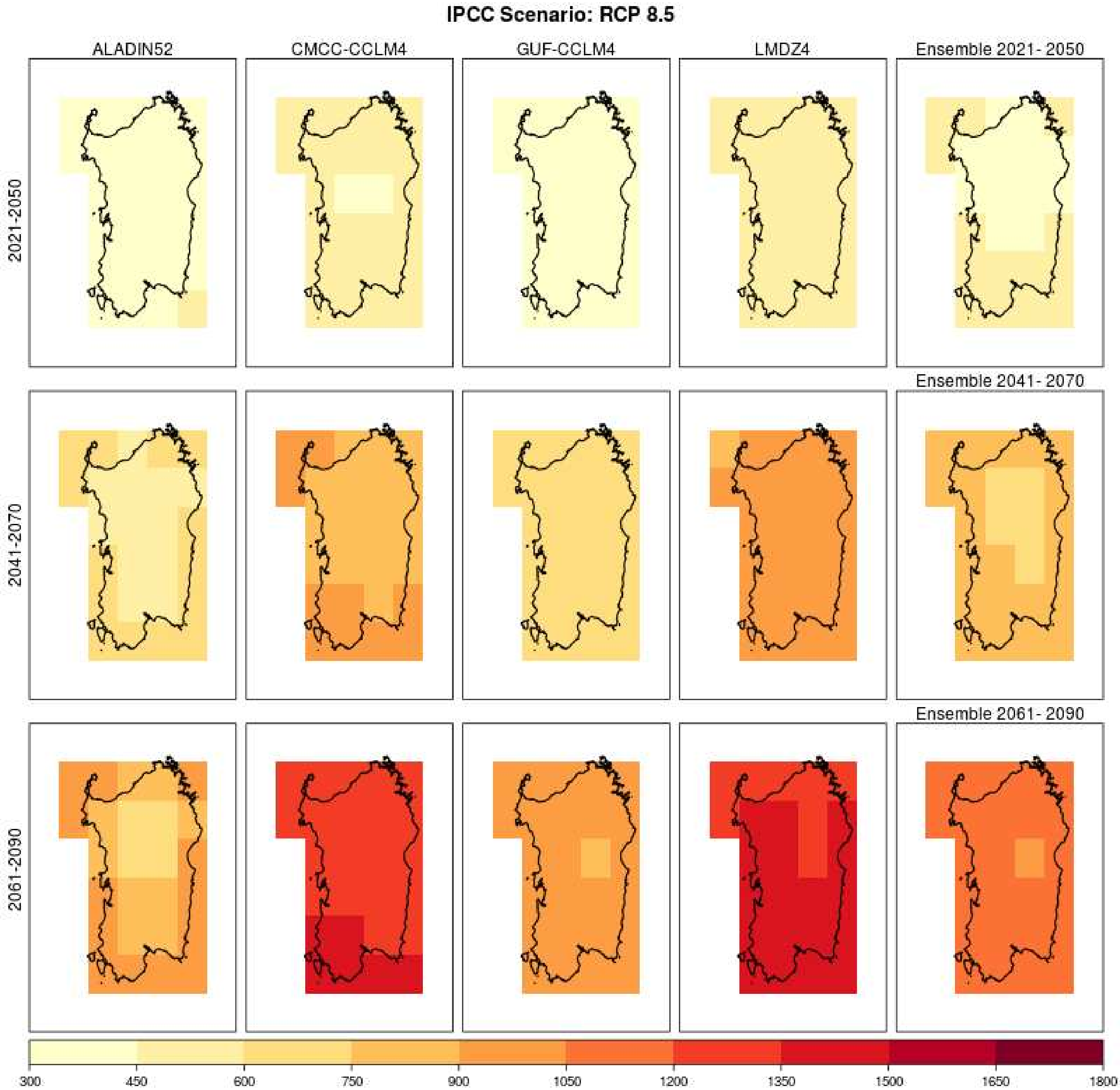


Figure 2.88 - As in figure 2.87, RCP8.5 scenario

2.2 Target areas

In the areas targeted by Action C3 future model projections were examined, following the same methodology applied to the Sardinia region. The outputs of Med-CORDEX models of grid point covering each selected area were extracted and examined to have indications about future climate. Mean temperature and total precipitation, as well as extreme values were evaluated for 2021-2050, 2041-2070 and 2061-2090, under the RCP4.5 and RCP8.5 scenarios, in term of anomalies with respect the 1971-2000 average. To analyse temperature and precipitation extremes, a subset of indices was selected from the ETCCDI indices examined for the Sardinia region.

The obtained results show a marked future warming for all the target areas, with an increase of minimum, maximum, and mean temperature. It is also expected a strong increase of warm extremes (SU25, TR20, WSDI) and a decrease of cold extremes (FD0). The ensemble mean projections show in general a slight reduction of total precipitation in all the areas, except for the area of Venice, where the indications are doubtful, showing a weak precipitation increase by 2041-2070 under RCP4.5 and by 2061-2090, under both the RCPs. The ensemble mean of precipitation extremes indicates in general a weak or moderate increase of RX1day, R95p, SDII, CDD, with some rare exceptions.

These results are shown in the following Tables for each target area.

2.2.1 The area of Venice

Mean temperature

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	+1.0	+1.6	+1.3	+1.2	+2.5	+1.9	+1.3	+3.0	+2.4
RCP8.5	+1.0	+2.0	+1.5	+1.8	+3.2	+2.6	+2.7	+4.6	+3.8

Table 2.10 - Mean temperature (°C). Projected variations with respect to the 1971-2000 average, under RCP4.5 and RCP8.5 scenarios; ensemble mean variation (Mean) and minimum and maximum projected variations among models

Precipitation

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	-54.9	+11.5	-17.4	-70.6	+44.6	-8.3	-43.9	+66.1	+9.7
RCP8.5	-74.0	+51.4	-1.6	-19.4	+101.5	+12.5	-36.5	+111.5	+17.6

Table 2.11 - As in table 2.10, for precipitation

Con il contributo dello strumento finanziario LIFE dell'Unione Europea
With the contribution of the LIFE financial instrument of the European Community
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Temperature extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
FD0	days	-19.3	-3.1	-9.5	-28.0	-3.9	-14.1	-33.5	-4.6	-17.5
SU25	days	+20.5	+22.6	+21.4	+19.9	+40.1	+32.4	+22.9	+44.1	+36.0
TR20	days	+18.2	+20.9	+19.7	+24.7	+36.3	+31.6	+28.4	+42.3	+36.7
WSDI	days	+16.7	+65.7	+39.6	+20.6	+95.5	+63.3	+25.7	+114.4	+82.1
RCP8.5										
FD0	days	-29.9	-2.5	-12.0	-36.0	-4.6	-18.0	-42.4	-6.5	-22.2
SU25	days	+18.8	+26.2	+23.2	+33.1	+46.6	+38.9	+44.5	+67.9	+54.4
TR20	days	+20.2	+23.8	+22.4	+33.7	+45.0	+40.6	+51.8	+71.5	+59.1
WSDI	days	+15.1	+73.5	+45.4	+35.3	+138.8	+94.1	+63.1	+215.6	+155.5

Table 2.12 - As in table 2.10, for temperature extreme indices

Precipitation extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
RX1day	mm	+0.4	+5.2	+2.8	-0.2	+8.1	+3.9	+2.2	+10.0	+6.4
R95p	mm	-5.9	+25.5	+10.8	+5.7	+46.3	+27.9	+14.5	+54.2	+37.3
SDII	mm/day	0	+0.5	+0.2	+0.1	+1.0	+0.5	+0.3	+0.9	+0.6
CDD	days	-5.8	+7.3	+1.6	+1.3	+8.4	+4.5	+1.7	+8.9	+5.1
RCP8.5										
RX1day	mm	-1.1	+12.5	+4.9	+5.1	+27.3	+11.9	+7.3	+24.3	+12.7
R95p	mm	-14.2	+70.8	+27.3	-0.3	+103.4	+47.5	+17.0	+116.2	+71.3
SDII	mm/day	+0.1	+0.8	+0.3	+0.4	+1.6	+0.8	+0.5	+2.1	+1.1
CDD	days	-2.4	+1.6	-0.1	-0.1	+19.9	+7.6	+1.9	+27.7	+15.0

Table 2.13 - As in table 2.10, for precipitation extreme indices

2.2.2 The aggregation of municipalities in northern Milan

Mean temperature

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	+1.0	+1.8	+1.3	+1.2	+2.7	+2.0	+1.5	+3.1	+2.5
RCP8.5	+1.0	+2.0	+1.5	+2.0	+3.4	+2.7	+2.9	+4.9	+4.0

Table 2.14 - Mean temperature (°C). Projected variations with respect to the 1971-2000 average, under RCP4.5 and RCP8.5 scenarios; ensemble mean variation (Mean) and minimum and maximum projected variations among models

Precipitation

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	-91.4	+35.1	-33.4	-102.3	+23.2	-43.8	-53.2	+22.2	-17.5
RCP8.5	-89.5	+27.2	-10.6	-101.4	+17.0	-35.7	-98.2	-11.9	-58.4

Table 2.15 - As in table 2.14, for precipitation

Temperature extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
FD0	days	-30.1	-11.6	-18.6	-40.0	-17.0	-25.7	-47.8	-20.2	-33.5
SU25	days	+16.2	+22.6	+19.0	+17.6	+39.2	+29.8	+23.3	+40.8	+33.4
TR20	days	+0.6	+13.3	+6.7	+1.9	+35.6	+15.2	+1.9	+50.2	+20.3
WSDI	days	+16.1	+33.5	+26.6	+18.2	+56.9	+43.1	+27.5	+78.3	+56.3
RCP8.5										
FD0	days	-37.8	-10.9	-21.0	-54.8	-24.4	-37.9	-71.3	-37.8	-53.2
SU25	days	+16.1	+22.5	+20.2	+30.7	+44.9	+36.4	+45.9	+66.0	+52.3
TR20	days	+0.8	+17.7	+7.8	+2.0	+50.6	+21.7	+6.3	+74.4	+36.6
WSDI	days	+15.0	+35.8	+27.5	+36.6	+96.8	+66.8	+72.5	+149.4	+115.6

Table 2.16 - As in table 2.14, for temperature extreme indices

Precipitation extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
RX1day	mm	-2.7	+10.0	+3.2	-3.2	+13.7	+5.0	+0.4	+6.9	+4.5
R95p	mm	-31.4	+50.4	+3.4	-13.1	+42.5	+18.9	+26.6	+49.8	+35.5
SDII	mm/day	-0.8	+0.6	+0.0	-0.2	+0.6	+0.2	+0.2	+1.0	+0.6
CDD	days	-0.5	+5.4	+3.4	+0.9	+6.0	+3.5	+2.4	+7.7	+4.1
RCP8.5										
RX1day	mm	-1.1	+6.4	+2.4	+0.2	+6.3	+4.1	+1.3	+13.5	+6.0
R95p	mm	-15.7	+54.8	+19.2	-20.5	+58.8	+25.7	+15.8	+73.6	+40.8
SDII	mm/day	-0.3	+0.9	+0.2	+0.3	+1.0	+0.6	+0.2	+1.5	+0.8
CDD	days	+0.3	+3.4	+1.9	+0.5	+9.2	+5.5	+1.1	+17.2	+10.0

Table 2.17 - As in table 2.14, for precipitation extreme indices

2.2.3 The metropolitan area of Cagliari and the metropolitan network of Sassari

Mean temperature (Sassari)

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	+1.0	+1.7	+1.3	+1.2	+2.4	+1.8	+1.6	+2.7	+2.2
RCP8.5	+1.1	+1.9	+1.5	+2.1	+3.1	+2.6	+3.0	+4.4	+3.6

Table 2.18 - Mean temperature (°C). Projected variations with respect to the 1971-2000 average, under RCP4.5 and RCP8.5 scenarios; ensemble mean variation (Mean) and minimum and maximum projected

Total precipitation (Sassari)

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	-32.8	+29.5	-6.0	-72.3	+28.8	-12.0	-66.6	+37.2	-15.7
RCP8.5	-61.1	-11.4	-31.2	-90.6	+13.9	-34.1	-95.6	+16.5	-45.3

Table 2.19 - As in table 2.18, for precipitation

Temperature extremes (Sassari)

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
FD0	days	-5.9	-0.5	-2.7	-7.5	-0.5	-3.5	-10.4	-0.9	-4.5
SU25	days	+11.6	+23.3	+19.7	+16.2	+35.0	+28.6	+22.6	+39.2	+32.6
TR20	days	+13.6	+27.7	+20.5	+22.1	+40.8	+30.7	+22.9	+50.4	+36.5
WSDI	days	+12.6	+30.9	+23.5	+17.7	+46.9	+34.1	+25.1	+68.8	+46.4
RCP8.5										
FD0	days	-6.5	-0.1	-3.0	-12.0	-0.7	-5.0	-15.1	-1.1	-6.1
SU25	days	+17.5	+25.2	+22.5	+29.2	+44.4	+36.4	+39.6	+65.0	+51.4
TR20	days	+15.3	+33.1	+22.8	+24.4	+59.5	+43.4	+41.8	+77.6	+63.4
WSDI	days	+16.4	+36.6	+26.5	+31.3	+93.1	+61.0	+58.2	+147.1	+105.2

Table 2.20 - As in table 2.18, for temperature extreme indices

Precipitation extremes (Sassari)

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
RX1day	mm	-0.3	+3.6	+1.4	+2.6	+6.9	+4.7	+3.8	+6.6	+5.0
R95p	mm	-1.8	+26.0	+12.8	-7.4	+26.9	+14.1	-5.1	+37.9	+13.7
SDII	mm/day	0	+0.4	+0.2	0	+0.8	+0.4	+0.2	+0.8	+0.4
CDD	days	+1.1	+11.8	+5.8	+1.4	+23.1	+13.0	+1.4	+20.0	+11.9
RCP8.5										
RX1day	mm	+2.9	+3.9	+3.4	+1.0	+7.7	+4.2	+4.6	+12.4	+7.4
R95p	mm	-11.1	+21.7	+5.5	-15.6	+21.4	+10.2	-3.4	+33.0	+16.7
SDII	mm/day	0	+0.6	+0.3	+0.2	+0.8	+0.4	+0.3	+1.0	+0.6
CDD	days	+0.6	+11.4	+6.9	+1.4	+26.8	+14.8	+1.5	+43.1	+25.3

Table 2.21 - As in table 2.18, for precipitation extreme indices

Mean temperature (Cagliari)

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	+1.0	+1.6	+1.3	+1.2	+2.3	+1.8	+1.5	+2.7	+2.1
RCP8.5	+1.1	+1.9	+1.5	+2.0	+3.1	+2.5	+2.9	+4.4	+3.6

Table 2.22 -Mean temperature (°C). Projected variations with respect to the 1971-2000 average, under RCP4.5 and RCP8.5 scenarios; ensemble mean variation (Mean) and minimum and maximum projected variations among models

Total precipitation (Cagliari)

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	-36.6	+2.3	-12.3	-57.3	+19.5	-26.7	-46.4	+41.3	-22.1
RCP8.5	-41.3	-12.4	-24.3	-67.0	-11.6	-37.6	-87.2	+10.2	-55.0

Table 2.23 - As in table 2.22, for precipitation

Temperature extremes (Cagliari)

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
FD0	days	-7.6	-0.3	-3.1	-8.1	-0.2	-3.6	-11.9	-0.4	-4.8
SU25	days	+16.3	+25.8	+21.7	+19.8	+38.5	+30.2	+23.3	+42.7	+33.9
TR20	days	+12.8	+25.4	+20.9	+20.1	+41.2	+30.9	+23.3	+47.0	+36.8
WSDI	days	+15.3	+42.2	+31.7	+22.9	+78.4	+51.4	+34.3	+110.9	+68.8
RCP8.5										
FD0	days	-7.2	-0.1	-3.2	-13.6	-0.3	-5.4	-17.5	-0.4	-6.7
SU25	days	+20.3	+27.2	+24.5	+30.9	+47.7	+39.0	+43.4	+64.7	+53.1
TR20	days	+16.1	+29.5	+24.4	+25.3	+53.6	+43.0	+42.2	+79.8	+61.1
WSDI	days	+24.0	+54.4	+39.0	+52.6	+139.9	+89.4	+92.4	+215.0	+150.8

Table 2.24 - As in table 2.22, for temperature extreme indices

Precipitation extremes (Cagliari)

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
RX1day	mm	-7.0	+9.5	-0.4	-6.7	+8.5	+1.7	-8.3	+13.0	+3.7
R95p	mm	-25.1	+23.1	+1.8	-23.6	+23.7	+0.7	-16.2	+36.8	+10.4
SDII	mm/day	-0.5	+0.8	+0.1	-0.4	+0.7	+0.1	-0.2	+0.9	+0.3
CDD	days	+0.2	+18.6	+7.3	-0.5	+29.5	+12.7	-0.5	+31.5	+16.9
RCP8.5										
RX1day	mm	-5.3	+9.4	+1.4	-8.4	+10.3	+2.5	-9.4	+7.9	+0.7
R95p	mm	-17.3	+24.6	+4.1	-23.7	+35.3	+5.3	-35.2	+24.0	-1.1
SDII	mm/day	-0.1	+0.9	+0.3	-0.2	+1.4	+0.5	-0.2	+0.9	+0.4
CDD	days	-0.1	+17.6	+8.4	+1.4	+33.5	+19.5	+1.3	+51.8	+28.4

Table 2.25 - As in table 2.22, for precipitation extreme indices

2.2.4 The union of municipalities in northern Salento

Mean temperature

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	+1.1	+1.6	+1.3	+1.3	+2.4	+1.9	+1.4	+2.9	+2.3
RCP8.5	+1.0	+1.9	+1.5	+2.0	+3.5	+2.6	+2.9	+4.8	+3.8

Table 2.26 - Mean temperature (°C). Projected variations with respect to the 1971-2000 average, under RCP4.5 and RCP8.5 scenarios; ensemble mean variation (Mean) and minimum and maximum projected

Total precipitation

scenario	2021-2050			2041-2070			2061-2090		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5	-55.2	+29.8	-12.7	-60.0	+60.0	-16.9	-72.1	+102.7	-5.2
RCP8.5	-49.8	+58.0	-7.9	-75.6	+61.8	-34.2	-121.7	+108.0	-35.7

Table 2.27 - As in table 2.26, for precipitation

Temperature extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
FD0	days	-3.7	-0.9	-1.8	-5.9	-0.6	-2.4	-6.3	-0.8	-2.8
SU25	days	+13.2	+19.9	+16.6	+14.7	+30.6	+23.5	+17.3	+34.0	+27.8
TR20	days	+24.7	+26.2	+25.7	+25.3	+44.1	+35.4	+26.8	+51.6	+40.5
WSDI	days	+23.8	+47.9	+35.2	+34.2	+96.0	+59.1	+35.0	+132.7	+75.3
RCP8.5										
FD0	days	-5.9	-0.4	-2.2	-6.1	-0.8	-2.7	-6.8	-1.0	-3.1
SU25	days	+14.1	+23.0	+19.2	+25.3	+39.4	+30.6	+35.2	+54.6	+43.1
TR20	days	+25.9	+30.9	+28.6	+37.0	+54.9	+45.1	+53.6	+78.2	+62.1
WSDI	days	+25.9	+62.8	+43.2	+52.1	+167.0	+94.6	+83.8	+250.8	+152.9

Table 2.28 - As in table 2.26, for temperature extreme indices

Precipitation extremes

Index	Unit	2021-2050			2041-2070			2061-2090		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RCP4.5										
RX1day	mm	-3.2	+1.0	-1.8	-1.9	+7.7	+1.5	-0.7	+6.0	+2.0
R95p	mm	-27.1	+14.0	-5.0	-30.0	+15.5	-5.1	-31.2	+50.6	+4.6
SDII	mm/day	-0.5	+0.2	-0.1	-0.3	+0.5	+0.1	-0.3	+0.6	+0.3
CDD	days	-0.9	+9.4	+4.2	-0.5	+16.5	+9.5	-0.4	+20.2	+10.9
RCP8.5										
RX1day	mm	-3.5	+4.7	+0.8	-5.3	+0.9	-1.6	-11.9	+10.5	+0.8
R95p	mm	-11.5	+24.6	+5.2	-18.8	+16.2	-7.5	-40.4	+55.8	-1.0
SDII	mm/day	-0.1	+0.5	+0.2	0	+0.4	+0.2	-0.1	+0.9	+0.3
CDD	days	-0.7	+9.4	+4.4	-1.9	+28.1	+13.0	-0.3	+46.1	+25.2

Table 2.29 - As in table 2.26, for precipitation extreme indices

3 VULNERABILITY ASSESSMENT

Assessing vulnerability can be considered the most challenging and resource-consuming step of the whole adaptation process.

Vulnerability is not a measurable characteristic of a system as the “vulnerometer” does not exist. This is why it is better to talk about “assessing vulnerability” rather than “measuring” it. Vulnerability is indeed a condition of a system or sector or area, resulting from a series of different categories of factors, such as environmental, social, economic features.

In scientific literature, the term “vulnerability” is used in different ways across different disciplines. The overall concept encompasses a variety of elements and expresses the complex interaction of different factors (i.e. sensitivity or susceptibility to harm and lack of capacity to cope and adapt) that determine a system’s propensity to be adversely affected by the impacts of climate change. However, there is no fixed rule suggesting which factors to consider, nor the methods used to quantify them.

Even the Intergovernmental Panel on Climate Change (IPCC) concept of vulnerability has underwent some changes during time. In its Third (AR3) and Fourth Assessment Report (AR4), the IPCC defined vulnerability as “*a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*” (IPCC, 2007). According to this definition, vulnerability to climate change is the result of an integrated assessment of biogeophysical and socio-economic factors: exposure, sensitivity and adaptive capacity (i.e. the social and economic means to withstand climate change impacts).

In its Fifth Assessment Report (AR5, 2014), the IPCC illustrates the core concepts of “risk” and “vulnerability” and their interrelation: risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. Changes in both the climate system and the socio-economic processes, including adaptation and mitigation are drivers of hazards, exposure and vulnerability (Figure 3.1).

In this context, the procedure adopted by the LIFE MASTER-Adapt partnerhsip in order to perform the vulnerability assessment was mainly based on a review of the existing conceptual framework and approaches used by the main authoritative international sources: the scientific literature offers a wide range of examples of vulnerability assessments and the large majority of examples belong to the previous IPCC approach (AR4), while few are at the moment the applications of the new IPCC framework (AR5).

The vulnerability assessment carried out within the LIFE MASTER-Adapt project was thus based on a common methodological approach but differences in the indicators selection, weighting, normalisation and classification of values have been maintained in some cases in order to respect intrinsic specifities of each target area and data availibility. For this reason, the results obtained for each target area are not comparable each other.

3.1 Concepts and definitions

As previously mentioned, key definitions for the vulnerability assessment have undergone some changes during the last decades. Due to the existence of a wide range of concepts, definitions and methodological approaches for the vulnerability assessment it is important to clarify that this Reports adopts the following definitions taken by the Glossary of the IPCC Fifth and Fourth Assessment Report (IPCC, 2014; IPCC, 2007).

Adaptation

The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Adaptive Capacity

The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Hazard

The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.

Exposure

The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Impacts

Effects on natural and human systems. In this report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

Risk

The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure.

Resilience

The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise).

3.2 Overview of relevant literature

This chapter reflects an extensive review of the existing literature dealing with the assessment of vulnerability to climate change.
A large number of tools, guidance and methods for the climate change impacts, vulnerability and risk assessment has been developed in the recent decades by many authoritative international scientific sources all over the world. Knowledge about the different types of methods and their outputs is important for the selection of the optimal and more feasible

method to be applied in accordance with the capacities of the local authorities.
In order to accomplish the objective of the Action 1 of the LIFE MASTER-Adapt project, the selection of the most suitable method was therefore based on an initial overview of the most relevant examples developed within the European context (Table 3.1).

ASSESSMENT GUIDANCE, METHODS, FRAMEWORKS	SOURCES
The Urban Adaptation Support Tool – Covenant of Mayors for Climate and Energy	European Commission
The Covenant of Mayors for Climate and Energy Reporting Guidelines	European Commission
Urban vulnerability to climate change in Europe – an interactive Mapbook	Climate - ADAPT
GIZ Vulnerability Sourcebook	Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH in cooperation with Adelphi and EURAC research
DG CLIMA Guidelines on developing adaptation strategies	European Commission
PROVIA Guidance on assessing vulnerability, impacts and adaptation to climate change	PROVIA, 2013: PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change. Consultation document, United Nations Environment Programme, Nairobi, Kenya, 198 pp.
UKCIP Wizard and UKCIP risk framework	UKCIP, United Kingdom Climate Impacts Programme
ESPON Climate – Climate change and Territorial Effects on Regions and Local Economies	Applied Research Project within ESPON 2013 Programme
Adaptation Compass Tool	Future Cities – urban networks to face climate change EU Interreg IVB-project

Table 3.1 - Vulnerability, impacts and risk assessment approaches analyzed

3.2.1 The Urban Adaptation Support Tool

The Adaptation Support Tool has been developed as a guidance within the framework of the EU Mayors Adapt initiative, which is now part of the EU Covenant of Mayors for Climate and Energy. Among the main steps identified by this tool, "Assessing risks and vulnerabilities to climate change" represents the step aiming at the development of a comprehensive picture of current and future climate change risks in an urban area. In particular, suggestions and recommendations aim at providing a support:

i. to identify the climate change impacts originated by the past and current weather on the city;
ii. to select the methodology for a risk and vulnerability assessment;
iii. to find and understand future climate and impact projections;
iv. to deal with the uncertainties associated to the future climate projections;
v. to identify which sectors are most likely to be impacted by climate change;
vi. to find information, data and analysis assistance;
vii. to set concrete targets for adaptation.

3.2.2 The Covenant of Mayors for Climate and Energy Reporting Guidelines

This guide has been developed by the Covenant of Mayors and Mayors Adapt Offices in collaboration with the European Commission's JRC with the purpose to assist signatories in understanding the Covenant reporting framework and to provide them with a step-by-step guideline throughout the reporting process. Among the various steps, the Sustainable Energy and Climate Action Plan (SECAP) is based on a Climate Risk and Vulnerability Assessment (RVAs) which provide an analysis of the current situation. Examples of indicators for vulnerability and risk reporting are illustrated in Table 3.2 and Table 3.3.

VULNERABILITY TYPE	VULNERABILITY-RELATED INDICATORS
Socio-Economic	Population density (compared to national/Regional average in year x in country/Region x)
	% share of sensitive population groups (i.e. elderly (65+)/young (25-) people, lonely pensioner households, low income/unemployed households)
	% of population living in areas at risk (e.g. flood/drought/heat wave/ forest or land fire)
	% of areas non-accessible for emergency / fire-fighting services
Physical and Environmental	Length of transport network (e.g. road/rail) located in areas at risk (e.g. flood/drought/heat wave/ forest or land fire)
	Length of coastline / river(s) affected by extreme weather conditions / soil erosion (without adaptation)
	% of low-lying or at altitude areas
	% of areas at coasts or rivers
	% of protected (ecologically and/or culturally sensitive) areas / % of forest cover
	% ofresidential, commercial, agricultural, industrial, and touristic areas at risk (e.g. for flood/drought/heat wave/forest or land fire)

VULNERABILITY TYPE	VULNERABILITY-RELATED INDICATORS
	Current energy consumption per capita vs. projections 2020/2030/2050
	Current water consumption per capita vs. projections 2020/2030/2050

Table 3.2 - Examples of vulnerability-related indicators

CLIMATE HAZARDS TYPE	RISK-RELATED INDICATORS
Extreme heat	Number of days/nights with extreme temperature (compared to ref. annual/seasonal temperatures at day/night times)
Extreme cold	Frequency of heat/cold waves
Extreme precipitation	Number of days/nights with extreme precipitation (compared to ref. annual/seasonal precipitation at day/night times for each season)
Drought	Number of consecutive days/nights without rainfall

Table 3.3 - Examples of risk-related indicators

3.2.3 Urban vulnerability to climate change in Europe – an interactive map book

The map book provides a Europe-wide overview of the potential vulnerability of major cities to climate change, based on the IPCC AR4 vulnerability framework (IPCC, 2007). For this purpose four climatic threats are taken into account: i. heatwaves; ii. water scarcity and droughts; iii. floods and iv. forest fires and for each of such threats three categories of indicators are identified:

- Exposure: provides information about the level of exposure to climate impacts. Exposure is not influenced by climatic factors alone, but also by morphological factors such as topography, hydrological and human factors.
- Sensitivity: provides information about the susceptibility of cities to such impacts, i.e. due to population composition, spatial planning or physical conditions.
- Response capacity: provides information about characteristics that help to reduce or overcome the impacts. In particular, response capacity includes both coping capacity and adaptive capacity and is further categorized into awareness, ability and action.

The map book provides a simple framework for urban vulnerability indicators, but it should be taken into account that the coverage in several indicators is limited and many data are not yet available for projections on demographics, land use and economic change. The selection of indicators is therefore driven by data availability and the approach is thus focused on a current vulnerability assessment (Table 3.4).

	HEAT WAVES	WATER SCARCITY AND DROUGHTS	FLOODS	FOREST FIRES
Exposure	Thermal comfort	Water stress	Soil sealing	Urban areas
	Green urban areas	Population	Green urban areas	Population
	Soil sealing			
Sensitivity	Elderly people	Water consumption	Socio-economic status	Elderly people
	Socio-economic status	Elderly people	Elderly people	Socio-economic status
		Socio-economic status	Commercial, residential areas	
		Green urban areas		
Response capacity	Green urban areas	Cities engaged in initiatives	Soil sealing	Cities engaged in initiatives
	Soil sealing	Education	Green urban areas	Trust
	Cities engaged in initiatives	Trust	Cities engaged in initiatives	Education
	Trust	Socio-economic status	Trust	Socio-economic status
	Education		Education	
			Socio-economic status	

Table 3.4 - Examples of indicators used for the vulnerability assessment in the Vulnerability map book

3.2.4 The Vulnerability Sourcebook

The Vulnerability Sourcebook (Fritzsche et al., 2014) offers a practical and scientifically sound methodological approach to vulnerability assessment and provides some examples from pilot applications in Bolivia, Pakistan, Burundi and Mozambique, based on the IPCC AR4 (IPCC, 2007), as well as vulnerability definitions and framework. In particular, the guidance provides a standardized quantitative approach to vulnerability assessments covering various sectors (i.e. water resources, agriculture, fisheries, etc),at different spatial levels (i.e. community, sub-national and national) and time horizons (i.e. current, medium-to-long term vulnerability).

The approach defines the following eight modules:

- *Preparing the vulnerability assessment*: it includes the assessment of the initial situation, helps defining objectives and making key decisions on the scope of the assessment;

- *Developing impact chains*: it suggests the approach to identify the potential impacts addressed in the vulnerability assessment and to develop the impact chain in order to better understand the cause-and-effect relationship;
- *Identifying and selecting indicators*: it helps selecting the most suitable indicators for the quantitative assessment;
- *Data acquisition and management*: it shows how to acquire, review and prepare data for the vulnerability assessment;
- *Normalization of indicator data*: it explains how to transform and interpret different data sets into unit-less values on a common scale;
- *Weighting and aggregating of indicators*: it explains how to assigns weights to the selected indicators and to aggregate them into vulnerability components;
- *Aggregating vulnerability components to vulnerability*: it shows how to aggregate the vulnerability components into a composite vulnerability indicator;
- *Presenting the outcomes of Vulnerability Assessment*: it shows how best to summarize and present the results of the vulnerability assessment.

Examples of indicators used for the vulnerability assessment are illustrated in Table 3.5.

	WATER SCARCITY IN AGRICULTURE	AGRICULTURE PRODUCTION
Exposure	Precipitation	Precipitation
	Temperature	Temperature
	Evapotranspiration	Evapotranspiration
		Extreme weather events
Sensitivity	Soil type	Vegetation coverage
	Land use type	Anti-erosion measures
	Crop type	Deforestation
	Type and efficiency of irrigation system	Slope gradient
	Water demand of crops	Population density
		Irrigation system
		Crop type
		Use of agricultural techniques
		Soil type
Adaptive Capacity	Know-how about irrigation systems	Resources and Technologies: Dimension and access to cultivation areas Financial resources of households Access to agricultural techniques
	Capacity to plant more resilient crops	Availability of information: Availability of prevention measures against erosion and droughts Access to weather forecasts
	Institutional capacity to improve water distribution	Institutions and Governance: Access to agricultural training institutions
	Access to technologies to improve land management	

Table 3.5 - Examples of indicators used for the vulnerability assessment in the Vulnerability Sourcebook (Source: Fritzsche et al., 2014)

3.2.5 DG CLIMA Guidelines on developing adaptation strategies

The Commission Staff Working Document from European Commission accompanying the EU Strategy on adaptation to climate change (EC, 2013) aims to make more operational the so-called Adaptation Support Tool, one of the key features of Climate-ADAPT. The document covers a wide spectrum of issues to be addressed when developing adaptation policy-making and offers also an approach for the assessment of risks and vulnerabilities to climate change.

In order to perform a risk assessment which is tailored to policy-making needs, the first suggestion is to collect and analyze the available information about the future threats (i.e. sectoral vulnerability assessment) and the opportunities. The minimum information request for the assessment includes:

- trends of various climate variables (i.e. temperature, rainfall, snow, etc) based on one or ideally on a range of different climate scenarios;
- expected indirect and direct impacts (threats and opportunities) as a result of the identification of the most relevant hazards as well as the area at most risk given an overlay of spatial distribution of total population, vulnerable populations, economic activities and value;
- timescale, with different climate impacts scenarios: short-term (2020), medium-term (2050) and long-term (2080-2100);
- indication of the level of confidence (i.e. high, medium, low) associated to such impacts;
- assessment of socio-economic development and other non-climatic factors and megatrends such as demographic change, use of resources, market trends which could have a significant influence on vulnerability to climate change.

3.2.6 PROVIA Guidance on assessing vulnerability, impacts and adaptation to climate change

The guidance is structured along a five-stage iterative adaptation learning cycle: i. identifying adaptation needs; ii. identifying adaptation options; iii. apraising adaptation options; iv. planning and implementing adaptation actions; v. monitoring and evaluation of adaptation.

In particular, the first step aims to gain more knowledge about the risks and opportunities by answering to the following questions: *what impacts may be expected under climate change*? *what are actors' vulnerabilities and capacities*? *are vulnerable actors aware of potential threats*? *what major decisions need to be addressed*? In this case the "vulnerability concept" is used in a broad way, as the IPCC in its Special Report on extreme events and disaster risk (IPCC, 2012) which differs from the widely used one in the IPCC AR4 (IPCC, 2007) where vulnerability is a function of exposure, sensitivity and adaptive capacity.

Two sub-tasks contribute to the identification of adaptation needs:

- analysing observed or expected impacts of climate change (with or without adaptation): this step focuses on gathering information on current and future biophysical and socio-economic impacts in order to identify adaptation needs.
- analyzing the potential capacity to prevent, moderate or adapt to these impacts.

3.2.7 UKCIP Wizard and UKCIP Risk framework

The United Kingdom Climate Impacts Programme (UKCIP) Adaptation Wizard is a 5-step process to help assessing an organisation's vulnerability to current climate and future climate change, identifying options to address the organisation's key climate risks, and developing and implementing a climate change adaptation strategy. In particular, a current climate vulnerability assessment guides the user in order to:

- assess how vulnerable the organization is to the current climate;
- provide background knowledge to help thinking about how future climate change might affect;
- identify where the organization's response to previous weather events could inform the adaptation plan.

A Local Climate Impacts Profile is suggested as a simple tool designed to help organizations to assess their exposure to the weather.

Furthermore, a future climate vulnerability analysis focuses on how the climate is expected to change and helps assessing how those climatic changes could affect the system.

Also in this case the vulnerability approach is based on the IPCC AR4 framework (IPCC, 2007), which considers exposure to climate hazards, sensitivity to climatic variability and capacity to adapt.

3.2.8 ESPON Climate – Climate change and Territorial Effects on Regions and Local Economies

The conceptual core of the ESPON Climate Change Research Framework is based on the IPCC AR4 approach (IPCC, 2007) and suggests a quantitative step-by-step methodological approach aimed at the assessment of exposure, sensitivity and adaptive capacity of a system and the combination of the different components to determine the overall vulnerability to climate change (Table 3.6). As an example, a Region with a high climate change impact may still be moderately vulnerable if it is well adapted to the anticipated climate change and, on the other hand, anticipated high impacts would result in high vulnerability to climate change if combined with low Regional adaptive capacities.

EXPOSURE	SENSITIVITY	ADAPTIVE CAPACITY (Determinants/proxy indicators)
Change in annual mean temperature	Physical sensitivity: Settlements prone to heavy rainfall Settlements prone to sea level rise Infrastructure prone to sea level rise	Economic resources: GDP per capita State expenditure at Regional level

EXPOSURE	SENSITIVITY	ADAPTIVE CAPACITY (Determinants/proxy indicators)
	Infrastructure prone to heavy rainfall	Public deficit
Change in annual mean number of frost days	Environmental sensitivity: Forests Especially sensitive/protected natural areas EcoRegions especially sensitive to climate change Areas of high ecological value Fragmented natural areas	Technology: R&D investment (%GNP) Scientists and engineers in R&D per million population Telecommunication uptake N. of patent applications per million inhabitants
Change in annual mean number of summer days	Cultural sensitivity: Cultural monuments especially sensitive to climate change UNESCO World Heritage Sites especially sensitive to climate change Cultural landscapes especially sensitive to climate change Museums, galleries, theatres and public libraries especially sensitive to climate change	Infrastructure: Roads (km) Percentage of NATURA 2000 Land use Water infrastructure Energy supply and management
Relative change in annual mean precipitation in winter months	Social sensitivity: Total population Coastal population Population endangered by heavy rainfall Urban population Senior citizens	Information and skills: Education expenditure as % of GNP Share of tertiary educated people in % Health expenditure per capita Public health expenditure per capita (% of GNP) Attitudes towards climate change Public information on climate change
Change in annual mean number of days with heavy rainfall	Economic dependency/sensitivity: Share of Gross Value Added (GVA) Number of beds per 1000 inhabitants Electricity consumption by sector	Institutions: Shift from Government to governance Government effectiveness index

EXPOSURE	SENSITIVITY	ADAPTIVE CAPACITY (Determinants/proxy indicators)
		N. of project co-operations Public attitudes towards the political-administrative system Existence of a National Adaptation Strategies

Table 3.6 - Examples of vulnerability assessment indicators used within the ESPON Project

3.2.9 Adaptation Compass Tool

The Adaptation Compass has been developed by the FUTURE CITIES partnership in order to help partner organizations and other similar organizations to find their way to cope with the impacts of climate change. Specifically, it is a computer-aided guide to interlink different interests and stakeholders and to check the vulnerability and adaptation options across the sectors, through five modules: i. Check vulnerability; ii. Understand climate change impacts; iii. Assess risks and opportunities; iv. Explore adaptation options; v. Need for action.

In particular, in order to assess the current vulnerability of receptors the Adaptation Compass indicates three steps:

- Get to know the receptors and sensitivities;
- Assess the local sensitivities;
- Check the vulnerability;

which provides an overview of the vulnerability assessed for the area in the output sheet.

Furthermore the second step "*Understand climate change impacts*" consists of three sheets providing information on:

- Regional trends;
- Impacts of climate change;
- Link lists.

Finally, the third step "*Assess risks and opportunities*" identifies two tasks consisting of the assessment of the future risks and opportunities and the ranking of the risk categories.

3.3 The methodological approach

The purpose of the Action A1 was to assess the vulnerability to climate change of the selected target areas. Specifically, as foreseen by the LIFE MASTER-Adapt project, the assessment performed focused both on the exposure and the vulnerability components, while the risks were not evaluated. The methodology used for the assessment was based on the IPCC AR5 framework (Figure 3.1) and its definitions of Hazards, Vulnerability (Sensitivity and Adaptive Capacity), and Exposure (IPCC, 2014).

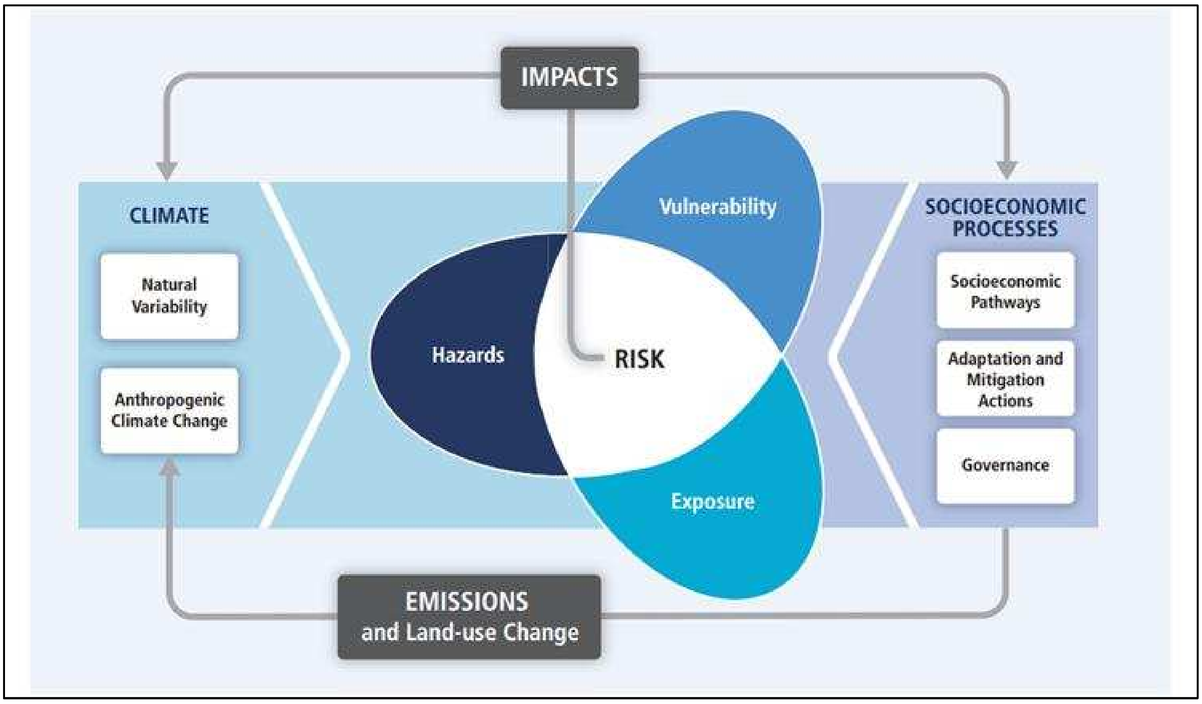

Figure 3.1 - Illustration of the core concepts of the IPCC WGII AR5 (Source: IPCC, 2014)

As illustrated in the figure, risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left side) and socio-economic processes, including adaptation and mitigation (right side), are drivers of hazards, exposure, and vulnerability.
Starting from the outcomes of the previous overview of the relevant literature, the methodological approach was definedmainly on the basis of the Vulnerability Sourcebook (Fritzsche et al., 2014). However, while the Vulnerability Sourcebook (VS) was based on the IPCC AR4 vulnerability framework (IPCC, 2007), MASTER-Adapt adapted the VS approach to the most recent IPCC AR5 vulnerability and risk framework (IPCC, 2014). Thus the following seven-steps process was identified.

3.3.1 Step 1 – Identifying the climate-related hazards

Starting from the occurrence of past climate-related hazard in each target area and based on the results of the climate analysis performed (see Chapter 2 for further details), two to four most likely climate-related hazards were selected for each area, with the help of questions such as:

- *what kind of climate-related hazards affected the target area in the recent decades*?
- *how are climate-related hazards expected to change in the target area in the future decades to the end of the century*?
- *is there adequate data for a site-specific analysis*?
- *are there experts, key local stakeholders, available to provide their support/expert judgement for this purpose*?

Both typology and probability, based on a qualitative approach, were listed for each target area (Table 3.7).

TARGET AREA	HAZARD TYPOLOGY	HAZARD PROBABILITY
Area 1	Heatwaves	High
	Extreme precipitation events	Very high
	…	…
Area 2	Sea level rise	Very high
	Average temperature increase	High
	…	…
Area n	…	…

Table 3.7 - Examples of climate-related hazards in the target areas

3.3.2 Step 2 – Identifying the potential impacts of climate change

The identification of the potential impacts which will likely to occur in the target areas as a consequence of the selected climate-related hazards was firstly performed starting with a desktop review of potential impacts based on the available local studies, researches, scientific sources and planning documents dealing with climate change and its impacts. Furthermore, local expert knowledge, statistics/data and IC technology provided highly useful information for this purpose.
In order to ensure that at least two to four relevant impacts affecting the area are captured, the list of potential impacts was then discussed, completed and shared with the key local stakeholders of each target area. In this case, examples of the most relevant questions have

been the following:

- *have previously identified climate-related hazards impacted the target area in the past/recent decades*?
- *what kind of natural resources have been affected as a result of these climate-related hazards*?
- *what socio-economic sectors have been affected as a result of these climate-related hazards*?

Based on such information dealing with the consequences of past climate-related events, a list of the two to four most relevant potential impacts that may occur in the future as a result of climate-related events was defined and clustered into a large category (Table 3.8).

TARGET AREA	HAZARD	POTENTIAL IMPACT
Area 1	Heat waves	Urban Heat Island
	Extreme precipitation events	Flooding
		Drought
		Yield loss in agriculture
Area 2	Sea level rise	Coastal erosion
	Average and extreme temperature increase	Loss of biodiversity
		Fire
Area n	…	…

Table 3.8 - Examples of potential impacts for each climate-related hazard

The potential impacts thus identified represent those impacts clearly related to/aggravated by climate change in each target area.

3.3.3 Step 3 – Defining the territorial and socio-economic context of the target area

Once identified the most relevant potential impacts for each target area, the next step was the definition of the general context of the target area: for each target area the territorial (e.g. localization of the area, climate macro-region, river basins, natural areas and resources, etc.) and social framework (e.g. population and its structure, density, main economic activities, etc.) were described with the aim to provide a preliminary basis for the vulnerability analysis.

3.3.4 Step 4 – Assessing exposure to climate-related hazards

Following the IPCC AR5 approach (IPCC, 2014), exposure is not included in the concept of vulnerability, which is just a combination of sensitivity and adaptive capacity (Step 7).
For this reason MASTER-Adapt's approach considered the exposure assessment as a standing-alone step, supporting a more adequate contextualisation of the analysis. Step 4 can be therefore considered as a specific in-depth analysis enriching the output of Step 3 and at the same time a complementary component to Sensitivity (Step 5) and Adaptive Capacity (Step 6).

Selection of the exposure indicators.
In addition to the general context of the area, the exposure analysis was performed in order to measure the presence of people, livelihoods, species or ecosystems, and so on, in places that could be adversely affected by climate change and to elaborate a synthetic global exposure index. Table 3.9 lists the main categories for exposure indicators and suggests some examples of receptors.

CATEGORIES FOR EXPOSURE	DESCRIPTION	RECEPTORS
Natural capital	Natural capital includes all the systems, the resources and the natural processes producing goods and services	Forested areas Natural protected areas Species and ecosystems
Human capital	Human capital focuses on health, knowledge, abilities, etc	Population
Manufactured capital	Manufactured capital includes all the manufactured goods produced by human beings	Industrial assets Commercial assets Cultural heritage
Economic and financial capital	Economic and financial capital allowing that the former types of capital are owned and traded	Gross Value Added Gross Domestic Product

Table 3.9 - Categories for exposure to climate change and examples of receptors

The key question here is: *are there people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, economic, social, cultural assets in places that could be adversely affected in the target area*?
For this purpose specific indicators were identified, possibly at least one indicator for each category.

CATEGORIES FOR EXPOSURE	EXPOSURE INDICATORS
Natural capital	Livestock: caw/sheep/pig density (n. km^{-2})
Human capital	Population in potentially affected area (%) (i.e. flood prone areas, drought prone areas, etc)
Manufactured capital	Key services in potentially affected area (%) (i.e. flood prone areas, drought prone areas, etc) Assets: industrial areas (%), residential areas (%)
Economic and financial capital	Gross Value Added – Agriculture (€) Gross Value Added – Industry (€)

Table 3.10 - Examples of exposure indicators

Data collection. Starting from the intrinsic specificities of each potential impact defined in Step 2, and the type of exposure indicators previously identified, a geodatabase allowing the collection, management, sharing and processing of geographic data structured by different information levels, has been realised.

By using the tools of Geographical Information System and the Remote Sensing analysis, it was possible to process data to build and analyse indicators. The main sources of data and information were the following: data from regional and local planning; Information and Communication Technology; Statistical National Institute (ISTAT); National Environmental Information System of ISPRA; and the Environmental Information System of Regions and Regional Environmental Protection Agencies (ARPA), and many others.

Normalisation of indicator values. In order to elaborate a synthetic global index on exposure, all the values obtained for the exposure indicators were "normalised" with the purpose to transform the indicators values measured at different scales and in different units into unit-less values on a common scale. In fact, if indicators are expressed in different units this means that they cannot be compared nor aggregated into a global index. Depending on the scale of measurement, (i.e. metric, nominal, ordinal) different methods of normalisation were used.

Normalisation of metric indicator values. Indicators measured using a metric scale (i.e. temperature, precipitation) were normalised by applying the following Min-Max method:

$$\mathbf{X_{i,0\ to\ 1} = (X_i - X_{min}) / (X_{max} - X_{min})}$$

where,

$X_{i,0\ to\ 1}$ = the new value normalised

X_i = the data point to be transformed

X_{min} = the lowest value for that indicator
X_{max} = the highest value for that indicator

The normalisation process transformed the indicator values in metric scales to a standardised value range from 0 to 1. After this transformation, the indicator values were examined in order to verify the "direction" of the value range: lower values should reflect positive conditions in terms of exposure and higher values negative conditions. In case the direction of the indicator's value range is negative, which means that exposure increases as the indicator values decreases, the value range of the indicator should be inverted so that the lowest value is represented by the standardised value of 1 and the highest is represented by the standardised value 0. This inversion means simply subtracting the value from 1.

Normalisation of categorical indicator values (ordinal and nominal category). In order to normalise categorical indicator values (i.e. ordinal category indicators such as education level and nominal category indicators such as type of crop) a five-class evaluation scheme was applied, with the most positive conditions represented by the lowest class and the most negative represented by the highest class (Table 3.11).

CLASS N.	DESCRIPTION
1	Optimal
2	Rather positive
3	Neutral
4	Rather negative
5	Critical

Table 3.11 - The five-class scale for categorical indicators

Each indicator value for nominally scaled data (i.e. type of crop) was then allocated to one of the five classes, on the basis of the meaning attributed to the indicator within the context of the exposure assessment. This allocation was supported by the best available knowledge (i.e. scientific literature, local experts, and other reliable sources).
The classified values were then transformed into the value range of 0 to 1 (Table 3.12).

CLASS N.	DESCRIPTION	CLASS VALUE		Indicator value range (0 to 1)
1	Optimal	0 – 0,2		0,1
2	Rather positive	➢ 0,2 – 0,4	=>	0,3
3	Neutral	➢ 0,4 – 0,6		0,5
4	Rather negative	➢ 0,6 – 0,8		0,7
5	Critical	➢ 0,8 - 1		0,9

Table 3.12 - Transformation of normalised indicator values on a categorical scale to the value range 0 - 1

Weighting of indicators. The selected indicators do not necessarily have equal influence on the evaluation. In case some indicators are considered more important than others, different weights should be assigned to them, thus meaning that indicators that receive a greater (or lesser) weight have a greater (or lesser) influence within the evaluation. Due to the lack of specifically sound scientific literature, information and expert opinion, and to the complexity of the process, in three target areas over four the indicators were not weighted and equal weights to all indicators were assigned (weight value 1). Just in the case of the aggregation of municipalities in the northern Milan area, a weighting process was attempted. In this latter case, the weighting procedure has been performed by means of the Analytic Hierarchy Process (AHP) method. The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), is an effective tool for dealing with complex decision making. It utilizes a series of pairwise comparisons to reduce complex decisions. A check over the consistency of the pairwise attributions is also integrated in the methodology, to evaluate the robustness of the choice made.
In the present case, the pairwise comparison has been submitted to the judgement of local and academic experts in order to obtain a tentative set of weights for the considered indexes. Admittedly, this procedure introduces an explicit share of subjectivity and discretion; yet, it aims to illustrate as an example the particular importance of the indicator weighting phase in the determination of the overall vulnerability.

Aggregation of indicators into a Global Exposure Index. In order to aggregate the normalised indicators into a synthetic global exposure index, a “weighted arithmetic aggregation” method was used, which is a common, simple and transparent aggregation procedure. With this method, the normalised values of the selected indicators were multiplied by their weight (when assigned), summed and subsequently divided by the sum of their weights based on the following formula:

$$\textbf{Global Exposure Index} = (E_1 * w_1 + E_2 * w_2 + \ldots E_n * w_n) / (w_1 + w_2 + \ldots + w_n)$$

In case of equal weighting (three target areas over four), indicators were simply summed and divided by the number of indicators. For meaningful aggregation of indicators, all the indicators were verified to be aligned in the right direction: a low score represents a low value and a high score a high value in terms of exposure.

Mapping the Global Exposure Index. The final result of the aggregation of indicators into a Global Exposure Index was represented through maps with a five-class classification.

3.3.5 Step 5 – Assessing Sensitivity

This step was addressed to identify the systems that are likely to be affected as a consequence of climate change, as they should be considered more sensitive to climate change. Examples of guiding questions here were the following (Fritzsche et al., 2014; Giordano et al., 2013):

- *what are the characteristics of the system which make it susceptible to adverse effects of the changing signal(s) identified in the previous step*?
- *are the systems subject to existing stress*?
- *how do these climate conditions affect these systems*?

There are various attributes or properties that could influence sensitivity to climate change, such as biophysical and/or physical characteristics of the system: physical and mental health and age (in case of socio-economic targets); type and density of vegetation cover, health, connectivity and robustness of the ecosystem (in case of ecosystems), and so on. These characteristics are usually inherent in the system and the indicators tend to be more stable and constant (Fritzsche et al., 2014).

In order to elaborate the Global Sensitivity Index the same procedure described in Step 4 was implemented, specifically:

i. selection of the sensitivity indicators;
ii. data collection;
iii. normalisation of indicator values;
iv. alignment of indicators;
v. weighting of indicators (when feasible);
vi. aggregation of indicators into a Global Sensitivity Index;
vii. mapping the Global Sensitivity Index.

Coherently to the categories for exposure, four categories were identified for sensitivity, including both the potential sensitive receptors as well as the factors that tend to increase sensitivity to climate change (Table 3.13).

CATEGORIES FOR SENSITIVITY INDICATORS	DESCRIPTION
Natural factors	Natural receptors characterized by conditions, structure, biophysical and physiological elements that make them susceptible to be affected by climate change. Natural elements sometimes could contributes themselves to increase the sensitivity of systems to climate change.
Human factors	Human receptors presenting a inherent physiological and/or socio-economic status which make them susceptible to be affected by climate change.
Manufactured factors	Manufactured receptors with inherent physical characteristics, structure, conditions, making them susceptible to be affected by climate change. Manufactured elements sometimes could contribute themselves to increase the sensitivity of systems to climate change.
Economic and financial factors	Economic and financial receptors which are susceptible to be affected by climate change as a consequence of their characteristics, structure, etc. Economic and financial elements sometimes could contribute themselves to increase the susceptibility of systems to be affected by climate change.

Table 3.13 - Categories for sensitivity indicators

The selection of sensitivity indicators (Table 3.14) was mainly based on scientific literature, even if the majority of examples available are still built within the previous IPCC vulnerability conceptual framework (IPCC, 2007). Some efforts were made in order to overcome the misunderstandings in moving from the previous approach to the new one. Key stakeholders were involved at this stage in order to share with them the selection of indicators. Where possible, at least one indicator for each category was selected.

CATEGORIES FOR SENSITIVITY INDICATORS	SENSITIVITY INDICATORS
Natural factors	Green urban areas (%) Type of vegetation cover (%)
Human factors	Population over 65 years (%) Population under 6 years (%) Population of low income households (%)
Manufactured factors	Low-level building state Soil sealing (%)
Economic and financial factors	Wine production incomes Business size

Table 3.14 - Examples of sensitivity indicators

3.3.6 Step 6 - Assessing Adaptive Capacity

The adaptive capacity of the system was investigated with respect to each potential impact identified in the Step 2. In order to elaborate the Global Adaptive Capacity Index the same procedure described in Step 4 was implemented, specifically:

i. selection of the adaptive capacity indicators
ii. data collection
iii. normalisation of indicator values
iv. alignment of indicators
v. weighting of indicators (when feasible)
vi. aggregation of indicators into a Global Adaptive Capacity Index
vii. mapping the Global Adaptive Capacity Index

Sensitivity and adaptive capacity could be sometimes confused. Adaptive capacity includes the intrinsic quality of a system that makes it more or less capable to adapt, but can also reflect the abilities to collect and analyze information, communicate, plan, and implement adaptation strategies that ultimately reduce vulnerability to climate change impacts (Giordano et al., 2013). The key question of this step was the following:

- *which capacities and resources within the system will allow to address climate change impacts*?

The capacity of a system to cope with a climate-related impact should be therefore evaluated on a future perspective, while the sensitivity was intended as a current characteristic of the system analysed.
In order to structure the approach, four dimension of adaptive capacity were taken into account (Table 3.15).

DIMENSIONS OF ADAPTIVE CAPACITY	DESCRIPTION
Institutions *(how does the institutional environment contribute to adaptive capacity?)*	Corruption, local budget, update of local urban plan, involvement and responsibility, effectiveness of government action, etc.
Knowledge and technology *(is there knowledge or expertise which might aid adaptation? are there technical options available and affordable which could enhance adaptive capacity?)*	Education level, university degree, master degree, research and development patents.
Manufacture/Infrastructure *(which infrastructure are available in order to enhance adaptive capacity?)*	Transport (roads, railways, etc), informal networks (families with telephone, mobile and internet connection), living conditions, access to water, internet use, use of the power grid, distance from public health structures, etc.
Economic resources *(which economic and financial resources are available for enhancing adaptive capacity or implementing adaptation measures?)*	Per capita income (GDP; etc.), poverty (% people living in poverty, etc), lack of access to financial resources, standard of living, population growth, diversification of income, dependence rate, unemployment rate, etc.).

Table 3.15 - The four dimensions of adaptive capacity

In identifying adaptive capacity, the specific characteristics directly linked to the potential impact as well as more generic issues were considered. Indicators for adaptive capacity were not always available and easy to access at local level due to resource constraints (time and budget). Key stakeholders were involved at this stage in order to find a consensus by the key actors at local level. Where feasible, at least one indicator for each category was selected (Table 3.16).

DIMENSIONS OF ADAPTIVE CAPACITY	DESCRIPTION
Institutions	Plans last update (Year) Institutional commitment against climate change (N initiatives)
Knowledge and technology	People with a degree (%) Early warning systems (N)
Manufacture/Infrastructure	People with internet connection (%) Beds in the hospital (N/tot population)
Economic resources	GDP per capita (€) Funds for environmental protection (€)

Table 3.16 - Examples of adaptive capacity indicators

In order to calculate the Global Adaptive Capacity Index, the normalization process was performed to assign values ranging from 0 to 1.

For representing the adaptive capacity of a system, most of the indicators were “inverted in sign”: lower values should reflect positive conditions in terms of adaptive capacity (higher adaptive capacity) and higher values negative conditions (lower adaptive capacity). The inversion means simply subtracting the value from 1.

3.3.7 Step 7 - Assessing Vulnerability to climate change

Based on the IPCC AR5 framework (IPCC, 2014), Vulnerability was elaborated as the combination result of the Global Sensitivity and Adaptive Capacity components. Also in this case, the Global Vulnerability Index was obtained by using the arithmetic aggregation of the two components. The Global Vulnerability Index was then obtained using the following formula:

$$V = (S * w_{s1} + AC * w_{ac}) / w_s + w_{ac}$$

where,

V = is the Global Vulnerability Index
S = is the Global Sensitivity Index
AC = is the Global Adaptive Capacity Index
w_i = is the weight assigned each time to each component

The results of the Global Vulnerability Index thus obtained were mapped for each target area, based on a five-class classification scheme.

3.4 Regional level: Sardinia

3.4.1 Characterization of the area

Sardinia, with an area of 24,100 km^2, is the second largest island in the Mediterranean Sea.
The territory has a wide variety of ecosystems with a mountainous hilly aspect of limited altitude (average 338 m asl), geologically rich: metamorphic formations in the Gennargentu (with the highest elevation of the island - Punta La Marmora 1,834 m) and in the southern area (Linas, Monte Arcosu and Sette Fratelli); calcareous-dolomite tabs (Tacchi) in the central-eastern part; the chains of Marghine, Goceano and Monti di Alà Dei Sardi that form a natural

barrier with SO-NE direction and divide Sardinia into two parts. In the northern part of Sardinia emerges the granitic massif of Limbara.

The dominant hilly aspect of the Sardinian landscape is due to the presence of highlands, among which are the granitic highlands of the Nuorese and Buddusò; the calcareous ones of Anglona, Logudoro and Planargia planks; the basaltic highlands of Abbasanta, Campeda and central-southern Sardinia (Giare).

The island is characterized by two broad plains: the plain of the Campidano, which develops for about 100 km between Cagliari and Oristano and the Nurra to the northwest of the island between the Gulf of Asinara and Alghero.

The coasts are largely high and rocky with small creeks, with shallow and sandy coasts and numerous coastal ponds in the southern and western areas. The region has several smaller islands, of which only a few inhabited (Sant'Antioco, San Pietro, La Maddalena) and numerous ones under protection, including the National Parks of Asinara and the archipelago of La Maddalena-Caprera.

The fauna and vegetation heritage is characterized by many endemism and, for species common to the Mediterranean and European context, differentiations due to geographical isolation.

Watercourses have irregular and torrential hydrological regimens, with flow rates linked to pluviometric events and characterized by highlights in late-fall and lean months in the summer season. Only the major waterways (Tirso, Flumendosa, Coghinas, Cedrino, Liscia, Flumini Mannu and Temo) have perennial character but also due to numerous artificial barriers along their course, they have considerably limited outflows during the summer months.

The lakes are all of artificial origin. The most important is Lake Omodeo, with a capacity of 800 million cubic meters (about half of the regional total). The only natural lake is the Baratz, located in the north-western part of the island.

The total regional production of municipal waste in 2013 amounts to approximately 732,667.90 t (+ 3% in one year), about half of which is differentiated.

Sardinia is a special statutory region with legislative and administrative autonomy in various fields, divided into four provinces (Sassari, Nuoro, Oristano and South Sardinia), a metropolitan city (Cagliari) and 377 municipalities, very variable in surface area (547 km^2 Sassari, 2.47 Modolo) and number of inhabitants (154,386 inhabitants Cagliari, 83 Baradili).

In 2016, Sardinia had 1,658,138 inhabitants: in the last ten years, the resident population has declined overall, despite the migration flows of predominantly young and active foreign nationals who do not compensate the demographic decline due to natural dynamics. The gradual aging of the population is evident from an old-age index (187.9), one of the highest value at national level.

Sardinia has a high number of people at risk of poverty and social exclusion (30.1% of the population in 2012) and a low labor intensity (15.6%). The Sardinian population registers an economic condition below the national average (average income tax for 2012: Italy € 19,309, Sardinia € 16,679) and with extremely different data within the Region.

In 2013, the employment rate of 20-64 years stands at an average of 51.66% with significant gender variations: 61% male and 42.3% female.

The data show a weight of hospital spending on total health more than the national standard (49.27% in 2013 vs. 44% national) to the detriment of district spending (45.6% in 2013 compared with 51% nationally), with a consequent contraction in the quantity and quality of the benefits provided.

This situation, coupled with the criticalities, associated with the demographic structure of the Sardinian population (over65 21% of the population, over75 10%), entails an increasing demand for services and assistance by municipal social services.

Urban settlement, excluding the polarities of Cagliari and Sassari and the city of Olbia, is distributed over the regional territory without major concentrations. The metropolitan area of Cagliari is the main attraction of the island and the municipalities of the first and second belts are all served at high levels. At the other end of the region is the area of gravity of Sassari, restricted to the municipalities of its first belt, and the urban area of Olbia.

The theme of sustainable mobility of people and goods has become one of the main topics in the region environmental policies in recent years. Data on TPL in the three urban poles of Cagliari, Sassari and Olbia show a growth in demand for mobility with public transport: Cagliari reached 3rd place in 2012 among provincial capitals.

The tendency to favor the use of the car is confirmed by the high motorization rate (628.8 cars per 1,000 inhabitants in Sassari, 671.1 in Cagliari and 703.6 in Olbia).

CO_2 emissions for 2011 are broken down by three main sectors: electricity 78.1%, heat 4.3% and transport 17.6%. The domestic sector is the one that has the highest incidence of consumption, followed by the industrial one in which the main carrier continues to be fuel oil.

The share of electric power consumption by FER is 19% versus 23.8% national. In recent years, the development of electricity generation from renewable sources has increased by 30%. This production has generated criticality in the regional distribution system, which is not yet adapted to the new electrical requirements that derive from distributed production. Another critical factor is due to the lack of natural gas that aggravates the energy bill.

The Sardinian economy is still a traditional one and substantially slow in the process of innovation and research, access to new markets and hence the definition of new productive and employment opportunities. The regional economic system shows a contraction of 2.6% of GDP (19,305.57 per capita in 2015) in real terms and an average annual growth of the last decade of 0.5%, with a modest level of commercial opening up to foreign markets and a low export capacity. The propensity to export in the most dynamic compartments at international level is steadily worsening since 2004 and is very far from the national figure (5.4% versus 29.6% in 2013), which is associated with an entrepreneurial structure formed by small businesses. The modest presence of exogenous investments and the weakness of the infrastructures represent a critical point for the establishment of new businesses.

The slowdown in network infrastructure development has helped to increase the gap between urban areas and internal areas by accentuating the marginalization of the latter ones, aggravated by the aging of the population and the gradual movement of the young population.

Sardinia is characterized by the presence of important cultural assets (both material and immaterial), an expression of a significant heritage of identity and of the archaeological and historical heritage of the island. Faced with this natural and cultural heritage, Sardinia has not yet fully exploited its resources, especially in terms of organization of management and amplitude of fruition.

Tourism is a strategic sector with broad potential in terms of economic growth, job creation, diversification of the productive structure, preservation of cultural specificities, protection and enhancement of the environment. Tourist attractions are concentrated in the months between June and September (about 83%) with a peak in August. Accommodation facilities are largely located along the coast.

The insularity and the considerable presence of rare endemic species and delicate and transitional habitats make the Sardinia environmental system particularly vulnerable to climate change impacts in the Mediterranean region which, along with the effects of anthropic pressures (fires, overpopulation, salinisation of the groundwater acquifer and irrigated soils, etc.), convey that area among the most vulnerable in Europe: the underlying studies of the National Adaptation Strategy (MATTM, 2013) agree that the effects will be particularly negative.

With different conclusions depending on the evolutionary reference scenario, in Sardinia there is a significant increase in extreme events, both in terms of precipitation and temperature.

The climate analysis in chapter 2 reports that a warming tendency characterizes medium, maximum, and minimum temperature series since the early ‘80s, especially there is an increase of the indices describing extremes of heat and a reduction of extremes of cold (number of tropical nights, summer days and warm nights), while a tendency to a precipitation reduction doesn’t show a clear and significant trend. Almost all the Sardinia Region is classified as “semi-arid”, with the exception of some north-western and south-eastern areas, which are “dry sub-humid”.

The insularity also makes the region particularly vulnerable to the effects of rising surface temperature (+1.3 ° C), level (up to 30 cm) and acidity of the sea in the Mediterranean basin.

Observable events concern the recent occurrence of calamitous phenomena linked to hydrogeological and flood disruption and the intensification of the coastal erosion phenomenon. On above over 1,800 km of coastline, 802 km of rocky coasts have been classified at risk of landslide, with 83 km of high criticality.

Because of the expansive and disordered urbanization of recent decades, alluvial events have caused heavy repercussions on the island's economic and social structure, until to the loss of human lives. The Hydrogeological Regional Plan shows that municipalities with landslide risk are 241 (64%) for an area of 3,044 km^2, while those with hydraulic risk are 228 for an area of about 306 km^2.

The risk of fires (caused by human activity for the 90%) is very high and concerns about a quarter of the regional territory. By 2013, the forest area covered by fire still accounted for 0.9% of the entire regional forested area: a figure that saw Sardinia in third place in Italy.

The fire occurrence dataset, obtained from the Corpo Forestale e di Vigilanza Ambientale (CFVA), reports fires involving areas bigger than 1 ha. From 2004 to 2016, fire activity in Sardinia showed a high variability. The dataset comprises a total of 226,480 ha of burned area, corresponding to 9.43% over the total Italian area, and about 12,770 fire ignitions. The annual average burned area was about 17,400 ha. The maximum recorded burned area occurred in 2004, 2007, 2009 and 2011 (52% of the total). After 2011, a significant decrease of burned area occurred. For example, the fire season in 2015 registered a -53% respect to the 2004-2016 mean, while the 2016 fire season was about -15% (similarly to 2012, 2013 and 2014). On the other hand, the mean burned area *per* ignition was about 23 ha in 2016, higher than the 32% of the 2004-2016 mean. During the analyzed period (2004 to 2016), fire ignitions in the summer period (July, 28%, August, 21%, and September, 16%) represented 65% over the total. The peak of burned area is observed in July, accounting for 52% of the annual area burned. Similarly to other Mediterranean areas, a relatively small number of large fires are responsible for the majority of the burned area; only the 2% of fires bigger than 100 ha were responsible for the 56% of the burned area. This trend varies among the different Sardinian provinces. In particular, the Metropolitan area of Cagliari registered a high number of small fires (87%) that accounted for the 39% of burned area.

In addition, drought is a particularly relevant issue for Sardinia Region, especially in the last years and during the summer seasons. The losses in water resource distribution networks are still a critical one: in 2012, the percentage value was 54.8%. Measured data revealed that in the hydrological year 2015-2016 rainfall was lower than average with a deficit of around 20% on a regional basis. In 2017, rainfall ranges from a minimum of 30% of Campidano Plain to a maximum of 45% of Logudoro area, where the first months of 2017 are the most drought recorded since the beginning of the observations in 1922. Also for other areas, 2017 is among the first critical cases recorded in nearly 100 years of observations. During spring (March-April-May) a deficit in precipitation of around 70% for all areas has been recorded, so 2017 is one of the most critical year ever recorded in Sardinia since 1922. Harvests of cereal growers are reduced at a minimum historical record. Natural pastures are not able to satisfy livestock need and it is necessary to buy hay at high prices. But also woods, vineyards, olive groves and orchards, and all field crops are suffering for drought.

The Sardinia Region already asked to the National government for the “state of natural calamity” for the severe drought that is kneeling the countryside from north to south of the island. The request does not concern individual areas but the entire regional territory.

Based on the climate analysis reported in Chapter 2, and on the historical events that affected Sardinia Region, the vulnerability analysis focused on two main potential impacts that can be exacerbated by the changing climate: Fire and Drought. Each potential impact is separately analyzed per each Municipality of the Region and the results are reported in the following section.

3.4.2 Fire and drought

Exposure analysis

The list of exposure indicators used to identify the main categories of assets and services exposed to fire and drought is reported in the table below. They vary from people and animals living in each municipality of the Sardinia Region to the density of arable farms. These indicators are expressed as number per km^2 to highlight the total amount of people, livestock, and farms insisting on the territory. Also industrial and residential areas could be affected by fire and are expressed as percentage of the surface occupied by these two categories. The regional surfaces occupied by forests and Mediterranean maquis vegetation are considered as the two vegetation categories mainly exposed to fire, while the used agriculture land is considered as indicator of the most exposed area to drought.

Each indicator has been classified in 5 classes, representing the level of exposure at the potential impact. The class 1 represents the lower exposure level (optimal condition), while class 5 indicates the highest exposure level (critical condition). Classes 2 and 4 represent the medium-low (rather positive condition) and medium-high level of exposure (rather negative condition), while class 3 indicates a medium level (neutral condition).

All indicators have been calculated for each municipality and the values reported in the table are the average values for the entire Region.

All indicators have been calculated for each municipality and the values reported in the table are the average values for the entire Region.

	Fire	Drought	Result	Normalized result
Inhabitants: Population density (n/km^2)	X	X	78,31	0,02
Livestock: Caws density (n/km^2)	X	X	9,09	0,02
Livestock: Sheep density (n/km^2)	X	X	160,83	0,12
Livestock: Pigs density (n/km^2)	X	X	7,27	0,02
Enterprises: Arable farms (n/km^2)	X		3,51	0,11
Assets: Industrial areas (%)	X		1,04	0,03

<table>
<tr><td>Assets: Residential areas (%)</td><td>x</td><td></td><td>2,31</td><td>0,06</td></tr>
<tr><td>Forested areas (%)</td><td>x</td><td></td><td>20,35</td><td>0,27</td></tr>
<tr><td>Maquis area (%)</td><td>x</td><td></td><td>21,83</td><td>0,31</td></tr>
<tr><td>Used agriculture land (%)</td><td></td><td>x</td><td>53,34</td><td>0,14</td></tr>
<tr><td colspan="5">Global Exposure Index</td></tr>
<tr><td rowspan="4">Brief comment</td><td colspan="4"><u>Human capital:</u> It is represented by population density at municipality level. Higher values mean higher exposure level. Population density varied from about 4 people km^{-2} to 3207 people km^{-2}. Lower value was reported for Semestene, a village in the north of Sardinia (in the Sassari County). Values higher than 1000 people km^{-2} were observed in Selargius and Cagliari, while the highest one in Monserrato, which represents an area close to Cagliari, with a recent development in the construction, economic, social and cultural sectors. In addition in Monserrato, in recent years, the University Citadel has grown up, a large complex in which several departments of the University of Cagliari have been devolved, and it also includes a University Medical Hospital. At regional level, however, human capital is classified as class 1 (low exposure level).</td></tr>
<tr><td colspan="4"><u>Manufactured capital</u>: Residential and industrial areas, as well as the density of arable farms are considered part of the infrastructure capital. Arable farms (>10 km^{-2}) are mainly concentrated in the north of Sardinia (Ittiri, Sorso, Sennori) and in the Medium Campidano plain. Residential and industrial areas are mainly located in the Cagliari Metropolitan Area. All these areas are the most exposed to fire, even if at regional level they are classified in class 1.</td></tr>
<tr><td colspan="4"><u>Economic capital:</u> It is represented by the caws, sheep and pigs bred in the Region. Caws are mainly located in Arborea (in the Campidano plain), which represents the municipality with the highest caws density (372 animals km^{-2}). It is the most productive area for milk and agriculture products. Most of sheep are, instead, bred in Ittiri (1290 animals km^{-2}), near Sassari, in the North of Sardinia. Pigs are bred all over the island, but at a general low density. At regional scale livestock is classified in class 1.</td></tr>
<tr><td colspan="4"><u>Natural capital:</u> Maquis vegetation is mainly distributed in the Sassari, Nuoro, and Cagliari Counties, with different municipalities having more than 50% of surface occupied by this vegetation type. Territories in the middle of Sardinia region are occupied by more than 50% with forested areas (up to 74%). These two vegetation categories cover high part of Sardinia, but at regional level they represent about the 40% of total area. The exposure class for fire is medium-low (2). The used agriculture land represents more than 50% of the Sardinian surface, and Sassari is the municipality with the highest value. However, the normalized indicator is in class 1 for drought.</td></tr>
</table>

Table 3.17 - Exposure indicators and Global Index

Sensitivity analysis

The table below summarizes the main sensitivity indicators used both for fire and drought at regional level.

To analyze the sensitivity level of the Sardinian territories to fire, the following indicators were selected: the percentage of forested, mixed and sparse vegetated areas and maquis areas, the presence of arable, not irrigated land, children (under 6 years), and older people (over 60 years). All indicators are expressed in %, and would give an indication of the typologies of areas and population that could be most impacted by fire and drought. Forested and maquis areas are used both as exposure and sensitivity indicators. In the first case they express the surface occupied by these two vegetation types that could be potentially exposed to fire, while in the second case they would represent the level of sensitivity (i.e. major areas mean major sensitivity of the surface to be impacted by fire). All indicators have been classified, and high class values represent higher sensitivity level (i.e. high indicator values mean that the potential impact of climate change will be higher for the respective category).

For drought, the percentage of arable irrigated areas has been added, but the normalized values were considered in an opposite order: most irrigated areas are present in the municipality, less sensitive the area will be to drought. In this case, low class was assigned to high normalized values and indicate a low sensitivity level.

	Fire	Drought	Result	Normalized result
Forested areas (%)	x		20,35	0,27
Maquis areas (%)	x		21,83	0,31
Arable, not irrigated, land (%)	x	x	30,22	0,36
Arable irrigated areas (%)		x	10,06	0,88
Areas with sparse vegetation (%)	x		1,51	0,07
Share of elderly people (> 60 yrs) (%)	x	x	30,94	0,41
Share of very young people (<6 yrs) (%)	x	x	5,34	0,55
Global Sensitivity Index				
Brief comment	<u>Natural factor:</u> *Forested and maquis areas are used to indicate the sensitivity of natural vegetation to fire. Higher class values mean higher sensitivity. The single indicators are described in the exposure table above and are classified in a medium-low sensitivity class (2). In addition, the areas with sparse vegetation cover a low part of the Region, so their sensitivity to fire is considered low (class 1).* *About 84 municipalities in the Region have more than 50% of the land not irrigated, so they are more sensitive both to fire and drought. However, at regional level this indicator is within class 2 (medium-low).*			

	Irrigation is quite diffuse for agriculture land. The Campidano plain has the higher percentage of irrigated land (> 50%), since it is the most agriculture productive area, while in the other areas irrigation is diffuse but with lower percentage values. Irrigated land is less sensitive to drought, so at regional level they are classified as class 1 (low level, see explanation in the text).
	Human factor: *It is recognized that climate change will primary affect children and old people. Only two municipalities have less than 10% of elderly people, while high values (up to 217 %) are common in most of Sardinia. Very young population (> 10%) is mainly concentrated in the middle and in the South of the Region. Elderly and young population have been classified at a medium sensitivity level both for fire and drought (neutral condition).*

Table 3.18 - Sensitivity indicators and Global Index

Adaptive capacity analysis

The level of education and economic resources available in the territory is considered an indication of the capacity to respond or manage an event. People with a high level of education (degree and master degree) and with higher *per capita* income can be facilitated to have easier access to information and tools (for example early warning tools) to understand and manage. So, a higher educational and economic level is considered an indicator of higher capacity of the society to respond and manage adverse events (i.e minor contribute to vulnerability). On the contrary, high level of unemployment represents low adaptive capacity and major contribute to vulnerability.

According to the methodological framework reported in paragraph 3.2, for espressing the adaptive capacity of the system, the normalized values of all indicators were changed in sign. The direction of adaptive capacity indicators was changed by simply subtracting from 1 the normalized value of the indicator. This means that low results in terms of adaptive capacity (i.e. low adaptation commitment, low incidence of farmers with agro-environmental diploma/degree, low per capita income) have higher normalized result (the lowest=1). So, high normalized values indicate a major contribution to the vulnerability analysis meaning a lower adaptive capacity (identified by the highest classes 4 and 5). The unemployment indicator, instead, followed the same rule as for the exposure and sensitivity analysis and the normalized values were not "inverted in sign".

Since fire and drought are mainly related to the agriculture and forestry sector, the percentage of people employed in the primary service has been used to analyze the capacity for adaptation.

Sardinia region is quite active in fire management. Different regional agencies have been established to cope and prevent wildfire events, such as FORESTAS and CFVA. In addition, fire fighters and voluntary people are involved in this regional priority. Per each of the four

Sardinian prefectures (Sassari, Cagliari, Oristano, and Nuoro) data on the number of people per km^2 involved in the management of fire have been collected. The same normalized value has been assigned to each municipality within the same prefecture. A normalized value equal to "1" has been assigned to municipalities within the prefecture with the lower level of people (i.e. representing a lower adaptive capacity), while the value "0" has been assigned to municipalities within the prefecture with the highest level of employed people.

The number of fire risk plan has been first classified in classes depending on the presence, absence, and the stage of plan development. Then, the values per municipalities have been normalized and classified in the 5 references classes.

	Fire	Drought	Result	Normalized result
N. Fire risk plans	x			0,26
Voluntary people employed in associations (n/km^2)	x		29,05	0,55
People employed in CFVA (operative stations) (n/km^2)	x		11,68	0,51
People employed in CFVA (offices)(n/km^2)	x		29,29	0,73
People employed in Fire fighters (n/km^2)	x		140	0,54
People employed in FORESTAS (n/km^2)	x		5,62	0,43
People employed in primary service (agriculture and silvicultural sectors) (%)	x	x	186,29	0,72
Unemployed (%)	x	x	7,67	0,41
People with a degree (%)	x	x	20,45	0,55
People with a Master Degree (%)	x	x	5,46	0,76
GDP (€/capita)	x	x	5,41	0,90
Global Adaptive Capacity Index				
Brief comment	Knowledge and technology: *in this category are included the people with a degree and a master degree and people employed in the primary services. They are both considered for fire and drought. Data reveal that the rate of graduates is higher than bachelor in the island. People with a higher percentage of master degree (between 10 and 20%) is mainly located in Sassari and Cagliari provinces, where the two Universities are located. However, they still represent a lower part of Sardinian population, so they are classified in the medium-low capacity class (4). People with a degree ranged from 10 to 33%, and represent a medium adaptive capacity (class 3). Most of people is employed in the service industry (mainly in the tourism sector) and in the primary service. The latter covers a range between*			

	2% to 43% of employed people. However, as normalized value, it represents a medium-low capacity for adaptation (class 4).
	Institutions and economical resources: *to represent the capacity of institutions for adaptation to fire, the indicators related to the number of plans and people employed in CFVA, FORESTAS, and voluntary people have been considered. In this case, data reveal a medium adaptive capacity to manage fire risk.* *Economical resources have been evaluated only with the GDP indicator. Since no recent data were available, the used data are related to 1991, indicating a low economical capacity for the Region (class 5).*

Table 3.19 - Adaptive Capacity indicators and Global Index

Global Vulnerability Index

	Fire	Drought
Global Sensitivity Index	0,33	0,55
Global Adaptive Capacity Index	0,58	0,67
Global Vulnerability Index	0,45	0,61
Brief comment	**FIRE:** *the Campidano plain is the area less sensitive to fire (class 1), since it is the area with less forested and natural zones. It is the most agricultural area of the region, with a lot of irrigated farm land. The most forested areas, in yellow, are in class 3 (medium sensitivity). Adaptive capacity is medium or medium-low in the island, and the Global Vulnerability Index is higher (class 3 = medium level) in the most natural and forested areas.* **DROUGHT:** *the Global Vulnerability Index ranges between class 4 and 3 (medium low and medium level). However, most sensitive areas are the most natural, forested, and agricultural zones. A general medium-low adaptive capacity (class 4) to drought is reported all over the island.The Global Vulnerability Index ranged between 4 (medium-low level) and 3 (medium level) in the most forested and agricultural lands.* **GENERAL COMMENT:** *climate projections confirm the warming tendency of the extreme temperature indices with a future reduction of frost days and an increase of tropical nights and summer days. A tendency to less frequent and more intense precipitation events seems to be expected, as well as a slight increase in Consecutive Dry Days (CDD), highlighting a likely increase of dry spells. Also a future reduction of summer precipitation is reported. Due to this consideration, higher level of vulnerability to both fire and drought is expected, especially in the areas already experiencing the higher sensitivity and vulnerability classes.*	

Table 3.20 - Global Vulnerability Index

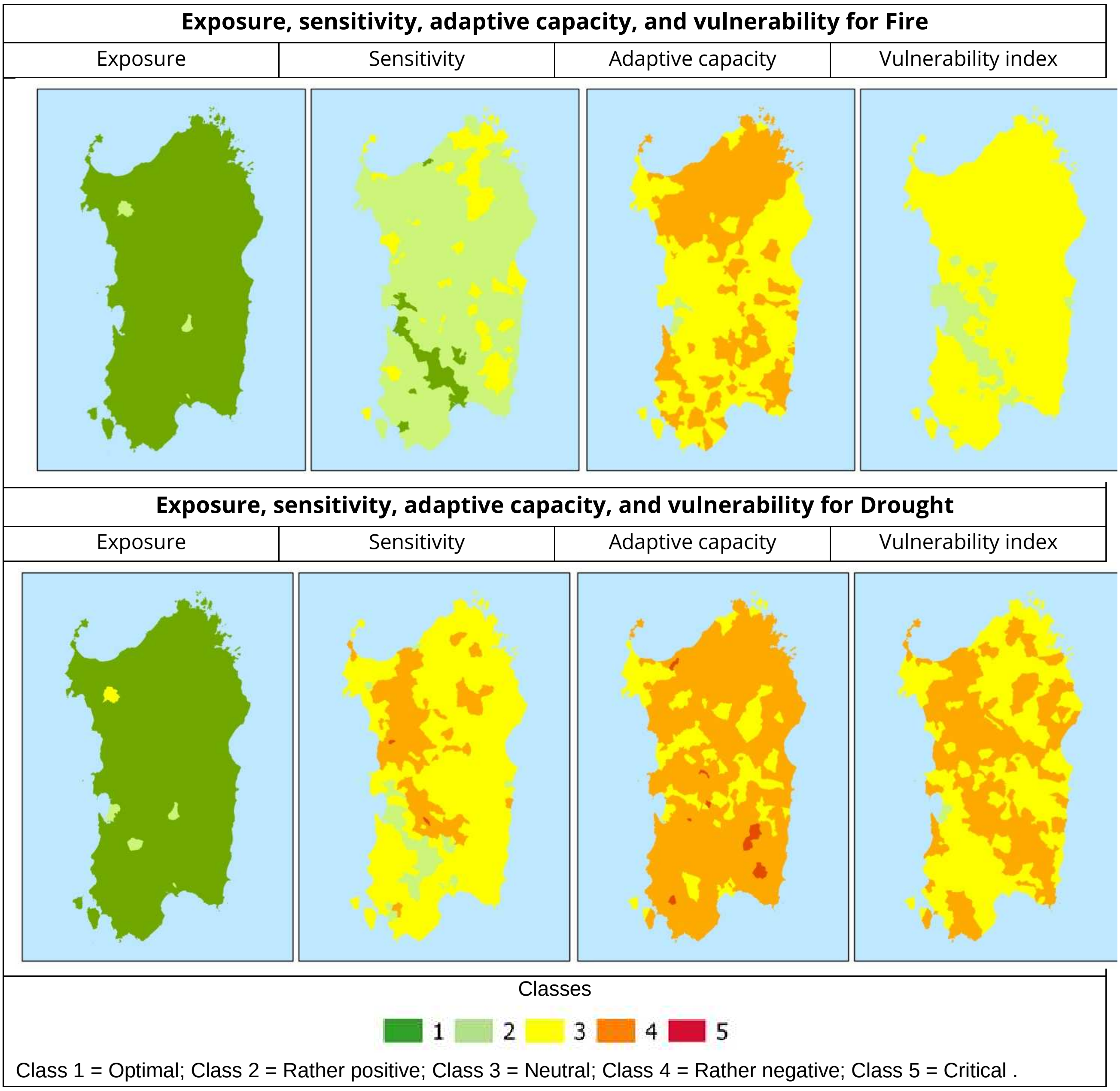

Figure 3.2 – Global Exposure, Sensitivity, Adaptive Capacity, and Vulnerability Index maps for fire and for drought

3.5 Target areas

3.5.1 The area of Venice

The territory of the three municipalities has been analysed as a continuous target area. The territory has been divided in urban and rural land use based on the Corine classification: an index higher than 142 is rural, lower than 142 is urban. Rural areas have been classified by the type of cultivation. Urban areas have been divided following the ISTAT census tract to better analyse the population distribution.

Concerning the urban areas, two potential impacts have been analysed: Urban Heat Island and Extreme Precipitations. Concerning the rural areas, three potential impacts have been analysed: Droughts, Flooding and Extreme events.

Eraclea

The municipality of Eraclea is located along the coastline of the Northern Adriatic and it is made up of the main town Eraclea and seven hamlets (Brian, Ca' Turcata, Eraclea Mare, Ponte Crepaldo, Stretti, Torre di fine, Valcasoni).

The municipality is divided into two different territorial areas. The coastal system, which includes the territories facing the sea between the river mouth of the Piave and the border with Caorle, consists of a sandy coastline interrupted only by the port's mouths and the streams of the numerous rivers;and the inland system, which consists of vast agricultural areas and the hydrographic network (Piave and Livenza basins).

The mobility system is composed of the East-West axis (A4 Trieste - Venice Motorway, the SS 14 and the Venice-Trieste railway line), the downstream Jesolana road (SP 42) that links Eraclea to Jesolo to the West and San Giorgio di Livenza to the East, and the connecting roads to the coast along San Donà di Piave–Eraclea Mare axis.

The main residential settlements are located along the road network and in Eraclea city, where the main services of the municipality are concentrated. Near the river mouth there are the most valuable natural areas, while the rest of the coast offers tourist facilities. Other territorial services are located in the second-tier urban centres, San Donà di Piave, and Portogruaro.

The municipality is in the climatic zones "E" (2100 < Degrees-Day DD < 3000), based on the energy consumption needed to maintain a comfortable temperature inside the building equalling to 20°C.

San Donà di Piave

The municipal territory of San Donà di Piave lies within the context of Eastern Veneto and it is made up of the hamlets of Mussetta di Sopra, Grassaga, Calvecchia, Fossà, Cittanova, Fiorentina, Isiata, Palazzetto, Passarella, Chiesanuova, and S. Maria di Piave.

The municipality is situated to the left of the Piave river, and then goes along the Piave Vecchia branch, skimming the Lagoon of Venice. It is bordered to the North by the courses of the Gondulmera and Grassaga canals, to the East by Parussola and Maliso ditch, to the South by the Piavon, Ramo, and Rosa canals.

The main territorial infrastructure runs along the East-West axis (Trieste-Venezia railway line, SS 14 Triestina, A4 Trieste - Venice Motorway). The node of the motorway toll, located in the Noventa di Piave municipality, connects directly with the network of San Donà through the SP 83. The provincial road system develops in radius, starting from the centre of San Donà, in relation to the node defined by the bridge on the Piave, linking with the coastal area of Caorle (SP 54) and Eraclea (SP 52 and SP 53).

The main residential settlement is San Donà di Piave city. The territorial scheme can be summed up considering the subsystems that make up it: a historic nucleus, the peri-urban ring system, and the transformation axis on which the commercial and production areas are engaged. In addition to the hamlets distributed along the territorial axis that depart from the centre of San Donà, the surrounding territory assumes a primary agricultural value.

The municipality is in the climatic zones "E" (2100 < Degrees-Day DD < 3000), based on the energy consumption needed to maintain a comfortable temperature inside the building equalling to 20°C.

Jesolo

Jesolo city is one of the largest seaside resorts in the Upper Adriatic, between the mouth of the Piave River and the Sile River (Piave Vecchia). It is characterized by the presence of wide, low-sloping beaches.

The territory of Jesolo extends along the Venetian coast and it is surrounded by the Jesolo Lagoon, the Sile and Piave rivers, and the Mort Lagoon, an extremely evocative naturalistic site.

Along the 12 km coast it is possible to recognize three homogeneous territorial areas. The first one includes the areas belonging to the Northern Lagoon of Venice and the territories in the right side of the Sile River. The lagoon area is made up of a series of fishing valleys and rivers with great environmental and ecological value. The second one corresponds to the spine of the Piave River, the last stretch of the great ecological corridor connecting alpine territories to the sea. Finally, the central area includes the city centre of Jesolo and the tourist town of Lido di Jesolo.

Two roads cross the municipality of Jesolo. The North-South axis is represented by the Regional road SR 43 which leaves from Caposile, runs beside the Sile River, passes by Jesolo city, and then arrives to the Jesolo and Cavallino litoral. The East-West axis (SP 46) crosses Cavallino and Punta Sabbioni, Jesolo Paese and Cortellazzo, along the Canal Cavetta.

The urbanization is developed in parallel with the coast, with decreasing density bands, and

different settlement types. The majority of the urban areas are on a sort of "island", delimited by the Piave River to the East, Piave Vecchio to the West, and the Cavetta canal, which leaves from the center of Jesolo city and enters towards Cortellazzo.
The municipality is in the climatic zones “E”(2100 < Degrees-Day DD < 3000), based on the energy consumption needed to maintain a comfortable temperature inside the building equalling to 20°C.

Foreword on the method in urban areas

In urban areas, data sources came from the latest census ISTAT (2011), the dataset of the Venice Metropolitan City of the Territorial Model, the Atlas of Surfaces and the Use of Soil in the Veneto Region.

In rural areas, data sources came from the digital model of the ground of the National Geoportal (Ministry of the Environment) and the agricultural zoning of the Land Use of the Veneto Region.

The analysis phases can be summed up in data collection, data processing, and summary and graphic representation of deliverables.

Data collection

In order to define an accurate territorial and socio-economic contest (see paragraph 3.3.3.), urban area and rural fields were split in two different territorial compartment and their indicators were based on different data. Land Use Data were used in order to separate urban uses from rural one based on a standard classification for area definition.

Istat data allows to locate data taken into account for each indicator by referring to the minimum available territorial partition, the census tract. Using the census tract as a spatial unit has the advantage of operating on units that are divided according to nationally based criteria and have relevant statistical features. This allows to step down the analysis in order to address results to a local scale and also to step up to higher administrative level simply by adding individual censorship units. Data presented in the tables of this document are summed up by administrative borders, while figures represent data census-tract based.

The digital territorial model was acquired through the technique known as dense image matching (DIM). DIM is used to extract a three-dimensional model of what emerges from soil, artifacts, vegetation and morphology from a photogrammetric survey. To construct this model, it works with stereoscopic images and with specific software capable of interpreting pixel images captured. The operations that are performed are divided into the steps of: (1) image rectification; (2) image matching and depth map extraction; (3) point cloud generation; (4) DSM computation; and (5) DSM texturing.

Data processing

The dataset built for the urban area is based on the data of Istat census tract unit managed within a geographic information system.

We used an object-oriented database management systems (OODBS), PostgreSQL, and its PostGIS spatial extension to relate the topographic database to a starting GIS desktop environment. This way you can co-exist, compare and implement information that is originally based on uneven geographic units.

The Topographic Database is built by importing the attributes of the Istat census tract (primary table) and the attributes of the various variables taken into consideration (schools, industrial areas, commercial areas, high vegetation, available area).

For each variable, we script a string command that adds a new column to the Istat section attribute table in the Database. This command allows to populate the primary table for each line, referring to each censorship section, by computing an area where the information source geometrically overlaps the original censorship unit to which it insists only where the geographic attributes intersect. The recorded result is a decimal number expressing the amount of surface for a variable date relative to the original censorship section only. If there is no overlap, the result will be 0.

We describe how variables are calculated to determine the potential impacts (see paragraph 3.3.2).

- Exposure:

Density: calculated as the ratio between the built surface and the total area of the census tract;

Public facilities, Commercial areas, Industrial areas: calculated as the amount in square meters of service present for each census tract.

- Adaptive capacity:

High vegetation: calculated as a land cover surface from tall shaft trees recognizable by extraction in the digital terrain model brought into census tract;

Avaible surface: obtained by subtraction between the impervious surface and the built surface.

- Sensitivity

for UHI

Young people (< 10 years): obtained by summing up the age classes under 10 years recorded in the census Istat (2011);

Old people (> 65 years): obtained by summing up the age classes over 65 years recorded in the census Istat (2011);

Soil sealing: calculated as presence of impervious surfaces

Building density: calculated as ratio between built volume and the area of census tract referred

for Flooding

Runoff: calculated using the runoff curve number equation (USDA, 1986) according to the pluvionometric data of the last 20 years

To have a global value referred to each examined municipality, census tracts with the same Istat municipal code are aggregated . Standardization is therefore made on a smaller territorial scale.

The indicators and vulnerability assessment (see paragraph 3.1) are calculated according the IPCC 2014 methodology.

Summary and graphic representation

For the tables, we have aggregated census data divided on the municipal administrative boundaries, while the global indicator value was obtained through the mean of the indicators in each table.

Integration into the GIS environment is done by correlating the Istat code of each census tract. Class values can thus find spatial correspondence, in the figures data is presented on the 1 to 5 class base, where 1 is very low and 5 is very high.

The identification of the class derives from the normalized value range according to the described range (see table 3.11). For the adaptive capacity the logic is opposite, so low values are ‘critical’, whereas for high values situations of ‘optimal’.

Urban areas - Urban Heat Island

Exposure analysis

Exposure in urban areas is defined by the sum of human, economical and infrastructure capital. The fields analysed are: total population, population density, schools, hospitals, commercial and industrial areas. The results column reports either the total amount of the particular field or the percentage referred to a whole (surface, population,...). Global Exposure Index is the mean of the normalized indexes for each municipality.

	Result	Normalized result
Inhabintants	**Inhab**	
Eraclea	12689	0,00

Jesolo	24479	0,42
San Donà di Piave	40646	1,00
Density	**Inhab/m^2**	
Eraclea	0,10	0,00
Jesolo	0,27	0,17
San Donà di Piave	1,05	1,00
Public facilities	**% of the built**	
Eraclea	4,14	0,00
Jesolo	9,39	1,00
San Donà di Piave	7,39	0,62
Commercial Areas	**% of the built**	
Eraclea	0,00	0,00
Jesolo	4,60	0,65
San Donà di Piave	7,05	1,00
Industrial Areas	**% of the built**	
Eraclea	25,24	1,00
Jesolo	16,94	0,00
San Donà di Piave	23,63	0,81

Global Exposure Index	
Eraclea	0,20
Jesolo	0,45
San Donà di Piave	0,88

Brief comment	Human capital *San Donà urban areas are by far the most populated in total number and density.*
	Manufactured capital *There are few critical infrastructures in Eraclea compared to its extension, while Jesolo doubles the density of critical infrastructure on its territory.*
	Economic capital *There are few economic infrastructures in the Corine land cover classification so most of the commercial activities are not mapped. Industrial activities are widespread in all the municipalities, reaching 25% of the built environment in Eraclea municipality.*

Table 3.21 - Exposure indicators and Global Index

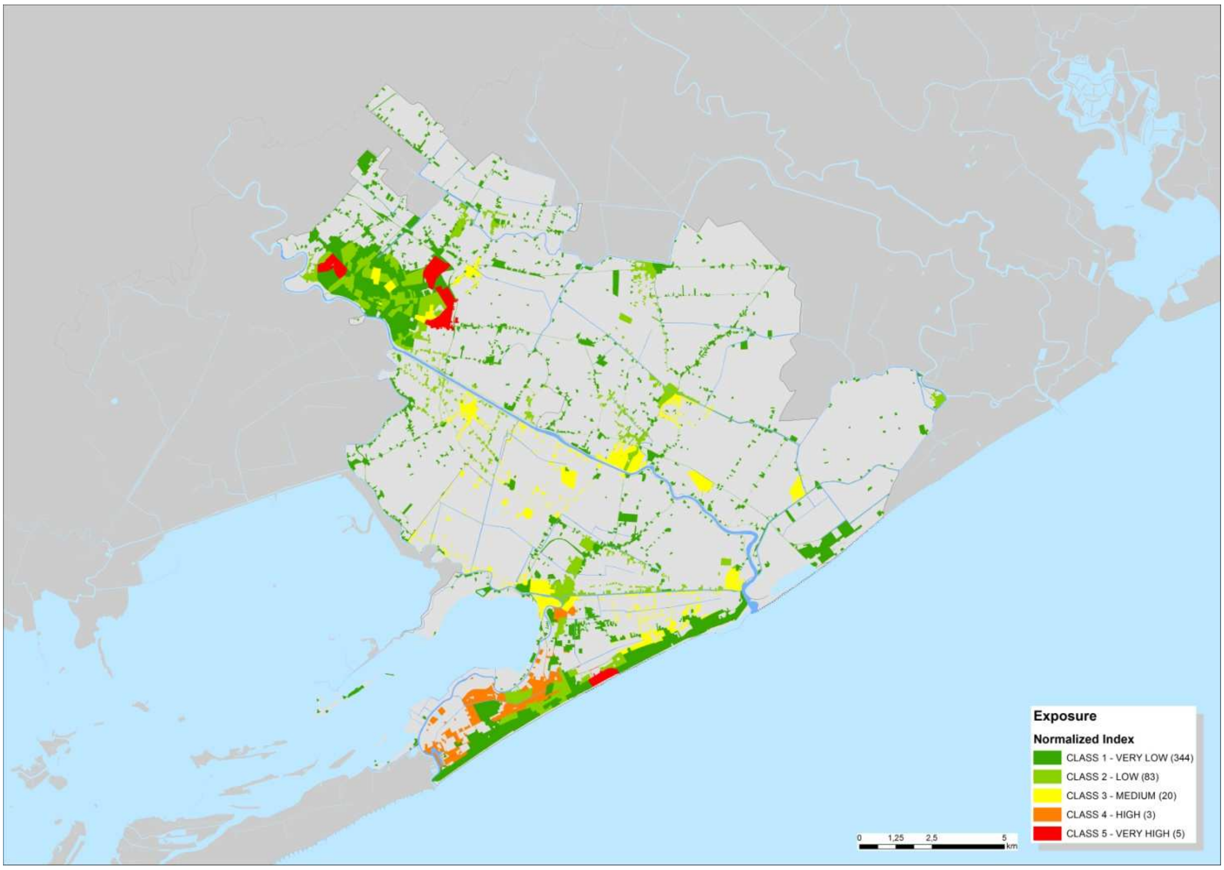

Figure 3.3 – Global Exposure Index map located in the three Municipalities

Sensitivity analysis

To understand the sensitivity of urban areas to Urban Heat Islands (UHI), human factor and built environment have been analysed. The population has been analysed distinguishing the elderl (older than 65) and the very young (younger than 6). The built environment is described by the amount of sealed surface (in percentage on the total urban area) and by the mean building density, calculated as buildings in m^3 on the total urban surface in m^2.

The results column reports either the total amount of the particular field or the percentage referred to a whole (surface, population,...). Global Exposure Index is the mean of the normalized indexes for each municipality.

	Result	Normalized result
Incidence of elderly people > 65	**% of tot. pop.**	
Eraclea	26,64	0,41
Jesolo	27,78	1,00
San Donà di Piave	25,86	0,00
Incidence of very young people <10	**% of tot. pop.**	
Eraclea	8,52	0,00
Jesolo	8,60	0,11
San Donà di Piave	9,31	1,00
Incidence of Soil Sealing	**% of tot. surf.**	
Eraclea	54,28	1,00
Jesolo	51,38	0,00
San Donà di Piave	53,12	0,60
Built Density on overall urban surface	**m^3/m^2**	
Eraclea	0,94	0,00
Jesolo	1,29	1,00
San Donà di Piave	1,27	0,95
Global Sensitivity Index		
Eraclea	0,35	
Jesolo	0,53	
San Donà di Piave	0,64	
Brief comment	Human capital All of the municipalities have similar high share of elderly people and normal shares of very young people.	
	Manufactured capital All the municipalities have more than 50% of sealed surface compared to the total urban surface. Jesolo and San Donà have higher amount of built cubic meters on the total urban surface.	

Table 3.22 - Sensitivity indicators and Global Index

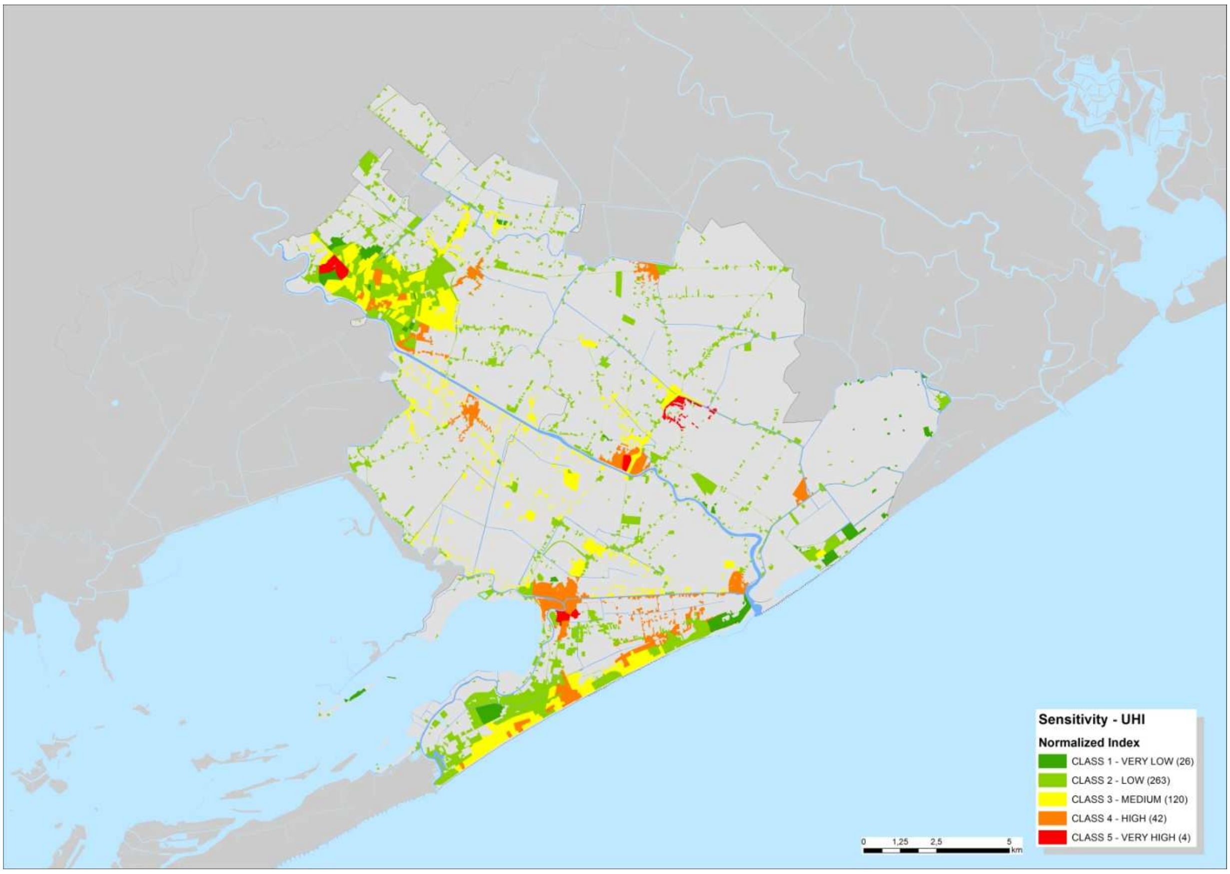

Figure 3.4 – Global Sensitivity Index map

Adaptive capacity analysis

To understand the adaptive capacity of urban areas to UHI, it has been analysed the urban environment. The first index calculates the amount of high vegetation in the territory. The second calculates the amount of surface that can host adaptive measures, refered as available surface on the ground (this has been calculated by subtracting the building to the impermeable surfaces). The results column reports either the total amount of the particular field or the percentage referred to a whole (surface, population,...). Global Exposure Index is the mean of the normalized indexes for each municipality.

<table>
<tr><th colspan="2"></th><th>Result</th><th>Normalized result</th></tr>
<tr><td colspan="2">High Vegetation</td><td>% of tot. surf.</td><td></td></tr>
<tr><td colspan="2">Eraclea</td><td>7,44%</td><td>0,11</td></tr>
<tr><td colspan="2">Jesolo</td><td>10,09%</td><td>1,00</td></tr>
<tr><td colspan="2">San Donà di Piave</td><td>7,10%</td><td>0,00</td></tr>
<tr><td colspan="2">Available surface</td><td>% of tot. surf</td><td></td></tr>
<tr><td colspan="2">Eraclea</td><td>36,91%</td><td>1,00</td></tr>
<tr><td colspan="2">Jesolo</td><td>33,81%</td><td>0,21</td></tr>
<tr><td colspan="2">San Donà di Piave</td><td>33,00%</td><td>0,00</td></tr>
<tr><td colspan="4">Global Adaptive Capacity Index</td></tr>
<tr><td>Eraclea</td><td colspan="3">0,44</td></tr>
<tr><td>Jesolo</td><td colspan="3">0,40</td></tr>
<tr><td>San Donà di Piave</td><td colspan="3">1,00</td></tr>
<tr><td>Brief comment</td><td colspan="3"><u>Environmental resources</u>
Jesolo has the highest presence of high vegetation compared to its total urban surface. All the municipalities share around 35% of available surface of their total urban surface.</td></tr>
</table>

Table 3.23 - Adaptive Capacity indicators and Global Index

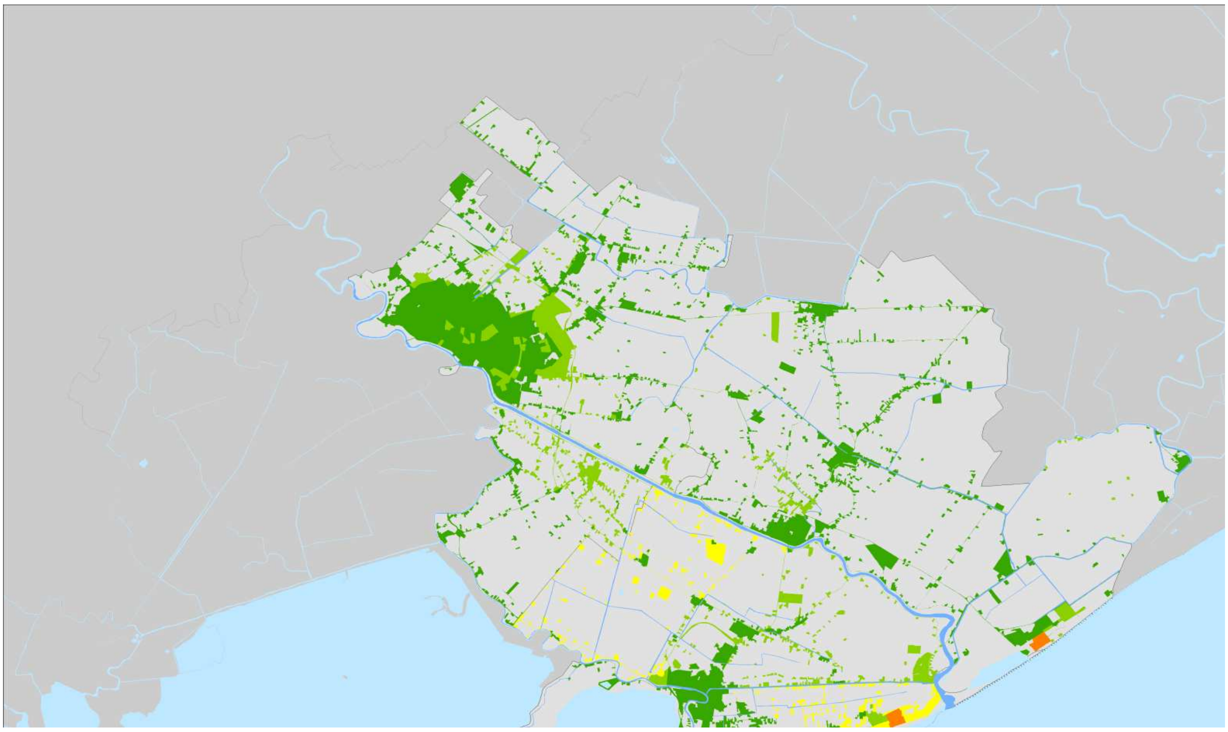

Figure 3.5 – Global Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.24).

	Normalized results
Global Sensitivity Index	
Eraclea	0,35
Jesolo	0,53
San Donà di Piave	0,64
Global Adaptive Capacity Index	
Eraclea	0,44
Jesolo	0,40
San Donà di Piave	1,00
Global Vulnerability Index	

Eraclea	0,40
Jesolo	0,46
San Donà di Piave	0,82
Brief comment	*San Donà di Piave has the highest vulnerability to UHI driven by the highest sensitivity and the lowest adaptive capacity. While Jesolo has a higher sensitivity to UHI compared to Eraclea, its slightly lower adaptive capacity make these to municipalities share a similar global vulnerability index.*

Table 3.24 - Global Vulnerability Index table

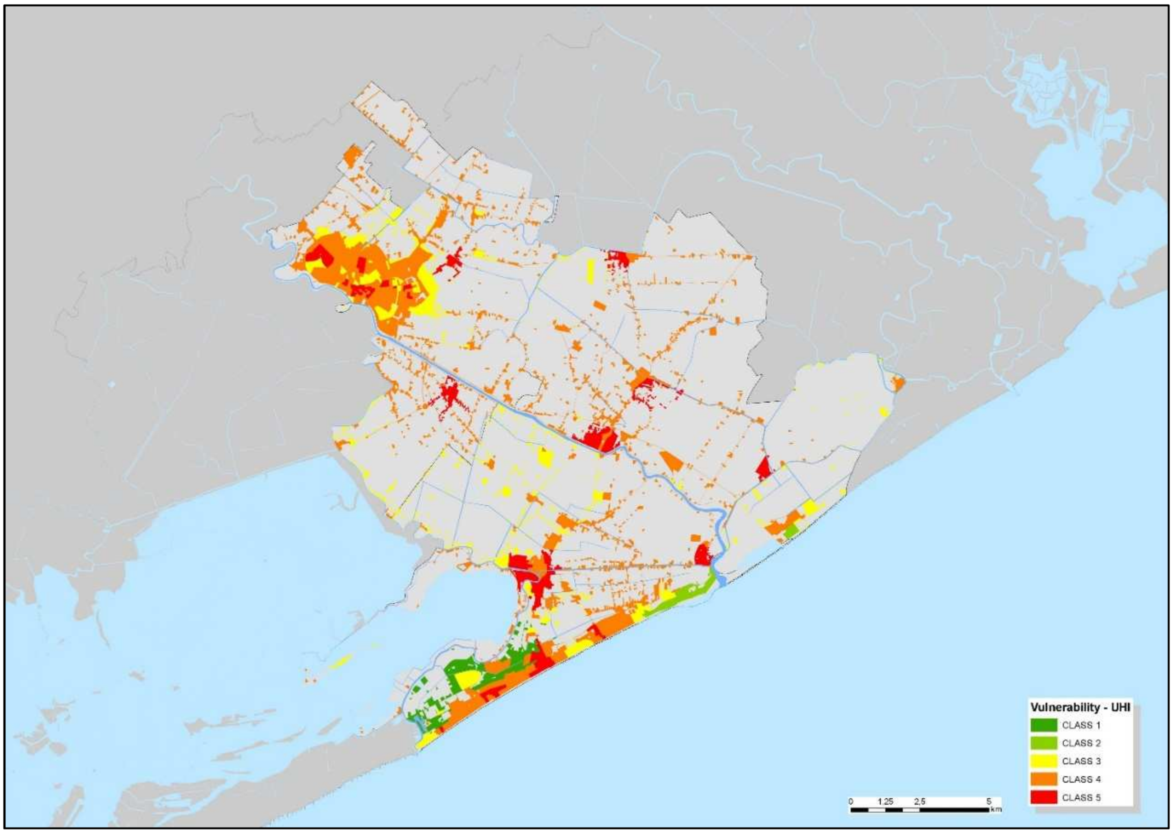

Figure 3.6 – Global Vulnerability Index map

Urban areas - Flooding

Exposure analysis

Exposure in urban areas is defined by the sum of human, economical and infrastructure capital. The fields analysed are: total population, population density, schools, hospitals, commercial and industrial areas. The results column reports either the total amount of the particular field or the percentage referred to a whole (surface, population,…). Global Exposure Index is the mean of the normalized indexes for each municipality.

	Result	Normalized result
Inhabintants	**Inhab**	
Eraclea	12689	0,00
Jesolo	24479	0,42
San Donà di Piave	40646	1,00
Density	**Inhab/m^2**	
Eraclea	0,10	0,00
Jesolo	0,27	0,17
San Donà di Piave	1,05	1,00
Public facilities	**% of the built**	
Eraclea	4,14	0,00
Jesolo	9,39	1,00
San Donà di Piave	7,39	0,62
Commercial Areas	**% of the built**	
Eraclea	0,00	0,00
Jesolo	4,60	0,65
San Donà di Piave	7,05	1,00
Industrial Areas	**% of the built**	
Eraclea	25,24	1,00
Jesolo	16,94	0,00
San Donà di Piave	23,63	0,81

Global Exposure Index	
Eraclea	0,20
Jesolo	0,45
San Donà di Piave	0,88

Brief comment	Human capital *San Donà urban areas are by far the most populated in total number and density.*
	Manufactured capital *There are few critical infrastructures in Eraclea compared to its extension, while Jesolo doubles the density of critical infrastructure on its territory.*
	Economic capital There are few economic infrastructures in the Corine land cover classification so most of the commercial activities are not mapped. Industrial activities are widespread in all the municipalities, reaching 25% of the built environment in Eraclea municipality.

Table 3.25 - Global Exposure Index

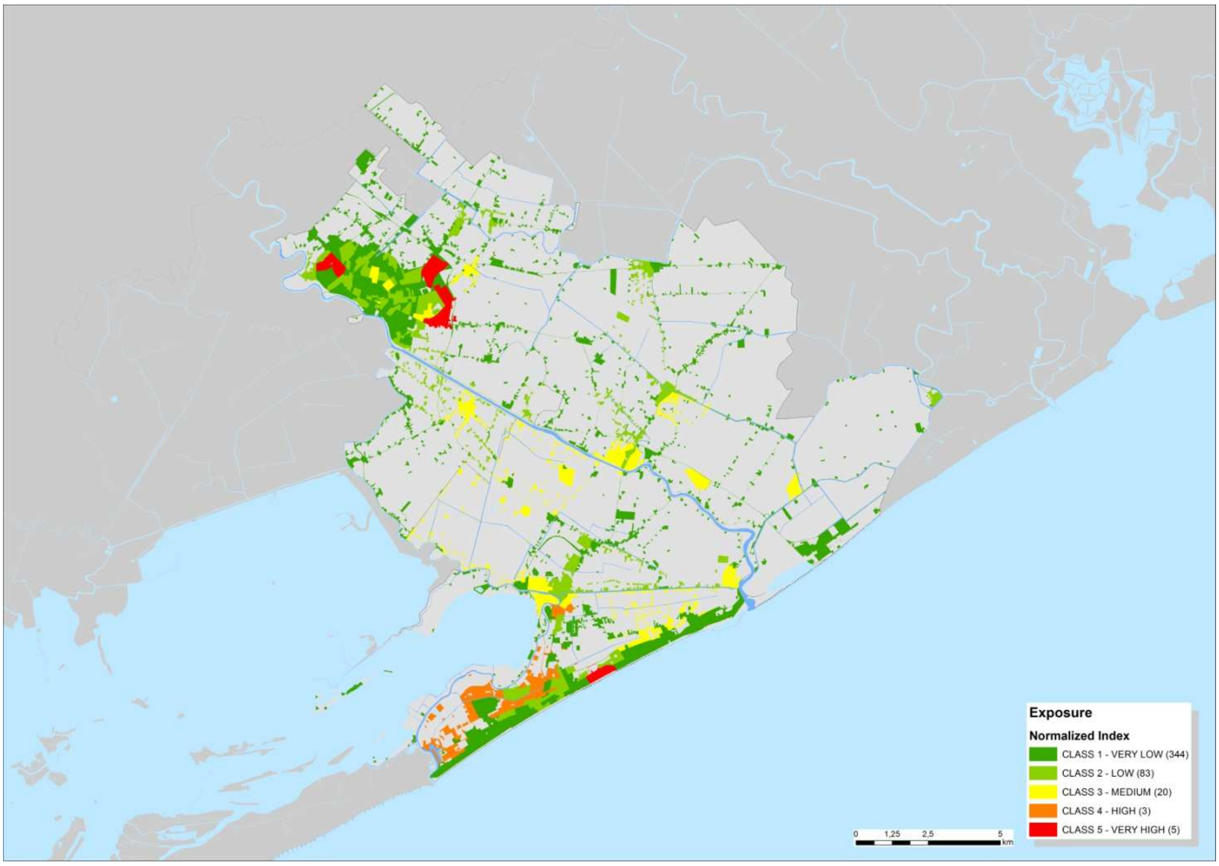

Figure 3.7 - Global Exposure Index map

Sensitivity analysis

To understand the sensitivity of urban areas to flooding, it has been analysed the built environment features classified by the type of surface: built, impervious, trees or green. The surfaces have been classified by their runoff and saturation index and it has been simulated an extreme precipitation of 168 mm (24hr, 2%). Surface runoff (also known as overland flow) is the flow of water that occurs when excess stormwater, meltwater, or other sources flows over the Earth's surface. This might occur because soil is saturated to full capacity, because rain arrives more quickly than soil can absorb it, or because impervious areas (roofs and pavement) send their runoff to surrounding soil that cannot absorb all of it. Estimating runoff curve calculated with “Hydrologic Soil-Cover Complexes” methodology (USDA 1972). The results column reports the percentage of runoff compared to the total amount of rain simulated. Global Sensitivity Index is the mean of the normalized indexes for each municipality.

	Result	***Normalized result***
Runoff during extreme precipitation	***%***	
Eraclea	***95,28***	***1,00***
Jesolo	***91,04***	***0,00***
San Donà di Piave	***93,58***	***0,60***
Global Sensitivity Index		
Eraclea	1,00	
Jesolo	0,00	
San Donà di Piave	0,60	
Brief comment	Manufactured capital All the municipalities have high percentage of runoff during extreme precipitations in their urban area. This is driven also by the fact that all the urban areas of the municipalities are densely built and sealed, and the small amount of green is quickly saturated by water.	

Table 3.26 - Sensitivity indicators and Global Index

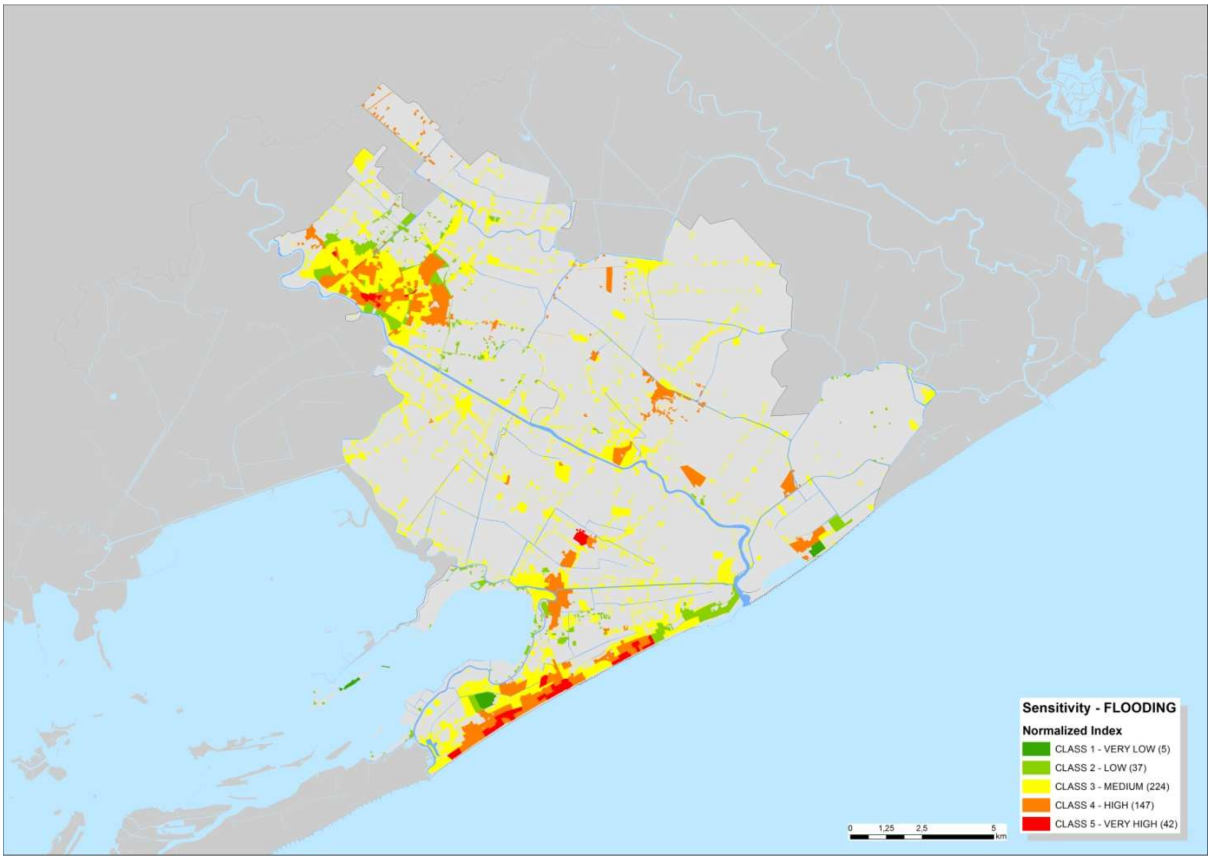

Figure 3.8 - Global Sensitivity Index map

Adaptive capacity analysis

To understand the adaptive capacity of urban areas to flooding, it has been analysed the urban environment. The first index calculates the amount of high vegetation in the territory. The second calculates the amount of surface that can host adaptive measures (this has been calculated subtracting the building to the impermeable surfaces).The results column reports the total percentage of the particular field on the total urban surface. Global Adaptive Capacity Index is the mean of the normalized indexes for each municipality.

	Result	**Normalized result**
High Vegetation	**% of tot. surf.**	
Eraclea	7,44%	0,11
Jesolo	10,09%	1,00
San Donà di Piave	7,10%	0,00
Available surface	**% of tot. surf**	

Eraclea	36,91%	1,00
Jesolo	33,81%	0,21
San Donà di Piave	33,00%	0,00
Global Adaptive Capacity Index		
Eraclea	0,44	
Jesolo	0,40	
San Donà di Piave	1,00	
Brief comment	Environmental resources Jesolo has the highest presence of high vegetation compared to its total urban surface. All the municipalities share around 35% of available surface of their total urban surface.	

Table 3.27 - Adaptive Capacity indicators and Global index

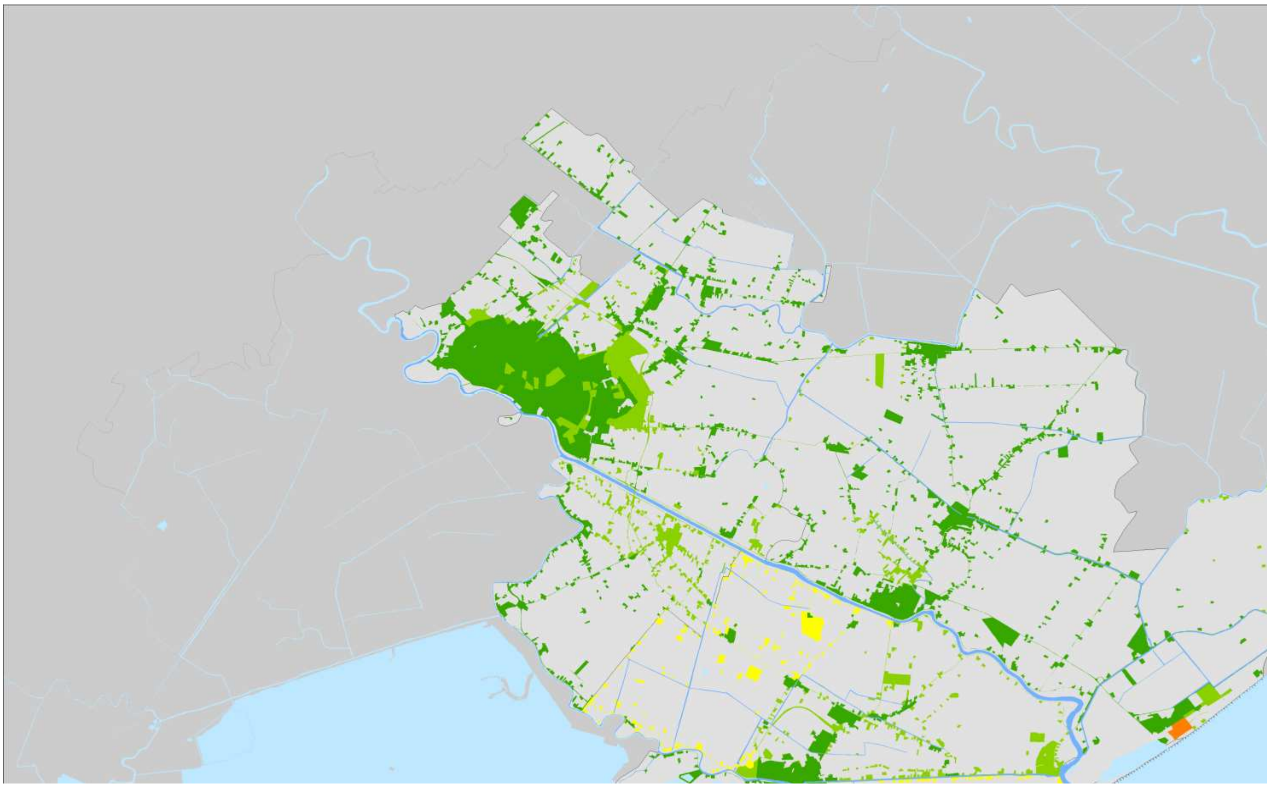

Figure 3.9 - Global Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.28).

	Normalized results
Global Sensitivity Index	
Eraclea	1,00
Jesolo	0,00
San Donà di Piave	0,60
Global Adaptive Capacity Index	
Eraclea	0,44
Jesolo	0,40
San Donà di Piave	1,00
Global Vulnerability Index	
Eraclea	0,72
Jesolo	0,20
San Donà di Piave	0,80
Brief comment	*San Donà di Piave urban areas have the highest vulnerability to flooding driven by the lowest adaptive capacity. Jesolo has the lowest vulnerability compared to the other municipalities, but its high urban runoff rates during intense precipitation, highlighted in the sensitivity analysis, still make its territory vulnerable.*

Table 3.28 - Global Vulnerability Index

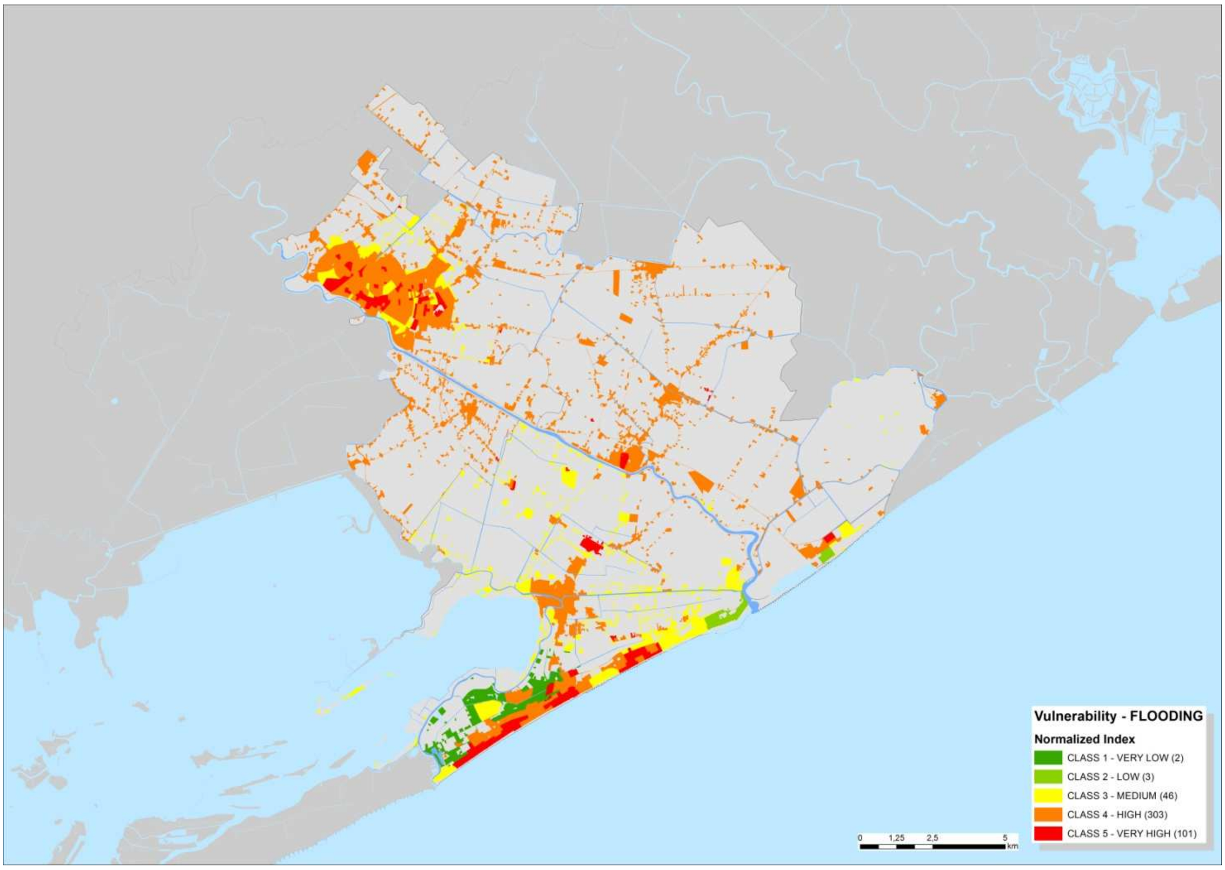

Figure 3.10 - Global Vulnerability Index map

Foreword on the method in rural areas

The analysis phases can be summed up in data collection, data processing, and summary and graphic representation of deliverables.

Data collection

As anticipated in the data collection paragraph of the urban areas analysis, the analysis for rural areas are based upon the second edition (2012) of the Soil Use Database of Regione Veneto ("seconda edizione della Banca Dati della Carta di Copertura del Suolo"), compliant with the Commission Regulation (EU) No 1089/2010.

The dataset is developed from the AGES color digital ortho-images of 2012, updating the previous dataset of 2007 and by considering the information extracted from the Regione Veneto atlas, the vector land covers from the regional geodatabase, the regional digital plan (CTRN), the local urban plans (PRG+PAT), the digital HOB from TerraItalyTM DSM, institutional websites and geodatabases.

For the purpose of the rural areas analysis, the Soil Use dataset has been filtered with the soil typologies that are not urbanized, taking out impermeable soils, houses, roads, infrastructures, etc. The soils that have been considered for the analysis are the following:

- Other permanent crops
- Arboriculture
- Shrubs
- Beets in irrigated land
- Hardwoods
- Cereals in irrigated land
- Cereals in non-irrigated land
- Annual crops associated to permanent crops
- Forage crops in irrigated land
- Forage crops in non-irrigated land
- Anthropogenic conifers development
- Orchards
- Sunflower in irrigated land
- Broadleaf tree planting
- Corn in irrigated land
- Corn in non-irrigated land
- Horticultural crops in irrigated land
- Horticultural crops in non-irrigated land
- Horticultural crops in greenhouse irrigated land
- Pastures
- Poplar plantations
- Willows and other riparian vegetation
- Seed in irrigated land
- Complex cultural and parcels systems
- Soy in irrigated land
- Soy in non-irrigated land
- Grasses
- Grassland
- Set-aside irrigated land
- Set-aside non-irrigated land
- Arable irrigated land
- Arable non-irrigated land
- Coast dunes vegetation
- Vineyards
- Nursery in irrigated land

The economic values of soil typologies have been taken from the Average Rural Values of the Venice province released by the National Fiscal Agency.

The average data of water stress have been taken from the Veneto Region reports on the

rural evaluation of compensations.
The values of the maximum amount of days that crops can tolerate under water have been taken from the ACER (Technical-scientific journal for the professionals in the field of green and cultivated areas) report "Water stress: prevention and mechanisms".

Data processing and graphic representation

The dataset built for the rural areas is based on the previously described filterd Soil Use dataset managed within an open source geographic information system (QGIS).

The dataset has been joined with a series of tables for each municipalites, resulted from the analysis for the exposure, adaptive capacity, sensitivity to droughts and floodings.

The joined tables have been calculated by attaching an indicator to each analysis (exposure to droughts, adaptive capacity to droughts, sensitivity to droughts, exposure to floodings, adaptive capacity to floodings, sensitivity to floodings) and classifying the resulted values in 5 categories (class 1 – very low, class 2 – low, class 3 – medium, class 4 – high, class 5 – very high):

- **Exposure to droughts:** the indicator is the economic value in euros per hectare. Each soil typology has an economic value which has been multiplied by the soil surface (in hectare) giving an absolute exposure value. The resulted values have been normalized and the soil typologies classified accordingly to the them.
- **Sensitivity to droughts:** the indicator is the water needs of cultivated soils in mc/ha. Each soil typology has a water need which has been multiplied by the soil surface (in hectare) giving an absolute sensitivity value. The resulted values have been normalized and the soil typologies classified accordingly to the them.
- **Adaptive capacity to droughts:** in this case the indicator is a boolean. If the soil is not irrigated the indicator is set to 1, to 0 in the opposite case. The binary value has been multiplied by the soil surface (in hectare) giving an absolute adaptive capacity value. The resulted values have been normalized and the soil typologies classified accordingly to the them.
- **Exposure to floodings:** the indicator is the economic value in euros per hectare. Each soil typology has an economic value which has been multiplied by the soil surface (in hectare) giving an absolute exposure value. The resulted values have been normalized and the soil typologies classified accordingly to the them.
- **Sensitivity to floodings:** the indicator is an intolerance index built upon the amount of maximum days that a crop can stand without great damage under water. The index has been multiplied by the soil surface (in hectare) giving an absolute sensitivity value. The resulted values have been normalized and the soil typologies classified accordingly to the them.
- **Adaptive capacity to floodings:** in this case the indicator is the normalized average elevation built upon the DTM dataset for the Regione Veneto. The normalized average elevation value has been multiplied by the soil surface (in hectare) giving an absolute

adaptive capacity value. The resulted values have been normalized and the soil typologies classified accordingly to the them.

The graphic representations show for each analysis and rural parcel their classified value, according to the 5 previously described classes.

Rural areas - Drought

Exposure analysis

Exposure in rural areas has been analysed taking into account the economic value of each soil typology as an indicator. The results column reports the total economic value of soils for each municipality. The economic values of terrains are an essential indicator when extreme weather events (such as droughts or flooding) cause an economic loss in terms of production and economic value decrease. The economic values of soil typologies have been taken from the Average Rural Values of the Venice province released by the National Fiscal Agency. Global Exposure Index is the same as the normalized result as there is only one entry.

	Result	Normalized result
Economic value	**€**	
Eraclea	556715333,77	1,00
Jesolo	393583322,49	0,13
San Donà di Piave	369420515,22	0,00
Global Exposure Index		
Eraclea	1,00	
Jesolo	0,13	
San Donà di Piave	0,00	
Brief comment	There is a low exposure for most of the soils of Eraclea, Jesolo and San Donà di Piave. Soils cultivate with corn and soy are the most exposed, respectively classified in class 5 and 4, and more extended in the territories. Eraclea results to be the most exposed since its soils are cultivated with high shares of these plantations, reaching 3700he compared to only 2100he in San Donà.	

Table 3.29 - Exposure indicators and Global Index

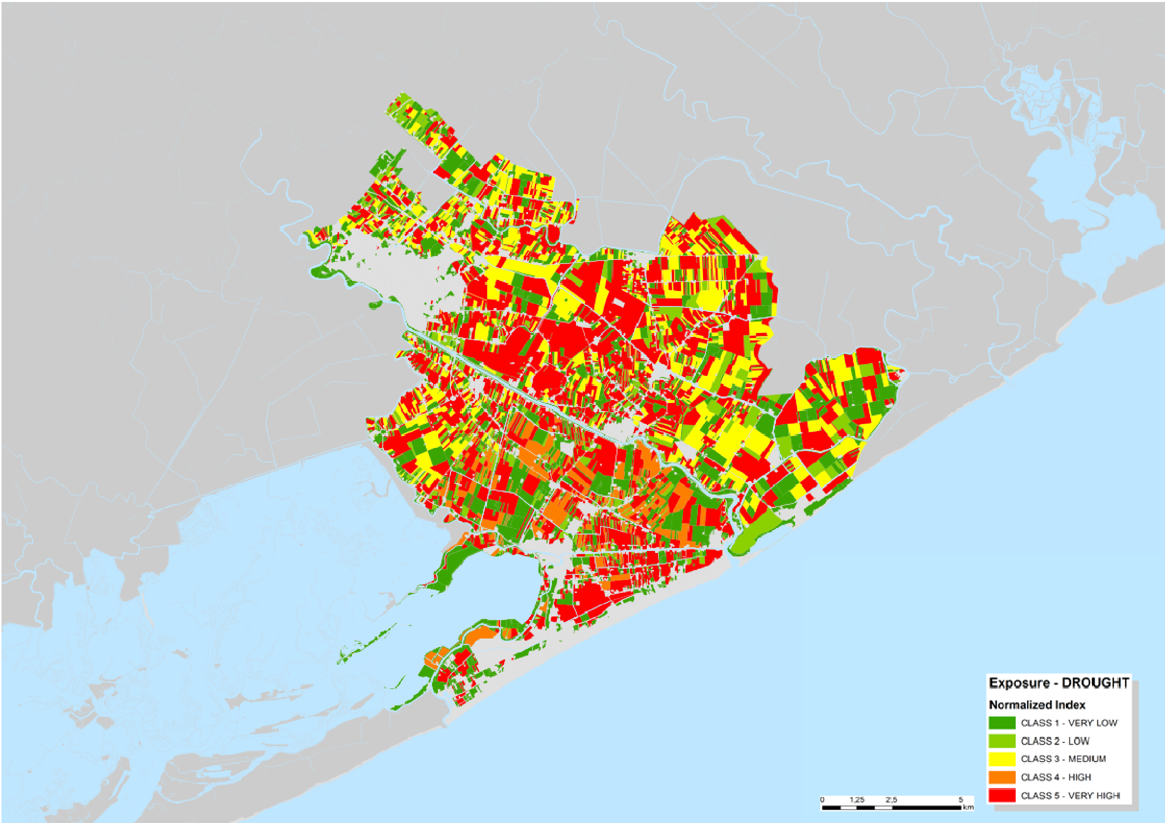

Figure 3.11 - Global Exposure Index map

Sensitivity analysis

The drought sensitivity analysis takes the cultivated soils and associates to each category their water needs in mc/ha. The values range goes from the crops with a low water need (1.200 mc/ha per year) to the ones with a high water need (7.200 mc/ha per year). The average data of water stress have been taken from the Veneto Region reports on the rural evaluation of compensations.

The reduction in cultivation yields, due to heat waves, has not been considered as its evaluation is problematic. High temperatures, for some crops, have to be necessarily associated with the level of CO_2 in ppm (parts per milion). In addition, in some cases, despite long-lasting high temperatures, the CO_2 fertilizing effect can even have an increasing effect in the crop yields. Very briefly, without a fixed value of CO_2 in ppm is hard to define the yields decrease/increase. The results column reports the total amount of the water supply needed by all the cultivations of the municipality. Global Sensitivity Index is the same as the normalized result as there is only one entry.

	Result	Normalized result
Water supply needed	**m^3**	
Eraclea	30429075,30	1,00
Jesolo	20346097,90	0,11
San Donà di Piave	19162499,05	0,00
Global Sensitivity Index		
Eraclea	1,00	
Jesolo	0,11	
San Donà di Piave	0,00	
Brief comment	For the three municipalities there is a low sensitivity for most of the different soils, however the great extension of corn and soy areas result in a great amount of water demand. Eraclea has the highest sensitivity to drought because of its high percentage of these souils.	

Table 3.30 - Sensitivity indicators and Global Index

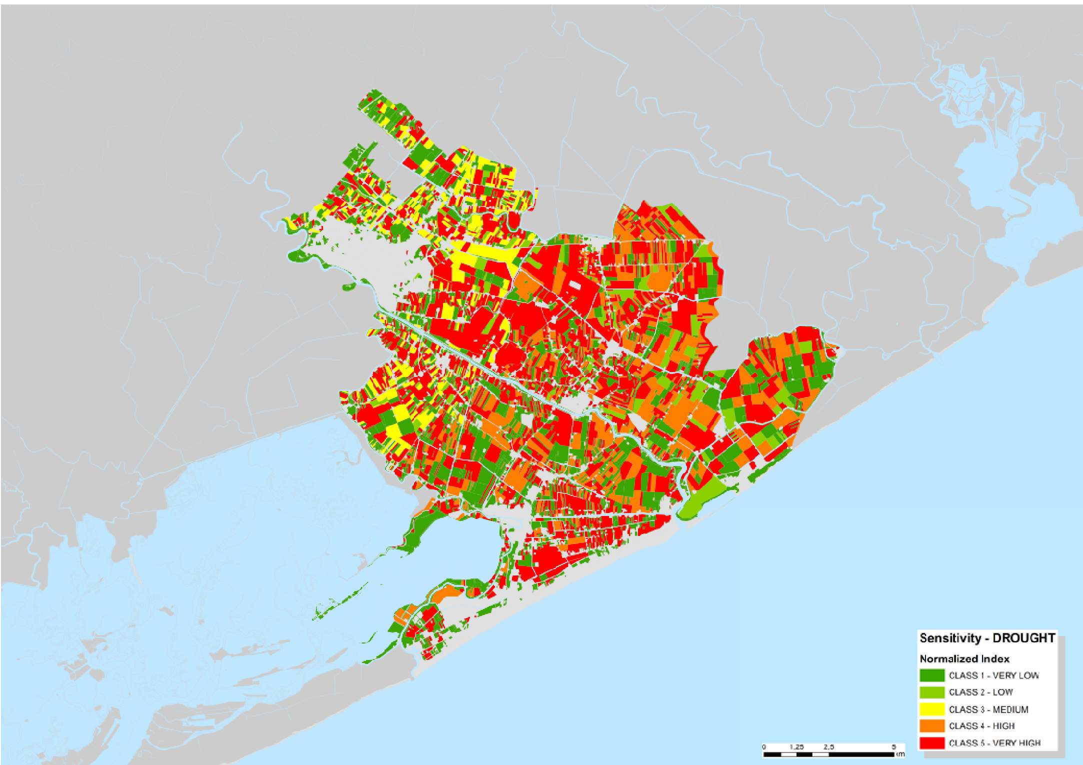

Figure 3.12 – Global Sensitivity Index map

Adaptive capacity analysis

The rural adaptive capacity to drought has been evaluated by considering for each soil typology the ones that are currently irrigated. These soils have an adaptive capacity to drought due to their possibility to satisfy their water needs by the availability of a nearby water supply (rivers, canals, water infrastructures, etc.).
The adaptive capacity to drought is a binary value, as such the indicator is set to 1 if the soil is irrigated and set to 0 if not. The results column reports, in percentage, the total amount of hectars of irrigated field. Global Adaptive Capacity Index is the same as the normalized result as there is only one entry.

	Result	**Normalized result**
Irrigated surface	**he**	
Eraclea	7712,42	0,00
Jesolo	5035,91	0,85
San Donà di Piave	4571,49	1,00
Global Adaptive Capacity Index		
Eraclea	0,00	
Jesolo	0,85	
San Donà di Piave	1,00	
Brief comment	There is a high adaptive capacity index to droughts as the majority of the cultivations are irrigated by the local water network and water infrastructures. The amount of irrigated fields compared to the total amount of the fields results in a 90% in Eraclea, 83% in Jesolo and 80% in San donà di Piave.	

Table 3.31 - Adaptive Capacity indicators and Global Index

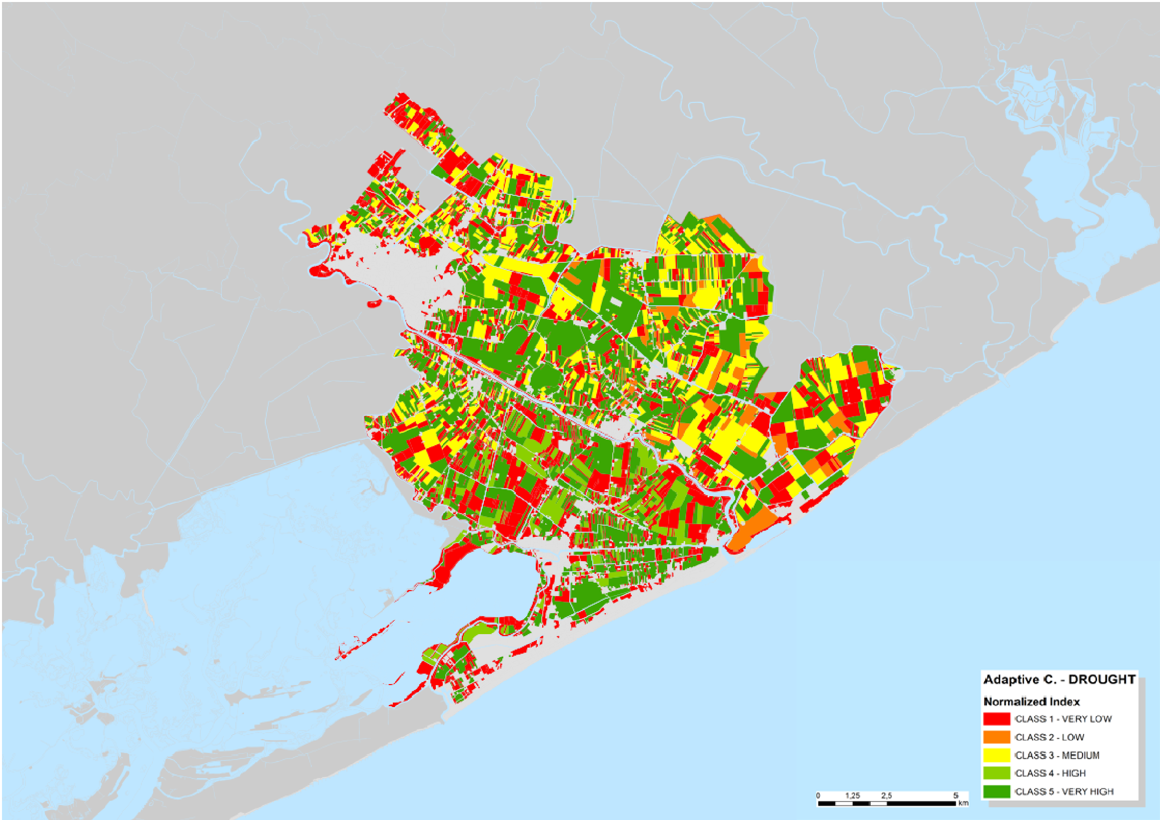

Figure 3.13 - Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.32).

	Normalized results
Global Sensitivity Index	
Eraclea	1,00
Jesolo	0,11
San Donà di Piave	0,00
Global Adaptive Capacity Index	
Eraclea	0,00
Jesolo	0,85

	Normalized results
San Donà di Piave	1,00
Global Vulnerability Index	
Eraclea	0,50
Jesolo	0,48
San Donà di Piave	0,50
Brief comment	The three municipalities have a similar global vulnerability index to droughts. This is the results of a better irrigation system where the soil value is higher. A better understanding of the vulnerability can be seen in the global vulnerability index map, that scale down to a field-unit precision.

Table 3.32 – Global Vulnerability Index

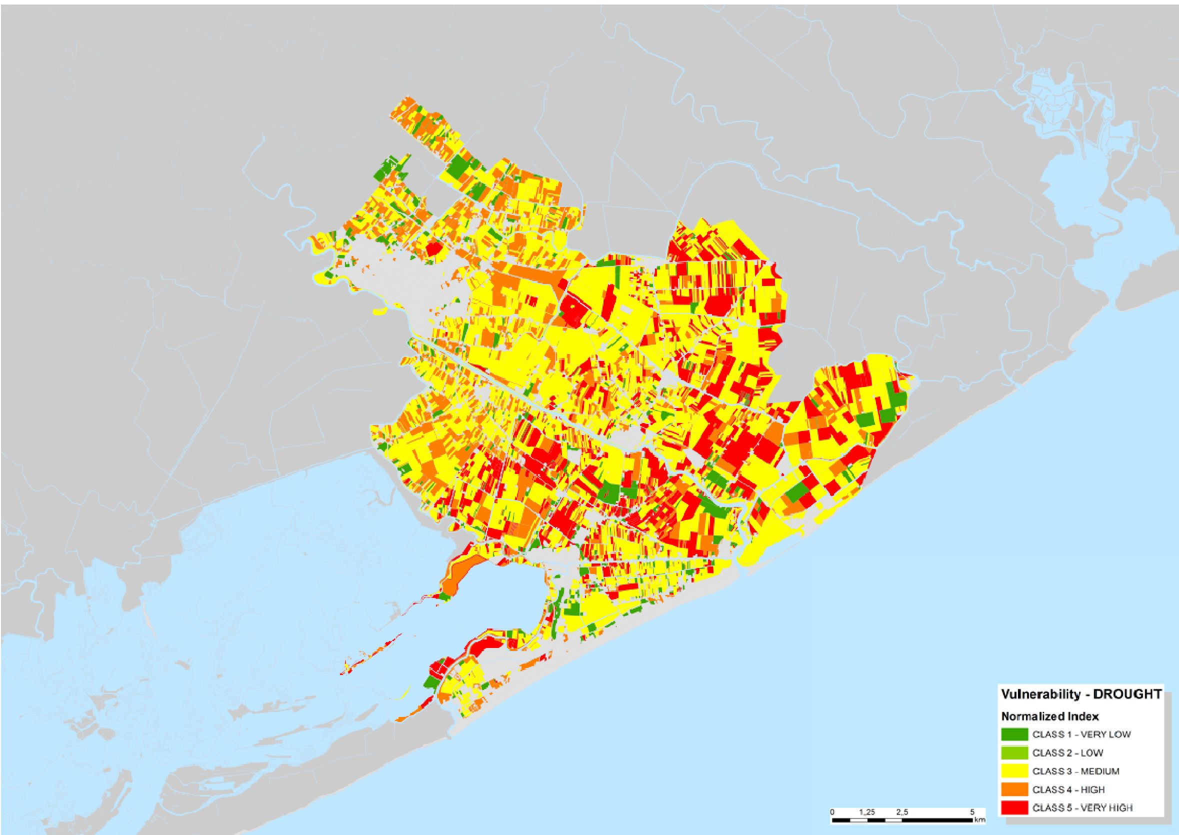

Figure 3.14 – Global Vulnerability Index map

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Rural areas - Flooding

Exposure analysis

As for the exposure analysis to drought, the exposure to flooding has been analysed taking into account the economic value of each soil typology as an indicator.
The results column reports the total economic value of soils for each municipality. Global Exposure Index is the same as the normalized result as there is only one entry.

Exposure in rural areas has been analysed taking into account the economic value of each soil typology as an indicator. The results column reports the total economic value of soils for each municipality. The economic values of terrains are an essential indicator when extreme weather events (such as droughts or flooding) cause an economic loss in terms of production and economic value decrease. The economic values of soil typologies have been taken from the Average Rural Values of the Venice province released by the National Fiscal Agency. Global Exposure Index is the same as the normalized result as there is only one entry.

	Result	Normalized result
Economic value	**€**	
Eraclea	556715333,77	1,00
Jesolo	393583322,49	0,13
San Donà di Piave	369420515,22	0,00
Global Exposure Index		
Eraclea	1,00	
Jesolo	0,13	
San Donà di Piave	0,00	
Brief comment	There is a low exposure for most of the soils of Eraclea, Jesolo and San Donà di Piave. Soils cultivate with corn and soy are the most exposed, respectively classified in class 5 and 4, and more extended in the territories. Eraclea results to be the most exposed since its soils are cultivated with high shares of these plantations, reaching 3700he compared to only 2100he in San Donà.	

Table 3.33 - Exposure indicators and Global Index

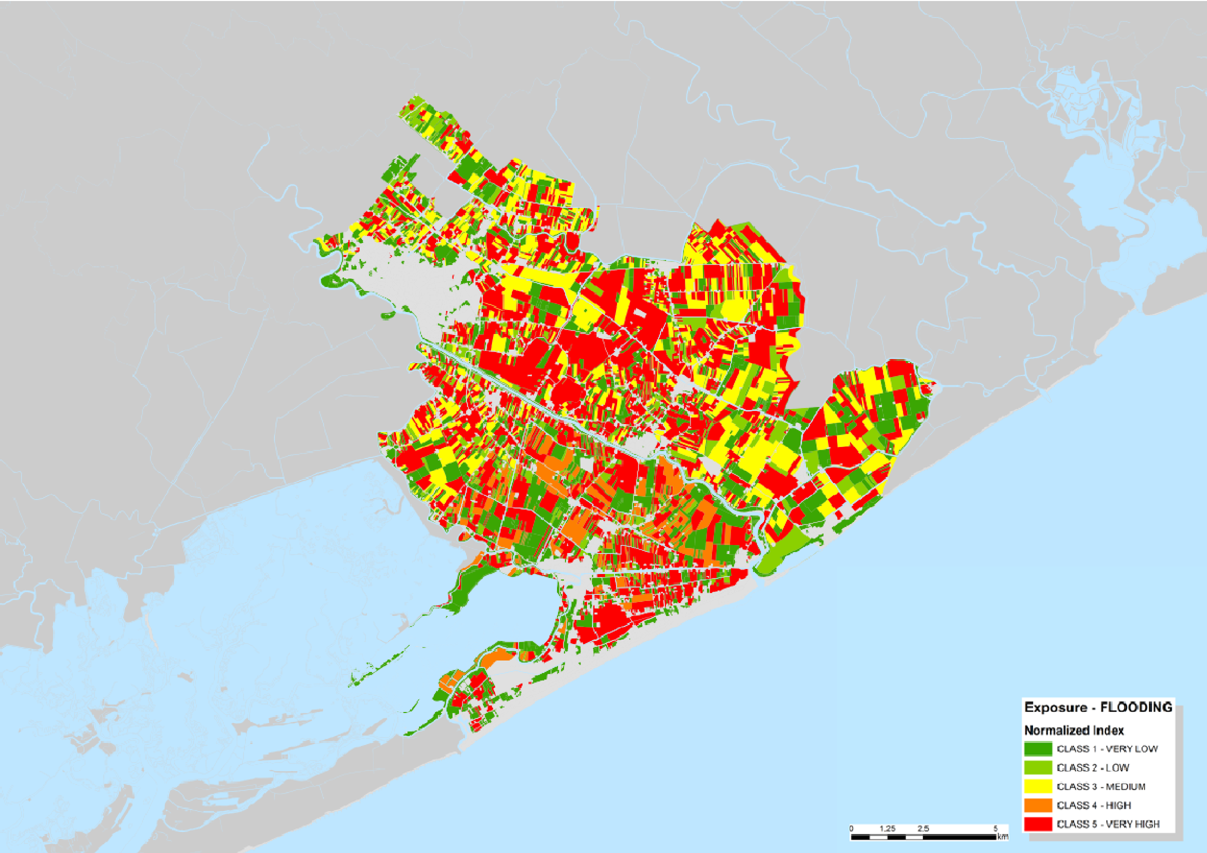


Figure 3.15 - Global Exposure Index map

Sensitivity analysis

The flooding sensitivity analysis takes the cultivated soils and associates to each category the maximum amount of days that crops can tolerate under water.
The values have been taken from the ACER (Technical-scientific journal for the professionals in the field of green and cultivated areas) report "Water stress: prevention and mechanisms".
As the day indicator is inversely proportional to the 5 classes, an intolerance indicator for each soil typology has been constructed as the inverse of the maximum day of tolerance (for example 1/9 = 0,11). The results column reports an adimensional value representing the whole cultivated areas multiplied by their specific intolerance index. Global Sensitivity Index is the same as the normalized result as there is only one entry.

	Result	Normalized result
Water stress	**Adimensional value**	
Eraclea	4692,834293	1,00
Jesolo	1351,563586	0,00
San Donà di Piave	2862,201522	0,45
Global Sensitivity Index		
Eraclea	1,00	
Jesolo	0,00	
San Donà di Piave	0,45	
Brief comment	Soils in Eraclea, Jesolo and San Donà di Piave range from 4 to 9 the maximum amount of days tolerable under water. Eraclea's most extended crops can tolerate only 4 days, and this boost its sensitivity to flooding.	

Table 3.34 - Sensitivity indicators and Global Index

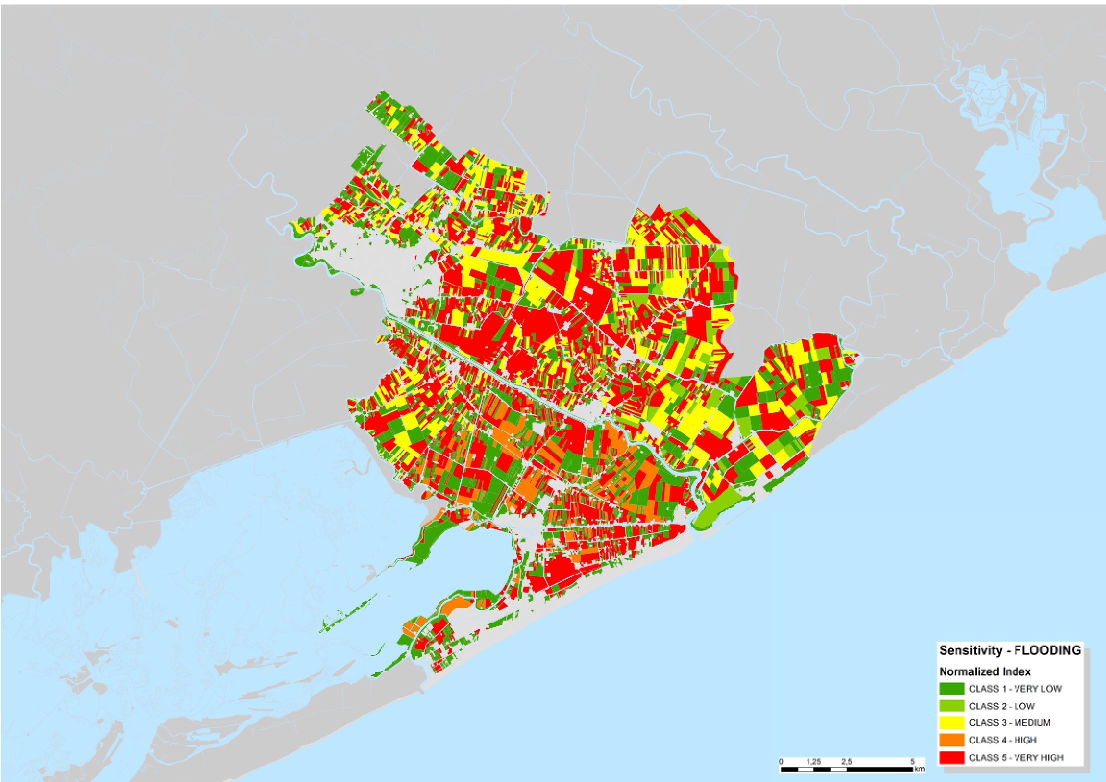


Figure 3.16 – Global Sensitivity Index map

Adaptive capacity analysis

The rural adaptive capacity to floodings has been evaluated by considering for each soil typology the ones that have a higher elevation. These soils have an adaptive capacity to floodings due to their possibility to avoid water stagnation and consequently not having the crops under water for many days. The elevation for each type of soil has been multiplied to its type of soil extension in order to construct the indicator to evaluate the adaptive capacity to floodings.
The results column reports the total volume of soil above mean sea-level for each municipality.
Global Adaptive Capacity Index is the same as the normalized result as there is only one entry.

	Result	Normalized result
Soil Volume above sea level	**m^3**	
Eraclea	3447,268688	0,00
Jesolo	2518,958018	0,85
San Donà di Piave	2358,445737	1,00
Global Adaptive Capacity Index		
Eraclea	0,00	
Jesolo	0,85	
San Donà di Piave	1,00	
Brief comment	San Dona' di Piave has the greatest amount of low-lying fields that result in a low adapative capacity, this is due to its mean elevation of 0,41meters.	

Table 3.35 - Adaptive Capacity indicators and Global Index

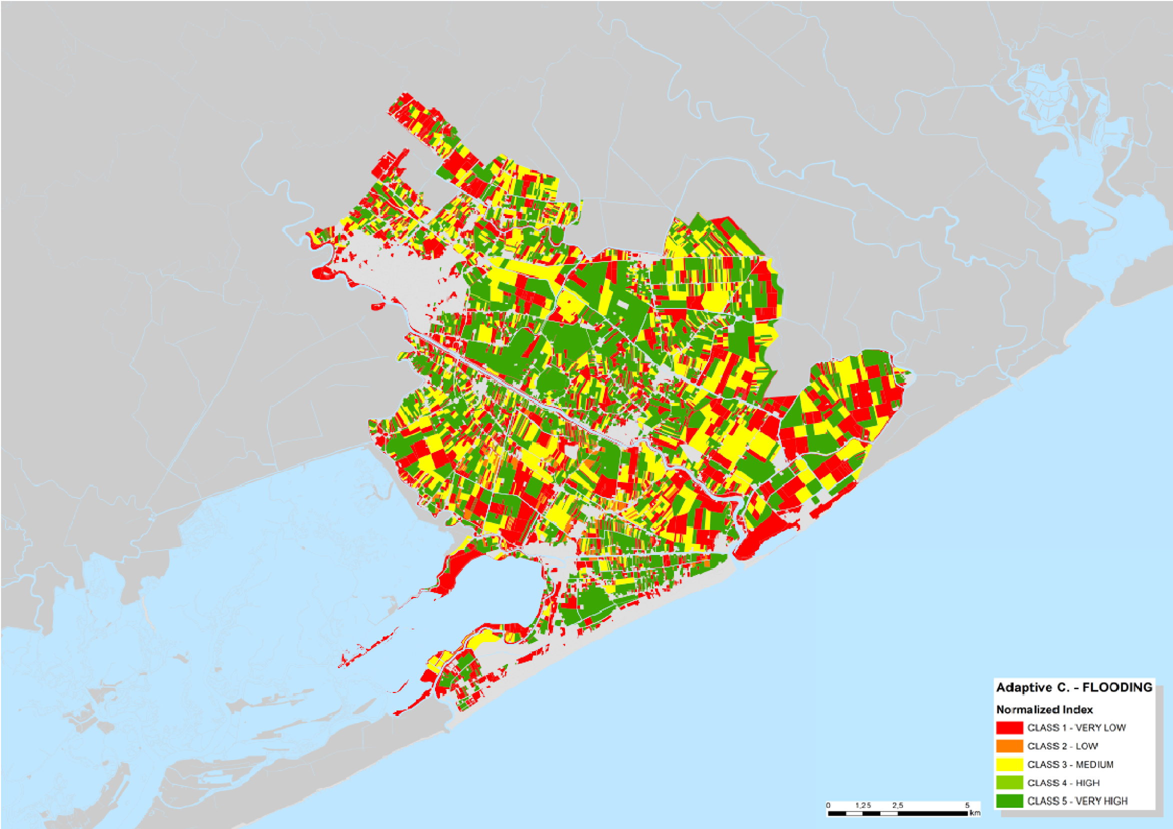


Figure 3.17 - Global Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.36).

	Normalized results
Global Sensitivity Index	
Eraclea	1,00
Jesolo	0,00
San Donà di Piave	0,45
Global Adaptive Capacity Index	
Eraclea	0,00
Jesolo	0,85

	Normalized results
San Donà di Piave	1,00
Global Vulnerability Index	
Eraclea	0,50
Jesolo	0,43
San Donà di Piave	0,73
Brief comment	San Donà di Piave has the greates global vulnerability index compared to the other to two municipalities. This is mostly driven by its low-lying fields. A better understanding of the vulnerability can be seen in the global vulnerability index map, that scale down to a field-unit precision.

Table 3.36 – Global Vulnerability Index

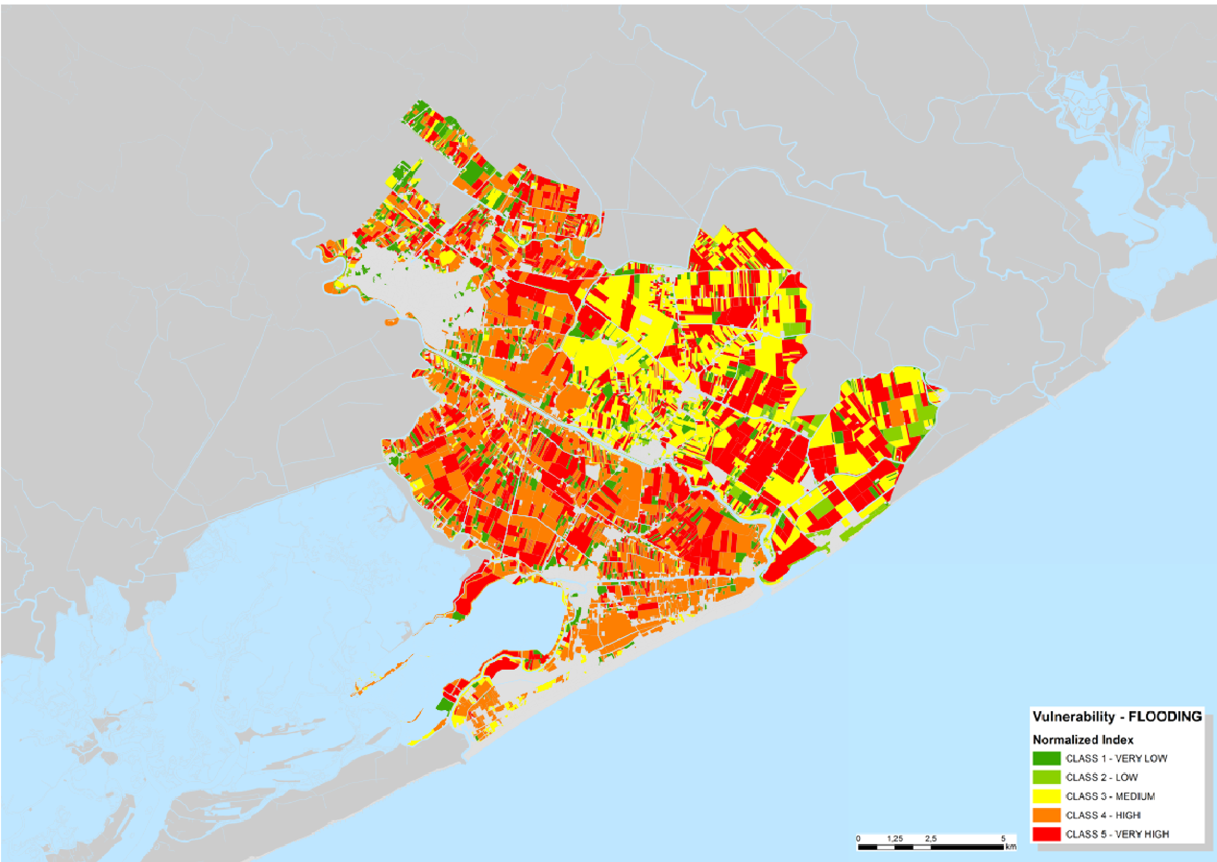


Figure 3.18 - Global Vulnerability Index map

3.5.2 The aggregation of municipalities in northern Milan

Three main impacts have been selected for the analysis and assessment on the area, reflecting the perceived and actual priorities of the territory in terms of climate-driven hazards. The area of the "*Seveso cluster*" is strongly characterized by urbanization (rate of impervious surface and building density) and the presence of a stream, the Seveso, with a riverbed almost completely artificial for the most part of its way in this area. During 20th century, the quick raise in the urbanization rate brought two complementary effects: to suffocate the river between the buildings and to increase dramatically the flow rate of the Seveso, which went from being a relatively low-flow torrential stream to collecting over-abundant sewer loads, both from civil buildings and factories. Consequently, the hydraulic risk is elevated over the whole territory, mainly for those municipalities directly exposed to the river, both in terms of frequency of events and of the exposed values in the proximity areas.
Urban flooding events are also a main concern in the area. Heavy storms are increasing in frequency in the climatic area of the cluster, making the drainage network more and more often undersized and inefficient. The situation is made even more critical as in the event of strong precipitation the drainage is discharging directly into the already saturated river flow.
Finally, the high population density, the thick urbanization and poor representativeness of green areas increase the risk related to summer heat waves impacts.

Territorial framework

The target area of the "Seveso river" cluster is an aggregation of eight Municipalities located in the area of Lombardy Region called Brianza, in the North of the city of Milano. The eight Municipalities are: Lentate sul Seveso, Barlassina, Seveso, Cesano Maderno, Bovisio Masciago, Varedo, Meda and Desio (Figure 3.19).

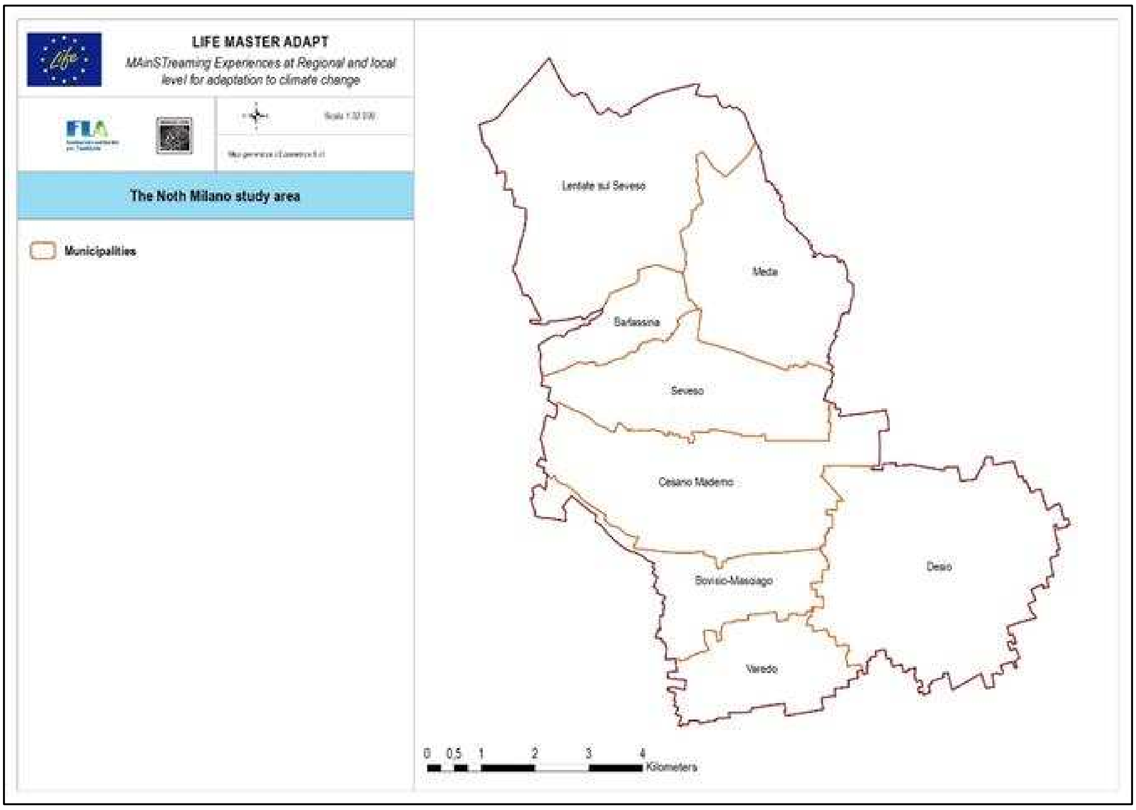


Figure 3.19 - Distribution of the eight municipalities included in the Seveso river cluster

Administratively, the area is part of the “Monza and Brianza” Province (although formerly it belonged to the Province of Milano), surrounded (Figure 3.20) by the metropolitan areas and Provinces of Como (North), Milano and Monza (South), Lecco (East).

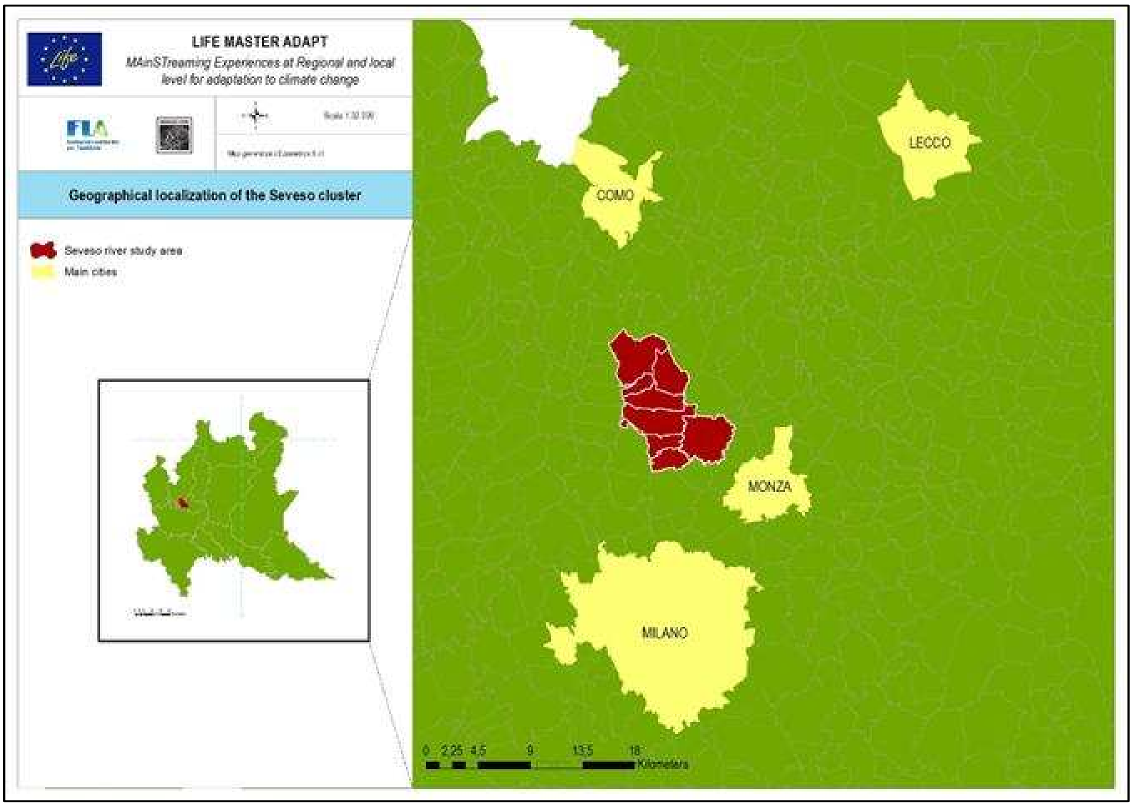


Figure 3.20 - Geographical localization of the cluster within Lombardy region and the major metropolitan areas

The territory has a clear vocation to industrial production. Coming from a long tradition, many factories are active in the textile, apparel and dyeing sector, as well as in the furniture crafting. The total surface amounts to about 68.6 km^2. The smallest municipal area is Barlassina (2.9 km^2) and the largest is Desio (14.7 km^2). The territory is highly urbanized and industrialized. The presence of areas left undisturbed and free is residual (Table 3.37).

Class	DUSAF class (lev. 1)	Surface (m^2)	Ratio
Anthropic	1	44.569.104	64,93
Agricultural	2	14.874.229	21,67
Forest and seminatural	3	9.123.832	13,29
Wetland	4	25.793	0,04
Water bodies	5	44.050	0,06

Table 3.37 - Distribution of land classes (according to DUSAF, after CLC) in the cluster

Population density is among the highest on a national level and built areas are practically continuous over the whole territory (Figure 3.21).

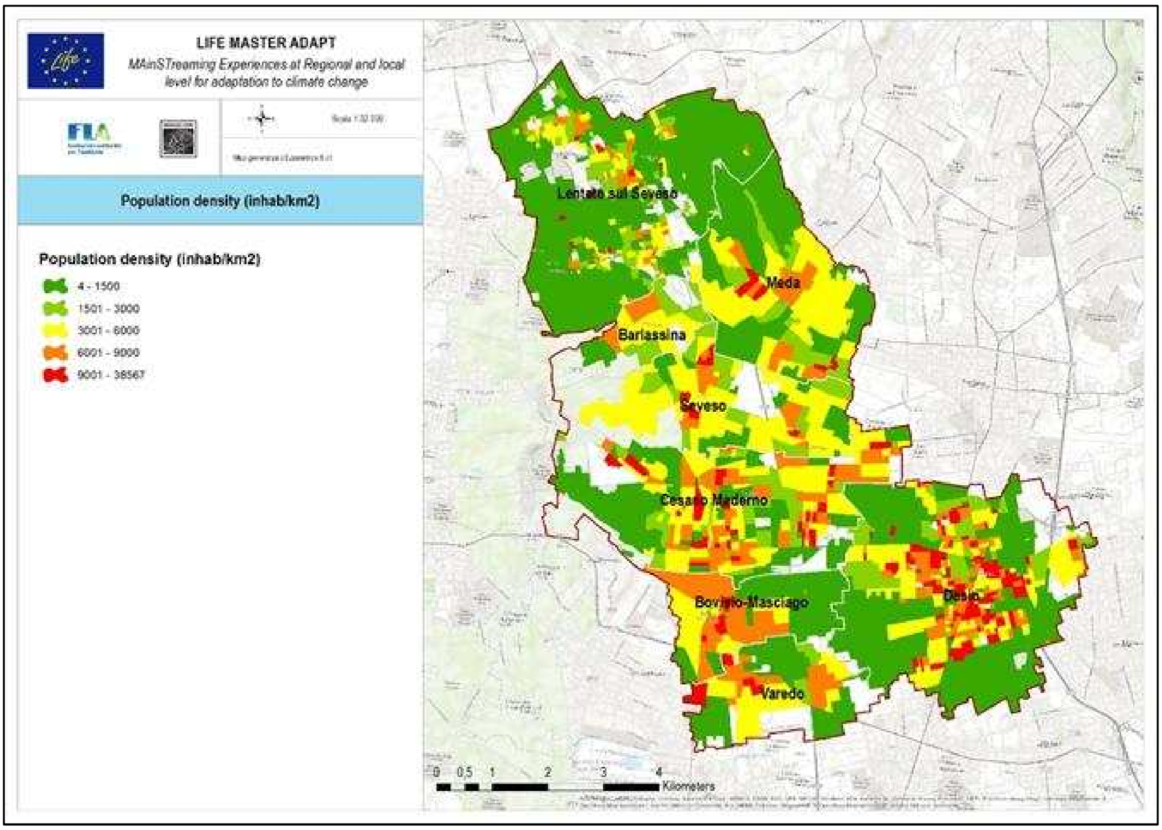


Figure 3.21 - Population density

Also, all the main road and railways network connections between Milano, Como and Lecco pass through this area.

Meteo-climatic characteristics

The area presents meteorological characteristics typical of the Po river basin.

Climate belongs to the continental classification, with relatively cold winters and warm summers, high humidity, frequent presence of fogs especially in winter, mild precipitation regime, well distributed all over the year.

Winds are normally scarce, whilst summer rainstorms are frequent. During winter, the area is often covered by a rather thick layer of cold air that, in conditions of scarce ventilation, produces persistent fogs, usually disrupted in the early afternoon.

Transition into spring is usually quite abrupt. Rains are frequent and relatively abundant during spring; further into late spring, precipitations tend to acquire the form of storms.

During summer, the high temperature together with high relative humidity and scarce ventilation produce prolonged periods of sultry weather. Summer precipitations are relatively frequent and mainly in the form of storms. Normally, the total amount of rain in summer is higher than the winter one, although less regularly distributed.

In autumn, weather is characterized by intense low-pressure areas and consequent conspicuous precipitations.

Overall, the distribution of the precipitation in the area has typically two peaks, the main one in autumn (October - November) and a secondary one in spring (April - May).

Wind regime is characterized by frequent periods of stillness, mainly as a consequence of the recurring persistence of anticyclonic conditions. Winds are light to moderate on the average, with hour speeds always lower than 10 m/s at 10 m above the ground.

River basins and watershed networks

Seveso river is the main watercourse of the area (Figure 3.22). Seveso river is a stream-like water course about 52 km long that runs across the provinces of Como, Monza e Brianza and Milano. The source is located on the Monte Sasso, close to the border to Switzerland at an elevation of 490 m asl. The river is completely covered and runs underground from the city limit between Bresso and Milano to the confluence with the Martesana canal (Naviglio della Martesana) in Milan (a segment about 9 km long). In the most part of the section included in the cluster of municipalities, the Seveso flows with almost zero slope and wholly within an artificial bed, where the walls are often the same wall of surrounding buildings. The area is characterized by an extremely high urbanization rate. Floods in the river are often disastrous: in 2010, the overflow of the river resulted in water invading several tunnels and station of the underground mass transit system of Milan. Damages caused to that event have been estimated in 20 million euro of direct costs. In 1954, the municipality of Milan built a drainage canal in order to prevent ovreflows; yet, the capacity of the canal grew insufficient as the urbanization of the area dramatically increased. In 2004, a first lot of expansion of the drainage canal was completed, but still proved insufficient to prevent floodings.

The smaller stream Tarò-Certesa flows into the Seveso from hydrographic left, whereas a minor tributary, Comasinella, comes from the right.

On the western part of the area runs the stream Garbogera. A minor watershed network, yet quiet densely developed, can be found in the territory of the "Groane" Park.

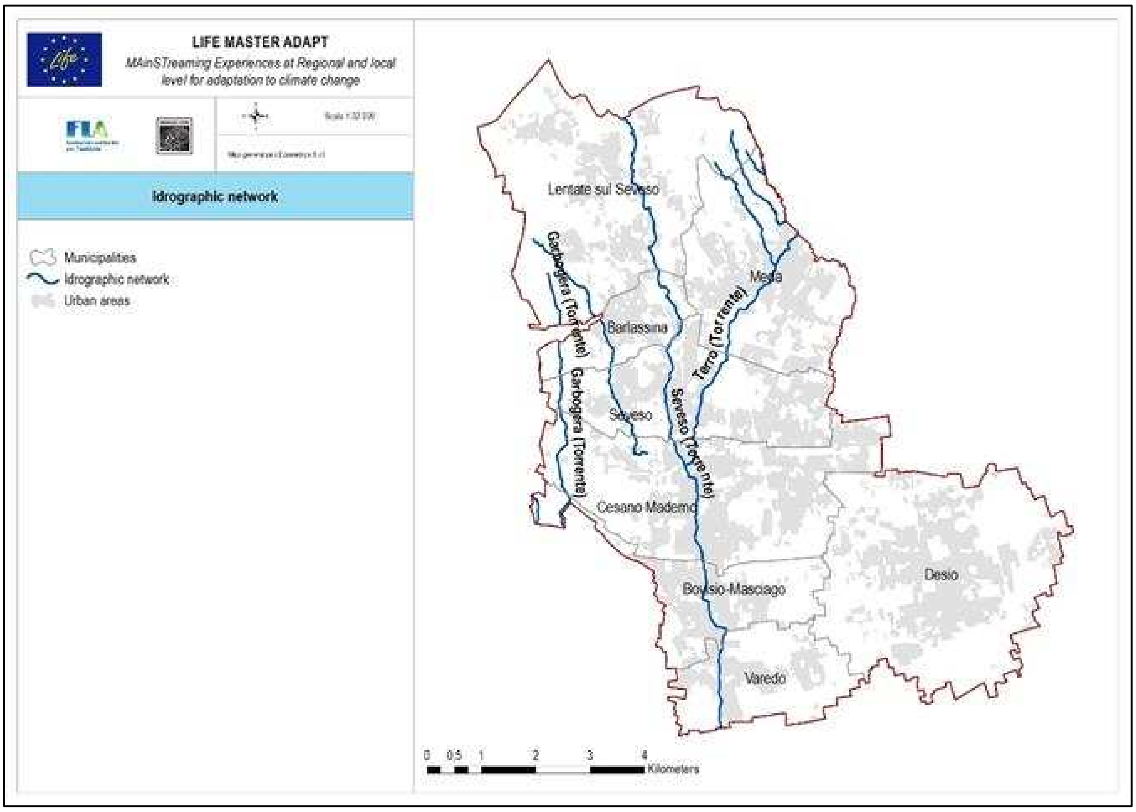


Figure 3.22 - Main hydrological network in the Seveso area

Natural areas

Three main naturalistic areas interest the territory of the Seveso river cluster (Figure 3.23).
The largest one is the "*Parco delle Groane*", a regional natural park that rests along the western border of the cluster, as shown in Figure 3.20. The Park has a total extension of approx. 4.170 ha, about which 900 ha within the area of the municipalities cluster (over 20%).
On the north-eastern corner of the cluster, the first hills of the pre-Alps start to rise. This geographical feature is part of a wider area, called "*Colline del Varesotto e dell'Alta Brianza*" in the context of the Regional Ecological Network.
Shared among the municipalities of Meda and Seveso, the regional park "*Bosco delle Querce*" has been realized in 1986 as the final intervention of the remediation of the ground severely polluted with dioxin as a consequence of the industrial accident of ICMESA (1976). The Park is about 43 ha large and has been designed with numerous indigenous species of trees with a naturalistic approach.
Finally, the "*Dorsale Verde Nord Milano*" runs across the shouthern part of the cluster area, with a West-East orientation. This area is considered to be a critical passageway for biodiversity within the Regional Ecological Network and it is intended to be protected from anthropic pressure, in order to guarantee ecological continuity in an area already severely

impacted by urbanistic pressure. At present, the passage is in fact an area of low-density urbanization and agricultural parcels.

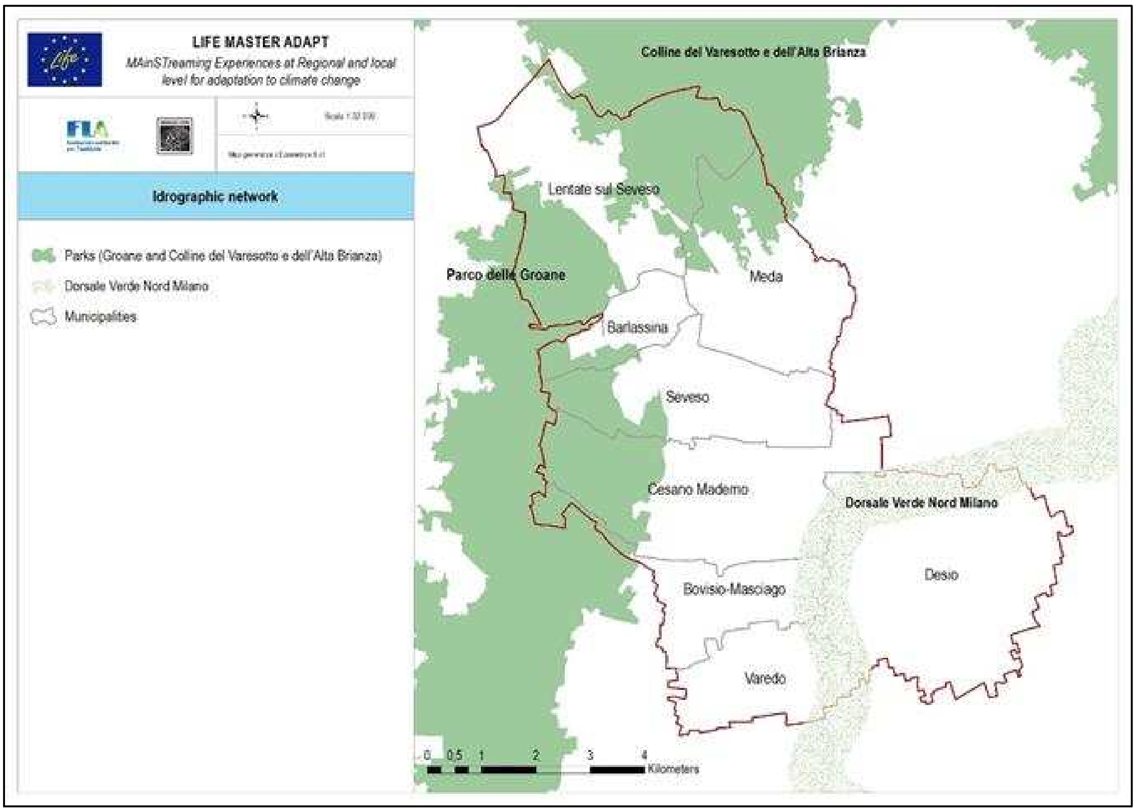


Figure 3.23 - Distribution of naturalistic areas over and nearby the territory of the cluster

Elements of the social framework

Population density in the area is among the highest in Italy. The distribution within the cluster is almost homogeneous, with the notable exception of Lentate sul Seveso (Figure 3.21), remarkably lower.

Table 3.38 presents statistics describing the distribution of overall population for gender and age classes (equal or younger than 10 years old, equal or older than 65 years old).

Table 3.39 presents the same data for the non-native speaker (foreign) population in the area, which represent an average of 7% of the overall population over the whole cluster of eight Municipalities.

Municipality	% M < 10	% F < 10	% M > 65	% F > 65	% Pop < 10	% > 65
Barlassina	53,9	46,1	43,0	57,0	33,8	66,2
Bovisio-Masciago	50,8	49,2	43,6	56,4	38,8	61,2
Cesano Maderno	51,8	48,2	43,5	56,5	35,1	64,9
Desio	51,0	49,0	42,5	57,5	35,4	64,6
Meda	53,0	47,0	43,6	56,4	31,3	68,7
Seveso	52,0	48,0	43,6	56,4	37,2	62,8
Varedo	50,6	49,4	44,4	55,6	30,3	69,7
Lentate sul Seveso	52,3	47,7	44,1	55,9	30,6	69,4
TOT	**51.7**	**48.3**	**43.4**	**56.6**	**34.4**	**65.6**

Table 3.38 - Distribution of the overall population in gender and age classes

Municipality	% M < 10	% F < 10	% M > 65	% F > 65	% Pop < 10	% > 65
Barlassina	59,5	40,5	58,8	41,2	88,1	11,9
Bovisio-Masciago	51,7	48,3	30,0	70,0	92,3	7,7
Cesano Maderno	52,0	48,0	36,5	63,5	89,9	10,1
Desio	49,9	50,1	27,1	72,9	88,9	11,1
Meda	54,0	46,0	40,0	60,0	86,6	13,4
Seveso	48,9	51,1	35,4	64,6	86,6	13,4
Varedo	55,0	45,0	23,8	76,2	89,6	10,4
Lentate sul Seveso	57,6	42,4	38,7	61,3	83,0	17,0
TOT	**52.2**	**47.8**	**34.7**	**65.3**	**88.5**	**11.5**

Table 3.39 - Distribution of the non-native speaker population for gender and age classes

Damage and loss due to river floods

Exposure analysis

On the study area, 15 exposure indicators have been computed by mean of GIS analysis. Values have been estimated for each municipality. Table 3.40 lists the results obtained, for each indicator, at municipality level.

Indicator	Results			Normalized		
Overall number of people in areas at risk	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**
Lentate sul Seveso	1	28	87	0,00	0,00	0,01
Barlassina	1	5	218	0,00	0,00	0,03
Seveso	16	19	126	0,00	0,00	0,01
Cesano Maderno	26	35	214	0,00	0,02	0,04
Bovisio Masciago	4	412	608	0,00	0,00	0,01
Varedo	3	3	86	0,00	0,04	0,04
Meda	0	936	936			
Overall number of workers in areas at risk	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**
Lentate sul Seveso	0	5	20	0,00	0,00	0,00
Barlassina	0	0	48	0,00	0,00	0,02
Seveso	0	0	4	0,00	0,00	0,00
Cesano Maderno	0	0	11	0,00	0,00	0,00
Bovisio Masciago	0	7	9	0,00	0,00	0,00
Varedo	1	1	2	0,00	0,00	0,00
Meda	0	35	35	0,00	0,00	0,00
Number of cultural heritage assets in areas at risk	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**
Lentate sul Seveso	0	1	1	0,00	0,01	0,01

Indicator	Results			Normalized		
Barlassina	0	0	4	0,00	0,00	0,17
Seveso	0	0	8	0,00	0,00	0,13
Cesano Maderno	1	1	2	0,02	0,02	0,03
Bovisio Masciago	0	5	5	0,00	0,23	0,23
Varedo	0	0	0	0,00	0,00	0,00
Meda	0	23	23	0,00	0,44	0,44
Length of roads (mt) in areas at risk	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**
Lentate sul Seveso	85	1.473	5.087	0,00	0,01	0,04
Barlassina	41	201	7.623	0,00	0,01	0,24
Seveso	65	698	1.255	0,00	0,01	0,01
Cesano Maderno	99	185	4.266	0,00	0,00	0,03
Bovisio Masciago	75	6.385	8.028	0,00	0,12	0,15
Varedo	65	74	1.365	0,00	0,00	0,03
Meda	0	12.850	12.850	0,00	0,12	0,12
Number of buildings Heritages in areas at risk	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**	**Ret. period 10 y P3**	**Ret. period 100 y P2**	**Ret. period 500 y P1**
Lentate sul Seveso	17	145	426	0,00	0,02	0,06
Barlassina	10	33	571	0,01	0,02	0,30
Seveso	40	85	193	0,01	0,01	0,03
Cesano Maderno	87	187	672	0,01	0,01	0,05
Bovisio Masciago	26	492	684	0,01	0,14	0,19
Varedo	36	63	284	0,01	0,02	0,07
Meda	0	926	926	0,00	0,15	0,15

Indicator	Results	Normalized
Global Exposure Index		
Lentate sul Seveso	0,004	
Barlassina	0,014	
Seveso	0,004	
Cesano Maderno	0,004	
Bovisio Masciago	0,025	
Varedo	0,003	
Meda	0,034	
Brief comment	Human capital: *At study area level, people exposed to the risk of floods raises from areas at high (return period 10 years), medium (return period 100 years) and low risk (return period 500 years): respectively 50, 1.437 and 2.275. Bovisio Masciago and Meda have the highest rates of exposed people: 412 and 936 in areas at medium risk and 618 and 936 in areas at high risk, respectively. Exposure of workers shows the same dynamic with 1, 47 and 129 units exposed in areas at high, medium and low risk of floods. As for inhabitants, also for workers Meda shows the most critical rates: 35 units in flooded areas with return period of 100 and 500 years.*	
	Manufactured capital: *The extension of roads potentially exposed to flood scenarios raises from 429 m (high risk) to 21.866 m (medium risk) and 40.473 m (low risk). The most critical situations have been highlighted in Bovisio Masciago and Meda, where infrastructures exposed to floods can potentially reach more than 8 km and almost 13 km, respectively. Also in terms of exposure of building the rates raise between areas at different return period. The units located in areas potentially subject to catastrophic (500 years) flood events are approx. 3.700. Meda (926), Bivisio Masciago (684) and Cesano Maderno (672) show the most critical situations.*	
	Economic capital: *The analysis on cultural heritages highlights that the area has respectively 1, 30 and 43 assets in areas prone to growing risk of floods. The highest rates (return period of 500 years) are in Meda (23) and Seveso (8).*	

Table 3.40 - Exposure indicators and Global Index

The Indicators have been weighted by means of an expert judgement. To this aim, the Analytic Hierarchy Process (AHP) method has been applied. It calculates priorities from pairwise comparisons, with eigen vector method.

Indicator	Weight
People in areas at high risk of flood (10 years)	23,6
People in areas at medium risk of flood (100 years)	12,1
People in areas at medium risk of flood (500 years)	4,7
Workers in areas at high risk of flood (10 years)	19,7
Workers in areas at medium risk of flood (100 years)	9,6
Workers in areas at low risk of flood (500 years)	6,4
Cultural Heritage assets in areas at high risk of flood (10 years)	3,5
Cultural Heritage assets in areas at medium risk of flood (100 years)	1,9
Cultural Heritage assets in areas at low risk of flood (500 years)	1,4
Length of roads in areas at high risk of flood (10 years)	3,9
Length of roads in areas at medium risk of flood (100 years)	2,2
Length of roads in areas at low risk of flood (500 years)	1,3
Buildings in areas at high risk of flood (100 years)	4,8
Buildings in areas at medium risk of flood (10 years)	3,2
Buildings in areas at low risk of flood (500 years)	1,5

Table 3.41 - Weights of the river flood exposure indicators computed by means of AHP method

Damage and loss due to extreme meteorological events and urban floods

Exposure analysis

As exposure indicator to urban floods, the rate of impervious surfaces at municipality level has been considered [1]. The following table lists the results obtained.

Indicator	Result	Normalized result
Rate of extension of impervious surfaces	**%**	
Lentate sul Seveso	40	0,40
Barlassina	67	0,67
Seveso	65	0,65
Cesano Maderno	67	0,67
Bovisio Masciago	67	0,67
Varedo	66	0,66
Meda	65	0,65

[1] The Municipality of Desio has not been considered, as data on urban floods were not available.

Overall population	**N**	
Lentate sul Seveso	10.020	1,00
Barlassina	6.826	1,00
Seveso	15.325	1,00
Cesano Maderno	27.614	1,00
Bovisio Masciago	16.428	1,00
Varedo	10.170	1,00
Meda	17.525	1,00
Global Exposure Index		
Lentate sul Seveso	0,70	
Barlassina	0,84	
Seveso	0,83	
Cesano Maderno	0,84	
Bovisio Masciago	0,84	
Varedo	0,83	
Meda	0,83	
Brief comment	Human capital: *The normalization has been computed within each municipality, considering that all the population is potentially exposed to urban flooding, as the extreme meteorological events driving the phenomenon are spatially unpredictable.*	
	Manufactured capital: *As a brief comment to the obtained results, it can be stated that the Municipality of Lentate sul Seveso, located at the North of the study area in a territorial context still preserving rural characteristics, has the lowest rated of impervious surfaces (40%). The other Municipalities are highly urbanized, with rates of impervious surfaces ranging from 65 % (Seveso and Meda) to 67% (Barlassina, Cesano Maderno and Bovisio Masciago).*	

Table 3.42 – Urbal flood exposure indicators and Global Index

Loss of life quality, health issues and casualties due to heat waves and heat island effects

Exposure analysis

As exposure indicator to heat waves, the overall number of inhabitants for each municipality has been considered.

Indicator	Result	Normalized result
Overall population	**N**	
Lentate sul Seveso	10.020	1,00
Barlassina	6.826	1,00
Seveso	15.325	1,00
Cesano Maderno	27.614	1,00
Bovisio Masciago	16.428	1,00
Varedo	10.170	1,00
Meda	17.525	1,00
Global Exposure Index		
Lentate sul Seveso	1,00	
Barlassina	1,00	
Seveso	1,00	
Cesano Maderno	1,00	
Bovisio Masciago	1,00	
Varedo	1,00	
Meda	1,00	
Brief comment	Human capital: *The normalization has been computed within each municipality, considering that all the population is potentially exposed to urban flooding, as the extreme meteorological events driving the phenomenon are spatially unpredictable.*	

Table 3.43 – Heat waves exposure indicators and Global Index

Damage and loss due to river floods

Sensitivity analysis

Based on the available data, the selection of Indicators has led to the identification of 14 indexes, estimated by mean of GIS analysis. Values have been computed at municipality level.

Indicator	Result %	Normalized result
Young people (< 10 years) in areas at high risk of flood (10 years)		

Indicator	Result %	Normalized result
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,04	0,00
Cesano Maderno	0,05	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Young people (< 10 years) in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,14	0,00
Barlassina	0,14	0,00
Seveso	0,08	0,00
Cesano Maderno	0,08	0,00
Bovisio Masciago	2,48	0,02
Varedo	0,00	0,00
Meda	4,52	0,05
Young people (< 10 years) in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,42	0,00
Barlassina	2,81	0,03
Seveso	0,55	0,01
Cesano Maderno	0,41	0,00
Bovisio Masciago	3,45	0,03
Varedo	0,71	0,01
Meda	4,52	0,05
Old people (> 65 years) in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,05	0,00
Cesano Maderno	0,10	0,00
Bovisio Masciago	0,04	0,00
Varedo	0,04	0,00
Meda	0,00	0,00
Old people (> 65 years) in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,25	0,00
Barlassina	0,07	0,00
Seveso	0,07	0,00
Cesano Maderno	0,14	0,00
Bovisio Masciago	2,62	0,03
Varedo	0,04	0,00
Meda	4,73	0,05

Indicator	Result %	Normalized result
Old people (> 65 years) in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,58	0,01
Barlassina	3,41	0,03
Seveso	0,58	0,01
Cesano Maderno	0,67	0,01
Bovisio Masciago	3,96	0,04
Varedo	0,78	0,01
Meda	4,73	0,05
Low income people in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Low income people in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	1,61	0,02
Varedo	0,00	0,00
Meda	5,41	0,05
Low income people in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	5,41	0,05
Seveso	3,81	0,04
Cesano Maderno	0,51	0,01
Bovisio Masciago	1,61	0,02
Varedo	0,00	0,00
Meda	5,41	0,05
Non-native speakers people in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,21	0,00
Cesano Maderno	0,10	0,00
Bovisio Masciago	0,00	0,00

Indicator	Result %	Normalized result
Varedo	0,00	0,00
Meda	0,00	0,00
Non-native speakers people in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,12	0,00
Barlassina	0,00	0,00
Seveso	0,21	0,00
Cesano Maderno	0,13	0,00
Bovisio Masciago	2,60	0,03
Varedo	0,00	0,00
Meda	5,81	0,06
Non-native speakers people in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,36	0,00
Barlassina	4,86	0,05
Seveso	1,55	0,02
Cesano Maderno	0,53	0,01
Bovisio Masciago	3,86	0,04
Varedo	0,38	0,00
Meda	5,81	0,06
Ratio between areas at high and medium risk of floods		
Lentate sul Seveso	0,16	0,16
Barlassina	0,10	0,10
Seveso	0,63	0,63
Cesano Maderno	0,44	0,44
Bovisio Masciago	0,05	0,05
Varedo	0,83	0,83
Meda	0,50	0,50
Number of bridges at risk in case of flood		
Lentate sul Seveso	60,00	0,60
Barlassina	60,00	0,60
Seveso	50,00	0,50
Cesano Maderno	55,56	0,56
Bovisio Masciago	88,89	0,89
Varedo	100,00	1,00
Meda	100,00	1,00

Global Sensitivity Index	
Lentate sul Seveso	0,04
Barlassina	0,04
Seveso	0,04

<table>
<tr><th colspan="2">Indicator</th><th>Result %</th><th>Normalized result</th></tr>
<tr><td colspan="2">Cesano Maderno</td><td colspan="2">0,04</td></tr>
<tr><td colspan="2">Bovisio Masciago</td><td colspan="2">0,07</td></tr>
<tr><td colspan="2">Varedo</td><td colspan="2">0,08</td></tr>
<tr><td colspan="2">Meda</td><td colspan="2">0,09</td></tr>
<tr><td rowspan="3">Brief comment</td><td colspan="3"><u>Human factor</u>: At study area level, can be highlighted that:
- young people: 5, 150 and 244 units live in areas at, respectively, high, medium and low risk of flooding. Most critical situations regard Meda (97 exposed both in medium and high risk areas) and Bovisio Masciago (46 and 64 units exposed in areas with return period of 100 and 500 years). Cesano Maderno shows the worst situation in terms of exposed in areas at high risk;
- old people: 11, 311 and 487 units live in areas at high, medium or low risk. Meda and Bovisio Masciago present the most critical situations in terms of overall exposure, whilst Cesano Maderno shows the highest exposure rate (7 units) in areas at high risk;
- low income people: exposure levels are very low (due to the good economic conditions characterizing the area), with respectively 1, 7 and 14 people located in areas at risk (return periods of 10, 100 and 500 years);
- non-native speakers people: 7, 130 and 203 foreigners are respectively located in areas at flood risk with return periods of 10, 100 and 500 years. Meda show the highest exposure rate (95 units potentially exposed to floods in area at medium or low risk), whilst Cesano Maderno and Seveso present the highest rates of exposure in high risk areas.</td></tr>
<tr><td colspan="3"><u>Natural factor:</u> The ratio between areas at high and medium risk of floods showed that Varedo presents the most critical situation (83%), followed by Seveso (63%) and Meda (50%).</td></tr>
<tr><td colspan="3"><u>Manufactured factor</u>: In the area, 42 bridges are considered at risk in case of flood events. Meda (10), Varedo (8) and Bovisio Masciago (8) show the highest rates.</td></tr>
</table>

Table 3.44 - Sensitivity indicators and Global Index

Table 3.45 lists the results obtained.

Indicator	Result %	Normalized result
Young people (< 10 years) in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,04	0,00
Cesano Maderno	0,05	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00

Indicator	Result %	Normalized result
Meda	0,00	0,00
Young people (< 10 years) in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,14	0,00
Barlassina	0,14	0,00
Seveso	0,08	0,00
Cesano Maderno	0,08	0,00
Bovisio Masciago	2,48	0,02
Varedo	0,00	0,00
Meda	4,52	0,05
Young people (< 10 years) in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,42	0,00
Barlassina	2,81	0,03
Seveso	0,55	0,01
Cesano Maderno	0,41	0,00
Bovisio Masciago	3,45	0,03
Varedo	0,71	0,01
Meda	4,52	0,05
Old people (> 65 years) in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,05	0,00
Cesano Maderno	0,10	0,00
Bovisio Masciago	0,04	0,00
Varedo	0,04	0,00
Meda	0,00	0,00
Old people (> 65 years) in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,25	0,00
Barlassina	0,07	0,00
Seveso	0,07	0,00
Cesano Maderno	0,14	0,00
Bovisio Masciago	2,62	0,03
Varedo	0,04	0,00
Meda	4,73	0,05
Old people (> 65 years) in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,58	0,01
Barlassina	3,41	0,03
Seveso	0,58	0,01
Cesano Maderno	0,67	0,01
Bovisio Masciago	3,96	0,04
Varedo	0,78	0,01

Indicator	Result %	Normalized result
Meda	4,73	0,05
Low income people in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Low income people in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	1,61	0,02
Varedo	0,00	0,00
Meda	5,41	0,05
Low income people in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	5,41	0,05
Seveso	3,81	0,04
Cesano Maderno	0,51	0,01
Bovisio Masciago	1,61	0,02
Varedo	0,00	0,00
Meda	5,41	0,05
Non-native speakers people in areas at high risk of flood (10 years)		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,21	0,00
Cesano Maderno	0,10	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Non-native speakers people in areas at medium risk of flood (100 years)		
Lentate sul Seveso	0,12	0,00
Barlassina	0,00	0,00
Seveso	0,21	0,00
Cesano Maderno	0,13	0,00
Bovisio Masciago	2,60	0,03

Indicator	Result %	Normalized result
Varedo	0,00	0,00
Meda	5,81	0,06
Non-native speakers people in areas at high risk of flood (500 years)		
Lentate sul Seveso	0,36	0,00
Barlassina	4,86	0,05
Seveso	1,55	0,02
Cesano Maderno	0,53	0,01
Bovisio Masciago	3,86	0,04
Varedo	0,38	0,00
Meda	5,81	0,06
Ratio between areas at high and medium risk of floods		
Lentate sul Seveso	0,16	0,16
Barlassina	0,10	0,10
Seveso	0,63	0,63
Cesano Maderno	0,44	0,44
Bovisio Masciago	0,05	0,05
Varedo	0,83	0,83
Meda	0,50	0,50
Number of bridges at risk in case of flood		
Lentate sul Seveso	60,00	0,60
Barlassina	60,00	0,60
Seveso	50,00	0,50
Cesano Maderno	55,56	0,56
Bovisio Masciago	88,89	0,89
Varedo	100,00	1,00
Meda	100,00	1,00

Global Sensitivity Index	
Lentate sul Seveso	0,04
Barlassina	0,04
Seveso	0,04
Cesano Maderno	0,04
Bovisio Masciago	0,07
Varedo	0,08
Meda	0,09

Brief comment	Human factor: *At study area level, can be highlighted that:* - ***young people****: 5, 150 and 244 units live in areas at, respectively, high, medium and low*

Indicator	Result %	Normalized result
risk of flooding. Most critical situations regard Meda (97 exposed both in medium and high risk areas) and Bovisio Masciago (46 and 64 units exposed in areas with return period of 100 and 500 years). Cesano Maderno shows the worst situation in terms of exposed in areas at high risk; - ***old people**: 11, 311 and 487 units live in areas at high, medium or low risk. Meda and Bovisio Masciago present the most critical situations in terms of overall exposure, whilst Cesano Maderno shows the highest exposure rate (7 units) in areas at high risk;* - ***low income people**: exposure levels are very low (due to the good economic conditions characterizing the area), with respectively 1, 7 and 14 people located in areas at risk (return periods of 10, 100 and 500 years);* - ***non-native speakers people**: 7, 130 and 203 foreigners are respectively located in areas at flood risk with return periods of 10, 100 and 500 years. Meda show the highest exposure rate (95 units potentially exposed to floods in area at medium or low risk), whilst Cesano Maderno and Seveso present the highest rates of exposure in high risk areas.*		
<u>Natural factor:</u> *The ratio between areas at high and medium risk of floods showed that Varedo presents the most critical situation (83%), followed by Seveso (63%) and Meda (50%).*		
<u>Manufactured factor</u>: *In the area, 42 bridges are considered at risk in case of flood events. Meda (10), Varedo (8) and Bovisio Masciago (8) show the highest rates*.		

Table 3.45 - River flood sensitivity indicators and Global Index

Table 3.46 shows the range of values to which we have applied the normalization for each index:

$$V_n = \frac{V_i - V_{min}}{V_{max} - V_{min}}$$

Index	Min	Max
Young people (< 10 years) in areas at high risk of floods (10 years)	0	100
Young people (< 10 years) in areas at medium risk of floods (100 years)	0	100
Young people (< 10 years) in areas at high risk of floods (500 years)	0	100
Old people (> 65 years) in areas at high risk of floods (10 years)	0	100
Old people (> 65 years) in areas at medium risk of floods (100 years)	0	100
Old people (> 65 years) in areas at high risk of floods (500 years)	0	100
Low income people in areas at high risk of floods (10 years)	0	100
Low income people in areas at medium risk of floods (100 years)	0	100
Low income people in areas at high risk of floods (500 years)	0	100
Foreign people in areas at high risk of floods (10 years)	0	100
Foreign people in areas at medium risk of floods (100 years)	0	100
Foreign people in areas at high risk of floods (500 years)	0	100
Ratio between areas at high and medium risk of floods	0	1
Number of bridges at risk in case of flood	0	Tot number of bridges in the municipality

Table 3.46 – Normalization ranges for the sensitivity indexes (river flood)

The weighting procedure, by means of the Analytic Hierarchy Process (AHP) method, was submitted to expert judgement. The following Table lists the weights obtained with the analysis.

Indicator	Weight
Young people (< 10 years) in areas at high risk of flood (10 years)	17,7
Young people (< 10 years) in areas at medium risk of flood (100 years)	9,8
Young people (< 10 years) in areas at high risk of flood (500 years)	4,1
Old people (> 65 years) in areas at high risk of flood (10 years)	22,8

Indicator	Weight
Old people (> 65 years) in areas at medium risk of flood (100 years)	9,5
Old people (> 65 years) in areas at high risk of flood (500 years)	4,6
Low income people in areas at high risk of flood (10 years)	5,5
Low income people in areas at medium risk of flood (100 years)	2,5
Low income people in areas at high risk of flood (500 years)	1,2
Non-native speakers people in areas at high risk of flood (10 years)	8,3
Non-native speakers people in areas at medium risk of flood (100 years)	4,3
Non-native speakers people in areas at high risk of flood (500 years)	1,6
Ratio between areas at high and medium risk of floods	1,9
Number of bridges at risk in case of flood	6,1

Table 3.47 - Weights of the river flood sensitivity Indicators computed by means of AHP method

Adaptive capacity analysis

The available data allowed to compute 4 indexes of adaptive capacity, listed in Table 3.48.

Indicator	Result %	Normalized result
Number (%) of Red & Orange Codes in case of critical levels of the river (1,8 m)		
Lentate sul Seveso	100,00	1,00
Barlassina	100,00	1,00
Seveso	100,00	1,00
Cesano Maderno	53,00	0,53
Bovisio Masciago	53,00	0,53
Varedo	53,00	0,53
Meda	0,00	0,00
Availability of local alert systems		
Lentate sul Seveso	1,00	1,00
Barlassina	1,00	1,00
Seveso	1,00	1,00
Cesano Maderno	1,00	1,00
Bovisio Masciago	1,00	1,00
Varedo	1,00	1,00
Meda	1,00	1,00

Availability of Operating Procedures in alert or emergency phases		
Lentate sul Seveso	1,00	1,00
Barlassina	1,00	1,00
Seveso	1,00	1,00
Cesano Maderno	1,00	1,00
Bovisio Masciago	1,00	1,00
Varedo	1,00	1,00
Meda	1,00	1,00
Availability of tools to alert population		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	1,00	1,00
Varedo	0,00	0,00
Meda	0,00	0,00

Global Adaptive Capacity Index		
Municipality	**AC Index (i)**	**Compl. AC Index (1-i)**
Lentate sul Seveso	0,95	0,05
Barlassina	0,95	0,05
Seveso	0,95	0,05
Cesano Maderno	0,79	0,21
Bovisio Masciago	0,84	0,16
Varedo	0,79	0,21
Meda	0,60	0,40

Brief comment	Knowledge and technology: *The capability of the local alert systems to predict critical situations in terms of exceptional streams of the rivers has been investigated. From the available data, forecasting systems seem to have better performances on the northern Municipalities (Lentate sul Seveso, Barlassina and Seveso) where all (100%) the most critical situations occurred in the last 5 years have been predicted by Lombardy Region Bulletins with Red Code Alerts. In the southern Municipalities (Bovisio Masciago, Cesano Maderno and Varedo) the alert system seems to have lower performances (33% Red Codes, 20% Orange Codes and 40% Yellow Codes). On the stream crossing Meda, no water gauges have been activated. In terms of indexing, we decided to count together the rates of red and orange codes as a measure of the accurateness of the system and, conversely, to consider the complementary yellow and green codes in case of critical condition of the river as a failure of the system.* *On all Municipalities, an Alert System managed by Lombardy Region is active, with emission of daily Bulletins.*

Table 3.48 - River flood adaptive aapacity indicators and Global index

Index	Min	Max
Number (%) of Red & Orange Codes in case of critical levels of the river (1,8 mt)	0	100
Availability of local alert systems	0 (NO)	1 (YES)
Availability of Operating Procedures in alert or emergency phases	0 (NO)	1 (YES)
Availability of tools to alert population	0 (NO)	1 (YES)

Table 3.49 - Normalization ranges for the adaptive capacity indexes (River Flood)

The weighting procedure, by means of the Analytic Hierarchy Process (AHP) method produced the following results.

Indicator	Weight
Number (%) of Red & Orange Codes in case of critical levels of the river (1,8 m)	34,6
Availability of local alert systems	46,4
Availability of Operating Procedures in alert or emergency phases	14,0
Availability of tools to alert population	5,0

Table 3.50 - Weights of the river flood adaptive capacity indicators computed by means of AHP method

Global Vulnerability Index

A final integration procedure has been applied to derive, from the indexes on sensitivity and adaptive capacity, the final Vulnerability Index. The final computation of the Vulnerability

Index has been obtained by applying the following formula:

$$V = \frac{S * w_S + AC * w_{AC}}{w_S + w_{AC}}$$

The weights assigned to the sensitivity and the adaptive capacity components has been chosen to be complementary, so that their overall sum is always 1. In the present case, a high weight to the sensitivity component (0,8) reflects the very critical value of human lives, as even a single casualty in local events would be considered an exceptional event.

Table 3.51, Figure 3.24 and Figure 3.25 show the final results.

	Normalized result
Global Sensitivity Index	
Lentate sul Seveso	0,04
Barlassina	0,04
Seveso	0,04
Cesano Maderno	0,04
Bovisio Masciago	0,07
Varedo	0,08
Meda	0,09
Global Adaptive Capacity Index	
Lentate sul Seveso	0,05
Barlassina	0,05
Seveso	0,05
Cesano Maderno	0,21
Bovisio Masciago	0,16
Varedo	0,21
Meda	0,40
Global Vulnerability Index	
Lentate sul Seveso	0,04
Barlassina	0,04
Seveso	0,05
Cesano Maderno	0,08
Bovisio Masciago	0,09
Varedo	0,11
Meda	0,15

Brief comment	*Based on the analysis carried out, the Municipality of Meda appears to be the most vulnerable to flood impacts, followed by Varedo (at the extreme south of the study area), Bovisio Masciago and Cesano Maderno. Meda suffers from both high levels of sensitivity (with high rate of exposure of infrastructures, e.g. bridges) and the lowest adaptive capacity among the seven municipalities, (lack of monitoring on stream levels). Varedo, Bovisio Masiago and Cesano Maderno are mainly affected by high exposure levels due to some critical bridges causing flood problems and by limited adaptive capacity, with forecasting systems performances to be improved.*

Table 3.51 - River flood vulnerability indicators and Global Index

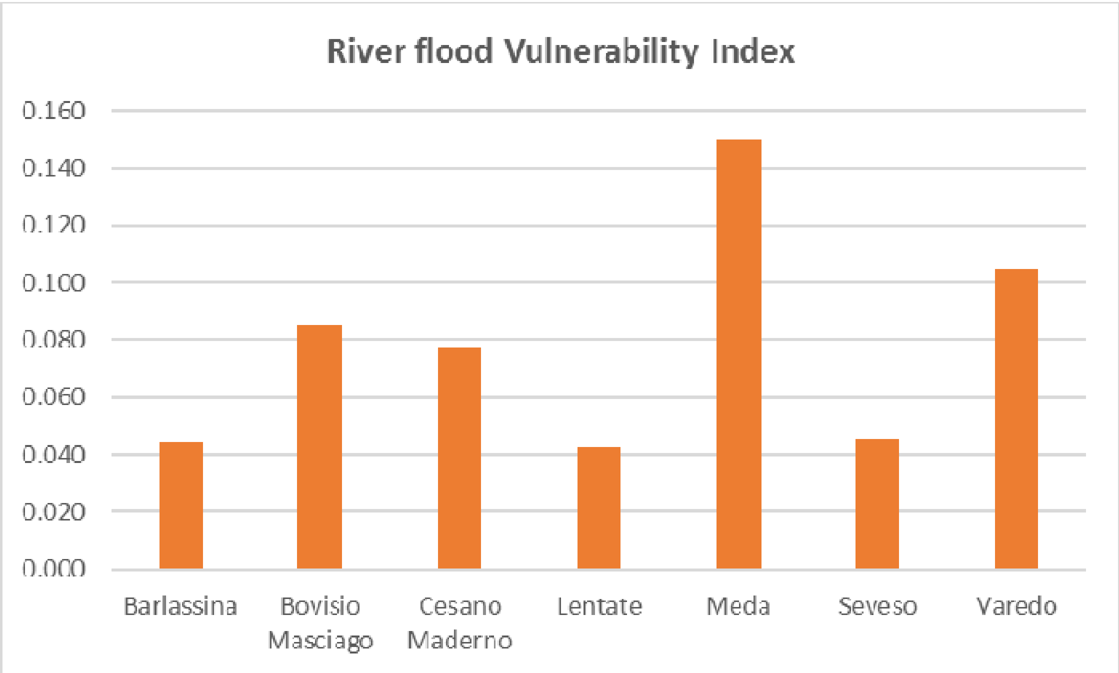


Figure 3.24 - River flood vulnerability index values for each municipality

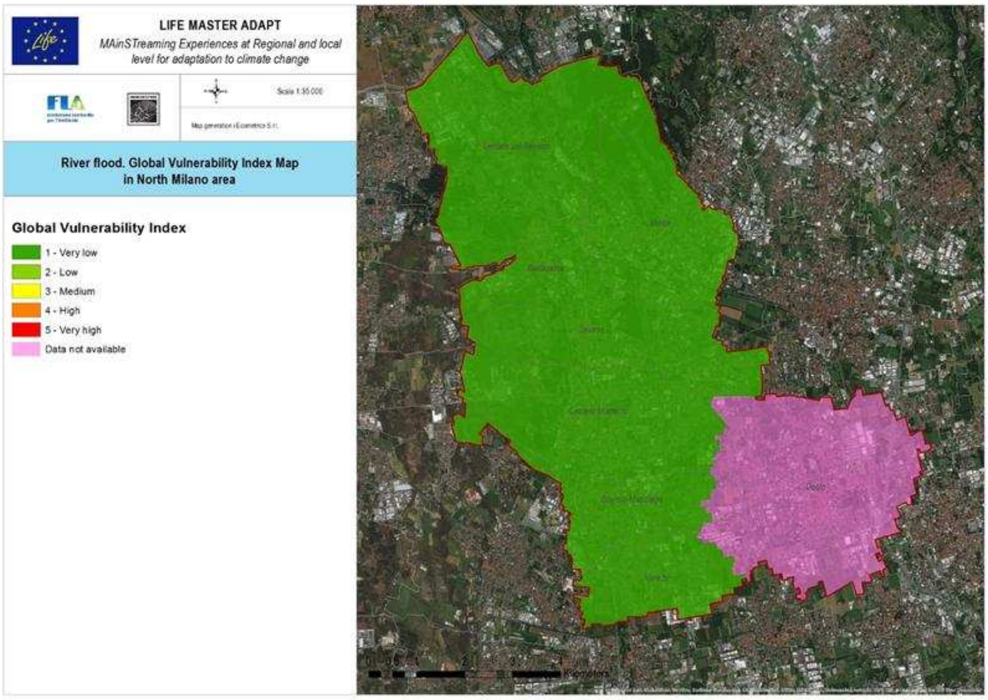


Figure 3.25 - River flood Global Vulnerability Index map

Damage and loss due to extreme meteorological events and urban floods

Sensitivity analysis

The available data allowed to select 5 sensitivity indicators, whose values are reported in Table 3.52.

Indicator	Result %	Normalized result
Percentage of young (< 10 years) people		
Lentate sul Seveso	9,00	0,09
Barlassina	10,00	0,10
Seveso	10,00	0,10
Cesano Maderno	10,00	0,10
Bovisio Masciago	11,00	0,11
Varedo	9,00	0,09
Meda	9,00	0,09
Percentage of old (> 65 years) people		
Lentate sul Seveso	21,00	0,21
Barlassina	21,00	0,21
Seveso	18,00	0,18

Cesano Maderno	19,00	0,19
Bovisio Masciago	17,00	0,17
Varedo	21,00	0,21
Meda	20,00	0,20
Percentage of Non-native speaker people		
Lentate sul Seveso	5,00	0,05
Barlassina	7,00	0,07
Seveso	6,00	0,06
Cesano Maderno	8,00	0,08
Bovisio Masciago	6,00	0,06
Varedo	6,00	0,06
Meda	7,00	0,07
Percentage of low income people		
Lentate sul Seveso	0,00	0,00
Barlassina	1,00	0,01
Seveso	0,00	0,00
Cesano Maderno	1,00	0,01
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Rate of critical underpasses		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	3,00 (100%)	1,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	3,00 (100%)	1,00
Rate of road network surface		
Lentate sul Seveso	1,48	0,11
Barlassina	1,96	0,15
Seveso	1,32	0,10
Cesano Maderno	0,79	0,06
Bovisio Masciago	1,57	0,12
Varedo	2,97	0,23
Meda	1,57	0,12
Rate of draining surface[2]		

[2] The Rate of draining surface index has been considered with an inverse direction in the value range, reflecting its positive influence on sensitivity.

Lentate sul Seveso	63,7	0,61
Barlassina	32,5	0,27
Seveso	34,5	0,29
Cesano Maderno	34,6	0,29
Bovisio Masciago	39,7	0,35
Varedo	34,8	0,29
Meda	37,8	0,33
Global Sensitivity Index		
Lentate sul Seveso	0,12	
Barlassina	0,18	
Seveso	0,17	
Cesano Maderno	0,53	
Bovisio Masciago	0,16	
Varedo	0,19	
Meda	0,54	
Brief comment	Human factor: *All Municipalities have equivalent rates of young people, old people, Non-native speakers and low-income people, respectively:* - ***young people**: from 9% (Lentate sul Seveso, Varedo and Meda) to 11% (Bovisio Masciago);* - ***old people**: from 17% (Bovisio Masciago) to 21% (Lentate sul Seveso, Barlassina and Varedo);* - ***non-native speakers people**: from 5% (Lentate sul Seveso) to 8% (Cesano Maderno);* ***low income people**: from 0% to 1% (Barlassina and Cesano Maderno).*	
	Manufactured factor: *In the area, 6 underpasses are in areas considered to be exposed to urban floods: 3 of them are located in Cesano Maderno and the other in Meda.*	

Table 3.52 - Urban flood sensitivity indicators and Global Index

Index	Min	Max
Percentage (%) of young (< 10 years) people	0	100
Percentage (%) of old (> 65 years) people	0	100
Percentage (%) of foreign people	0	100
Percentage (%) of low income people	0	100
Rate of critical underpasses	0	Tot. in the municipality
Rate of road network surface	Min. over the homogeneous area[3]	Max. over the homogeneous area

[3] Lombardy, with the exclusion of the alpine mountainous area of its territory. Road network rate: min = 0,0007; max = 13,06; mean = 0,88. Draining surface rate: min = 7,89; max = 99,22; mean = 76,27 (mq/mq).

Rate of draining surface	Min. over the homogeneous area	Max. over the homogeneous area

Table 3.53 - Normalization ranges for the sensitivity indexes (Urban Flood)

The weighting procedure, by means of the Analytic Hierarchy Process (AHP) method has produced the following results.

Indicator	Weight
Percentage of young (< 10 years) people	9,0
Percentage of old (> 65 years) people	9,7
Percentage of Non-native speakers people	5,1
Percentage of low income people	5,2
Rate of critical underpasses	36,9
Rate of road network surface	17,2
Rate of draining surface	16,9

Table 3.54 - Weights of the urban flood sensitivity indicators computed by means of AHP method

Adaptive capacity analysis

The available data allowed to compute 4 indexes of adaptive capacity, listed in Table 3.55.

Indicator	Result %	Normalized result
Number of Orange Codes in case of heavy rains		
Lentate sul Seveso	66,67	0,67
Barlassina	66,67	0,67
Seveso	66,67	0,67
Cesano Maderno	66,67	0,67
Bovisio Masciago	66,67	0,67
Varedo	66,67	0,67
Meda	66,67	0,67
Availability of local alert systems		
Lentate sul Seveso	1,00	1,00
Barlassina	1,00	1,00
Seveso	1,00	1,00
Cesano Maderno	1,00	1,00

Bovisio Masciago	1,00	1,00
Varedo	1,00	1,00
Meda	1,00	1,00
Availability of Operating Procedures in alert or emergency phases		
Lentate sul Seveso	1,00	1,00
Barlassina	1,00	1,00
Seveso	1,00	1,00
Cesano Maderno	1,00	1,00
Bovisio Masciago	1,00	1,00
Varedo	1,00	1,00
Meda	1,00	1,00
Availability of tools to alert population		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	1,00	1,00
Varedo	0,00	0,00
Meda	0,00	0,00

Global Adaptive Capacity Index		
Municipality	**AC Index (i)**	**Compl. AC Index (1-i)**
Lentate sul Seveso	0,85	0,15
Barlassina	0,85	0,15
Seveso	0,85	0,15
Cesano Maderno	0,85	0,15
Bovisio Masciago	0,89	0,11
Varedo	0,85	0,15
Meda	0,85	0,15

Brief comment	Knowledge and technology: *The capability of the local alert systems to predict critical situations in terms of extreme rainstorms has been investigated. From the available data (a reference rain gauge has been used for the analysis), in 66% of extreme rainstorm occurrences, the Lombardy Region Bulletins had been emitted with Orange Code (the highest level of Alert for such events) and in 33% with Yellow Code.* *On all Municipalities the Alert System managed by Lombardy Region is active, with emission of daily Bulletins.* *Every Municipality has a Civil Protection Plan (with different update levels) and operating procedures, to be applied in case of alert or emergency.* *The only Municipality of Bovisio Masciago is managing an innovative tool to alert the population.*

Table 3.55 - Urban flood adaptive capacity indexes values

Index	Min	Max
Number (%) of Orange Codes in case of heavy rains	0	100
Availability of local alert systems	0 (NO)	1 (YES)
Availability of Operating Procedures in alert or emergency phases	0 (NO)	1 (YES)
Availability of tools to alert population	0 (NO)	1 (YES)

Table 3.56 - Normalization ranges for the adaptive capacity indexes (Urban Flood)

Table 3.57 lists the weights obtained with the Analytic Hierarchy Process (AHP) method analysis.

Indicator	Weight
Number of Orange Codes in case of heavy rains	32,1
Availability of local alert systems	50,5
Availability of Operating Procedures in alert or emergency phases	13,1
Availability of tools to alert population	4,2

Table 3.57 - Weights of the urban flood adaptive capacity indicators computed by means of AHP method

Global Vulnerability Index

A final integration procedure has been applied to derive, from the indexes on sensitivity and adaptive capacity, the final Vulnerability Index.

The final computation of the Vulnerability Index has been obtained by applying the following formula.

$$V = \frac{S * w_S + AC * w_{AC}}{w_S + w_{AC}}$$

The weights assigned to the sensitivity and the adaptive capacity components has been chosen to be complementary, so that their overall sum is always 1.

Similarly, to the river flood vulnerability assessment, also in the present case a high weight to the sensitivity component (0,8) reflects the very critical value of human lives, as even a single casualty in local events would be considered an absolutely exceptional event.

Table 3.58 and Figure 3.26 show the final results.

	Normalized result
Global Sensitivity Index	
Lentate sul Seveso	0,12
Barlassina	0,18
Seveso	0,17
Cesano Maderno	0,53
Bovisio Masciago	0,16
Varedo	0,19
Meda	0,54
Global Adaptive Capacity Index	
Lentate sul Seveso	0,15
Barlassina	0,15
Seveso	0,15
Cesano Maderno	0,15
Bovisio Masciago	0,11
Varedo	0,15
Meda	0,15
Global Vulnerability Index	
Lentate sul Seveso	0,12
Barlassina	0,18

Seveso	0,16
Cesano Maderno	0,46
Bovisio Masciago	0,15
Varedo	0,18
Meda	0,46
Brief comment	*Based on the analysis carried out, the Municipality of Cesano Maderno (0,455) and Meda (0,457) appear to be the most vulnerable to urban flood impacts* (Figure 3.27). *The result is mainly due to the relevant presence, on those Municipalities, of underpasses potentially flooded in case of extreme rains. The Municipality where floods due to extreme rainstorms are expected to produce lower impacts is Lentate sul Seveso (0,123), mainly due to its lower rate of impervious surfaces. Barlassina, Bovisio Masciago, Seveso and Varedo have almost equivalent vulnerability levels, ranging from about 0,15 to 0,18.*

Table 3.58 - Urban flood Global Vulnerability Index

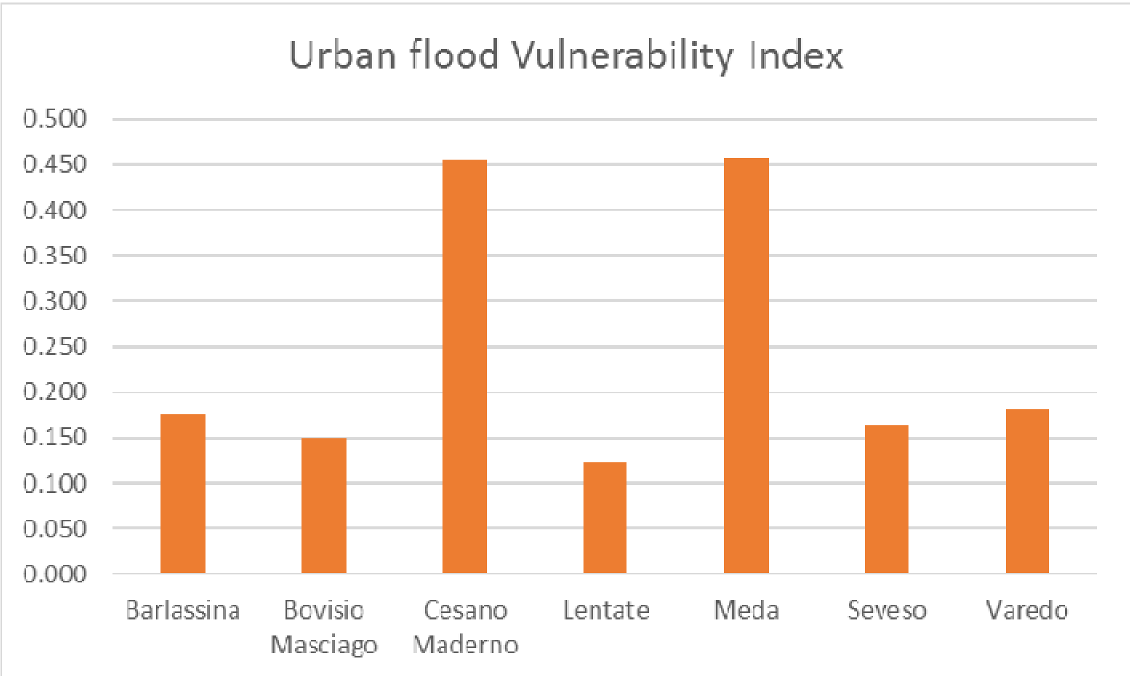


Figure 3.26 - Urban flood Vulnerability Index values for each Municipality

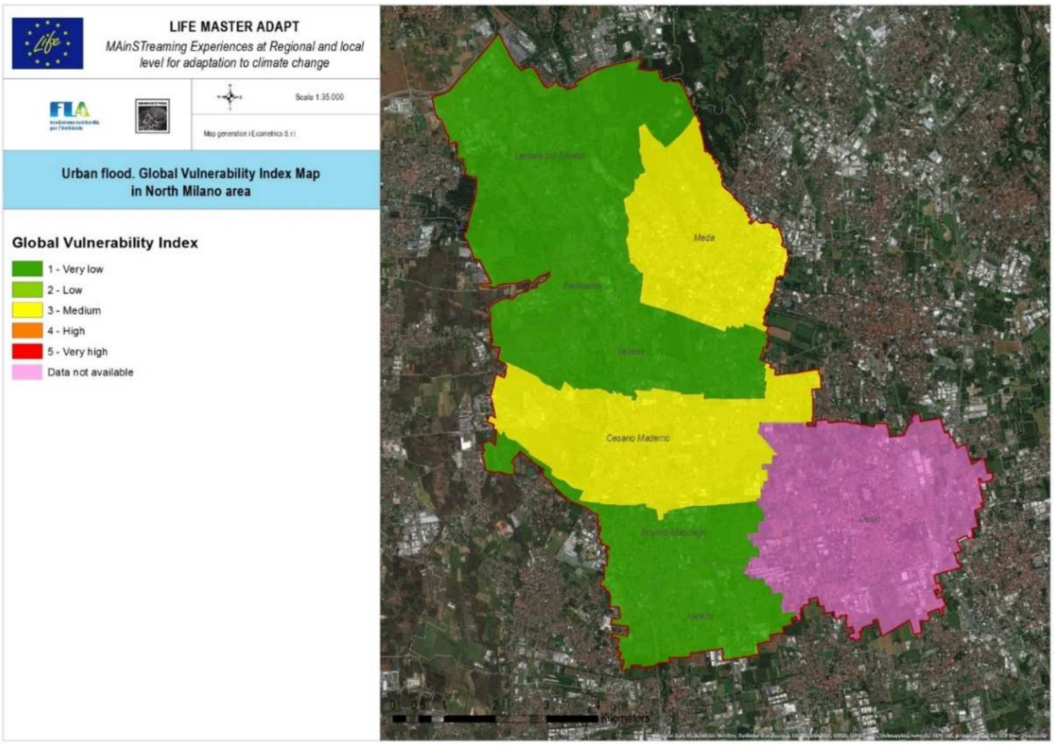


Figure 3.27 - Urban flood Global Vulnerability Index map

Loss of life quality, health issues and casualties due to heat waves and heat island effects

Sensitivity analysis

The available data allowed to select 6 sensitivity indicators, whose values are reported in Table 3.59.

Indicator	Result %	Normalized result
Percentage of young (< 10 years) people		
Lentate sul Seveso	9,00	0,09
Barlassina	10,00	0,10
Seveso	10,00	0,10
Cesano Maderno	10,00	0,10
Bovisio Masciago	11,00	0,11
Varedo	9,00	0,09
Meda	9,00	0,09

Desio	10,00	0,10
Percentage of old (> 65 years) people		
Lentate sul Seveso	21,00	0,21
Barlassina	21,00	0,21
Seveso	18,00	0,18
Cesano Maderno	19,00	0,19
Bovisio Masciago	17,00	0,17
Varedo	21,00	0,21
Meda	20,00	0,20
Desio	19,00	0,19
Percentage (%) of old people living alone		
Lentate sul Seveso	24,00	0,24
Barlassina	24,00	0,24
Seveso	24,00	0,24
Cesano Maderno	26,00	0,26
Bovisio Masciago	25,00	0,25
Varedo	25,00	0,25
Meda	24,00	0,24
Desio	26,00	0,26
Impervious surface rate		
Lentate sul Seveso	-	0,40
Barlassina	-	0,67
Seveso	-	0,65
Cesano Maderno	-	0,67
Bovisio Masciago	-	0,67
Varedo	-	0,66
Meda	-	0,65
Desio	-	0,58
Green areas per capita[4]		
Lentate sul Seveso	45,9	0,37
Barlassina	8,4	0,07
Seveso	26,6	0,22
Cesano Maderno	0,0	0,00
Bovisio Masciago	0,0	0,00
Varedo	0,0	0,00
Meda	14,5	0,12
Desio	0,0	0,00

[4] The Green areas per capita has been considered with an inverse direction in the value range, reflecting its positive influence on sensitivity.

Population density		
Lentate sul Seveso	953,9	0,10
Barlassina	2.231,5	0,49
Seveso	2.289,2	0,51
Cesano Maderno	2.759,9	0,65
Bovisio Masciago	2.500,3	0,57
Varedo	2.225,2	0,49
Meda	2.591,1	0,60
Desio	2.574,5	0,59
Global Sensitivity Index		
Lentate sul Seveso	0,27	
Barlassina	0,27	
Seveso	0,28	
Cesano Maderno	0,28	
Bovisio Masciago	0,27	
Varedo	0,27	
Meda	0,28	
Desio	0,24	
Brief comment	Human factor: *All the Municipalities show comparable values of the Sensitivity Indicators considered:* - *values of "Percentage of young (< 10 years) people" range from 9 to 11% (Seveso);* - *values of "Percentage of old (> 65 years) people" range from 17 to 21% (Lentate sul Seveso, Barlassina and Seveso);* - *values of "Percentage (%) of old people living alone" range from 24 to 26% (Cesano Maderno and Desio).* *Also population density is remarkably high almost everywhere, with the exception of Lentate sul Seveso (normalized values calculated over the Province of Monza and Brianza).*	
	Natural factor: *All the Municipalities are afflicted by a general low rate of green areas (non-agricultural) per individual. As reported in the general description, the area is highly urbanized, with values of built environment among the highest in the region and even on the national scale.*	
	Manufactured factor: *impervious surface rate has been computed from the land use classes of the DUSAF classification of Lombardy territory. Once again, the values reflect the heavy urbanization of the area and the very high percentage of sealed surface and built volumes.*	

Table 3.59 - Heat waves sensitivity indicators and Global Index

Index	Min	Max
Percentage (%) of young (< 10 years) people	0	100
Percentage (%) of old (> 65 years) people	0	100
Old people (> 65 years) living alone	0	100
Impervious surface rate	0	100
Green areas per capita	Min. over the homogeneous area[5]	Max. over the homogeneous area
Population density	Min. over the homogeneous area	Max. over the homogeneous area

Table 3.60 - Normalization ranges for the sensitivity indexes (Urban Flood)

Table 3.61 lists the weights obtained with the analysis.

Indicator	Weight
Percentage of young (< 10 years) people	3,7
Percentage of old (> 65 years) people	28,1
Percentage (%) of old people living alone	40,8
Impervious surface rate	9,1
Green areas per capita	9,1
Population density	9,1

Table 3.61 - Weights of the heat waves sensitivity indicators computed by means of AHP method

Adaptive capacity analysis

The available data allowed to compute 3 indicators of adaptive capacity, listed in Table 3.62.

Indicator	Result %	Normalized result
Rate (%) of domestic conditioned volumes		
Lentate sul Seveso	16,00	0,16
Barlassina	9,00	0,09

[5] The Province of Monza and Brianza.

Seveso	10,00	0,10
Cesano Maderno	12,00	0,12
Bovisio Masciago	15,00	0,15
Varedo	18,00	0,18
Meda	12,00	0,12
Desio	22,00	0,22
Rate (%) of people living close (<300m) to non-domestic conditioned volumes		
Lentate sul Seveso	48,00	0,48
Barlassina	66,00	0,66
Seveso	58,00	0,58
Cesano Maderno	71,00	0,71
Bovisio Masciago	54,00	0,54
Varedo	57,00	0,57
Meda	62,00	0,62
Desio	64,00	0,64
Number of beds in hospital / 10k inhabitants		
Lentate sul Seveso	0,00	0,00
Barlassina	0,00	0,00
Seveso	0,00	0,00
Cesano Maderno	0,00	0,00
Bovisio Masciago	0,00	0,00
Varedo	0,00	0,00
Meda	0,00	0,00
Desio	8,00	0,48

Global Adaptive Capacity Index		
Municipality	**AC Index (i)**	**Compl. AC Index (1-i)**
Lentate sul Seveso	0,15	0,85
Barlassina	0,12	0,88
Seveso	0,12	0,88
Cesano Maderno	0,14	0,86
Bovisio Masciago	0,15	0,85
Varedo	0,18	0,82
Meda	0,14	0,86

<table>
<tr><td colspan="2">Desio</td><td>0,31</td><td>0,69</td></tr>
<tr><td rowspan="2">Brief comment</td><td colspan="3"><u>Knowledge and technology:</u> Desio shows by far the highest values of domestic conditioned volumes (22%), followed by Varedo (18%). The lowest rates came out in Barlassina and Seveso (9 and 10%, respectively).</td></tr>
<tr><td colspan="3"><u>Infrastructure:</u> The rate of people living close (<300 m) to non-domestic conditioned values (medium and big dimension malls) has its highest values in Cesano Maderno (71%), Barlassina (66%) and Desio (64%). The lowest values came out in Lentate sul Seveso (48%)) Desio is the only municipality among the 8 in the cluster to have a hospital within its territory. The index is provided by ISPRA; yet it has to be considered that there are more hospital in the municipalities closely surrounding the cluster (including Milano).</td></tr>
</table>

Table 3.62 - Adaptive capacity indicators and Global Index

Index	Min	Max
Rate (%) of domestic conditioned volumes	0	100
Rate (%) of people living close (<300m) to non-domestic conditioned volumes	0	100
Number of beds in hospital / 10k inhabitants	Min. over the homogeneous area[6]	Max. over the homogeneous area

Table 3.63 - Normalization ranges for the adaptive capacity indexes (Urban flood)

The weighting procedure has led to the weights reported in Table 3.64.

Indicator	Weight
Rate (%) of domestic conditioned volumes	70,5
Rate (%) of people living close (<300m) to non-domestic conditioned volumes	8,4
Number of beds in hospital / 10k inhabitants	21,1

Table 3.64 - Weights of the heat waves adaptive capacity Indicators

Global Vulnerability Index

A final integration procedure has been applied to derive, from the lìindexes on sensitivity and adaptive capacity, the final Vulnerability Index.

The final computation of the Vulnerability Index has been obtained by applying the following formula:

[6] The Province of Monza and Brianza

$$V = \frac{S * w_S + AC * w_{AC}}{w_S + w_{AC}}$$

The weights assigned to the sensitivity and the adaptive capacity components have been chosen to be complementary, so that their overall sum is always 1.
In the present case, we assigned a higher weight to the sensitivity component (0,8) than to adaptive capacity (0,2).
The adaptive capacity weight is still relatively high, reflecting the fact that some of the indexes (conditioned volumes) are very specific in countering the effects of the heat.

	Normalized result
Global Sensitivity Index	
Lentate sul Seveso	0,27
Barlassina	0,27
Seveso	0,28
Cesano Maderno	0,28
Bovisio Masciago	0,27
Varedo	0,27
Meda	0,28
Desio	0,24
Global Adaptive Capacity Index	
Lentate sul Seveso	0,85
Barlassina	0,88
Seveso	0,88
Cesano Maderno	0,86
Bovisio Masciago	0,85
Varedo	0,83
Meda	0,86
Desio	0,69
Global Vulnerability Index	
Lentate sul Seveso	0,35
Barlassina	0,46
Seveso	0,44
Cesano Maderno	0,40
Bovisio Masciago	0,38

Varedo		0,38
Meda		0,45
Desio		0,38
Brief comment	*The least vulnerable municipalities in the cluster appear to be Lentate sul Seveso (likely due to its lower sensitivity, lower impervious rate and higher values of green areas/capita). Desio benefits from being the only municipality with an hospital on its territory.*	

Table 3.65 - Heat waves Global Vulnerability Index

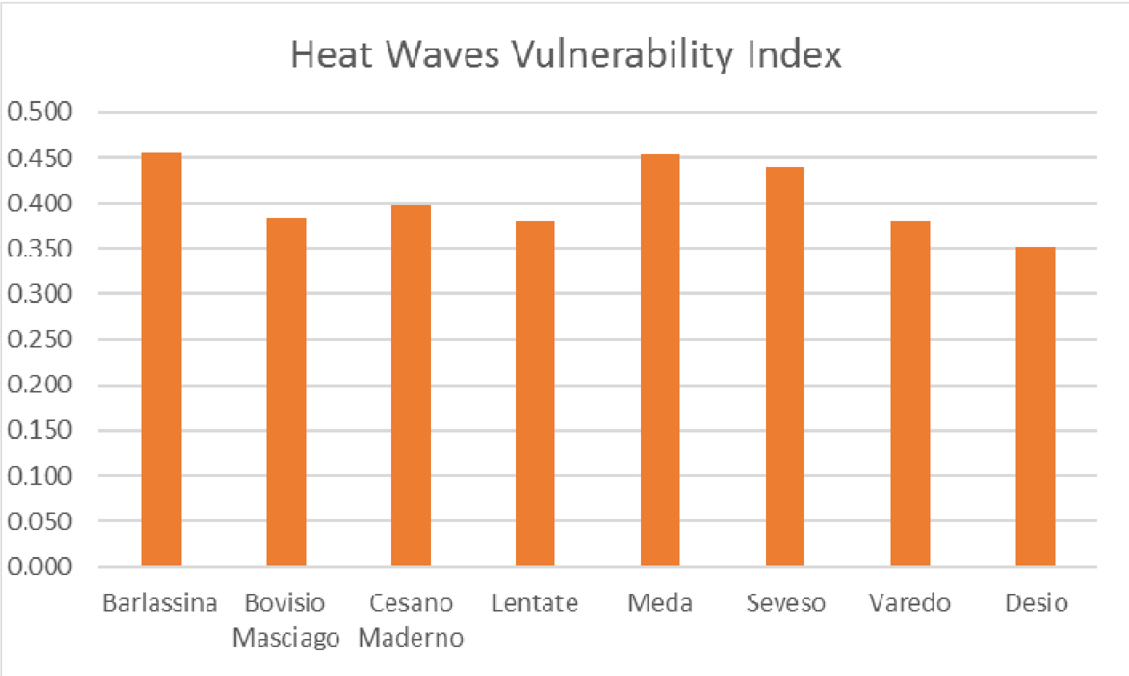


Figure 3.28 - Heat waves Vulnerability Index values for each Municipality

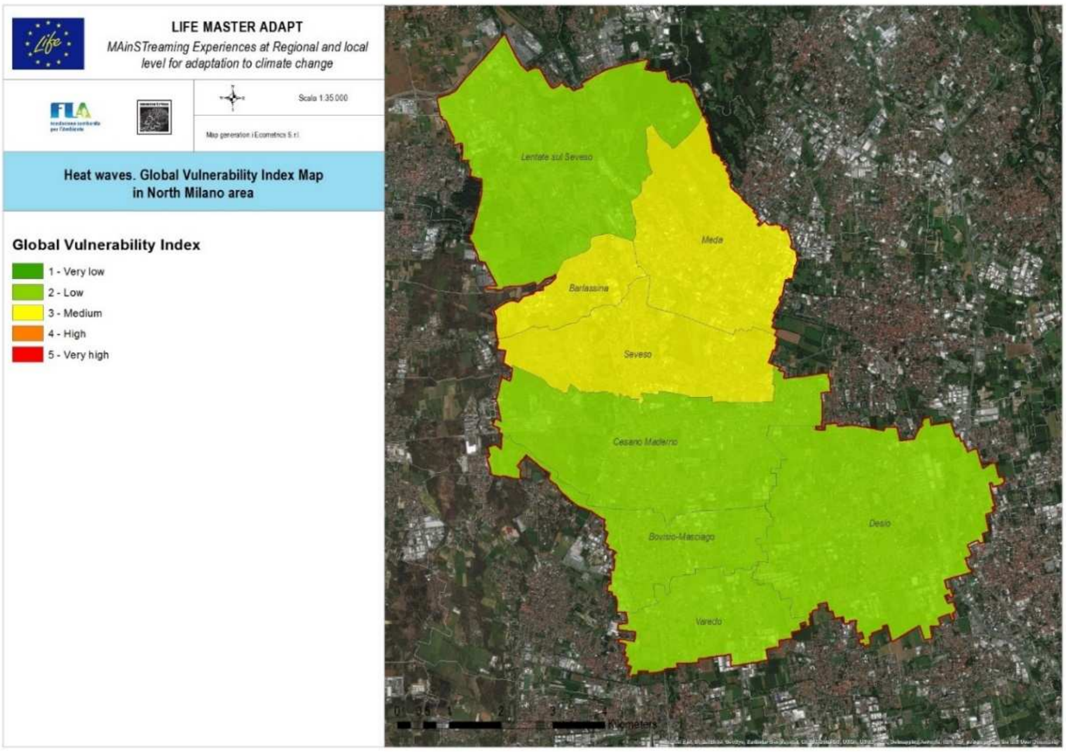


Figure 3.29 - Heat waves Global Vulnerability Index map

3.5.3 The metropolitan area of Cagliari and the metropolitan network of Sassari

As for the analysis at Regional level, the climate vulnerability to fire and drought have been investigated for the Metropolitan Area of Cagliari and the Metropolitan network of Sassari. In addition, urban areas are affected by the phenomenon of the "Urban Heat Island" (UHI), due to the increased surface temperature in the urbanized area. An urban heat island is defined as "an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities".

Urban building materials have different thermal (heat capacity and thermal conductivity) and radiative (reflectivity and emissivity) properties compared to surrounding rural areas, which results in a more absorption of the sun's energy in the urban surfaces. In addition, city structure (height and exposition of buildings) affects the rate of release, during the night, of the sun's energy absorbed during the day by building materials. Urban areas then cool at a much slower rate than rural areas at night, maintaining comparatively higher air temperatures.

Climate change is significantly exacerbating this phenomenon, since the number of hot days and heat waves is increased in the last years, thus leading towards a more warming of urban surfaces. During extreme weather events such as heat waves, the urban heat island has the potential to inhibit the city from cooling down, maintaining night-time temperatures at a level that affects human health and comfort. For this reason, the UHI has been investigated for the two areas of Cagliari and Sassari.

Results for fire and drought are jointly reported, while results for heat waves (representing the Urban Heat Island potential impact) are reported in a separated section.

The Metropolitan City of Cagliari

The Metropolitan City of Cagliari was established by law on 4 February 2016 and represents, so far, the only one Metropolitan City in Sardinia Region (Figure 3.30). Its capital is the city of Cagliari and includes 17 municipalities (Table 3.66). The resident population is 431.657 with a population density of about 350 inhabitant per km^2. In the area, 470 km^2 are covered by forests, lagoons, ponds and salt marshes, so the real populated area is equal to 777,8 km^2. Population density rises then to 553 inhabitants km^{-2}.

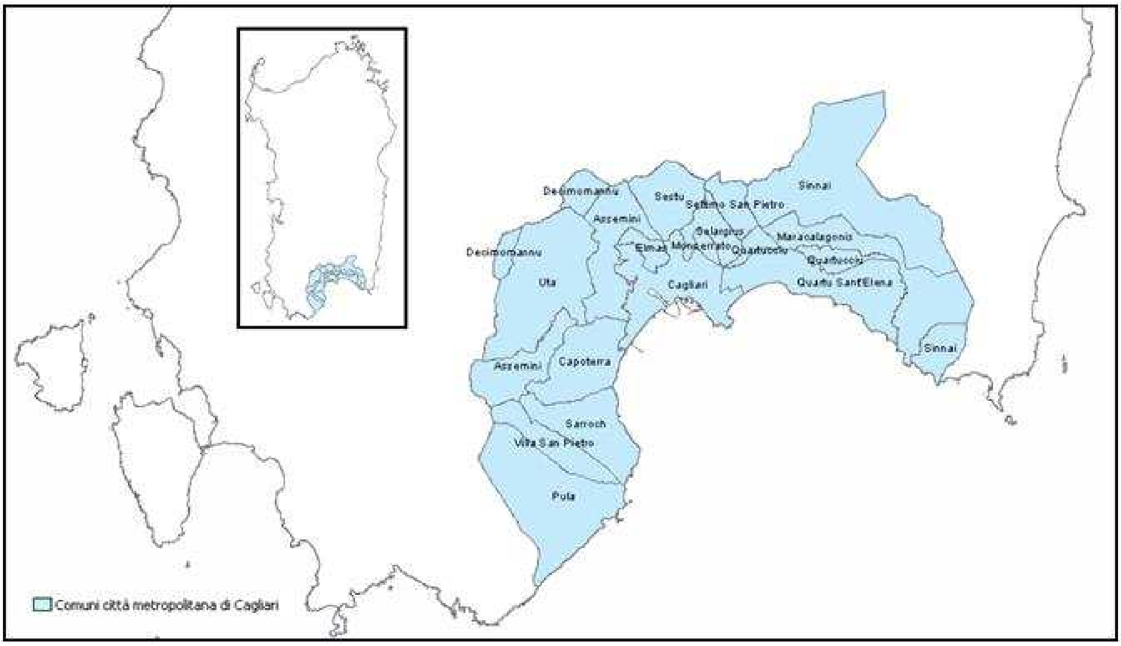


Figure 3.30 - The Metropolitan City of Cagliari in Southern Sardinia

Two mountain ranges surround the Metropolitan area: in the west direction, the Sulcis Range includes Monte Arcosu, Monte Serpeddi, and Punta Sebera, while in the east direction there are the Monte Linas and Sette Fratelli. Mountains areas are mainly covered by Mediterranean forests, dominated by evergreen species such as holm oak, cork oak, and strowberry tree (Arbutus unedo). About 22% (273 km^{-2}) of total forested surface is managed by the Regional Forest Agency (FORESTAS). In the Monte Arcosu forest, a WWF (World Wildlife Fund) Oasis (3.600 hectares) was created to protect and preserve the subspecies of Sardinian deer (*Cervus elaphus ssp. Corsicanus*).

The territory is also rich in several beaches. The biggest one (10 km) is the Poetto beach within Cagliari and Quartu Sant'Elena municipalities. To the east of Cagliari are the beaches of Geremeas (municipality of Maracalagonis) and Solanas (municipality of Sinnai), while to the west are the beaches of Nora and Santa Margherita (municipality of Pula). In the metropolitan area, numerous archeological sites are present, with ruins of Neolithic and Chalcolithic villages, as well as several Domus de Janas and Nuraghes. Ruins of the Punic and Roman periods are also located in the Nora municipality, while the Tuvixeddu necropolis and a Roman Amphitheatre are located in Cagliari.

Municipality	Area (km²)	Census (January 2016)	Inhab./km²
Cagliari	85,45	154.460	1.808
Quartu Sant'Elena	96,20	71.125	739
Selargius	26,71	28.975	1.085
Assemini	117,50	26.686	227
Capoterra	68,25	23.661	347
Sestu	48,32	20.786	430
Monserrato	6,50	20.055	3.085
Sinnai	223,38	17.225	77
Quartucciu	27,87	13.224	474
Elmas	13,70	9.395	686
Uta	134,46	8.553	64
Decimomannu	28,05	8.139	290
Maracalagonis	101,60	7.912	78
Pula	138,79	7.422	53
Settimo San Pietro	23,21	6.697	289
Sarroch	67,88	5.244	77
Villa San Pietro	39,61	2.098	53
Total	**1.248,42**	**431.657**	**346**

Table 3.66 - Municipalities within the Metropolitan City of Cagliari, with information about the covered area and population characteristics

Regarding the economic tissue of the area, in 2014 the *per capita* income (GDP) was 103% of the national average, while for the Sardinia region it was 86% (data from the Ministry of Economy and Finance). The Metropolitan City of Cagliari represents then a more productive area respect to the rest of the Island. The 26% of the island population living in Cagliari Metropolitan City produces, in fact, 31% of the island's GDP and the urban-area income is greater than that of the rest of Sardinia. However, the unemployment rate (17,7%) is higher than national rate of 12,2% and higher than the regional unemployment rate of 17,5%[7].

Traditional economy of the metropolitan area is mainly based on agriculture, with the cultivation of wheat, olive groves and vineyards, gardens and orchards supported by irrigation in the dry summers. Mountain areas were exploited for firewood and for coal and iron extraction through mines. Actually, the Cagliari-Sarroch port system has increased its economic and touristic importance, representing the third largest port in Italy, mainly in terms of transferred goods. An important industrial areas is located in the Macchiareddu-Grogastru area, between Cagliari and Capoterra, which represent the most important industrial area of Sardinia. In addition, near Sarroch is located one of the six oil refinery supersites in Europe. The communications provider, Tiscali, has its headquarters in the boroughs of Cagliari.

Fire and drought

Exposure analysis

The table below reports the list of exposure indicators used to identify the main categories of assets and services exposed to fire and drought. The indicators are similar to those used to perform the analysis at regional level, but only refer to the municipalities included into the Metropolitan Area of Cagliari (Table 3.66). So, they include the number per km^2 of people and animals living in the Metropolitan Area, and the arable farms, as well as the percentage of industrial and residential areas that could be mainly affected by fire and drought. The natural vegetated land occupied by forest and Mediterranean maquis have been considered to investigate the exposure to fire, while the used agriculture land has been used to estimate the exposure level to drought.

Each indicator has been classified in 5 classes, representing the level of exposure. The class 1 represents the lower exposure level (optimal condition), while class 5 indicates the highest exposure level (critical condition). Classes 2 and 4 represent the medium-low (rather positive) and medium-high (rather negative) level of exposure, while class 3 indicates a medium level (neutral condition).

All indicators have been calculated per each municipality and the values reported in the table are the average values for the Metropolitan Area.

[7] http://www.urbistat.it/AdminStat

	Fire	Drought	Result	Normalized result
Inhabitants: Population density (n/km^2)	x	x	579,98	0,18
Livestock: Caws density (n/km^2)	x	x	2,32	0,01
Livestock: Sheep density (n/km^2)	x	x	61,08	0,05
Livestock: Pigs density (n/km^2)	x	x	6,78	0,02
Enterprises: Arable farms (n/km^2)	x		2,76	0,09
Assets: Industrial areas (%)	x		6,10	0,18
Assets: Residential areas (%)	x		8,43	0,24
Used agriculture land (%)		x	24,57	0,06
Global Exposure Index				

Brief comment	Human capital: *Population density varies from 50 to 3.207 people km^{-2}. The highest population density is reported for the Monserrato town, which recently acquired importance for different economical sectors, for Universities, and for the establishment of the University Medical Hospital. The entire area is quite dense for population. However, the average value, normalized respect to the regional minimum and maximum values, indicates a medium-low class (2) for human capital exposure to fire and drought.*
	Manufactured capital: *Arable farms density and the percentage of residential and industrial areas are used to indicate the exposure level to fire. Arable farms are mainly located in Settimo S. Pietro, Decimomannu, Selargius, and Sestu (up to 9 farms per km^2). The highest percentage in residential area (34%) is reported for Monserrato, confirming the highest population density value, while the highest industrial area is located in Elmas (34%), where the Cagliari airport is located. The exposure level to fire for these indicators is low and medium-low.*
	Economic capital: *Livestock represents the indicator for the exposure of the economical capital to both fire and drought. Caws, pigs, and sheep all are classified at a low exposure level, since this area is not the main suitable for livestock.*
	Natural capital: *Drought is related to the used agriculture land. Also, in this case, this area is not particularly suitable for agriculture respect to others all over the region, so it is classified with a low exposure level.*

Table 3.67 - Exposure indicators and Global Index

Sensitivity analysis

The table below summarizes the main sensitivity indicators used both for fire and drought for the Metropolitan Area of Cagliari. The same indicators used at regional level are summarized below, using the same units. High class values represent higher sensitivity level (i.e. high indicator values mean that the potential impact of climate change will be higher for the respective category) for all indicators, except for Arable Irrigated Land and Green Urban areas (i.e. parks, private gardens, etc.). For fire and drought, it is considered that most irrigated areas are present in the municipality, less sensitive the area will be to the potential impact. High class values are, then, reported to indicate low sensitivity level. Similarly, high percentage value of green urban areas mean less sensitivity to drought since green areas usually have high humidity due to some irrigation performed.

	Fire	Drought	Result	Normalized result
Forested areas (%)	x		17,11	0,23
Maquis areas (%)	x		17,51	0,25
Arable, not irrigated, land (%)	x	x	9,77	0,11
Arable irrigated land (%)	x	x	19,71	0,78
Green urban areas (%)		x	0,69	0,79
Share of elderly people (> 60 yrs) (%)	x	x	21,94	0,17
Share of very young people (<6 yrs) (%)	x	x	6,42	0,71
Global Sensitivity Index				
Brief comment	<u>Natural factor:</u> *Half of the municipalities within the Metropolitan Area have more than 10% of Mediterranean maquis and forest surfaces, with values up to 40-46%. Arable irrigated land prevails on the not irrigated land. Green urban areas reach more than 3% only in Cagliari, while other municipalities have less than 1% of green spaces. Normalized values indicate more than 70% of green urban areas meaning a less sensitive level. Medium and medium-low sensitivity classes are reported for all these categories.*			
	<u>Human factor:</u> *A high level of sensitivity is reported for the very young population. The metropolitan area is characterized by the presence of Universities and services, stimulating young families to live there.*			

Table 3.68 - Sensitivity indicators and Global Index

Adaptive capacity analysis

The adaptive capacity to cope with fire and drought has been analyzed considering the level of education, the economic resources available *per capita*, the people employed in the agriculture and silvicultural sectors, as well as the people employed to manage fires risk. In addition, the presence of fire risk plans, as well as projects or plans related to climate change adaptation per each municipalities have been investigated. As for the regional analysis, the normalized values of all indicators where changed in sign, except for the unemployment indicator: high normalized values of these indicators mean higher contribution to vulnerability, and identify a lower adaptive capacity (critical condition).

Projects related to climate change mainly consider, besides this LIFE project MASTER-Adapt, the municipality membership to the Covenant of Mayors for Climate & Energy and the submission/adoption of the SECAP (Sustainable Energy and Climate Action Plan) (for 10 municipalities over 17), as well the presence of a Strategic Plan with some issues related to climate change (Elmas municipality).

	Fire	Drought	Result	Normalized result
N. Fire risk plans	x			0,12
Voluntary people employed in associations (n/km^2)	x		52,36	0
People employed in CFVA (operational stations) (n/km^2)	x		14,75	1,00
People employed in CFVA (offices) (n/km^2)	x		40	0,81
People employed in Fire fighters (n/km^2)	x		218	0,17
People employed in FORESTAS (n/km^2)	x		5,60	1,00
People employed in primary service (agriculture and silvicultural sectors) (%)	x	x	143,35	0,91
Unemployed (%)	x	x	9,06	0,51
People with a degree (%)	x	x	25,92	0,32
People with a Master Degree (%)	x	x	8,40	0,62
GDP (€/capita)	x	x	8,68	0,81
N. projects and plans on climate change	x	x	29	0,77
Global Adaptive Capacity Index				
Brief comment	Knowledge and technology: *People with a degree and a master degree and people employed in the primary services are considered for fire and drought. As for the regional level, in the Metropolitan Area of Cagliari, the rate of graduates is higher than bachelor, even in Cagliari a higher percentage of people with a master degree (in respect to the island) is located due to the presence of the University. However, they do not represent the majority of population, so they are classified in the medium-low capacity class (4), while people with a degree is classified with a medium-high adaptive capacity. As seen before, this area is not mainly used for agriculture scope, so people employed in the primary service does not reach high percentage. The assigned class is the then the highest one (5) indicating a critical condition for this aspect.*			

	Institutions and economical resources: *High level of adaptation capacity is reported for fire related to the fire fighters and voluntary people percentage, and the development of fire risk plans. Low adaptive capacity is, instead, associated with the people employed in the regional agencies (CFVA and FORESTAS). Also, the number of projects on climate change is low (an average of 1.7 per municipality). Economical resources are represented by the rate of unemployment (with a medium adaptive capacity level) and the GDP (with a low level).*

Table 3.69 - Adaptive capacity indicators and Global Index

Global Vulnerability Index

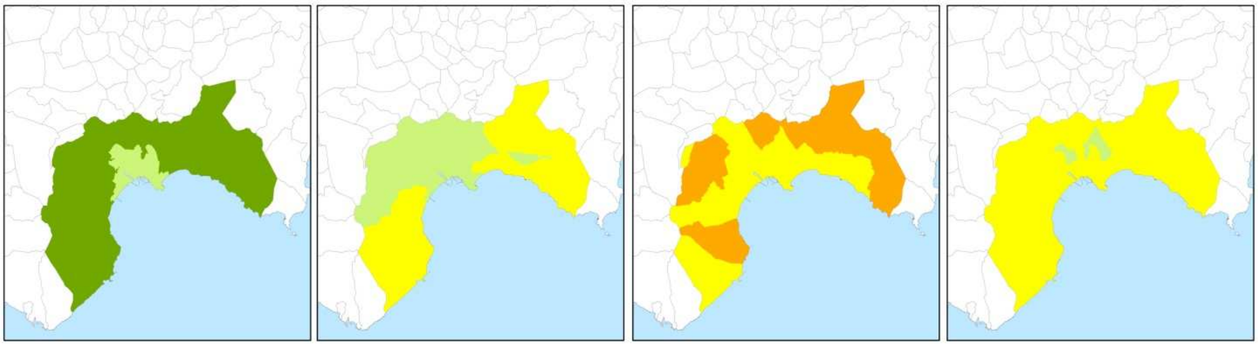
The Global Vulnerability Index derives from the aggregation of the normalized values of the Global Sensitivity Index and the Global Adaptive Capacity Index. The table below reports the values obtained for the Metropolitan city of Cagliari.

	Fire	Drought
Global Sensitivity Index	0,38	0,51
Global Adaptive Capacity Index	0,59	0,66
Global Vulnerability Index	0,48	0,58
Brief comment	**FIRE:** *A general low level of sensitivity is reported in almost the entire Metropolitan area, since irrigated lands and green urban areas are present. The city of Cagliari is, however, more sensitive due to the higher number of young population. Medium adaptive capacity is reported for the area, so the Global Vulnerability Index is classified at a mediumlevel (class 3).* **DROUGHT:** *Medium sensitivity to drought is reported for the area, except for Sinnai and Villa S. Pietro municipalities with a medium-high sensitivity level. Cagliari Municipality reported a sensitivy class equal to 2. The Global Vulnerability Index is then classified at a medium and medium high level with classes 3 and 4.* **GENERAL COMMENT:** *Climate projections report a marked future warming for the Cagliari Metropolitan area, with an increase of minimum, maximum and mean temperature (from +1,3°C-3,6°C, depending on the RCP scenario and the considered future period). It is also expected a strong increase of warm extremes (summer days, consecutive dry days, etc.) and a decrease of cold extremes. A general slight reduction of total precipitation is also expected, thus possibly exacerbating fire and drought.*	

Table 3.70 - Global Vulnerability Index

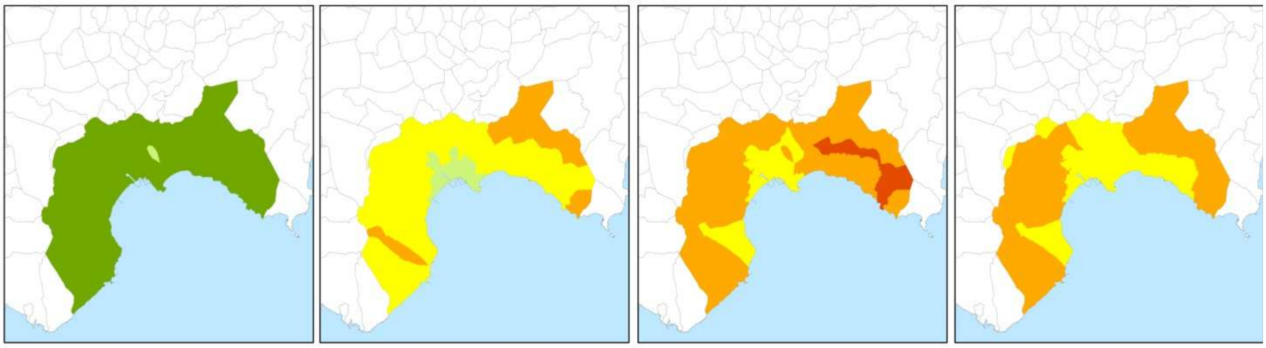
Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Fire

Exposure	Sensitivity	Adaptive capacity	Vulnerability index

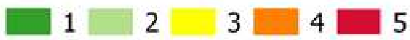


Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Drought

Exposure	Sensitivity	Adaptive capacity	Vulnerability index



Classes



Class 1 = Optimal; Class 2 = Rather positive; Class 3 = Neutral; Class 4 = Rather negative; Class 5 = Critical

Figure 3.31 - Global Exposure, Sensitivity, Adaptive Capacity, and Vulnerability Index maps for fire and for drought

Heat waves

Exposure analysis

	Result	Normalized result
Inhabitants: Population density (n/km^2)	579.98	0.18
Global Exposure Index		

Brief comment	Human capital: *Only the population density is considered as indicator for heat waves exposure, that determines the "Urban Heat Island" effect. Population density varies from 50 to 3207 people km^{-2}, with the highest population in Monserrato, which is the most exposed municipality. However, the entire area is classified with a medium-low level of exposure.*

Table 3.71 - Exposure indicators and Global Index

Sensitivity analysis

It is recognized that there is a direct relationship between urban heat island (UHI) intensity peaks and heat-related illness and fatalities. Conditions of thermal discomfort lead to problems related to the human cardiovascular and respiratory systems. During extreme weather events, such as heat waves, the UHI maintains high night-time temperatures affecting human health and comfort, with stress such as heatstroke, heat exhaustion, heat syncope, and heat cramps. In addition, a wide number of diseases may become worse, particularly in the elderly and children population. These two categories are then representative to investigate the heat wave sensitivity. The presence of industrial and residential areas is also considered since they represent areas with more concrete surfaces, able to absorb and storage suns' energy during the day and release heat during the night. High percentage of these areas indicates higher sensitivity to heat stress. On the contrary, the presence of forested and green urban areas can benefit the heat storage due to their capacity to reduce air temperature, cooling the environment. Cities with high level of vegetated areas (high class value) should be then intended as less sensitive to heat stress.

	Result	**Normalized result**
Forested areas (%)	17,11	0,77
Green urban areas (%)	0,69	0,79
Assests: Industrial areas (%)	6,10	0,18
Assests: Residential areas (%)	8,43	0,24
Share of elderly people (> 60 yrs) (%)	21,94	0,17
Share of very young people (<6 yrs) (%)	6,42	0,71
Global Sensitivity Index		
Brief comment	Natural factor: *Both forested areas and green urban areas could help in reducing air temperature. Green urban areas reach more than 3% only in Cagliari, while other municipalities have less than 1% of green spaces. Forested areas reach more than 40% in Pula and Villa San Pietro. Normalized values indicate more than 70% of such surfaces, so the presence of these areas allows to have a medium-low sensitive level (inverted values, see explanation in the text).*	

	Human factor: *A high level of sensitivity is reported for the very young population, since the metropolitan area is characterized by the presence of Universities and services, stimulating young families to live there.*
	Manufactured factor: *A maximum values of 34% is reported for residential area in Monserrato, confirming the highest population density value, and for industrial area in Elmas, where the Cagliari airport is located. The sensitivity level to heat stress for these indicators is medium-low.*

Table 3.72 - Sensitivity indicators and Global Index

Adaptive capacity analysis

The adaptive capacity to cope with heat waves has been analyzed considering the level of education, the economic resources available per capita, the percentage of unemployment and the number of medical points and projects related to climate change. High class values of these indicators mean loweradaptive capacity, while the level of unemployment is considered in the opposite way. All calculation follow the methodology described for the Regional analysis.

Projects related to climate change mainly consider, besides this LIFE project MASTER-Adapt, the municipality membership to the Covenant of Mayors for Climate & Energy and the submission/adoption of the SECAP (Sustainable Energy and Climate Action Plan) (for 10 municipalities over 17), as well the presence of a Strategic Plan with some issues related to climate change (Elmas municipality).

	Result	Normalized result
Unemployed (%)	9,06	0,51
People with a degree (%)	25,92	0,32
People with Master Degree (%)	8,40	0,62
GDP (€/capita)	8,68	0,81
N. medical points	22	0,84
N. projects and plans on climate change	29	0,77
Global Adaptive Capacity Index		
Brief comment	Knowledge and technology: *In the Metropolitan Area of Cagliari, the rate of graduates is higher than bachelor, even if in Cagliari a higher percentage of people with a master degree (in respect to the island) is located due to the presence of the University. However, they do not represent the majority of population, so they are classified in the medium-low capacity class (4), while people with a degree is classified with a medium-high adaptive capacity.*	

	Institutions and economical resources: *The number of projects on climate change is low (an average of 1,7 per municipality). Economical resources are represented by the rate of unemployment (with a medium adaptive capacity level) and the GDP (with a low level).*
	Infrastructure: *A total of 22 medical points are located in the Metropolitan area, with the most distributed in Cagliari (6) and Quartu S. Elena (3). The presence of medical points is considered helpful to manage pathologies derived from heat stress, so they are important for the adaptive capacity response. However, a normalized value indicates a low level (class 5).*

Table 3.73 - Adaptive capacity indicators and Global Index

Global Vulnerability Index

The Global Vulnerability Index derives from the aggregation of the normalized values of the Global Sensitivity Index and the Global Adaptive Capacity Index. The table below reports the values obtained for the Metropolitan city of Cagliari.

		Normalized result
Global Sensitivity Index		0,48
Global Adaptive Capacity Index		0,64
Global Vulnerability Index		0,56
Brief comment	*Sensitivity mostly depends on the population categories, so the Cagliari municipality has the highest class in the area (3) due to its high young population percentage. Cagliari has also the medium-high level of adaptive capacity (higher number of medical points), while other municipalities are classified in class 4 and 3 (medium low and medium level, respectively). The Global Vulnerability Index for heat wave, however, reports higher class for the interland of Cagliari.* *Climate projections report an increasing trend in temperature extremes, especially in tropical nights (+21-61 days) and summer days (+22-53 days). This could lead to higher vulnerability for heat waves, especially for Cagliari municipality.*	

Table 3.74 - Global Vulnerability Index

MASTER ADAPT

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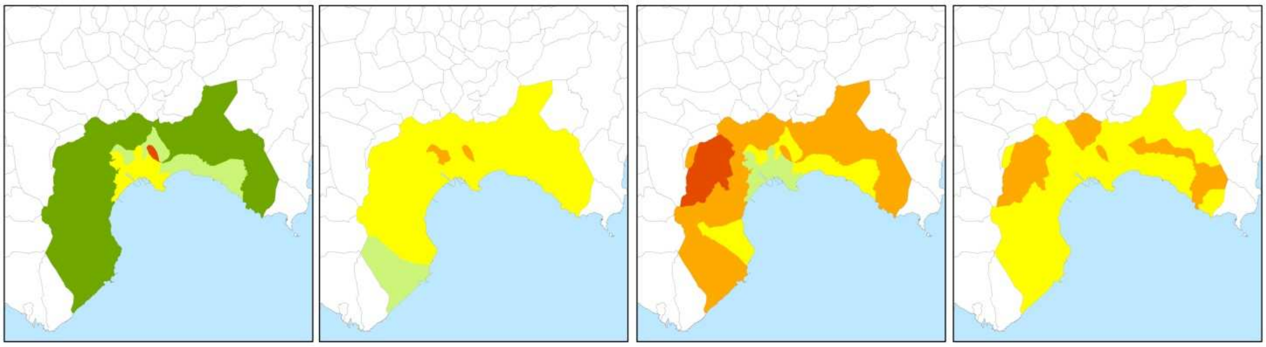
Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Heat Wave			
Exposure	Sensitivity	Adaptive capacity	Vulnerability index



Classes

1 2 3 4 5

Class 1 = Optimal; Class 2 = Rather positive; Class 3 = Neutral; Class 4 = Rather negative; Class 5 = Critical

Figure 3.32 - Global Exposure, Sensitivity, Adaptive Capacity, and Vulnerability Index maps for the Heat Wave

The Metropolitan Network of Sassari

The constitutive act of the Metropolitan Area Network (MAN) of Northern Sardinia was signed on 29 July 2016 by the municipalities of Sassari, Alghero, Castelsardo, Porto Torres, Sennori, Sorso, Stintino and Valledoria. The MAN extends over a total area of 1103,53 km^2 and has a resident population of 227.772 inhabitants, with a population density of about 206 inhabitants per km^2 (Table 3.75).

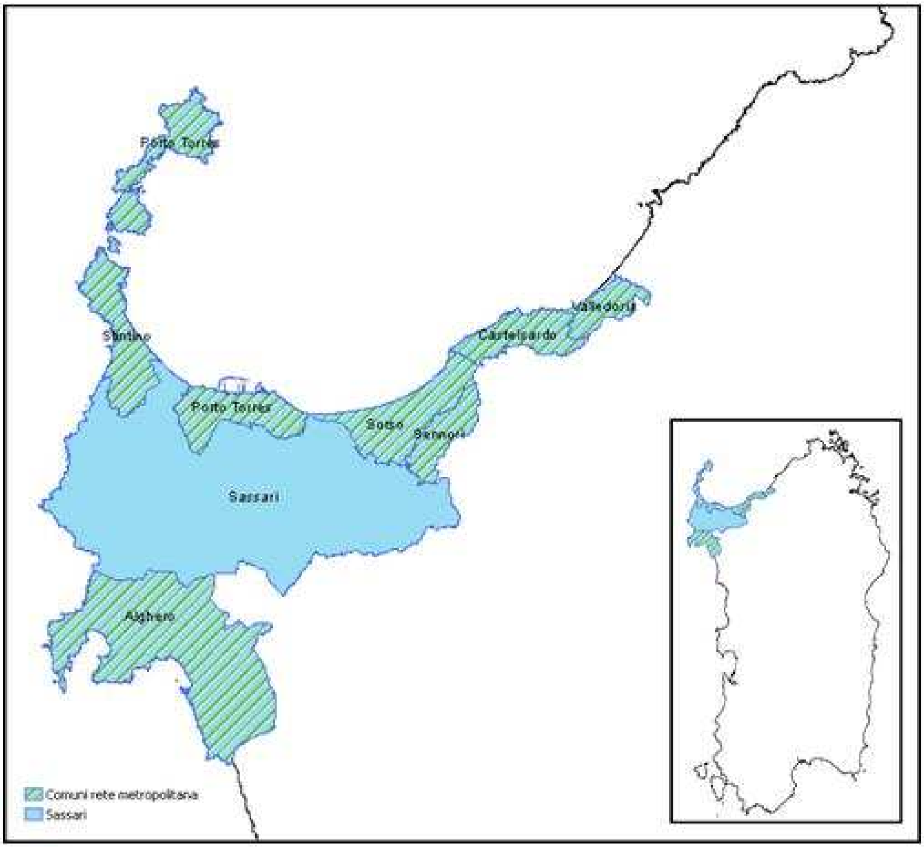


Figure 3.33 - The Metropolitan Network of Sassari in Northern Sardinia

Municipality	Area (km²)	Inhabitants (ISTAT, 01/01/2016)	Inhab. Km^{-2}
Sassari	547,04	127.525	233,12
Alghero	225,40	44.019	195,30
Porto Torres	104,41	22.313	213,70
Sorso	67,01	14.714	219,58
Sennori	31,34	7.318	233,50
Castelsardo	43,34	6.006	138,56
Valledoria	25,95	4.251	163,79
Stintino	59,04	1.626	27,54
Total	**1.103,53**	**227.772**	**206,40**

Table 3.75 - Municipalities within the Metropolitan Network of Northern Sardinia, with information about the covered area and population characteristics

The area is characterized by a Mediterranean climate, with mild and humid winters and hot and dry summers, classified as Csa according to the Köppen-Geiger climate classification. The annual average temperature ranges from 15,5 °C of Sennori to 16,5 °C of Valledoria and Porto Torres. Precipitation, mainly concentrated in winter and autumn, ranges from about 550 mm/year of Porto Torres and Stintino to 650 mm/year of Sennori and Sassari, depending on the altitude and the distance from the sea. Snowfall is sporadic, but not exceptional, and is generally concentrated in January and February.

The climate of Sassari is, according to a survey of the US magazine Weatherwise, among the 10 most suitable for the human species. More precisely, it was at the 4th place, among the 10 most pleasant cities in the world. Sassari is the second most populated city in Sardinia. The economy of the city mainly relies on services and the advanced tertiary sector. The big industry is located in Fiume Santo (Porto Torres), where there is a thermoelectric power plant, while a number of small and medium-sized enterprises are located in the industrial areas of the city. Traditional agricultural products, such as olive oil, wine, fruit and vegetable, dairy and textile, still have an important role for the economy of the city and the surrounding territory. Tourism is mainly concentrated along the coast (main beaches are Platamona, Porto Ferro, Porto Palmas and Argentiera). Sassari is the principal administrative center of central and northern Sardinia and hosts several research institutes.

The second largest city in the MAN of Northern Sardinia is Alghero, located in the northwestern coast of Sardinia. With its several beaches, bays and natural parks, Alghero has a strong touristic vocation and is one of the main destinations in the island (in 2012 it was the 10^{th} most visited city by tourists in Italy). It is the capital of the “Riviera del Corallo”, due to the presence of a large quantity of the high-quality red coral. Alghero is the third university town of Sardinia (after Sassari and Cagliari) and holds an international airport situated in the nearby village of Fertilia.

The municipality of Porto Torres, located on the northern coast, has the only Sardinian port linked to Spain. Half of its territory is occupied by the urban area, the industrial area (the largest in Sardinia: 23 km^2) and the Romanic ruins. Asinara Island, with the smaller Isola Piana, encloses the remaining part of the territory, which was declared a national park in 1997. The economy of the territory is mainly supported by industrial activities, even if other traditional activities such as fisheries and agriculture, seaside and cultural tourism, persist.

Other relevant cities within the MAN that have a strong touristic vocation are Stintino and Castelsardo. Castelsardo has an economy mainly based on tourism, fishing, and handicraft products. The Valledoria municipality, located in the center of Asinara Gulf, is a very interesting and well-known location for watersports.

The remaining two cities that belonging to the MAN are Sennori and Sorso, that have predominantly agricultural and touristic vocation. Both municipalities are surrounded by fertile lands, cultivated with olive trees, vineyards and orchards. Sorso has also about 18 km of coast, with the famous beaches of Marina di Sorso and Platamona.

Fire and drought

Exposure analysis

The table below reports the list of exposure indicators used to identify the main categories of assets and services exposed to fire and drought. All indicators refer to the municipalities included into the Metropolitan Network of Sassari. The indicators are those used for the Cagliari area.

Each indicator has been classified in 5 classes, representing the level of exposure. The class 1 represents the lower exposure level (optimal condition), while class 5 indicates the highest exposure level (critical condition). Classes 2 and 4 represent the medium-low (rather positive) and medium-high (rather negative) level of exposure, while class 3 indicates a medium level (neutral condition). All indicators have been calculated per each municipality and the values reported in the table are the average values for the Metropolitan Area.

	Fire	Drought	Result	Normalized result
Inhabitants: Population density (n/km^2)	x	x	220,84	0,07
Livestock: Caws density (n/km^2)	x	x	4,55	0,01
Livestock: Sheep density (n/km^2)	x	x	72,96	0,06
Livestock: Pigs density (n/km^2)	x	x	2,21	0,01
Enterprises: Arable farms (n/km^2)	x		29,24	0,15
Assets: Industrial areas (%)	x		2,29	0,07
Assets: Residential areas (%)	x		4,90	0,14
Used agriculture land (%)		x	48,10	0,13
Global Exposure Index				
Brief comment	Human capital: *Population density varies from 25 to 590 people km^{-2}. The highest population density is reported for the Porto Torres town, which represents the industrial area of the Metropolitan Network. The average value normalized respect to the regional minimum and maximum values indicates a low class (1) for human capital exposure to fire and drought.*			
	Manufactured capital: *Arable farms density and the percentage of residential and industrial areas are used to indicate the exposure level to fire. Arable farms are mainly located in Sorso and Sennori, (up to 10 per km^{-2}). Porto Torres has the highest surface occupied by the industrial zone and the lower surface occupied by residential buildings. The exposure level to fire for these indicators is low.*			
	Economic capital: *Livestock represents the indicator for the exposure of the economical capital to both fire and drought. Maximum caws density is reported for Stintino (13 %) where pasture lands are present, while sheep are mainly located in Sassari, Porto Torres and Castelsardo. Livestock is classified at a low exposure level.*			

	Natural capital: *Drought is related to the used agriculture land. All municipalities have similar values of used agriculture land, varying from 34 to 64 %. It is classified with a low exposure level.*

Table 3.76 - Exposure indicators and Global Index

Sensitivity analysis

As for previous analysis, high class values represent higher sensitivity level (i.e. high indicator values mean that the potential impact of climate change will be higher for the respective category) for all indicators, except for Arable Irrigated Land and Green Urban areas (i.e. parks, private gardens, etc.). For fire and drought, it is considered that the most irrigated areas are present in the municipality, the less sensitive the area will be to the potential impact. High class values are, then, reported to indicate low sensitivity level. Similarly, high percentage value of green urban areas mean less sensitivity to drought since green areas usually have high humidity due to some irrigation performed.

	Fire	Drought	Result	Normalized result
Forested areas (%)	x		7,47	0,10
Maquis areas (%)	x		19,35	0,28
Arable, not irrigated, land (%)	x	x	29,24	0,34
Arable irrigated land (%)	x	x	14,84	0,84
Green urban areas (%)		x	0,36	0,89
Share of elderly people (> 60 yrs) (%)	x	x	26,21	0,30
Share of very young people (<6 yrs) (%)	x	x	5,68	0,62
Global Sensitivity Index				
Brief comment	Natural factor: *Highest value of forested area is reported for the Castelsardo municipality (about 20%). More than 20% of maquis vegetation is present in 5 out of 8 municipalities, representing a medium-low sensitivity class. Arable irrigated land is minimum in Alghero (9%) and maximum in Stintino (about 58%). Irrigated land is only present in Alghero, Sassari, and Valledoria, were vineyard, and olive trees are mainly cultivated. The percentage of green urban areas is less than 1% in all municipalities. Medium and medium-low sensitivity classes are thus reported for all these categories.*			
	Human factor: *A high level of sensitivity is reported for the very young population. The metropolitan area is characterized by the presence of Universities and services, stimulating young families to live there.*			

Table 3.77 - Sensitivity indicators and Global Index

Adaptive capacity analysis

The same indicators as for Cagliari area have been used to analyze the adaptive capacity to cope with fire and drought. All calculation follow the methodology described for the Regional analysis. Projects related to climate change mainly consider, besides this LIFE project MASTER-Adapt, the municipality membership to the Covenant of Mayors for Climate & Energy and the submission/adoption of the SECAP (Sustainable Energy and Climate Action Plan) (for all municipalities), as well as the presence of the City Urban plan (Porto Torres) and an Interreg Project on climate change adaptation (Alghero).

	Fire	Drought	Result	Normalized result
N. Fire risk plans	x			0
Voluntary people employed in associations (n/km^2)	x		33	0,72
People employed in CFVA (operational) (n/km^2)	x		10,50	0,57
People employed in CFVA (offices) (n/km^2)	x		30	1,00
People employed in Fire fighters (n/km^2)	x		124	1,00
People employed in FORESTAS (n/km^2)	x		3,60	0,42
People employed in primary service (agriculture and silvicultural sectors) (%)	x	x	155,62	0,89
Unemployed (%)	x	x	8,88	0,50
People with a degree (%)	x	x	24,11	0,40
People with Master Degree (%)	x	x	7,59	0,66
GDP (€/capita)	x	x	8,07	0,83
N. projects and plans on climate change adaptation	x	x	15	0,80

Global Adaptive Capacity Index	
Brief comment	Knowledge and technology: *The rate of graduates is higher than bachelor, even if in Sassari and Alghero a higher percentage of people with a master degree (respect to the island) is located due to the presence of the Universities. However, they are classified in the medium-low capacity class (4), while people with a degree is classified with a medium-high adaptive capacity. People employed in the primary service does not reach high percentage identifying the lowest adaptive capcity (class 5).*

	Institutions and economical resources: *High level of adaptation capacity is reported for the development of fire risk plans, while a medium classisreported for people employed in Forestas and critical condition for employed in CFVA. Fire risk related to the fire fighters and voluntary people represents low and medium-low adaptive capacity classes. Also, the number of projects on climate change is medium-low (an average of 1.8 per municipality). Economical resources are represented by the rate of unemployment (with a medium adaptive capacity level) and the GDP (with a low level).*

Table 3.78 - Adaptive capacity indicators and Global Index

Global Vulnerability Index

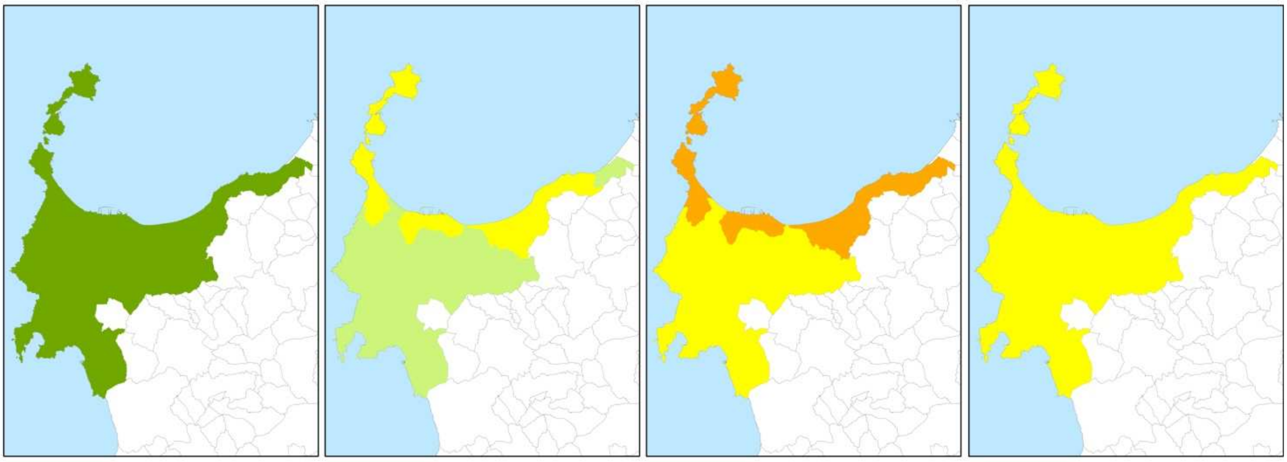
The Global Vulnerability Index derives from the aggregation of the normalized values of the Global Sensitivity Index and the Global Adaptive Capacity Index. The table below reports the values obtained for the Metropolitan area of Sassari.

	Fire	Drought
Global Sensitivity Index	0,41	0,60
Global Adaptive Capacity Index	0,65	0,68
Global Vulnerability Index	0,53	0,64
Brief comment	**FIRE:** *A medium level of sensitivity is reported for fire all over the Metropolitan network, while adaptive capacity showed a medium-lowlevel.TheGlobal Vulnerability Index showed a neutral condition (class 3) with no differences between municipalities.* **DROUGHT:** A medium-high level (class 4) of sensitivity for drought is reported, except for Sassari, *Valledoria and Alghero that showed a neutral condition due to the presence of most irrigated land. Higher adaptive capacity is reported for Sassari and Alghero, characterized by higher medical points and plans on climate change. AGlobal Vulnerability Index at a medium-high level is reported in most of the network (class 4).* **GENERAL COMMENT:** *Climate projections report also for Sassari metropolitan network a marked future warming with an increase of minimum, maximum and mean temperature (from +1,3°C-3,6°C, depending on the RCP scenario and the considered future period), and a decrease in total precipitation (from -6 to -45 mm). It is also expected a strong increase of extremes indexes (summer days, consecutive dry days, dry spell etc.) and a decrease of cold extremes. Fire and drought could be then exacerbated by climate change.*	

Table 3.79 - Global Vulnerability Index

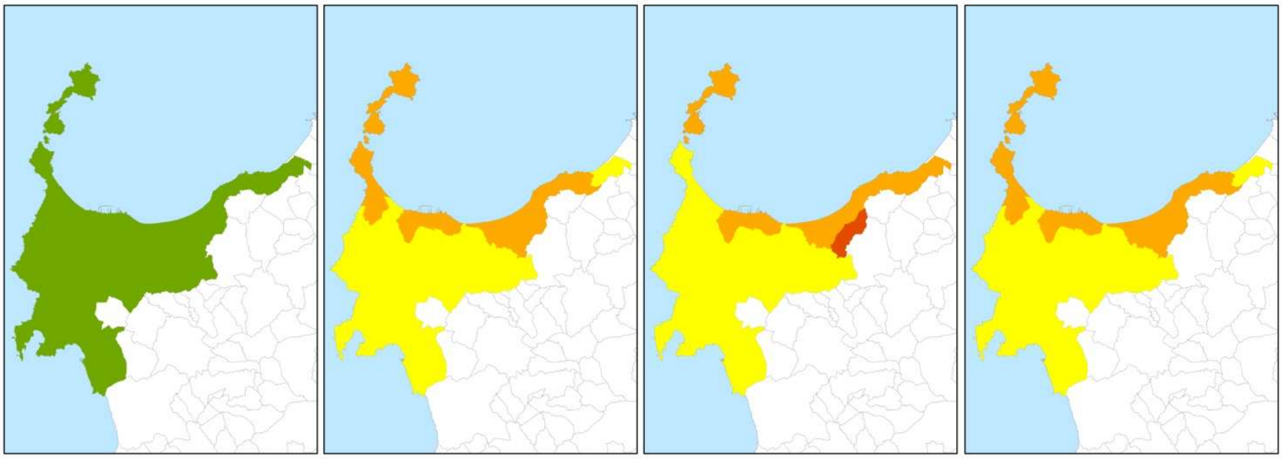
Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Fire

Exposure	Sensitivity	Adaptive capacity	Vulnerability index



Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Drought

Exposure	Sensitivity	Adaptive capacity	Vulnerability index



Classes

1 2 3 4 5

Class 1 = Optimal; Class 2 = Rather positive; Class 3 = Neutral; Class 4 = Rather negative; Class 5 = Critical

Figure 3.34 - Global Exposure, Sensitivity, Adaptive Capacity, and Vulnerability Index maps for fire and for drought.

Heat waves

Exposure analysis

The table below reports the values of the exposure indicators analysed for the Metropolitan network of Sassari.

	Result	Normalized result
Inhabitants: Population density (n/km^2)	220.84	0.07
Global Exposure Index		
Brief comment	<u>Human capital:</u> *Only the population density is considered as indicator for heat waves exposure, that determines the "Urban Heat Island" effect. Population density varies from 25 to 590 people km^{-2}, and the most exposed municipality is Porto Torres. However, the entire area is classified with a low level of exposure.*	

Table 3.80 - Exposure indicators and Global Index

Sensitivity analysis

Elderly and young population are two categories considered as representative to investigate the heat wave sensitivity. High percentage of industrial and residential areas also indicates higher sensitivity to heat stress. On the contrary, the presence of forested and green urban areas can benefit the heat storage due to their capacity to reduce air temperature, cooling the environment. Cities with high level of vegetated areas (high class value) should be then intended as less sensitive to heat stress.

	Result	Normalized result
Forested areas (%)	7,47	0,90
Green urban areas (%)	0,36	0,89
Assests: Industrial areas (%)	2,29	0,07
Assests: Residential areas (%)	4,90	0,14
Share of elderly people (> 60 yrs) (%)	26,21	0,30
Share of very young people (<6 yrs) (%)	5,68	0,62
Global Sensitivity Index		
Brief comment	<u>Natural factor:</u> *Both forested areas and green urban areas could help in reducing air temperature. Respect to the normalized regional values, forested areas and green urban areas for the municipalities included into the network are classified with a low sensitivity level.*	

	Human factor: *A high level of sensitivity is reported for the very young population, since the metropolitan network is characterized by the presence of Universities and services, stimulating young families to live there.*
	Manufactured factor: *Low values of residential and industrial areas are reported for the metropolitan network compared to the regional level, even if Porto Torres has the highest percentage of industrial areas.* *These indicators are classified at a low sensitivity level for heat stress (1).*

Table 3.81 - Sensitivity indicators and Global Index

Adaptive capacity analysis

Also for Sassari metropolitan network, the adaptive capacity to cope with heat waves has been analyzed considering the level of education, the economic resources available per capita, the percentage of unemployment and the number of medical points and projects related to climate change. High class values of these indicators mean lower adaptive capacity, while the level of unemployment is considered in the opposite way. All calculation follow the methodology described for the Regional analysis.

Projects related to climate change mainly consider, besides this LIFE project MASTER-Adapt, the municipality membership to the Covenant of Mayors for Climate & Energy and the submission/adoption of the PAES (Action Plan for Sustainable Energy) (for all municipalities), as well as the presence of the City Urban plan (Porto Torres) and an Interreg Project on climate change adaptation (Alghero).

<table>
<tr><th></th><th></th><th>Result</th><th>Normalized result</th></tr>
<tr><td colspan="2">Unemployed (%)</td><td>8,88</td><td>0,50</td></tr>
<tr><td colspan="2">People with a degree (%)</td><td>24,11</td><td>0,40</td></tr>
<tr><td colspan="2">People with a Master Degree (%)</td><td>7,59</td><td>0,66</td></tr>
<tr><td colspan="2">GDP (€/capita)</td><td>8,07</td><td>0,83</td></tr>
<tr><td colspan="2">N. of emergency medical services</td><td>15</td><td>0,75</td></tr>
<tr><td colspan="2">N. projects and plans on climate change adaptation</td><td>15</td><td>0,80</td></tr>
<tr><td colspan="4">Global Adaptive Capacity Index</td></tr>
<tr><td rowspan="2">Brief comment</td><td colspan="3">Knowledge and technology: In the Metropolitan Network of Sassari, the rate of graduates is higher than bachelor, even if in Sassari and Alghero a higher percentage of people with a master degree (compared to the island) is located due to the presence of the Universities. They are classified in the medium-low capacity class (4), while people with a degree is classified with a medium-high adaptive capacity (2).</td></tr>
<tr><td colspan="3">Institutions and economical resources: The number of projects on climate change is low (an average of 1,8 per municipality). Porto Torres, Alghero, and Sassari have the</td></tr>
</table>

	higher number of projects and plans on climate change, but the adaptive capacity of the network is medium-low for this indicator. Economical resources are represented by the rate of unemployment (with a medium adaptive capacity level) and the GDP (with a low level).
	Infrastructure: *A total of 15 medical points are located in the Metropolitan network, with the most distributed in Alghero (4) and Sassari (3). The normalized values indicates a medium-low adaptive capacity level (class 4).*

Table 3.82 - Adaptive capacity indicators and Global Index

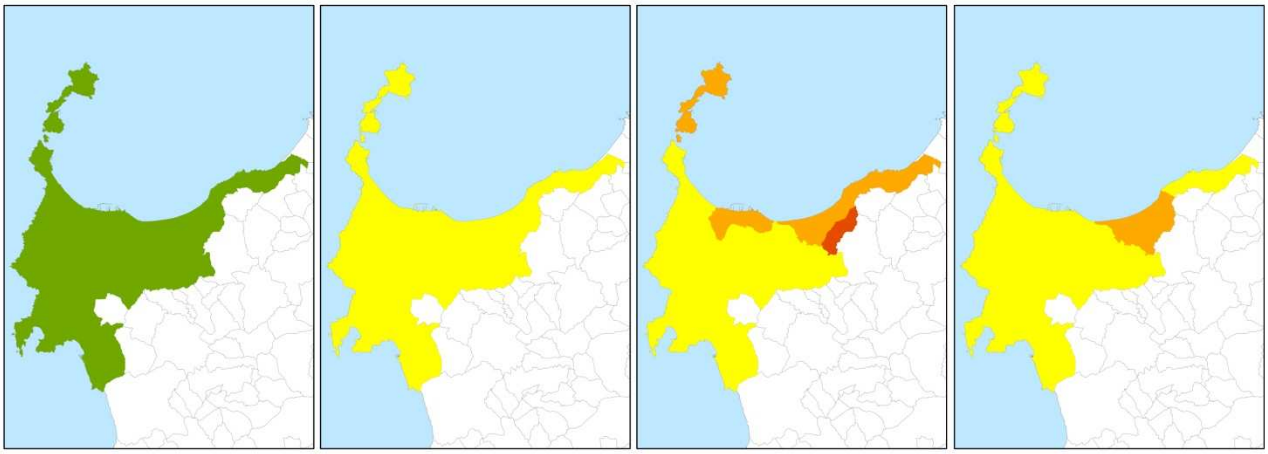
Global Vulnerability Index

The Global Vulnerability Index derives from the aggregation of the normalized values of the Global Sensitivity Index and the Global Adaptive Capacity Index. The table below reports the values obtained for the Metropolitan network of Sassari.

	Normalized result
Global Sensitivity Index	0,49
Global Adaptive Capacity Index	0,66
Global Vulnerability Index	0,57
Brief comment	*In the Sassari metropolitan network results showed a general medium level (class 3) of sensitivity to Heat Waves. Medium adaptive capacity (class 3) is also reported for the Municipalities with the higher number of medical points and ongoing activities related to climate change (such as projects and plans) (Sassariand Alghero), while other municipalities reported a medium-low adaptive capacity.* *A general medium vulnerability index is reported for all municipalities within the network (class 3) except for Sennori and Sorso that reported class 4 (medium-high level).* *Climate projections reports a significant increasing trend in temperature extremes, especially in tropical nights (+21-63 days) and summer days (+20-51 days). Sassari metropolitan area could be then possible affected by a major vulnerability for heat waves.*

Table 3.83 - Global Vulnerability Index

Exposure, Sensitivity, Adaptive Capacity, and Vulnerability for Heat Wave			
Exposure	Sensitivity	Adaptive capacity	Vulnerability index



Classes

1 2 3 4 5

Class 1 = Optimal; Class 2 = Rather positive; Class 3 = Neutral; Class 4 = Rather negative; Class 5 = Critical

Figure 3.35 - Global Exposure, Sensitivity, Adaptive Capacity, and Vulnerability Index maps for Heat Waves.

3.5.4 The union of municipalities in northern Salento

The target area of the Union of municipalities in Northern Salento is located in the province of Lecce (Apulia) and includes the following municipalities: Campi Salentina, Salice Salentino, Guagnano, Novoli, Squinzano, Surbo, Trepuzzi (Figure 3.36).

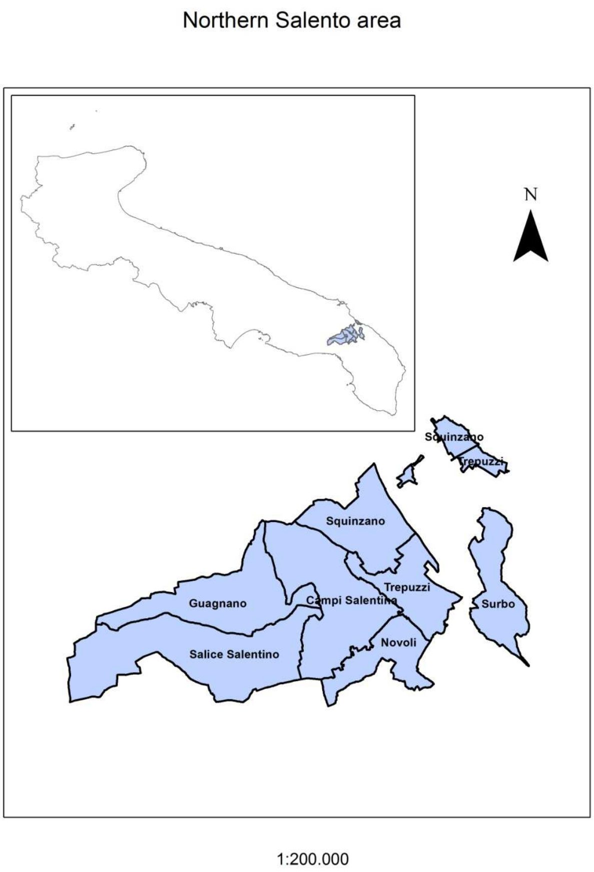


Figure 3.36 - Map of the Union of municipalities of Northern Salento

Municipality	Area (km²)	Census (inhab January 2017)	Inhab./km² (average)
Campi Salentina	45,88	10.389	226,44
Guagnano	38,03	5.748	151,15
Novoli	18,08	8.078	446,87
Salice Salentino	59,87	8.287	138,41
Squinzano	29,78	14.100	473,40
Surbo	20,78	15.135	728,23
Trepuzzi	23,43	14.603	623,17
TOT	**235,85**	**76.340**	**398,24**

Table 3.84 - Municipalities of Northern Salento, with information about the covered area and population (Source: ISTAT, 2017)

Territorial framework

The area extends between the Adriatic and the Ionian Sea and is characterized by a flat and uniform morphology, composed by a limestone scaffold consisting of long backbones separated each other by depressed areas converging towards the south.

The arid and flat landscape is due both to the climate and to the geological characteristics of the area which does not have surface water courses but a hydrographic network of natural drainage channels in the rock.

In this area, groundwater represents the only possible source of supply for the satisfaction of all needs. In the inner part of the area irrigation takes places through artesian wells which draw from the existing karst cavities. For this reason, saltwater intrusion has a high significance and is heavily influenced by periods of water crisis. As a matter of fact, during these periods an increase in withdrawals overlaps to the reduction of the natural recharge thus triggering a salt intrusion process from the coast.

As far as hydrogeomorphological characteristics, the area is affected by many problems related to the anthropic impact on the karst environment. Interventions on the sinkholes and the hydrographic network in the last 150 years, have altered the hydrogeological conditions of the area, accelerating the dynamics underway and causing several floods events. Final water delivery takes place in areas with a lower topography than the adjacent ones.

Such permeable zones ensure the disposal of rainwater by infiltration and are close to karst structures characterized by a high water absorption capacity. In some portions of the area, clay soils, which are almost waterproof, allows the existence of surface water. In these areas a hydrographic network consisting essentially of natural and/or artificial canals, performs drainage and reclamation functions with respect to the areas which are prone to floods and prolonged stagnation phenomena. Some important karst structures represent then the final delivery point able to ensure the absorption of large amounts of water.

Finally, some areas affected by flooding of such canals are found and due to possible water stagnation health problems can arise.

The area of Northern Salento under consideration is almost completely characterized by an agricultural soil use associated to reduced natural portions, such as small forested woods or green areas belonging to farmhouses and dry walls stone.

Agriculture is one of the most important item in the local economy, with the production of typical wines such as Negramaro and Malvasia Nera produced and distributed by cooperatives and private operators. Apulia has the highest italian wine production and the target area produces many valuable grapes with numerous DOC products in the areas, such as: Matino DOC, Leverano DOC, Galatina DOC, Squinzano DOC, Alezio DOC, Copertino DOC, Salice Salentino DOC and Nardò DOC. Grapes must be produced in the production area, which includes all the administrative territory of Salice Salentino, Veglie and Guagnano, Campi Salentina in the province of Lecce and Cellino San Marco in the province of Brindisi.

Along with wine production, oil and vegetable processing characterize the local production.

The food and wine production brings in these areas about 200.000 tourists each year mainly along the Ionian coast and, to a lesser extent, in the rural areas.

The area has been affected by the expansion of the *Xylella fastidiosa* bacteria. Some studies have established that the virulence of this pathogen is the consequence, and not the cause, of the disease of olive trees which have become more vulnerable due to the loss of biodiversity caused by pollution and the failure of the application of good farming practices. Studies suggest that such aspect can be an indicator of environmental change and the increased use of pesticides and herbicides may, together with climatic anomalies, play a decisive role. In these areas, the consumption of herbicide per hectare is two to four times the use of other Apulia provinces and the percentage of organic farming is the lowest in Apulia.

In the area around Lecce, many soils are becoming sterile because of the high environmental impact of farming, resulting in a greater vulnerability of vegetation due to lower availability of nutrients and the almost complete destruction of microflora. The reduced fertility of the Salentine soils due to the total abandonment of good farming practices has certainly contributed to the diffusion of the bacterium.

The area is characterized by a typical Mediterranean climate with very hot and dry summers and rainy and windy winters, with dominant winds coming from the West, causing heavy rainfall on the peninsula.

Socio-economic framework

The area is characterized by the presence of many small urban centers, with a dotted countryside of farmhouses and villas apartment, which are the sign of the typical rural architecture of Salento, and the dispersal of residential and productive settlements in agricultural area.

Since 2002, the local population has recorded a more or less constant decline, due in particular to the negative balance between birth and mortality rate.

The 2011 Census shows for the entire province of Lecce an average annual growth of 0,2% compared to 2001, while the national average growth is about 0,4%. During this period, a further aging process has been observed: compared to the values of 2001 the old-age index rises and remains above the national average (148,7%).

These tendencies are reflected in the family structure: while the proportion of elderly people alone in 2011 increases, the presence of young couples with children decreases.

The number of foreign residents (17,9 per 1,000 inhabitants) is one of the lowest intensity observed at national level (67,8 per 1,000 inhabitants), as well as the incidence of couples with a non-italian partner (1,0% compared to the average value of 2,4%).

Despite the improvement observed in the last ten years, the education indicators show several trends: people aged between 25 and 64 who have completed at least the high school are in fact lower than the italian average of 55,1%.

On the other side, every 100 young people between the ages of 15 and 19, only 1,3 do not have the diploma, much less than the national average of 2,1%.

The employment rate is increasing since 2011 and results more than 8 points lower than the italian value. The unemployment rate decreases but young people still have many problems to start working: values of employed of 45 years old and more are in fact 2,6 times higher the value of employed between 15 and 29. These values are however lower than the national average (298,1%) and are rising since 2001.

The structure of employment is changing: in 2011 professions with a medium-high level of expertise and specialization represent 29,6% of the total, which is 5 points lower than 2011. Approximately 18% of employment is absorbed by crafts or agricultural professions which are also decreasing by almost 7% compared to 2011. Low-level professions accounts for 18,6%, which is slightly growing compared to the previous census.

The number of people who daily move from the area for work and study reasons is increasing, thus demonstrating the gradual concentration of opportunities offered in large urban centers.

The living space available to each inhabitant is increasing to 45 m^2. The incidence of unused building assets is decreasing, while the proportion of homes equipped with indoor drinking water services, indoor toilet, bathtub or shower and hot water is almost constant (99 out of 100). Based on some indicators, some municipalities rank among the most critical and vulnerable from the social point of view. The percentage of households who are in a potential disadvantaged condition is higher than the national figure: the presence of only sixty-five years old people and at least one 80 years old person is 3,3% compared to the average value of 3%. The share of young people who are not studying and who is at the same time out of the job market (14,5% vs 12,3% average value), however this value is improving with respect to the past.

As far as the social activities it can be pointed out that the Union of Municipalities in Northern Salento aim to perform some joint administrative and service functions, such as: training and upgrading of Civil Protection staff personnel, urban and neighborhood road maintenance services, public green maintenance services, Informagiovani centre, social services, civilian disabled services. Furthermore, the Union has among its strategical objectives: planning and enhancing the territory by integrating the urban, environmental, rural and sustainable development dimension with integrated programs of interventions aiming at renovating the functions of historical centres, peripheries and rural areas in the area defined as the Park of Olives and Negroamaro.

Finally, the municipalities of the target areas have signed a Social Area Plan guided by Campi Salentina, envisaging a series of activities and services such as: family centres, aggregation centres for young people, home care for elderly, home help for disabled.

On the basis of the past events occurred in the area and the results of the future scenarios (see Climate analysis chapter) climate change hazards and the related potential impacts

identified in the target area of Salento are the following:
- heavy rainfall with consequent flooding events;
- drought periods and increase in mean temperature with consequent losses in agriculture.

Flooding

Exposure analysis

Exposure analysis was performed in order to evaluate the level of exposure to flooding in the area of Salento. However, according to the most recent IPCC approach exposure was not included in the vulnerability computation. Table 3.85 provides the list of exposure indicators analysed for flooding, the results for each indicator and the normalized values.
First of all "Population Density" was selected as the indicator of human capital exposure to potential flooding, as it indicates where the population is more concentrated in a given municipality. Clearly, a high exposure of the human capital is associated to higher population density values.
Furthermore, the "Road Network" (km in the municipal area) and the "Urban Areas"(% over the total municipal area) were considered among the most important exposed elements of the manufactured capital. Again, high exposure levels are found in the municipalities where the road network is more extended and the urban areas are larger.
Finally, due to the importance of agricultural activity, the extension of "Agricultural Areas" was included in the exposure analysis.
The Global Exposure Index was elaborated as the weighted arithmetic mean using equal weights of the normalized values of the exposure indicators identified.

	Result	**Normalized result**
HUMAN CAPITAL		
Population density	**Inhab/km^2**	
Campi Salentina	226,44	0,14
Guagnano	151,15	0,02
Novoli	446,87	0,52
Salice Salentino	138,41	0
Squinzano	473,4	0,56
Surbo	728,23	1,00
Trepuzzi	623,17	0,82
MANUFACTURED CAPITAL		

Road network	km	
Campi Salentina	203	0,41
Guagnano	204	0,42
Novoli	102	0
Salice Salentino	343	1,00
Squinzano	159	0,23
Surbo	168	0,27
Trepuzzi	175	0,30
Urban areas	**%**	
Campi Salentina	6,73	0,21
Guagnano	4,50	0,08
Novoli	11,93	0,51
Salice Salentino	3,09	0
Squinzano	15,72	0,73
Surbo	20,23	1,00
Trepuzzi	16,91	0,80
ECONOMIC CAPITAL		
Agricultural areas	**%**	
Campi Salentina	91,99	0,79
Guagnano	94,24	0,92
Novoli	86,78	0,48
Salice Salentino	95,65	1,00
Squinzano	82,86	0,26
Surbo	78,46	0
Trepuzzi	81,73	0,19

Global Exposure Index	
Campi Salentina	0,38
Guagnano	0,36
Novoli	0,38
Salice Salentino	0,50
Squinzano	0,45
Surbo	0,57
Trepuzzi	0,53

Brief comment	Human capital *Surbo is the municipality with the highest value of population density, followed by Trepuzzi with respectively about 728 and 623 inhab/kmq, while Salice Salentino has the lowest value of the indicator.*
	Manufactured capital *The influence of the infrastructure capital is prevalent in Salice Salentino with 343 km of road network, followed by Guagnano and Campi Salentina with about 204 and 203 km of roads. As referred to artificial surfaces, Surbo and Trepuzzi are the municipalities more exposed with about 20% and almost 17% of artificial surfaces respectively.*
	Economic capital *All the municipalities of the Northern Salento have a very large agricultural area exposed (more than half of the total area), with Salice Salentino and Guagnano that have almost the totality of the municipality area.*

Table 3.85 - Exposure indicators and Global Index

Figure 3.37 illustrates the final map of the Global Exposure Index. The results were classified into 5 equal classes ranging from 0 to 1.
The map shows a medium-low level of elements exposed to flooding, mainly due to a general low population density in the area as well as a limited road network and a low presence of urban areas. On the other hand, one indicator such as “Agricultural Areas” shows very high values all over the target area.

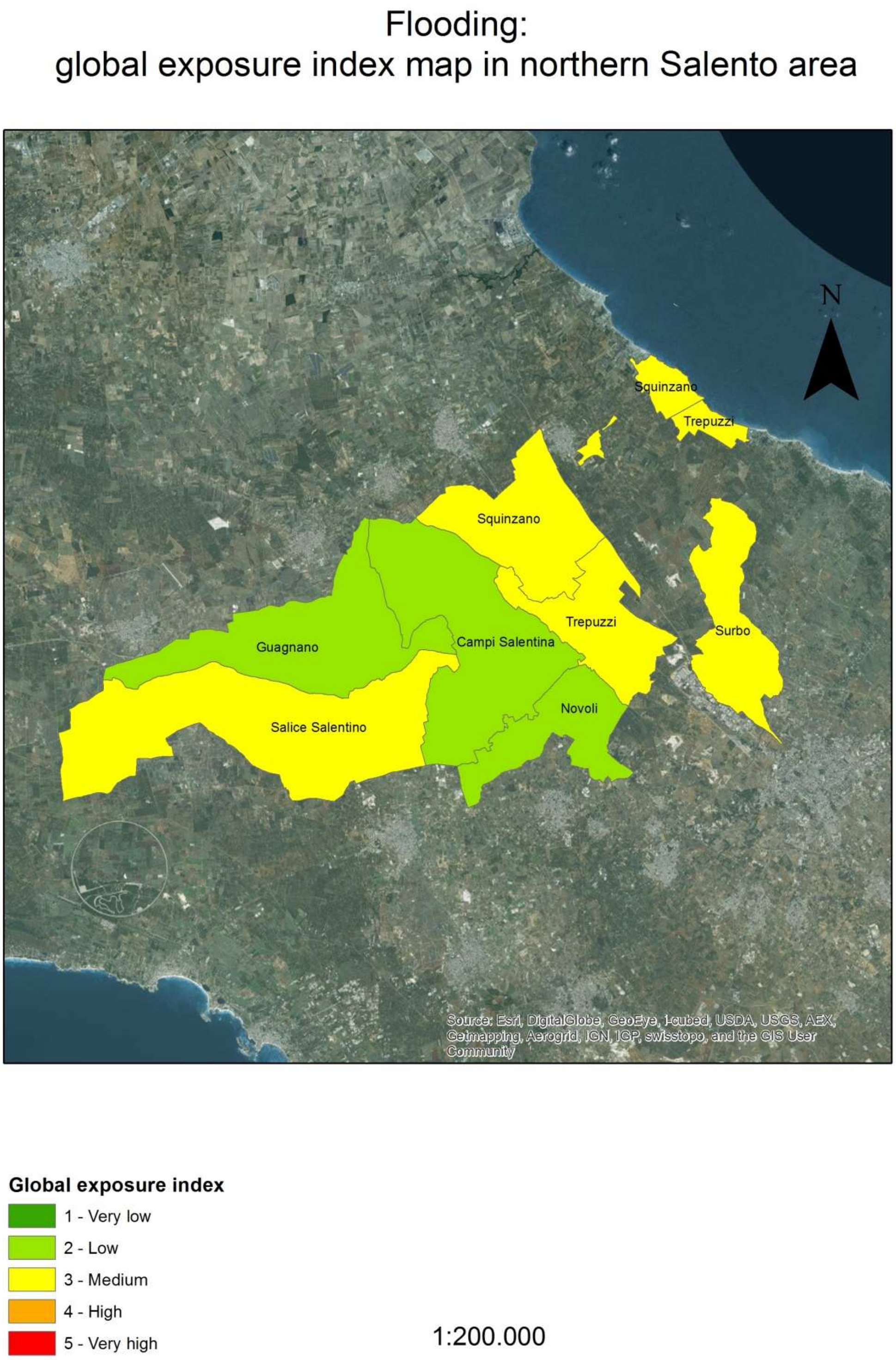


Figure 3.37 - Global Exposure Index map

Sensitivity analysis

In order to analyse the sensitivity of the target area to flooding, human, manufactured and economic factors were taken into account (Table 3.86). As far as human elements, specific population categories were considered: "People over 65", "Elderly people living alone", "Children under 6", and "Illiterates". In general, older people, in particular if living alone, are more sensitive to health risks posed by flooding as they tend to be less mobile in case of disaster. Furthermore, very young children and babies (under 6) have less capacity to react to potential risks as they become more scared and worried when they do not know what is happening in case of disaster. In addition, illiterates are reported as a population category with a poor ability to respond to the effects of natural hazards as they do not know well the risks posed by specific events (i.e. flooding) and are hardly reached by media, social network, early warning systems as they cannot read. Therefore, a high presence of these population categories in the area means a higher sensitivity to the climate hazard.

Furthermore, the Incidence of buildings in a bad state of conservation is among the manufactured capital indicators. With respect to flooding sensitivity, this indicator is considered to be representative of bad conditions in which people live, with a particular focus on people living in low floors.

Socio-economic factors were included in the economic capital. Indicators such as the Incidence of families living in potential discomfort conditions were considered as people and families holding a lower socio-economic status are more likely to lack access to information, technologies and other resources needed for effective adaptation such as knowledge, adequate housing, insurance. The Global Sensitivity Index was elaborated as the weighted arithmetic mean using equal weights of the normalized values of the sensitivity indicators identified.

	Result	**Normalized result**
HUMAN CAPITAL		
Incidence of elderly people > 65	**%**	
Campi Salentina	24,2	0,61
Guagnano	29,2	1,00
Novoli	27,3	0,85
Salice Salentino	24,4	0,62
Squinzano	25,3	0,69
Surbo	16,5	0
Trepuzzi	22,5	0,47
Incidence of very young people <6	**%**	
Campi Salentina	5,2	0,27
Guagnano	5,0	0,18
Novoli	5,0	0,21

Salice Salentino	5,0	0,20
Squinzano	4,5	0
Surbo	6,8	0,99
Trepuzzi	5,8	0,54
Incidence of illiterates	**%**	
Campi Salentina	3,00	1,00
Guagnano	2,80	0,80
Novoli	2,60	0,60
Salice salentino	2,70	0,70
Squinzano	3,00	1,00
Surbo	2,00	0
Trepuzzi	2,40	0,40
Incidence of elderly people alone	**%**	
Campi Salentina	24,6	0,69
Guagnano	23,1	0,33
Novoli	25,9	1,00
Salice salentino	22,4	0,16
Squinzano	21,7	0
Surbo	21,8	0,02
Trepuzzi	24,9	0,76
MANUFACTURED CAPITAL		
Incidence of buildings in a bad state of conservation	**%**	
Campi Salentina	1,7	1,00
Guagnano	1,2	0,59
Novoli	0,5	0,00
Salice salentino	1,2	0,56
Squinzano	1,2	0,56
Surbo	0,5	0
Trepuzzi	1,1	0,46
ECONOMIC CAPITAL		
Incidence of families in potential discomfort	**%**	
Campi Salentina	3,5	0,48
Guagnano	4,9	1,00
Novoli	3,5	0,48
Salice salentino	3,8	0,59
Squinzano	4,1	0,70
Surbo	2,2	0
Trepuzzi	2,9	0,25

Global Sensitivity Index	
Campi Salentina	0,67
Guagnano	0,65

Novoli	0,52
Salice Salentino	0,47
Squinzano	0,49
Surbo	0,16
Trepuzzi	0,48
Brief comment	Human capital *Novoli and Guagnano are the municipalities with the larger incidence of elderly people > 65, and Novoli has also the larger incidence of elderly people alone, while Surbo has the larger incidence of very young people <6. Campi Salentina and Squinzano have the highest value of illiterates people, followed by Guagnano and Salice Salentino.*
	Economic capital *Guagnano has the larger number of families in potential discomfort (4,9%), followed by Squinzano (4,1%).*

Table 3.86 - Sensitivity indicators and Global Index

Figure 3.38 illustrates the final map of the Global Sensitivity Index. The results were classified into 5 equal classes ranging from 0 to 1. The map shows higher levels of sensitivity in the municipalities of Campi Salentina and Guagnano and the lower levels in the municipality of Surbo. The sensitivity levels of Campi Salentina could be mainly associated to the higher presence of illiterates in the overall area and buildings in a bad state of conservation, with relatively high percentages of elderly people living alone. The municipality of Guagnano shows the higher values of elderly people and the higher incidence of families living in potential discomfort conditions. Also the high presence of illiterates could contribute to the high sensitivity of this municipality.

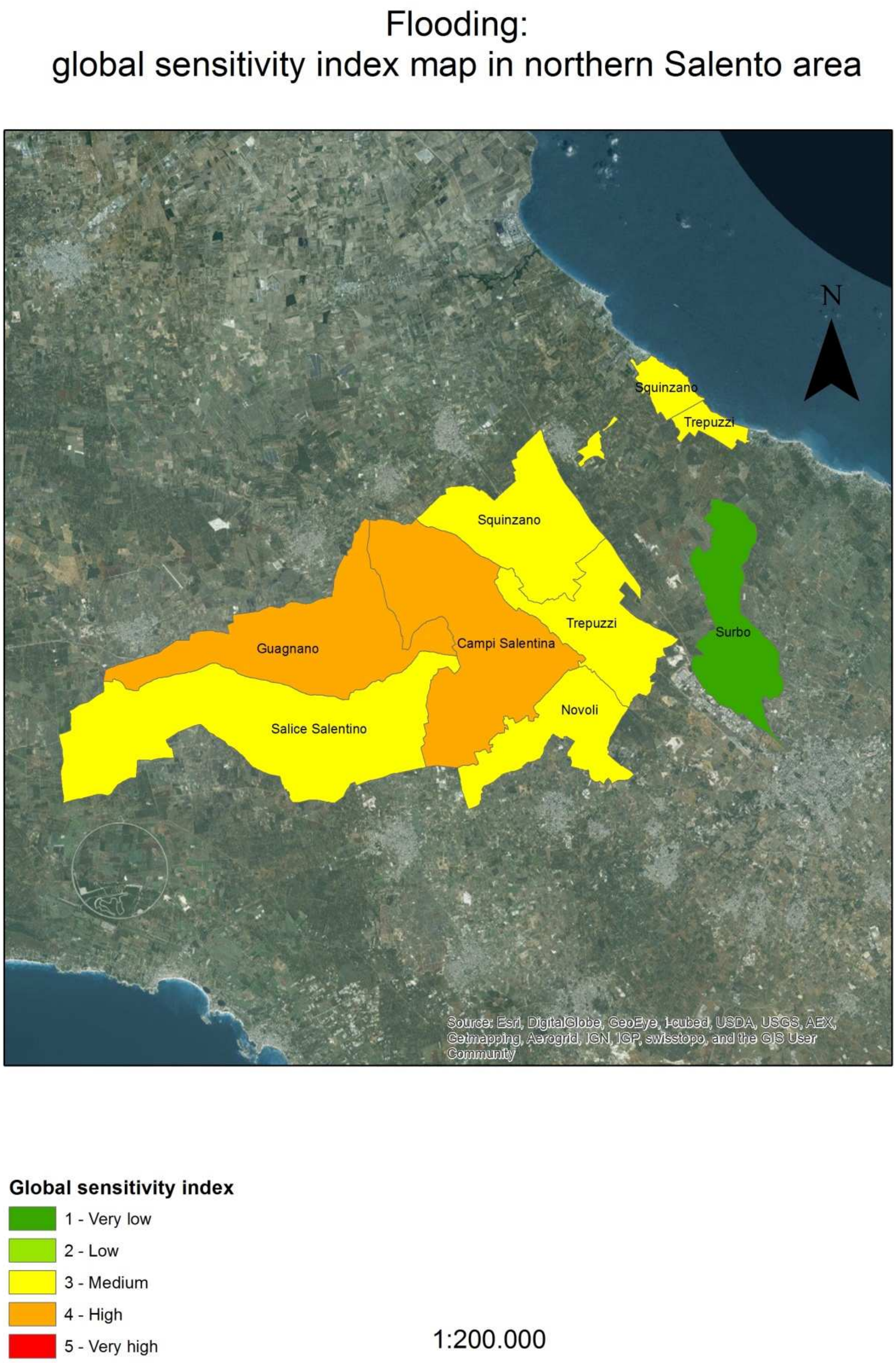


Figure 3.38 - Global Sensitivity Index map

Adaptive capacity analysis

Adaptive capacity was analysed through indicators of the following dimensions: i. Institutions; ii. Knowledge and technology; iii. Economic resources (Table 3.87).
In particular, the institutional contribution to the local adaptive capacity was analysed on the basis of the "Municipal budget commitment on environmental management" and the "International mitigation/adaptation commitment". The first indicator demonstrates the willingness and capability of the local institutions to invest in environmental protection, thus strengthening the capacity of the system to cope with climate change impacts. Even if the indicator is not strictly focused on expenses aimed at coping with climate change, higher levels of investment clearly mean higher capacities to cope with the future environmental and climate risks. The second indicator refers to the signatories commitments of the European Covenant of Mayors: Covenant of Mayors for Sustainable Energy Action Plans, Mayor's Adapt and the most recent Covenant of Mayors for Climate and Energy. By signing the Covenant of Mayors, municipalities voluntarily commit to actively supporting the implementation of climate change policies (both mitigation and adaptation) at EU level. Within two years following the date of the local council decision, the commitment obliges municipalities to translate their political action into practical measures and projects, by preparing local sustainable energy and/or adaptation plans. In this perspective, those municipalities that have signed both the commitments (or just the last Covenant of Mayors for Climate and Energy focused on mitigation and adaptation) are considered to have a higher adaptive capacity, while non-signatories cities have a very low interest in this kind of policies. Even if not directly engaged in adaptation policies, municipalities carrying out mitigation policies demonstrate a high attention to climate policies and are therefore assigned a 0,5 value. As far as knowledge and technology, it is recognized that the presence in the target area of high "Adult incidence with degree" means that the society has a high capacity to respond and manage disasters, due to a facilitated/improved access and use of information (i.e. weather forecast on internet) and technology (i.e. early warning systems). Finally, the availability of economic resources clearly is a determinant of adaptive capacity: the "Per capita income" contributes to depict the welfare of a society, where an equitable distribution of economic resources among its inhabitants implies a greater capacity to adapt due to a major possibility to invest in adaptive measures, included eventually investing money in insurance.
As explained in paragraph 3.2 due to the opposite direction towards vulnerability, the direction of adaptive capacity indicators was changed by simply subtracting the normalized value of the indicator from 1. This means that low results in terms of adaptive capacity (i.e. low municipal budget, low adaptation commitment, low adult incidence with degree, low per capita income) have higher normalized result (the lowest=1).
The Global Adaptive Capacity Index was elaborated as the weighted arithmetic mean using equal weights of the normalized values of the adaptive capacity indicators identified.

	Result	Normalized result
INSTITUTIONS		
Municipal budget commitment on environmental management[8]	**%**	
Campi Salentina	0,001	1,00
Guagnano	32,88	0,64
Novoli	19,53	0,79
Salice salentino	18,90	0,79
Squinzano	28,48	0,69
Surbo	89,44	0
Trepuzzi	1,40	0,99
International mitigation/adaptation commitment	**Y/N**	
Campi Salentina	1,00	0
Guagnano	0,50	0,50
Novoli	0,50	0,50
Salice salentino	0	1,00
Squinzano	0	1,00
Surbo	0	1,00
Trepuzzi	0	1,00
KNOWLEDGE AND TECHNOLOGY		
Adult incidence with degree	**%/inhab**	
Campi Salentina	10,5	0
Guagnano	8,9	0,39
Novoli	10,3	0,05
Salice salentino	7,0	0,85
Squinzano	7,5	0,74
Surbo	6,4	1,00
Trepuzzi	8,4	0,51
ECONOMIC RESOURCES		
Per capita income	**euro/inhab**	
Campi Salentina	15.026	0
Guagnano	13.169	1,00
Novoli	14.221	0,43
Salice salentino	13.608	0,77

[8] The "Budget commitment" indicator was drawn up on the basis of the consultation of the municipalities target budgets. Expenditure commitments for the year 2017 have been added, relating to measures to protect natural areas (as areas that cooperate with water absorption), interventions on integrated water services (as interventions on sewage networks for the removal of waters of rainfall) and civil protection interventions, all in relation to the total expenditure set for the 2017 budget.

Squinzano	14.183	0,46
Surbo	14.395	0,34
Trepuzzi	14.636	0,22
Global Adaptive Capacity Index		
Campi Salentina	0,25	
Guagnano	0,63	
Novoli	0,44	
Salice Salentino	0,85	
Squinzano	0,72	
Surbo	0,59	
Trepuzzi	0,68	
Brief comment	Institutions *Campi Salentina has the lowest value of budget commitment on environmental management (0,001%), while Surbo has the highest value (89%). However, Campi Salentina is the only municipality to have signed the EU Covenant of Mayors on both mitigation and adaptation policies.*	
	Knowledge and technology *Surbo and Salice Salentino are the municipalities with the lowest value of adult incidence with degree (6,4 and 7%), while Campi Salentina has the highest value of the indicator (10,5%).*	
	Economic resources *The per capita income is rather homogeneously low in the whole target area. The higher value belongs to Campi Salentina, while Guagnano and Salice Salentino has the lowest values.*	

Table 3.87 - Adaptive Capacity indicators and Global Index

Figure 3.39 illustrates the final map of the Global Adaptive Capacity Index. The results were classified into 5 equal classes ranging from 0 to 1, where higher values mean lower levels of adaptive capacity. The map shows that just one municipality is characterised by a high adaptive capacity, due to its commitment in international initiatives on climate change as well as the highest percentage of adults with degree and the per capita income. However, three municipalities in the area result in the low class of adaptive capacity: Squinzano, Trepuzzi, Guagnano. Finally, the municipality of Salice Salentino presents the lowest values of adaptive capacity, mainly due to the absence of a specific commitment in European initiatives on climate change and to relatively high values of all the indicators analysed.

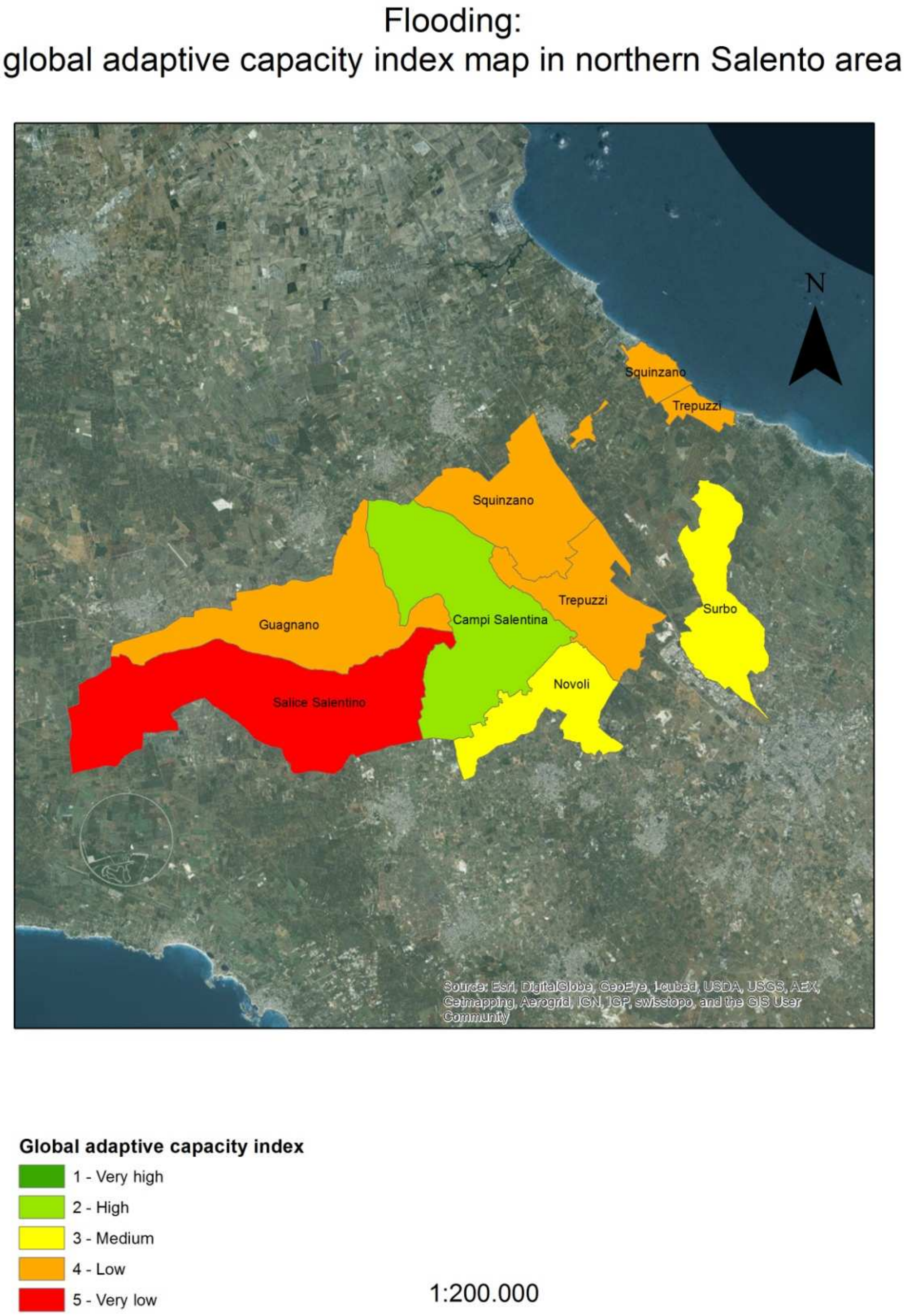


Figure 3.39 - Global Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.88).

	Normalized results
Global Sensitivity Index	
Campi Salentina	0,67
Guagnano	0,65
Novoli	0,52
Salice salentino	0,47
Squinzano	0,49
Surbo	0,16
Trepuzzi	0,48
Global Adaptive Capacity Index	
Campi Salentina	0,25
Guagnano	0,63
Novoli	0,44
Salice salentino	0,85
Squinzano	0,72
Surbo	0,59
Trepuzzi	0,68
Global Vulnerability Index	
Campi Salentina	0,46
Guagnano	0,64
Novoli	0,48
Salice salentino	0,66
Squinzano	0,61
Surbo	0,38
Trepuzzi	0,58
Brief comment	*Guagnano is the municipality with the highest Global Vulnerability Index (0,64), followed by Campi Salentina and Salice Salentino respectively with 0,59 and 0,53. The most favorable situation in terms of vulnerability is represented by Surbo (0,24).*

Table 3.88 - Global Vulnerability Index

Figure 3.40 shows the final map of the Global Vulnerability Index. The results were classified into 5 equal classes ranging from 0 to 1.
Except for the municipality of Surbo, which shows the lowest values of vulnerability in the target area due to a low sensitivity and a medium adaptive capacity, the municipalities of the area are equally distributed among the medium and the high vulnerability class. The municipalities of Squinzano, Guagnano and Salice Salentino result as the highest vulnerable areas in the target area. Clearly, these values result from a low adaptive capacity of all the municipalities combined with a relatively medium-high sensitivity to flooding.

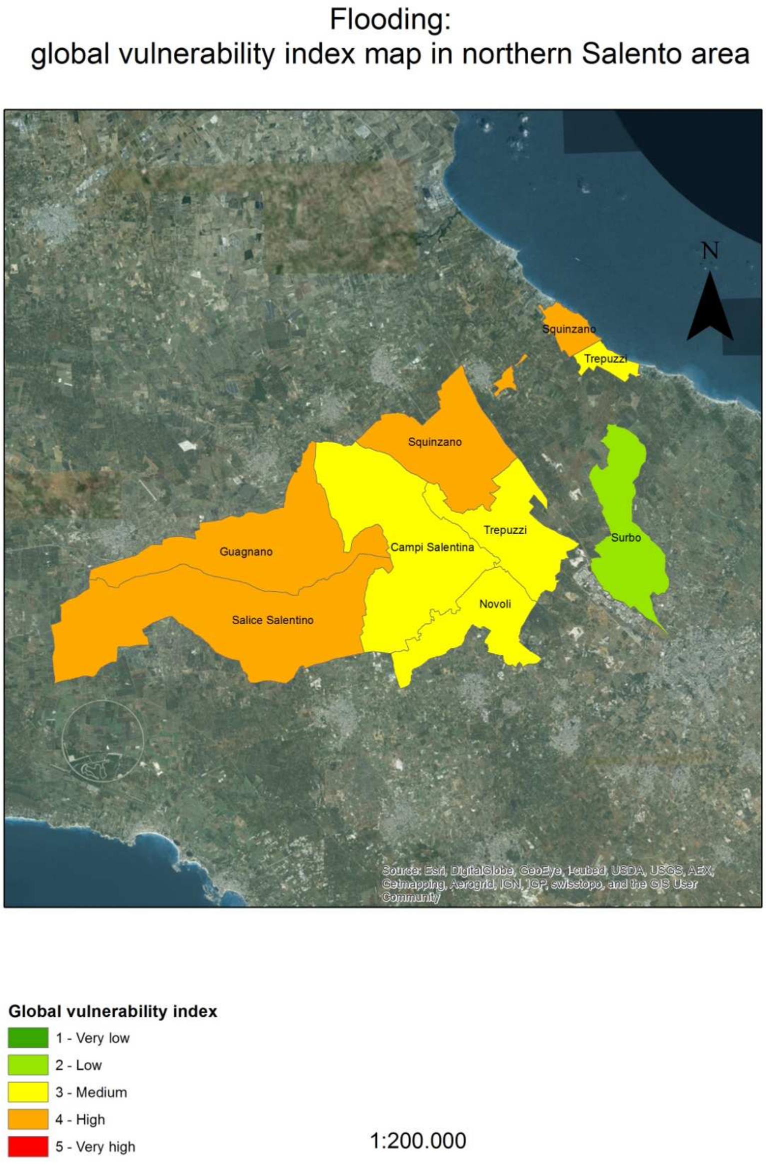


Figure 3.40 - Global Vulnerability Index map

Loss in agriculture

Exposure analysis

Exposure analysis was performed in order to evaluate the level of exposure of the agricultural system to climate change in the area of northern Salento. However, according to the most recent IPCC approach exposure was not included in the vulnerability computation.
Table 3.89 provides the list of exposure indicators analysed for the potential impact “loss in agriculture”, the results for each indicator and the normalized values.
As far as the human capital, the percentage of the “Employed in the agricultural sector” was considered in order to evaluate the exposure level of people working in the sector: clearly a higher percentage of employed corresponds to a higher exposure level.
The economic capital was analysed through the following indicators: i. “Number of active farms”; ii. “Utilised Agricultural Area” and iii. “Total Agricultural Area”. The first indicator accounts for the existence in the area of farms which could be potentially exposed to climate change: a higher number of farms implies a major potential exposure to climate threats.
Finally, the “Utilised Agricultural Area (UAA)” and “Total Agricultural Area (TAA)” were selected in order to take into account both the extension of the area used for farming and the total area, considering the sum of UAA and the not utilised agricultural areas, which means the areas actually unused but potentially used, and therefore exposed.
The Global Exposure Index was elaborated as the weighted arithmetic mean using equal weights of the normalized values of the exposure indicators identified.

	Result	**Normalized result**
HUMAN CAPITAL		
Employed in agricultural sector	**%**	
Campi Salentina	6,2	0,14
Guagnano	17,7	1,00
Novoli	5,7	0,10
Salice Salentino	10,2	0,44
Squinzano	9,5	0,39
Surbo	6,3	0,14
Trepuzzi	4,4	0
ECONOMIC CAPITAL		
Active farms	**N**	
Campi Salentina	1131	0,83
Guagnano	959	0,66
Novoli	446	0,14
Salice Salentino	1297	1

Squinzano	691	0,39
Surbo	309	0
Trepuzzi	584	0,28
UAA - Utilised Agricultural Area	**Ha**	
Campi Salentina	2.742,2	0,66
Guagnano	2.297,4	0,48
Novoli	1.101,5	0
Salice Salentino	3.602,4	1
Squinzano	2.888,5	0,71
Surbo	1.199,6	0,04
Trepuzzi	1385,6	0,11
TAA – Total Agricultural Area	**Ha**	
Campi Salentina	2.857,6	0,63
Guagnano	2.478,5	0,49
Novoli	1.170,2	0
Salice Salentino	3.841,0	1,00
Squinzano	2.971,2	0,67
Surbo	1.242,0	0,03
Trepuzzi	1.425,8	0,10

Global Exposure Index	
Campi Salentina	0,56
Guagnano	0,66
Novoli	0,06
Salice Salentino	0,86
Squinzano	0,54
Surbo	0,05
Trepuzzi	0,12

Brief comment	Human capital *The highest percentage of employed in the agricultural sector is found in the municipality of Guagnano, while Trepuzzi shows the lowest values. Values are rather different among the municipalities.*
	Economic capital *Salice Salentino has the highest number of active farms in the area, which is more than three times the lowest value found in the municipality of Surbo. As far as the UAA again Salice Salentino shows values that are three times the minimum values of the municipality of Novoli.*

Table 3.89 – Exposure indicators and Global Index

Figure 3.41 illustrates the final map of the Global Exposure Index. The results were classified into 5 equal classes ranging from 0 to 1. The map shows a very high level of exposure of the municipality of Salice Salentino mainly due to the large extension of UAA and TAA as well as the highest presence of active farms in the territory. High levels of exposure are found also in the municipality of Guagnano: in this area the highest value of employed in the agricultural sector is found.

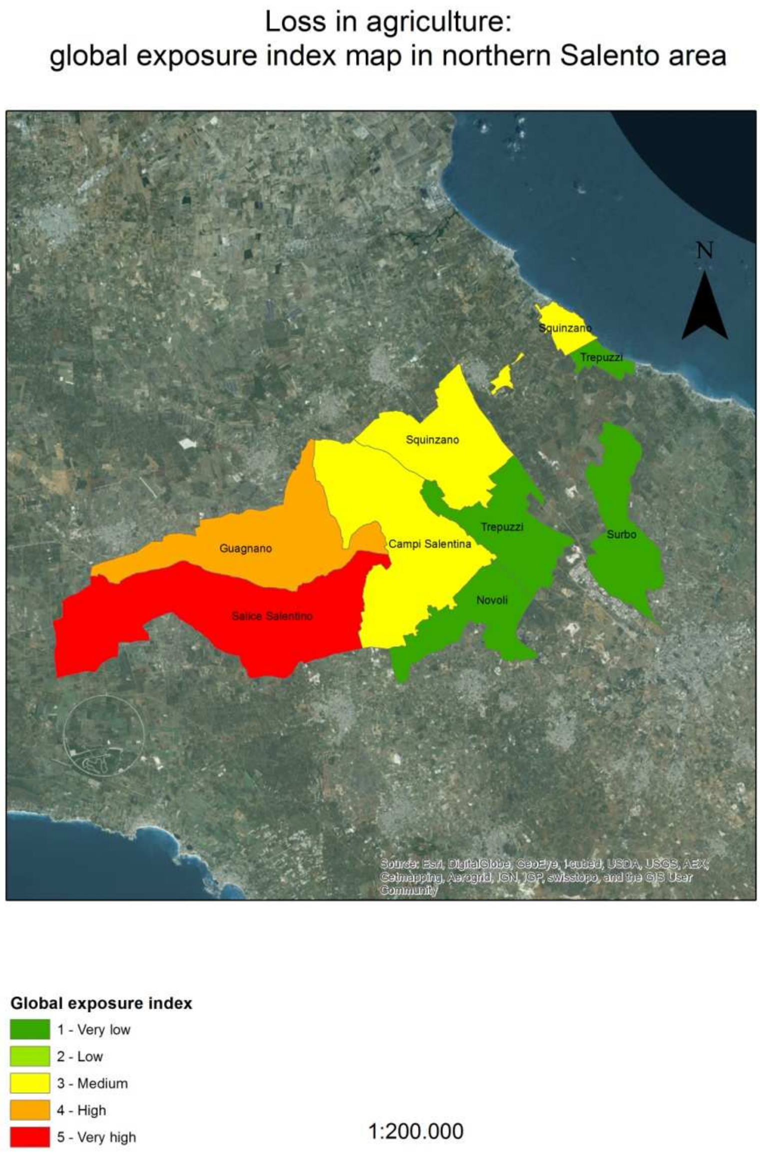


Figure 3.41 - Global Exposure Index map

Sensitivity analysis

In order to analyse the sensitivity of the target area to the loss in agriculture, the following indicators were taken into account: i. "Farms with salaried employees"; ii. "Wine farms"; iii. "UAA Wine farms"; iv. "Oil-Olives farms"; "UAA Oil-Olives farms". The indicator values and their normalized results are illustrated in Table 3.90: they are statistically accessible and well suited for a detailed geographic assessment.

The indicator "Farms with salaried employees" accounts for the dimensional class of farms. Taking into account that high sensitivity means that the potential impact of climate change on this sector will be higher, it is assumed that stronger economic damages would occur where the presence of farms with salaried employees is higher, due to the high number of people economically dependent on this sector.

In addition, the indicators selected for the sensitivity analysis are those that identify the farms number and the dimensional factors (UAA and TAA) related to the most climate-sensitive and relevant crops in the area such as wine and oil-olive production. In fact, the municipalities of northern Salento can be considered as the cornerstone of the wine district of the Apulia region, with the production of high quality wines such as Negramaro and Salice Salentino, and the production of oil and olives, mostly distributed by cooperatives and private operators in Italy and abroad.

	Result	**Normalized result**
ECONOMIC CAPITAL		
Farms with salaried employees	**N**	
Campi Salentina	26,0	0,93
Guagnano	28,0	1,00
Novoli	10,0	0,33
Salice Salentino	23,0	0,81
Squinzano	1,0	0
Surbo	6,0	0,19
Trepuzzi	6,0	0,19
Wine farms	**N**	
Campi Salentina	222	0,67
Guagnano	329	1,00
Novoli	46	0,14
Salice Salentino	305	0,93
Squinzano	19	0,05
Surbo	1	0
Trepuzzi	2	0
UAA Wine farms	**Ha**	
Campi Salentina	372,9	0,58
Guagnano	641,2	1,00
Novoli	80,4	0,12

Salice salentino	607,3	0,95
Squinzano	57,0	0,09
Surbo	0,4	0
Trepuzzi	1,2	0
Oil-Olives farms	**N**	
Campi Salentina	0	0
Guagnano	1	0,50
Novoli	0	0
Salice salentino	0	0
Squinzano	2	1,00
Surbo	1	0,50
Trepuzzi	0	0
UAA Oil-Olives farms	**Ha**	
Campi Salentina	0	0
Guagnano	8,4	0,08
Novoli	0	0
Salice salentino	0	0
Squinzano	105,3	1,00
Surbo	59,2	0,56
Trepuzzi	0	0
Global Sensitivity Index		
Campi Salentina	0,44	
Guagnano	0,72	
Novoli	0,12	
Salice Salentino	0,54	
Squinzano	0,43	
Surbo	0,25	
Trepuzzi	0,04	
Brief comment	Economic capital *The highest distribution of farms and the largest extension of vineyards is found in the municipalities of Guagnano and Salice Salentino.* *The highest values of agricultural areas used for oil-olives production are identified in the municipality of Squinzano.*	

Table 3.90 - Sensitivity indicators and Global Index

Figure 3.42 illustrates the final map of the Global Sensitivity Index. The results were classified into 5 equal classes ranging from 0 to 1. The map shows the highest levels of sensitivity in the municipality of Guagnano, mainly due to highest number of farms with salaried employees and the largest presence and extension of wine farms. Oil production is less relevant in this area. In addition, a medium sensitivity characterizes the areas of the municipalities of Squinzano, Campi Salentina e Salice Salentino.

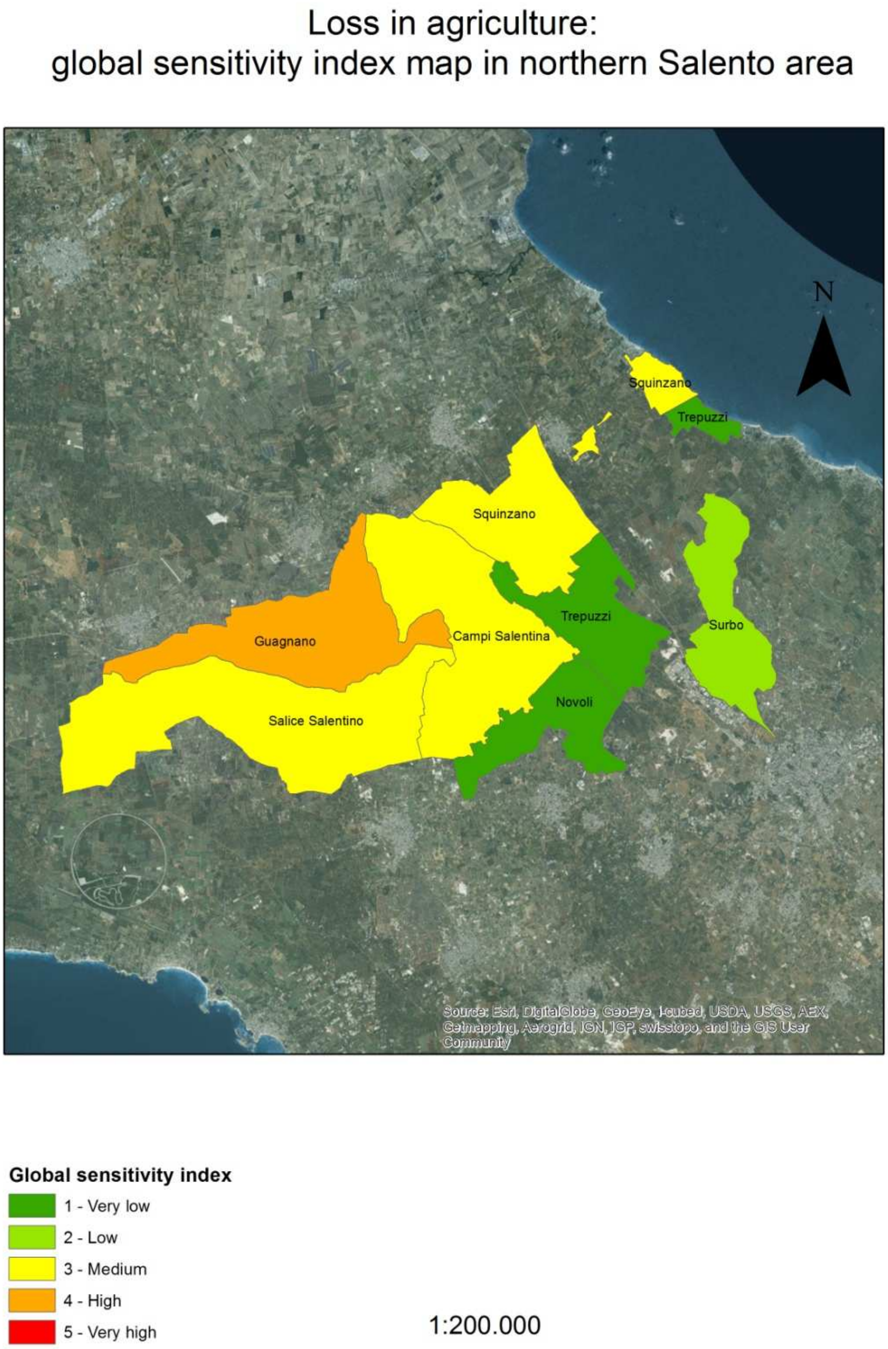


Figure 3.42 - Global Sensitivity Index map

Adaptive capacity analysis

Adaptive capacity was analysed through indicators of the following dimensions: i. Institutions; ii. Knowledge and Technology; iii. Economic resources (Table 3.91).

As explained in the previous paragraph, "International mitigation/adaptation commitment" refers to the signatories commitments of the European Covenant of Mayors: Covenant of Mayors for Sustainable Energy Action Plans, Mayor's Adapt and the most recent Covenant of Mayors for Climate and Energy. By signing the Covenant of Mayors, municipalities voluntarily commit to actively supporting the implementation of climate change policies (both mitigation and adaptation) at EU level. Within two years following the date of the local council decision, the commitment obliges municipalities to translate their political action into practical measures and projects, by preparing local sustainable energy and/or adaptation plans. In this perspective, those municipalities that have signed both the commitments (or just the last Covenant of Mayors for Climate and Energy focused on mitigation and adaptation) are considered to have a higher adaptive capacity, while non-signatories cities have a very low interest in this kind of policies. Even if not directly engaged in adaptation policies, municipalities carrying out mitigation policies demonstrate a high attention to climate policies and are therefore assigned a 0,5 value.

As far as the level of knowledge and technology, the "Incidence of farmers with agro-environmental diploma/degree" accounts for a major technical expertise and specialization of farmers, meaning that farmers could have a facilitated/improved access and use of information (i.e. weather forecast), a major attention to new technologies (i.e. early warning systems) and new farming techniques and eventually more awareness about the new risks for agriculture posed by climate.

Finally, the availability of economic resources clearly is a determinant of adaptive capacity: the indicator contributes to depict the welfare of a society, where an equitable distribution of economic resources among its inhabitants implies a greater capacity to adapt due to a major possibility to invest in adaptive measures, included eventually investing money in insurance.

As explained in paragraph 3.2 due to the opposite direction towards vulnerability, the direction of adaptive capacity indicators was changed by simply subtracting the normalized value of the indicator from 1. This means that low results in terms of adaptive capacity (i.e. low adaptation commitment, low incidence of farmers with agro-environmental diploma/degree, low per capita income) have higher normalized result (the lowest=1).

The Global Adaptive Capacity Index was elaborated as the weighted arithmetic mean using equal weights of the normalized values of the adaptive capacity indicators identified.

	Result	Normalized result
INSTITUTIONS		
International mitigation/adaptation commitment	**Y/N**	
Campi Salentina	1,00	0
Guagnano	0,50	0,50
Novoli	0,50	0,50
Salice salentino	0	1,00
Squinzano	0	1,00
Surbo	0	1,00
Trepuzzi	0	1,00
KNOWLEDGE AND TECHNOLOGY		
Incidence of farmers with agro-environmental diploma/degree	**%**	
Campi Salentina	2,21	0,03
Guagnano	1,56	0,72
Novoli	2,24	0
Salice salentino	1,54	0,74
Squinzano	1,59	0,69
Surbo	1,29	1,00
Trepuzzi	1,54	0,74
ECONOMIC RESOURCES		
Per capita income	**euro/inhab**	
Campi Salentina	15.026	0
Guagnano	13.169	1,00
Novoli	14.221	0,43
Salice salentino	13.608	0,77
Squinzano	14.183	0,46
Surbo	14.395	0,34
Trepuzzi	14.636	0,22

Global Adaptive Capacity Index	
Campi Salentina	0,01
Guagnano	0,74
Novoli	0,31
Salice Salentino	0,84
Squinzano	0,72
Surbo	0,78
Trepuzzi	0,65

<table>
<tr><td rowspan="3">Brief comment</td><td><u>Institutions</u>
The municipality of Campi Salentina already signed both mitigation and adaptation commitment at EU level. This initiative accounts for a willingness to actively support European policies in this field and therefore a high adaptive capacity. The municipalities of Guagnano and Novoli are engaged in mitigation initiatives thus demonstrating a high attention to climate change.</td></tr>
<tr><td><u>Knowledge and technology</u>
The municipalities of Novoli and Campi Salentina have the highest percentage of farmers with agro-environmental diploma/degree, even if values are in general low in the overall target area.</td></tr>
<tr><td><u>Economic resources</u>
The per capita income is in general low in the whole area. However, the highest values are found in the municipality of Campi Salentina.</td></tr>
</table>

Table 3.91 - Adaptive capacity indicators and Global Index

Figure 3.43 illustrates the final map of the Global Adaptive Capacity Index. The results were classified into 5 equal classes ranging from 0 to 1, where higher values mean lower levels of adaptive capacity. The adaptive capacity of the area results low to very low, except for the municipality of Campi Salentina and Novoli. Due to the absence of an international commitment on adaptation, a relatively low percentage of farmers with agro-environmental diploma/degree and low levels of per capita income, the municipality of Salice Salentino shows the lowest adaptive capacity in the whole target area, while the municipalities of Guagnano, Trepuzzi, Squinzano and Surbo belong to the low adaptive capacity class.

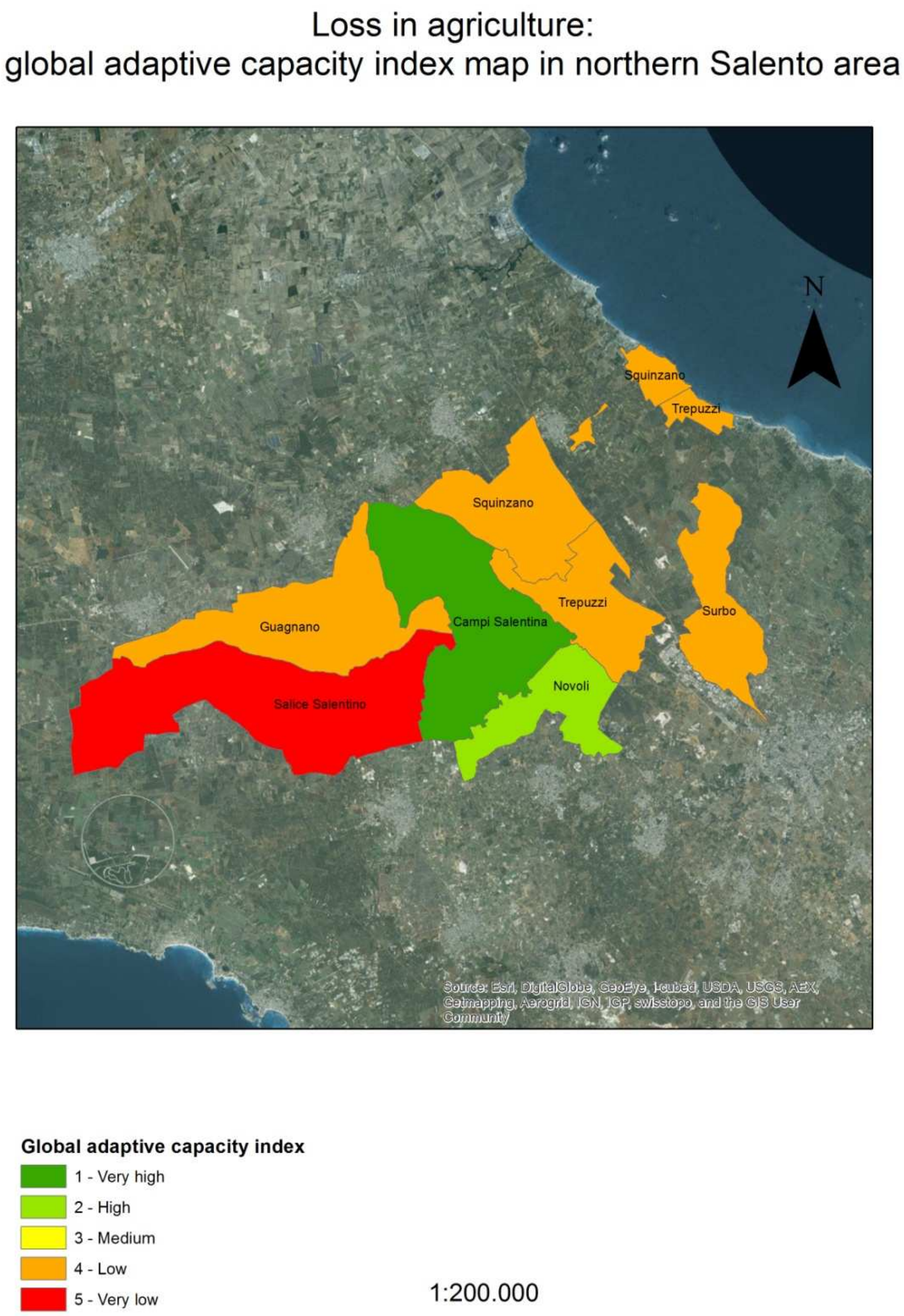


Figure 3.43 - Global Adaptive Capacity Index map

Global Vulnerability Index

The Global Vulnerability Index was elaborated as the weighted arithmetic mean using equal weights between Global Sensitivity Index and Global Adaptive Capacity Index (Table 3.92).

	Normalized results
Global Sensitivity Index	
Campi Salentina	0,44
Guagnano	0,72
Novoli	0,12
Salice salentino	0,54
Squinzano	0,43
Surbo	0,25
Trepuzzi	0,04
Global Adaptive Capacity Index	
Campi Salentina	0,01
Guagnano	0,74
Novoli	0,31
Salice salentino	0,84
Squinzano	0,72
Surbo	0,78
Trepuzzi	0,65
Global Vulnerability Index	
Campi Salentina	0,22
Guagnano	0,73
Novoli	0,21
Salice salentino	0,69
Squinzano	0,57
Surbo	0,51
Trepuzzi	0,35
Brief comment	*The municipality of Campi Salentina, Novoli and Trepuzzi show the lowest vulnerability values, while the municipalities of Salice Salentino and Guagnano are the most vulnerable municipalities in the whole target area.*

Table 3.92 - Global Vulnerability Index

Figure 3.44 shows the final map of the Global Vulnerability Index. The results were classified into 5 equal classes ranging from 0 to 1. Due to a relatively low sensitivity and a good capacity to commit into adaptation initiatives, while having also good values for the other adaptive capacity indicators, the municipalities of Campi Salentina and Novoli show the lowest vulnerability in the area. Even with a relatively low adaptive capacity, the municipality of Trepuzzi belong to the same low vulnerability class due to its very low sensitivity to the potential impact of climate change in agriculture. On the other side, the municipalities of Salice Salentino and Guagnano are the most vulnerable municipalities in the target area as a consequences of their highest distribution of farms and the largest extension of agricultural climate-sensitive production such as wine.

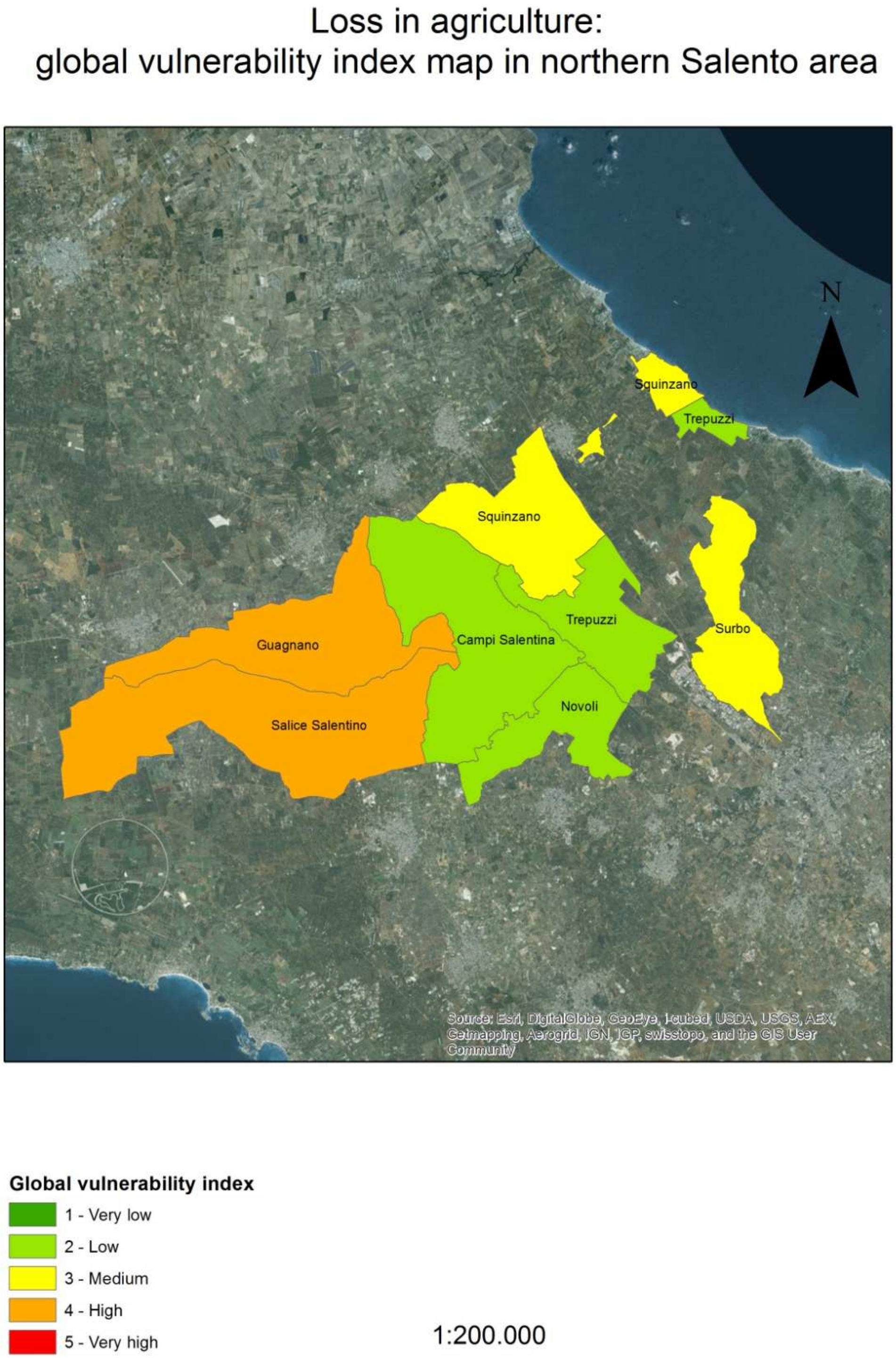


Figure 3.44 - Global Vulnerability Index map

4 CONCLUSIONS

The analysis illustrated in Chapter 2 provided climate analysis at regional level (Sardinia) with also a focus on the target areas. Past and current climate trend and future climate projections were elaborated over a time period useful to define adaptation policies (i.e. 2030-2050) and perform the mainstreaming into sectoral policies.
Standardised and tested approaches and procedures were adopted in this case, as it is demonstrated by the wide authoritative scientific references used.

Dissimilarly, the vulnerability analysis performed and described above represents one of the first attempt in Italy to implement a standardised methodology to quantify vulnerability to climate change at local level. Many examples currently exist in particular at an international level, but the approaches, definitions, theoretical frameworks still differ from each other, thus making this step even more complex and challenging.

The procedure adopted within the LIFE MASTER-Adapt project was mainly based on the experience and the guidelines published by Fritzsche et al (2014) and was further adapted to the most recent IPCC AR5 vulnerability and risk framework (IPCC, 2014), without referring to already implemented examples.

For this purpose, a seven-steps process was identified and a combination of sensitivity factors with adaptive capacity factors was performed in order to elaborate Global Vulnerability Indexes for each target areas and for each potential impact of climate change previously identified.

However, the implementation of such analysis highlighted methodological strengths and weaknesses.

On one side, the methodological procedure identified seems to be quite easy to replicate, as long as appropriate, specific and significant indicators are selected for the context to be investigated. Data availability and technical expertise in the use of Geographical Information Systems (GIS), and of course human resources, are the prerequisites needed for the implementation of such analysis.

On the other hand, each step of the methodology implies a certain degree of approximation that could undermine and influence the significance of the results.

First of all, the selection of indicators needed for the elaboration of the Global Indexes. In this case, a high level of subjectivity could affect the choice of one indicator rather than another. Furthermore, the unavailability of the required data or the limited access to data sources may limit the choice and force to use proxy indicators, as it usually happened in the case of adaptive capacity indicators.

Secondly, the definition of minimum and maximum values when dealing with the normalisation of metric data may represent a pitfall. In this case, a context-specific knowledge (i.e. local expert judgement) in defining appropriately thresholds may be very useful. This step is particularly relevant when considering the need to compare the results between different areas. However, in the cases illustrated in this report, the results obtained for each target area are not comparable each other. This means that a low vulnerable municipality in the northern Milan is less vulnerable than the other municipalities within the same target area but it cannot be compared with the municipalities in the other target areas.

In addition, the weighting procedure introduces a further approximation factor due to the high subjectivity in the assignment of weights based on the expert judgement. Weighting can have a major influence on the results and should be undertaken with care. However, this step is strongly required so as to get as close to reality as possible: in fact, in nature each element has its own weight and importance with reference to a particular phenomenon and considering equal weights may be actually misleading.

Furhermore, the classification of Global Indexes into equally distributed classes risks again to represent a too simplified reality which does not correspond to the evolution of natural phenomena.

Finally, alignment of indicators and their aggregation represent another challenging step, which should be further analysed and discussed, due to the strong influence they may have on the final result and the significance of the whole analysis.

Further insights are therefore needed in order to minimize as much as possible the influence and the subjectivity of each choice on the final results.

For this purpose, additional methodological details will be further discussed within the next deliverable of the MASTER-Adapt project "*Guidelines, principles and standardized procedures for climate analysis and vulnerability assessment at regional and local level*".

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ANNEX 1. DATA SOURCES

List of indicators and relative data source

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
All target areas	SU25, Summer days (Tmax > 25°C)	Climate hazard	ISPRA
	Mean Temperature (°C)	Climate hazard	ISPRA
	CDD, Consecutive Dry Days	Climate hazard	ISPRA
	PRTOTSUMMER, Summer Pcp	Climate hazard	ISPRA
Venice	Density	Exposure	GIS integration from ISTAT 2011
	Public Facilities	Exposure	Land cover of Regione Veneto
	Commercial Areas	Exposure	Land cover of Regione Veneto
	Industrial Areas	Exposure	Land cover of Regione Veneto
	High Vegetation	Adaptive Capacity	Dem extraction from Città Metropolitana di Venezia
	Available surface	Adaptive Capacity	GIS integration from ISTAT 2011
	Young people (< 10 years)	UHI/Sensitivity	ISTAT 2011
	Old people (> 65 years)	UHI/Sensitivity	ISTAT 2011
	Soil sealing	UHI/Sensitivity	Dem extraction from Città Metropolitana di Venezia
	Building density	UHI/Sensitivity	GIS integration from ISTAT 2011
	Runoff	Flooding/Sensitivity	GIS integration from Atlas of surfaces

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
	Soil typologies	All	Regione Veneto Soil Use Database
	Parcel surfaces	All	Regione Veneto Soil Use Database
	Economic values of soils	Drought Exposure and Flooding Exposure	National Fiscal Agency
	Crop water needs	Drought sensitivity	Regione Veneto reports
	Maximum amount of days crop can tolerate under water	Flooding sensitivity	ACER (Technical-scientific journal for the professionals in the field of green and cultivated areas)
	Irrigated/Non-irrigated land	Drought adaptive capacity	Regione Veneto Geodatabase (IDT)
	Regione Veneto DEM	Flooding adacptive capacity	Regione Veneto Geodatabase (IDT)
Seveso	People in areas at high risk of flood (10 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	People in areas at medium risk of flood (100 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	People in areas at medium risk of flood (500 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			census (2011)
	Workers in areas at high risk of flood (10 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Industry and Services census (2011)
	Workers in areas at high risk of flood (100 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Industry and Services census (2011)
	Workers in areas at high risk of flood (500 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Industry and Services census (2011)
	Cultural Heritage assets in areas at high risk of flood (10 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and data of the Regional Informative System about the Cultural Heritage in Lombardy (2016)
	Cultural Heritage assets in areas at high risk of flood (100 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and data of the Regional

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			Informative System about the Cultural Heritage in Lombardy (2016)
	Cultural Heritage assets in areas at high risk of flood (500 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and data of the Regional Informative System about the Cultural Heritage in Lombardy (2016)
	Length of roads in areas at high risk of flood (10 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and road network map of Lombardy Region (2016)
	Length of roads in areas at high risk of flood (100 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and road network map of Lombardy Region (2016)
	Length of roads in areas at high risk of flood (500 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and road network map of Lombardy Region (2016)
	Buildings in areas at high risk of flood (100 years)	River Flood/Exposure	GIS integration of Lombardy Region

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			Flood Directive maps (2015) and photogrammetric map of the study area
	Buildings in areas at high risk of flood (10 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and photogrammetric map of the study area
	Buildings in areas at high risk of flood (500 years)	River Flood/Exposure	GIS integration of Lombardy Region Flood Directive maps (2015) and photogrammetric map of the study area
	Young people (< 10 years) in areas at high risk of flood (10 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Young people (< 10 years) in areas at medium risk of flood (100 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Young people (< 10 years) in areas at high risk of flood (500 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Old people (> 65 years) in areas at high risk of flood (10 years)	River Flood/Sensitivity	GIS integration of Lombardy Region

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			Flood Directive maps (2015) and ISTAT Population census (2011)
	Old people (> 65 years) in areas at medium risk of flood (100 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Old people (> 65 years) in areas at high risk of flood (500 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Low income people in areas at high risk of flood (10 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Low income people in areas at medium risk of flood (100 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Low income people in areas at high risk of flood (500 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Non-native speakers people in areas at high risk of flood (10 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			census (2011)
	Non-native speakers people in areas at medium risk of flood (100 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Non-native speakers people in areas at high risk of flood (500 years)	River Flood/Sensitivity	GIS integration of Lombardy Region Flood Directive maps (2015) and ISTAT Population census (2011)
	Ratio between areas at high and medium risk of floods	River Flood/Sensitivity	Region Flood Directive maps (2015)
	Number of bridges at risk in case of flood	River Flood/Sensitivity	Data collected in the framework of "Il Fiume chiama" project, finance by CARIPLO Foundation
	Number of Red Codes in case of critical levels of the river (1,8 m)	River Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre and local Civil Protection Plans
	Number (%) of Orange Codes in case of critical levels of the river (1,8 m)	River Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre and local Civil Protection Plans
	Number (%) of Yellow Codes in case of critical levels of the river (1,8 m)	River Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			and local Civil Protection Plans
	Number (%) of Green Codes in case of critical levels of the river (1,8 m)	River Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre and local Civil Protection Plans
	Availability of local alert systems	River Flood/Adaptive Capacity	Dedicated survey
	Availability of Operating Procedures in alert or emergency phases	River Flood/Adaptive Capacity	Analysis of local Civil Protection Plans
	Availability of tools to alert population	River Flood/Adaptive Capacity	Dedicated survey
	Municipality rate of impervious surfaces	Urban Flood/Exposure	GIS analysis of Lombardy Region DUSAF (Use Categories of Agricultural and Forest Soils) map
	Percentage of young (< 10 years) people	Urban Flood/Sensitivity	ISTAT Population census (2011)
	Percentage of old (> 65 years) people	Urban Flood/Sensitivity	ISTAT Population census (2011)
	Percentage of Non-native speakers people	Urban Flood / Sensitivity	ISTAT Population census (2011)
	Percentage of low income people	Urban Flood/Sensitivity	ISTAT Population census (2011)
	Rate of critical underpasses	Urban Flood/Sensitivity	Data collected in the framework of "Il Fiume chiama" project, finance by CARIPLO Foundation
	Number of Orange Codes in case of heavy rains	Urban Flood/Adaptive	Daily Bulletins emitted by

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
		Capacity	Lombardy Region Functional Centre
	Number of Yellow Codes in case of heavy rains	Urban Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre
	Number of Green Codes in case of heavy rains	Urban Flood/Adaptive Capacity	Daily Bulletins emitted by Lombardy Region Functional Centre
	Availability of local alert systems	Urban Flood/Adaptive Capacity	Dedicated survey
	Availability of Operating Procedures in alert or emergency phases	Urban Flood/Adaptive Capacity	Analysis of local Civil Protection Plans
	Availability of tools to alert population	Urban Flood/Adaptive Capacity	Dedicated survey
	Municipality rate of impervious surfaces	Heat Waves/Exposure	GIS analysis of Lombardy Region DUSAF (Use Categories of Agricultural and Forest Soils) map
	Percentage of young (< 10 years) people	Heat Waves/Sensitivity	ISTAT Population census (2011)
	Percentage of old (> 65 years) people	Heat Waves/Sensitivity	ISTAT Population census (2011)
	Percentage (%) of old people living alone	Heat Waves/Sensitivity	www.urbanindex.it
	Rate (%) of domestic conditioned volumes	Heat Waves/Adaptive Capacity	Building energy certification database (CENED, Lombardy region)
	Rate (%) of people living close (<300m) to non domestic conditioned volumes	Heat Waves/Adaptive Capacity	GIS integration of Lombardy Region

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			map of commercial structures and ISTAT Population census (2011)
Sassari and Cagliari	SU25, Summer days (Tmax > 25°C)	Climate hazard	ISPRA
	Mean Temperature (°C)	Climate hazard	ISPRA
	CDD, Consecutive Dry Days	Climate hazard	ISPRA
	PRTOTSUMMER, Summer Pcp	Climate hazard	ISPRA
	Population density (n° km^{-2})	Exposure	ISTAT 2011
	Caws, sheep, and pigs (n° km^{-2})	Exposure	ISTAT 2010
	N. of arable farms (n° km^{-2})	Exposure	ISTAT 2010
	Used agriculture land (%)	Exposure	Census 2010
	Assets (industrial and residential areas) (%)	Exposure/Sensitivity	Uds 2008
	Green urban areas (%)	Sensitivity	Uds 2008
	Forested areas (%)	Sensitivity	Uds 2008
	Maquis areas (%)	Sensitivity	Uds 2008
	Arable, not irrigated, land (%)	Sensitivity	Uds 2008
	Arable irrigated land (%)	Sensitivity	Uds 2008
	Share of elderly people (> 60) (%)	Sensitivity	ISTAT 2011
	Share of very young people (<6) (%)	Sensitivity	ISTAT 2011
	People with a degree (%)	Adaptive capacity	ISTAT 2011
	People with a Master degree (%)	Adaptive capacity	ISTAT 2011
	GDP (€/capite)	Adaptive capacity	ISTAT 1991
	Emergency medical services (n°)	Adaptive capacity	Municipality data
	Projects on Climate Change adaptation (n°)	Adaptive capacity	Municipality data
	Fire risk plans (n°)	Adaptive capacity	Regional data 2016
	Voluntary people employed in associations (n° km^{-2})	Adaptive capacity	Regional dataset 2015
	People employed in CFVA, Fire Fighters, FORESTAS (n° km^{-2})	Adaptive capacity	Regional dataset 2015
	People employed in the primary service (agriculture and silvicultural sectors) (%)	Adaptive capacity	ISTAT 2011

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
	People unemployed (%)	Adaptive capacity	ISTAT 2011
Salento	Population density	Exposure	ISTAT 2011
	Road network	Exposure	Open street map
	Urban area	Exposure	Artificial surface of Corine Land Cover
	Agriculture areas	Exposure	ISTAT 2011
	Incidence of elderly people > 65	Sensitivity	ISTAT 2011
	Incidence of very young people <6	Sensitivity	ISTAT 2011
	Incidence of illiterates	Sensitivity	ISTAT 2011
	Incidence of elderly people alone	Sensitivity	ISTAT 2011
	Incidence of buildings in a bad state of conservation	Sensitivity	ISTAT 2011
	Incidence of families in potential discomfort	Sensitivity	ISTAT 2011
	Municipal budget commitment on environmental management	Adaptive capacity	Municipality data
	International mitigation/Adaption commitment	Adaptive capacity	Municipality data
	Adult incidence with degree	Adaptive capacity	ISTAT 2011
	Per capita income	Adaptive capacity	MEF, 2015
	Employed in agricultural sector	Exposure	ISTAT, 2011
	Active farms	Exposure	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	UAA - Utilised Agricultural Area	Exposure	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	TAA – Total Agricultural Area	Exposure	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	Farms with salaried employees	Sensitivity	ISTAT

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
			6° Censimento generale dell'Agricoltura, 2010
	Wine farms	Sensitivity	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	UAA Wine farms	Sensitivity	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	Oil-Olives farms	Sensitivity	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	UAA Oil-Olives farms	Sensitivity	ISTAT 6° Censimento generale dell'Agricoltura, 2010
	International mitigation/adaptation commitment	Adaptive capacity	Municipality data
	Incidence of farmers with agro-environmental diploma/degree	Adaptive capacity	ISTAT, 2011
	Per capita income	Adaptive capacity	MEF, 2015
Sardinia Region	SU25, Summer days (Tmax > 25°C)	Climate hazard	ISPRA
	Mean Temperature (°C)	Climate hazard	ISPRA
	CDD, Consecutive Dry Days	Climate hazard	ISPRA
	PRTOTSUMMER, Summer Pcp	Climate hazard	ISPRA
	Population density (n° km^{-2})	Exposure	ISTAT 2011
	Caws, sheep, and pigs (n° km^{-2})	Exposure	ISTAT 2010
	Arable farms (n° km^{-2})	Exposure	ISTAT 2010

	Indicator	Category (Impact/Exposure/Sensitivity/Adaptive Capacity)	Data source
	Assets (industrial and residential areas) (%)	Exposure	Uds 2008
	Farms (n° km^{-2})	Exposure	ISTAT 2010
	Used agriculture land (%)	Exposure	Census 2010
	Forested areas (%)	Exposure/Sensitivity	Uds 2008
	Maquis areas (%)	Exposure/Sensitivity	Uds 2008
	Share of elderly people (> 60) (%)	Sensitivity	ISTAT 2011
	Share of very young people (<6) (%)	Sensitivity	ISTAT 2011
	Arable, not irrigated, land (%)	Sensitivity	Uds 2008
	Arable irrigated land (%)	Sensitivity	Uds 2008
	Areas with sparse vegetation (%)	Sensitivity	Uds 2008
	People with a degree (%)	Adaptive capacity	ISTAT 2011
	People with a Master degree (%)	Adaptive capacity	ISTAT 2011
	GDP (€/capite)	Adaptive capacity	ISTAT 1991
	Fire risk plans (n°)	Adaptive capacity	Regional data 2016
	Voluntary people employed in associations (n° km^{-2})	Adaptive capacity	Regional dataset 2015
	People employed in CFVA, Fire Fighters, FORESTAS (n° km^{-2})	Adaptive capacity	Regional dataset 2015
	People employed in the primary service (agriculture and silvicultural sectors) (%)	Adaptive capacity	ISTAT 2011
	People unemployed (%)	Adaptive capacity	ISTAT 2011