D.3.1.1 Definition of a set of climate change indicators

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1 Abbreviations

AR5: 5^{th} Assessment Report of the Intergovernmental Panel on Climate Change

CMIP5: 5^{th} phase of the Coupled Model Intercomparison Project

CMCC: Fondazione Centro euro-Mediterraneo sui Cambiamenti Climatici

GCMs: General Circulation Models

NetCDF: Network Common Data Form

RCMs: Regional Climate Models

RCP4.5: Representative Concentration Pathway to a radiative forcing of 4.5 W/m2 at the end of 2100 wrt

preindustrial values

RCP8.5: Representative Concentration Pathway to a radiative forcing of 8.5 W/m2 at the end of 2100 wrt

preindustrial values

SD: Statistical Downscaling

2 Introduction

This document provides a short description of the climate data that will be delivered by CMCC to the ADRIADAPT project users, covering the period from 1951 to 2100 following two different possible scenarios for the XXI century. High resolution (order of 10 km) meteorological fields (temperature, wind, precipitation among others) will be made available in a common format over the case study domains defined within ADRIADAPT. Based on these fields a series of extreme events indicators at the daily time scale will be identified and suggested. This list of parameters will be modified and improved during the ADRIADAPT co-designing process and then computed during the project. A set of four Regional Climate Models (RCMs) participating to the EURO CORDEX project on the EUR-11 grid is used. Additional present and future climate information based on statistical downscaling techniques (Arpae-Simc) applied to global climate models from CMIP5 experiments, will be also available over Italian case studies from Emilia-Romagna, namely Cervia and Savio Valley Municipalities Union.

3 Model and numerical simulations description

The performance and the spatial resolution of General Circulation Models (GCMs) have continuously improved in the recent years, but the typical state of the art spatial scale is still too coarse to realistically reproduce present climate and eventually project climate change signals on local scales, especially in the presence of complex orography (Rummukainen, 2010; IPCC, 2001). Therefore, in order to improve the description of the small-scale processes and their effects on climate, dynamical and statistical downscaling are performed using–Regional Climate Models (RCMs) and a Statistical Downscaling scheme (SDs). The EURO-CORDEX (COordinated Regional climate Downscaling EXperiment) (Nikulin et al., 2012) on the 12.5 km EUR-11 (Figure 1) spatial domain is one source of data foreseen within ADRIADAPT. In addition outputs from the statistical downscaling scheme will be available over the case studies of Emilia-Romagna region (Italy). The following subsection describes the RCMs and SDs (2.1 and 2.2) together with the considered future scenarios definition (2.3).

3.1 *The EURO-CORDEX Regional Climate Models*

EURO-CORDEX is the European branch of the international CORDEX initiative, which is sponsored by the World Climate Research Program (WRCP) to organize an internationally coordinated framework to produce improved regional climate change projections for all land regions world-wide (http://www.euro-cordex.net/). The CORDEX-results serve as input for climate change impact and adaptation studies within the timeline of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and beyond. The experiments used to provide the RCM dataset described in this report are based on the standard setup of the model for the CORDEX (COordinated Regional climate Downscaling EXperiment) ensemble simulations (see e.g. Table 1 of Nikulin et al., 2012, Vautard et al. 2013) over the EUR-11 domain (Figure 1).

Four RCMs are considered, based on the availability of a sufficiently high number of climate parameters at the daily time frequency and already found suitable for extreme event analysis at least in terms of temperature and humidity (Scoccimarro et al. 2017). Table 1 lists the considered RCMs. In Table 1 the list of the driving GCMs, furnishing boundary conditions to the relative RCM is also provided.

In addition, the provision of a series of derived parameters to characterize extreme conditions over the ADRIADAPT case study domains is planned. Table 3 shows a preliminary list of climate indices CMCC considers of potential interest for ADRIADAPT stakeholders. The defined derived parameters will be computed for historical and future periods over the required domains at the annual or seasonal scale, based on user specific requirements.

Model name	Driving GCM	Institute
SMHI-RCA4	CNRM-CM5	Swedish Meteorological and Hydrological Institute, Rossby Centre
KNMI-RACMO22E	ICHEC-EC-EARTH	Royal Netherlands Meteorological Institute
INERIS-WRF331F	IPSL-CM5A-MR	IPSL (Institut Pierre Simon Laplace) and INERIS (Institut National de l Environnement industriel et des RISques)
CNRM-ALADIN53	CNRM-CM5	Centre National de Recherches Meteorologiques

Table 1: Regional Climate Models involved in ADRIADAPT data collection.

Field Description	Field Acronym	Vertical level	frequency	Field Unit
Precipitation	pr	Surface	Daily	[$kgm^{-2}s^{-1}$]
Surface relative humidity	hurs	surface	daily	[%]
Wind module	sfcWind	10 meter	daily	[$m\ s^{-1}$]
Wind module max	sfcWindmax	10 meter	daily	[$m\ s^{-1}$]
2 meter Temperature	tas	2 meter	daily	[°C]
2 meter Air Temperature max	tasmax	2 meter	daily	[°C]
2 meter Air Temperature min	tasmin	2 meter	daily	[°C]

Table 2: List of meteorological fields provided at the 10 km spatial resolution.

3.2 The statistical downscaling scheme (SDs)

Statistical downscaling technique (SDs) is another tool developed by the scientific community to increase climate information at small scale, often required by the impact community. The advantages of statistical downscaling technique are: it produces information at a specific station or grid point, rapid application from multiple GCMs and emission scenarios and, is computationally inexpensive in terms of time. In addition, SDs applied to a dense network of stations have been especially recommended in the areas characterized by complex topography (Hanssen Bauer et al. 2005). The SDs presents also some disadvantages, one of this is the fact that it needs long observed time series, for set-up of the statistical relationship.

There are different statistical downscaling tools applied in the climatology, ranging from Model Output Statistics and Perfect-Prog approaches. As regards the Model Output Statistics technique, this is based on statistical scheme that are calibrated using *simulated* large scale fields (predictors) and observed local fields (predictands). The Perfect-Prog is a statistical scheme built using only *observational* predictand-predictor data and, scheme that is applied then to predictor of GCM experiments so as to evaluate local future climate (Wilks 2006).

The statistical downscaling technique used in the present project is a Perfect-Prog approach. The SD scheme is represented by a multivariate regression based on the Canonical Correlation Analysis (CCAReg scheme; Tomozeiu et al., 2007, 2017). The canonical correlation analysis method finds the best linear combination of two multidimensional vectors (predictor and predictand) and selects pairs of spatial patterns such as their coefficient time series are optimally correlated (Von Storch et al., 1993). The statistical scheme, that links anomalies of the large-scale flows with anomalies of the local climate through a linear relation, assumes that this relation will not be altered even under future scenario conditions (Von Storch et al., 1993). So, once the most skilful statistical relationship/model is set-up over observed period for each climate index, this is then applied to the large-scale predictors simulated by GCMs, under various emission scenario, in order to obtain local climate-change information. Before the analysis, the predictands and predictors are filtered, in order to eliminate unwanted noise and to reduce the dimension of the data space. The SDs (CCAReg scheme) had been applied in previous works, to GCMs from STARDEX (http://www.cru.uea.ac.uk/stardex) and ENSEMBLES (http://www.ensembles-eu.org) experiments, over different Italian regions in the framework of A1B emission scenarios (Tomozeiu et al. 2007,2017).

In ADRIADAPT project, the calibration and validation of the SDs will been done using observed local data from the case studies of Emilia-Romagna region (predictands) over 1961-2015 period (see Figure 3). The data set is composed from daily temperature and precipitation at a resolution of 5kmx5km, period 1961-2015 (Antolini et al.,2015). As regards large scale fields data from

ERA40 and ERA-interim (http://www.ecmwf.int/products/), namely T850, MSLP, Z500, that cover the period 1961-2010 will be used. The large scale data cover the window 90°W-90°E and 0°-90°N.

The performance of the statistical downscaling model is evaluated through Spearman rank-correlation coefficient, BIAS and root-mean square-error (RMSE), computed over the validation period. Ones the seasonal SDs have been setup this is then applied to the predictors simulated by the GCMs from CMIP5 experiment (https://pcmdi.llnl.gov/mips/cmip5/terms-of-use.html), in the framework of RCP4.5 and RCP8.5 over the future period. Table3 presents a list with GCMs planned to feed the SDs scheme for the ADRIADAPT case studies from Emilia-Romagna.

Global Climate Model (GCMs name)	**Modelling Centre**
CMCC-CM	Centro Euro-Mediterraneo per i Cambiamenti Climatici
MPI-ESM-MR	Max Planck Institute for Meteorology
CNRM-CM5	Centre National de Recherches Meteorologiques
CanESM2	Canadian Centre for Climate Modelling and Analysis

Table 3 List of GCMs from CMIP5 experiment planned to feed the statistical downscaling scheme (CCAReg scheme)

According to the RCM and SDs simulations a series of meteorological parameters, listed in Table 4 will be collected and made available to ADRIADAPT partners. The indices presented in Table 4 are selected such as to describe the frequency and the intensity of extreme events. The extreme events are defined based on threshold percentile (STARDEX (http://www.cru.uea.ac.uk/stardex) and a final selection will be done taking into account the stakeholders opinions.

In order to give an idea on the percentile approach, considering daily data, over a 3-month season (June to August for instance), the 99 percentile of a 30-year time series of temperature data, correspond to the temperature value reached in 27 days only: about once in a year.

The defined thresholds for indexes computation shown in Table 4 are mainly based on percentiles 1, 5, 95 and 99, following common approaches to define intense to extreme events. Based on ADRIADAAPT user requirements such percentiles can be adapted to the local needs.

Field		Field Description	unit
1	Extreme Precipitation	99 percentile of precipitation	$[Kgm^{-2}s^{-1}]$
2	Intense Precipitation	95 percentile of precipitation	$[Kgm^{-2}s^{-1}]$
3	R95N	number of days with daily precip. exceeding the long term 95th percentile	[d]
4	R10mm - Heavy precip. index	Number of days with precip. higher than 10mm	[d]
5	RL5N	number of days with daily precip. below the 5th long term percentile	[d]
6	CDD	Consecutive dry days	[d]
7	Extr. High Temperature	99 percentile of temperature	[°C]
8	Extr. High Max Temperature	99 percentile of max daily temperature	[°C]
9	Extr. Low Temperature	1 percentile of temperature	[°C]
10	Extr. Low min Temperature	1 percentile of min daily temperature	[°C]
11	High Temperature	95 percentile of temperature	[°C]
12	High Max Temperature	95 percentile of max daily temperature	[°C]
13	Low Temperature	5 percentile of temperature	[°C]
14	Low min Temperature	5 percentile of min daily temperature	[°C]
15	CFD	Consecutive frost days	[d]
16	Tropical nights index	N.of days with temperature newer below 20°C	[d]
17	HWDI	heat wave duration	[d]
18	HWFI	warm spell days index	[d]
19	HUMIDEX	Perceived temperature based on temp. and rel.h.	[]
20	Extreme HUMIDEX	99 percentile of Perceived Temperature	[]
21	Extreme Wind	99 percentile of daily wind	[m/s]
22	Extreme Max Wind	99 percentile of daily max wind	[m/s]
23	HDG	Heating degree-day (indicator for heating energy demand)	(°C)

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24	CDG	Cooling degree-day (indicator for cooling energy demand)	(°C)

Table 4: List of climate indices for the characterization of extreme events.

3.3 The simulations

In addition to the historical simulation produced by RCMs covering the 1951-2005 period, two future emission scenarios are considered among those developed for the last IPCC assessment report, to provide data to ADRIADAPT users, covering the period 2005-2100. Specifically, the RCP8.5 (Representative Concentration Pathway 8.5), considered as a sort of worst case in terms of radiative forcing and the RCP4.5, considered as a more moderate scenario (Riahi et al. 2011, Taylor et al. 2012), have been selected within the ones available from the Coupled Models Intercomparison Project phase 5 (CMIP5, Meehl and Bony, 2012). The historical simulation has been performed forcing the CMIP5 models with observed concentration of greenhouse gasses, aerosols, ozone and solar irradiance, starting from an arbitrary point of a quasi-equilibrium control run. The RCPs scenarios follow a rising radiative forcing pathway leading to 8.5 W/m^2 and 4.5 W/m^2 in 2100.

As concerns the case studies from Emilia Romagna, namely Cervia and Savio Valley Municipalities Union, the simulations produced by statistical downscaling (SDs) will be available over the grid points represented in figure 2. Seasonal future changes of temperature and precipitation indices will be produced and analysed in each grid points, in the framework with RCP4.5 and RCP8.5 radiative forcings. The availability of different simulations produced by SDs fed with different GCMs (see table 3) allows to reduce the uncertainties due to global climate models and to compute an Ensemble Mean of seasonal future changes. Different future periods of 20 years will be considered for both tools (RCMs and SDs) to eventually cluster the aforementioned indexes (i.e. 2021-2040, 2041-2060, 2061-2080, 2081-2100) and to be compared with historical (1986-2005) results.

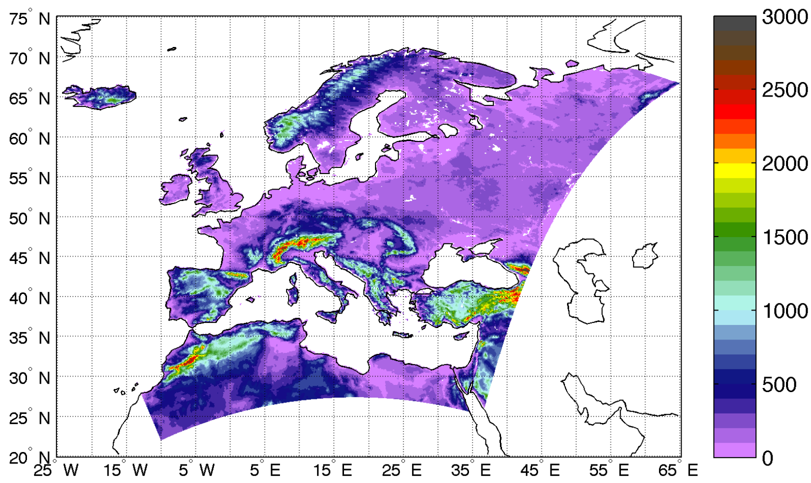

Figure 1 The EURO-CORDEX EUR-11 domain. The figure shows the representation of the orography. Units are [m].

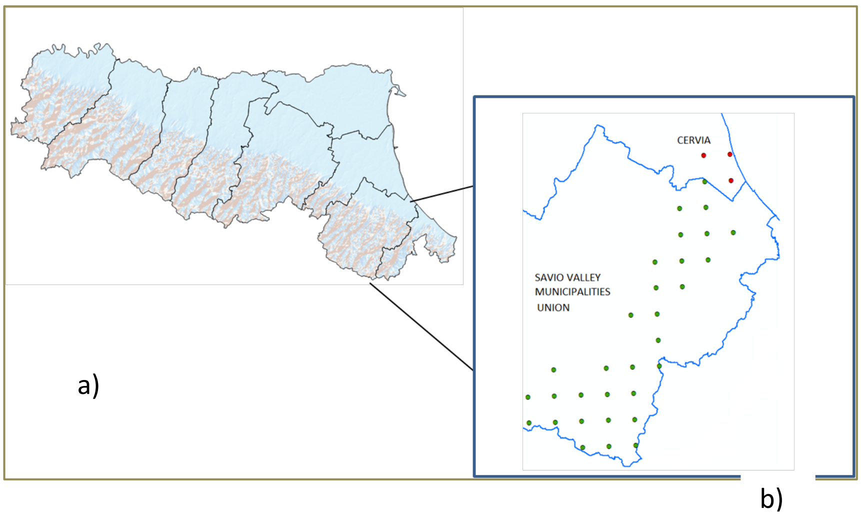

Figure 2 The SDs domain of Emilia-Romagna (a) case studies: Cervıa and Savio Valley municipalities Union (b)

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4 Data availability

Climate parameters (Table 2) and climate derived parameters (Table 4) will be made available for ADRIADAPT partners over the domain shown in figure 3. In addition, present and future changes of the temperature and precipitation indices from Emilia-Romagna case studies, could be available for the grid points with the resolution 5kmx5km(Figure2). Plots and maps of changes over the selected period will be produced and analysed for these areas.

The statistical downscaling model will be also tested in Croatia area, where long time series of climatic data are available.

A reference person for each case study within the ADRIADAPT project, will be in contact with CMCC to define specific requirements and delivery methodology.

The data format used is NetCDF (http://www.unidata.ucar.edu/software/netcdf/). NetCDF is an abstraction that supports a view of data as a collection of self-describing, portable objects that can be accessed through a simple interface. Array values may be accessed directly, without knowing details of how the data are stored. Auxiliary information about the data, such as what units are used, is stored with the data. Generic utilities and application programs can access NetCDF datasets and transform, combine, analyze, or display specified fields of the data.

Any additional data elaboration leading to extreme parameters computation based on the proposed fields listed in table 4, can be discussed. Also, the case study users are supposed to provide the spatial boundaries of the domain, together with few additional information about the kind of information (gridded data or data averaged over the domain) they are interested in.
Despite few cases, data will be made available through the CMCC ftp server (download.cmcc.bo.it – user and password sent privately to the ADRIADAPT partners reference person).

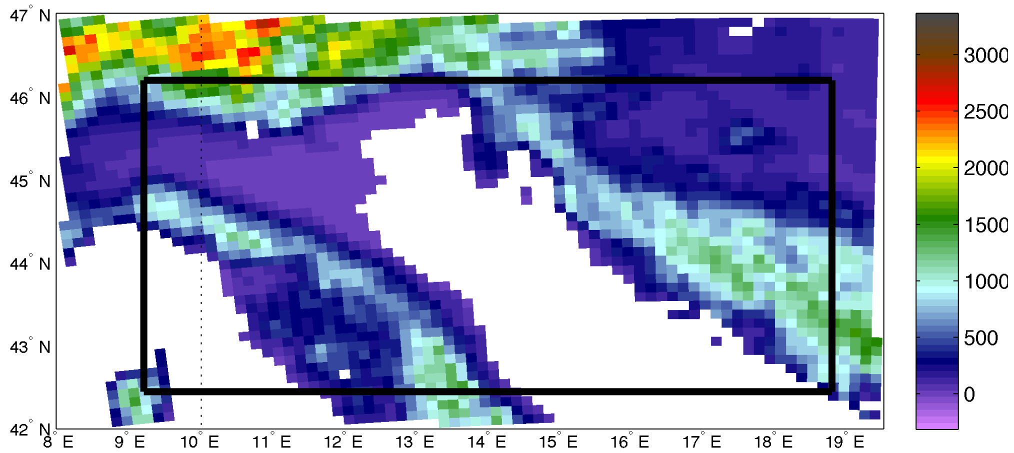

Figure 3: Domain selected (black contour) for the provision of climate (table 2) and extreme (table 4) parameters within ADRIADAPT. Colors represent the local orography (same as Figure 1). Units are [m].

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5 Stakeholder engagement

Extreme events and their impacts on societies have highlighted the need for timely adaptation strategies to changes in their occurrence. To this aim appropriate information about likely changes in event frequency and magnitude on relevant spatiotemporal scales must be provided and tailored on the different impact sites. However, to support robust climate information for decision-making, an effective communication between scientists and stakeholders is crucial (Sippel et al. 2015). In this context, the suggested parameters (Table 3) will serve as a starting point for the internal ADRIADAPT discussion on the definition of indicators useful for the definition of local adaptation strategies to extreme events. The evaluation of return periods over the current climate, together with the provision of future projections of the defined parameters, will help in the definition of the occurrence of environmental conditions suggesting the needs of tailored adaptation strategies over the different ADRIADAPT sites.

It is important to recognize that indicators on extreme environmental conditions must be presented in such a way as to complement the existing information, making it as simple as possible for the stakeholder to assimilate this new information: the ADRIADAPT co-design process will start comparing the parameters listed in the present document to already available indicators as suggested step by step by the different stakeholders over the different sites.

This key aspects of stakeholder engagement, will productively feed back into how extreme event indicators will be designed to ensure practical relevance and usefulness for the stakeholder community. As an example, a number of indicators on heat stress conditions is proposed (Table 3), but the choice of the proper one, for a particular site, strongly depends on local vulnerability and already existent adaptation plans: indoor (air-conditioning, building design for natural ventilation, etc.) or outdoor (green and blue infrastructures) adaptation strategies could need different indicators.

Also integrating climate change adaptation into existing local strategic planning mechanisms (a part from the adaptation ones) could be of great impact on the local costs, thus the definition of the final list of extreme events parameters suggested in table 4 will strongly depend on the interaction with local stakeholders.

6 Conclusions

This document provides a description of the climate data that will be delivered by CMCC to the ADRIADAPT project users, covering the period from 1951 to 2100 following two different possible scenarios for the XXI century. High resolution (order of 10 km) meteorological fields (temperature, wind, precipitation among others) will be made available in a common format over the case study domains defined within ADRIADAPT. Based on these fields a series of extreme events indicators at the daily time scale will be identified and suggested. It is important to recognize that indicators on extreme environmental conditions must be presented in such a way as to complement the existing information, making it as simple as possible for the stakeholder to assimilate this new information: the ADRIADAPT co-design process will start comparing the parameters listed in the present document to already available indicators as suggested step by step by the different stakeholders over the different sites. A list of 24 predefined parameters characterizing extreme events is provided and will be modified during the project based on local requirements. A set of four Regional Climate Models (RCMs) participating to the EURO CORDEX project on the EUR-11 grid is used to provide these parameters. Additional present and future climate information based on statistical downscaling techniques (Arpae-Simc) applied to global climate models from CMIP5 experiments, will be also available over Italian case studies from Emilia-Romagna, namely Cervia and Savio Valley Municipalities Union.

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We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed in Table 3 of this document) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

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