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Climate risk for economic activities of the Province of Belluno (NE Italy). I. Climate-related hazard assessment

edited by
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Carlo Giupponi et al.

1. Foreword

The unprecedented threat of climate change is posing a severe risk for human economic activities, due to the increasing frequency and magnitude of extreme events.

Practitioners in multiple economic sectors, from infrastructural to financial ones, are becoming increasingly more aware of the importance of **climate proofing** in strategic planning and decision-making, to cope with **climate risk**.

Essential information for climate proofing is the assessment of risk to exposed receptors, considering their vulnerability to climate hazards (e.g. floods, heat waves, etc.) in the different combinations of environmental and socio-economic features, within the so-called social-ecological system.

The dimensions of risk to be considered, according to the IPCC (2012) definitions are:

- **Hazard**, i.e. "*the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources*";
- **Exposure**, defined as the presence of receptors, i.e. "*people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected*" by hazard events;
- **Vulnerability,** i.e. "*the propensity or predisposition to be adversely affected*" by hazard events.

In the Alpine Region, climate change has already shown remarkable effects in terms of temperature rise (2 °C over the last 120 years) at a pace that is as much as twice the global average, with dramatic consequences in terms of glacier retreat and disappearance.

Future projections confirm the past trend and foresee further effects on temperature, seasonality of precipitation, global radiation, relative humidity and frequency/intensity of extreme precipitation and floods (Gobiet et al., 2014). The limited accessibility of mountain areas, due to harsh geomorphological gradients, may exacerbate consequences of extreme events, for example when damaged connections between settlements prevents or slows down the recovery from critical situations.

Recent extreme events in the Belluno Province (eastern Alps at the border between Italy and Austria), such as the disastrous Vaia storm in 2018, provide further evidence of the importance of climate proofing in spatial planning to cope with adverse effects climate change for ordinary and extraordinary management of infrastructures and to grant access to essential public services, i.e. water, electric power, etc.

This working paper presents the first part of results on climate hazards assessment of a collaborative project between Venice International University (VIU), the Foundation Euro-Mediterranean Centre on Climate Change (CMCC) and Ca' Foscari University of Venice, with the scientific and financial support of Enel Foundation.

The main aim of the project was the assessment of multiple risks from climate hazards in the Belluno Province in Italy (south-eastern Alps). The approach adopted herein derives from the **Socio-Economic Regional Risk Assessment** (**SERRA**) method developed by the EU Kulturisk Project (Giupponi et al., 2015). This integrated approach combines accurate spatial risk assessment with socio-economic analysis and evaluation, to estimate the potential damages associated with risks of different kind and magnitude. These features made it suitable for the assessment of four key economic sectors of the Belluno Province: summer tourism, the eyewear industry, electricity distribution and winter sports and events.

As previously reported, the **SERRA integrated approach** combines classical spatial risk assessment with socio-economic analysis, enabling the estimation of the damages associated with potential risks of different types and entities (see **Errore. L'origine riferimento non è stata trovata.**), based on the following sequence of steps (Mojtahed et al. 2013):

1. qualitative and quantitative description of the hazards;
2. identification and description of the environment subject to the hazards considered (e.g. urban areas, ecosystems, infrastructures);
3. selection of receptors exposed directly and indirectly to hazards (residential buildings, industrial areas, warehouses, retailers, people, infrastructures, vehicles, etc.);

4. identification of the spatial characteristics of susceptibility, coping and adaptive capacities mapped by means of indicators which are subsequently aggregated into a vulnerability index for each type of receptor;
5. identification of the set of value factors for exposed receptors and their indirect correlations;
6. calculation of the risk from the previous steps;
7. designation of the risk of receptors in the quadrants of the Total Cost Matrix.

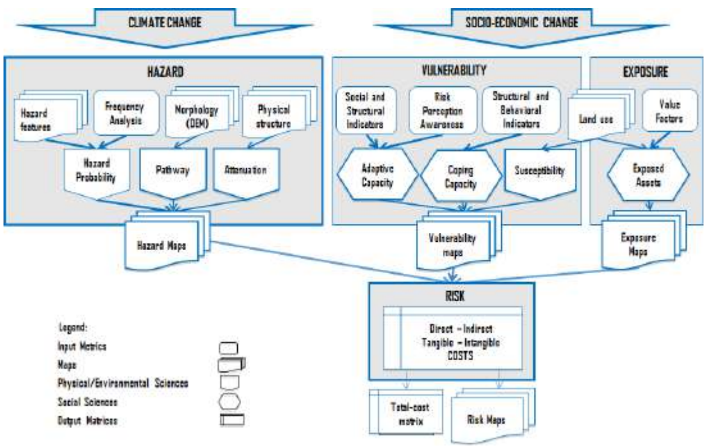

fig. 1
General flow-chart of the SERRA methodological framework for risk assessment

This climate hazard evaluation is based on use of a different high-resolution regional climate models (RCMs) available over the area of interest. Moreover, it involves the use of specific spatial indicators tailored on the local characteristics of the area and on the hazards to be analysed. Such approach follows the conceptual framework proposed by the Intergovernmental Panel on Climate Change (IPCC) in the fifth Assessment Report which, in turn, is in line with the prevailing literature on risk reduction (Disaster Risk Reduction - DRR) (IPCC 2012; 2014b). According to that framework, the three dimensions of risk previously defined (Hazard, Exposure and Vulnerability) are quantified by means of case specific indicators from which the sectoral climate risk indexes are calculated and mapped. This index-based approach is widely used in the literature, furthermore it has been adopted within the Italian National Plan for Adaptation to Climate Change (MATTM, 2017).

The **climate risk indexes** are quantified on the basis of the general formula:

$$Risk = f(Hazard, Exposure, Vulnerability)$$

In this work, the general formula has been implemented with a combination of multiplicative and multi-criteria operators adapted to the four sectors assessed.

The analysis of multiple risks, multiple receptors and multiple climate scenarios generates a huge number of possible combinations. The current work has opted for a statistical approach, aimed at providing both synthesis by means of averaged results and maps of risk, and also extensive documentation of the various sources of uncertainty and their effects on final results. Therefore, the results are presented as sets of maps (and related statistical summaries), focused on highlighting the diversity of situations within the study area, taking due account of the uncertainty deriving from the different data sources considered, such as the multiplicity of possible future scenarios.

This issue of VIU WPs reports on the results of the assessment of climate hazards, while a following WP will present the analysis of the exposure of economic activities and vulnerability of local socio-ecosystems and the analysis of climate-related risks. The third WP of this series will report on a demonstration study for climate-proofed solutions for local development.

2. Main elements for climate hazard assessment

The climate hazards are defined on the basis of a selection of **indicators** defining the expected change of specific weather extreme characteristic (mainly frequency and magnitude) and on the **probability** that intense phenomena will occur within fixed time frames, known as return periods (Reder et al; 2018). Then, the climate hazards are combined with physical and structural factors of the exposed assets (exposure) and the local socio-economic factors (vulnerability) through mathematical relationships that express the relative damage of exposed assets as a function of the magnitude of various extreme events. In this perspective, it should be noted that the choice of relevant extreme climate events of interest for risk assessment should depend upon the exposed receptors. For example, extreme precipitation events can generate floods and thus damages on tourism lodging facilities. These events can lead to diverse impacts and problems, depending on the nature of the emergency. Damages from climate events could be both direct on structural assets, such as flooded hotels, because of the accumulation of heavy rains, and indirect losses, such as interruptions of the road network impeding the accessibility of production sites. In addition to short-term damages, events might have long-term economic impacts, for instance permanently affecting the viability of structures or infrastructures, or indirectly affecting the tourist attractiveness of a certain area.

The index-based approach, used for climate hazard evolution assessment, is largely used in the literature for supporting the assessment of local impacts and the evaluation of risk, as well as for defining tailored adaptation strategies (EEA 2009; 2018; Mysiak et al., 2018).

Accounting for the indicators considered, it is important to highlight that there is not a unique definition of "extreme" since it can describe either a characteristic of a climate variable or that of an impact (Stephenson, 2008). In the case of a variable related to weather or climate (e.g. temperature or precipitation), an extreme can be defined as a value located in the tails of the distribution of the variables, occurring infrequently. It is generally agreed that extreme events are those exceeding two standard deviations in long term observational series (Kislov and Krenke, 2009).

In the case of a specific impact, it is more difficult to define the extreme, since generally there is not a unique way to quantify it. The IPCC Assessment Report 4 (IPCC, 2007) defines an extreme climate event as one that is rare within its statistical reference distribution at a place and time. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed Probability Density Function (PDF).

By definition, the characteristics of what is called "extreme weather" may vary from place to place. One single extreme event cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance that the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g. drought or heavy precipitation over a season). The IPCC Special Report on "Managing the risks of extreme events" defines an extreme as the occurrence of a value of a variable above or below a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC, 2012).

The concept of "extreme" is also particularly important for the design of infrastructures. Indeed, these ones are generally built under the hypothesis that climate is stationary, meaning that physical variables could vary from day to day, but always around an unchanging mean state. Information about weather extreme values on a specific area is generally taken from historical series: in particular, percentiles corresponding to predetermined return periods in the historical sample are generally considered the normative value for design. However, this approach could be no longer adequate, since it is evident that climate change is unequivocal and will alter the mean, variability and extreme values. The warming of the climate system in the recent decades is evident from observations and it is mainly related to the increase of anthropogenic greenhouse gas concentrations (IPCC, 2012). Therefore, also precipitation will be altered, since a warmer atmosphere will hold more water vapour, resulting in heavier rains or, on the other side, in severe droughts due to larger water absorption from soil and vegetation. In the same way, other atmospheric variables, such as wind and snowfall, are expected to change their patterns (Croce et al., 2018). A changing climate may lead to changes in the frequency, intensity, spatial extent, duration and timing of weather and climate extremes.

Climate change is usually assessed in terms of average climate properties rather than on variability or extremes, but often the latter ones have more impact on the society than averages values (Katz and Brown, 1992). As climate extremes will change, it is likely that risks for infrastructure failure will increase worldwide, since extreme weather conditions become more variable and regionally more intense.

In order to assess the hazard, two kinds of indicators have been defined in the present activities. The **descriptive indices developed by ETCCDI** refer to moderate extremes that typically occur several times every year and they have been used in the first task of the activities to provide a general overview of the expected extreme climate change over the Belluno area. On the other side, but complementary, **intensity and frequency of rare events**, in terms of percentiles and return values, are evaluated by means of the well-known Extreme Value Analysis, and specifically relying on the Generalized Extreme Value (GEV) probability model. Such values are particularly appreciated for risk analysis because they allow, for example, for the quantification of expected variations (e.g. reduction) in the frequency of extreme events that currently occur once in a given period, typically 50- and 100- years. The so obtained wide selection of climate indicators (see the following chapter), allowed for the estimation of **climate variation for all the extremes of interest.**

For the present case, return values are estimated using datasets of 30 years, and resulting variations due to climate change are referred to this timescale. It is worth noting that sample size (in this case 30 years) deeply affects the reliability of the so estimated return values. As highlighted in Table 1, the larger the sample size, the narrower the uncertainty band, the higher the reliability of the estimation.

Table 1 Length of data record versus expected error rate for statistical calculation

Return period (years)	± 10% error level (years of record)	± 25% error level (years of record)
10	90	18
25	105	31
50	110	39
100	115	48

In order to capture the real spatial variability of the atmospheric patterns, analysis were performed by using high-resolution climate scenarios considering different IPCC scenarios.

Climate scenarios are defined by accounting for different Representative Concentration Pathways (RCPs), which represent future trajectories of concentrations of the full suite of greenhouse gases (GHGs), aerosols and chemically active gases (Moss et al., 2008). In this study, the analysis of the climate variations has been carried out by considering the RCP4.5 and RCP8.5 scenarios and, when available, the RCP2.6 scenario. Specifically, RCP4.5 represents an intermediate stabilization pathway for which substantial emission reductions are expected by the end of the century. On the contrary, RCP8.5 represents a very high concentration pathway, for which very high emissions are expected to continue without the implementation of mitigation strategies; this scenario is also known as "business as usual". RCP8.5 is considered the worst-case scenario, whereas RCP4.5 is more optimistic. Finally, RCP2.6 is a relatively optimistic scenario predicting that, by the year 2100, the GHGs concentration will be only a little higher than today.

In general, climate projections are provided by Global Climate Models (GCMs), which can simulate the response of the global climate system to external forcing for both historical (reference) and future (projections) periods with a resolution of about 50-100 km. Nevertheless, in order to capture smaller-scale extreme events, modelled climate data needs to be downscaled in time and space. One of the most effective tools developed for providing high-resolution climate analysis, physically consistent on a selected geographical area, is the dynamical downscaling method represented by Regional Climate Models (RCMs), which allow for a better description of climate variability at the local scale. The results of RCMs are often used to evaluate local impacts of climate change, since their improved resolution is more compatible with the physical scale of environmental impacts than GCMs.

In this study, climate indices and related variations are calculated based on the data simulated by the following RCMs:

- COSMO-CLM regional model (Bucchignani et al., 2016; Zollo et al., 2016) with the specific configuration developed by CMCC over Italy. It covers the Italian territory with a spatial resolution of about 8 km. Climate simulations are available from 1971 to 2100 under two IPCC scenarios (RCP4.5 and RCP8.5); This model has been adopted by a large number of private and public institutions in Italy for hazard and adaption analysis.
- EURO-CORDEX regional models (Jacob et al., 2014, Jacob et al.,2020). The models, developed under the EURO-CORDEX program, cover all the European territory with a spatial resolution of about 12 km. Climate simulations are available from 1971 to 2100 under three IPCC scenarios (RCP2.6, RCP4.5, RCP8.5).
  EURO-CORDEX is the European branch of the international CORDEX initiative (https://www.euro-cordex.net/).), which is a worldwide program sponsored by the World Climate Research Program (WRCP). This program aims to organize an internationally coordinated framework in order to produce improved regional climate change projections for all land regions world-wide. Further specific information about the EURO-CORDEX data is provided in Hennemuth et al. (2017). Climate data used in this study are based on the ensemble of the results of 18 models for scenarios RCP4.5 and RCP8.5 and 11 models for RCP2.6.

About the use of the EURO-CORDEX models, it is important to highlight that the use of an ensemble of regional climate models allows evaluating the ensemble mean (the more robust representation of climate change under a probabilistic interpretation) and the distribution of the different single models, building the ensemble, around the ensemble mean (Tebaldi et al., 2005). This distribution is the result of different layers of uncertainty that can be grouped into three major categories: (i) scenario uncertainty, (ii) internal climate variability and (iii) model uncertainty (Hawkins and Sutton, 2009, 2011). In order to quantify the uncertainty of the ensemble, the variability between EURO-CORDEX models is expressed by the standard deviation of the ensemble of all models (Von Trentini et al., 2019), computed at the grid-point level.

Results coming from the analysis of climate models are adopted to provide data and maps of the climate variations for a number of relevant indicators for the definition of the expected local climate conditions, achieving the main objectives of Task 1. The climate variations are evaluated over two 30-year periods centred on 2026 (the year of the Olympic games of Milan and Cortina) and 2050 (2012-2041 and 2036-2065, respectively) and for two different climate scenarios (RCP 4.5 and 8.5), according to the IPCC's fifth assessment report (AR5; 2014a). In order to harmonize the horizontal resolution of the current climate data (about 10 km) with the usually reduced scale of impacts, further statistical downscaling, when necessary, is performed based on the availability of observational data covering the area of Belluno, morphological information of the areas (such as elevation), and relevant specific documentation available at ARPA VENETO.

3. Local climate-related hazard assessment

Work Package 1 (WP1) is aimed at assessing climate-related hazards and their expected future evolution (in terms of spatial and temporal occurrence) because of climate change in the Belluno area (North-eastern Italy).

WP1 comprises two Tasks. The activities carried out in Task 1 are aimed at characterizing the current local climate conditions and providing a database of maps on the expected effects of climate change. To this scope, a number of indices/indicators has been identified and evaluated allowing a general characterization of the variation of climate-related hazards potentially affecting the investigated area. The produced data and maps provide a general description of local climate change scenarios which, in the last phase of the project, will be included in the platform DATACLIME (www.dataclime.com) developed by CMCC Foundation by consulting the climate service “Visualize climate data - Province of Belluno” (available only after registration and after specific permission of Enel Foundation). Task 2 is aimed at supporting the comprehensive risk analysis for the investigated area. The activities of Task 2 represent the first step of the procedure defined, in collaboration with VIU, to evaluate climate-related risks for the area of Belluno, accounting for four identified economic sectors (**summer tourism, eyewear industry, electricity distribution, winter sports and events**), which are of paramount importance for the local economy. The climate-related hazard assessment here proposed is therefore carried out with the goal of providing suitable data for the evaluation of the hazard component to be used in the comprehensive risk analysis procedure.

In the following paragraphs, more details concerning these two Tasks are reported.

3.1 Task 1: General evaluation of the expected local climate change conditions

The assessment of potential hazards related to climate change is provided by the selection of suitable and relevant climate indicators. The first step of this procedure requires the identification of climate-related hazard events (hazardous events) that can affect the relevant economic sectors of the investigated area.

Specifically, based on the classification adopted in the International Disaster Database (EM-DAT - https://www.emdat.be/classification), where hazardous events are classified as "main type" and "sub-type", the following events have been selected for the area of Belluno:

- Storm – snowstorm, rainstorm, windstorm, thunderstorm;
- Extreme temperature – cold wave, heatwave, temperature decreasing (in winter) and temperature increasing (in summer);
- Flood – river flood, flash and torrential flood;
- Mass movement – landslide and rock fall, mudslide and debris flow, snow avalanche;
- Wildfire – forest fire, land-fire (brush, bush, pasture).

Furthermore, taking into account a specific user requirement, wet snow events have been included in the list of the potentially hazardous events to be considered. This kind of events may negatively impact different local economic sectors. The most relevant consequence of a wet snow event is related to the accumulation of snow on cables that may affect power lines causing the interruption of power distribution (Bonelli et al., 2011; Llasat et al., 2014). In addition, intense wet snow events can affect transports and limit the accessibility to tourism and recreational destinations as well as workplaces.

Most of the climate indices used in this study are defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (Silliman et al., 2013a,b), which can be calculated by using temperature and precipitation data. These indices are integrated with those proposed in the framework of the European Climate Assessment & Dataset project (ECA&D), whose calculation accounts for data such as wind, precipitation (rain and snow), temperature, cloudiness, radiation, and pressure. Additionally, other indicators have been considered based on literature works already adopted by CMCC, for similar scopes, in previous research activities. For the definitions, formulas, and indications on how to calculate the ETCCDI and ECA&D indices, it is possible to consult the following webpages:

- http://etccdi.pacificclimate.org/list_27_indices.shtml
- https://www.ecad.eu/indicesextremes/indicesdictionary.php

For a detailed and complete list of indicators, please consider**Errore. L'origine riferimento non è stata trovata.** 2. All these indices/indicators provide useful information for the analysis of the spatial and temporal evolution of a specific climate-related hazard of interest. Furthermore, in order to highlight the period of the year most affected by a potentially hazardous event, the indices have been analysed on both the annual and seasonal time scale.

Table 2 List of indicators used for the assessment of current and expected climate conditions over the area of Belluno. For each indicator, maps are provided showing expected climate variations for the two future periods taken into account (2012-2041 and 2036-2065 vs 1981-2010).

HAZARDOUS EVENT (SUB-	Indicator Definition and Unit of Measurement	Acronym	Unit of Measurement	Riferimenti
SNOW STORM	**SSA50 (days):** Number of days with surface snow amount >= 50 mm	SSA50	days	ECAD-EU
	SSA500 (days): Number of days with surface snow amount >= 500 mm	SSA500	days	ECAD-EU
	SF99prctile (mm): 99° percentile of snowfall flux	SF99prctile	mm	ECAD-EU
	SFX1DAY (mm): Maximum value of daily snowfall	SFX1DAY	mm	ECAD-EU
	Sfint (mm): Snowfall intensity (mm) - Mean snowfall intensity at days with snowfall > 1 mm	Sfint	mm	ECAD-EU
WETSNOW	**WETSNOW1 (days):** Number of wet snow event (0<TX<1.5 °C and Pr>10 mm) days	WETSNOW	days	Bonelli et al., 2011; Llasat et al., 2014
	WETSNOW2 (days): Number of wet snow event (0<TX<1.5 °C and Pr>10 mm and max wind<5 m/s) days	WETSNOW	days	User Requirement
RAIN STORM	**PRCPTOT (mm):** Total Precipitation - precipitation sum in wet days (days with precipitation greater than or equal to 1 mm)	PRCPOTOT	mm	ETCCDI
	SDII (mm/wet day): simple precipitation intensity index	SDII	mm/wet day	ETCCDI
	RX1DAY (mm): maximun 1-day precipitation amount	RX1DAY	mm	ETCCDI
	RX5DAY (mm): maximun consecutive 5-day precipitation amount	RX5DAY	mm	ETCCDI
	PR95prctile (mm): 95 percentile of precipitation	PR95prctile	mm	Kumar et al, 2020
	PR99prctile (mm): 99 percentile of precipitation	PR99prctile	mm	Kumar et al, 2020
	R10 (days): number of heavy precipitation days - number of days with precipitation greater than or equal to 10 mm	R10	days	ETCCDI
	R20 (days): number of very heavy precipitation days - number of days with precipitation greater than or equal to 20 mm	R20	days	ETCCDI
WIND STORM	**EWS (Extreme Wind Speed)- (m/s):** 98th percentile of daily maximum wind speed	EWS	%	EEA, 2017
	WX1DAY (m/s): Maximum value of daily maximum wind speed	WX1DAY	%	ECAD-EU
THUNDERSTORM	**Thunderstorm index (day):** Pr>10 mm e wind speed max >5 m/s.	Thunderstom index	days	http://www.rse-web.it/applications/webwork/site_r
Winter temperature decreasing	**TNN (°C)**: minimun value of daily minimum temperature.	TNN	°C	ETCCDI
	TNX (°C): maximun value of daily minimum temperature	TNX	°C	ETCCDI
	TN10 percentile of minimum temperature (°C).	TN10prctile	°C	Kumar et al, 2020
	ID: Number of ice days (TX<0°C) (days).	ID	days	ETCCDI
Summer temperature increasing	**TX95 percentile** of maximum temperature (°C).	TX95prctile	°C	Kumar et al, 2020
	TX99 percentile of maximum temperature (°C).	TX99prctile	°C	Kumar et al, 2020
	TXX (°C): maximun value of daily maximum temperature	TXX	°C	ETCCDI
	TXN (°C): minimun value of daily maximum temperature	TXN	°C	ETCCDI
COLD WAVE	**CSDI (days):** Cold Spell Duration Index - total number of days per period (annual or seasonal) in which the minimum temperature is less than the 10° percentile* of the minimum temperature in intervals of at least 6 consecutive days.	CSDI	days	ETCCDI
	CFD (days): Consecutive Frost Days - maximum number of consecutive days with minimum temperature less than 0°C.	CFD	days	ETCCDI
	ID: Number of ice days (TX<0°C) (days)	ID	days	ETCCDI
HEAT WAVE	**HW (days):** Hot Waves - number of days with maximum temperature greater than 35°C	HW	days	ETCCDI
	TX99p (days): Very warm days-time (days)- Days with Tx>99th percentile of daily maximum temperature calculated for a 5 day window centred on each calendar day of the reference period (1971-2000)	TX99p	days	ETCCDI
	WSDI (days): Warm Spell Duration Index - total number of days per period (annual or seasonal) in which the maximum temperature is greater than the 90° percentile* of the maximum temperature in intervals of at least 6 consecutive days	WSDI	days	ETCCDI
	Humidex (days): measure of perceived heat that results from the combined effect of excessive humidity and high temperature.	Humidex	days	Masterton and Richardson, 1979
	WD: Number of warm (Tg>75th percentile) - dry (Pr≤25th percentile) days (days).			ECAD-EU
River flood, Flash and torrential flood, Landslide and rockfall, Mudslide and debris flow	**PRCPTOT (mm):** Total Precipitation - precipitation sum in wet days	PRCPTOT	mm	ETCCDI
	SDII (mm/wet day): simple pricipitation intensity index.	SDII	mm/wet day	ETCCDI
	RX1DAY (mm): maximun 1-day precipitation amount	RX1DAY	mm	ETCCDI
	RX5DAY (mm): maximun consecutive 5-day precipitation amount	RX5DAY	mm	ETCCDI
	PR95prctile (mm): 95 percentile of precipitation	PR95prctile	mm	Kumar et al, 2020
	PR99prctile (mm): 99 percentile of precipitation	PR99prctile	mm	Kumar et al, 2020
	R10 (days): number of heavy precipitation days - number of days with precipitation greater than or equal to 10 mm.	R10	days	ETCCDI
	R20 (days): number of very heavy precipitation days - number of days with precipitation greater than or equal to 20 mm	R20	days	ETCCDI
Snow avalanche	**SAI200 (days)**: number of day with H72>200mm and Tmean >0°C	SAI200	days	
	SAI100(days): number of day with H72>100mm and Tmean >0°C	SAI100	days	Wilhelm, 1975; Bocchiola and Medagliani, 2007
Forest and Land Fire	**CDD (days)**: Consecutive Dry Days - largest number of consecutive days with precipitation less than 1 mm	CDD	days	ECAD-EU
	Maximum Temperature (°C): mean of daily maximum temperature	Tx	°C	ETCCDI
	HW (days): Hot Waves - number of days with maximum temperature	HW	days	ETCCDI
	WD: Number of warm (Tg>75th percentile) - dry (Pr≤25th percentile) d	WD	days	ETCCDI
	FWI (days): Fire Weather Index (max wind speed)	FWI	days	Van Wagner, 1987

Some general considerations about the indicators reported in Table 2:

- The Cold Spell Duration Index (CSDI) and the Warm Spell Duration Index (WSDI) are evaluated taking into account the 10^{th} and 90^{th} percentile, respectively, estimated for the period 1971-2000.
- For the heatwave events, it is worth noting that there is no unique definition since they are, in general, evaluated to highlight the effect of temperature increase on a specific sector of interest (such as human health) (Pasqui and Di Giuseppe, 2019). Based on the indications provided by the ETCCDI, a heatwave event is defined as the occurrence of at least six sequential days with maximum daily temperature above the corresponding daily threshold value at the 90^{th} percentile estimated on the period 1971-2000; this is the WSDI indicator. Furthermore, for the heatwave another indicator has also been considered, provided by the European Environment Agency (EEA, 2018): this indicator (HW) evaluates the days with the maximum daily temperature higher than 35°C, which represents a limit value for the well-being of human health. Additionally, following specific user requirements, another indicator has been added, labelled as TX99p, concerning the number of days with a daily maximum temperature higher than the 99^{th} percentile of the maximum daily temperature calculated for a 5 day-window centred on each calendar day of the period 1971-2000.
- Differently from the wind storm indices, which take into account wind speed only (in terms of 98^{th} percentile and maximum daily values compared to the reference period 1981-2010 and expressed as a percentage of variation), the thunderstorm indices consider the combined occurrence of intense wind (expressed considering either the mean or the maximum daily value) and precipitation events.
- From the literature review, it results that a wet snow event can occur under two conditions: i) the maximum daily temperature is in the range 0-1.5°C and, ii) the daily precipitation is higher than 10 mm. Based on this definition, the wet snow indicator (Wetsnow_01) has been proposed. Furthermore, accounting for a specific user requirement, a second indicator has been evaluated (Wetsnow_02) also considering wind intensity (<5m/s).

After the identification of the indicators for all the considered economic sectors, climate variations are evaluated based on both the

RCMs COSMO-CLM data and EURO-CORDEX models' ensemble mean. Additionally, in order to provide information on the value of these indicators under current climate conditions, the same climate indices have been also calculated based on observational data collected at *in situ* stations and made available by ENEL Distribution and ARPA VENETO over the reference climate period 1981-2010. Information on the analysis performed with observations is reported in the last part of the document.

By definition, climate variations are calculated as the comparison between the value of the selected climate index for the future period and the value of the climate index for the historical period (1981-2010), as provided by the considered climate model. Specifically, two future periods (2012-2041 and 2036-2065) under different concentration scenarios proposed by the IPCC in the Fifth Assessment Report (AR5; IPCC, 2014a) have been considered in this activity.

Typical results provided by climate data analysis are reported in the next pictures. For example, in **Errore. L'origine riferimento non è stata trovata.**2 the ensemble of climate variations of the maximum 1-day precipitation amount (RX1DAY) expected for the period 2036-2065 with reference period 1981-2010 under concentration scenario RCP4.5 is shown. In this case, there is a higher variability in the South-East parts of the area of interest, where there is also an increase of the maximum 1-day precipitation amount. F**Errore. L'origine riferimento non è stata trovata.** is a typical representation of results obtained by using an ensemble of climate projections.

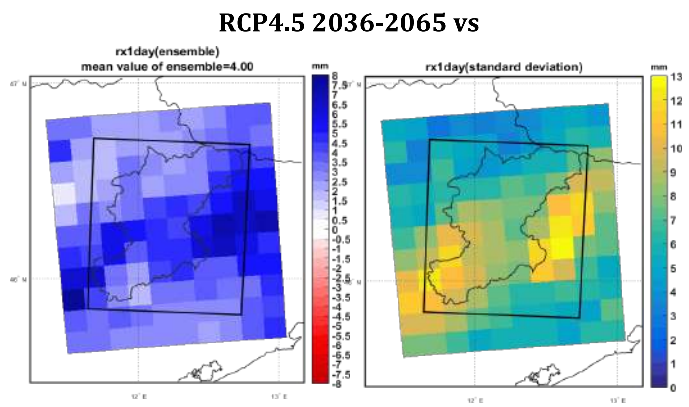

fig. 2
(left) Annual maximum 1-day precipitation amount anomaly provided by the EURO CORDEX-11 multi-model ensemble mean for RCP4.5 scenario over 2036–2065 period compared to 1981–2010. (right) the standard deviation of the maximum 1-day precipitation amount variations of all models in each ensemble for the future period 2036-2065.

Additionally, another typical way to report the results of an ensemble analysis, for each climate indicator, is to evaluate the spatial mean value of the multi-model ensemble variation over the area of interest together with a measure of the uncertainty, which can be evaluated following different metrics (e.g. percentiles, standard deviation) starting from the spatial mean value of variation of each model. An example of this analysis, for TR20 maximum daily precipitation, is reported in the table 3.

Table 3 Ensemble mean (first row) for TR20 maximum daily precipitation and evaluation of uncertainty (2nd, 3rd and 4th rows) starting from the spatial mean value of variations of each model over Belluno area.

	RCP4.5		RCP8.5	
	2012-2041 vs 1981-2010	2036- 2065 vs 1981-2010	2012-2041 vs 1981-2010	2036-2065 vs 1981-2010
mean	2%	5%	5%	12%
standard deviation	9%	8%	7%	11%
5° percentile	-7%	-11%	-7%	-9%
95° percentile	20%	17%	17%	29%

Due to the climate model bias (systematic error), it is not possible to evaluate the absolute value of the climate indicators on the selected period but only the variation expected on the future period with respect to the reference climate. However, expected variations can be superimposed to the absolute values of the selected indices/indicators, which can be computed over the historical period by using observational data provided by the Regional Agency for Environmental Protection (ArpaV).

To provide a complete climatology of a specific geographical area, the World Meteorological Organization (WMO) indicates the use of a dataset, for the atmospheric variables of interest, covering at least a 30-year period. However, in order to consider observations-based analysis as a reference for the climate change analysis herein shown, it should cover the period 1981-2010. Unfortunately, the dataset provided by ArpaV does not cover completely the requested period for all the stations and all the variables of interest. For this reason, in Section 3.3 more detailed information on the observational data availability is provided and, based on such information, the different local climatologies are evaluated. It is important to highlight that a shorter length can lead to an underestimation of the more extreme (rare) values of the atmospheric variable distribution.

The results of the index-based analysis, expressed as climate variations expected for the periods 2012-2041 and 2036-2065 with reference period 1981-2010 under the scenarios RCP4.5 and RCP8.5 (and RCP2.6 for the EURO-CORDEX models), are calculated for each grid point with the same resolution of the climate models but, in general, they are represented as maps.

3.2. Specific hazard assessment for supporting risk analysis

High-resolution hazard assessment is also a fundamental step in the framework for the local climate change risk assessment for specific social and economic sectors, which is the main objective of WP2. To this scope, additional climate indicators have to be evaluated, tailored to specific requirements that emerged during the definition of the comprehensive risk assessment procedure.
The final list of the specific indicators identified in the activity related to wind-, rain-, snow- and warm-related hazard assessment for the economic sectors analysed in this study is reported in **Errore. L'origine riferimento non è stata trovata.** Table 4. These indicators also take into account the user's requirements that emerged during a number of project's meetings. Finally, the indicators have been selected by considering the following economic sectors:

Summer tourism: The hazardous events of interest for this sector are **extreme precipitation events** that can generate flooding phenomena and damage buildings and infrastructure. These events can lead to inconveniences and safety problems linked to the nature of the emergency (for example, temporarily limiting the accessibility of the civil protection bodies or tourists themselves to the accommodation facilities in the area) and long-term economic impacts (direct impacts on the viability of the structures or indirect effects on the tourist attractiveness of a certain area). In particular, the climate hazard refers to extreme precipitation that occurs in the summer season with a return period of 100 years.

Winter sports and events: The hazardous events of interest for this sector are **snow reliability-related events** that can interfere with the development of winter sports, with particular reference to the Winter Olympic Games of Milano-Cortina 2026. In the analysis of the winter sport activities and events sector, the climate hazard refers to the lack of natural snow cover by considering two indicators: (i) snow cover duration (SCD), calculated as the number of days (from November 1th to March 31th of the following year) with snow depth greater than 30 cm, which might decrease in the future because of climate change (Durand et al. 2009; Marcolini et al. 2017); (ii) snow production days (SPD), calculated as the number of days from November 1st to December 31st with an average temperature lower than -2.5° C. The SPD index has been defined in collaboration with local experts of ARPAV.

Electricity distribution: The hazardous events of interest for this sector are **wet snow events** that can lead to the formation of **ice sleeves**, due to the combination of specific temperature and wind conditions (moderate winds, snowfall and temperatures that favour the accumulation of wet snow).

Eyewear industry: The hazardous events of interest for this sector are **extreme windstorm and precipitation events** characterized by an intensity that can generate landslide and flooding phenomena, potentially limiting the accessibility to production plants. These events can lead to long-term economic impacts, i.e. indirect effects on economic activities of eyewear industries.

As defined in collaboration with the project's team, the hazard indicators for risk assessment have been calculated taking into account the values related to defined return periods. In other words, such values can be interpreted as those expected to be exceeded on average once every return period, or with a probability of 1/(return time period) (Vezzoli et al., 2012).

In detail, **accounting for the daily time series**, the indicators related with the **wind speed** (i.e. the daily maximum speed expressed in m/s) and **precipitation intensity** (i.e. the daily total amount of rain expressed in mm) are evaluated by considering:

- the 90th, 95th, and 99th percentiles of the maximum daily values;
- the percentiles corresponding to the return periods of 20, 50, 100, 150 years (i.e. the 95th, 97.5th, 99th, 99.3th percentiles, respectively) of the annual maxima extracted from the daily series.

Snow-related indicators have been calculated taking into account 20, 50, 100, 150 years (i.e. the 95th, 97.5th, 99th, 99.3th percentiles, respectively) of the annual maxima extracted from the daily series of **snowfall intensity** (i.e. the daily total amount of fallen snow, expressed in mm), **snow amount** (i.e. the amount of snow accumulated on the surface, expressed in cm), and two possible variants of **wet snow indicators**, i.e., wetsnow1 (number of days with 0 < temperature < 1.5 °C and precipitation > 10 mm) and wetsnow2 (number of days with 0 < temperature < 1.5° C, precipitation > 10 mm and maximum wind speed < 5 m/s). The second indicator (hereafter simply referred to as "wet snow") is closer to commonly adopted analyses by electrical companies and is thus adopted for the risk assessment. The analysis focuses on the winter season (December, January, and February) which returns the widest anomaly among all seasons. The analysis is carried out for extreme events with 20, 50, 100 and 150-year return periods but only the 100-year threshold is adopted for risk assessment and mapping, in analogy with the evaluation of the other economic sectors.

It is important to highlight that the so-defined the wet snow indicators do not provide information on the magnitude or intensity of the accounted variable, but rather evaluate the number of events (days) occurring in a constant time interval, namely the year or the four seasonal periods: winter (December-January-February or DJF), spring (March-April-May or MAM), summer (June-July-August or JJA), and autumn (September-October-November or SON). In other words, wet snow events are evaluated in terms of frequency, following a probabilistic approach which does not rely on the GEV probability model but on the Poisson distribution, since the adopted variable is discrete (day with wet snow vs. day without wet snow). For example, the 95th percentile provides the maximum number of wet snow days expected to occur once in 20 years, on average.

In addition to all the above-mentioned indicators, further indicators can also be considered in the framework of the WP5, where specific case studies will be analysed.

All the indicators listed in **Errore. L'origine riferimento non è stata trovata.**4 have been calculated as annual and seasonal variations for the two future periods of analysis 2012-2041 and 2036-2065 (versus the reference period 1981-2010) by means of the EURO-CORDEX simulations (under the RCP2.6, 4.5 and 8.5 scenarios) and COSMO simulations (under the RCP4.5 and 8.5 scenarios). In the case of the snowfall intensity indicator (related with the eyewear industry), the seasonal indicator has been calculated only for DJF and MAM while the snow amount indicator (related with the winter tourism sector) has been calculated only for the winter season. Furthermore, in this last case, the simulations are available only for the EURO-CORDEX models.

Table 4 List of indicators evaluated for each economic sector selected for the hazard evaluation in the framework of the climate risk assessment. The indicators with an asterisk are also reported in table 2, where more details on their definition are reported. It is worth noting that when the indices are calculated from observational data, the daily maximum wind speed value is replaced by the daily wind gust value.

INDICATOR	Summer tourism	Winter Sport and events	Electricity distribution	Eyewear industry
WIND-RELATED INDICATORS				
90th, 95th, 99th percentile for the **daily maximum wind speed (m/s)**	X			
20, 50, 100, 150 yrs return period for the **daily maximum wind speed (m/s)**	X			X
RAIN-RELATED INDICATORS				
90th, 95th, 99th percentile for the **daily precipitation (mm)**	X			
20, 50, 100, 150 yrs return period for the **daily precipitation (mm)**	X			X
SNOW-RELATED INDICATORS				
20, 50, 100, 150 yrs return period for the **daily snowfall intensity (mm)**				X
20, 50, 100, 150 yrs return period for the **daily surface snow amount (cm)**				
Wetsnow_01 (days): number of wet snow event (0<TX<1.5 °C and Pr>10 mm)			X	
Wetsnow_02 (days): number of wet snow event (+ max wind<5m/s)			X	
20, 50, 100, 150 yrs return period for the **wetsnow_01 (days)**			X	
20, 50, 100, 150 yrs return period for the **wetsnow_02 (days)**			X	
20, 50, 100, 150 yrs return period for the **wetsnow_01 (days) - User defined**			X	
20, 50, 100, 150 yrs return period for the **wetsnow _02 (days) - User defined**			X	
SNOW RELIABILITY-RELATED INDICATORS				
Snow cover duration (days)*		X		
Snow production days (days)		X		

Typical results for these analyses are reported in fig. 3; for a detailed explanation of the data reported in the next figures and table, see Table 2.

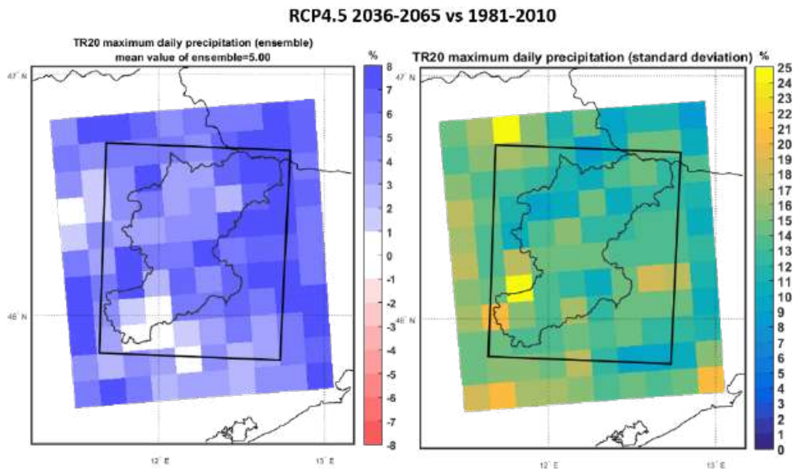

fig. 3
20 years return time period (TR20) of maximum daily precipitation amount anomaly provided by EURO CORDEX-11 multi-model ensemble mean for RCP4.5 scenario over 2036–2065 period compared to 1981–2010; (right) standard deviation of the TR20 maximum daily precipitation variations for the future period 2036-2065.

3.3 Analysis of observed dataset

As previously mentioned, in order to provide information on the current climate condition, a calculation of the climate indicators previously defined has been also performed, based on observational data made available from ARPA VENETO by in situ stations. Specifically, data provided so far concern:

- Daily cumulative precipitation (mm);
- Daily mean temperature at the height of 2 meters(°C);
- Daily maximum temperature at the height of 2 meters(°C);
- Daily minimum temperature at the height of 2 meters(°C);
- Daily mean wind speed and direction at the height of 5 meters(m/s);
- Daily maximum wind speed (based on 10 minutes averaged wind speed) at the height of 5 meter (m/s);
- Daily maximum wind speed (based on wind gust data) at the height of 5 meter (m/s);
- Daily snow depth (mm).

The geographical position of the weather stations available for the Province of Belluno is reported infig.4. Additionally, data concerning daily snow depth (mm) recorded by ARPA VENETO snow stations (geographical position reported infig.5) have also been analysed.

Before performing the climate analysis, the different datasets were subjected to a data completeness test. In order to be coherent with the climate analysis previously performed, the observation reference period is 1981-2010; then the completeness test has been performed on this time period. Specifically, for each year of the reference period 1981-2010 and for each station, the availability of at least 75% of data is checked because the occurrence of missing data can lead to insignificant, strongly distorted and/or even incorrect analysis. Afterwards, the stations with at least 75% of years available out of the reference period were retained for the subsequent climate analyses, with the exception of daily snow depth data where a percentage of 70% was used and of daily wind gust data where a percentage of 67% was used. Two indicators have been defined for the snowfall events: 1) the total snowfall intensity sum (SI) and 2) the maximum value of daily snowfall intensity (SFX1DAY).

Since observational data on the daily amount of fallen snow were not available, the **snowfall intensity indicators** (which are expressed in mm) have been calculated by means of a rough formula that allows to have a general idea of snowfall intensity as the difference between the **surface snow accumulated** in two consecutive days (observed data are available as “snowfall surface amount”). If the difference is negative, no snow has fallen; if the difference is positive, the calculated value corresponds to the amount of snow fallen in one day. This analysis does not consider many important factors, such as density of the snowfall, melting effect and many others; it is only computed to have a very basic idea of snowfall intensity.

Results of the completeness test for each weather station and atmospheric variable are reported respectively in the following tables. In the following pictures, some selected indicators obtained using this dataset are reported.

fig. 4
The geographical position of the ARPA VENETO weather stations available for the Province of Belluno.

fig. 5
The geographical position of the ARPA VENETO snow stations available for the Province of Belluno

Table 5 For each station with daily precipitation data, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**		**27**	**90**
Caprile	**1984-2020**		**27**	**90**
Gares	**1984-2020**	**1984**	**26**	**87**
Sappade Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1998 1999 2000 2002 2003 2004 2005 2006 2007 2008 2009 2010	2	7
Agordo	**1984-2020**	**1984**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2019**	**1984 1989**	**25**	**83**
Sant'Antonio Tortal	1988-2019	1984 1985 1986 1987 1988	22	73
Sospirolo	**1984-2019**	**1984**	**26**	**87**
Passo Falzarego	**1985-2019**	**1984 1985**	**25**	**83**
Faloria	**1984-2019**	**1984 1985 1987 1991**	**23**	**77**
Podestagno (Cortina d'Ampezzo)	**1985-2019**	**1984 1987 1988**	**24**	**80**
Villanova (Borca di Cadore)	**1985-2019**	**1984 1988**	**25**	**83**
Auronzo	**1985-2019**	**1984**	**26**	**87**
Pian del Crep (Val di Zoldo)	1985-2019	1984 1988 1989 1990 1991 1992	21	70
Forno di Zoldo - Campo	**1985-2019**	**1984**	**26**	**87**
Domegge di Cadore	1988-2019	1984 1985 1986 1987 1988	22	73
Cimacanale (Santo Stefano di Cadore)	1997-2019	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Monte Avena	**1985-2019**	**1984 1985**	**25**	**83**
Passo Pordoi	**1985-2019**	**1984**	**26**	**87**
Passo Monte Croce Comelico	**1986-2019**	**1984 1985 1986**	**24**	**80**
Col Indes (Tambre)	**1986-2019**	**1984 1985 1986**	**24**	**80**
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Soffranco	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998	12	40
San Martino d'Alpago	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

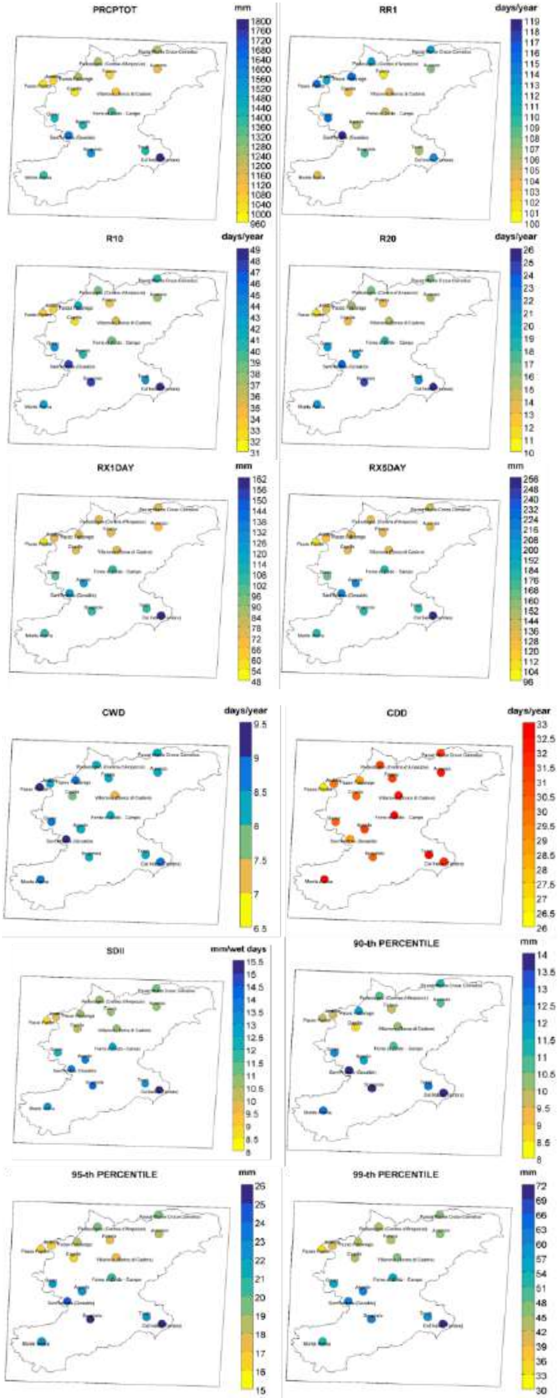

fig. 6
Maps for some selected precipitation extreme indicators (PRCPTOT, RR1, R10, R20, RX1DAY, RX5DAYS, CWD, CDD, SDII, 90° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table2.

Table 6 For each station with daily mean air temperature data at 2m, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**	**1984**	**26**	**87**
Caprile	**1984-2020**	**1984**	**26**	**87**
Malga Ciapela	**1984-2020**	**1984**	**26**	**87**
Gares	**1984-2020**	**1984**	**26**	**87**
Sappade Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 2002 2003 2004 2005 2006 2007 2008 2009 2010	5	17
Agordo	**1984-2020**	**1984**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2019**	**1984**	**26**	**87**
Sant'Antonio Tortal	1988-2019	1984 1985 1986 1987 1988	22	73
Sospirolo	**1984-2019**	**1984**	**26**	**87**
Passo Falzarego	**1985-2019**	**1984 1985**	**25**	**83**
Faloria	**1984-2019**	**1984**	**26**	**87**
Podestagno (Cortina d'Ampezzo)	**1985-2019**	**1984 1988**	**25**	**83**
Villanova (Borca di Cadore)	**1985-2019**	**1984**	**26**	**87**
Auronzo	**1984-2019**	**1984**	**26**	**87**
Pian del Crep (Val di Zoldo)	1985-2019	1984 1988 1989 1990 1991 1992	21	70
Forno di Zoldo - Campo	**1985-2019**	**1984**	**26**	**87**
Domegge di Cadore	1988-2019	1984 1985 1986 1987 1988	22	73
Cimacanale (Santo Stefano di Cadore)	1997-2019	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Monte Avena	**1985-2019**	**1984 1985**	**25**	**83**
Passo Pordoi	**1985-2019**	**1984**	**26**	**87**
Passo Monte Croce Comelico	**1986-2019**	**1984 1985 1986**	**24**	**80**
Col Indes (Tambre)	**1986-2019**	**1984 1985 1986**	**24**	**80**
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Soffranco	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998	12	40
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

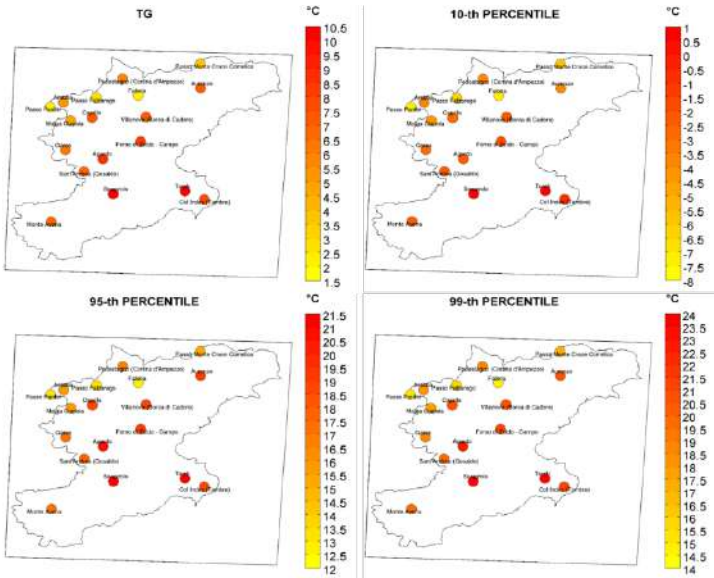

fig. 7
Maps for the climate indicators related to daily mean temperature (TG, 10° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

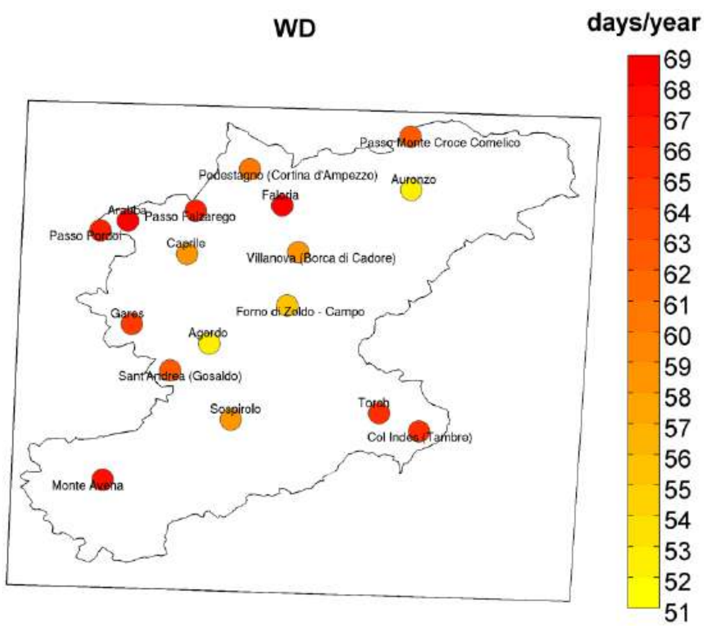

fig. 8
Maps for the climate indicator relating to daily mean temperature and daily precipitation (WD) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicator see Table 2.

Table 7 For each station with daily wind direction data at 5m, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**		**27**	**90**
Caprile	**1984-2020**	**1984 1985**	**25**	**83**
Sappade Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010	4	13
Agordo	**1984-2020**	**2004**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2019**	**1984 1985 1986 1988**	**23**	**77**
Sant'Antonio Tortal	1989-1996	1984 1985 1986 1987 1988 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010	8	27
Sospirolo	1984-2019	1984 1986 2002 2003 2004	22	73
Passo Falzarego	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Faloria	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Villanova (Borca di Cadore)	**1985-2019**	**1984**	**26**	**87**
Auronzo	1990-2019	1984 1985 1986 1987 1988 1989 1990	20	67
Forno di Zoldo - Campo	**1987-2019**	**1984 1985 1986**	**24**	**80**
Santo Stefano di Cadore	**1985-2015**	**1984 1985 1987**	**24**	**80**
Domegge di Cadore	1989-2019	1984 1985 1986 1987 1988	22	73
Monte Avena	1990-2019	1984 1985 1986 1987 1988 1989 1990	20	67
Passo Pordoi	**1986-2019**	**1984 1985 1986**	**24**	**80**
Passo Monte Croce Comelico	1990-2019	1984 1985 1986 1987 1988 1989 1990 1999	19	63
Col Indes (Tambre)	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003	7	23
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

Table 8 For each station with daily mean wind speed data at 5m, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Caprile	**1984-2020**		**27**	**90**
Sappade Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 2002 2003 2004 2005 2006 2007 2008 2009 2010	5	17
Agordo	**1984-2020**	**1984 1985**	**25**	**83**
Sant'Andrea (Gosaldo)	**1984-2019**	**1984 1985**	**25**	**83**
Sant'Antonio Tortal	1989-1996	1984 1985 1986 1987 1988 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010	8	27
Sospirolo	**1984-2019**	**1984 2002 2003 2004**	**23**	**77**
Passo Falzarego	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Faloria	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Villanova (Borca di Cadore)	**1985-2019**	**1984**	**26**	**87**
Auronzo	1990-2019	1984 1985 1986 1987 1988 1989 1990	20	67
Forno di Zoldo - Campo	**1985-2019**	**1984 1989**	**25**	**83**
Domegge di Cadore	1989-2019	1984 1985 1986 1987 1988	22	73
Monte Avena	1990-2019	1984 1985 1986 1987 1988 1989 1990	20	67
Passo Pordoi	**1986-2019**	**1984 1985 1986**	**24**	**80**
Passo Monte Croce Comelico	1990-2019	1984 1985 1986 1987 1988 1989 1990	20	67
Col Indes (Tambre)	1991-2019	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003	7	23
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

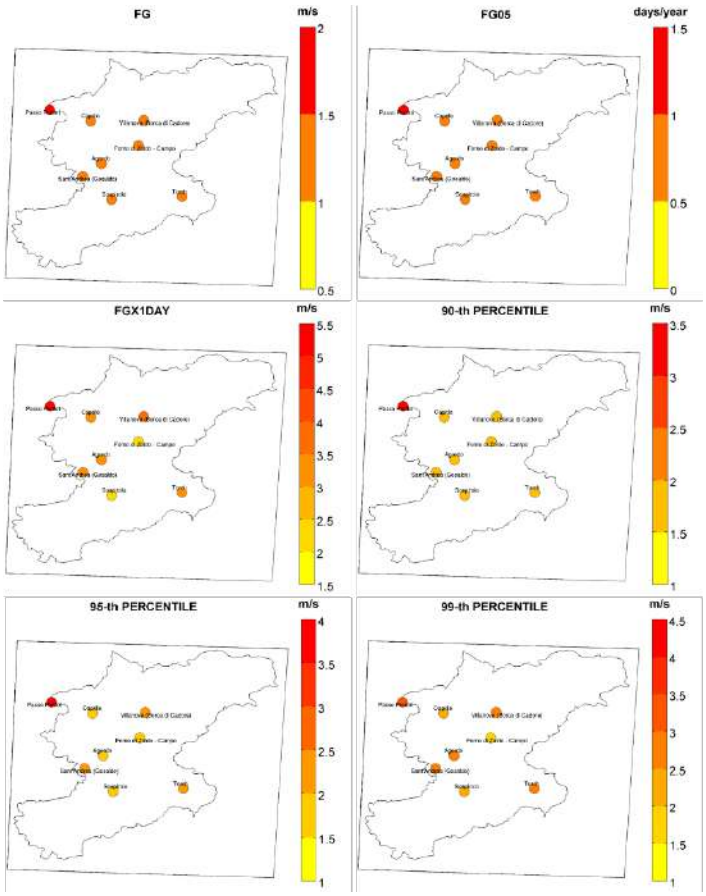

fig. 9
Maps for the climate indicators related to daily mean wind speed (FG, FG05, FGX1DAY, 90° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

Table 9 For each station with daily maximum wind speed data (analysis is based on 10 minute averaged wind intensity values) at 5m, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**	**1983 1985 1989**	**25**	**83**
Caprile	**1984-2020**	**1983 1989**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2020**	**1983 1984 1985 1989**	**24**	**80**
Sospirolo	1983-2020	1983 1984 1989 2002 2003 2004	22	73
Faloria	1984-2020	1983 1984 1985 1986 1987 1988 1989 1990 1991	19	63
Villanova (Borca di Cadore)	**1984-2020**	**1983 1984 1989**	**25**	**83**
Auronzo	1984-2020	1983 1984 1985 1986 1987 1988 1989 1990	20	67
Forno di Zoldo - Campo	**1985-2020**	**1983 1984 1989**	**25**	**83**
Monte Avena	1985-2020	1983 1984 1985 1986 1987 1988 1989 1990	20	67
Passo Pordoi	**1984-2020**	**1983 1984 1985 1986 1989**	**23**	**77**
Passo Monte Croce Comelico	1986-2020	1983 1984 1985 1986 1987 1988 1989 1990	20	67
Col Indes (Tambre)	1986-2020	1983 1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003	7	23
Cortina d'Ampezzo - Gilardon	1992-2020	1983 1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1983 1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

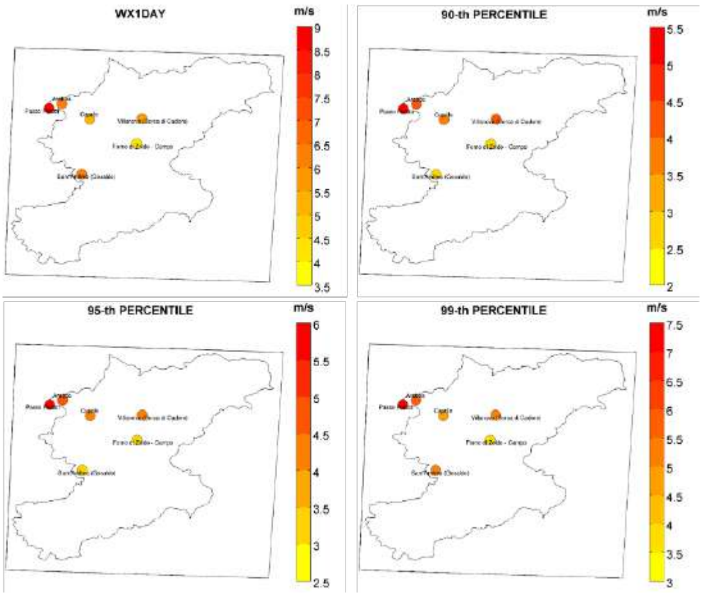

fig. 10
Maps for the climate indicators related to daily maximum wind speed (WX1DAY, 90° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

Table 10 For each station with daily snow depth data, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Monti Alti di Ornella	1985-2019	1985 1986 1987	23	77
Cima Pradazzo	1985-2019	1985 1986 1998	23	77
Col dei Baldi	1985-2019	1985 1986 1996	23	77
Ra Valles	1986-2019	1985 1986 1991 1992	22	73
Faverghera	1988-2019	1985 1986 1987 1988	22	73
Casera Doana	1988-2019	1985 1986 1987 1988	22	73
Malga Losch	1988-2019	1985 1986 1987 1988 1998	21	70
Monte Piana	1989-2019	1985 1986 1987 1988 1989	21	70
Casera Coltrondo	1989-2019	1985 1986 1987 1988 1989	21	70
Casera Palantina	1991-2019	1985 1986 1987 1988 1989 1990 1991	19	63

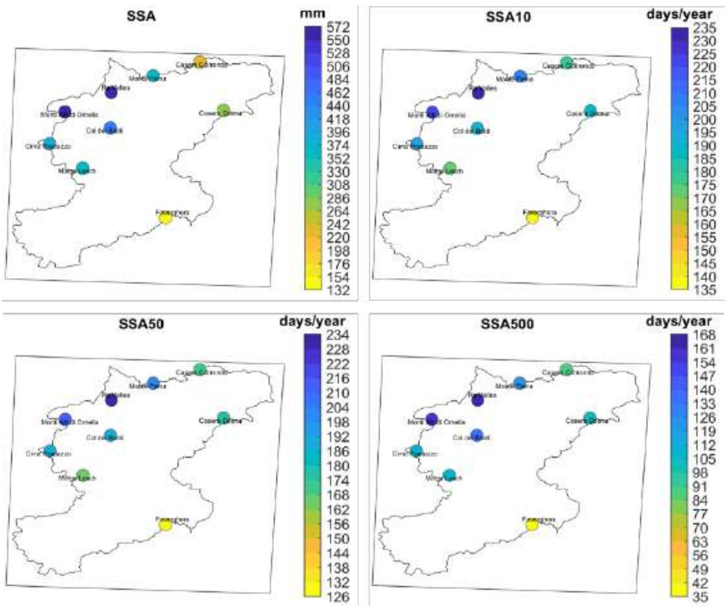

fig. 11
Maps for the climate indicators related to daily snow depth (SSA, SSA10, SSA50, SSA500) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

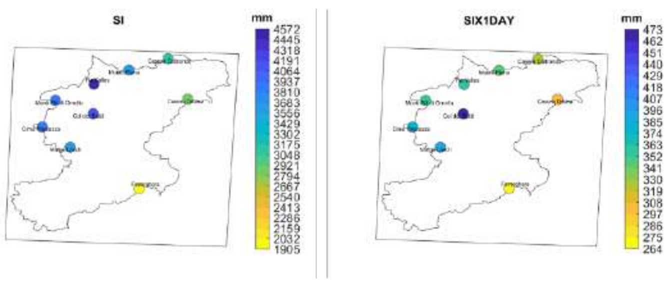

fig. 12
Maps for the climate indicators related to daily snow intensity (estimated as the difference between the surface snow accumulated on two consecutive days) indicator (SI, SIX1DAY), over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

Table 11 For each station with daily maximum air temperature data at 2m, the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**	**1984**	**26**	**87**
Caprile	**1984-2020**	**1984**	**26**	**87**
Malga Ciapela	**1985-2020**	**1984**	**26**	**87**
Gares	**1984-2020**	**1984**	**26**	**87**
Agordo	**1984-2020**	**1984**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2020**	**1984**	**26**	**87**
Sant'Antonio Tortal	1988-2020	1984 1985 1986 1987 1988	22	73
Sospirolo	**1984-2020**	**1984**	**26**	**87**
Passo Falzarego	**1985-2020**	**1984 1985**	**25**	**83**
Faloria	**1984-2020**	**1984**	**26**	**87**
Podestagno (Cortina d'Ampezzo)	**1985-2020**	**1984 1988**	**25**	**83**
Villanova (Borca di Cadore)	**1984-2020**	**1984**	**26**	**87**
Auronzo	**1984-2020**	**1984**	**26**	**87**
Pian del Crep (Val di Zoldo)	1985-2020	1984 1988 1989 1990 1991 1992	21	70
Forno di Zoldo - Campo	**1985-2020**	**1984**	**26**	**87**
Santo Stefano di Cadore	**1984-2020**	**1984 1985**	**25**	**83**
Domegge di Cadore	1988-2020	1984 1985 1986 1987 1988	22	73
Cimacanale (Santo Stefano di Cadore)	1985-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Monte Avena	**1985-2020**	**1984 1985**	**25**	**83**
Passo Pordoi	**1984-2020**	**1984**	**26**	**87**
Passo Monte Croce Comelico	**1986-2020**	**1984 1985 1986**	**24**	**80**
Col Indes (Tambre)	**1986-2020**	**1984 1985 1986**	**24**	**80**
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Soffranco	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998	12	40
San Martino d'Alpago	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Costalta	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

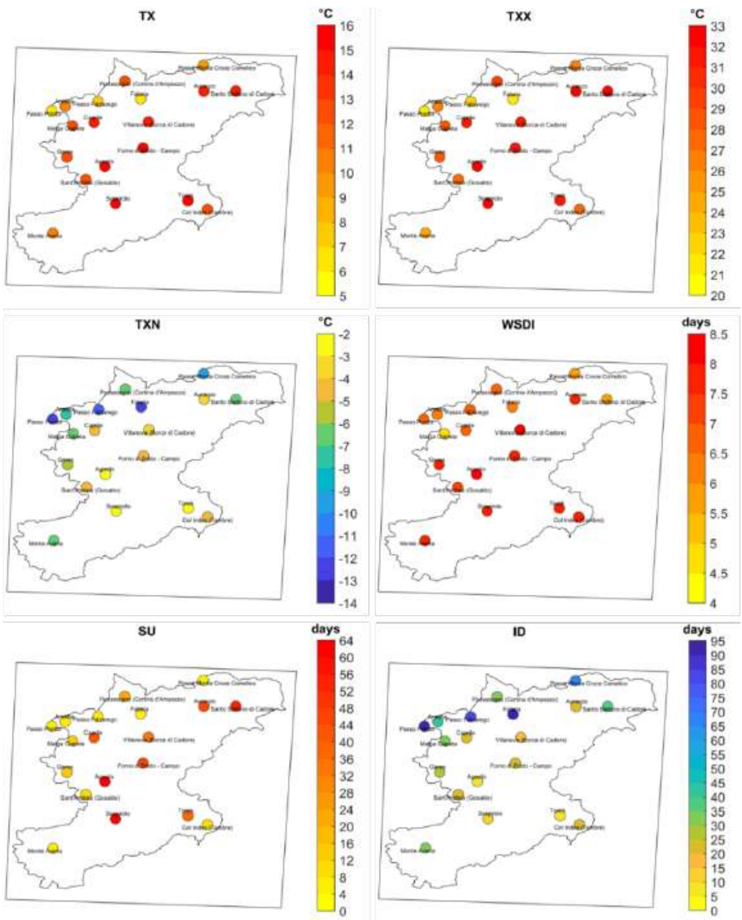

fig. 13
Maps for the climate indicators related to maximum daily temperature (TX, TXX, TXN, WSDI, SU, ID, 10° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see the Table 2.

Table 12 For each station with daily minimum air temperature data at 2m,the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 75%) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**	**1984**	**26**	**87**
Caprile	**1984-2020**	**1984**	**26**	**87**
Malga Ciapela	**1985-2020**	**1984**	**26**	**87**
Gares	**1984-2020**	**1984**	**26**	**87**
Agordo	**1984-2020**	**1984**	**26**	**87**
Sant'Andrea (Gosaldo)	**1984-2020**	**1984**	**26**	**87**
Sant'Antonio Tortal	1988-2020	1984 1985 1986 1987 1988	22	73
Sospirolo	**1984-2020**	**1984**	**26**	**87**
Passo Falzarego	**1985-2020**	**1984 1985**	**25**	**83**
Faloria	**1984-2020**	**1984**	**26**	**87**
Podestagno (Cortina d'Ampezzo)	**1985-2020**	**1984 1988**	**25**	**83**
Villanova (Borca di Cadore)	**1984-2020**	**1984**	**26**	**87**
Auronzo	**1984-2020**	**1984**	**26**	**87**
Pian del Crep (Val di Zoldo)	1985-2020	1984 1988 1989 1990 1991 1992	21	70
Forno di Zoldo - Campo	**1985-2020**	**1984**	**26**	**87**
Santo Stefano di Cadore	**1984-2020**	**1984 1985**	**25**	**83**
Domegge di Cadore	1988-2020	1984 1985 1986 1987 1988	22	73
Cimacanale (Santo Stefano di Cadore)	1985-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Monte Avena	**1985-2020**	**1984 1985**	**25**	**83**
Passo Pordoi	**1984-2020**	**1984**	**26**	**87**
Passo Monte Croce Comelico	**1986-2020**	**1984 1985 1986**	**24**	**80**
Col Indes (Tambre)	**1986-2020**	**1984 1985 1986**	**24**	**80**
Torch	**1986-2020**	**1984 1985 1986**	**24**	**80**
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Soffranco	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998	12	40
San Martino d'Alpago	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Costalta	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

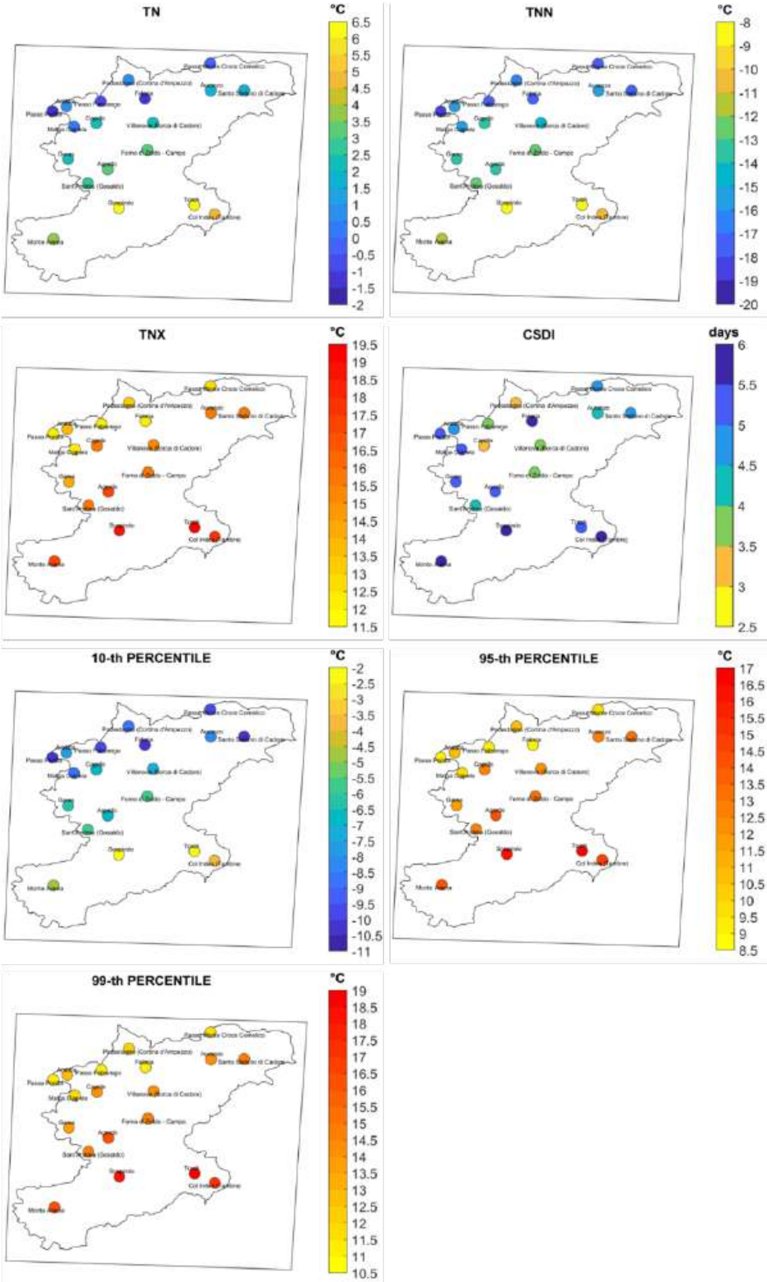

fig. 14
Maps for the climate indicators related to minimum daily temperature (TN, TNN, TNX, CSDI, 10° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see the Table 2.

Table 13 For each station with daily wind gust data at 5m (analysis is based on instantaneous wind intensity values), the following data are indicated: the period in which the data are available (column 2); the years available for the period 1981-2010 in which the dataset does not pass the completeness test (percentage of missing data greater than 25%) (column 3); the total number of years in the 1981-2010 period in which the dataset passes the completeness test (percentage of missing data less than 25%) (column 4); the percentage of years available over the period 1981-2010 (column 5). The lines in bold represent the ARPA Veneto stations that have passed the completeness test (percentage of years available over the 1981-2010 period greater than 66.6%[1]) for the 1981-2010 period.

ARPA Veneto stations	Available period	Invalid years in the period 1981-2010 (percentage of missing data per year greater than 25%)	Number of available years in the period 1981-2010	Completeness (%)
Arabba	**1984-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Caprile	**1984-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Agordo	**1984-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Sant'Andrea (Gosaldo)	**1984-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Sant'Antonio Tortal	1988-2020	1984 1985 1986 1987 1988 1989 1990 1991 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010	5	17
Sospirolo	1984-2020	1984 1985 1986 1987 1988 1989 1990 2002 2003 2004	17	57
Passo Falzarego	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Faloria	1984-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Villanova (Borca di Cadore)	1984-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Auronzo	1984-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Forno di Zoldo - Campo	**1985-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Santo Stefano di Cadore	**1985-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Domegge di Cadore	**1988-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Monte Avena	**1985-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Passo Pordoi	**1986-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Passo Monte Croce Comelico	**1986-2020**	**1984 1985 1986 1987 1988 1989 1990**	**20**	**67**
Col Indes (Tambre)	1986-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Torch	1986-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Sappada	1997-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997	13	43
Longarone	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Lamon - Sala	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Passo Valles	1991-2020	1984 1985 1986 1987 1988 1989 1990 1991	19	63
Cansiglio - Tramedere	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003	7	23
Feltre	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Falcade	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Valle di Cadore	1996-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996	14	47
Cortina d'Ampezzo - Gilardon	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Misurina	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60
Casamazzagno	1992-2020	1984 1985 1986 1987 1988 1989 1990 1991 1992	18	60

[1] In this case, no station passes the completeness test (percentage of years available in the period 1981-2010 greater than 75%). For this reason, the 75% threshold has been reduced to 66.6%, which identifies as complete the stations with at least 20 years in which the data set of each year passes the completeness test (percentage of missing data less than 25%).

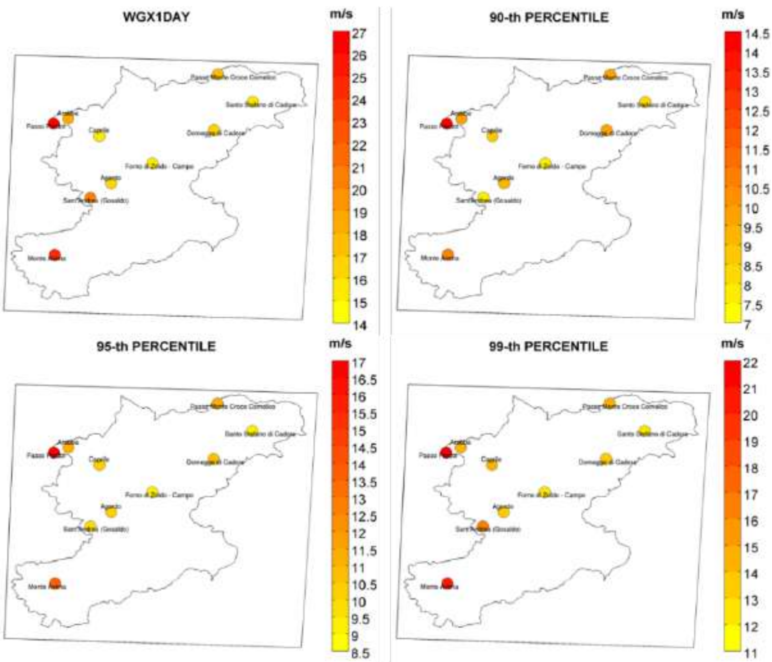

fig. 15
Maps for the climate indicators related to daily wind gust, based on instantaneous wind intensity value, (WG, WG05, WG10, WG15, WG20, WG25, WGX1DAY, 90° PERCENTILE, 95° PERCENTILE, 99° PERCENTILE) over the period 1981-2010 using ARPA Veneto weather stations. For additional details on the definition of the indicators see Table 2.

3.4. Main results of climate analysis

In the framework of the WP1 a climate change analysis has been performed, in terms of evaluation of future variations of climate indicators related to temperature, precipitation and wind, over the investigated domain (Belluno Province). Variations for the selected indicators have been obtained are evaluated based on both the regional climate model RCMs COSMO-CLM data model (Bucchignani et al., 2016) and EURO-CORDEX models' ensemble mean (Jacob et al., 2020).

The selected climate indicators have been evaluated for two future time periods: 2012-2041 and 2036-2065. Each indicator has been calculated for two RCPs scenarios (RCP4.5 and RCP8.5) in order to evaluate climate variations under different scenarios of expected GHGs concentrations. Some of the selected indicators have been considered to perform the following risk analysis (WP2). The full set of all the indicators will be available on the online web-platform (WP6) in form of downloadable tables and maps.

In the following part of the current paragraph, the main results highlighted by the analysis of the COSMO Italy model for the period analysed 2036-2065 under both the evaluated RCP scenarios are reported.

In fig. 16 and fig. 17, the indicators related to the temperature pattern (the TX99p representing the 99th percentile of daily maximum temperature and the TXX representing the maximum annual value of the daily maximum temperature) are represented. In both cases, there is a general expected increase in the high temperature over all the investigated area.

In details, considering the 99th percentile of daily maximum temperature, temperature values are expected to be higher than 3°C in both RCP scenarios, with respect to the reference period (1981-2010); more in detail, considering the RCP8.5, simulations show that these values are expected to increase up to 4°C, especially in the northern part of the investigated domain.

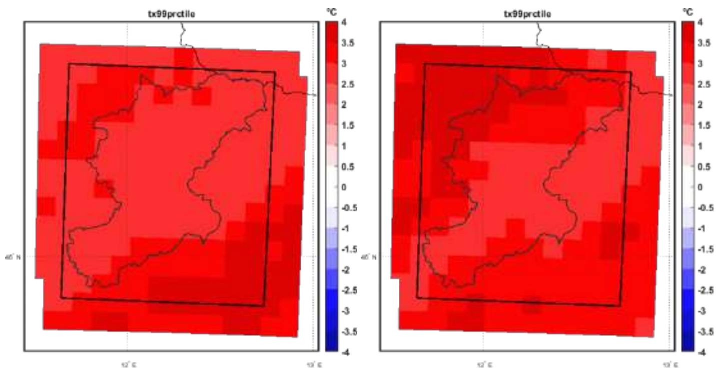

fig. 16
99th percentile of daily maximum temperature (°C) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

Considering the variations expressed by the indicator related to the annual maximum value of daily maximum temperature, a general increase is expected with variations ranging between 1°C and 3°C; also in this analysis, the highest variations are expected to affect the northwestern part of the domain, with increasing value up to 4°C under the worst-case scenario (RCP8.5). Furthermore, a general increase in temperature is also expected for all the seasons under both RCP scenarios and over the two considered time periods.

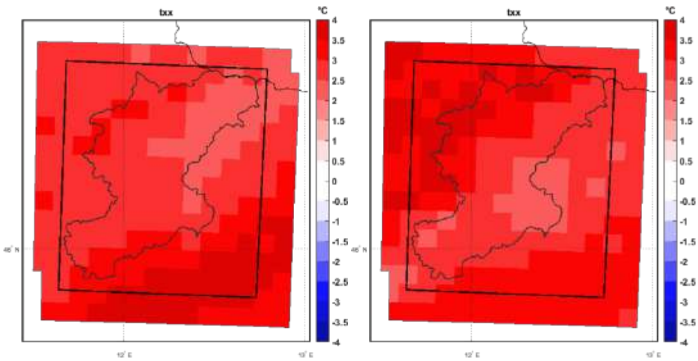

fig. 17
Maximum value of daily maximum temperature (°C) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

Accounting for the maximum annual value of daily maximum wind speed (WX1day), the variations (shown as percentage values in fig. 18) are quite low (lower than 8% for either the scenarios) and the spatial pattern is not homogeneus and different for the two RCP scenarios considered. Specifically, under RCP4.5, the wind speed variations are generally negative (ranging between 2 and 5 %) in the west part of the domain. On the other hand, simulation carried out under the RCP8.5 shows a different spatial distribution of the variations: the southern area is characterized by an increase in the wind speed (up to 6-7%) while negative values are expected in the remaining part (with values that decrease up to 7%).

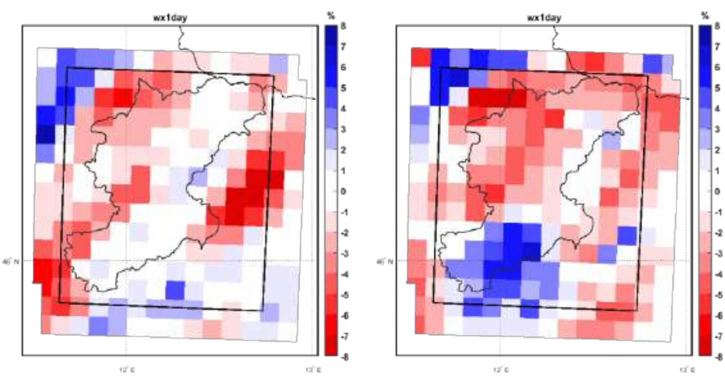

fig. 18
Maximum value of daily maximum wind speed (%) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

The spatial distribution of the expected variation for annual number of wetsnow events (wetsnow_01, expressed as the number of days in which a wetsnow events occurs) for the period 2036-2065 is characterized by a slight variation of the indicator with a clear signal pattern (positive in the northern part and negative in the southern part) in both the accounted RCP scenarios (**Errore. L'origine riferimento non è stata trovata.**). In detail, under the RCP4.5 scenario, the wetsnow indicator shows a light increase in the number of events per year up to 2 days in the north part and a decrease up to 3-4 days per year in the southern part. Under the RCP8.5, the northern area is characterized by a higher increasing number of events (up to 4 days per year) whilst the southern sector shows a decrease more similar to the results of simulations carried out for the RCP4.5 scenario (3-4 days per year).

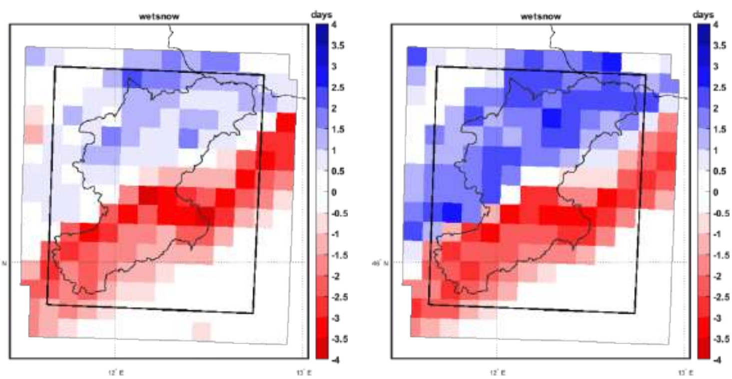

fig. 19
Number of wet snow events ($0<TX<1.5$ °C and $Pr>10$ mm) (days) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

In the case of the indicators related to the precipitation distribution, two indicators (RX5DAYS: maximum consecutive 5-day precipitation amount, expressed in mm, and CDD: largest number of consecutive days with precipitation less than 1 mm, expressed in days) are analyzed. In detail, for the variation over the period 2036-2065 of RX5DAYS at the annual scale (fig. 20), the analysis reports a consistent increase in the amount of precipitation under the RCP4.5 scenario, with values up to 35-40 mm in the southernmost sector of the domain. Under the RCP8.5, there is a different spatial distribution of the variations for this indicator with low variations: positive in the southern area (ranging between 8 and 16 mm) whilst the northern-eastern sector is characterized by a light low decrease (with variations values ranging between -4 and 12 mm).

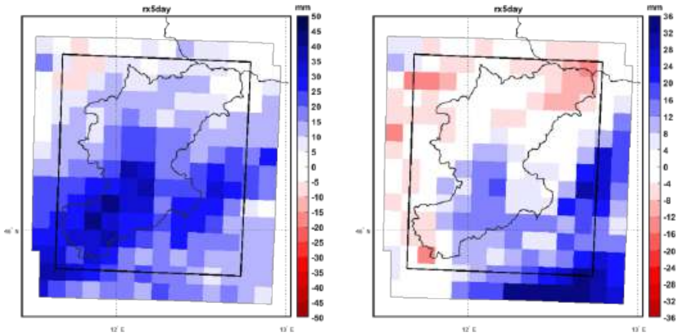

fig. 20
Maximum consecutive 5-day precipitation amount (mm) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

Concerning the variations evaluated for the annual number of dry days (CDD indicator), simulation under the RCP4.5 scenario (left panel in fig 21) shows a general light increase in the northern sector (with values up to 2 days) and a light decrease in a very limited area in the southern part of the domain (with decreasing values of -1, -2 days per year). Accounting for RCP8.5 scenario (right panel in fig 21), the simulation shows that the entire investigated domain is expected to be characterized by an increase in the annual value of consecutive dry days, with higher variations (up to 4 days) in the northern sector and lower anomaly values (1-2 days) in the southern sector.

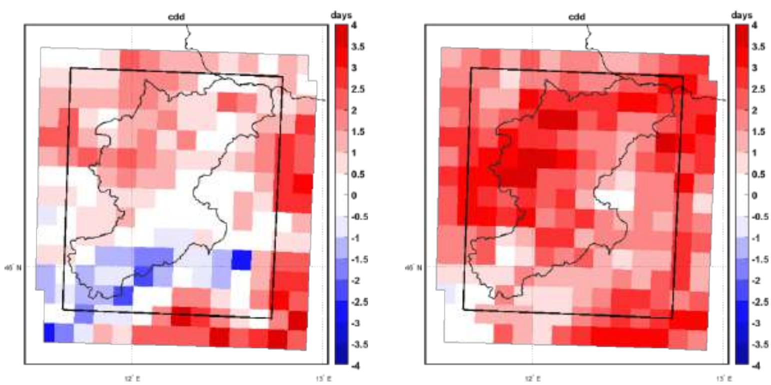

fig. 21
Largest number of consecutive days with precipitation less than 1 mm (days) for the period 2035-2065 under the scenario RCP4.5 (left panel) and RCP8.5 (right panel).

The indicators shown in the maps are in general assumed as a proxy for rapid evaluations about future expected changes in the occurrence and severity of local hydrological/hydraulic hazards. Specifically, expected variations could affect the occurrence of weather-induced hazards with different magnitude according to the local characteristics of the investigated area, the time horizon and the selected scenario. In particular, the strongest variations in temperature expected in the high-altitude areas could cause strong variations both in rain and in snow dynamics, with consequent impacts on environmental resources and economic activities.

Bibliography

Bonelli, P., Lacavalla, M., Marcacci, P., Mariani, G., & Stella, G. (2011). Wet snow hazard for power lines: a forecast and alert system applied in Italy. Natural Hazards and Earth System Sciences, 11(9), 2419-2431.

Bucchignani, E., Montesarchio, M., Zollo, A.L., Mercogliano, P. (2016). High-resolution climate simulations with COSMO-CLM over Italy: Performance evaluation and climate projections for the 21st century. Int. J. Climatol. 36, 735–756.

Christidis, N., & Stott, P.A. (2016). Attribution analyses of temperature extremes using a set of 16 indices. Weather and Climate Extremes, 14, 24-35

Croce P., Formichi P., Landi F., Mercogliano P., Bucchignani E., Dosio A., Dimova S. (2018). The snow load in Europe and the climate change – Climate Risk Management https://doi.org/10.1016/j.crm.2018.03.001

Dosio, A., & Fischer, E. M. (2018). Will half a degree make a difference? Robust projections of indices of mean and extreme climate in Europe under 1.5 C, 2 C, and 3 C global warming. Geophysical Research Letters, 45(2), 935-944

Durand, Y., Giraud, G., Laternser , M., Etchevers, P., Mérindol, L. and Lesaffre, B.: Reanalysis of 47 years of climate in the French Alps (1958–2005): climatology and trends for snow cover., Journal of Applied Meteorology and Climatology, 48 (12) , 2487-2512, https://doi.org/10.1175/2009JAMC1810.1, 2009.

European Environment Agency (EEA) (2018). National climate change vulnerability and risk assessments in Europe, 2018. EEA Report No 1/2018. https://www.eea.europa.eu/publications/national-climate-change-vulnerability-2018.

European Environmental Agency (EEA). (2009a). Regional Climate Change and Adaptation: The Alps Facing the Challenge of Changing Water Resources. https://www.eea.europa.eu/publications/alps-climate-change and-adaptation-2009

European Commission (2019) https://composite-indicators.jrc.ec.europa.eu/?q=10-step-guide/step-4- multivariate-analysis

Fioravanti, G., Piervitali, E., & Desiato, F. (2016). Recent changes of temperature extremes over Italy: an index-based analysis. Theoretical and applied climatology, 123(3-4), 473-486

Hawkins E. , Sutton R. (2009). The potential to narrow uncertainty in regional climate predictions. Bulletin of the American Meteorological Society 90 (8), 1095-1107.

Hawkins E. , Sutton R. (2011). The potential to narrow uncertainty in projections of regional precipitation change. Climate Dynamics 37 (1), 407-418.

Hennemuth,T.I., Jacob,D., Keup-Thiel, E., Kotlarski, S., Nikulin,G., Otto, J. et al. (2017) Guidance for EURO-CORDEX climate projections data use. Version1.0 - 2017.08. Link: https://euro-cordex.net/imperia/md/content/csc/cordex/euro-cordex-guidelines-version1.0-2017.08.pdf

Giupponi, C., Mojtahed, V., Gain, A.K., Biscaro, C., and Balbi, S.: Integrated Risk Assessment of Water-Related Disasters, In: G. Di Baldassarre, P. Paron, and J. F. Shroder (eds.), Hydro-Meteorological Hazards, Risks and Disasters. Elsevier, Boston. 163-200, https://doi.org/10.1016/B978-0-12-394846-5.00006-0, 2015.

Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J.and Stoffel, M.: 21st century climate change in the European Alps—A review., Science of the Total Environment, 493, 1138-1151, https://doi.org/10.1016/j.scitotenv.2013.07.050, 2014.

Hong, Y. I. N., & Ying, S. U. N. (2018). Characteristics of extreme temperature and precipitation in China in 2017 based on ETCCDI indices. Advances in Climate Change Research, 9(4), 218-226

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment

Report of the Intergovernmental Panel on Climate Change (Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)). IPCC, Geneva, Switzerland, pp. 104

IPCC (2012). Managing the Risks of Extreme Events and Disaster to Advance Climate Change Adaptation. A special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (Field CB et al. (eds), Cambridge University Press, Cambridge (UK) and New York (USA), pp.582

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M., &Georgopoulou, E. (2014). EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional environmental change, 14(2), 563-578.

Jacob, D., Teichmann, C., Sobolowski, S., et al.: Regional climate downscaling over Europe: perspectives 715 from the EURO-CORDEX community, Reg. Environ. Change, 20, 51, https://doi.org/10.1007/s10113-020- 716 01606-9, 2020.

Katz, R.W., Brown, B.G. Extreme events in a changing climate: Variability is more important than averages. Climatic Change 21, 289–302 (1992). https://doi.org/10.1007/BF00139728

Kislov, A.V., Krenke,A.N.(2009). Climate-Related Hazards in: Natural Disaster Vol. II, Encyclopedia of LifeSupport System, UNESCO.

Klein Tank, A. M. G., F. W. Zwiers, and X. Zhang (2009). Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation, Climate data and monitoring WCDMP-No. 72, WMOTD No. 1500, 56 pp.

Llasat, M. C., Turco, M., Quintana-Seguí, P., &Llasat-Botija, M. (2014). The snowstorm of 8 March 2010 in Catalonia (Spain): a paradigmatic wet-snow event with a high societal impact. Natural Hazards and Earth System Sciences, 14(2), 427.

Marcolini G., Bellin A., Disse M., Chiogna G.: Variability in snow depth time series in the Adige catchment., Journal of Hydrology: Regional Studies, 13, 240-254, https://doi.org/10.1016/j.ejrh.2017.08.007, 2017.

MATTM, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2107. Piano Nazionale di Adattamento ai Cambiamenti Climatici PNACC. Prima stesura per la consultazione pubblica. https://www.minambiente.it/sites/default/files/archivio_immagini/adattamenti_climatici/documento_pnacc_luglio_2017.pdf

Mojtahed, V., Giupponi, C., Biscaro, C., Gain, A.K. and Balbi, S.: Integrated Assessment of Natural Hazards and Climate Change Adaptation: II - The Serra Methodology, SSRN Electron. J., https://doi.org/10.2139/ssrn.2233312, 2013.

Moss, R., M. Babiker, S. Brinkman, E. Calvo, T. Carter, J. Edmonds, I. Elgizouli, S. Emori, L. Erda, K. Hibbard, R. Jones, M. Kainuma, J. Kelleher, J. F. Lamarque, M. Manning, B. Matthews, J. Meehl, L. Meyer, J. Mitchell, N. Nakicenovic, B. O'Neill, R. Pichs, K. Riahi, S. Rose, P. Runci, R. Stouffer, D. van Vuuren, J. Weyant, T. Wilbanks, J. P. van Ypersele and M. Zurek. (2008). Towards new scenarios for analysis of emissions, climate change, impacts and response strategies. IPCC Expert Meeting Report, 19-21 September 2007, Noordwijkerhout, (p. 132). Netherlands, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

Mysiak, J., Torresan, S., Bosello, F., Mistry, M., Amadio, M., Marzi, S., Furlan, E. &Sperotto, A. (2018). Climate risk index for Italy. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2121), 20170305.

Pasqui, M., & Di Giuseppe, E. (2019). Climate change, future warming, and adaptation in Europe. Animal Frontiers, 9(1), 6-11

Reder, A., Iturbide, M., Herrera, S. et al. (2018). Assessing variations of extreme indices inducing weather-hazards on critical infrastructures over Europe—the INTACT framework. Climatic Change 148, 123–138

Rianna, G., Reder, A., Mercogliano, P., & Pagano, L. (2017). Evaluation of variations in frequency of landslide events affecting pyroclastic covers in Campania region under the effect of climate changes. Hydrology, 4(3), 34.

Stephenson, D.B. (2008). Definition, diagnosis and origin of extreme weather and climate events. In: Diaz HF, Murnane RJ (eds) Climate extreme and society, Cambridge University Press, Cambridge.

Tebaldi, C., Smith, R.L., Nychka, D. & Mearns, L.O. (2005) Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multimodel ensembles. J. Climate 18(10), 1524-1540.

Vezzoli, R., Mercogliano, P. and Pecora S.: A Brief Introduction to the Concept of Return Period for Univariate 763 Variables, CMCC Research Paper No. 139, http://dx.doi.org/10.2139/ssrn.2195426, 2012.

von Trentini, F., Leduc, M., and Ludwig, R.: Assessing natural variability in RCM signals: comparison of a multi model EURO-CORDEX ensemble with a 50-member single model large ensemble, Climate Dynamics, doi:10.1007/s00382- 019-04755-8, 2019.

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C., ... & Zwiers, F. W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. Wiley Interdisciplinary Reviews: Climate Change, 2(6), 851-870

Zollo, A.L., Rillo, V., Bucchignani, E., Montesarchio, M., Mercogliano, P. (2016). Extreme temperature and precipitation events over Italy: Assessment of high-resolution simulations with COSMO-CLM and future scenarios. Int. J. Climatol. 36, 987–1004

Zwiers, F. W., Alexander, L. V., Hegerl, G. C., Knutson, T. R., Naveau, P., Nicholls, N., ... & Wang, X. L. (2011). Challenges in estimating and understanding recent changes in the frequency and intensity of extreme climate and weather events. Community paper on climate extremes. In Proceedings of World Climate Research Programme Open Science Conference, Denver, CO, WCRP.