CLIMAAX
climate ready regions

Deliverable Phase 1 – Climate risk assessment

Extended multi-risks analysis for forecasting, monitoring, mitigation and adaptation strategies in Molise - CLIMoL

Italy, Molise

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Abbreviations and acronyms

Abbreviation / acronym	Description
CLIMol	Extended multi-risks analysis for forecasting, monitoring, mitigation and adaptation strategies in Molise (CLIMol)
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
CRA	Climate Risk Assessment
ERA5	ECMWF Reanalysis 5th Generation Dataset
FWI	Fire Weather Index
WUI	Wildland Urban Interface
D.L.	Decreto legislativo
RCP	Representative Concentration Pathway
EURO-CORDEX	Coordinated Regional Climate Downscaling Experiment - European Domain
GCM	General Circulation Model
RCM	Regional Climate Model

Executive summary

This report outlines the key findings from Phase 1 of the Climate Risk Assessment for the Molise Region, Italy, conducted as part of the CLIMAAX project. The study emphasizes the need for an evidence-based and systematic assessment of climate risks to guide policy development and strengthen regional adaptive capacity. The analysis provides a comprehensive review of the primary climate hazards affecting Molise, with a specific focus on heavy rainfall and forest fires(wildfires).

In this initial phase, the primary activities involved applying the standardized Climate Risk Assessment (CRA) methodology developed by CLIMAAX, using the CLIMAAX Toolbox and data from recognized sources such as EURO-CORDEX or ERA5. The analysis allowed for a detailed assessment of hazards, highlighting vulnerabilities and critical exposure factors associated with each climate risk.

The analytical workflows highlighted critical future scenarios for the region.

The timeframe of wildfire risk is expected to lengthen, worsened by extended droughts that increase the combustibility of dead biomass. At the same time, the area's vulnerability to forest fires(wildfires) is likely to increase, driven by the expansion of the urban-forest boundary resulting from the conversion of agricultural land to urban use. These dynamics require further study using higher spatial resolution datasets in Phase 2 of the CLIMol Project.

Similar risks have been identified in relation to intense rainfall events. A decrease in overall yearly rainfall is accompanied by increases in total rainfall, leading to a higher frequency and severity of extreme weather events. These developments are also believed to increase regional vulnerability, as such phenomena could spread over a larger area rather than stay localized.

Overall, Phase 1 has significantly enhanced the understanding of climate risks in the Molise region, laying a foundation for subsequent project phases. The work provides tangible, practical insights that are valuable for shaping adaptation strategies, land-use planning, and emergency preparedness efforts.

The key conclusions from this phase emphasize the urgent need to build a resilient system to shield the population and infrastructure from floods, as well as to enhance wildfire management through community participation and proactive risk reduction strategies.

1 Introduction

1.1 Background

The Molise region, located in south-central Italy, is bordered by the regions of Abruzzo, Lazio, Campania, and Puglia. It has an estimated population of 289,224 people, mainly concentrated in the urban centers of Isernia, Campobasso, and Termoli. The terrain is mostly hilly and mountainous, gradually giving way to flatter coastal areas.

About 55.3% of Molise's land is mountainous, while 44.7% consists of hilly areas. The region has a semi-continental climate, with cold, snowy winters and hot, humid summers. Recently, climate trends show milder winters with less snowfall and drier summers. Rivers are primarily torrential, with water levels dropping significantly during the summer. Molise is home to several protected natural areas, including the Abruzzo, Lazio, and Molise National Park, which is renowned for its high biodiversity within its forested ecosystems.

The CLIMAAX methodological framework will provide essential data and analytical insights for a thorough assessment of climate risks at the regional level. It will enhance the understanding of specific risk types and optimize both financial and human resources required for the effective implementation of climate change adaptation strategies.

1.2 Main objectives of the project

As outlined in the Molise Regional Adaptation Strategy, the primary goal of the regional administration is to enhance climate risk assessment by adopting cutting-edge scientific methods and the latest research findings. The use of the CLIMAAX handbook framework helps make this goal operational. The multi-risk approach introduced by the CLIMol project represents a significant step forward, enhancing the detail of vulnerability analyses, updating hazard maps, and incorporating future scenario modeling into policy development. These analytical results aim to assist local authorities and communities in developing evidence-based adaptation plans and implementing targeted, relevant actions. Enhancing response capacity and strengthening regional resilience requires deploying structured analytical tools at the local level, enabling the creation of ongoing climate risk monitoring systems. These infrastructure improvements are significant for effectively managing wildfire events and hydrogeological hazards.

The risk typologies addressed within the CLIMol initiative are diverse in both their nature and effects; however, they collectively represent interconnected aspects of regional vulnerability. The primary objective of the project is to mitigate these risks through a combined analysis, which involves establishing shared objectives within a unified multi-risk management framework. This approach involves identifying strategic management points within the territory that, due to their strategic nature, have low implementation costs (being minimal areas compared to the total surface of the region) but have a significant impact on the surrounding environment.

In summary, the main expected benefits of the project involve thorough analysis of risks related to heavy rainfall and forest fires(wildfires), using standardized methods and new technological tools. The project also includes the planning and development of risk mitigation structures explicitly designed to address these climate threats.

1.3 Project team

The CLIMol Project involves a group of stakeholders, each with a specific role within the project structure. The Civil Protection Service of the Molise Region provides centralized coordination, supported by the specialized expertise of external consultants.

Furthermore, involving representatives from local communities is expected during the intervention planning stage, ensuring the inclusion of context-specific knowledge and participatory governance in the procedural framework.

This multidisciplinary approach, involving administrative, technical, and community-based actors, forms a strong foundation that supports achieving the strategic objectives outlined by the CLIMol project.

1.4 Outline of the document's structure

The first part of this document (Phase 1 report) offers a comprehensive overview of the study region, the objectives of the CLIMol project, and the working group. The central portion focuses on the analysis of floods resulting from heavy rainfall and wildfire hazards and risks, including details on the methodologies and workflows employed. The end section presents the findings of the risk analysis, accompanied by a discussion on prospective developments in the risk mitigation process for subsequent phases of the CLIMol initiative. The document is finalized with a compilation of all referenced documentation.

2 Climate risk assessment – phase 1

2.1 Scoping

The scoping phase defines the objectives, content, and personnel involved, all of which are necessary for a proper risk assessment.

2.1.1 Objectives

The primary goal of the Climate Risk Assessment (CRA) within the CLIMol project is to provide a clear, data-driven understanding of two climate hazards relevant to the Molise Region: heavy precipitation and forest fires(wildfires). This is accomplished using the methodology and tools provided by the CLIMAAX Climate Risk Assessment. These tools will be an essential aid to political decision-making, whether at a social, environmental, or territorial level, by supporting sound and practical choices that protect both the natural heritage and the population. Specifically, CLIMol seeks to produce a series of maps, including risk, hazard, vulnerability, and exposure maps. These will enable a targeted focus on interventions to reduce the impacts of extreme events and offer a clear, comprehensible picture of the potential effects on the population and the territory.

However, it is crucial to consider the limits of the objectives. These can be economic (good planning involves targeted interventions to reduce costs), geographic/topographic (interventions at strategic points in areas like Molise are often made difficult by steep slopes), and temporal (the planned interventions must have a time frame aligned with the expected scenarios). It is believed that the list of limits is not comprehensive or exhaustive, but rather represents the expected constraints at this stage of the project. Other limitations will likely emerge in later phases of CLIMol.

2.1.2 Context

The Italian Civil Protection is governed by Legislative Decree No. 1 of January 2, 2018, which defines the responsibilities and duties of both the government and individual regions. However, this law does not specify particular social and territorial planning procedures for addressing civil protection issues associated with climate risks. Furthermore, regions are entirely responsible for wildfire prevention, forecasting, and active firefighting. Regions have the authority to delegate these tasks to either their Civil Protection or Forestry sectors. In Molise, wildfire management falls under the jurisdiction of the Civil Protection.

The CLIMol project operates within a regional setting where the Civil Protection Service oversees both forest fires(wildfires) and heavy rainfall events. However, while a document exists for wildfire management and planning based on national laws and guidelines (Molise Region Wildfire Operational Plan / Piano operativo Antincendio Boschivo Regione Molise), the legal framework for heavy rainfall only addresses event forecasting and monitoring, and not the operational handling of emergencies (Molise Region Multi-Risk System, Cardillo, 2018 / Sistema Regionale Multirischio della Regione Molise, Cardillo, 2018). This, combined with a regional context of scarce resources, has led to the absence of comprehensive risk planning (or multi-risk strategies). The political and institutional environment promotes an emergency-focused response to environmental crises, emphasizing prevention mainly through operator training at different levels.

There is still a strong belief that environmental emergencies should be handled with emergency response rather than prevention. While operator training has gained more importance recently, which is a positive step, it remains inadequate. A preventive approach appears to be the most effective solution, and thanks to CLIMol, Molise now has this opportunity.

The sectors most vulnerable to extreme events are specifically those that sustain the region's rural economy, such as agriculture and pastoral farming, along with the rural communities themselves. However, it's important to highlight that almost the entire population is exposed to environmental hazards, particularly from heavy rainfall, owing to the region's topographical features.

The CLIMol project aims to coordinate the management of various risks and develop a proactive approach to emergencies, with essential support from the population and multiple stakeholders, including trade associations and local authorities.

2.1.3 Participation and risk ownership

The initial phase of the CLIMol project focuses, among other things, on identifying key stakeholders. We targeted individuals and groups that could benefit from the project, such as those involved in co-managing risks and environmental emergencies, as well as organizations that can help disseminate CLIMol's processes and results. These include:

- Trade associations
- Regional bodies and agencies
- Educational institutions
- Public institutions
- Media
- NGOs
- Research and training (Academia)
- Healthcare

In Italy, individual municipalities play a crucial role in managing and organizing Civil Protection emergencies, as the Mayor serves as the local Civil Protection Authority for events that affect their municipality. During incidents, the National Fire and Rescue Service responds first, followed by volunteer organizations and, when applicable, trade associations that have agreements with regional or municipal officials.

The relationships and interactions among stakeholders during both emergencies and peacetime are not governed by specific regulations. These connections are built during interventions and are managed by the emergency response leader on a case-by-case basis. Although this approach has been somewhat practical in recent incidents, it has exposed significant managerial and operational flaws. To address this, creating a strong network of relationships and agreements, such as contracts between landowners or trade associations and local governments for supplying mechanical equipment, would be advantageous.

As discussed, the current system primarily relies on an emergency-driven approach that necessitates cooperation among various institutions. However, the CLIMol project aims not only to improve collaboration among entities and stakeholders but also, more importantly, to focus on preventing and reducing environmental risks.

2.2 Risk Exploration

Specifically, Phase 1 of the CLIMol Project begins with a comprehensive assessment of all potential climate risks facing the Region, identifying particularly vulnerable groups and relevant stakeholders.

2.2.1 Screen risks (selection of main hazards)

Drawing on evidence, previous analysis, and Civil Protection officials' experience, the climate risks to Molise are outlined as follows:

1. Forest fires(Wildfires): On average, about 1,200 hectares burn yearly since 1992, with nearly 400 fires annually. Recent events, however, have been notable exceptions: in 2007, approximately 4,000 hectares were affected, and in 2021, over 2,100 hectares burned. These incidents caused damage to public and private buildings, led to the evacuation of many people, and severely impacted livestock and agricultural businesses, necessitating extraordinary efforts from state and regional agencies. A state of emergency was declared by the Council of Ministers on August 26, 2021, for six months due to the exceptional wildfire spread. Increasingly frequent droughts and longer fire seasons heighten the risk of fire spread across the entire Molise region.
2. River and Coastal Floods: In spring 2023, exceptional rainfall caused river and coastal floods, resulting in landslides, road closures, and damage to farms. The region requested that the Ministry of Agriculture, Food Sovereignty, and Forests declare a natural disaster in the affected municipalities, enabling targeted intervention measures. Total damages amounted to € 5.981.987, supplementing the impacts of droughts in 2021 and 2022. Moreover, the January 2003 Biferno River flood not only caused economic losses but also resulted in the death of many livestock.
3. Drought and heatwaves: water resources decreased by 51.5% nationwide within a year, compared to the average since 1950. The agriculture and hydroelectric sectors were hardest hit. Moreover, Molise faced an unprecedented water crisis during 2021-2022, marked by a significant drop in total precipitation and a large snow cover deficit compared to typical levels. As a result, regional authorities had to manage numerous support requests due to the damage incurred.
4. Snow and wind: these often lead to mobility problems, service disruptions, neighborhood isolation, scattered houses, large-scale municipal impacts, roof collapses, and crop damage. In 2017, severe weather, including heavy snowfall, low temperatures, and storm-force winds, affected coastal areas, resulting in significant issues. A 180-day emergency was declared, with € 2.932.466,15 allocated to private entities. More recently, in April 2024, snow events caused difficulties, mainly due to the timing, resulting in damage to crops that were already in germination.

Scenarios from the Copernicus Atlas concerning the Mediterranean region, where Molise is located, have been examined. The maps illustrate observed trends, notably a rise in extreme events, more frequent heatwaves, and a decline in average daily rainfall. Of these, the first two are considered the most significant due to their greater influence on the Molise population and ecosystems.

2.2.2 Workflow selection

Following the screening of the previous chapter, the CLIMol team identified two main hazards, forest fires(wildfires) and heavy rainfall, based on evidence and experience. The project utilized the workflows from the CLIMAAX handbook and toolbox to tackle these hazards.

2.2.2.1 Workflow #1: Forest fires(Wildfires)

The chosen workflow for assessing forest fires(wildfires) focused on the FWI, covering both risk and hazard analyses. This method enables the visualization of spatial and temporal trends in FWI values, facilitating an understanding of shifts in the fire season. It utilizes FWI data from the Copernicus Climate Data Store based on the RCP2.6 projection model, with RCP4.5 and RCP8.5 as alternative options. As noted earlier, this indicates a higher risk for the Molise region, impacting valuable ecosystems and, most critically, the local population. This is corroborated by observations from local technicians and the FWI model, which suggest increased future exposure, especially in the growing urban-wildland interface zones (WUI).

Another key aspect is the nature of fires; unlike other environmental emergencies, fire is a manageable factor as long as it stays within the capabilities of terrestrial and aerial firefighting forces. Nature offers a range of possibilities that humans can manage, and for this reason, wildfire prevention is a sector that deserves funding and proper structure.

2.2.2.2 Workflow #2: Heavy Rains

The risk linked to heavy rainfall was chosen for CLIMol because the area is highly vulnerable to these events, which have been widely recorded in recent years. Furthermore, the mountainous terrain worsens these events, making them especially intense and frequent, often causing major disruptions like flooding and landslides.

The 'heavy rainfalls' workflow focuses on extreme precipitation. It involves extracting annual maximum rainfall data for 3-hour and 24-hour periods, fitting statistical distributions to forecast maximum precipitation, and calculating return periods for specific durations and scenarios across Europe. The analysis utilizes data from the EURO-CORDEX climate model, as detailed in the CLIMAAX Handbook, which offers a 12 km grid resolution and focuses on the frequency and intensity of extreme precipitation events. Historical data from 1976 to 2005 were utilized for calibration, while climate projections encompass 2041-2070. These scenarios were developed employing a combination of General Circulation Models (GCMs), Regional Climate Models (RCMs), and Representative Concentration Pathways (RCPs).

It is noted that the data used and future scenarios do not include convective precipitation because of its unpredictable behavior and limited scope.

2.2.3 Choose Scenario

For forest fires(wildfires), the multi-model ensemble average has been chosen as the initial projection because it offers the most reliable outcome. This setup also enables selecting from three projection options at the end: the 'best,' 'worst,' or 'average."

For "heavy rainfalls,' the model used is from the CLIMAAX workflows, which integrate global models (General Circulation Model, Regional Climate Model, and Representative Concentration Pathways) with the European EURO-CORDEX model. Specifically, the CORDEX-EUR-11 model has been employed, offering output at a higher spatial resolution of 0.11°, roughly 12.5 km.

2.3 Risk Analysis

2.3.1 Workflow #1: Forest fires(Wildfires)

Table 2-1 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Copernicus Climate Data Store – Fire Weather Index (FWI), Seasonal FWI, EURO-CORDEX scenarios: historical and RCP scenarios (low: 2.6, intermediate: 4.5, high: 8.5)	. European Forest Fire Information System	. European Forest Fire Information System	Pareto analysis of risk
European Forest Fire Information System			

Molise is located in a Mediterranean environment where plant ecosystems have evolved to withstand forest fires(wildfires). Some species actively use fire for renewal (active pyrophiles), while others withstand fire through the development of defense mechanisms (passive pyrophiles). The issue of forest fires(wildfires) becomes particularly urgent when human settlements are located within these ecosystems. The most challenging areas for fire management are the interface zones, commonly referred to as the wildland-urban interface (WUI). These areas are becoming more problematic due to the abandonment of nearby agricultural lands.

The annual average, which from 1992 to 2004 recorded about 400 fires covering approximately 1,200 hectares, has been greatly surpassed by extreme years, such as 2007 or 2021, when cumulative extents of 4,000 and 2,100 hectares were recorded, respectively.

This situation reveals a critical context that is made worse by steep and often inaccessible terrain. A proactive preventive approach is essential, focusing on identifying high-risk, vulnerable areas for targeted interventions to lessen fire damage to buildings, while also considering economic factors. The CLIMol project can support regional authorities and communities in minimizing both human and economic impacts.

CLIMol utilized the workflow linked to the FWI index, of Canadian origin, to generate projections based on the RPC2.6 model. This index relies on other indices and codes, simplified into four environmental variables: relative humidity, wind speed at 2 meters above ground, temperature, and accumulated precipitation.

2.3.1.1 Hazard assessment

The FWI index solely evaluates meteorological factors (see previous chapter), whereas the risk map incorporates additional data such as urban settlements, land use, and flammability. This approach highlights the risk of forest fires(wildfires), particularly within metropolitan areas, and identifies the most vulnerable zones. As previously noted, this enables targeted prevention strategies aimed at optimizing economic, temporal, and resource allocation.

Seasonal data on the fire weather index are obtained from the Copernicus Climate Data Store. The seasonal FWI index represents the average value of the fire index during Europe's fire season (June-September). This value is calculated by dividing the total of daily fire index values during the fire season by the number of days in that period. The seasonal FWI data are available in five-year intervals, and in the CLIMol project, two intervals were selected: 2046-2050 and 2051-2055. The RCP2.6 emission scenario was used, with RCP4.5 and RCP8.5 as alternatives. The multi-model ensemble mean served as the projection source because it provides the most reliable results. Finally, regarding the severity of the predictions, users can choose among the “best,” “worst,” or “average” scenarios, with the latter being selected in this example.

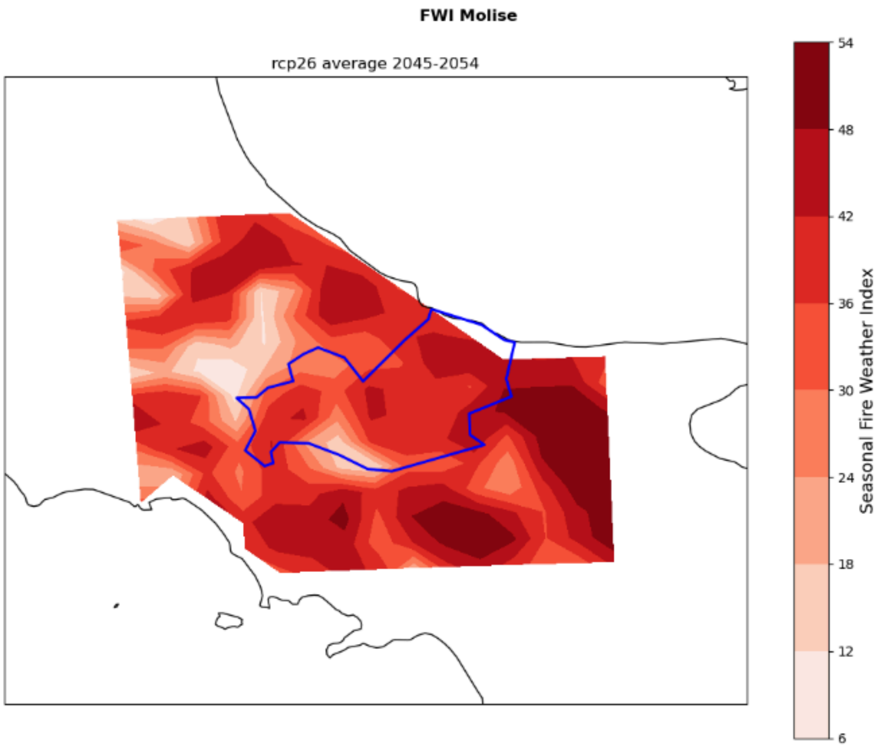
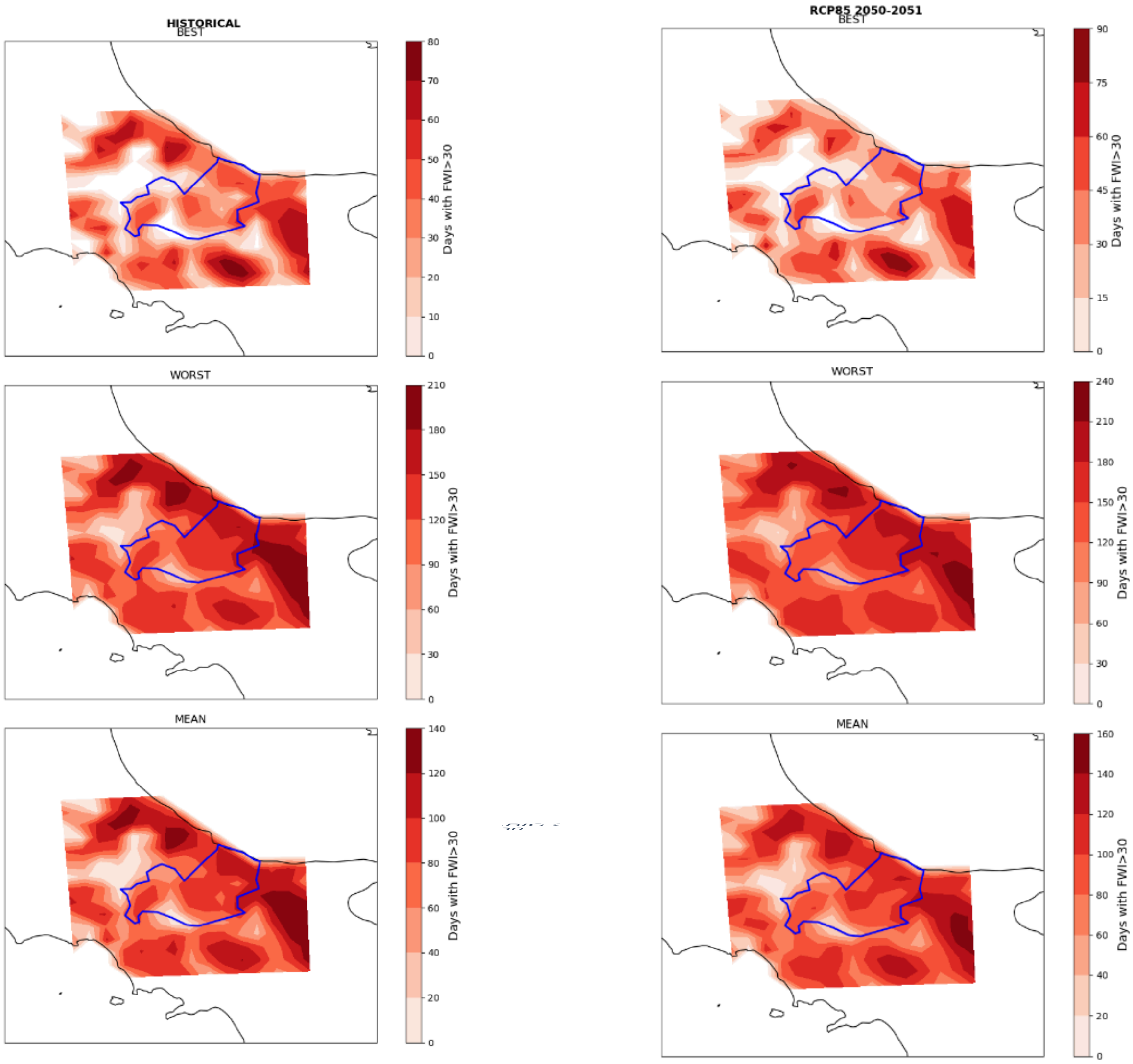


Figure 2-1: Seasonal average of the FWI based on RCP2.6 projection.

Historical and future maps assist in understanding how climate change might affect fire seasons. Comparing various scenarios, such as the best, worst, and average, reveals the range of potential variations. The 'best' and 'worst' scenarios are derived by respectively subtracting and adding the inter-model and inter-annual standard deviation of wildfire weather season data. These scenarios can differ significantly from each other and the average, mainly due to variations in FWI forecasts from different climate models. This variability does not imply inaccuracy, as all values within these scenarios have an equal chance of occurrence and illustrate the most positive, adverse, or extreme conditions possible in the Molise Region.



Figures 2.2: Historical and projected days with FWI>30, across different scenarios (best, worst, mean)

2.3.1.2 Risk assessment

The risk of wildfire is defined by the European Forest Fire Information System (EFFIS), which combines fire danger and vulnerability (Jacome Felix Oom, 2022). Essentially, fire danger is estimated by combining climatic factors (such as seasonal FWI) and available fuel loads. These danger measures are normalized and averaged to create a spatial fire danger index. This index is then paired with various vulnerability indicators, also from EFFIS, to generate a comprehensive risk score. The vulnerability indicators include factors that could be directly impacted by forest fires(wildfires), such as:

- Population: this indicator considers the percentage of residents living in WUI (urban-wildland interface zones) and the population density in the Molise region.
- Ecology: for this aspect, the chosen indicators are:
  - Protected areas: distribution within the region
  - Indispensability index: indicates the uniqueness and value of each pixel
  - Ecological restoration index: reflects the restoration cost in the event of fire loss

To generate the risk index from the hazard index and vulnerability indicators, a Pareto analysis is conducted to determine which regions have the highest overall risk based on the chosen indicators. This method assumes that all factors equally influence the risk of forest fires(wildfires).

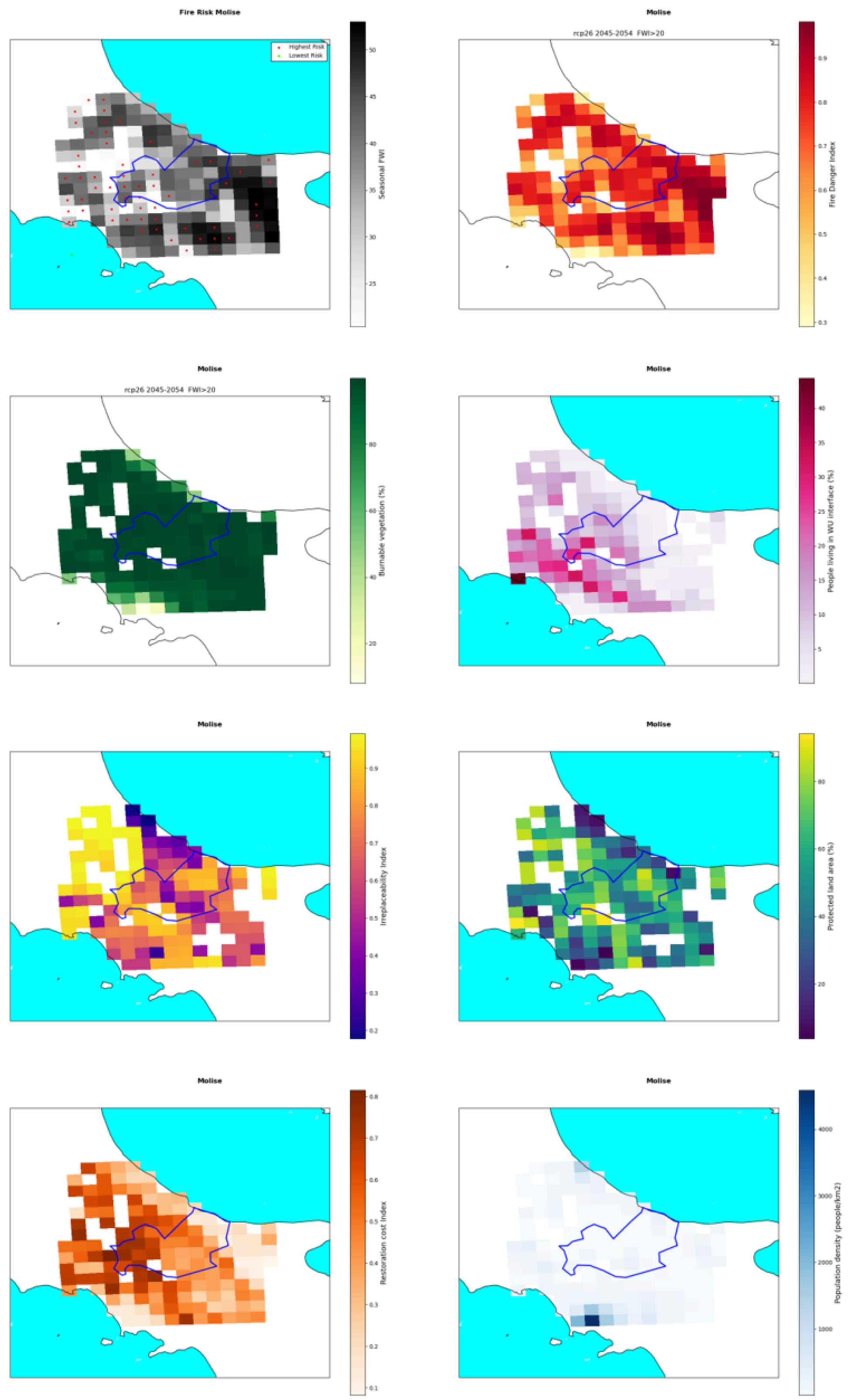


Figura SEQ Figura * ARABIC 3: Indicatori del risultato dell'analisi del rischio

Figures 2-3: On the left from the top: Seasonal FWI, Burnable vegetation (%), Irreplaceability index, Reconstruction Index. On the right from the top: Fire Danger index, People living in WUI(%), Protected land areas (%), Population density (%)

2.3.2 Workflow #2: Heavy Rains

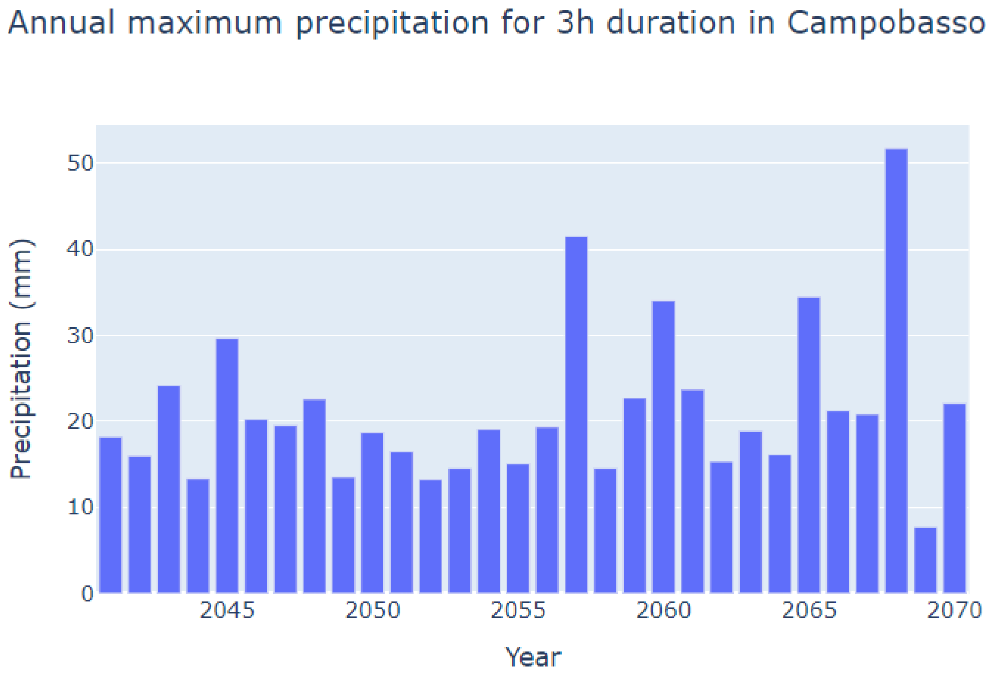
The primary datasets are summarized in the table below.

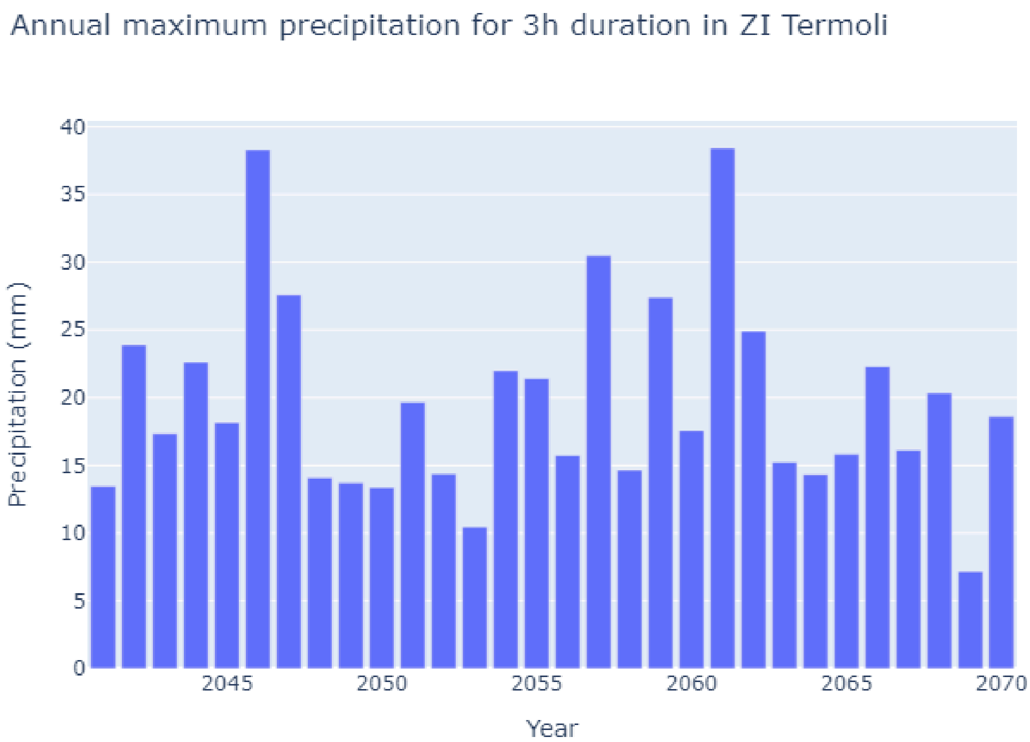
Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
•EURO-CORDEX from the Climate Data Store: two different 30-year frames the historical one (1976-2005) and the projection one (2041-2070) RCP 8.5	–	–	–
•EURO-CORDEX precipitation datasets (temporal series of annual maximum precipitation for 3h and daily resolution)	–	–	–

2.3.2.1 Hazard assessment

The hazard assessment was performed in a Python environment utilizing Copernicus data. The analyzed time series served as input for generating future projections spanning 30 years. The study also examined the maximum precipitation levels for key cities in Molise: Campobasso, Isernia, and Termoli.





Figures 2-4: Annual maximum precipitation for 3h duration in (from the top) Isernia, Campobasso and Termoli cities

In addition to the maximum 3-hour precipitation projections, other results include the probability distribution of maximum precipitation series, calculated using the "General Extreme Values" (GEV) distribution.

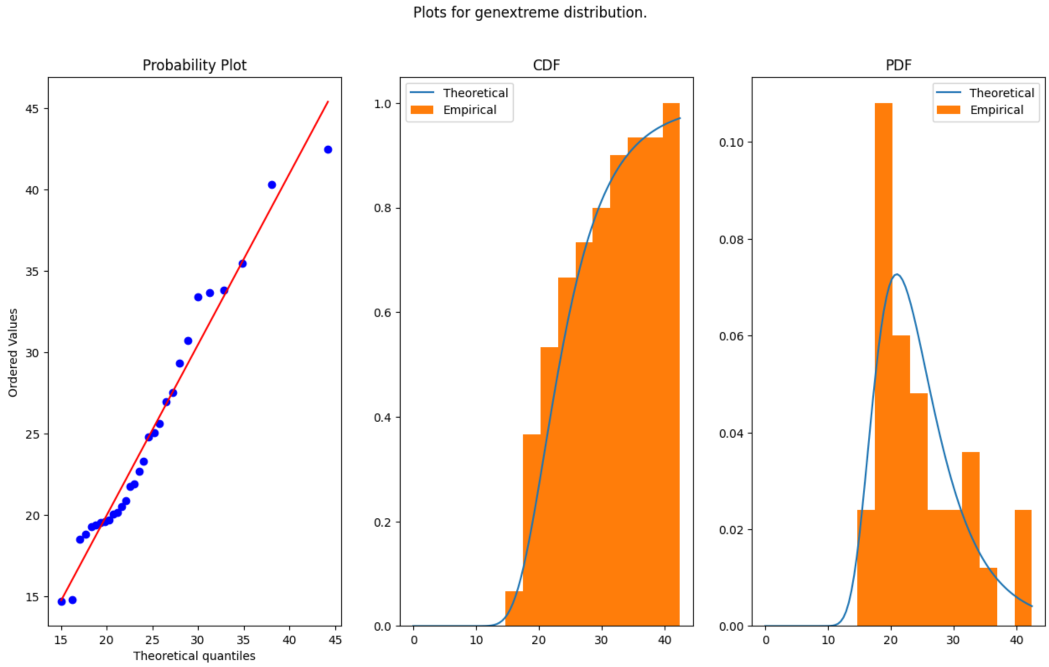
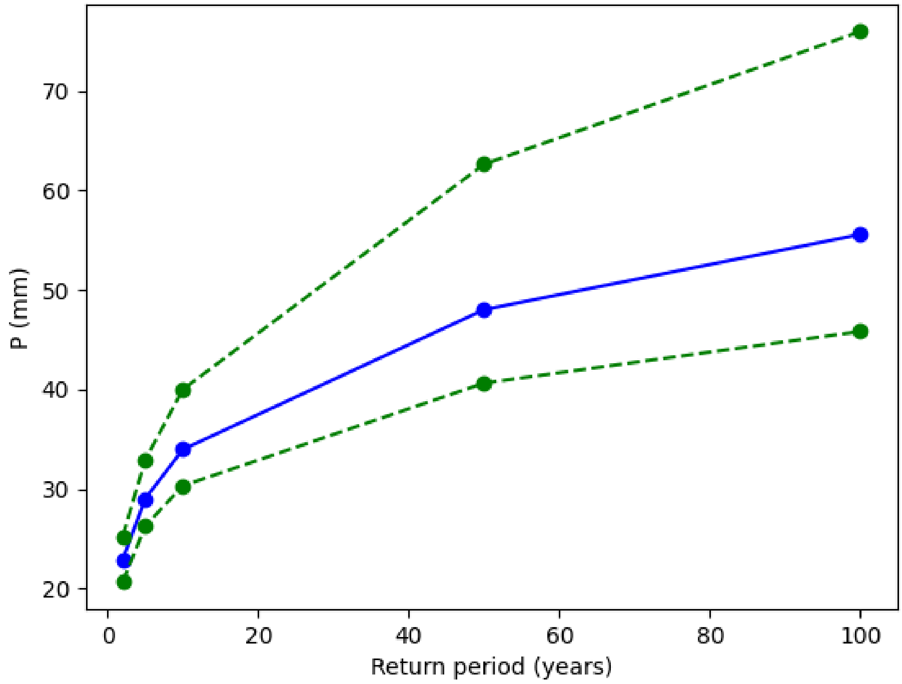


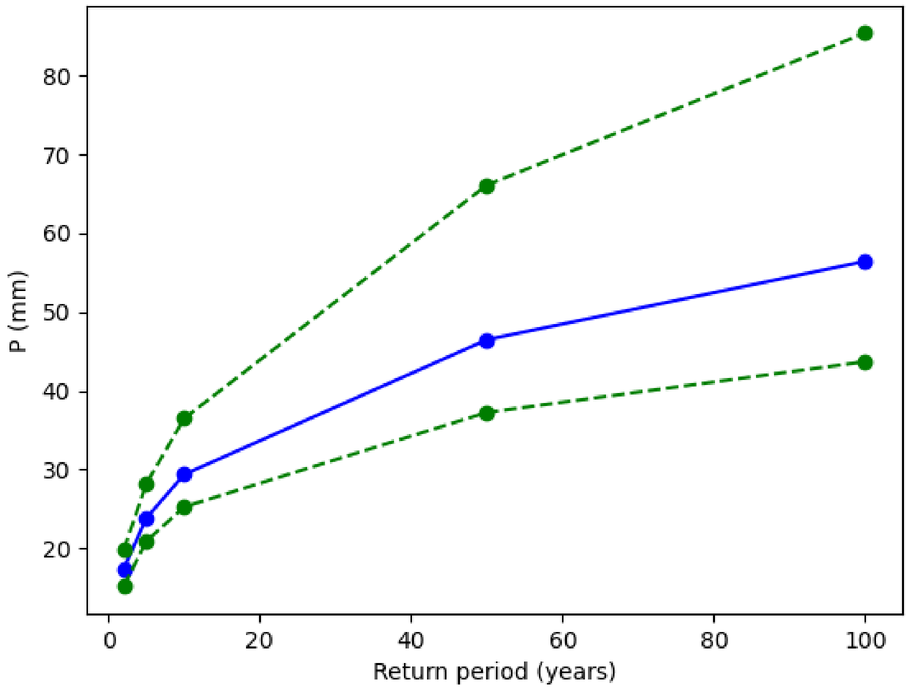
Figure 2-5: Probability distribution (probability of occurrence) to the annual maximum precipitation series, considering General Extreme Value (GEV) distribution

Graphs depicting 3-hour precipitation forecasts for the 2041-2070 projection have been created for Molise's main cities: Isernia, Campobasso, and Termoli, covering various return periods (2, 5, 10, 50, and 100 years).

Expected precipitation for 3h event for 2041-2070 period in Isernia.

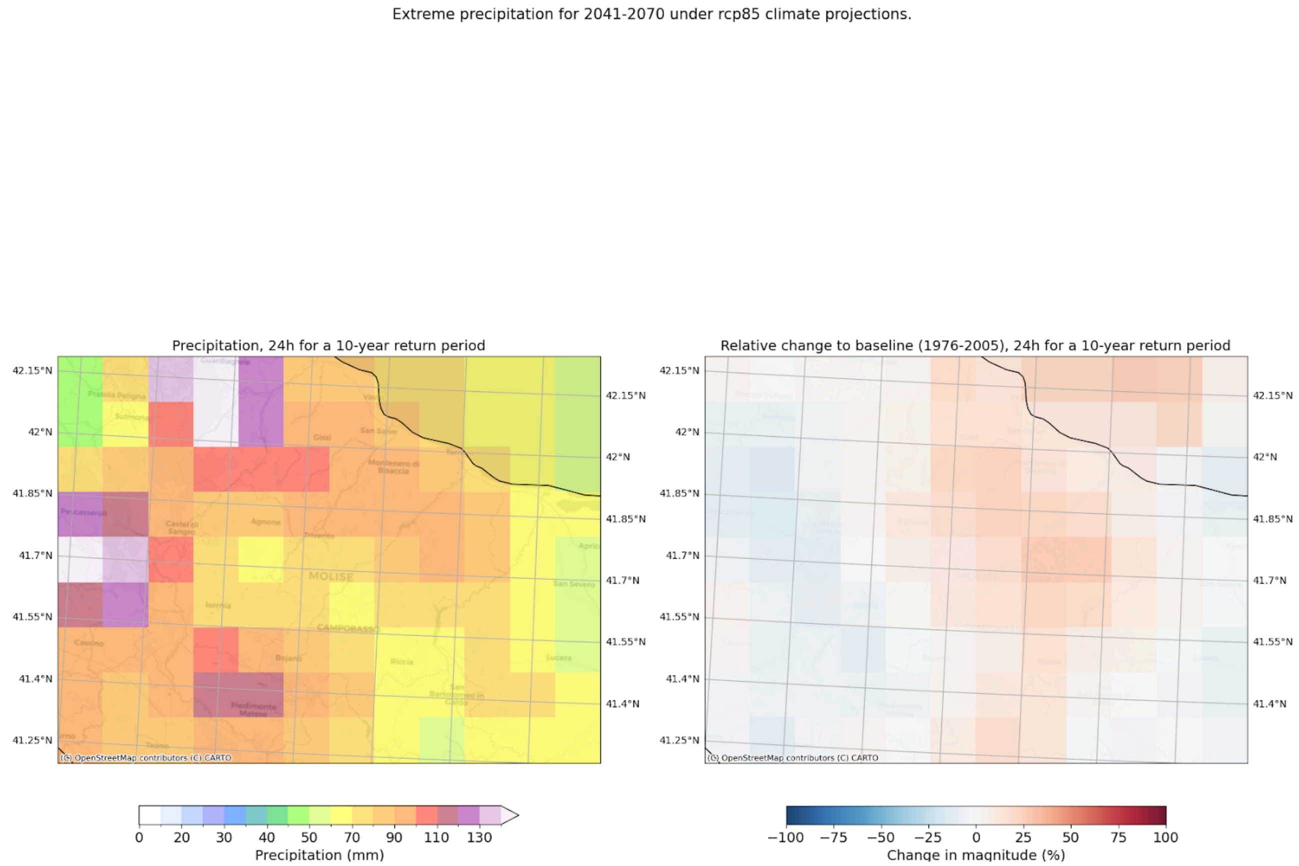


Expected precipitation for 3h event for 2041-2070 period in ZI Termoli.



Figures 2-6: Expected precipitation for 3h event for 2041-2070 period in (fom the top) Campobasso, Isernia, Termoli cities considering the following returning periods: 2, 5, 10, 50, 100 years.

In conclusion, the most recent graphs illustrate the projected changes in 24-hour precipitation with a 10-year return period, as predicted by the RCP8.4 model.



Figures 2-7: Extreme precipitation 24h (mm) for 2041-2070 period under RCP 8.5 climate projections

2.3.2.2 Risk assessment

The risk assessment could not be finalized due to the unavailability of the GeoTiff file containing threshold values for 3-hour and 24-hour precipitation, as the provided link directs to a non-existent webpage: https://object-store.os-api.cci1.ecmwf.int/climaax/precipitation_idf_europe/.

Nonetheless, this circumstance does not impact the CLIMol project, as the Molise Functional Center possesses the requisite data to complete the assessment. This dataset is specific to the Molise Region, making it a localized dataset that is therefore designated for use in Phase 2 of the project.

2.4 Preliminary Key Risk Assessment Findings

The evaluation of the severity and urgency of risks identified in the CLIMol Project helps interpret the results and prioritize actions for mitigation. Additionally, analyzing capacities, viewed as a regional emergency response system, can reveal the strengths and weaknesses of the Regional Civil Protection System. At this stage, it was crucial to consider the capabilities of all entities and personnel involved in this system.

2.4.1 Severity

Severity refers to the extent of a climate risk's effects on a specific target or its frequency of occurrence. In CLIMol, environmental risk severity is defined as:

- "Heavy rainfalls”: refers to the total precipitation over a period or the frequency of exceptional rainfall events.
- "Forest fires(Wildfires)": refer to the extent of damage to targets such as ecosystems, infrastructure, or humans, as well as the length of the wildfire season, which may indicate a rise in frequency.

A useful post-event measure of severity is the cost required to restore the affected area to its original state.

Phase 1 of CLIMol shows that the Molise Region faces a very high risk of heavy rainfall and wildfire now and in future projections:

- Forest fires(Wildfires): projections from the maps indicate that from 2045-2054, the severity of the relative risk will increase due to several factors: rising FWI index values, longer fire seasons, and increased exposure from the growth of urban-forest interface zones. This could lead to various issues affecting the population, including higher flame intensity, which would make restoration more difficult and prolonged, likely changes in vegetation, loss of ecological and environmental values in the overstory, and greater impacts on structures and infrastructure that could threaten human life. Irreversible consequences might include loss of human lives and high-value ecosystems, and there could also be cascading effects on the regional economy, especially since agriculture remains a dominant sector.

- Intense precipitation: from the graphs produced during the hazard assessment phase, it is clear that intense rainfall will increase over the years. Both 3-hour and 24-hour events pose a growing risk, not only because of their potential magnitude (resulting in more millimeters within the same time frame) but also because the return periods are likely to decrease, leaving the entire region more vulnerable to extreme events.

2.4.2 Urgency

The urgency relates to how quickly danger can happen. If a hazard is likely to occur sooner or more rapidly than expected, the urgency increases.

- Forest fires(Wildfires): Medium and long-term forecasts indicate a rise in both the frequency of fires and the length of periods favorable for their occurrence. This situation demands urgent attention, resembling a "rapid onset" scenario, as these conditions are projected to last for an extended period in the medium term. Data from multiple sources reveal that over the past 25 years, severe summer fire seasons have occurred roughly every five years, reflecting a significant increase compared to earlier decades. While these events may seem sudden, occurring within a year or a few years, their impacts are long-lasting. It typically takes at least five to seven years for a burned ecosystem to recover to its original state. Current models suggest that, if environmental conditions stay the same, such fire events are likely to persist.

- Heavy Rainfall: Projections for medium to long-term scenarios indicate an increase in both the frequency (shorter return periods) and the intensity of heavy rainfall events, highlighting a pressing urgency (“rapid onset”).

In this case, the risk is also considered rapid due to its short duration over several years, although recovery from the damage could take a considerable amount of time. Like wildfire risks, intense rainfall will continue with the same certainty until environmental factors change.

It is important to note that preventive measures to reduce heavy rainfall risk may be more costly and take longer to implement than those for forest fires(wildfires).

2.4.3 Capacity

Resilience capacity delineates the ability to respond to, confront, and adapt to potential threats. It primarily relies on personnel stability, the availability of economic resources, and the robustness of existing defensive and preventative structures.

The Molise Region currently lacks specific regional regulations for managing extreme weather events. However, recent initiatives and reports suggest that this issue will soon be incorporated into the regional decision-making framework. Notably, recent developments come from the ADRIACLIM project (Interreg IT-HR) and the VALORADA project (Horizon 2020).

The Molise Region's personnel includes staff from the Civil Protection Service of Molise, members of the National Fire Brigade, specialized forest fire-fighting workers from ARSARP, and volunteers from Civil Protection and local groups. All personnel possess a wide range of practical skills and theoretical knowledge. Although they are well-trained to handle extreme and hazardous events, such training does not always ensure the safety of the territory and population, as incidents are increasingly beyond human operational capacity. This is clear in cases of forest fires(wildfires) and heavy rainfall, where tools, equipment, or techniques are often inadequate to contain events due to their scale.

The Molise Region has limited economic resources, as its economy primarily relies on agriculture and, to a lesser extent, industry. Nonetheless, strategic planning of organization, land use, and scheduling can facilitate the effective deployment of preventive measures. Moreover, the regional government may obtain additional funding in the future from national or European sources.

The current infrastructure is considered insufficient to mitigate the risks identified by the CLIMol project. At a socio-cultural level, concerns related to extreme environmental hazards are increasingly prominent; however, substantial deficiencies persist in their management, preparedness, and prevention.

The CLIMol Project offers a range of improvements for resiliency, including access to community funds and the sharing of best practices and knowledge on managing and mitigating climate risks with stakeholders and the broader public.

2.5 Preliminary Monitoring and Evaluation

The initial stage of the CLIMol process identified several positive and negative aspects, which nonetheless form a strong foundation for phase 2 of the project. Notably, the standardization of hazard and risk assessments at the community level for various environmental dangers provides a solid basis for effective territorial planning and prevention. However, some key issues have arisen in this context:

1 Although European data can be a useful initial reference, more detailed data is required for a comprehensive analysis. This is due to Molise's significant topographical, ecological, and social variability, which makes low-resolution data less effective.

2 The risk assessment for extreme precipitation could not be completed because retrieving the GeoTiff of the threshold values is impossible, as the webpage with the code no longer exists.
3 It has also become clear that European-origin data needs to be harmonized with local data from the Molise Functional Center. This harmonization process is expected to start in the second phase of the CLIMol project.

The CLIMol project has shown advantages in stakeholder engagement, such as delivering detailed technical analyses and funding prevention initiatives. However, it has also been noted that organizations like trade associations, NGOs, and rural communities are not adequately involved. Additionally, broader promotion of the project is necessary to enhance environmental education efforts.

Ultimately, engaging a diverse group of stakeholders and collaborators contributed to the development of the two CLIMol workflows. However, involving information technology staff was also vital for analyzing and executing the code. The outcomes are detailed in the earlier chapters, but to produce outputs that more accurately represent reality and support mitigation strategies, it is necessary to enhance the source data.

2.6 Work plan

The first phase of the CLIMol Project has established a comprehensive framework for assessing Climate Change risks. Through workflows, we've pinpointed major vulnerable regions susceptible to hazards such as forest fires(wildfires) and intense rainfall. Collaborating with various stakeholders, particularly local and regional authorities, has yielded an initial draft analysis of strategies designed to mitigate these risks.

The upcoming phases of this project will focus on enhancing the understanding of these risks, both geographically (using high-resolution data) and technically (by involving expert technical personnel for each specific risk), to create a risk map that effectively guides mitigation efforts.

The upcoming phases aim to achieve several goals: first, to identify key strategic management points that can reduce the effects of extreme events on the environment and population; second, to establish a network of stakeholders and personnel who can respond to these events, prevent their impacts, and create a comprehensive, multifunctional territorial management system.

3 Conclusions Phase 1- Climate risk assessment

This section reviews the results from phase 1 of the CLIMAAX project in the Molise Region. The CLIMol Project focused on two significant environmental risks: heavy rainfall and forest fires(wildfires). To assess these risks, the workflows from the CLIMAAX Toolbox were used. The findings provide a strong basis for further detailed research and, more importantly, support a practical, integrated land management approach centered on prevention, with clear goals and deadlines.

- Forest fires(Wildfires): projections, especially under RCP8.5, forecast an increase in the Canadian FWI index. This analysis indicates a higher likelihood of more summer days with FWI > 30 in both 'moderate' and 'worst' scenarios. An examination of other ecological factors, such as vegetation flammability and irreplaceability, reveals a general decline in socio-environmental conditions as population exposure to forest fires(wildfires) increases and vegetative health deteriorates.

- Heavy rainfall: again, future projections show an increase in problems related to heavy rain. Models suggest that the return periods of extreme events may decrease, while the intensity of each event (3 hours and 24 hours) could grow during 2041-2070.

The initial phase of the CLIMol Project was essential for initiating investigations into the primary issues related to climate change in the Molise Region. It demonstrated that European datasets and a standard workflow used across the EU can effectively guide future analyses. However, it was also recognized that in the second phase, different factors should be addressed to develop a product that is genuinely relevant and practical for the Molise context.

- Data Integration: The data used allows for an objective standardization of workflows across Europe; however, the resulting maps are mainly generic and indicative. These results have helped Molise's administration understand risks related to fires and heavy rainfall (with future RCP projections being essential for better intervention planning). Nonetheless, they are not sufficient for the project's ultimate goal: to plan territorial and social actions such as improving risk mitigation infrastructure, identifying Strategic Prevention Points, updating legislation related to Civil Protection and Environmental Emergency Management, and expanding Civil Protection personnel. Phase 2 of the CLIMol project will focus on providing a more detailed analysis to support phase 3 in planning effective interventions. The highest data quality is found not only in the model's higher spatial resolution but also in input data, including historical fire records with typologies, urban settlements, land use, and more.

- Stakeholder Integration: Currently, only regional administration and sector technicians have been involved. However, effective preventive measures need a wider range of stakeholders. Including more groups will make the adaptation process more participatory and beneficial for the entire Molise community, including local authorities, the private sector, and industry groups.

- Funding Integration: The next challenge is securing the necessary resources to sustain the CLIMol project. It is essential to identify regional and national funding sources that can support the planned initiatives. Success depends on the project's professionalism and pragmatic approach.

4 Progress evaluation and contribution to future phases

The following KPIs show good progress in the CLIMol Project during Phase 1. Notably, the two scheduled workflows focusing on wildfire risk and heavy rainfall have been completed, though stakeholder engagement goals were only partly met. The findings highlight Molise Region's vulnerability to climate change and underscore the importance of analyzing data at finer spatial scales to identify at-risk areas better. Moreover, engaging various stakeholders has facilitated the development and dissemination of these results, enhancing their influence in the Molise region.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
At least [2] workflows successfully applied on Deliverable 1	Completed
A minimum of [2] communication actions taken to share results with stakeholders (specific project sections also on www.regione.molise.it and www.protezionecivile.molise.it)	Completed
A minimum of [3] publications and dissemination actions (also using official social media pages (@pcmolise) while creating the hashtag #CLIMol for better spreading information)	Completed In September 2025 (September 19, 2025), we will present the initial results of Phase 1 of the CLIMAAX-CLIMOL project at the international REMTECH workshop in Ferrara, with an oral presentation.
[2] press conference	The initial results presentation conference is currently being organized.
A minimum of [2] articles in regional media mentioning the project	The initial results are currently being published.
A minimum of [2] fully updated hazard maps of the applicant territory included in Deliverable 2	
A minimum of [2] updated exposure maps of the applicant territory included in Deliverable 2	
A minimum of [2] updated risk maps of the applicant territory included in Deliverable 2	
A minimum of [7] different categories of stakeholders are involved in the activities of the project	Partially completed

Phase 1 was dedicated to fully implementing the CLIMAAX Climate Risk Assessment (CRA) methodology, building a foundational understanding of the risks facing the Molise Region. During this phase, the goals outlined below in the table were achieved.

Table 4-2 Overview of milestones

Milestones	*Progress*
MS1: CLIMAAX 1st workshop participation in Barcelona	Completed
MS2: Stakeholders mapping	Completed

Milestones	*Progress*
MS3: Workflow 1 application	Completed
MS4: Workflow 2 application	Completed
MS5: Data collection	
MS6: Risks scenario(s) refinement and improvement	
MS7: Evaluate impacts on RM plans	
MS8: Stakeholders' participation meetings	
MS9: Stakeholders' mitigation proposals integration	
MS10: CLIMAAX 2nd workshop participation in Brussels	…

MS1: The first workshop in Barcelona. The Project Team (Cardillo, Tocci, De Lisi) attended, presenting an illustrative poster outlining the activities planned for the CLIMAAX-CLIMOL project.

Figures 4-1: Workshop participation in Barcelona

MS2: Stakeholder mapping involves engaging various stakeholders, including local and regional administrations, academia, and professionals. This creates a network for exchanging ideas and information, ensuring that Phase 1 is practical and provides a strong foundation for the subsequent phases.

MS3 and MS4 involve Workflow 1 and 2 applications. The processes addressing wildfire risk and heavy rainfall have been successfully executed using the CLIMAAX Toolbox. This approach has been crucial for ensuring consistent, precise results across Europe and serves as a solid foundation for more detailed and accurate work in Phase 2.

5 Supporting documentation

- Main report
- Workflow:
    - Wildfire: FWI
    - Heavy rainfalls

6 References

- Sistema Regionale Multirischio della Regione Molise, Cardillo, 2018. https://doi.org/10.5281/zenodo.16937104.
- F. Avanzi, S. Gabellani, F. Delogu, F. Silvestro, F. Pignone, G. Bruno, L. Pulvirenti, G. Squicciarino, E. Fiori, L. Rossi, S. Puca, A. Toniazzo, P. Giordano, M. Falzacappa, S. Ratto, H. Stevenin, A. Cardillo, M. Fioletti, O. Cazzuli, E. Cremonese, U. Morra di Cella, and L. Ferraris: IT-SNOW: a snow reanalysis for Italy blending modeling, in situ data, and satellite observations (2010–2021), https://doi.org/10.5194/essd-15-639-2023, 2023.
- Bisci C., Fazzini M., Beltrando G., Cardillo A., and Romeo V.: "The February 2012 exceptional snowfall along the Adriatic side of Central Italy". Meteorologische Zeitschrift, 21, 5, 503-508. (IF2012 MZ - 1.084).
- Bisci C., Fazzini M., Cardillo A., Romeo V. "Intense snowfalls of January 2017 along the central-southern Apennines (Italy), in comparisons with the 2015, 2012 and 205 events" presentato alla "34th International Conference on Alpine Meteorology, Reykjavík, Iceland" ICAM 2017.
- Cardillo A. : "Progetto SNOW Life, analisi della densità nevosa nel Massiccio del Matese ai fini dell'analisi della disponibilità idrica", 28 pp, www.protezionecivile.molise.it.
- Cardillo A., Cassardo C., Fazzini M., Scarlatelli S.: "The incorrect information of extreme weather events: the case of the "record snowfall" in the mountains of Abruzzo and Molise of March 2015". 33rd International Conference on Alpine Meteorology, ICAM, 31/8 - 4/9 2015 Innsbruck – Austria, pp 115-116 (P 3.19). https://www.uibk.ac.at/congress/icam2015/.
- Cardillo A., Di Pilla S.: "Piano Dinamico di Utilizzazione della Risorsa Idrica Conseguente alla Situazione Meteoclimatica in Atto - 28.11.07", www.protezionecivile.molise.it.
- Cardillo A., Di Pilla S., Fazzini M: "Exceptional snowfalls in the region Molise (Central Italy) in a contest of extremes of climate". 32nd International Conference on Alpine Meteorology, ICAM, 3-7 giugno 2013, Kranjska Gora, Slovenia. ISBN 978-961-6024-60-0, pp. 98.
- Cardillo A., Di Pilla S., Fazzini M.: « Analyse statistique des champs de précipitations pendant 30 ans sur le versant adriatique de la Région Molise (Italie centrale): premiers résultats ». Actes XXIII Colloque de l'Association internationale de climatologie. 1-5 settembre 2009, Cluj-Napoca, Romania, pp. 109-114.
- Cardillo A., Di Pilla S.: "Sistema di Allertamento per il Rischio Meteo, Idraulico ed Idrogeologico della Regione Molise, approvato con Deliberazione di Giunta Regionale n. 550 del 29.11.2016.

- Cardillo A., Di Talia V., Antonioni A. " Citizens as additional mobile sensors in case of natural disasters: a new emergency decision support system" https://dx.doi.org/10.13140/rg.2.2.19433.98405, 2022.
- Cardillo A., Fazzini M. "Janvier 2017: enneigements exceptionnels sur l'Apennin central, étude de cas de la région du Molise". Presentato al XXXIE Colloque Annuel de l'Association Internationale de Climatologie – Nice, France – juillet 2018. (in corso di valutazione) - § Sciencesconf.org:aic2018:181727.
- Cardillo A., Fazzini M., Scarlatelli S.: « L'analyse de la distribution spatiale du réseau de surveillance de la défense civile de la Région de Molise ». XXVIII Colloque de l'Association Internationale de Climatologie, 1-4 juillet 2015, Liège, Belgique. ISBN 978-2-907696-21-0, pp. 111-116.
- Cardillo A., Fazzini M., Beltrando G., Romeo V.: « L'enneigement exceptionnel de février 2012 dans la Région de Molise (Italie centrale). Actes XXV Colloque de l'Association International de Climatologie. 5-8 settembre 2012, Grenoble, Francia. ISBN 978-2-907696-18-0, pp171-176.
- Chow, V.T., Maidment, D.R. and Mays, L.W. (1988) Applied Hydrology. International Edition, McGraw-Hill Book Company, New York.
- Christensen, O.B., Kjellström, E. Partitioning uncertainty components of mean climate and climate change in a large ensemble of European regional climate model projections. Clim Dyn 54, 4293–4308 (2020). https://doi.org/10.1007/s00382-020-05229-y.
- Déqué, M., D. P. Rowell, D. Lüthi, F. Giorgi, J. H. Christensen, B. Rockel, D. Jacob, E. Kjellström, M. de Castro, B. van den Hurk, 2007: An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections. Climatic Change 81:53–70, https://doi.org/10.1007/s10584-006-9228-x.
- El Garroussi, S., Di Giuseppe, F., Barnard, C., & Wetterhall, F. (2024). Europe faces up to tenfold increase in extreme fires in a warming climate. Npj Climate and Atmospheric Science, 7(1). https://doi.org/10.1038/s41612-024-00575-8.
- Fazzini M., Bisci C., Cardillo A., Perucci R., Aringoli D., Farabollini P., Materazzi M., Pambianchi G. "Earthquake-triggered avalanches along Central Apennines (Italy) in January 18th, 2017" presentato alla "34th International Conference on Alpine Meteorology, Reykjavík, Iceland" ICAM 2017.
- Fazzini M., Cardillo A., Di Fiore T., Lucentini L., Scozzafava M. "Extreme temperatures in the cold air pool of the central Apennines (Italy): comparison with those of the Veneto Pre-Alps during winter 2016-17" presentato alla "34th International Conference on Alpine Meteorology, Reykjavík, Iceland" ICAM 2017.

- Fazzini M., Cardillo A., Di Pilla S., Beltrando G.: "Tendances des précipitations depuis le milieu du XXe siècle sur le versant adriatique de la Région Molise (Italie Centrale)". Actes XXVI Colloque de l'Association International de Climatologie 3-7 settembre 2013, Cotonou, Benin. ISBN 10-999919-58-64-9; ISSN 18405452, pp. 230-235.
- Fisher, R. A., & Tippett, L. H. (1928). Limiting forms of the frequency distribution of the largest or smallest member of a sample. Mathematical Proceedings of the Cambridge Philosophical Society, 24(2), 180–190. https://doi.org/10.1017/s0305004100015681.
- Fosser, G., Gaetani, M., Kendon, E. J., Adinolfi, M., Ban, N., Belušić, D., Caillaud, C., Careto, J. A., Coppola, E., Demory, M.-E., de Vries, H., Dobler, A., Feldmann, H., Goergen, K., Lenderink, G., Pichelli, E., Schär, C., Soares, P. M., Somot, S., & Tölle, M. H. (2024). Convection-permitting climate models offer more certain extreme rainfall projections. Npj Climate and Atmospheric Science, 7(1). https://doi.org/10.1038/s41612-024-00600-w.
- Jacome Felix Oom, D., De Rigo, D., Pfeiffer, H., Branco, A., Ferrari, D., Grecchi, R., Artes Vivancos, T., Durrant, T., Boca, R., Maianti, P., Libertà, G. and San-Miguel-Ayanz, J. (2022). Pan-European wildfire risk assessment, EUR 31160 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-55138-6, doi:10.2760/437309, JRC130136.
- Jenkinson, A. F. (1955). The frequency distribution of the annual maximum (or minimum) values of meteorological elements. Quarterly Journal of the Royal Meteorological Society, 81(348), 158–171. https://doi.org/10.1002/qj.49708134804.
- Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., et al. (2022). Global and regional trends and drivers of fire under climate change. Reviews of Geophysics, 60, e2020RG000726. https://doi.org/10.1029/2020RG000726.
- Knutti, R., G. Abramowitz, M. Collins, V. Eyring, P.J. Gleckler, B. Hewitson, and L. Mearns, 2010: Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. In: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and Combining Multi-Model Climate Projections [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, and P.M. Midgley (eds.)]. IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland. https://archive.ipcc.ch/pdf/supporting-material/expert-meeting-assessing-multi-model-projections-2010-01.pdf.
- Lund, M. T., Nordling, K., Gjelsvik, A. B., & Samset, B. H. (2023). The influence of variability on fire weather conditions in high latitude regions under present and future global warming. Environmental Research Communications, 5(6), 065016. https://doi.org/10.1088/2515-7620/acdfad .

- Manuele P., Cardillo A. “Gestion des risques météorologiques et hydrogéologiques avec un système de suivi en temps réel et en continu: l'étude de cas du glissement de terrain de Civitacampomarano”. Presentato al XXXIE Colloque Annuel de l'Association Internationale de Climatologie – Nice, France – juillet 2018. (in corso di valutazione) - § Sciencesconf.org:aic2018:182243.
- Maraun, D., Widmann, M., Gutiérrez, J. M., Kotlarski, S., Chandler, R. E., Hertig, E., Wibig, J., Huth, R. and Wilcke, R. A.I. (2015), VALUE: A framework to validate downscaling approaches for climate change studies. Earth's Future, 3: 1–14., https://doi.org/10.1002/2014EF000259
- Martel, J.-L., Brissette, F. P., Lucas-Picher, P., Troin, M., & Arsenault, R. (2021). Climate change and rainfall intensity–duration–frequency curves: Overview of Science and guidelines for adaptation. Journal of Hydrologic Engineering, 26(10). https://doi.org/10.1061/(asce)he.1943-5584.0002122he.1943-5584.0002122).
- Rasmus Benestad, Erasmo Buonomo, José Manuel Gutiérrez, Andreas Haensler, Barbara Hennemuth, Tamás Illy, Daniela Jacob, Elke Keup-Thiel, Eleni Katragkou, Sven Kotlarski, Grigory Nikulin, Juliane Otto, Diana Rechid, Thomas Remke, Kevin Sieck, Stefan Sobolowski, Péter Szabó, Gabriella Szépszó, Claas Teichmann, Robert Vautard, Torsten Weber, Gabriella Zsebeházi (2021). Guidance for EURO-CORDEX climate projections data use. EURO-CORDEX community. https://euro-cordex.net/imperia/md/content/csc/cordex/guidance_for_euro-cordex_climate_projections_data_use__2021-02_1_.pdf
- Sven Kotlarski, Péter Szabó, Sixto Herrera, Olle Räty, Klaus Keuler, Pedro M. Soares, Rita M. Cardoso, Thomas Bosshard, Christian Pagé, Fredrik Boberg, José Manuel Gutiérrez, Francesco A. Isotta, Adam Jaczewski, Frank Kreienkamp, Mark A. Liniger, Cristian Lussana, Krystyna Pianko, Kluczyńska, 2017: Observational uncertainty and regional climate model evaluation: a pan European perspective, Int. J. Clim., doi: https://doi.org/10.1002/joc.5249.