D4.1 – Use cases' set-up

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Document History

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0.1	2025-03-31	NOA	First version of D4.1 shared to technical partners for input
0.2	2025-05-31	MITIGA, LINKS, NOA, RoA, SIS2B, INGV	Contributions by all partners to Use Case descriptions
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1.0	2025-09-30	NOA	Submitted
2.0	2025-09-30	NOA, LINKS, MITIGA	Revised version — Additions and changes on sections 6.1, 6.2i and 7.

Contents

Acronyms

Acronym	Explanation
API	Application Programming Interface
ARW	Advanced Research WRF
BSM	Burnt Scar Mapping
BUI	Build-up Index
C3S	Climate Change Service
CAMS	Copernicus Atmosphere Monitoring Service
CN	Curve Number
DC	Drought Code
DEM	Digital Elevation Model
DEMs	Digital Elevation Models
DMC	Duff Moisture Code
DPC	Department of Civil Protection
DTM	Digital Terrain Model
dNBR	Differential Normalized Burn Ratio
EC	European Commission
EFAS	European Flood Awareness System
FAIR	Findable, Accessible, Interoperable, and Reusable
FFMC	Fine Fuel Moisture Code
FWI	Fire Weather Index
GIS	Geographic Information System / Geographic Information Systems
IMD	Imperviousness Density
ISI	Initial Spread Index
LU/LC	Land Use/Land Cover
LULC	Land Use and Land Cover
MCC	Mattheus Correlation Coefficient
MFS	Mitiga Fire System
MOR	Mean observed rainfall
MSG	Meteosat Second Generation
NBR	Normalized Burn Ratio
NWP	Numerical Weather Predictions
RDBMS	Relational Database Management System

Acronym	Explanation
RMSE	Root Mean Square Error
SDGs	Sustainable Development Goals
UC	Use Cases
UPCM	EU Civil Protection Mechanism
VONAs	Volcano Observatory Notifications for Aviation
WP	Work Package
WRF	Weather Research and Forecasting

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1   Executive summary

The UNICORN project aims to develop and operationalize innovative Copernicus-based applications tailored to the needs of businesses, policymakers, and civil protection authorities to improve resilience and preparedness for extreme natural events. Deliverable D4.1 focuses on the foundational setup of the project's four use cases: flood forecasting, wildfire early detection and fire danger forecasting, and lava flow emergency management. These pilots are strategically designed to demonstrate the capacity of Copernicus-based services to address real-world challenges across different geographies and hazard types.

The document describes the co-design process between technical partners and end-users, leading to the detailed specification of each use case. It presents the multi-step methodology adopted for their definition, including requirements gathering, data identification, technical planning, and stakeholder engagement. The deliverable outlines the data sources, technologies, regulatory considerations, and expected impacts of each use case, setting the stage for their implementation and validation. By establishing these pilots, D4.1 ensures a coherent and actionable framework for the deployment of high-impact EO applications that can be scaled and replicated across Europe.

2   Scope of the document

UNICORN's primary objective is to develop Copernicus-based applications tailored for businesses and policymakers. These applications aim to enhance the preparedness of local authorities, citizens, and industries in response to the increasing frequency of extreme events and geohazards.

The UNICORN methodology begins with a Conceptualisation phase, which is critical as it establishes the basis for subsequent project stages. The use case framework serves as a core component throughout all phases of the project. During the initial Conceptualisation phase, technical partners and end-users collaborate to co-design use cases for the case studies.

This document outlines the detailed requirements and expectations for applications to be developed under Work Package 3. Each use case undergoes a comprehensive analysis, including an in-depth examination of various parameters.

2.1   Applicable documents

ID	Title	Version	Date
[AD. 1]	Grant Agreement incl. Description of Action	1.0	23/09/2024
[AD. 2]	Consortium Agreement	1.0	01/10/2024

2.2   Reference documents

ID	Title	Version	Date
[RD.1]	D2.1 End-users' requirements report	1.0	31/03/2025

3   Introduction

Deliverable D4.1 of the UNICORN project presents the setup of the use cases that will serve as testbeds for the implementation of innovative services targeting natural hazards. These use cases were co-designed through a collaborative process involving end-users and technical partners, ensuring their relevance, feasibility, and potential for uptake. The deliverable is an outcome of Work Package 4 and supports the broader objective of UNICORN to enable the integration of Copernicus services into actionable tools for emergency preparedness, risk mitigation, and policy support.

The initial delivery of D4.1 was scheduled for Month 18; however, the deadline was brought forward to Month 12 to ensure alignment with Task 4.1, which focuses on the set-up of the use cases.

The document is structured as follows:

- Chapter 1 (Executive Summary) provides a high-level overview of the deliverable and its main outcomes.

- Chapter 2 (Scope of the Document) outlines the purpose and intended audience of the deliverable and references key applicable and related documents.

- Chapter 3 (Introduction) introduces the context and relevance of the use cases within UNICORN's objectives and describes the structure of the document.

- Chapter 4 (Methodology) details the workflow and steps undertaken to define and set up the use cases, from user requirements collection to planning for deployment and evaluation.

- Chapter 5 (Use Cases High-Level Analysis) summarizes the rationale behind the selected use cases, involved stakeholders, and thematic areas addressed.

- Chapter 6 (Definition of Use Cases) provides detailed descriptions of each of the four use cases, including technical setup, data and methods used, stakeholder needs, and expected impacts.

- Chapter 7 (Conclusions and Next Steps) reflects on the work completed and outlines the roadmap for pilot implementation, testing, and evaluation.

This deliverable sets the operational and conceptual foundation for the pilots and will guide their development, monitoring, and validation through the next phases of the project.

4   Methodology

This section presents the overall methodological approach adopted for the setting up and defining the use cases of the UNICORN project. To establish a common ground on the main outputs of this deliverable, Table 1, presents the terminology definition of use cases and requirements.

Table 1: Terminology definition for Use Cases and Requirements

Item	Definition	Reference
Use Case	A use case describes how a user uses a system to accomplish a particular goal. It is a technique for capturing, modelling and specifying the requirements of a system.	Bittner, Kurt (2003). *Use case modelling*. Spence, Ian. Addison Wesley. ISBN 0-201-70913-9. OCLC 50041546.
Requirement	A requirement is a statement which translates or expresses a need and its associated constraints and conditions with the purpose to transform through their analysis the stakeholder, requirement-driven view of desired services into a technical view of a required product that could deliver those services	ISO/IEC/IEEE 29148:2011

Figure 1 shows the use case development logic using a flowchart that describes the individual work steps, their sequential arrangement and their interdependencies.

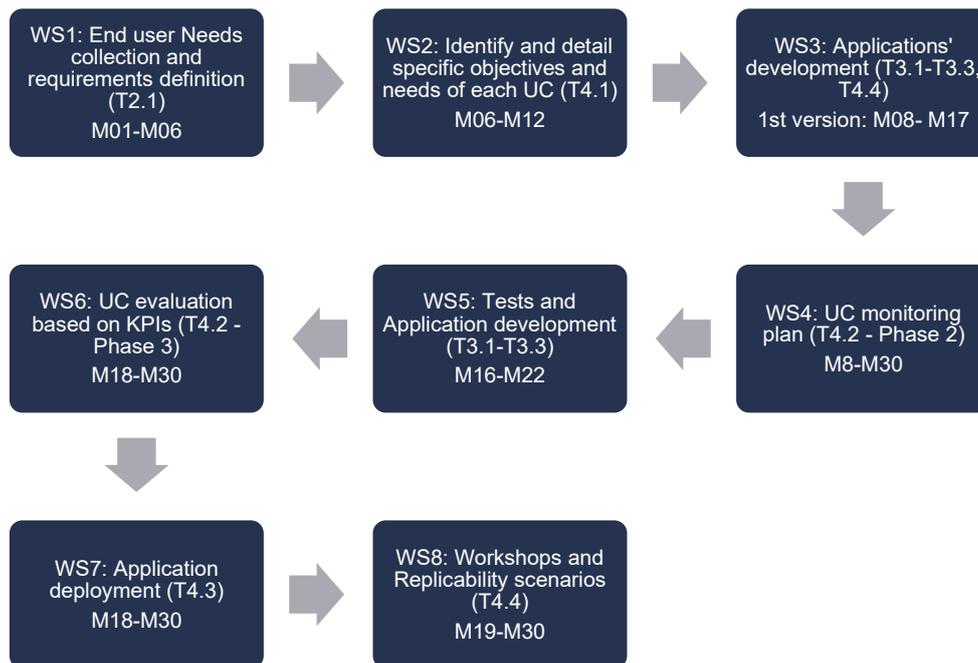Figure 1: High-level UC implementation methodology

The following section provides an analysis of all Work Steps (WS) depicted in the figure above. For each step, the timeline and the responsible partner are detailed. The term "technical partners" refers to those involved in application development, specifically NOA in collaboration with EDGE, LINKS, and MITIGA. Meanwhile, "end users" refers to RoA, SIS2B, and INGV-OE.

<u>Work Step 1 - End user Needs collection and requirements definition</u>: Work Step 1 was part of the Task 2.1 that has delivered the "D2.1 End-users' requirements report" in Month 6, which meticulously undertook an exhaustive evaluation of the requirements and preferences of end users. The survey that has been created, collected data and knowledge that are used for the establishment and refinement of the use cases (T4.1).

Timeline: October 2024 (M1) — March 2025 (M6).

Responsible partners: EDGE

Progress: DONE

<u>Work Step 2 - Identify and detail specific objectives and needs of each UC</u>: This work step includes the meticulous preparation of targeted interventions, seeking to delve into the intricacies of each use case by identifying and detailing specific objectives and needs to elicit detailed requirements and expectations for applications to be implemented. Each use case undergoes a comprehensive analysis (Section 4), encompassing a thorough examination of the data to be utilised, an anticipatory assessment of the final output, an exploration of the potential integration of Copernicus data or services and others. This work step also includes the development of an implementation plan for the Use Cases tailored to the specifics of each application, hazard, data, geographical area, target stakeholder group and scale of operation, and the identification of KPIs for their evaluation.

Timeline: March 2025 (M6) — September 2025 (M12).

Responsible partners: Technical partners to define data, technical details, implementation plan and end-users to provide input on the detailed description of the area of interest as well as the needs of the applications.

Progress: DONE

<u>Work Step 3 - Applications' development</u>: This part involves the design, and the development of the applications related to the use cases (T3.1-T3.3) till they reach a first solid version on Month 17 when there is the Milestone 3: Innovation Flame. WS3 will output a set of standalone systems, one for each task, that will be used throughout the next WS to gather the end-users feedback during a first round of workshops (T4.4).

Timeline: May 2025 (M8) — February 2026 (M17).

Responsible partners: Technical partners to have a first draft of the application. End users can arrange a workshop with the technical partners during this period to gather feedback on the first version of the application.

Progress: Ongoing

<u>Work Step 4 - UC monitoring plan</u>: All Use Case Leaders, together with WP3 (LINKS) and WP4 (NOA) leaders should develop and keep track of a monitoring plan according to the specific conditions of each Use Case. This monitoring plan will assess the performance of the Use Case every two weeks. This work step starts on Month 8, when the development of the applications starts and will continue till the end of the project.

Timeline: May 2025 (M8) — March 2027 (M30).

Responsible partners: WP3 and WP4 leaders, Use case leaders.

Progress: Ongoing

<u>Work Step 5 - Tests and Application development</u>: This part involves the development and fine-tuning of the applications related to the use cases (T3.1-T3.3) till they reach a final solid version on Month 22 when there is the Milestone 4: Innovation Fire. WS5 will implement the users' feedback gathered during the first round of workshops at the end of WS3. The fine-tuned systems will be integrated in the final UNICORN application, to be released alongside a set of user-oriented manuals. A final round of feedback collection, using the fully-integrated application, is planned in WS8 and the gathered feedback will be used to iteratively fine-tune the application experience.

Timeline: January 2026 — July 2026 (M22).

Responsible partners: Technical partners to finetune the applications.

Progress: Not started yet

Work Step 6 - UC evaluation: Use Case Leaders will establish a process for the ongoing evaluation of the Use Case services and outcomes. This process will be based on the KPIs identified in WS2 (T4.1 and T4.2 Phase 1), the data collected in WS4 (T4.2, Phase 2) and the feedback received from end users and other stakeholders involved in the testing phase. This process will assess the usability of the services provided, user satisfaction and the overall performance of the applications developed.

Timeline: January 2026 (M16) — March 2027 (M30).

Responsible partners: Use Case leaders

Progress: Not started yet

Work Step 7 - Application deployment: WS7 is dedicated to the application deployment and to the identification of optimal scenarios for leveraging services within a marketplace, focusing on enhancing the accessibility and usability of data for researchers, scientists, and developers. The review will encompass all existing platforms (T4.3).

Timeline: March 2026 (M18) — March 2027 (M30).

Responsible partners: LINKS as Task 4.3 leader to organize the technical partners as well as the end users to provide their knowledge on existing platforms.

Progress: Not started yet

Work Step 8 - Workshops and Replicability scenarios: WS8 identifies and defines replicability scenarios of the UNICORN services tested during the execution of the use cases, according to the similarities of needs and challenges identified, demonstrating the possibility of replicating practices and procedures in different contexts and settings. Workshops are also conducted for the use case end-users to ensure the continuous refinement of user requirements as well as the engagement of other potential end users in each area (T4.4).

Timeline: April 2026 (M19) — March 2027 (M30).

Responsible partners: End users to organize a workshop with the broader community to promote the application. LINKS as Task 4.4 leader to assist.

Progress: Not started yet

The timeline of the Use Cases set up, implementation and validation can be found in Figure 2.
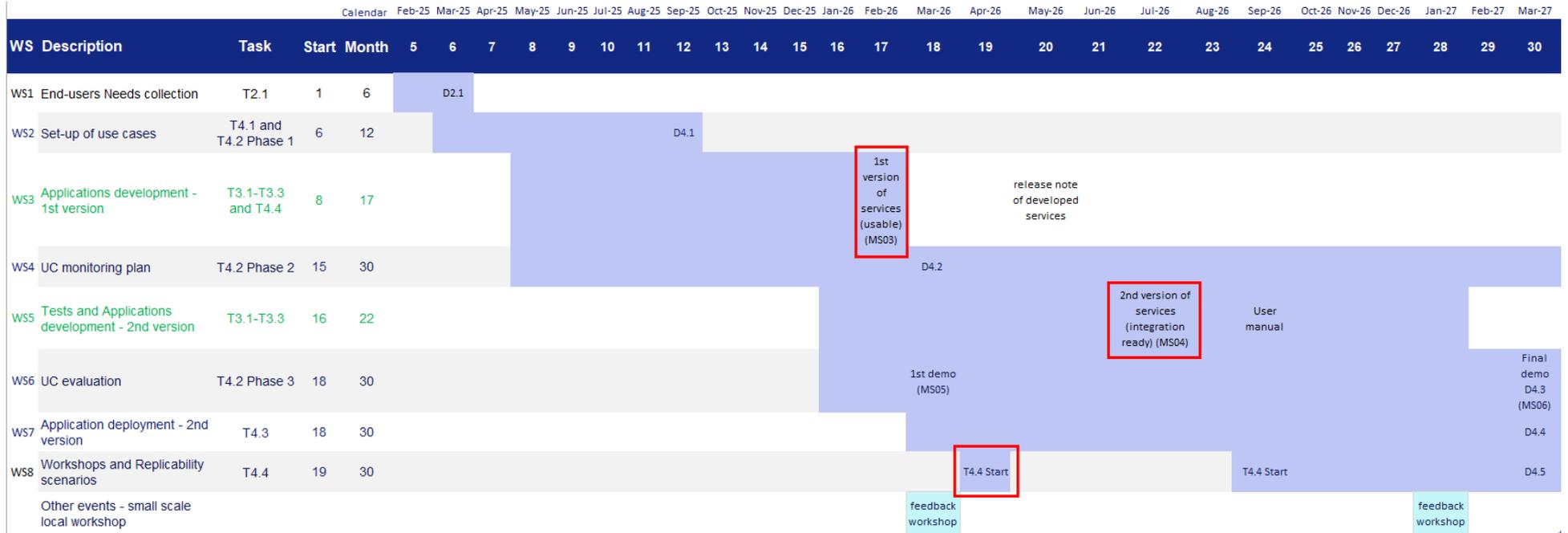
Figure 2: Timeline of Use Cases

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5   Use Cases high-level analysis

The format adopted for the elicitation of UCs is based on internal UNICORN discussions and tries to address the pursued objective, the involved stakeholders, the means of realization (tools developed in the framework of the project), as well as existing knowledge, technologies used, and Copernicus data and services associated with the implementation of the UCs.

As described in the GA, the total number of 4 UCs were defined (Table 2).

Table 2: Summary of Use Cases

UC	Use Case	Task	Partners
1	Flood forecasting integrating Copernicus data and weather forecast fusion	3.1	NOA, EDGE, RoA
2	Copernicus-based wildfire early detection, mapping and nowcasting	3.2a	LINKS, MITIGA, RISC, SIS2B
3	High-resolution fire danger forecast	3.2b	MITIGA, Allianz S.E. (through Letter of Support)
4	Lava flow emergency management tool based on Copernicus data merged with numerical modelling	3.3	MITIGA, INGV-OE

Figure 3 presents the four use cases and outlines the key features that characterise each one and Figure 4 shows the geographic area in which the use cases are located.
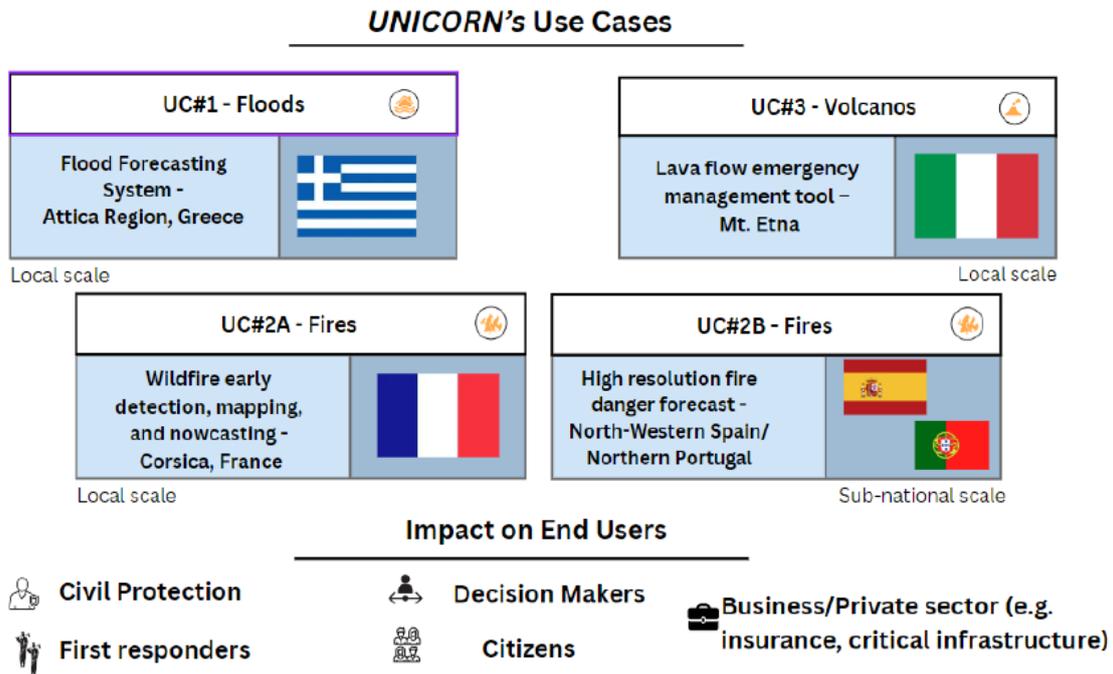
Figure 3: Overview of UNICORN's use cases
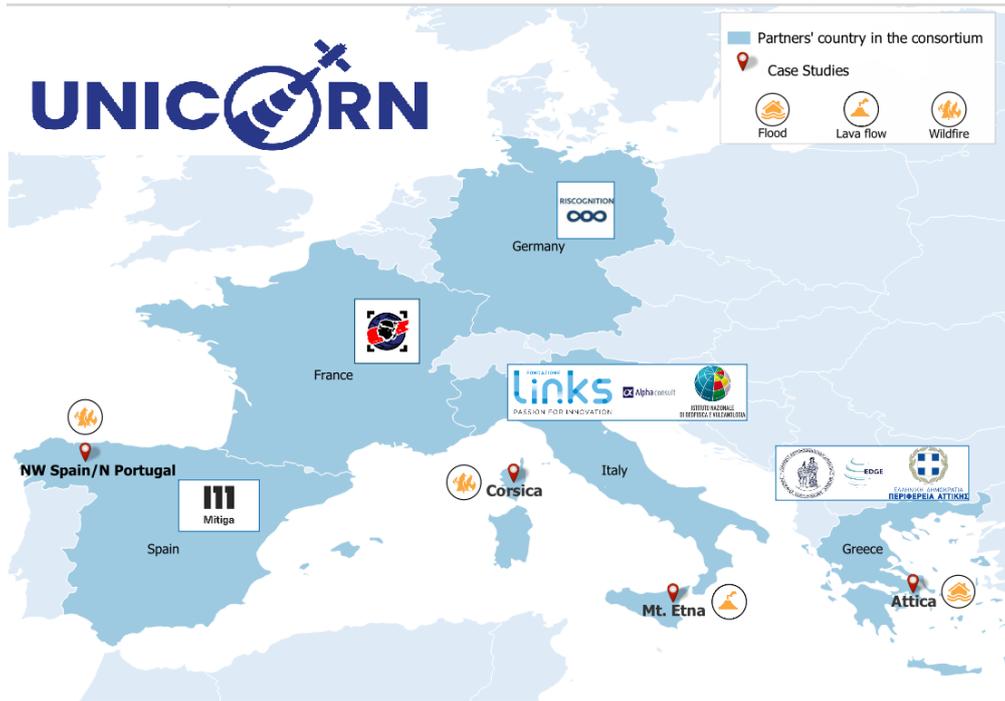
Figure 4: UNICORN countries & use cases

The use cases picked for UNICORN demonstrate the wide range of stakeholders (Figure 5) from the value chain that the project aims to target. It is evident that Practitioners and Policy Makers are the primary focal point of UNICORN's anticipated services. Private sector operators and Investors, rank also very high in the value chain of UNICORN's pursued targets, closely followed by the Scientific community, NGOs, citizens and media.
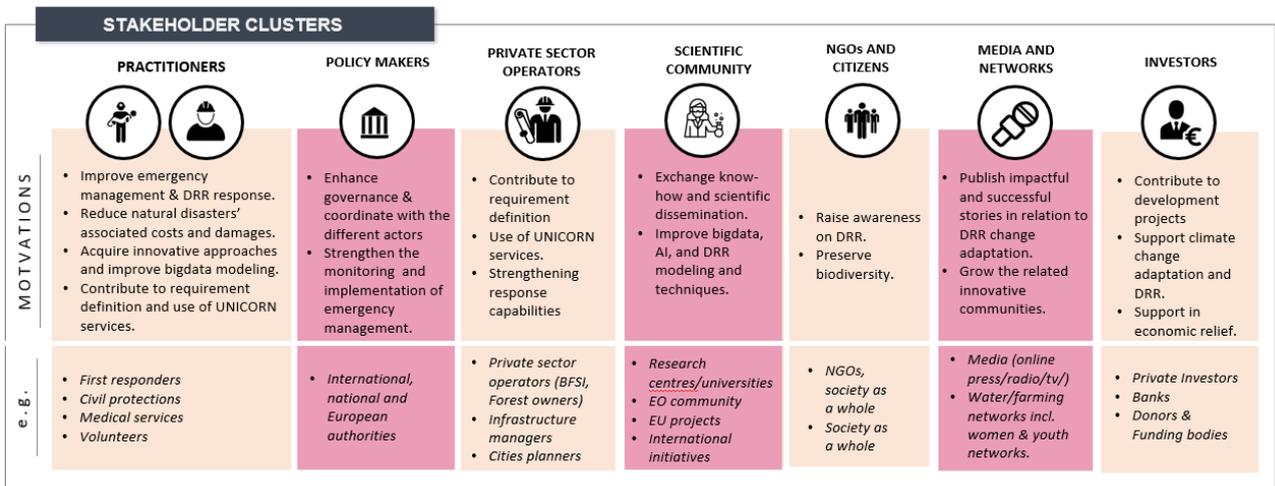
Figure 5: Stakeholder identification

6   Definition of Use Cases

This section provides a detailed analysis of each use case, which plays a pivotal role in the coordinated execution of activities essential for ensuring their seamless setup and implementation. This process involves navigating both technical and non-technical complexities, extending beyond a supervisory function to include the strategic design of targeted interventions. These interventions aim to uncover the specific objectives and requirements of each use case, ensuring a precise alignment with stakeholder expectations.

The current UC analysis fosters a collaborative approach by actively engaging stakeholders to refine and define the detailed requirements for applications to be developed under Work Package 3. Each use case is systematically examined, covering key aspects such as the data to be utilized, an anticipatory assessment of expected outputs, potential integration with Copernicus data and services, and a critical evaluation of the solution's alignment with the current state of the art.

6.1   Use case 1 - Flood forecasting integrating Copernicus data and weather forecast fusion

Floods pose significant dangers, causing widespread disasters globally. In 2024 alone, 142 floods resulted in 5,883 deaths, affecting 48.8 million people and causing economic losses of $32.8 billion euros (CRED, 2025). Flood events in urban and peri-urban areas pose significant risks to lives, infrastructure, and economic stability, particularly in flash flood prone regions like Mandra in Attica, Greece. Flash floods develop rapidly, leaving little response time for authorities and the public.

The UNICORN flood forecasting system enhances preparedness by integrating Copernicus satellite Earth Observation (EO) data, high-resolution weather models, in-situ observations and pre-run hydrological and hydraulic simulations. The system offers an operational image of flood extent and flood depth for the 2-days weather forecast.

Triggering event

Floods

Location

The chosen location is the Mandra river basin area, a suburban area in West Attica, Greece. The Western part of Attica is one of the biggest industrial units in Greece including oil refineries, factories, metallurgical industries, dockyards as well as the waste disposal site of the entire Attica prefecture (Varlas et al., 2019).

The AOI is bounded by Parnitha mountain from the north, Aigaleo mountain from the east and Pateras mountain from the west. The elevations range from 17 m to 824.36 m and the average value of slope is 13% according to the Digital Elevation Model at 2m spatial resolution of the National Cadastre and Mapping Agency SA of Greece.

The climate in Mandra is warm and temperate. The average annual rainfall in the area is approximately 410 mm and the average temperature ranges from 16 ° C to 18 ° C (YPEKA). The small industrial town of Mandra located 40 km west of Athens has a population of about 11.000 people (Brinkhoff, 2020) and has significantly urbanized during the last decades.

The catchment area consists of highly permeable geological formations (limestone and dolomites of Middle-Upper Triassic to Upper Cretaceous age which belong to the Subpelagonic geotectonic zone) and streams of the drainage networks that are developed from alluvial deposits (Institute of Geology and Mineral Exploration).
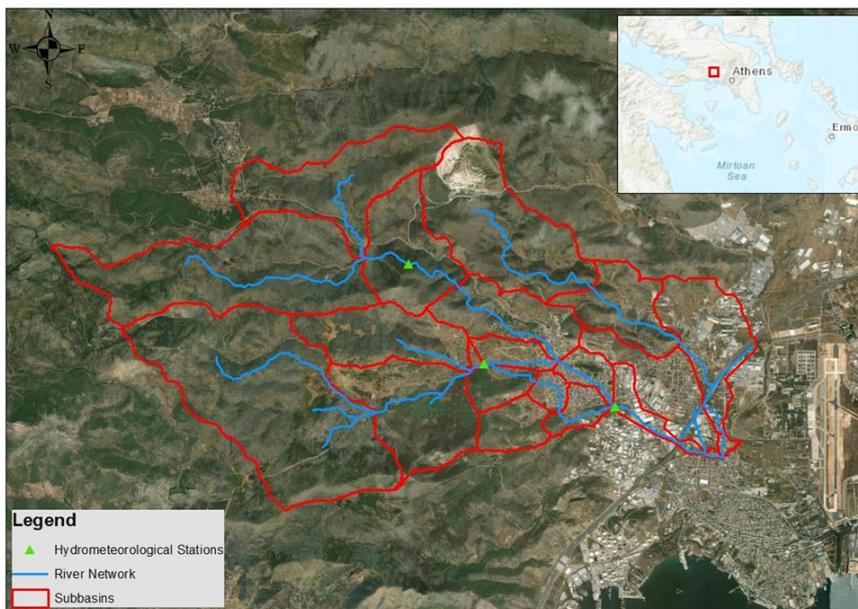
Figure 6: Flood forecasting Use Case #1 Study area of Mandra Basin, Greece: Map of hydrographic network, river subbasins of Mandra and Beyond EO Center's hydrometeorological stations

Mandra river basin area, Attica Greece	
Area size	57 sqkm
Municipalities included	Municipality of Mandra – Idilia, Municipality of Elefsina
Population	11126 (city of Mandra) and 4957 (city of Magoula) (2021)
More information	https://www.patt.gov.gr/

Background and Challenge to be addressed and Anticipated Benefits

The Region of Attica has experienced severe floods. While an existing real-time nowcast flood assessment and early warning system currently provides alerts every five minutes for the Mandra Basin, it lacks the capability to forecast future flood events. Given the high risk of flash floods in small river basins like Mandra, predictive capabilities are crucial to enable timely emergency response and mitigate potential fatalities and infrastructure damage.

The small town of Mandra is among the most damaged areas due to floods as it has a history of flooding with several known events in the last decades, where existing flood databases of the Special Secretariat for Water and related studies as stated in (Diakakis et al., 2012) describe at least 5 flood events since the 1960s: November 1963, February 1978, January 1996 (causing two fatalities), December 1999 and February 2015 (DAEFK, 2016). The disastrous flash flood event occurred in November 2017 caused 24 fatalities and extensive million-euro damages to property and infrastructure (Tsouni et al., 2023). Seven months later, after extensive and heavy raining on 26 June 2018 the town of Mandra was hit again by flash flooding. No loss of life was reported but many streets, houses and establishments were flooded (BEYOND, 2018).

UNICORN Use Case #1 expands existing capabilities to offer flood predictions up to 2 days in advance, through the integration of Copernicus satellite data with advanced weather forecast fusion techniques in combination with pre-run hydrological and hydraulic simulations and real time hydrometeorological station measurements. This will support the decision making of the civil protection authorities for the issuing of alerts and the provision of accurate instructions to the public, including the prohibition of movement and/or the evacuation order towards safe

locations, for the traffic management, for the provision of immediate and effective first aid, as well as for the application of both short and long-term mitigation measures.

The need for sufficient and effective flash flood forecasting leads to the development of a flash flood forecast system, with a fully transferable and scalable modular architecture integrating multisource data (satellite, in situ, crowdsourced) as well as advanced modelling. Moreover, while Numerical Weather Predictions (NWP) for a medium range time horizon with coarse spatial resolution exist, they lack detail over a more local scale. Under the context of the Unicorn Use Case #1, high-resolution regional models are used to decrease the uncertainty of the forecast modelling outputs. These models efficiently resolve more highly localized physical processes (i.e. the latest WRF-ARW model implementation with 2-km grid spacing over Greece). Therefore, they are very efficient for effective flood forecasting systems.

The system aligns with key European and international policies, including:

- EU Floods Directive 2007/60/EC (flood risk assessment and management)
- Sendai Framework for Disaster Risk Reduction
- United Nations Sustainable Development Goals (SDGs)
- UN Early Warnings for All Initiative.

Overall, the system aims to enhance the existing Flood Monitoring system by developing new forecasting applications relying on Copernicus data and services providing flood extent and flood depth predictions for the next-2-days that ultimately strengthen operational flood risk management by benefiting emergency responders and policymakers. It should be highlighted that the new application will contribute to the European Flood Awareness System (EFAS) by delivering in-situ observations from three telemetric hydro-meteorological stations (GNSS) and high-resolution flood forecasting at the local level, specifically for flash floods. Furthermore, it will support the Copernicus Atmosphere Monitoring Service (CAMS) by providing precipitation forecasts from the latest WRF-ARW model implementation (2-km grid spacing over Greece).

Requirements from task 2.1 and Key Stakeholder Needs

The requirements and needs of key stakeholders are comprehensively outlined in Section 8.2 (Flood Hazards) of D2.1 End-users' Requirements Report. The respondent panel, comprising seven participants, represents a balanced mix of local authorities and first response entities, thereby ensuring comprehensive coverage of civil protection needs. While local authorities emphasized requirements related to strategic flood risk management and long-term preparedness, first responders highlighted the necessity for immediate operational support, including evacuation and rescue operations. The input from both stakeholder groups has been carefully considered, acknowledging their critical roles in enhancing disaster resilience.

In response to these needs, the existing FloodHub service already delivers high-frequency "hydrometeorological data" and provides "early warning and near-real-time flood monitoring and alerts" through a three-tier system (medium, high, very high risk), updated every five minutes to support "situational awareness". The service also includes "evacuation recommendations," supporting rapid and informed decision-making.

Existing knowledge

The FloodHub system, developed by the BEYOND Center of Excellence at the National Observatory of Athens (NOA), an integrated Flood Early Warning and Near-Real-Time Flood Monitoring System, forms the foundation of the Use Case #1 system. The existing operational system integrates flood modelling with multi-source data, including in-situ observations with crowdsourced data, and advanced web-based technologies to provide an assessment of the flooded areas in near-real-time basis.

For hydrological and hydraulic application, the river basin of Mandra is divided into 21 subbasins given that the hydrographic network contains three main streams; Soures, Agia Ekaterini and Magoula, which cross the city of Mandra and Magoula, respectively. Also, the three hydrometeorological stations provided by the Beyond EO Center of NOA were established in upstream location in Soures stream, in diversion of Agia Ekaterini stream and in confluence of Soures and Agia Ekaterini streams (Figure 6).

The existing system is based on a dataset of pre-calculated Hydrological and Hydraulic simulations, and processes in real-time the recorded hydrometeorological measurements to automatically display the estimation of the flooded areas every 5-min via a web-based application.

The link for the existing platform is the following *https://floodhub.beyond-eocenter.eu/floodHub/#/pages/intro* and only registered users have access using their credentials.
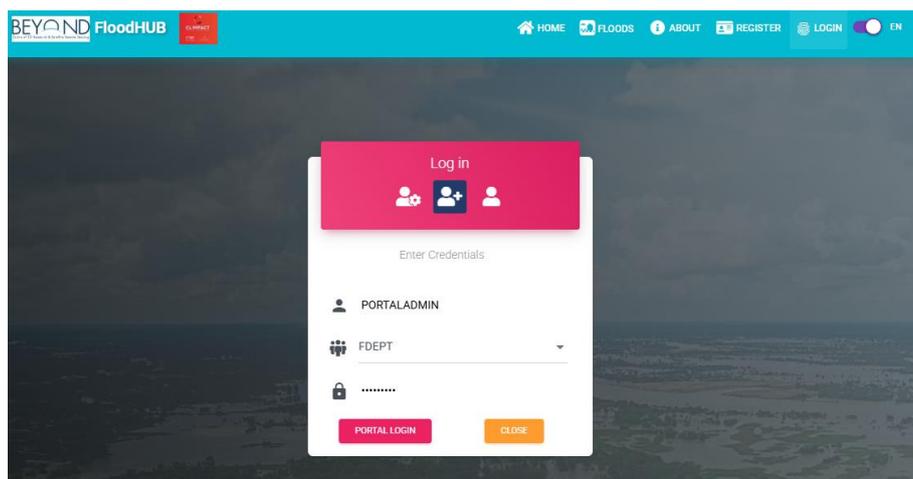

Figure 7: FloodHub platform login interface for registered users.

Building on this operational foundation, the new service developed under UNICORN will deliver "actionable forecasts" on a continuous basis, utilizing fully automated workflows that will be seamlessly integrated into the existing FloodHub platform.

Feedback from end-users regarding the current service has been overwhelmingly positive. Civil protection authorities, first responders (including fire services), and volunteer organizations recognize the value of the FloodHub platform. For instance, Mr. Eleftherios Kosmopoulos, Regional Vice-Governor of Attica, remarked at a recent international conference: "The BEYOND/FloodHub service monitors flood events in real time, offering immediate and accurate information that supports effective crisis management."

Data to be used and Copernicus services

The flood forecasting system relies on a combination of static and dynamic inputs, which are necessary for modelling and for the analysis. Static inputs include essential datasets such as the DTM (National Cadastre and Mapping Agency SA of Greece), Curve Number data (Ministry of Environment & Energy), Land use/Land cover (Copernicus Land Service), Burnt scar mapping (FireHub/NOA), hydrography data (Ministry of Environment & Energy) and the Ombrian curves (Ministry of Environment & Energy), and infrastructure details like buildings and road networks from OpenStreetMap. The dynamic inputs include real-time data from the three telemetric hydrometeorological stations, particularly water stage and precipitation time series (NOA). The precipitation and soil moisture forecasts are derived by the NOA operational weather forecasting model, which uses the Advanced Research WRF (ARW) model, a configuration of the Weather Research and Forecasting (WRF) model. Additionally, surface soil moisture data from Copernicus Land Monitoring Service together with the forecasted surface soil moisture and precipitation

data from WRF-ARW are integrated in the flood forecasting system. The integration of both static and dynamic inputs ensures that the system can accurately capture the evolving conditions that contribute to flood risk.

Table 3: Input data for the flood forecast system

Description	Spatial resolution/scale	Source
Static Inputs		
Digital Terrain Model	2 m	National Cadastre and Mapping Agency SA of Greece
Curve Number	Heterogeneous vectorial layer	Ministry of the Environment and Energy of Greece
Copernicus Urban Atlas Land Cover/Land Use	Heterogeneous vectorial layer	Copernicus
Burnt Scar Mapping (BSM)	Heterogeneous vectorial layer	NOA
Hydrography	Heterogeneous vectorial layer	Ministry of the Environment and Energy of Greece
Ombrian (I-D-F) curves	5 km	Ministry of the Environment and Energy of Greece
Open street map (buildings, road network)	Heterogeneous vectorial layer	Open street map (buildings, road network)
Dynamic Inputs		
Water stages timeseries from hydrometeo stations	Point	NOA
Precipitation timeseries from hydrometeo stations	Point	NOA
Surface Soil Moisture	1 km	Copernicus
Forecast Surface Soil Moisture (WRF)	2 km	NOA
Accumulated precipitation forecast (WRF)	2 km	NOA

Description of the Use Case

The overall objective of the use case is to expand the existing FloodHub's operational system by developing an advanced next 2-day flood forecasting system that integrates Copernicus satellite data with advanced weather forecast fusion techniques and hydrologic and hydraulic modelling for the Mandra Basin, Greece. More specifically, the new system will provide daily forecasts of flood extent and water depth for the following two days, at a spatial resolution of 2 meters—matching the highest-resolution Digital Terrain Model currently available.

The new UNICORN system leverages multi-source data, including precipitation and soil moisture forecasts from WRF-ARW model on a 2-km grid spacing, in-situ hydro-meteorological observations from 3 telemetric stations, pre-run scenarios derived by advanced modelling and data fusion analytics, to provide 2-day forecast of flood depth

and extent for the entire Mandra Basin to support practitioners and flood disaster managers in planning and preparedness actions. A key function of the system is to generate a-priori knowledge about flood-prone areas. This information is produced offline utilizing automated flood simulations based on HEC-HMS (rainfall-runoff model) and HEC-RAS 2D (hydraulic model) for numerous representative scenarios. These scenarios account for different return periods (T), precipitation durations (d), and Curve Number (CN) values, following the EU Flood Directive 2007/60/EC recommendations for flood hazard assessments. An extensive pre-calculated dataset of flood scenarios is stored in the system and appropriately retrieved for hazard map visualization.

Concerning the pre-run scenarios, hyetographs (precipitation timeseries) derived from ombrian curves, with different return periods (T), antecedent soil moisture conditions (CN I, II, III) and rainfall duration are the initial input data for rainfall-runoff model (HEC-HMS), which derives flood hydrographs (discharge timeseries) across the river basin. Then, flood hydrographs for each subbasin are utilized as input for the hydraulic modelling (HEC-RAS), exporting flood extent and flood depths. The geometry of each model is developed individually using GIS procedures and python-based automated procedures for HEC-HMS and HEC-RAS, respectively. Except for the HEC-RAS project creation, control and execution of multiple flood scenarios are also automatically run.

The meteorological forecasts of atmospheric and soil parameters will be provided from NOA/BEYOND's operational Numerical Weather Prediction (NWP) model, ensuring high-accuracy predictions. The forecasting system is based on the Weather Research and Forecasting – Advanced Research WRF (WRF-ARW) model, a widely used and advanced numerical weather prediction tool that supports research and operational weather forecasting worldwide. At NOA/BEYOND, WRF-ARW is running daily on a powerful in-house High-Performance Computing (HPC) infrastructure, which allows high-resolution simulations. The model operates in a multi-scale configuration, with a grid spacing of 6x6-km covering Europe and North Africa and an even finer 2x2-km grid over Greece. This fine spatial resolution enables the model to capture local atmospheric phenomena, such as convective storms, wind fields and temperature variations in complex terrains, including coastal and mountainous regions. Also, the model is initialized every day using data from the 12Z forecasting cycle of the Global Forecast System (GFS) from NCEP. Once initialized, the WRF-ARW model runs a detailed simulation of the atmospheric and soil conditions, generating forecasts for more than 300 parameters, including precipitation and soil moisture that will be input into the system consequently as part of our operational pipeline. The forecasts extend up to 60 hours (2.5 days).
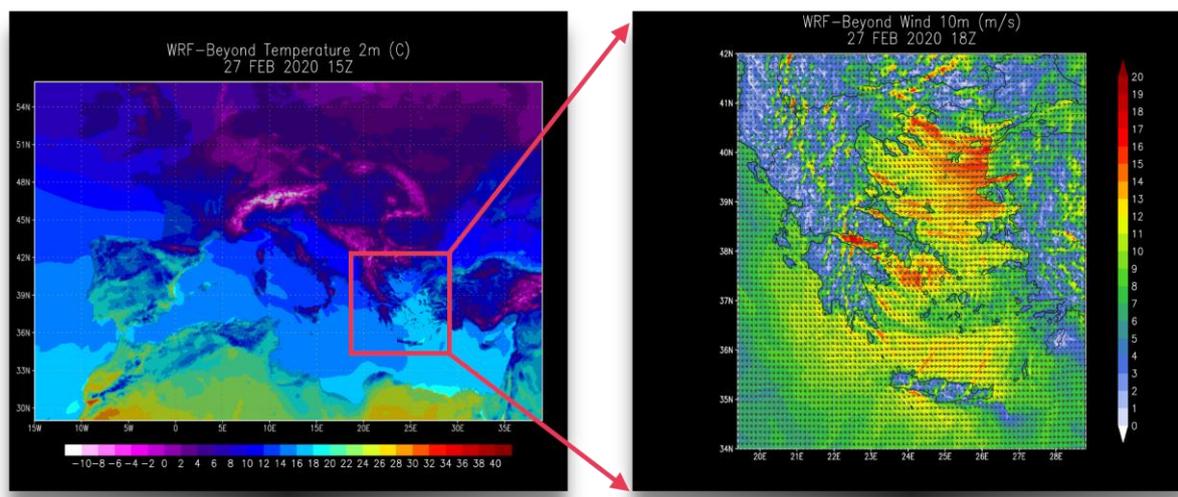
Figure 8: An example of temperature across Europe and wind speed across Greece on February 27, 2020, derived from the WRF model

Therefore, for operational performance, the system receives in real-time the 2-day high-resolution regional precipitation forecast from the latest WRF-ARW model with 2-km grid spacing. When forecasted rainfall reaches a critical threshold, the system automatically activates the rapid query and best fits the most relevant pre-run flood scenario to depict the flood extent and depth Map, by accounting for:

- Return period (T) and duration (d) of the forecasted precipitation
- 5-day antecedent soil moisture condition for Curve Number (CN) classification derived from the fusion of:
  - Precipitation data from the three telemetric stations positioned at critical points
  - Forecasted precipitation
  - Forecasted soil moisture
  - Copernicus Sentinel-1 Surface Soil Moisture data from the Copernicus Land Monitoring Service

Once the flood scenario is identified, the system generates a rapid and informed forecast. Moreover, the developed system will contribute to the European Flood Awareness System (EFAS) by providing in-situ observations from the 3 telemetric hydrometeorological stations, as well as the flood forecasts at very high-resolution at local level, addressing flash floods.

In principle, the hydrodynamic models, which are necessary for inundation maps production, can be computationally demanding, hence forming a significant burden in real-time flood forecasting. In this Use Case, instead of running models in real time, the system relies on a database of pre-computed simulations, to rapidly retrieve the appropriate inundation map from the database, minimizing delays while maintaining accuracy (an average running of the model requires around 1 hour, while the use of pre-run scenarios provides automated results in near-real-time).
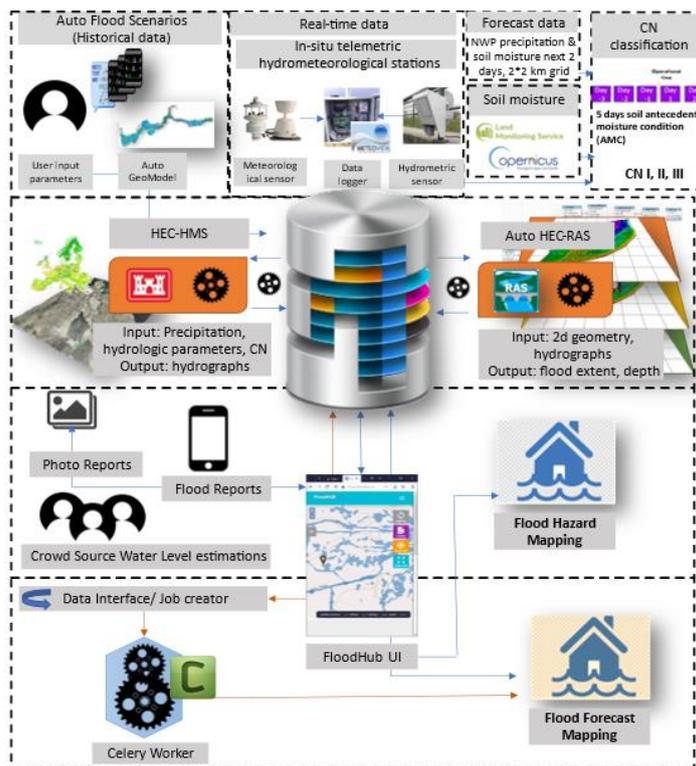
Figure 9: UNICORN's Flood Forecasting System Architecture and Modules

Methodology and Technologies to be used

The following technologies are planned to be used in the Use Case:

- Hydrological Modelling: HEC-HMS software for runoff estimation for the flood scenarios.

- Hydraulic Modelling - Automated creation, control and execution of the flood scenarios using python programming language: HEC-RAS 2-Dimensional models for flood extent and depth calculations.

- NOA' s operational Weather Forecasting system: WRF-ARW (2-km grid) for high-resolution precipitation predictions.

- Data Fusion:

  o Surface Soil Moisture from the Copernicus Land Monitoring Service for real-time CN adjustments.

  o WRF-ARW (2-km grid) for high-resolution soil moisture predictions.

  o In-situ hydro-meteorological observations from three telemetric stations (precipitation, water level, discharge).

  o WRF-ARW (2-km grid) for high-resolution precipitation predictions.

- Scenario Matching Algorithm: Automated selection of the most relevant pre-run flood scenario.

- Automated Processing: End-to-end system for real-time data integration, model selection, and hazard mapping. A backend infrastructure making use of the Flask WSGI web application framework in order to implement a restful API exposing a number of appropriate endpoints for data transmission between in-situ information, hazard maps, etc.

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- Web application: Web-based User Interface platform for flood forecasting, visualization, and decision support. The front-end of the existing platform will be co-designed/fine-tuned to facilitate specific user needs based on consultation with the relevant stakeholders. The web application architecture consists of:
  - o The MapServer Open-Source platform (https://mapserver.org/) for publishing the monitoring system's spatial data to the web.
  - o A Relational Database Management System (RDBMS) further extended to support Geographic Information System (GIS) operations on vector and raster datasets. The RDBMS of choice is the PostgreSQL relational database (https://www.postgresql.org/), extended via the PostGIS spatial extension (https://postgis.net/), in order to support geo-processing of vector and raster datasets. An appropriately configured raster data cube into the PostGIS RDBMS is utilized which in turn provides the tools in order to automatically publish the relevant hazard web-maps via the MapServer.
  - o The FloodHub Near-Real-time monitoring system User Interface (UI), implemented by making use of the Angular framework. The UI exposes the appropriate user control and mapping elements, thus allowing the dissemination of the relevant hazard maps and in-situ information, as well as the full management (publish, edit, delete, modify) of crowdsource information.
  - o The platform is fully asynchronous in order to distinguish data dissemination and crowdsource submission services from the background CPU intensive and time-consuming tasks. For this, in order to communicate between asynchronous threads, the Redis in-memory data structure store is used as a message broker in pair with Celery asynchronous job framework.
  - o The system also makes heavy use of the WebSockets protocol in order to achieve real-time data transfer between the server and the users disseminating crowdsource information. WebSocket is a computer communications protocol, providing full-duplex communication channels over a single TCP connection, thus allowing broadcasting of information to all connected clients without the need of hand shaking signals or the use of continuous polling requests from clients to flood monitoring system servers.

- Scalability & Efficiency: No need for real-time hydraulic simulations, allowing fast and accurate flood forecasts for decision support.

- Flood Risk Assessment: In the framework of a Programming Agreement with the Region of Attica which was recently concluded, flood hazard, vulnerability, exposure and risk were estimated at high spatial resolution (building block level), and safe shelters as well as evacuation routes were proposed to address the extreme scenario of a 1000-year return period flood (Tsouni et al., 2024).

Key Stakeholder involved directly and indirectly

The end user partner for the use case is the Civil Protection Directorate of the Region of Attica (RoA), which is responsible for the state-of-the-art Civil Protection Operations Center which offers a versatile asset that can be utilized in various corresponding tools. This advanced facility serves as a centralized hub for strategic decision-making and resource coordination, allowing for effective emergency management and response. Its capabilities can be adapted to meet the specific needs and requirements of different consortium projects.

Main targeted stakeholders / end-users are:

i. Public authorities: operational needs of the Civil Protection authority of the Mandra Municipality, Civil Protection authority of the Attica Region, Ministry of Climate Crisis and Civil Protection, as well as Civil Protection Volunteers' Associations, Fire Brigade, Schools and Traffic police to aid traffic control in evacuation situations

ii. Insurance sector

iii. Private businesses and Industry in the industrial area of Mandra which have premises in the river basin.

The outputs of the system will be considered as a useful tool in the hands of the relevant authorities supporting the decision – making process for the Civil Protection authority of the Attica Region, the Civil Protection authority of the Mandra Municipality, Fire Brigade and Traffic police. The outputs will be used for flood management purposes, as well.

The private companies and industries of the use case area could monitor the flood expansion in case of emergency. The insurance companies could also utilize the outputs of the system, detecting the flood prone areas. Schools could serve as potential shelters, provided they are safely located away from the flood zone.

Regulation and regulatory barriers (if any)

Flood forecasting systems must comply with multiple regulations (EU Floods Directive 2007/60/EC), Sendai Framework for Disaster Risk Reduction, United Nations Sustainable Development Goals (SDGs), UN Early Warnings for All Initiative), but face barriers such as data restrictions. Collaboration and policy updates can help overcome these challenges.

Scalability and replicability

The scalability and replicability of the flood forecasting system are significantly enhanced by its robust data integration capabilities. Ensuring the system can ingest diverse datasets, such as Digital Terrain Models (DTMs), Land Use and Land Cover (LULC) changes, soil properties changes allow it to adapt seamlessly to new regions without extensive reconfiguration. Furthermore, the system's flexibility to integrate and be further adapted using new datasets, such as newly acquired DTMs, updated LULC with forest fires, ensures it remains dynamic and responsive to evolving environmental conditions. This adaptability enables the system to be effectively scaled across different geographic areas and replicated in various hydrological contexts enhancing its overall reliability and utility.

Expected impact of the service

The expected impact of the flood forecasting system is substantial, particularly in enhancing early warning capabilities and reducing response times. By transitioning from a reactive monitoring approach to a proactive forecasting tool, the system enables authorities to predict potential flood events with greater accuracy and lead time. This shift empowers emergency planners with actionable insights, allowing them to implement targeted preparedness measures such as issuing timely evacuation alerts, mobilizing resources, and reinforcing vulnerable infrastructure. Civil protection agencies can make faster decisions, improving coordination and response efforts. Ultimately, this proactive approach minimizes property damage, mitigates economic losses, and enhances public safety by ensuring communities are better prepared for forthcoming flood events.

Visualization

Flood forecasts will be visualized as a supplement to the existing FloodHub platform (Figure 10) and will be updated following the respective temporal scale. A designated time window will indicate the reference time of the forecast outputs.
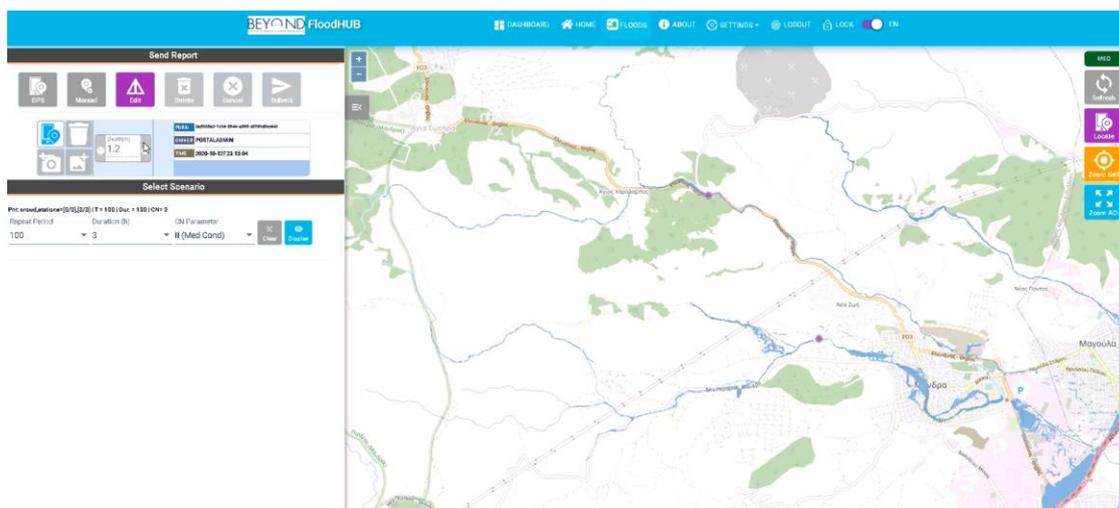
Figure 10: FloodHub web application and crowdsource platform

KPIs

The completeness and accuracy of input data are essential, as incomplete data can compromise the reliability of model outputs. By consistently assessing data such as DTMs, LULC changes that result in Curve Number adjustments, and the completeness of precipitation and water stage records, the system can maintain high data integrity. Additionally, during the testing period the predicted discharges and forecast precipitation need to be compared with the observed, for evaluating forecast and model accuracy, to achieve models' calibration with further improvements.

These two key performance KPIs "the completeness and accuracy of input data, and the comparison of predicted vs. observed precipitation, discharges and water levels" ensure the system leads to precise flood predictions that support effective decision-making.

For the quantification of the prediction error in terms mm of precipitation calculated by the model, the root mean square error (RMSE) is selected. Specifically, RMSE assesses the accuracy of modelled compared to observed data for precipitation. This indicator is frequently used, and its definition is given by

$$RMSE = \sqrt{\frac{\sum_{i-1}^{N}\ (O_i - P_i)^2}{N}}$$

where Oi represents the sample (of size N) containing the observations and Pi the model estimates, respectively.

An RMSE values range from 0 to ∞, with values closer to 0 indicating better model performance. The evaluation will take place through the intercomparison of daily accumulated precipitation derived from the 3 hydrometeorological stations in the region of Mandra against with atmospheric model outputs from the nearest grid point to the station.

Table 4: Performance ratings for precipitation based on RMSE and mean observed rainfall

Performance	RMSE (mm/day)
Good	< 10
Satisfactory	10-20
Unsatisfactory	> 20

For the calibration of the rainfall-runoff model, discharges will be utilized, while water levels will be used for the calibration of the hydraulic model. In hydrological modelling, the Root Mean Square Error (RMSE) serves as a key metric for evaluating model performance. However, establishing a universal RMSE threshold applicable across all hydrological models is challenging due to the diverse scales, data variability, and specific objectives inherent to each model. To address this variability, the Ratio of the RMSE to the Standard Deviation of observed data (RSR) is often employed, as it standardizes the RMSE, facilitating comparisons across different datasets (Moriasi et al., 2007).

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} - (\gamma_i^{obs} - \gamma_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n} - (\gamma_i^{obs} - \gamma_i^{mean})^2}\right]}$$

where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y mean is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

RSR combines the advantages of error index statistics with a scaling/normalization factor, allowing the resulting statistic and reported values to be applicable to different constituents. RSR ranges from an optimal value of 0, representing zero RMSE or residual variation—indicating perfect model simulation—to a large positive value. A lower RSR corresponds to a lower RMSE, signifying improved model simulation performance.

According to the Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS) guidelines, model performance ratings based on RSR values are categorized as follows:

Table 5: Performance ratings based on RSR values

Very Good: RSR between 0.00 and 0.50
Good: RSR between 0.50 and 0.60
Satisfactory: RSR between 0.60 and 0.70
Unsatisfactory: RSR greater than 0.70

Finally, during the testing period, the flood extent derived from the hydraulic model will be evaluated properly from the end users by assessing the flood extent. The overall accuracy should be over 85 % (> 85%) based on the feedback from the end users, namely the difference between simulated and observed (by the end users) flood extent should be <15%.

Risks

One potential risk in the implementation of the flood forecasting system is the delayed delivery of the hydraulically accurate DTM created during the recent updated phase of the Flood Risk Management Plans, which was requested from the Ministry of the Environment and Energy of Greece. In the case of such a delay, the initial DTM provided by the National Cadastre and Mapping Agency SA of Greece, will be used with appropriate modifications.

Another critical risk to consider is the potential failure or non-operation of hydrometeorological stations. Such disruptions can compromise the availability of critical real-time data, such as precipitation records. To mitigate this risk, alternative precipitation datasets from another hydrometeorological station in the wider area, named Gyra

Sarantapotamos, will be utilized. These datasets are freely accessible through the OpenHi platform (https://system.openhi.net/). This approach ensures the continuity of data inputs and maintains the system's functionality.

Monitoring plan

The proposed monitoring plan includes several key actions to ensure data reliability and system effectiveness.

First, the plan includes regular checks (every month) on the consistency and accuracy of data transmitted from hydrometeorological stations to quickly detect and address any errors or issues. First, for calibration of the WRF-ARW model, precipitation forecast will be evaluated as described in the KPIs. Afterwards, discharges will be checked necessarily for the calibration of rainfall-runoff model. Additionally, the plan involves monitoring significant changes in Land Use and Land Cover (LULC), such as areas affected by fires, which will be assessed once a year at the end of the summer. Furthermore, the plan includes an annual inspection of newly constructed technical works (e.g. culverts, diversions), that may alter river flow patterns and impact flood dynamics.

By implementing these measures, the monitoring plan ensures the system remains robust, adaptable, and capable of delivering accurate flood forecasts.

6.2 Use case 2A - Copernicus-based wildfire early detection, mapping and nowcasting

Wildfire events in regions with dense vegetation pose significant risks to lives, property, and the environment, particularly in vulnerable areas such as North Corsica where drought, strong winds, and rapid urban expansion exacerbate fire risks. The UNICORN wildfire early detection system enhances preparedness by integrating Copernicus satellite Earth Observation data, real-time weather forecasts, and advanced AI-driven analysis. This system delivers operational mapping and simulation of wildfire spread—including precise fire delineation and risk assessment—to support timely decision-making and optimize resource allocation during emergency response operations.

Triggering event

Wildfires

Location

The chosen location for this wildfire monitoring and prediction use case is Northern Corsica (Haute-Corse), France. Corsica is an island in the Mediterranean Sea characterized by its diverse landscape of mountains, forests, and coastal areas, making it particularly vulnerable to wildfire events.

Northern Corsica is managed by the Fire and Rescue Service of Haute-Corse (SIS2B), which is responsible for preventing, protecting, and fighting fires across the region. SIS2B protects a population that varies from approximately 180,000 permanent residents to 400,000 people during the summer tourist season, managing this area through a network of 20 fire brigades strategically spread throughout the territory.

The topography of Northern Corsica features varied elevations and terrain types. The region includes both coastal areas and mountainous zones, with fire risk heightened during the dry summer months. The Mediterranean climate, characterized by hot summers and mild winters, combined with specific wind patterns, creates conditions conducive to wildfire propagation.

The selected area includes the municipality of Biguglia, which was significantly impacted by the "Olmeta di Tuda" fire in 2017. This historical fire event occurred during a period when the island experienced unfavorable weather conditions including drought, strong winds, and high temperatures, leading to multiple fires across the area. The Olmeta di Tuda fire was characterized by its high intensity and had severe impacts on homes and the local population.

SIS2B manages approximately 450,000 hectares of highly flammable forest and vegetation in this region, with an average of less than 1,500 hectares of forest burned yearly since 2003. The organization also maintains a comprehensive database containing more than 15,000 scenarios for fighting forest fires, providing valuable historical data for analysis.
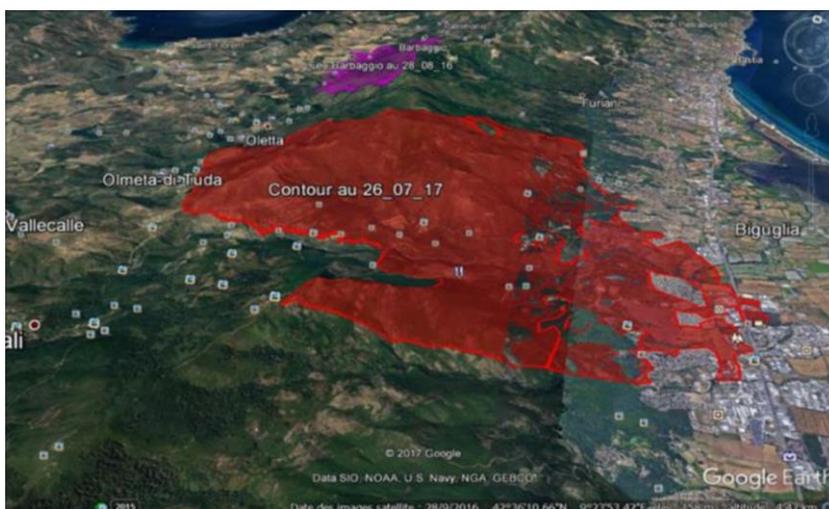
The Fire and Rescue Service operates an advanced operations coordination centre with 7-17 employees present 24/7 for management and control, equipped with numerous tactical coordination and modelling tools to support emergency response operations.

Background and Challenge to be addressed and Anticipated Benefits

Wildfires pose significant dangers across Mediterranean landscapes, with increasing frequency and severity due to climate change conditions. In Europe, 2022 marked the second-worst year for wildfires, causing substantial environmental and economic impacts. Wildfires affected 26 out of 27 EU countries, burning 837,212 hectares—an 86% increase from 2021, with Spain, Romania, Portugal, Bosnia and Herzegovina, and France among the most affected regions.

Current fire management in Corsica faces several gaps that need to be addressed:

- Lack of precise fire detection with accurate location mapping capabilities

- Absence of automatic simulation systems for fire propagation

- Limited capability to define emergency scenarios involving affected homes and appropriate fire-fighting strategies

- Need for improved operational mapping using satellite data (including burnt area assessment and active/inactive fire front identification)

The UNICORN project aims to address these challenges by developing a comprehensive wildfire monitoring and prediction system that integrates Earth Observation (EO) data from Copernicus services with advanced modelling techniques. This system will provide a seamless data chain for wildfire detection, mapping, and simulation to enable faster response times and better-informed decision-making regarding fire suppression strategies.

The anticipated benefits of this use case include:

- Enhanced precision in wildfire mapping (delineation) through advanced AI models
- Improved accuracy of fire simulations considering current weather conditions and vegetation
- Accelerated activation of alerts to responsible authorities
- Optimized resource utilization for maximum efficiency
- Delivery of real-time, accurate maps to operations commanders showing fire delineation, burned area, and impacted houses
- Development of AI solutions for propagation risk simulation, risk assessment for homes, and population risk analysis
- Access to crucial parameters such as real-time weather, spread speed, and fire front positions—vital information for successful forest firefighting in extreme weather conditions when data from ground or aerial reconnaissance may not be reliable

By implementing this system, UNICORN's results could significantly assist first responders and operational commanders in managing large-scale forest fires in North Corsica and eventually be extended to other fire-prone regions across Europe.

Requirements from task 2.1 and Key Stakeholder Needs

The requirements and needs of key stakeholders—from "disaster management" professionals to the "scientific community" and "industry" players—are clearly delineated in both the D2.1 End-users' Requirements Report and the UNICORN proposal. In the context of wildfires, particularly for Use Case 2A—Copernicus-based wildfire early

detection, mapping, and nowcasting—it is evident that there is an acute demand for "high temporal resolution (2-5 hours or daily)" data across all products. Such frequent updates are vital to enable users to rapidly implement preparedness plans and adapt their emergency management strategies in response to the evolving nature of wildfire events.

In addition to temporal sensitivity, there is a pronounced user preference for "local scale" information. This is especially critical for products that deliver insights into "meteorological conditions", "danger specific indexes", "early warning and near real-time alerts", "actionable forecasts", "situation awareness", and "evacuation recommendations". The emphasis on local-scale data underlines the necessity for detailed forecasting and precise assessment of a wildfire's spatial extent and progression.

The Corsica pilot, a prime example within Use Case 2A, reinforces these requirements. Here, the integration of satellite-based Earth Observation data with advanced processing techniques is used to generate near real-time alerts and detailed fire mapping. Local stakeholders in Corsica have validated the importance of continuous, high-resolution data delivered via an intuitive "web portal"— demonstrating the system's capacity to enhance decision-making and resource allocation during wildfire emergencies.

Overall, the approach encapsulates a robust integration of cutting-edge Copernicus services with direct end-user feedback, ensuring that the resulting applications are finely tuned to meet the operational challenges posed by wildfires. This synthesis of technology and user requirements not only supports proactive emergency management but also strengthens the resilience of communities impacted by these increasingly frequent and severe wildfire events.

Data to be used and Copernicus services

The wildfire monitoring and prediction system for Northern Corsica relies on a combination of static and dynamic inputs necessary for effective modelling and analysis. These inputs are integrated to support all phases of the emergency management cycle: prevention and preparedness, detection and response, and adaptation and restoration.

Table 6: Input data for the fire detection and delineation system

Description	Spatial resolution/scale	Source
Static Inputs		
Land Cover/Land Use	10m	LINKS
Critical infrastructure and technical works	Vector layer	Technical studies, field visits, OSM
Population and building data	1km2	Riscognition
Historical fire database	Vector layer	Haute Corse database, EFFIS
Fuel data	~100m	FIRE-RES / FireEUrisk / MITIGA
Elevation, Slope and Aspect (DEM)	10m	Copernicus
Dynamic Inputs		
Active fire detection (hotspots)	375m-1km	NASA/NOAA
Sentinel-2 data	10m-60m	Copernicus

Sentinel-3 data	300-1000m	Copernicus
Real-time fire monitoring	Various	MSG SEVIRI satellite data
Meteorological variables (wind, temperature, precipitation, relative humidity)	Various	Copernicus (ERA5) / ECMWF (IFS) / Meteo-France (AROME)

i. Active Fire Detection (Hotspots)

The system employs a multi-satellite approach that begins detection with the first available satellite data and progressively refines the detection as additional satellite passes become available. The use of multiple satellite sources (Sentinel-2/3, EUMETSAT MSG/MTG, NASA MODIS/VIIRS) addresses well-known limitations of satellite-based applications, such as revisit time and variable image quality. For example, the MODIS sensors aboard NASA's Terra satellite detect hotspots at 1km resolution, while VIIRS provides enhanced detection capabilities at 375m resolution. On the European side, Copernicus provides Sentinel-2 and Sentinel-3 products at resolutions of tens and hundreds of meters respectively. The Meteosat Second Generation (MSG) SEVIRI and Meteosat Third Generation (MTG) FCI instruments, with their low revisit times, provide fire detection capabilities with high temporal resolution, enabling continuous monitoring despite their coarser spatial resolution. By leveraging the different orbital patterns and overpass times of multiple satellites, the system maximizes temporal coverage, potentially providing multiple observations per day over the same location. Initial detections from lower-resolution sensors are subsequently validated and refined when higher-resolution data becomes available, creating a cascading detection system that balances speed of detection with accuracy. This is particularly valuable for tracking rapidly evolving fire situations.

ii. Burned Area Mapping

The system utilizes advanced Earth Observation data processing to deliver accurate burned area assessments:

1. Satellite-based Mapping: The primary source for burned area delineation is Sentinel-2 multispectral imagery, processed through AI algorithms to produce maps with 10m resolution. The service is activated "on demand" by triggering a map request that defines the area of interest and time interval.
2. Fire Severity Assessment: Using pre- and post-fire satellite imagery comparisons, the system calculates burn severity indices such as the Normalized Burn Ratio (NBR) and differential NBR (dNBR) to quantify fire impacts on vegetation, soil, and infrastructures comparing the affected area to static maps.

iii. Fire Spread Nowcasting

The system provides forecasts of fire spread and other fire behaviour metrics for the next hours using a physics-based model. This module consists of the following steps:

3. Identification of fire initial state: Fire spread simulations can start from one or multiple ignition points, or from a fire perimeter. This information is provided as an input to this module, which converts it to the appropriate geographical format to be used by the model.
4. Meteorological data preprocessing: Information about the wind, temperature, relative humidity and precipitation is required to forecast the evolution of the fire, but also to set up the initial fuel humidity and weather conditions. In this step the meteorological data is downloaded from ERA5 (for historical events), AROME or ECMWF-IFS (for forecasting); and then it is pre-processed to be used as inputs by the model.

5. Landscape preparation: According to the location of the fire, a file containing information about the terrain, fuel models and other vegetation characteristics is prepared.

6. Fire spread modelling: The spread of the fire is predicted using the two-dimensional deterministic fire growth model FARSITE (Finney, 1998). FARSITE incorporates existing models of surface fire, crown fire, spotting, and fuel moisture, which are integrated using a vector propagation technique for fire perimeter expansion, simulating the fire growth over the landscape.

Description of the Use Case

The overall objective of this use case is to develop an advanced wildfire management system for Northern Corsica that enhances the detection, monitoring, prediction, and impact assessment capabilities throughout all phases of the disaster risk management cycle: prevention and preparedness, detection and response, and adaptation and restoration.

The UNICORN system leverages multi-source data integration, combining EO data from Copernicus services with weather forecasts, topographic data, and crowdsourced information to create a comprehensive emergency management solution. The system implements several intelligent services that work in coordination to support decision-making during wildfire events.

The core of the system is built around the following interconnected modules:

1. Active Fire Detection System: The system implements a multi-satellite approach for near real-time fire detection, leveraging thermal data from multiple sensors. Detection begins with the first available satellite data (MODIS, VIIRS, MSG SEVIRI, Sentinel) and progressively refines as higher-resolution data becomes available. This cascading detection mechanism balances detection speed with accuracy, providing crucial early information about new fire starts.

2. EO-Based Fire Delineation and Burned Area Mapping: This service provides automated mapping of active fires and burned areas using Sentinel-2 multispectral imagery. When activated with a specified area of interest and time interval, the system retrieves relevant satellite imagery, applies machine learning algorithms to extract burned area boundaries, and generates severity estimations. The outputs include standardized GeoTIFF files that can be easily integrated with other geospatial tools.

3. On-Demand Wildfire Nowcast and Forecast: When a fire is detected, this service provides predictions of fire spread and potential impacts based on established fire propagation models. The system integrates meteorological data (relative humidity, air temperature, precipitation, wind speed and direction), land cover information, and topographic data to simulate fire behaviour. It produces hourly vector files showing probabilistic fire perimeters and high-resolution raster maps of rate of spread and fireline intensity. This enables responders to develop strategic response plans, including potential evacuation needs or resource allocation.

All these services are integrated through a centralized platform that provides a unified web-based dashboard for visualization and interaction. The platform follows a service-oriented architecture with standardized APIs that enable efficient data exchange between components. Data is stored in a GeoData repository that enforces INSPIRE-compliant metadata standards, ensuring that all information is Findable, Accessible, Interoperable, and Reusable (FAIR).

The use case will be demonstrated and validated in Northern Corsica in collaboration with the Fire and Rescue Service of Haute-Corse (SIS2B), focusing particularly on areas that have been affected by significant fire events in the past, such as the "Olmeta di Tuda" fire of 2017. By combining these advanced technological solutions with

operational expertise from local stakeholders, the UNICORN system aims to significantly enhance the resilience of Corsican communities against the growing threat of wildfires in the Mediterranean region.

Existing knowledge

The ERMES platform, created within the SAFERS project, developed by LINKS Foundation and partners within the Horizon 2020 program, forms the foundation of this use case. ERMES is a comprehensive Emergency Management System that integrates Earth Observation data from Copernicus with crowdsourced information and sensor data to support the entire disaster risk management cycle for forest fires.

LINKS has developed an advanced EO-based fire delineation and burned area mapping service that forms a key component of the ERMES ecosystem. This service employs deep learning image segmentation techniques to automatically map burned areas with high accuracy using Sentinel-2 data. Unlike previous approaches that rely on simple spectral indices, the LINKS solution delivers improved spatial resolution (10m) and classification accuracy through state-of-the-art convolutional neural networks.

MITIGA has extensive experience in the use of numerical models for the prediction of wildfire spread or for the calculation of fire damage indices, both in high-performance computing environments and in cloud services, using technologies such as Argo Workflows, Terraform, Kubernetes, APIs or Docker for cloud cluster environments. MITIGA has developed previous work on wildfire forecast systems in projects such as FIRE-RES or MedEWSa.
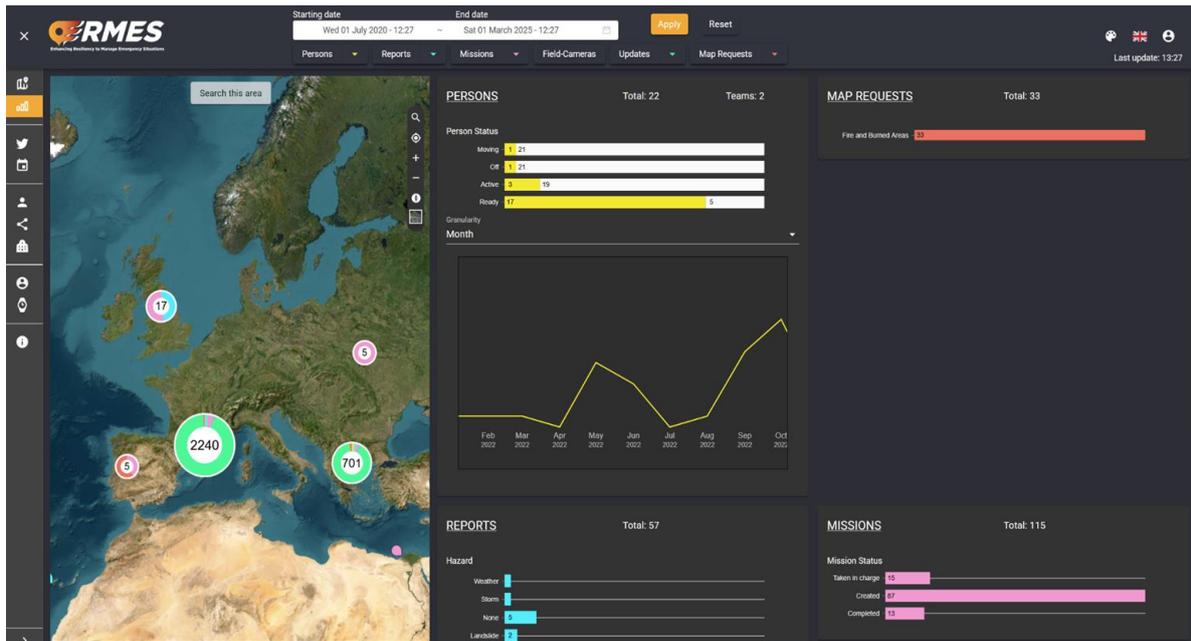
Figure 12: ERMES' dashboard example

The burned area mapping service can be activated on-demand and produces not only binary burned/unburned, but also a multiclass severity assessment that quantifies damage levels across the affected landscape. This capability is critical for both immediate emergency response and post-fire recovery planning.

The current system is accessible via a web-based dashboard that serves as the central interface for all ERMES services, allowing users to visualize different data layers, request on-demand processing, and receive alerts about

ongoing events. The system also includes a common Geodata Repository and utility databases/storages to facilitate the interaction between different services.

Figure 13: Overview of the ERMES platform's architecture with the relevant EO services

Methodology and Technologies to be used

The proposed approach utilizes state-of-the-art AI models for image analysis and segmentation, integrating multiple data 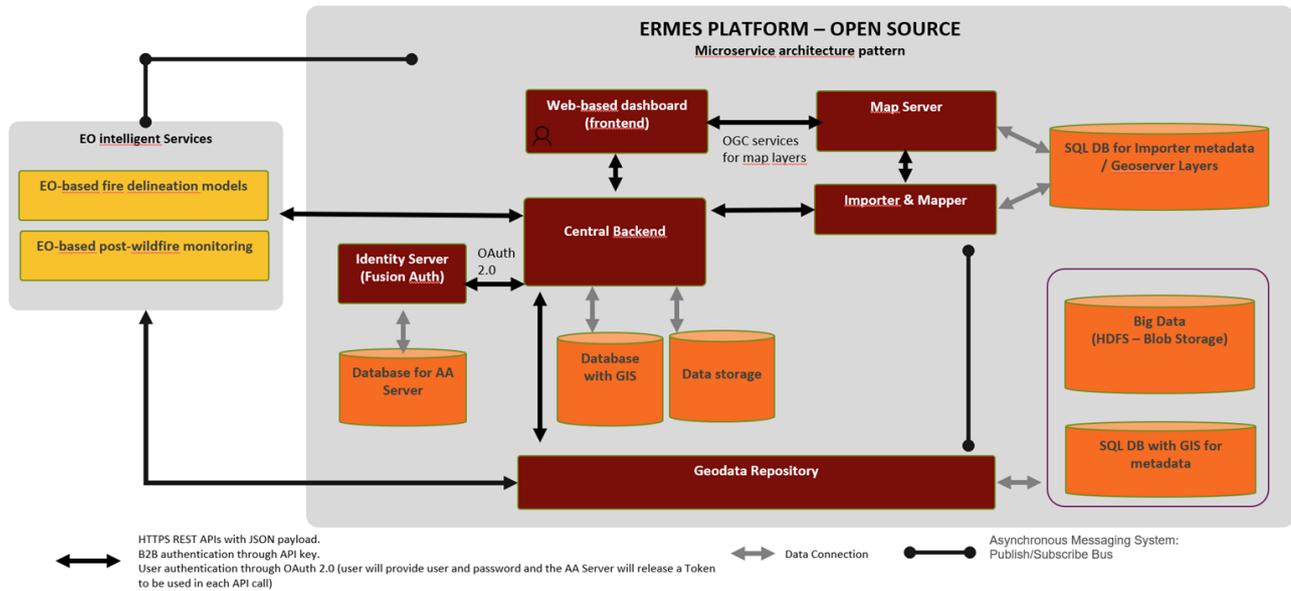streams from satellites and aerial sources. Data fusion is carried out to combine real-time imagery with weather forecasts and topographic inputs. The system leverages advanced deep neural network architectures, such as convolutional neural networks (CNNs) or transformer-based models (e.g., U-Net variants or SegFormer), to detect fires and delineate the impacted areas.

The methodology incorporates comprehensive data collection and preprocessing pipelines to handle diverse inputs including Sentinel-1 SAR data, Sentinel-2 multispectral imagery, and high-resolution aerial photography when available. These pipelines implement automated cloud masking, atmospheric correction, and image registration to ensure data quality and consistency. The AI models are supported by extensive training processes using labelled datasets of historical fire events, with regular model updates to adapt to seasonal changes in vegetation patterns. For fire propagation modelling, the system implements physics-based simulations that account for fuel characteristics, topography, and meteorological conditions. These models balance computational efficiency with predictive accuracy, enabling rapid scenario generation for decision support. The entire workflow is orchestrated through a modular architecture that allows for component-level updates and enhancements as new methods and data sources become available.

Key Stakeholder involved directly and indirectly

The end user partner for the use case is the Fire and Rescue Service of Haute-Corse (SIS2B), which is responsible for preventing, protecting, and fighting fires in North Corsica. SIS2B benefits from 20 fire brigades geographically spread throughout North Corsica and an operations platform which manages 17,000 operations annually (including more than 1,000 forest fires). With a team of 1,300 firefighters, SIS2B protects a population varying from 161,000 to approximately 400,000 people in summer. This advanced operational coordination centre serves as a centralized hub for strategic decision-making and resource management, allowing for effective emergency response across the region.

Main targeted stakeholders / end-users are:

1. Public authorities: operational needs of the Civil Protection authorities at local and regional levels, including SIS2B, municipal fire services, Collectivité de Corse (regional government), Office National des Forêts (ONF), as well as Civil Protection Volunteers' Associations that support firefighting operations during peak fire seasons
2. Insurance sector: companies providing coverage for properties and assets in wildfire-prone areas who require accurate risk assessment and damage evaluation
3. Tourism industry: operators of campsites, resorts, and tourist accommodations in forested areas who need timely evacuation information and risk awareness
4. Forestry sector: managers responsible for wildfire prevention, forest management, and post-fire restoration across Corsica's extensive forest lands
5. Local communities: permanent residents in the wildland-urban interface areas who need early warnings and evacuation guidance during fire events.

The outputs of the system will be considered as a useful tool in the hands of the relevant authorities supporting the decision-making process for SIS2B's operational coordination centre, local fire brigades, and municipal emergency services. The system's fire detection, spread prediction, and impact assessment capabilities will be used for strategic resource allocation, evacuation planning, and post-event damage assessment.

The tourism operators in wildfire-prone areas could monitor fire danger levels and active fire progression to ensure visitor safety during the critical summer season. The forestry sector could utilize burned area mapping and severity assessment for prioritizing restoration efforts. Insurance companies could leverage the system's risk mapping and damage assessment capabilities to improve policy pricing and claims processing. Local communities would benefit from timely warnings and clear evacuation guidance based on the system's predictions.

Regulation and regulatory barriers (if any)

Wildfire monitoring and prediction systems must comply with multiple regulations including the EU Civil Protection Mechanism, EU Forest Strategy 2030, and international frameworks such as the Sendai Framework for Disaster Risk Reduction and UN Sustainable Development Goals. Key regulatory requirements include INSPIRE compliance for spatial data and GDPR compliance for personal information processing.

Potential regulatory barriers include:

- Data privacy restrictions when collecting location data from field personnel and citizens
- Limitations on sharing sensitive infrastructure information across national borders
- Varying emergency communication regulations in different countries
- Liability concerns regarding actions taken based on fire prediction models

In Corsica specifically, SIS2B operates under French national emergency management protocols that govern how alerts can be issued and evacuations ordered. The system design accommodates these requirements through appropriate user authentication levels, clear uncertainty communication, and standardized alert protocols compliant with French regulatory frameworks.

These barriers can be addressed through stakeholder collaboration, transparent data policies, and the system's modular architecture that adapts to regional regulatory requirements.

Scalability and replicability

The scalability and replicability of the wildfire monitoring system are significantly enhanced by its robust Earth Observation data processing capabilities. The system's core functionalities of hotspot detection and burned area mapping rely on standardized satellite data products that are available globally, particularly Sentinel-2 multispectral imagery and thermal anomaly detection from Sentinel-3, MODIS, and VIIRS.

The deep learning models developed for burned area mapping can be efficiently transferred to new regions through fine-tuning with limited local training data. This transfer learning approach significantly reduces the adaptation effort when deploying the system in new geographic contexts. The 10-20m resolution capability of the burned area mapping service provides consistent performance across diverse Mediterranean landscapes.

Furthermore, the system's modular design allows for the hotspot detection and burned area mapping components to be deployed independently or as part of the complete UNICORN ecosystem. This flexibility enables organizations with varying technical capabilities to adopt only the components that meet their specific needs.

The experience from the Corsican pilot site with SIS2B will provide valuable implementation insights, particularly regarding the integration of satellite-derived burned area maps with local firefighting operations. The successful validation of these capabilities in Corsica's diverse landscape of Mediterranean maquis vegetation will establish a solid foundation for replication in similar ecosystems.

This adaptability enables the system to be effectively scaled across different geographic areas and replicated in various wildfire management contexts, enhancing its overall utility for fire detection and impact assessment throughout Europe's fire-prone regions.

Expected impact of the service

The system is expected to significantly enhance the precision of wildfire mapping and the accuracy of propagation simulations, thereby accelerating alert activations and optimizing the allocation of firefighting resources. By providing operational commanders with real-time, detailed maps—including burned areas, fire fronts, and threatened homes—the system aims to improve overall emergency response outcomes during wildfire events.

Visualization

Real-time visualization components will display the detected wildfire, including its delineation (burned area and active or inactive fronts) and the simulated propagation path. These visual outputs are designed to deliver clear, actionable information to operations commanders to support rapid decision-making during firefighting operations.
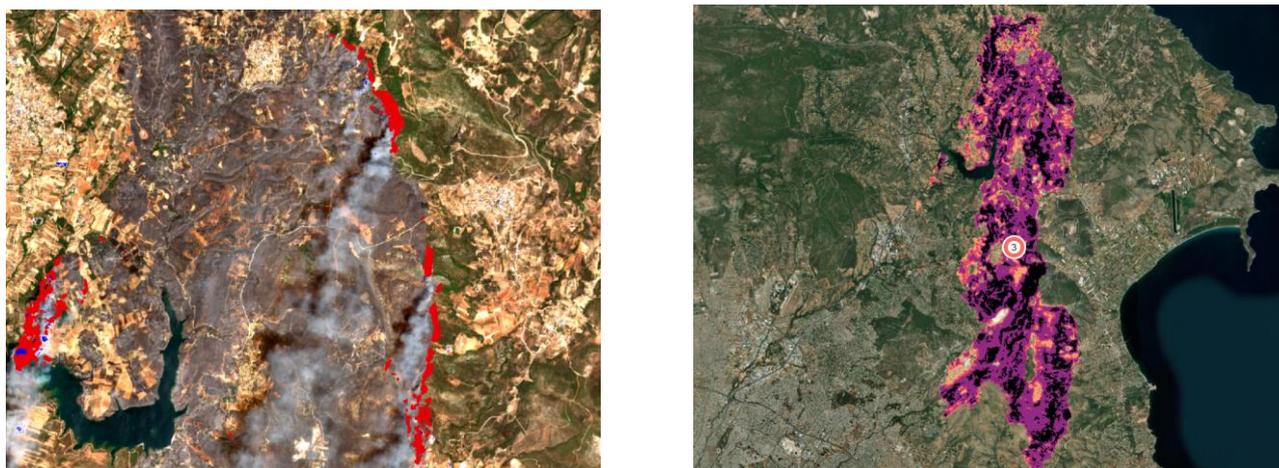
Figure 14: Example of hotspot identification and burned area mapping layers

KPIs

The performance of the system will be evaluated based on several KPIs: the involvement of more than 15 organizations in solution validation, detection of more than 90% of fire events, mapping accuracy of at least 85%, detection speed under 15 minutes, fire simulation speed under 3 minutes, and mapping speed under 1 minute.

To rigorously measure these KPIs, we will track organizational involvement through workshop participation and system usage during validation. For technical performance, we will develop a curated dataset of historical fire events to evaluate detection rates using standard metrics (precision, recall, F1-score). Mapping accuracy will be assessed by comparing system-generated fire perimeters with validated reference data using Intersection over Union calculations.

Speed-related KPIs will be measured by timing the complete processing chain under various conditions, with results normalized to standard area sizes for consistency. All performance metrics will undergo both laboratory testing with historical data and field validation during the pilot implementation phase, ensuring the system meets operational requirements while delivering tangible benefits to end-users.

Risks

Identified risks include potential delays or inaccuracies in obtaining near real-time aerial or satellite data, limitations inherent in AI model performance under varying conditions, and the overall challenge of transitioning from manual reconnaissance methods to an automated detection system. These issues could affect the system's real-time effectiveness if not properly mitigated.

Monitoring plan

A continuous monitoring strategy will be implemented that involves regular performance validation against the defined KPIs, stakeholder feedback loops, and periodic reviews of data quality and system accuracy. This plan ensures the system remains robust and responsive, and that any emerging issues are rapidly addressed through collaborative efforts among the involved agencies.

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6.3   Use case 2B - High-resolution fire danger forecast

Wildfires in Europe are predominantly of anthropogenic origin, a characteristic that distinguishes them from other natural disasters. Despite this, fire damage indices are generally based on meteorological conditions or vegetation conditions, leaving aside the important factor of human activity. By combining machine learning techniques with physics-based models, Unicorn's high-resolution fire danger product aims to fill this gap and serve as a basis for emerging parametric insurance products in the forestry sector.

Triggering event

Wildfires

Location

The area of interest for this use case is the Northwest of the Iberian Peninsula, a cross-border region encompassing the north of Portugal and the Spanish regions of Galicia, Asturias and Leon (Figure 15).
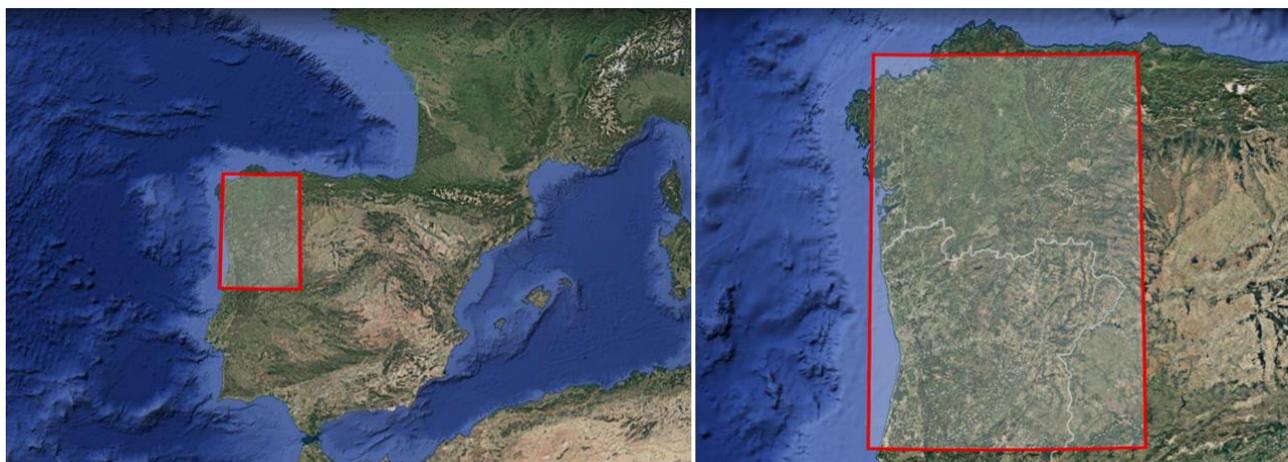

Figure 15: Area of interest of Use case 2B in the Northwest of the Iberian Peninsula.

Wildfires are a significant environmental and socioeconomic challenge in this region. It has a high fuel availability due to its climatic conditions of abundant rainfall and warm temperature out of the fire season, which together with the very dry and hot conditions during the summer months make this region highly susceptible to wildfires, becoming one of the most fire-prone regions in Europe.

In addition to favourable climatic conditions, wildfires in this region are also linked to certain human activities. Many fires are caused by negligence or intentional arson. In addition, the process of rural abandonment experienced by this region in recent decades has forced changes in land use, which also conditions fire activity.

Background and Challenge to be addressed and Anticipated Benefits

Given the high activity and fires in this region, the economic and social impacts are notorious. In 2017, more than 500,000 hectares burned in Portugal resulting in more than 120 fatalities (Turco et al., 2019). In 2006 more than 100,000 hectares burned in the region of Galicia alone, whose direct and indirect losses related to forest and their services have been estimated between 220 and 300 M€ (San-Miguel-Ayanz et al., 2013).

In recent years, this region has experienced multiple fire extreme events that have resulted in large economic losses and significant risks for local communities. The fires of July 2022, enhanced by the extreme heat wave in south-western Europe, also experienced extreme behaviour, with multiple fires developing pyroconvective processes (Rodrigues et al., 2023). The October 2017 fires occurred under extremely favourable spread conditions associated

with the passage of Hurricane Ophelia off the coast of the Iberian Peninsula (Turco et al., 2019). Along with the high simultaneity of human-caused ignitions, this resulted in multiple fatalities and a major socio-ecological impact.

Common fire danger indexes, like the well-known Canadian Fire Weather Index (FWI, Canadian Forestry Service. (1970) and Simard, A. J. (1970)), are useful tools for identifying the weather conditions that are suitable for fire activity. But they do not take into account some important features that can have also an influence on wildfire damages: they do not represent the ignition probability (since this is closely related with human activities), they do not consider vegetation characteristics like fuel continuity, they do not solve how the fires will spread and they do not measure the exposure or vulnerability of assets.

In addition, the characteristic ownership regime of the forest in this region, which combines private and public owners and very different sizes of properties, hampers both the implementation of mitigation measures and the estimation of damage. This makes low-resolution fire danger products of limited applicability in the insurance sector.

UNICORN Use Case #2B aims at building a system for fire danger forecasts that can fill these mentioned gaps. It will be based also on weather data, but with the use of Machine Learning models trained with historical data we can also take into account other factors, like vegetation or ignition probability, in addition to achieving a higher spatial resolution.

The system aligns with key European and international policies, including:

- EU Civil Protection Mechanism (UPCM)
- EU Forest Strategy for 2030
- Sendai Framework for Disaster Risk Reduction
- United Nations Sustainable Development Goals (SDGs)

The system will analyse weather and vegetation data and combine Machine Learning models trained with fire observations with physics-based models, to produce high-resolution fire danger forecasts that can be suitable for their application in the insurance sector.

Requirements from task 2.1 and Key Stakeholder Needs

As detailed in Deliverable D2.1 End-users' Requirements Report, there is a clear need for wildfire products of "local spatial scale" and "high temporal resolution (daily)". Regarding the spatial resolution, the lack of high-resolution fire danger products is already pointed out as an existing gap, and achieving a high spatial resolution is defined as a key point in this Use Case.

The requirements in terms of temporal resolution are more variable. Although in general the Deliverable D2.1 indicates a preference for daily products, the insurance company Allianz S.E., as partner of this Use Case through a Letter of Support, has indicated a seasonal temporal resolution need for "danger specific indexes", and a yearly temporal resolution for a probabilistic severity model.

The ignition probability part of the system is expected to be provided on a continuous basis, while the much more computationally demanding fire spread modelling of the ignitions is expected to be provided on demand.

Data to be used and Copernicus services

The UNICORN high-resolution fire danger system relies on multiple input datasets, both dynamic and static. Many of these datasets are provided by Copernicus. A description of each input is included in the following table.

Table 7: Input data for the high-resolution fire danger forecast system

Description	Spatial resolution/scale	Source
Static Inputs		
Historical ignition points	Vector layer	ICNF (Portuguese forestry service) and Spanish Ministry for Ecological Transition and the Demographic Challenge
Historical burned areas	Vector layer	Copernicus Emergency Service, European Forest Fire Information (EFFIS)
Elevation, Slope and Aspect (DEM)	10m	Copernicus
Imperviousness Density (IMD)	10m	Copernicus
CORINE Land Cover	100m	Copernicus
Electric lines	Vector layer	Open Street Maps
Roads	Vector layer	Open Street Maps
Rails	Vector layer	Open Street Maps
Fuel models	~100m	FIRE-RES / FireEUrisk / MITIGA
Dynamic Inputs		
Meteorological variables (wind, temperature, precipitation, relative humidity)	0.25 degrees	Copernicus (ERA5) and NOAA (GFS)
Climate projections (wind, temperature, precipitation, relative humidity)	Variable	Coupled Model Intercomparison Project (CMIP6)
Satellite observations	Variable	NASA's Terra and Aqua satellites, Suomi NPP, Copernicus Sentinel
Fire Weather Index (FWI)	8 km / 0.25 degrees	Copernicus
Fine Fuel Moisture Code (FFMC)	8 km / 0.25 degrees	Copernicus
Duff Moisture Code (DMC)	8 km / 0.25 degrees	Copernicus
Drought Code (DC)	8 km / 0.25 degrees	Copernicus
Initial Spread Index (ISI)	8 km / 0.25 degrees	Copernicus
Build-up index (BUI)	8 km / 0.25 degrees	Copernicus

Description of the Use Case

The main objective of this use case is to evaluate and test a methodology for high resolution fire danger that is flexible and accurate enough to be used by and fits the requirements of the insurance sector for pricing methodologies.

This new methodology will integrate multiple databases, many of them provided by Copernicus, to model both the influence of meteorology and the human factor on fires in the northwest of the Iberian Peninsula. This system consists of two clearly different components, a first model that will estimate the probability of ignition over the entire domain on a daily basis, and a second model that will analyse the spread conditions of potential fires.

The probability of ignition is calculated using a data-driven technique. Multiple datasets are used, characterising vegetation (such as land cover or fuels), meteorology (such as components of the Fire Weather Index) or certain human activities (such as land use, roads or electric lines). A machine learning model ingests all these variables, with different resolutions, dimensions and units, and is trained with historical ignition data in the area of interest. The ignition historical observations dataset, coming from public agencies, must be previously homogenised, since our area of interest comprises two different countries, with different methodologies for reporting wildfires. After the training phase, the model will allow us to produce forecasts of the ignition probability, which will be quantified as a value between 0 and 1, which can be made available on a daily basis.

For the subset of the area of interest with the highest probability of ignition, fire behaviour will be characterised with a physically based model. With meteorology, orography and fuels data we can predict the rate of spread of a fire, as well as other fire behaviour characteristics, based on the Rothermel equations. Fire behaviour is a fundamental characteristic for quantifying and forecasting fire damage, since in addition to directly influencing the area that can burn, it also conditions the effectiveness of extinguishing tasks and the magnitude of the damage.

Existing knowledge

MITIGA has extensive experience in data science solutions, such as machine learning or artificial intelligence, and combining these methodologies with geographic information systems (GIS). It also has experience in the use of numerical models for the prediction of wildfire spread or for the calculation of fire damage indices, both in high-performance computing environments and in cloud services. Technologies such as Argo Workflows, Terraform, Kubernetes, APIs or Docker for cloud cluster environments are frequently used in MITIGA.

MITIGA has developed previous work on wildfire forecast systems, as well as on their possible integration in risk transfer and parametric insurance solutions, in projects such as FIRE-RES or MedEWSa. This knowledge will serve as a basis for the system developed in the framework of UNICORN.

Methodology and Technologies to be used

The following technologies are planned to be used in the Use Case:

- Datasets preparation and homogenization. It interpolates different-resolution datasets and calculates the distance of different vector layers to each grid point. Based on GDAL and PostgreSQL.
- Ignition probability model. It calculates the ignition probability on a daily basis. It is based on Python machine learning libraries XGBoost from Scikit-learn and models can be stored using ONNX.
- Fire event generation. It selects random fire events based on their ignition probability distribution for a specific map in time. It is based on the Python statistics library SciPy and NetCDF4.
- Weather data download and processing. MITIGA weather service in Azure, consisting of technologies such as RabbitMQ for queuing or WGRIB2 and ECCODES for processing grib files.

- Fire spread modelling. Mitiga Fire System (MFS), consisting of an Argo Workflow that interconnects preprocessing modules based on GDAL and Python libraries such as xarray or pandas with the FARSITE fire spread model.

Key Stakeholder involved directly and indirectly

This high-resolution fire danger system shall be designed with the objective that it can serve as a tool in the field of forest fire insurance products, especially for the use of parametric insurance products or as a source of information for pricing methodologies. The insurance company Allianz S.E. is engaged through a Letter of support that also provides their end-user requirements.

In addition, the application to be developed may be of interest to other stakeholders, as it represents a novel approach to fire danger forecast in a very fire-prone area. This tool could also be used for fire prevention or for the application of forest resilience measures, which is of interest for local or national governments.

Regulation and regulatory barriers (if any)

The development and implementation of parametric insurance products for wildfire risks in Europe are subject to regulatory oversight and legal considerations. At a European level, parametric insurance methodologies for wildfires in Europe are influenced by EU directives such as the Solvency II Directive (2009/138/EC) or the Insurance Distribution Directive (IDD, EU 2016/97). Regulatory barriers, licensing requirements, and compliance standards may vary across jurisdictions, complicating the process of designing and offering parametric coverage solutions. Additionally, legal challenges related to contract enforceability, liability issues, and dispute resolution mechanisms can impede the widespread adoption of parametric insurance for wildfires.

Scalability and replicability

The high-resolution fire danger forecast system has a high capacity to be replicated in different areas or regions, as it is mainly based on data from Copernicus, which has a global or European coverage.

However, we note two important limitations to this scalability. The first is due to the data itself. Historical ignition observations from different countries can be difficult to obtain, as there is no agency or institution that collects and makes these data available, and estimates of ignition points from satellite imagery are subject to large uncertainties. In addition, high-resolution fuel data are also difficult to obtain in many regions, as they are usually based on observational techniques such as LiDAR.

On the other hand, the fact that the ignition probability model is based on machine learning techniques also poses a certain limitation to its scalability. The importance of each factor considered in the ignition probability model (vegetation, human settlements, meteorology) will vary in each region considered, so the training phase must be specific to each area. This does not preclude its applicability to other regions, but it does make it more costly.

Expected impact of the service

The expected impact of the high-resolution fire danger forecast system is divided into three different sectors: the insurance, the scientific and the fire prevention sector. A direct impact on the insurance sector is expected, as this system is designed to serve as a basis for new parametric insurance techniques for the forestry sector. The system will provide an alternative method for the calculation of fire damage by combining predictions of ignitions and fire behaviour in a single product.

Indirectly, some scientific impact is expected as a result of the novel methodology of ignition modelling, a field of study with increasing interest, in which multiple organisations and research groups are developing their own models.

Finally, we consider that the system can have an impact on wildfire prevention measures in the study region. The introduction of parametric insurance solutions opens up the possibility of incentivising risk mitigation measures by forest owners. Furthermore, the product can be used as a mere fire danger index by administrations or other sectors.

Visualization

The use of a specific platform for the visualisation of the results is not planned. The results will be visualised through specific reports and images stored in storage accounts.

KPIs

The performance of the high-resolution fire danger forecast system can be assessed based on different Key Performance Indicators, defined as follows.

● Evaluation of models applied for transboundary locations (2 countries). The performance of the ignition probability model will be quantified through different metrics such as Accuracy, Precision, Recal, F1 Score or the Mattheus Correlation Coefficient (MCC).
● Risk of ignition maps computed for the time span of the local fire event databases (10 years). This amount of output data allows us to make a consistent assessment of the quality of the product.
● Catalogue of fire spread simulations. The fire behaviour module of the high-resolution fire danger system will be tested over a shorter period of one year, due to the high computational costs.

In the grant proposal is mentioned a quality assessment applying one Climate Change Service (C3S) seasonal forecast as a KPI. However, after further analysing the characteristics of the C3S seasonal forecasts, we conclude that the use of this dataset would not result in a useful quality assessment, because the data to be generated by our system and the seasonal forecasts have very different resolutions, and the temporal period covered by each forecast is very different, making these two systems too different to be comparable.

Risks

A potential risk identified in the proposed fire danger forecasting system is the application to a transboundary region. Since the ignition probability module is based on a data-driven model, it is very sensitive to the homogeneity and consistency of the training dataset. In this case, the historical fire ignition points come from two different administrations, the Spanish and Portuguese forest services. The number of events reported or the location accuracy may change between these two countries, and this could alter the model results, creating biases in the probability of ignition predicted for one or the other country.

Another potential risk is the interaction between the ignition and fire behaviour modules. The final results could be very sensitive to the definition of the ignition probability threshold selected to create the subset of points considered in the fire behaviour module.

Monitoring plan

The development and performance of the system will be regularly evaluated by different means and actions as part of the monitoring plan. These include stakeholder feedback, comparisons with public data sets on fire danger or rapid reports on specific fire events. These actions ensure an adaptable and consistent development of the system, while avoiding deviations from end-users' requirements.

6.4 Use case 3 - Lava flow emergency management tool based on Copernicus data merged with numerical modelling

Lava flows are a significant threat to the built environment, agriculture, and any immobile asset in many volcanic areas. Their flow path cannot usually be diverted and all value in its way is inevitably lost as it is set on fire and covered by layers of rock. This use case aims to develop a coherent and easy-to-access platform for emergency managers that integrates (1) lava flow detection and monitoring through satellite imagery, (2) lava flow path forecasting and (3) operational loss forecasting.

Triggering event

Lava flow

Location

Figure 16 is a geological map of Etna Volcano showing lava flows from the last 3.5 thousand years. The city of Catania is southward, and the villages scattered around the volcano's flanks are clearly visible. The inset shows Sicily in the southern part of Italy. Etna volcano in Sicily is Europe's most active volcano with both explosive and effusive (i.e., lava flow) eruptions taking place at the summit craters every year. While the summit of the volcano is uninhabited, infrastructure of the tourism industry (cable cars, gravel roads, souvenir shops and cafes at the entrance gates) is at a certain risk from these high-elevation flows. But Etna does not only erupt at its central craters. The flanks of the volcano are covered in more than 200 scoria cones and fractures, geological evidence of historical flank eruptions that pose a much bigger threat to the communities around the volcano. These events are rarer, but usually more intense with long-lasting and voluminous flows. Due to their sheer volume and lower-elevation origin, these flows are well capable of invading the villages on the flanks and have caused massive damages in the past. In 1669, even the city of Catania was invaded by a lava flow and in 1928, the village of Mascali was covered by a more than 10 m thick lava flow.
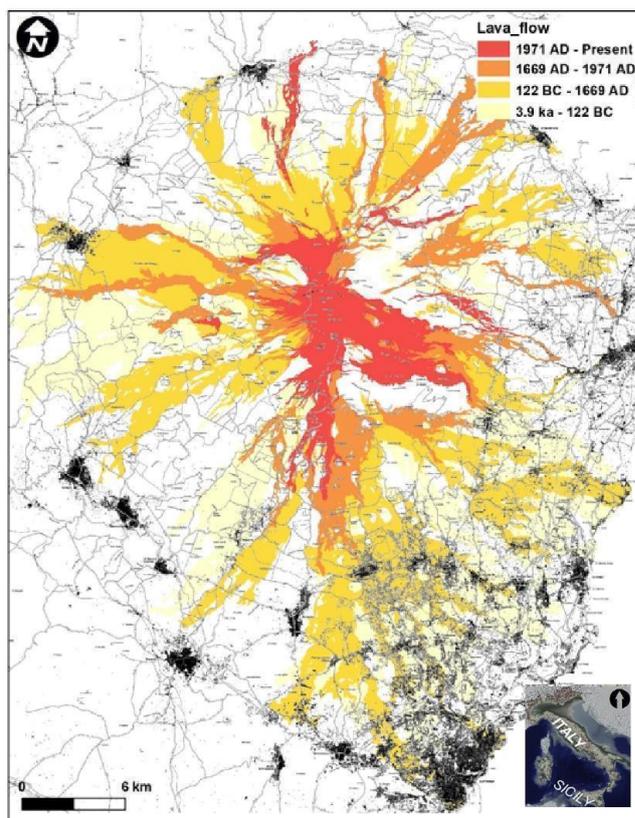
Etna volcano provides an ideal test case for this use case as:

(1) There is (almost) a guarantee that the tool can be tested on an active lava flow happening throughout the project duration.
(2) There are plenty of detailed datasets about past eruptions that can be used as further test cases.
(3) There is a significant threat to the municipalities on Etna's flanks and thus a real interest in the product.
(4) The volcano is very well studied and intensely monitored by INGV-OE. Thus, there is extensive knowledge and sufficient data available about this volcano within the consortium.

Background and Challenge to be addressed and Anticipated Benefits

Recent events in Iceland and the Canary Islands have demonstrated the destructive potential of effusive eruptions. While there have been a few successful attempts at lava flow diversion, the only real risk mitigation measure in a lava flow crisis is the complete evacuation of all people and livestock at risk. With sufficient warning time, people will at least be able to save mobile assets and personal values from their homes and businesses. Therefore, knowledge about an ongoing lava flow, its likely future direction and impact on infrastructure are essential for emergency managers and decision-makers for optimized evacuation planning.

Most volcano observatories already apply different versions of lava flow detection (usually through hotspot detection in thermal imagery) and flow path forecasting (usually through numerical modelling). However, the observatories are not the decision-makers and have to communicate the outcomes of their evaluations to the respective stakeholders in varying forms. In Sicily, INGV-OE, according to the framework agreement stipulated between INGV and the Department of Civil Protection (DPC), carries out surveillance activities through the collection, processing and analysis of data collected by multi-parameter monitoring networks. In particular, the information collected through the instrumental networks is shared with the DPC through the sending of Press Releases, Bulletins (links) and Reports, documents drawn up according to formats and methods agreed between the two Entities (INGV and DPC). The reports are used to transmit information relating to the occurrence of volcanic events or seismic events in volcanic areas or other significant events for civil protection purposes, such as swarms and sudden changes in the monitored parameters. The bulletins report an overall summary of the activity status of a specific volcano, and information on the composition and maintenance status of the monitoring networks. They are published with a frequency agreed with the DPC and can be on a daily, weekly or monthly basis. The press releases describe the state of the monitored volcanoes and a summary evaluation of the observed phenomena. These documents are also available on INGV's website.

This use case aims to provide added value by:

(1) develop an easy-access tool that provides comprehensive information for emergency managers and decision-makers in an eruptive crisis;
(2) provide outcomes of lava flow modelling with a very recently developed numerical model; and
(3) provide operational loss forecasts during ongoing eruptions.

The last point is particularly important for the insurance aspect of this project. Most if not all damages induced by volcanic eruptions are uninsured, as relevant insurance is usually very expensive or completely unavailable. Furthermore, management of claims in traditional insurance can be very lengthy and complicated in the aftermath of an eruption. So-called parametric insurance structures can be a solution for these issues as they are very cost-efficient and transparent in their payout. Payouts are not determined by claimed losses, but by officially reported intensity measures of the ongoing event. There is an automatic payout as soon as the intensity overcomes a predefined threshold. This "intensity measure" could be, e.g., wind velocity for a storm insurance, flood depth for flood insurance, etc. Recent collaborative work between Mitiga Solutions and the insurance broker Willis Towers Watson within an EC−funded research project has developed a novel methodology for a parametric lava flow insurance. In order for this methodology to be transferred into practice, the insurance companies require what is called a calculation agent: the tool that assesses the intensity of an ongoing event to facilitate potential payouts from the parametric insurance structures. In the case of lava flows, the best intensity-measure for these structures is modelled loss and thus the calculation agent must provide modelled loss estimates.

Requirements from task 2.1 and Key Stakeholder Needs

The requirements and needs of key stakeholders for the lava flow use case are described in detail in Section 8.3 (Lava Flow Hazards) of D2.1 End-users' Requirements Report. The 5 respondents for the analysis of D2.1 belong to entities of the local administration, the scientific community and the first response sector. The analysis showed a

clear preference for local products with daily provision of information, which is in line with the aims of the here foreseen methodology.

Data to be used and Copernicus services

This use case requires a number of input data, listed in the table below. Static input includes a Digital Elevation Model, OpenStreetMap data as well as the configuration data for the numerical model that have to be tuned to each volcano. These data are the basis for flow modelling and loss estimates. Dynamic input are available satellite images provided by Copernicus for Etna during ongoing eruptions, as well as vent locations and effusion rates that will be provided by INGV for each eruption.

Table 8: Input data for the lava flow emergency management tool

Description	Spatial resolution/scale	Source
Static Inputs		
Digital Elevation Model	5m	INGV
OpenStreetMap (buildings, road network)	Heterogeneous vectorial layer	OpenStreetMap (buildings, road network)
Configuration data for lava flow models	n/a	Mitiga Solutions by tuning the model to past eruptions (maps from various academic publications)
Dynamic Inputs		
Satellite thermal images	variable	Copernicus
Satellite optical images	variable	Copernicus
Vent location	tbc	INGV
Effusion rate	n/a	INGV

Description of the Use Case

The goal of this use case is to develop an emergency management platform specifically designed for early warning, monitoring, and forecasting of active lava flows.

The lava flow tool will include:
  (1) Early Warning: The user will receive an alert once a new lava flow is detected with INGV's remote sensing systems.
  (2) Monitoring of the ongoing eruption: Any satellite imagery available through Copernicus services will be made available to the user to be able to visually assess the ongoing situation.
  (3) Flow path forecasting: Numerical modelling is applied to forecast likely inundation paths of the lava flow.
  (4) Operational loss forecasting: By overlaying likely inundation paths (or, once the flow has ceased, the final flow map) with exposure maps, i.e. the location and values of infrastructure and

buildings, the platform will provide an estimate of the damages / losses caused by the eruption.

Existing knowledge

While this use-case aims to set up a prototype from the ground up, it does build on existing knowledge in the volcanological community:

Several algorithms have been developed that use satellite-derived thermal imagery to detect lava extrusion in volcanic eruptions. Operational examples are the MIROVA and HOTSAT systems (Ganci et al., 2011; Coppola et al., 2020). These tools and their optimal handling have been developed over many years and are best placed in the expert hands of the responsible volcano observatories. This project thus does not aim to rebuild or copy a similar system, but leverage the alerts issued by the Osservatorio Etneo.

The combination of various kinds of remote sensing data with lava flow modelling during eruptive crises is performed at many observatories. Examples can be found at Piton de La Fournaise (Harris et al., 2019) and Etna volcano (Ganci et al., 2012). Several lava flow models exist in the academic community with big ranges in complexity and accuracy (e.g., Dietterich et al., 2017), although those used in operational settings are generally the most primitive types. The output of these models is the emplacement area of the lava flow - depending on the model with varying additional levels of information such as time-dependent advancement, lava flow thickness, temperature or velocity. However, none of the operational models in observatory settings provide loss forecasting to our knowledge. Mitiga Solutions has built a lava flow catastrophe model in a previous research project under the Tecniospring Industry program. It is built on the lava flow model "MrLavaLoba", which is a fairly recent development and represents an ideal compromise between physical accuracy and computing speed (De' Michieli Vitturi and Tarquini, 2018). It has been successfully applied for operational forecasting during the 2014-15 Holuhraun eruption in Iceland (Tarquini et al., 2018). The catastrophe model by Mitiga combines probabilistic lava flow simulations for a range of possible vent locations and flow volumes with a loss modelling layer. The loss calculation engine will be applied in this use case to facilitate operational loss forecasting.

Mitiga Solutions has furthermore developed an early warning platform for volcanic ash (Figure 17) that has been operational and used by aviation clients operating at Catania airport for years. This use case will leverage the knowledge and experience gained from this platform that prioritizes streamlined information according to the client's operational needs. It is based on so-called VONAs (Volcano Observatory Notifications for Aviation), released by INGV-OE, and Volcanic Ash Advisories issued by the Centre in Toulouse. These official alerts trigger numerical simulations of the ash cloud on Mitiga's systems, which are compiled into a customizable report. The client is notified via email about the status of the volcano and new report releases which can be downloaded from a website. This use case will

apply a similar structure.

Methodology and Technologies to be used

Figure 18 illustrates the foreseen architecture of the lava flow emergency management tool:

Once a new lava flow is detected by INGV, the volcanologist on duty can submit inferred data to Mitiga's system via an API interface. These data are the vent location and, if available, lava effusion rate. Furthermore, a flag indicating whether the eruption is still ongoing is required. If the

eruption is defined as "ended", a final volume (if available) or duration should be added. The vent location will have an uncertainty that will be reflected either by adding this uncertainty directly, or - instead of providing the exact coordinates of a vent - by providing the coordinates of a square that indicates the vent opening area.
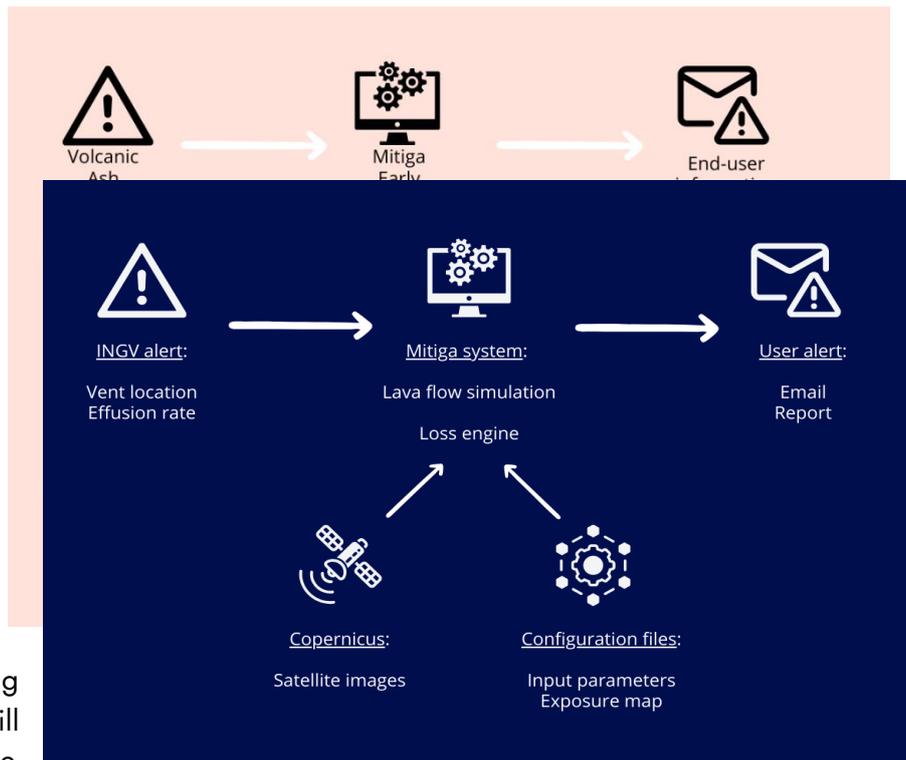
Mitiga's systems will be continuously "listening" for input of data. As soon as data is received, an Argo Workflow is initiated. This workflow will incorporate the following steps:

1. Run lava flow simulations

The lava flow simulator "MrLavaLoba" requires a list of input parameters that need to be tuned to the considered volcano and eruption. Most of these parameters that determine the general flow behaviour will be fixed in input files on storage and not changed for each eruption. They will be tuned to Etna volcano by comparing simulations to maps of past eruptions when preparing the tool. Most likely, Mitiga Solutions will create two separate input files on storage for lava flows emanating from the central vent or flanks, respectively, as different behaviours can be expected between these two main effusive eruption types. The most important parameters, however, that need to be changed for each eruption are vent location and lava flow volume. Based on the box or circle representing the vent opening area provided by INGV, a grid with nodes representing possible vent locations will be created (from now on called the "vent grid"), and the system will run simulations for each of these vents. The lava flow volume can be estimated based on flow effusion rate if we assume constant effusion and know the final eruption duration. Since the latter cannot be predicted at the start of an event, the system will run three simulations per node of the vent grid: a short (e.g., 1 day), medium (e.g., 1 week) and long (e.g., 1 month) eruption scenario. If effusion rate data is not available, the system will use a small, medium or big volume, whereas these categories will be based on the analysis of past eruption data. If the eruption is defined as "ended" the system will only run one simulation with the final volume (given or estimated from the duration).

These simulations will run on Mitiga's cloud clusters, using Argo Workflows as the simulations' orchestrator. Parallelization will be used, when possible, to try to reduce the time to obtain data and make the system more scalable and robust.

2. Create inundation maps

The simulation results from step 1 will be combined into 3 "inundation likelihood maps" - one each for small, medium or big eruptions - by counting per pixel how many out of all simulations cover this pixel with lava.

3. Run the loss engine

The simulated flow maps are then combined with exposure data to provide an operational loss forecast. During the preparation of the tool, Mitiga Solutions will create an exposure dataset for Etna volcano that will include buildings and infrastructure as saved in OpenStreetMap. If available, monetary values will be assigned to individual buildings and assets. Any asset covered in lava will be considered 100% lost and separate loss forecasts for small, medium or large eruptions as outlined above can be created.

4. Download complementary satellite images

If available, complementary satellite images will be downloaded via the Copernicus API to facilitate further monitoring.

5. Create a report

The above information will be compiled into an easily digestible report that prioritizes streamlined information for decision-makers and non-scientific stakeholders in an effusive crisis.

6. Inform users and provide the report

Finally, users of the platform are informed about a newly created report via email.

Possible enhancements of this basic structure are dependent on available resources that remain after the main system has been successfully built. They may include:
- updating and continuous improvement of simulations throughout an eruption with available maps
- ensemble modelling accounting for ranges of parameters

Once an eruption has finished, another data input from INGV should be received with the final duration or - if available - volume of the flow. The above workflow will start again and provide a final loss estimate.

Key Stakeholder involved directly and indirectly

A main involved stakeholder is INGV Catania. They are the responsible and official observatory for Etna volcano and will provide the information stemming from 24/7 monitoring. At the same time, they can be considered end-users as they will be able to use the reports from this tool for comparison with their own simulation results and gain additional information through the loss forecasting layer.
Main targeted end-users for the final produced reports will be: (i) first responders and emergency management / civil protection agencies; (ii) local businesses; (iii) land-use infrastructure planning agencies, (iv) insurance sector with assets in the region; (v) the general public — inhabitants of areas at

risk and volcano enthusiasts; (vi) insurance companies that provide (parametric) insurance products in volcanic regions and require loss forecasting tools as triggers for parametric structures and/or for their internal claims cost forecasting during an effusive disaster.

Regulation and regulatory barriers (if any)

The use case may face challenges or barriers regarding the use of third-party (e.g., OpenStreetMap, Copernicus) and INGV-owned data or other inputs. Together with Mitiga's legal team, we will carefully assess the situation and correct handling of these instances, in particular when entering a commercialisation stage.

Scalability and replicability

This tool can be reproduced at any observatory with a similar setup as INGV, i.e., with a lava flow detection system and a 24/7 staffed observatory room in place. It can also be set up for any other volcano (without a readily installed detection system) where thermal satellite imagery is available, however this would require (1) licensing or reproducing a hotspot detection algorithm to detect the lava and (2) offering a 24/7 human monitoring service at Mitiga, as the alert system is not 100% automated and requires human interaction. The 24/7 aspect may be relaxed at some volcanoes considering lava flows are reasonably slow phenomena.

Expected impact of the service

This service aims to develop an application for emergency managers and first responders, societies affected by volcanic risk, and the insurance sector. It will create a transferable state-of-the-art lava flow monitoring warning system that can be applied to numerous global regions (e.g., Canaries, Iceland, Hawaii). This use case aims to develop an accessible and user-friendly tool for early warning and mapping that improves existing systems through its loss forecasting layer for enhanced emergency management and use in the insurance sector.

Visualization

For each initiated workflow, the system will create a report with all the produced information, i.e.: inundation-likelihood maps, complementary satellite imagery, and forecasted losses / impact on infrastructure. The reports will be either sent by email, or available by download through a website. The design of the report is not yet finally decided but will be based on end-user feedback.

KPIs

This use case aims to fulfil the following KPIs:
- Application of the tool in hypothetical eruption scenarios (>2) at Etna volcano
  After thorough internal testing, eruption simulations will be performed together with INGV using data from past eruptions. That way the accuracy, speed, and user-friendliness of our tool can be assessed and continuously improved.
- Accuracy of forecasted loss (< 30% error)
  The forecasted loss should deviate <30% from reported numbers where available.
- Calculation agent speed (time from hotspot detection at INGV - payout information for a parametric insurance provider: <1 day)
  As one main advantage of a parametric insurance structure is the speed of payout, a sufficient

speed in the calculation agent must be ensured. Meaning, from the time the new lava flow is detected in a satellite image to the loss forecast provided by Mitiga, less than a day should pass.

Risks

Since this service is built more or less from the ground up, some (technical) problems may not be obvious at this stage. Some possible risks include:

- availability of exposure and loss data

    To estimate and finally validate loss created by an eruption, the availability of exposure and loss data is crucial. While OpenStreetMap can at least be trusted to provide numbers of buildings, streets and other infrastructure, it does not contain information about the value of assets. If the latter is not available, impact estimates can also be provided by simply listing expected numbers of destroyed buildings - however, actual expected losses in terms of € would be preferred. To validate our calculations, loss data from past eruptions are needed and are not always available or complete, which needs to be taken into account with care.

- technical compatibility of systems (INGV, Mitiga and Copernicus)

    The envisioned system requires a certain communication between the systems at Mitiga, INGV and Copernicus which can raise technical difficulties.

- ability of MrLavaLoba to incorporate existing maps of an ongoing eruption

    While MrLavaLoba has been tested throughout an ongoing eruption before, it was not used operationally at large scales in different areas, and not by Mitiga. Adjustments to the model may be required if data assimilation is implemented.

Monitoring plan

Each step of the workflow, as well as its complete process, will be extensively tested internally with past eruption data before being released, followed by testing with INGV and finally external stakeholders to iteratively build the service according to end-user needs. Observability capabilities will be incorporated into the system by design, so that Mitiga personnel are aware of its status and performance and are also able to react if incidents occur.

7   Conclusions and next steps

Deliverable D4.1 outlines the foundational setup of the UNICORN project's pilot use cases. These use cases were selected to demonstrate the potential of Earth Observation and Copernicus-enabled services in addressing pressing societal and environmental challenges. Each use case reflects a distinct thematic domain, yet collectively they emphasize the project's overarching goals: to improve resilience, sustainability, and the uptake of geospatial technologies across sectors.

The document captures the rationale and strategic approach behind the use case selection, highlighting criteria such as feasibility, impact, stakeholder relevance, and alignment with European policy priorities. Furthermore, it introduces the initial operational frameworks, identifies key actors and responsibilities, and describes the types of data, tools, and services to be leveraged or developed. This preparatory work ensures that the pilots are not only technically sound but also contextually relevant, involving end-users and decision-makers early in the process to facilitate adoption and maximize value.

Additionally, D4.1 establishes a roadmap for the subsequent stages of pilot implementation, including data acquisition, service deployment, and user validation. This structured approach will support the monitoring of progress and the evaluation of results, enabling the project to generate robust, transferable insights and good practices. Ultimately, the use cases set up in this deliverable will serve as concrete testbeds for showcasing how EO and GNSS services can be integrated into operational workflows, bridging the gap between innovation and societal application. The work undertaken here lays a solid foundation for the development, execution, and impact assessment of the UNICORN pilots in the upcoming phases of the project.

Finally, the current status of the related risks can be seen in the Table below. All the risks are being commented in D1.1 Project reporting.

Table 2: Status of critical risks

#	Description of risk	Did your risk materialise?	Applied mitigation?	Comments
1	Data unavailability, lack of accuracy or extent of data	No	No	All data were available as required.
2	EO technologies are of low accuracy	No	No	This risk has not been materialised so far.
3	Low interest of regional stakeholders or inadequate participation in events	No	No	End users have successfully mobilized their networks e.g to collect responses for the questionnaire under T2.1.

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