COMMUNITY ROADMAP

EARTH OBSERVATION FOR HIGH IMPACT MULTI-HAZARDS SCIENCE (EO4MULTIHAZARDS)

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1. INTRODUCTION

1.1. PURPOSE

This document presents a Community Roadmap Report aimed at offering recommendations for advancing scientific activities and defining a research agenda to address key gaps in the domain of Earth Observation (EO) in multi-(hazard-)risk assessment and management.

The frequency and intensity of natural hazards have increased over the last decades (Poljansek et al. 2017; Cutter 2018; IPCC 2023). In 2023, natural hazards caused an estimated $250 billion in global economic losses and resulted in over 74,000 deaths, significantly exceeding the 10-year average (Munich Re, 2024). While much research tends to concentrate on individual hazard events, it is crucial to acknowledge that, when multiple hazards interact, the resulting impact is not just the combination of the single impacts, as nonlinear effects may come into play and may significantly increase the effects (e.g. Kappes et al. 2012; Terzi et al. 2019; De Ruiter et al., 2020). According to the UNDRR, Multi-hazards are "the selection of multiple major hazards that the country faces, and the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects" (UNDRR 2017). Multi-hazard risk, on the other hand, is defined as "risk generated from multiple hazards and the interrelationship between those hazards", without considering interrelationships on the vulnerability level (Zschau 2017), while the interrelationships on the vulnerability level are also considered by the term multi-risk. Multi-(hazard-)risk is used collectively when referring to all the definitions above (multi-hazard, multi-hazard-risk, and multi-risk) (Ward et al. 2022). The severity of natural hazards prompted the United Nations (UN) to conceptualize the 2015-2030 Sendai Framework for Disaster Risk Reduction (DRR), which seeks to minimize the risk of ongoing disasters and avoid future disasters via the integrated execution of social, economic, political, environmental, structural, educational, institutional, cultural, health, technological and legal measures (UNDRR 2015).

The importance of EO data for improving our understanding of hazards and risks is well recognized in the scientific community, with numerous studies showcasing the unique capabilities of satellites in characterizing hydro-meteorological and geological hazard events (Novellino et al. 2024; Gosset et al. 2023). However, there have been limited attempts to integrate satellite imagery into the workflow of multi-(hazard-)risk analysis, modelling, forecasting, and added-value generation. The new Sentinels missions are changing the paradigm, offering the potential to delve deeply into the multi-(hazard-)risk domain where EO data can play a pivotal role. Despite advancements in modeling capabilities, access to reliable data has not kept pace: a primary obstacle to comprehensive understanding multi-(hazard-)risk phenomena lies now on the low time and space resolution of data; however, high quality satellite imagery holds promise in bridging gap between modelling capabilities and data quality (Abbasi and Nawaz 2020; Van Westen 2000). Understanding how EO information can support the assessment and management of multi-(hazard-)risks presents a unique opportunity, and in some cases a necessity, for enhancing societal and environmental preparedness and response to such complex events. With the increasing availability of EO data and the growing significance of multi-(hazard-)risk analysis, urgent attention is required for these two evolving research domains to co-evolve rather than develop independently.

The report will summarize the prevailing thoughts developed during the first 6 months of the project and it will evolve and grow during the project (two years total), gathering relevant recommendations for future scientific efforts by identifying research gaps and areas for exploration. We will introduce insights from an initial paper (van Maanen et al., in preparation) that will be submitted to a high-impact peer-reviewed scientific journal assessing the role of EO in multi-(hazard-)risk assessment and management. In the paper we identify research gaps, propose a research agenda, and explore stakeholder engagement. Our proposed ideas presented in this deliverable will closely align with the recommendations identified in the Paper. Additionally, this deliverable will outline strategic actions to expand current project activities towards larger scientific and operational endeavors over a 3 to 5-year period in the domain of EO and multi-(hazard-)risk assessment and management.

Regular updates to this document by the consortium will ensure ongoing scrutiny of research gaps and anticipation of future research needs while fulfilling the commitments of the project. The Community Roadmap lays the groundwork for a mutually agreed multi-hazard community white paper.

1.2. DEFINITIONS AND ACRONYMS

1.2.1.DEFINITIONS

Concepts and terms used in this document and needing a definition are included in Table 1-1. Other relevant concepts and terms can be consulted in the glossary of the Disaster Risk Gateway, an online crowdsourced platform for sharing existing approaches for understanding, analysing, and managing multi-hazard and multi-hazard risks and definitions, adopted by the EO4Multihazards project.

Table 1-1: Definitions

Concept / Term	Definition
All hazards approach	To strengthen technical and scientific capacity to capitalize on and consolidate existing knowledge and to develop and apply methodologies and models to assess disaster risks, vulnerabilities, and exposure to all hazards.
Amplification relationship	The occurrence of one hazard can increase the likelihood and/or magnitude of additional hazards in the future (e.g., forest fires can amplify the triggering of debris flows during heavy rain) (Ciurean et al., 2018)
Cascading hazard	Cascading hazard processes refer to an initial hazard followed by a chain of interrelated hazards (e.g., earthquake triggering landslide, landslide triggering flooding, flooding triggering further landslides) (Adapted from UNDRR, 2019)
Cascading risk	Cascading risk is used to highlight the progressive impact of disaster events in which the impact of a physical event or the development of an initial technological or human failure generates a sequence of events distinguished by increase in progression over time and secondary events that spread from one component to the others. Cascading risk is complex and is associated more with the magnitude of the impact than with that of hazards. Low-level hazards can generate broad chain effects if vulnerabilities are widespread in the system or not addressed properly in sub-systems. These subsequent and unanticipated secondary crises can be exacerbated by the failure of critical infrastructure, and the social functions that depend on them (adapted from Pescaroli and Alexander 2015, 2016, 2018). This can also include so-called NaTech disasters, where extreme events with a natural origin (e.g. earthquake) cause a secondary technological disaster chain (Krausmann et al., 2011)
Compound (hazard) relationship	Two different natural hazards that impact the same period and spatial area. Compound hazards can have a footprint with spatial and temporal characteristics that differs from the component single hazards (Tilloy et al., 2021, Zscheischler et al., 2018)
Disaster Risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity (UNDRR, 2017)
Exposure	The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any hazard to estimate the quantitative risks associated with that hazard in the area of interest (UNDRR, 2017)
Hazard	Potentially dangerous phenomenon, process or activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation (UNDRR, 2017)
Interacting risk	A general term to indicate that several hazardous events worsen the impact on society. The term interacting risk is used to highlight the importance of hazard interactions, in terms of their causal mechanisms and effect they have on other hazardous processes.
Interconnected risk	Used to highlight the importance of interconnected causality networks that generate and amplify disasters, and the interlinkages between human, environmental and technological components (Helbing, 2013), which can be analysed using network analysis.
Multi-(hazard-)risk	Term used when collectively referring to multi-hazard, multi-hazard risk, and multi-risk (Ward et al., 2020)

Multi-Hazard	Multiple major hazards that an area faces, and the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and considering the potential interrelated effects (UNDRR, 2017)
Multi-hazard risk	Risk generated from multiple hazards and the interrelationships between these hazards (but not considering interrelationships on the vulnerability level) (Zschau, 2017)
Multi-risk	Risk generated from multiple hazards and the interrelationships between these hazards (and considering interrelationships on the vulnerability level) (Zschau, 2017)
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions (IPCC, 2023)
Systemic risk	Risk of a 'system' due to interaction effects of elements of a system (Gill et al., 2022). Systemic risk refers to those impacts that may impede the functioning of a system. For example, the cascading impacts of one or more interacting extreme events may pass over to other sectors of society and to other regions, causing cross-boundary effects that may lead to the collapse of the functioning of a part of society, or event extending to several geographical areas (Silmann et al, 2022)
Triggering relationship	One hazard causing another hazard to occur. Any natural hazard might trigger zero, one, or more secondary natural hazards, with these being either the same or different from the primary hazard (Ciurean et al., 2018, Tilloy et al., 2021)
Vulnerability	The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards (UNDRR, 2017)

1.2.2.ACRONYMS

Acronyms used in this document and needing a definition are included in Table 1-2:

Table 1-2: Acronyms

Acronym	Definition
CERIS	Community for European Research and Innovation for Security
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici
DRR	Disaster Risk Reduction
EGU	European Geosciences Union
EO	Earth Observation
ESA	European Space Agency
ESRIN	European Space Research Institute
GDP	Gross domestic product
IPCC	Intergovernmental Panel on Climate Change
NHESS	Natural Hazards and Earth System Sciences
SDC	Science and Demonstration Case
UNDRR	United Nations Office for Disaster Risk Reduction
VUA	Vrije Universiteit Amsterdam

2. RECOMMENDATIONS FOR FURTHER SCIENTIFIC ACTIVITIES

To exploit the potential of the role of Earth Observation in assessing multi-(hazard-)risks, it is important to identify potential research gaps and needs at the early stages of the ESA-funded EO4Multihazards project.

In this chapter, we will discuss the research gaps and needs that have been identified: in section 2.1 we discuss the underexplored potential of EO for vulnerability assessments; in section 2.2 we highlight the need for close collaboration across disciplines; in section 2.3 we discuss the need of organizing existing openly available information in a systematic and effective fashion; in section 2.4 we describe the need to present EO information in a format that is easily understandable, ensuring its utility for a broad spectrum of stakeholders involved in multi-(hazard-)risk management; we recommend the development of more comprehensive case studies able to fully exemplify the EO's role in multi-(hazard-)risk assessment, where in-situ data (bottom-up) are used to complement, validate and compare the data and imagery derived from EO (top-down).

Combining both bottom-up and top-down approaches could enable the provision of information at various stages of the disaster risk management cycle, including prevention, preparedness, response, and recovery.

2.1. EO FOR EXPOSURE AND VULNERABILITY ASSESSMENT

Understanding the frequency, timing, and causes of multi-(hazard-)risk is crucial due to the potential of cascading effects between risk factors, as well as the nonlinear interactions between compounding hazards, which generate significant impacts on both society and the environment, spanning economic and non-economic spheres. Despite numerous efforts to address these complex events, there remains a lack of understanding regarding the interactions among the various components, including exposure, vulnerability, and the multiple interacting hazards.

EO already plays a pivotal role in assessing exposure to multi-hazards by providing comprehensive information on fixed assets, land cover, infrastructure distribution, and terrain characteristics. Through the utilization of satellite imagery and other EO technologies, researchers can identify vulnerable areas and assess the extent of exposure to various hazards, thereby enhancing our understanding of complex risk dynamics (e.g., see METEOR Project).

Despite increased awareness of the socioeconomic consequences of natural hazards, studies on the dynamics of natural hazards and their impact on socioeconomic indicators remain limited across diverse contexts. While efforts are ongoing to understand certain components of vulnerability in the disaster risk management cycle, such as examining levels of recovery after a multi-hazard event using nighttime light satellite data or estimating short-term disaster losses, challenges persist (Owen et al., 2021; Jia et al., 2023). These challenges include underlying noise in the nightlight data and the lack of measurements due to cloud cover. Moreover, vulnerability depends on factors such as the level of development and economic structure, which are not immediately accessible from space. Recently, EO data, in conjunction with Deep Learning techniques, have been utilized to estimate socio-economic indicators. For instance, nightlights have been used as a proxy to track poverty evolution in African countries, and similar applications have been developed for estimating county-level GDP in China from nighttime light intensity. To comprehensively understand the effects of multi-hazards on different income groups, especially in less developed countries where in-situ data is often scarce, there is a critical need to explore how EO data can be harnessed to understand the complex characteristics that contribute to risk.

Given the integral roles of both exposure and vulnerability in multi-(hazard-)risk, it's imperative to explore how and where EO data can be further utilized to enhance our understanding of their interaction and contribution to overall risk dynamics.

2.2. COLLABORATION ACROSS DISCIPLINES

We argue that there is a need for enhanced collaboration across disciplines to identify synergies and leverage advancements, thereby improving the collective capacity for a more comprehensive understanding of multi-(hazard-)risks and the usefulness of EO data and tools. For example, we recommend interaction between climate scientists, which can provide insights on future hazards scenario (e.g., heat waves, droughts, cold spells, and floods) (Khan et al. 2023), with risk scientists, able to assess interactions between risk factors, and analyze compound and cascading effects, and disaster risk reduction scientists, who can provide insights into the societal dimensions of risk, including the risk governance and decision-making landscape. Such interactions must be underpinned by an acknowledgment of differences and strengthening of consistency in understanding and use of terminology and concepts across disciplines (Gill et al.,2022).

In general, it is crucial to foster partnerships between academic researchers, practitioners, local communities, and the public sector. Integrating scientific and local knowledge through methods that facilitate knowledge exchange and bi-directional dialogue, such as (community-based) participatory (action) research and knowledge co-development, is paramount to comprehensively understand and mitigate complex risks, integrating diverse perspectives and enhancing the resilience of communities to various hazards (Cadag and Gaillard 2012). A blend of qualitative and quantitative methodologies is essential to bridge diverse research domains pertinent to multi-hazard risk.

2.3. HARMONIZATION OF EXISTING DATABASES

Various resources are already widely available (e.g., Copernicus Land Monitoring Service, European Ground Motion Service, Copernicus Climate Change Service) that could be utilized to advance the broader objective of utilizing EO data in the multi-(hazard-)risk domain. Instead of creating new databases, there should be an initiative to make existing data easily and efficiently accessible, enabling stakeholders who are not highly familiar with the topic to utilize them effectively. Enhanced and accessible communication of findings, as well as comprehensible use of data, is essential. As highlighted by the United Nations, there is a lack of capacity to interpret data and develop risk information, which hampers risk-informed decision-making and policy uptake. Increased support for capacity-building is necessary to address this issue (United Nations, 2023).

2.4. STAKEHOLDERS AND COMMUNICATION

Overall, the successful implementation of disaster risk reduction strategies in a multi-risk context requires an effective mechanism for conveying knowledge about risks and their underlying causes to diverse stakeholders involved in decision-making (Komendantova et al. 2014). These stakeholders encompass government agencies, emergency management organizations, non-governmental organizations, the private sector, as well as communities and civil society organizations, each with varying levels of expertise in multi-risk assessment and management, thus necessitating tailored modes of communication, information extraction, and dissemination, particularly in the context of EO perspectives, which can be complex. Particularly in engaging stakeholders, it is crucial to ascertain the specific informational needs of frontline communities, such as first responders, and provide them with easily digestible and pertinent data to significantly enhance their support.

Recent studies, such as the one by Khan et al. (2023), emphasize the potential of disaster risk reduction options, including early warning mechanisms, updated emergency plans, utilization of the latest technologies, comprehensive training, and effective responses, to significantly reduce both human and economic losses in multi-(hazard-)risk scenarios. Similarly, Zsarnóczay et al. (2023) highlight the urgent need to enhance the accessibility and credibility of datasets, stressing the importance of integrating existing tools into computational workflows to facilitate sharing and reusing models and results. Prioritizing reliability, reproducibility, and replicability in establishing databases is essential for ensuring widespread adoption and utilization across various stakeholders.

3. RESEARCH AGENDA

The EO4Multihazards project is dedicated to bolstering preparedness for high-impact multi-hazard events with the aid of Earth Observation technologies for enhanced identification, characterization and assessment of associated vulnerability, impacts, and risk on society and ecosystems. Earth Observations technologies can provide data and information on hazards, vulnerability, exposure, and impact with a spatial and temporal resolution that could never be achieved by in situ measurements, and hence they play a pivotal role in multi-(hazard-)risk studies. The creation of a comprehensive database for risk factors and impacts easily accessible by researchers and stakeholders would prove itself a powerful tool for effective disaster risk management.

By advancing the scientific state-of-the-art in the multi-risk domain, the project promises to make significant contributions to the field: it adopts an agile approach, which involves identifying and addressing gaps in knowledge and methodologies, while also aligning with ongoing initiatives in disaster risk reduction and management. Through a series of workshops, the project provides a platform for diverse scientific contributions from various disciplines, fostering collaboration and knowledge exchange among experts. This holistic approach ensures that the project's outcomes are comprehensive, robust, and applicable across different contexts.

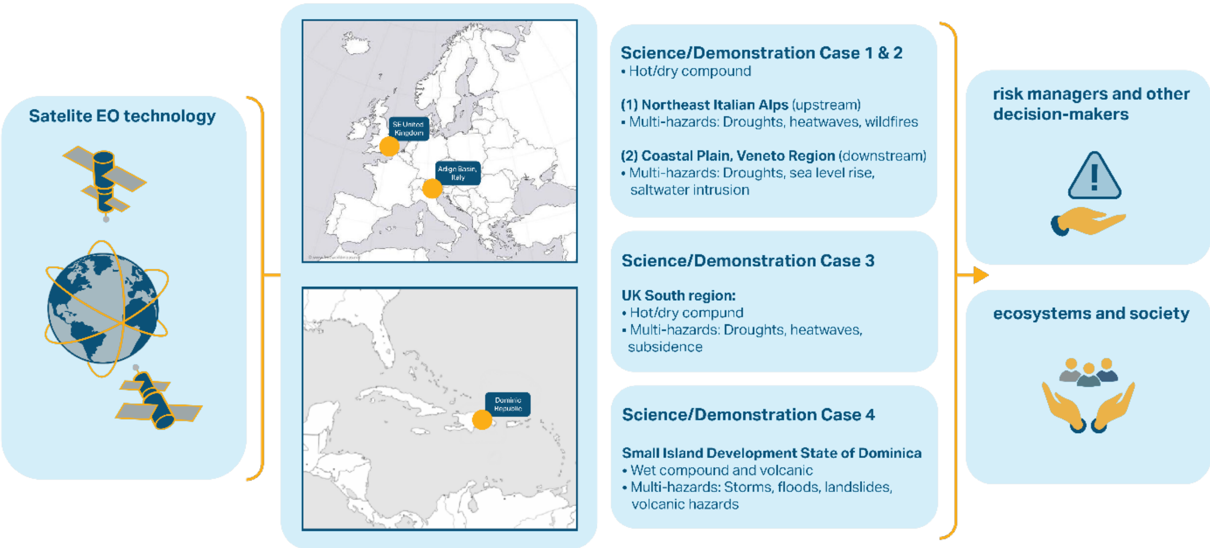

Figure 3-1: Concept of the ESA-funded EO4Multihazards project including the introduction of the Science- and Demonstration Cases in the Northeast Italian Alps (Science/ Demonstration Case 1), the Coastal Plain of the Veneto Region (Science/Demonstration Case 2), the UK South Region (Science/ Demonstration Case 3) and the Small Island Developing State of Dominica (Science/ Demonstration Case 4).

The project aims to bridge the gap between the scientific and user-driven domains by integrating so-called science and demonstration cases (Figure 3-1). These cases inform the scientific process with real-world experiences but also ensure the inclusion of local contexts in scientific endeavors. These cases are introduced to showcase different spatial scales, geographical locations, socioeconomic characteristics and a range of hazards and their interrelated effects. The science cases will conduct a comprehensive multi-hazard assessment utilizing EO data. They will focus on three distinct geographical regions characterized by a variety of events, including hot, dry, and wet conditions, and will examine different types of hazard interactions. These cases will encompass climate-driven hazards like floods, as well as geological hazards such as earthquakes. Illustrated in Figure 1, the science cases will encompass Italy, the United Kingdom, and the Caribbean Island of Dominica. In a subsequent phase, the demonstration cases will expand this assessment by incorporating data on exposure and vulnerability, thereby moving from a multi-hazard assessment to a comprehensive multi-risk assessment. The findings from both science and demonstration cases will be scalable and transferable to other regions worldwide. Hereafter, each case study will be referred to as Science and Demonstration case (SDC).

SDC 1-2 is analyzes compound and cascading events in hot and dry conditions along the Adige River, in North-East Italy. They will examine the interactions between the upstream and downstream parts of the Adige River basin and assess impacts of hot and dry events on water quantity and quality, as well as their effects on the surrounding vegetation. Specifically, SDC 1-2 will both consider interactions between droughts, heatwaves, and wildfires in the upstream part of the river basin as well as investigate downstream effects, including other hazards such as saltwater intrusion. SDC 3, situated in the Southeast region of the UK, will assess the effects of compound hot and dry conditions in a scenario of prolonged high temperatures leading to or else amplifying the occurrence and impact of droughts and heatwaves. It will also investigate how these conditions influence the occurrence and impact of other types of hazards, such as wet events (e.g., extreme precipitation, flooding, etc.). in relation to the stability of the terrain and the likelihood of geo-hazards such as shrink-swell driven subsidence. SDC 4 will focus on the Small Island Developing State of Dominica, to evaluate multi-hazard scenarios primarily from a wet compound and volcanic perspective.

An initial conceptualization of the complex multi-(hazard-)risk conditions and interactions is conducted applying the Impact Chains approach (Zebisch et al. 2022), able to pinpoint biophysical and socio-economic factors and illustrate the role of compounding and cascading effects. Building on this initial conceptualization, a data screening process is employed to select available data, providing a comprehensive overview of the quantitative information required to model specific conditions. For instance, data pertaining to atmospheric and meteorological conditions (e.g., precipitation, temperature), biophysical elements (e.g., topography, land cover, soil type), socio-economic factors (e.g., population density, land use), and recorded impacts (e.g., forest fires, vegetation/crop damage, water quality) are essential for the development of science and demonstration cases. These will include both EO datasets as well as non-EO datasets. Within the SDCs, EO datasets will be complemented by local, regional, national, and global models and in-situ data, where available.

In this project, we will use a combination of advanced modelling techniques and established models to characterize and assess exposure and vulnerability leading to multi-risk. More specifically, we will employ network diagrams and impact chains to illustrate causality between different exposure and vulnerability factors; descriptive analytics tools (e.g., correlation analysis, multivariate distribution analysis, multivariate regression) to provide us insights into possible relationships between hazards, exposure, and vulnerability indicators and assessment endpoints. If the quality and quantity of input data allow, AI and ML methods will then be used to quantify these relationships and weigh the importance of different indicators. Narrative descriptions will allow us to better understand the indirect impacts of previous multi-(hazard-)risk events and communicate in a more accessible way complex information captured via impact chains, for example. Generalized Additive Mixed Models (GAMMs) will be used to model non-linear relationships and account for between-group variability in data, while simultaneously retaining a high model interpretability (Zuur, et al., 2009, Pedersen, et al., 2019). Physical-based modelling and digital twinning combined with scenario-based quantitative risk assessment will explore future multi-risk scenarios, while the identification of common points of failure and hazard combinations with the greatest societal response will be investigated using vulnerability scenarios (Pescaroli and Alexander, 2018) and multi-hazard, multi-risk indicators.

Conducting in-depth case studies across varied geographical contexts can foster consistent collaboration among researchers from diverse disciplines. By leveraging multiple methods, these studies can ensure a holistic approach to more informed multi-hazard risk assessment and management. This effort should span all phases of risk management, as different stages may require distinct sets of information. However, operationalizing this information for first responders may exceed the current project's timeframe and capacity.

4. STRATEGIC ACTIONS

This deliverable will highlight strategic actions already implemented to address identified research gaps, along with outlining forthcoming steps within the scope of the project. Moreover, we will offer recommendations which extend beyond the boundaries of the project, contributing to a broader research agenda.

To address the need to collaborate closely with other research projects focused on similar research activities, several strategic actions have already been implemented in the first six months of the project. Among others, multiple project participants attended the European Commission – European Space Agency Joint Earth System Science Initiative 2023 workshop that took place on the 22-24th of November at ESA-ESRIN in Frascati, Italy. The workshop focused on reviewing the latest advances in EO and Earth System Science across domains and to showcase the latest ESA and EC funded results, projects, and initiatives as a basis for networking and to encourage interdisciplinary scientific collaboration. The team presented a poster (GMV) and a keynote presentation (VU) on the EO4Multihazards project in the session for Earth Observation for Multi-Hazards and Compound Events (Climate Adaptation – Extremes, Multi-hazards, and Compound Events theme) of the workshop. The poster was showcased as a lightning talk in the session for setting priorities for a better understanding and assessment of extremes and multi-hazards.

Furthermore, members of the team attended the annual event of the CERIS Disaster Resilient Societies which took place in Brussels from 4-7th December 2023. The EO4Multihazards project was presented (by VU) during the Societal Resilience and Risk Governance session and involved a panel discussion on connecting multi-hazard and compounding risk initiatives at EU level. Multiple Horizon Europe projects were present during the event, which allowed for some networking among projects research groups, leading to the identification of synergies (e.g., with regards to existing databases).

To address the identified gaps in collaboration among research communities, the consortium is organizing a first workshop aimed at fostering dialogue on the role of Earth Observation in multi-hazard risk assessment and management, as highlighted in the Community Roadmap. This workshop is scheduled to take place during the General Assembly of the European Geosciences Union from April 14th to 19th, 2024 (EGU 2024), specifically on Wednesday afternoon. Careful consideration was given to scheduling to ensure it does not conflict with pertinent Earth Observation or multi-(hazard-)risk sessions or meetings, thus maximizing participation from both communities. The workshop will feature panel discussions and group sessions focusing on the three research questions outlined in the Requirements Baseline (D1.1):

- What role do EO technologies, methods, data, and tools play in advancing our understanding of multi-(hazard-)risk scenarios?
- What specific EO products are currently absent or needed to enhance our understanding of hot, dry, and wet multi-(hazard-)risks across diverse spatial and temporal scales?
- What methods are necessary to integrate EO products with in-situ data and advance our understanding of multi-(hazard-)risk?

Following the workshop, we aim to facilitate informal conversations to foster stronger connections among the diverse research communities involved by inviting participants to informal drinks afterward. Several project participants will also be attending EGU 2024 to present research related to the EO4Multihazards project, seeking feedback from the wide array of scientists present at this annual conference.

Looking ahead, the second workshop of the project, planned for next year 2025, will leverage the insights gleaned from the activities implemented in the first year of the project. This forthcoming workshop will serve as a platform to convene various research communities and stakeholders. While the specific topic of the second workshop will be determined closer to the date, it will closely align with the research gaps and recommendations outlined in this document.

The existence of multiple projects such as AI4Drought, Deep-extremes, and ExtrAIM, which assess various components of disaster risk reduction with a focus on Earth Observation information, creates a risk of redundancy between projects, that can be avoided with collaboration between research teams. To consolidate and integrate research across the EO domain and the broader disaster risk spectrum, including other ESA-funded projects, we have proposed a special issue within the journal Natural Hazards and Earth System Sciences (NHESS) on the role of Earth Observation for Disaster Risk Reduction.

It is imperative to collectively explore how synergies between these projects can yield the most impactful and sustainable outcomes, not only within academia but also in broader societal contexts. This entails ensuring that risk managers and decision-makers are properly informed, ultimately benefiting both society and the environment. For this purpose, stakeholder involvement is crucial. The proliferation of concurrent research projects underscores the necessity of preventing stakeholder fatigue. This issue arises when stakeholders are repeatedly engaged, often separately across projects with overlapping objectives, without clear goals or tangible benefits for them (Canfield, Mulvaney, and Chatelain 2022). To foster sustainable relationships with stakeholders relevant to multi-hazard risks and address stakeholder fatigue, we propose extending the typical duration of projects (i.e., 2-4 years) to allow for deeper insights and contributions from local stakeholders or simplifying the application process for project extensions.

We contend that the appropriate duration of projects depends on the objective of the research. While it is crucial to swiftly allocate funds in disaster scenarios to aid communities on the ground - particularly when earth observation data can support recovery efforts – there is also a necessity for longer-term funding to support continuous stakeholder engagement. We recommend increasing the flexibility- and simplify the procedures to apply for extensions, particularly for successful projects with significant stakeholder involvement.

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