TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. SOUNDNESS OF THE CHALLENGE

1.1.1. DESCRIPTION OF THE STATE OF THE ART

Human-induced climate change is causing more frequent and intense extreme weather events and making them more unpredictable. The result is widespread adverse impacts and related losses and damages to society, economy and the environment, with the most vulnerable people and systems disproportionately affected (IPCC, 2022). Since 1970, more than 1,700 disasters have been recorded across Europe resulting in more than 165,000 fatalities. The unprecedented hot and dry European summer 2022, for example, caused 15,000 excess deaths (WHO, 2022). However, recorded increases in disaster impacts are not only due to more frequent and intense natural hazards, but also due to the uneven progress in integrating disaster risk management and investment in early warning capacity. The impacts of extreme events are strongly influenced by anticipatory preparation and action by emergency services and responders, communities, and national and local authorities. Anticipatory action refers to activities taken to reduce the impacts of an extreme event before it occurs, or before its most acute impacts are felt (IFRC, 2020). Such actions are dependent on knowledge of when, where and how an event will unfold, and the availability, quality and timely communication and use of forecasts and early warnings (WMO, 2023). For early warning systems to be able to provide adequate predictions of extreme weather events and their likely impacts, information on the type of hazards that an area is exposed to, the suitable forecast lead-times required by a range of end-users (White et al., 2022) and an understanding of the likely impacts all need to be considered (Golding, 2022).

Operational forecasts and early warnings are generally limited to numerical weather prediction timescales (i.e., up to ~10 days ahead), while warnings are often only issued a few days in advance. However, a new generation of experimental and semi-operational ensemble 'extended-range' weather predictions that sit between the weather forecasting and long-range forecasting timescales (i.e., up to 46 days forecast lead-time, often referred to as subseasonal-to-seasonal or 'S2S' prediction) have been developed over the last decade by the world's leading meteorological centres (Vitart et al., 2017). A key motivation of exploring this predictive timescale is to capitalise on the expertise across both the weather forecasting and climate research communities. This extended-range timescale has seen recent skilful predictability advances that have spurred an increasing interest in this timescale for predictions of extremes (Vitart and Robertson, 2018) and improved early warning and action (Woolnough et al., 2024). As our climate warms and extreme events become more pervasive and impactful, there is an increasing demand for this new generation of these forecasts to compliment climate adaptation measures. However, for extended-range predictions to be developed and used effectively for anticipatory action, it is important that, along with science advances, they are developed, communicated and used appropriately for the range of hazardous extreme weather events an area can experience (White et al., 2022; Domeisen et al., 2022). Crucially, operational extreme weather warnings are generally limited to single hazards, with their appraisal made on a hazard-by-hazard basis without considering the interconnections and dependencies between hazards, assets or societal systems and networks. The likely forecasted impacts of events are therefore often underestimated (IPCC, 2022). These complex interconnections are referred to as 'multi-hazard' events, where hazardous events may occur alone, or may occur simultaneously, cascade or compound over time (UNISDR, 2017). It is increasingly recognised that if two disasters occur simultaneously or in succession in the same place, the combination can be more impactful than if they occurred in isolation. In these cases, responders that were capable of handling the impacts of one event may find themselves overwhelmed by multiple events (e.g., First et al., 2022). Research has shown that risk reduction measures aimed at reducing the risk of one hazard can have opposing effects on the risk of another hazard that are not accounted for in the traditional single hazard approach. Moreover, the challenges faced by a community when hit by a disaster while recovery from an earlier event is still on-going, are substantially different from disasters that occur in isolation. Knowledge of these complex multi-hazard interconnections and dependencies and their potential impacts on increasingly long forecasting timescales is therefore crucial for making robust decisions to prepare for these events and reduce impacts when they occur.

A true anticipatory forecasting and early warning approach that embraces a range of forecasting timescales (i.e., connecting weather forecasts and extended-range ensemble predictions) can only be achieved through a multi-hazard and early warnings system (MHEWS) that combines the complex

interconnections between hazards and their drivers across the relevant forecast lead-times, together with knowledge of the direct and indirect impacts and the anticipatory actions required for a given area. MHEWS approaches aim to deliver timely alerting messages to those in affected areas, allowing them to take action to mitigate the impacts of several hazards and/or take into account any potential interrelated effects. Operational MHEWS systems, however, do not yet exist. There remains a vital need to build a common understanding of multi-hazards and their impacts and define and explore windows of opportunity for developing multi-hazard predictions and early warnings on the extended-range timescale. The complexity of predicting and communicating multi-hazard early warnings, however, especially on longer lead-times such as the extended-range timescale, requires assessment approaches capable of capturing multiple components (e.g., different hazards, drivers, impacts) and their interactions in a coherent framework. Communicating early warnings that result in effective action also requires finding a balance between too much and too little detail in the warning (Krocak et al., 2023), including the effective communication of predictability and uncertainty to the end-user. The success of multi-hazard early warning system development is therefore heavily dependent on knowledge and existing approaches from local weather forecasters and action taken on the ground by first responders (e.g., Sengupta et al., 2022). To be effective, MHEWS needs to include the participation of different stakeholders and actively involve the people and communities at risk to ensure that the system has an enabling environment, which incorporates the appropriate technology and adequate operational capacities, as well as to have clearly defined roles and responsibilities.

In 2022, led by the United Nations, the World Meteorological Organization (WMO) launched the Early Warnings for All (EW4All) initiative to ensure every person on Earth is protected by early warning systems within five years. However, despite strong advocacy for a MHEWS approach supported by the EW4All initiative (WMO, 2023), very few examples of MHEWS implementation exist on predictive timescales beyond ~10 days (Boult et al., 2022). Capacity building for multi-hazard predictions is in its infancy, with the weather forecasting communities (predominantly comprising research and operational meteorologists) and the multi-hazard communities (stemming largely from climate change risk assessment and management) largely disconnected. While both communities are very active (e.g., Woolnough et al., 2024 for extended-range predictions; Ward et al., 2022 and Šakić Trogrlić et al., 2024 for multi-hazards), and despite recent promising technological advances with the advent of Artificial Intelligence (AI) and Machine Learning (ML) approaches (e.g., Reichstein et al., 2024), to date there has been no coordinated effort to connect these dynamic disciplines and communities towards MHEWS development. However, to operationalise MHEWS systems and fulfil the United Nations EW4All agenda, it is essential that these communities come together to explore and define windows of opportunity and instigate a step-change in the way multi-hazard anticipatory forecasts are designed, produced and used on a range of prediction timescales (Merz et al., 2020; Woolnough et al., 2024). While some multi-hazards will always present challenges to forecast (e.g., flash floods and landslides), the high predictability of some multi-hazard events (e.g., heatwaves and droughts) components provides an exciting opportunity to create warning systems (Brimicombe et al., 2024) that enhance exiting capabilities and skills, and which are co-designed with users and practitioners to ensure the necessary data, context, and uncertainties are incorporated. This approach will ensure successes and shortcomings are learnt from and shared as a connected MHEWS community.

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The challenges addressed by the Action: Increasingly impactful and destructive extreme events continue to highlight the need for multi-hazard events to be better predicted and for society to be able to take informed anticipatory actions to mitigate their impacts. Skilful multi-hazard predictions and early warnings beyond the ~10-day weather forecasting timescales could save lives, reduce damages and losses, and mitigate the worst effects of a warming climate on society by providing more time to prepare and react. However, despite the dual efforts by the scientific community to understand and explore the processes that govern forecast skill on timescales of more than 10 days ahead, and recent developments to understand and manage the increased risk posed by multi-hazard events, the two areas of research remain largely detached. **The main aim of the ANTICIPATE COST Action for extended-range multi-hazard predictions and early warnings is to bring together existing but largely disconnected research communities and operational practitioners to forward the science and implementation of extended-range multi-hazard predictions and warnings.** It aspires to create a leap forward in our capacity to understand multi-hazards and how we predict and prepare for them on extended timescales as a climate adaptation measure to prevent the worst impacts. ANTICIPATE will draw upon multiple disciplines, communities and users, including weather forecasting, extended-range prediction and dynamics, disaster risk reduction, multi-hazards and risks, artificial intelligence and

machine learning, social sciences, and communications to drive forward the development of effective early warnings that enable preparedness and action across hazards and forecasting lead-times. ANTICIPATE will help train the next generation of multi-hazard forecasters, increase public awareness of multi-hazards and their impacts, enhance preparedness and support better anticipatory actions, and reduce the increasingly dramatic impacts of extreme weather events across the rapidly warming regions across Europe.

Relevance and timeliness: ANTICIPATE will create the first pan-European network to bring together a wide range of disciplines to explore multi-hazard predictions and warnings on extended-range timescales. The Action will address the very real challenges posed by less predictable but often severe extreme weather events in a changing climate by building capacity and exploring novel solutions to ensure timely, precise and actionable predictions and early warnings. The current United Nations EW4All initiative runs up to 2027, making the ANTICIPATE Action incredibly timely. However, this is just a start; the EW4All initiative is a “call to action”, but decades of further work will be needed to put many of its objectives into practice and support the integration of extended-range predictions and warnings. This places ANTICIPATE in a unique position where it can contribute to both the delivery of the EW4All initiative but also play a role in jump-starting the further development and growth of multi-hazard prediction systems through the training and connecting the next generation of scientists, engineers and practitioners who will deliver and use them.

ANTICIPATE will build on and complement multiple – but largely separate – past and ongoing international projects, programmes and initiatives, including those led by intergovernmental bodies such as the WMO (see section 2.1.1). Research in the last decade has moved towards longer extended-range predictive timescales supported by the WMO S2S Prediction Project, which ended in 2023. There has been some success at operationalising these forecasts (e.g., ECMWF, 2024), together with notable, ongoing attempts to explore and quantify forecast skill for extreme events (e.g., Domeisen et al., 2022) and their wider cross-sectoral application and uptake (e.g., White et al., 2022). However, to date, a coordinated international effort to exploit the synergistic potential of bringing together the multi-hazard and extended-range prediction disciplines is largely missing. Instead, projects and initiatives have been / are often thematically focused, with research progress largely achieved in a semi-siloed way. It is this lack of scientific coordination that is inhibiting the advancement of multi-hazard predictions for the benefit of society, economy and civil protection that ANTICIPATE will seek to redress. The ANTICIPATE COST Action is therefore a timely proposition to link European research and operational institutions, creating a step-change in the development of multi-hazard predictions and warnings and a mechanism to foster the exchange of knowledge with a wide range of end-users and emergency responders across Europe.

Against this background, ANTICIPATE will also respond to the need for more general, comprehensive approach to risk management and hazard prediction and preparation that incorporates multi-hazard thinking and approaches as a climate change adaptation measure. This was first stated in the Hyogo Framework for Action by the United Nations Office for Disaster Risk Reduction (UNDRR) and then embedded in the United Nations Sendai Framework for Disaster Risk Reduction in 2015. Multi-hazard risk management was also recognised as an important way to achieve the Sustainable Development Goals (SDG) and the Millennium Development Goals (MDG) before them. The UNDRR acknowledges this approach in its Global Assessment Report (GAR) on Disaster Risk Reduction (UNDRR, 2022), calling for action to reflect the interconnected nature of hazards and risks and to foster a joined-up and pluralistic approach to understanding and managing these risks within the Sendai Framework. However, this still contrasts with current approaches that tend to focus on individual hazards and regions without reference to the potential for hazards to interact and their impacts propagate through connected parts of a complex system. This is where ANTICIPATE will make a significant contribution to knowledge and society by improving the understanding of multi-hazards and how we predict and prepare for them.

1.2. PROGRESS BEYOND THE STATE OF THE ART

1.2.1. APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE OF THE ART

Climate change is driving more severe and more impactful multi-hazards coupled with the emergence of new climate-driven risks. International policies for disaster risk reduction and climate adaptation are increasingly recognising the importance of addressing multi-hazard risks, but this has yet to translate into predictions and early warnings. Effective early warnings are, however, only possible if these phenomena are understood and quantified. In Europe, 75% of people are covered by some single

hazard early warning systems, though coverage is much lower in some countries outside of Europe. However, there is a recognition that most impactful extremes are actually multi-hazard events, yet advancements in forecasting multi-hazards do not exist yet. A multi-hazard perspective is missing in traditional weather forecasts meaning that multi-hazard capacity building for forecasters and emergency responders is still very much in its infancy. Crucially, there have been no attempts globally to connect multi-hazard approaches with the extended-range forecasting timescale and the two communities are largely disconnected. ANTICIPATE will therefore create a ground-breaking network that bridges the gap between the extended-range predictions and multi-hazards communities – working together to drive forward the development of early warnings and actions on yet-to-be explored forecasting timescales. It will approach this challenge and progress beyond the state-of-the-art in the following ways:

- The current limited understanding of the **sources of predictability of multi-hazards, including their drivers and their spatial and temporal dependencies,** leads to large uncertainties, especially on timescales that extend beyond the ~10 days weather forecasting capabilities. Spatiotemporal lags and overlaps, and dependencies between multiple and interrelated hazards and their risks, differences in scales, and varying land use patterns all play a significant role in the modulation and intensification of multi-hazard events. Incorporating these cross-scale multi-hazard predictive capabilities in forecasts are rare; however, they are extremely important at scales such as the pan-European level and for organising emergency preparedness and response. This limitation represents major challenges to the adoption of effective anticipatory actions, some of which require multiple weeks to prepare for. This is a crucial deficiency. ANTICIPATE will therefore advance the science by bringing together existing fragmented multi-hazard and predictive approaches to explore sources of predictability and quantify multi-hazard dynamics and their spatiotemporal dependencies.
- MHEWS approaches, supported by the United Nations EW4All philosophy, integrate hazard and impact information to provide meaningful predictions and early warnings that allow governments, communities, and individuals to understand the risks related to impending events, take anticipatory actions to minimise impacts, and save lives. Whether through public safety, health and wellbeing, supporting agricultural productivity, water security, reducing poverty, enhancing economic growth, or supporting resilient energy systems, cities, oceans and land, MHEWS are a vital tool for decision makers. However, to date, while operational services such as ARISTOTLE (see section 2.1.1) provide a multi-hazard perspective, they are limited to monitoring and analysing the occurrence of a single hazard that follows an assessment of consequences to other hazards and do not have predictive capabilities. ANTICIPATE will therefore – for the first time – **explore the potential of using extended-range forecasts up to 46 days ahead for multi-hazard predictions and improved early warnings**.
- ANTICIPATE will also achieve **technological advances** beyond the state-of-the-art by exploring the possibilities for improving multi-hazard predictions and warnings using **AI/ML**. Existing ML solutions are applied in different domains, including being used to develop models that provide services like real-time alerts, predictions, and simulations of disasters. AI-based solutions are though only developed for single hazard solutions, such as the Google Flood Forecasting Initiative or scalable ingestion and fusion workflows that deploy state-of-the-art ML models to produce predictions. Furthermore, recent advances in extended-range forecasting include fully data driven models that are starting to be competitive as compared to traditional dynamical models (e.g., the AIFS model developed and operated by ECMWF and other open source models). Building on such recent advancements in **AI/ML**, these technologies will be explored in ANTICIPATE, enabling a more comprehensive understanding of multi-hazard dynamics, dependencies and impacts and provide interventions and warnings of multi-hazard events to civil protection authorities and decision-makers on extended-range timescales.
- Finally, ANTICIPATE will **support the wider application and dissemination of scientific advancements** in multi-hazard predictions on extended-range timescale to the needs of operational weather prediction centres, emergency responders and the general public. The activities will be cross-cutting and co-designed with the Action's partners, ensuring needs of all participants and their own extended stakeholders and end-users will be enhanced through close collaboration between stakeholders, researchers and forecasting experts. Bringing together these communities around the central theme of predicting multi-hazards has no precedent and is one of the core-objectives of this Action. ANTICIPATE will therefore provide an ideal platform for different communities to exchange modelling skills, expertise and knowledge as well as to foster a dialogue with end-users. This will facilitate international cooperation, establishing a long-term robust platform for improving the prediction of multi-hazards on extended-range timescales through collaboration with operational forecasting centres and stakeholders.

1.2.2. OBJECTIVES

1.2.2.1. Research Coordination Objectives

The aim of ANTICIPATE is to form a pan-European multidisciplinary network to drive forward the prediction and early warning of multi-hazard events on the extended-range forecasting timescale. This will be accomplished through the following **Research Coordination Objectives** (RCO):

RCO1. Build a common understanding of multi-hazard risks and impacts, their mechanisms and causes, their changes due to global warming, and their sources of predictability on the extended-range forecasting timescale;
RCO2. Devise a conceptual framework for the development of extended-range predictions and early warning of multi-hazards that align with the MHEWS and EW4All initiatives;
RCO3. Identify methodological advancements for the development of multi-hazard predictions on the extended-range timescale using existing models and datasets and integrate novel methods including AI/ML;
RCO4. Provide clear guidance on the use of open datasets, indicators and new methods suitable for recording and predicting multi-hazards and their impacts on extended-range forecasting lead-times;
RCO5. Explore the potential development and communication of early warnings of multi-hazard events through the co-production of applications with stakeholders to support future operational integration and public-facing services and warnings; and
RCO6. Raise awareness of ANTICIPATE's activities and outcomes using a variety of methods and media, including online seminars and multimedia videos supported by graphics and case study narratives, to a wide range of stakeholders, targeting operational forecasters and intergovernmental organisations including UNDRR and WMO and the general public.

1.2.2.2. Capacity-building Objectives

ANTICIPATE creates a network of organisations, experts, researchers and stakeholders keen to advance the state-of-the-art of multi-hazard predictions and warnings and explore novel predictive timescales. ANTICIPATE will create a multidisciplinary research environment that bridges typically siloed disciplines and builds a permanent international network to support the development of the next generation of informed developers, operational practitioners and users of multi-hazard predictions and warnings. To achieve this ambition, ANTICIPATE's **Capacity-building Objectives** (CbO) are to:

CbO1. Create a pan-European network to accelerate scientific progress in multi-hazard predictions and warnings, towards a more informed and prepared Europe;
CbO2. Establish a community that blends expertise, knowledge and approaches from across disciplines, communities and sectors (including weather forecasting, extended-range prediction and dynamics, disaster risk reduction, multi-hazard risk assessment and management, and the social and communications sciences) to drive a step-change in the way multi-hazards are understood, predicted and prepared for;
CbO3. Produce a cross-European network that provides unique multidisciplinary training and knowledge exchange opportunities to the next generation of developers and operational practitioners of multi-hazard predictions and warnings;
CbO4. Ameliorate stakeholders' understanding of the impacts of multi-hazard events affecting European regions and communities in a changing climate; and
CbO5. Improve the awareness of the potential benefits of predicting of multi-hazards beyond the traditional weather forecasting timescales (i.e., embracing the extended range for increased awareness and preparedness).

2. NETWORKING EXCELLENCE

2.1. ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

As well as embracing the MHEWS and EW4All initiatives, ANTICIPATE will seek to build on and complement past and ongoing European and international state-of-the-art operational and research projects, programmes and initiatives focused on multi-hazards, extended-range predictions, early

warnings and anticipatory action. In particular, ANTICIPATE will build on / collaborate with the following:

Projects, programmes and initiatives	Relation to ANTICIPATE
S2S Prediction Project (World Weather Research Programme (WWRP) / World Climate Research Programme (WCRP), 2013-23)	ANTICIPATE will build on the project's legacy of exploring and improving forecast skill and understanding sources of predictability on sub-seasonal to seasonal forecasting timescales.
PEOPLE (WMO, 2024-28)	ANTICIPATE will connect with the PEOPLE programme to explore the elements of an effective early warning system and the social processes needed to support it.
Sub-seasonal applications for Agriculture and Environment (SAGE) (WWRP, 2024-)	ANTICIPATE will work with WWRP's new initiatives including SAGE to incorporate sub-seasonal predictions with sectoral applications.
C3S_330 Seasonal Forecasts (Copernicus)	Knowledge of the operational seasonal forecast development output from ECMWF will provide the blueprint for many of ANTICIPATE's RCOs and CBOs.
MEDiate (HE 2022-25) and Myriad-EU (HE 2021-25)	ANTICIPATE will build on two projects exploring the challenges of multi-hazards and multi-risks for improved decision-making and management.
MedEWSa (HE, 2024-27)	ANTICIPATE will align and collaborate with MedEWSa's exploration of a multi-hazard forecasting system for the Mediterranean region.
HIWeather (WMO, 2018-24)	ANTICIPATE will benefit from the learnings from HIWeather's themes, including user-evaluated forecasts and multi-scale forecasting of hazards.
Knowledge-Action-Network on Emergent Risks and Extreme Events (Risk KAN)	ANICIPATE will connect with the Risk KAN hub for the exchange of information, knowledge, and data.
DAMOCLES (CA17109) (COST, 2018-23)	ANTICIPATE will extend the learnings from the DAMOCLES COST Action on compound events.
CLINT (H2020, 2021-25)	ANTICIPATE will benefit from CLINT's AI/ML tools for the prediction of extreme events and their impacts at the extended-range time horizon.
CEMS Hydrological Forecasting (Copernicus, 2022-2028)	CEMS runs forecast production at a European/global scale, which will provide a key example of an operational early warning system to support for ANTICIPATE's activities.
IMPREX (H2020, 2015-19)	ANTICIPATE will take advantage of the outcomes from the development of early warning systems and climate services approaches for forecasting extremes / impacts.
SEE-MHEWS-A (WMO, 2016-)	ANTICIPATE will connect with SEE-MHEWS-A's expertise in developing a regional MHEWS and operational hydrological forecasting system.
ARISTOTLE (2019-)	ANTICIPATE will seek technical advancements from delivering a multi-hazard advice service for the EU Emergency Response Coordination Centre (ERCC).

Links to these projects and programmes are largely already available through previous and ongoing collaborations. ANTICIPATE will further interact with and involve representatives from other international projects to connect disparate scientific communities, broaden perspectives and expand geographic coverage, including for example the recently-funded ACACIA project (2024-) that will enhance the resilience of at-risk communities in Sub-Saharan Africa to climate impacts using sub-seasonal forecasts. ANTICIPATE will also strive to involve other complimentary international networks and frameworks with the Action's meetings and activities. This includes the Global Risk Assessment Framework (GRAF) Expert group of the UNDRR; the ClimXtreme network in Germany; and the International Federation of Red Cross and Red Crescent Societies (IFRC) and the Red Cross Red Crescent Climate Centre's Anticipation Hub. ANTICIPATE's activities will also seek to feed into the ongoing global disaster and assessment reporting cycles, including the UNDRR's GAR reporting cycle. By bringing together

participants from these diverse scientific projects, programmes and initiatives through one multidisciplinary network, ANTICIPATE will enhance the exchange of knowledge between traditionally disparate disciplinary silos and create new synergies and opportunities.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS, EXPERTISE AND GEOGRAPHICAL BALANCE WITHIN THE COST MEMBERS AND BEYOND

ANTICIPATE assembles the critical mass of expertise required for an inclusive multidisciplinary network to further the development of extended-range multi-hazard predictions. Our proposers include experts in earth and related environmental sciences, civil / environmental engineering / other technologies, social and physical sciences. Participants have multidisciplinary expertise spanning operational weather forecasting, extended-range prediction and dynamics, disaster risk reduction, multi-hazards and risks, social sciences and communications. The network encompasses not only people from academia and associated research organisations but crucially also members from global / international intergovernmental scientific research and governance organisations and UN specialist agencies (3), members from governmental organisations (4) and not-for-profit organisations (3), bringing direct connections to public-facing civil protection, emergency planning and disaster management groups. It is envisioned that ANTICIPATE's network will be easily expanded during the lifetime of the Action by exploiting existing partnerships and synergies with existing international projects, programmes and intergovernmental initiatives (see section 2.1.1), drawing on both public and private entities (e.g., civil protection, insurance) and through implementing other dissemination activities (see section 3.2.2).

ANTICIPATE will provide Young Researchers and Innovators (YRI's) with a unique opportunity to learn from and contribute equally to the development of a crucial area of scientific development, ensuring active knowledge transfer towards less advantaged research groups, institutions and countries. The geographical footprint of the network is also purposefully pan-European, selected to be inclusive by integrating contrasting 'at risk' multi-hazard areas across Europe where the need to predict and prepare for multi-hazard events is particularly acute. This is supported through four identified regions that will form testbeds throughout the Action (see section 4.1.1). This broad coverage of ANTICIPATE is crucial to improve the capacity to understand, predict and prepare for impactful multi- hazard events in a wide range of societal settings and distinct geographical regions of Europe.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

Several European countries have large weather prediction centres, with active, internationally renowned research groups (mainly national weather services) supported by academia, while others, especially in eastern Europe, mainly focus on operational weather forecasting and do not have such clearly defined research-oriented activities. ANTICIPATE takes the diversity of the organisational structures and prediction capabilities of Europe's weather and climate research groups and centres into account through the weather prediction centres also acting as stakeholders in the network. This dual role will benefit the activities of ANTICIPATE and help promote the outcomes by further engaging with their existing stakeholder and end-users including the general public. ANTICIPATE will also actively support the uptake and use of the extended-range multi-hazard predictions by our stakeholders. Each WG (see section 4) has been organised to embed engagement and dissemination activities. This structure aims at optimal communication at national and regional levels, where each WG will identify and involve stakeholders in collaboration with the MC. Inclusion of stakeholders will be achieved generally through invitations, periodic emails/newsletters and other activities including recorded seminars published on ANTICIPATE website. Through our partners (including operational meteorology services and government agencies), ANTICIPATE aims to engage with a wider range of stakeholders through a range

of different workshops and activities (see section 4), developing an open-source information ecosystem with knowledge and outcomes available to all including emergency responders and the general public.

A further innovation of ANTICIPATE is to go beyond the research and operational forecasting communities and involve international intergovernmental scientific research and governance organisations and UN specialist agencies in the network from the outset. Therefore, ANTICIPATE's stakeholders will have an unprecedented opportunity to co-design many of the Action's activities and collaborate at the international level. ANTICIPATE will build on numerous established links to relevant stakeholders such as UNDRR, WMO, the International Science Council, and the European Joint Research Council through long-term partnerships and memberships in international expert panels and task groups, projects and programmes. We also aim to attract additional relevant stakeholders from already-established projects, programmes and initiatives (see section 2.1.1), including the WMO MHEWS and UNDRR EW4All initiatives and various WMO groups (e.g., WWRP, WCRP) focused on extreme weather prediction, multi-hazards, early warnings and anticipatory action. This ambition will be further supported through the Action's activities including workshops, online seminars, and focus groups with the public, but also through training schools and STSMs that will support exchanges between researchers, operational forecasters, emergency responders and the Action's wider stakeholders.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAKTHROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

ANTICIPATE's **research and innovation** will align with and build on insights from previous and ongoing projects, including technological advances that explore the possibility for improving predictions and warnings using AI/ML, to explore the elements needed for effective multi-hazard early warnings for anticipatory actions that go beyond the traditional weather forecasting timescales. ANTICIPATE will incorporate knowledge systems as well as governance dimensions, focusing on science for (and with) policy and practice in mind. Throughout the Action, ANTICIPATE will engage an inclusive range of stakeholders and individuals (see section 2.2.2) in developing a contextual understanding of priorities and experiences that would ensure a successful and sustainable implementation of an equitable extended-range multi-hazard early warning system. ANTICIPATE will initiate and test processes that include representatives of key stakeholder groups and a multidisciplinary team of scientists that have the potential to integrate scholarly knowledge and experienced practitioners' contextual knowledge to provide the pathway to an effective system. This will advance the state-of-the-art and ensure impact by integrating the needs of stakeholders and/or the public in the communication of multi-hazard predictions and warnings, including science stakeholder cooperation to bridge the gap between the so called "scientific and technological" and "societal" knowledge and values to develop a comprehensive, multidisciplinary approach that can be used to implement multi-hazard predictions at various levels.

ANTICIPATE addresses the **societal demand** for accurate, reliable and useful longer-range predictions and warnings. This is a crucial issue for populations in vulnerable areas that are disproportionately exposed to a changing climate. The expected impact of this Action is to improve and harmonise high-impact multi-hazard predictions across European countries on forecasting timescales that have not been previously explored. This will support earlier warnings and anticipatory actions that would be of particular benefit to research centres in less research-intensive countries and in countries with limited operational forecasting capacities. ANTICIPATE will foster direct collaboration between different weather prediction centres through the development of a common understanding, approach and vocabulary. This enhanced cooperation is expected to be solidified through the Action's STSMs and training schools. Therefore, in alignment with the EW4All initiative, this Action is expected to contribute to improvements in the readiness for multi-hazard events at the European level.

The design of ANTICIPATE consists of five interlinked Working Groups (WGs) (see Figure 1 in section 4.1.1), each enriched with agile approaches to offer the development of new approached and breakthroughs that will **support the long-term development, implementation and operationalisation** of multi-hazard predictions and warnings, ensuring impact beyond the lifetime of the Action. The need to inject agility into ANTICIPATE arises from the fact that the Action envisions breakthrough approaches, products and innovations. To this end, ANTICIPATE's activities are planned

to start early in the network's time plan (see Gantt chart in section 4.1.4), which will lead to early progress and developments. ANTICIPATE will also seek to exploit the rapidly advancing AI/ML techniques to explore increased knowledge and spatial coverage to reduce the impacts of multi-hazards in communities across Europe. Explicit focus will also be given to "last mile" communications through our stakeholder and user community partners to support uptake and Research to Operations (R2O).

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

ANTICIPATE aims to create impact both within the research community as well as for stakeholders, emergency responders and the general public. Early warnings of natural hazards – and especially multi-hazards – will strongly benefit from increased collaboration between all involved entities. Hence, ANTICIPATE will bring together the experiences of researchers at all career stages, forecasters from operational services, and stakeholders from international and intergovernmental organisations, national government authorities and not-for-profit organisations to ensure cross-communication between all those involved in the early warning pipeline. The nature of multi-hazard extremes inherently involves the need for collaboration to bridge the gap between the multi-hazard and extended-range communities that have so far progressed separately. ANTICIPATE will embed an ethos of collaboration between these communities to co-design and co-develop scientific advances and products that will ensure research advances in the understanding and modelling of multi-hazard extremes directly benefit those predicting such events as well as those impacted by such extremes. Considerable advancements in the understanding of multi-hazard extremes and their extended-range prediction are expected over the next few years, hence this Action represents a timely and mutually beneficial opportunity to create a supportive network that understands the importance of anticipatory action in response to complex, hazardous events as our climate changes.

A key goal of ANTICIPATE is the development and training of a multidisciplinary community with a focus on knowledge creation and exchange between experienced researchers, YRIs, government authorities, international intergovernmental organisations, stakeholders and practitioners in research and operational weather services. The participants in the Action are therefore drawn from the two multi-hazards and extended-range prediction communities. By working in collaboration, they will have a unique opportunity to develop new knowledge and skills and significantly influence their careers. This goal will be achieved for YRIs through the following mechanisms:

- Training schools to expose YRIs to the two disciplines of multi-hazard and extended-range predictions and early warnings. These unique training opportunities will include experts from a range research and stakeholder organisations, providing hands-on training opportunities jointly led by researchers and practitioners with a focus on implementation and operationalisation.
- STSMs to advance the careers of the next generation of developers and operational practitioners, providing them with opportunities to enhance their research through access to research and operational infrastructures and emergency responders across Europe and boost the creation of new multidisciplinary knowledge and its transfer from one discipline to another.
- Creation of an early career multi-hazard prediction and early warning community that creates and leads online seminars and other activities for knowledge generation and transfer that are organised by and for other YRIs across Europe.

This goal will also be achieved for researchers and practitioners at all levels through:

- Providing the opportunity to build new and enhance existing collaborations that span the multi-hazard and extended-range predictions and early warnings disciplines.
- Co-developing new methods and products for investigating multi-hazards, their predictability and addressing their uncertainties.
- Influencing how research can influence and be co-designed with operational weather forecasting and warnings centres.
- Increasing their visibility to the general public on issues that are relatively poorly understood.
- Contributing to achieving international initiatives such as EW4All and MHEWS and influencing the work of intergovernmental networks and organisations across Europe and beyond.

3.2.2. PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

The development and implementation of a cross-cutting **engagement and dissemination plan**, managed by WG5 (see section 4.1), will oversee many of ANTICIPATE's interlinked activities to build effective awareness of the results, creating a common understanding and the laying out the steps towards implementation among the Action's stakeholders and target end-users and the wider general public. The execution of this plan will facilitate the best use and uptake of the outcomes and research insights generated throughout the Action's lifetime, reinforcing impacts and expected outcomes. ANTICIPATE will **maximise the dissemination and influence** of its outcomes by interacting, consulting and collaborating with its partners and wider stakeholders throughout its timeline to identify refinements and fill gaps in existing information. The Action will operate on multiple levels and for different types of end-users, focusing on predicting short-term, local-scale multi-hazard events to larger-scale transboundary events. It will explore collaborations with existing systems at national, regional and European levels as well as with international intergovernmental organisations. Dissemination activities will be uploaded to a dedicated Action website and promoted through social media and other activities. Materials including multimedia videos, graphics and case study narratives will be developed and communicated to increase visibility and appeal of the Action's outcomes. The Action's annual meetings will each have a specific focus to support stakeholder engagement and uptake. Year 1 will include a stakeholder-mapping exercise to establish needs and wants from multi-hazard predictions. A case study workshop in the third year will focus on learning lessons from past multi-hazard events and will be used by relevant stakeholders and decision-makers to identify best practices. During the third annual meeting, stakeholders will be asked to provide input on the conceptual design of an extended-range multi-hazard prediction system beyond the duration of the Action. Finally, the fourth annual meeting will bring together the Action's partners and stakeholders in an interactive workshop to set a pathway to operationalising an extended-range multi-hazard prediction and early warning system. The use of regional 'testbeds' (see WG2 in section 4.1.1) will also be used throughout the Action to foster collaboration, communication, sharing of best practices and meaningful knowledge transfer between areas with different capacities and practices.

ANTICIPATE will create and **increase public awareness** of multi-hazard events through a range of activities including a dedicated website and social media feeds with interviews, blogs, articles and online seminars by Action members. Activities will include workshops and focus groups and demonstrations open to both the research community and the public by members associated with or interested in the Action, including operational personnel from national weather services. These activities will also include dedicated training information and case studies on past multi-hazard events to support education, capacity and awareness-building. The Action will also prioritise strengthening **open science** through open access sharing of knowledge and open, transparent cooperation among all researchers, stakeholders and the general public to maximise knowledge transferral, uptake and impact. The network embraces the vision that large and unrestricted access to knowledge is essential to further the science and uptake of extended-range multi-hazard predictions. Many of ANTICIPATE's partners have open access science portals that will be used to host or disseminate ANTICIPATE's materials ensuring that ANTICIPATE's results and outputs will be accessible to all.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

The core objectives of ANTICIPATE will be achieved through an interlinked framework comprising five cross-cutting WGs (Figure 1), corresponding to the overall challenges of this Action (see section 1): **WG1**: Setting the capability landscape: sources of multi-hazard predictability; **WG2**: Linking multi-hazards with extended-range predictions; **WG3**: Multi-hazard impacts and databases; **WG4**: Exploring multi-hazard early warnings products for anticipatory actions; and **WG5**: Cross-cutting co-design, stakeholder engagement and dissemination. The framework will be flexible and responsive to scientific developments, the needs of stakeholders interested in the multi-hazard predictions, and general public awareness where interest may range from the explanation of events to the future of predictions and warnings. Therefore, each WG will be organised to address both research and capacity-building objectives (RCOs and CbOs; see section 1.2.2) and aligned with the wider Action's engagement and dissemination activities (see section 3.2.2).

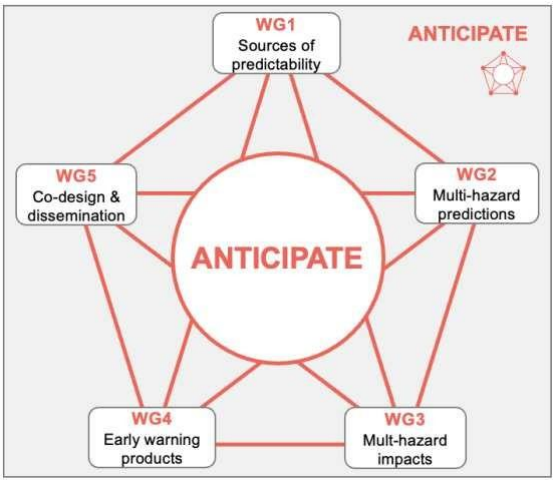


Figure 1. ANTICIPATE's interlinked framework of five cross-cutting Working Groups

ANTICIPATE's interlinked WGs and activities will be strengthened using representative 'testbeds' across Europe, based on regions with a history of being impacted by multiple natural hazards. The testbeds have been selected with different climatic and physiographic conditions yet facing similarly impactful multi-hazard events. These testbeds will be used throughout ANTICIPATE to demonstrate multi-hazard forecast skill and uncertainty across a range of spatial and temporal scales, test the potential effectiveness of early warning products, support local capacity-building (including operational weather centres, emergency responders and YRIs), and aid dissemination to deliver meaningful and long-term knowledge exchange of ANTICIPATE's outcomes. The four testbed regions ANTICIPATE will utilise throughout the lifetime of the Action are: Testbed #1: Central and Eastern Europe: heavy rain and widespread transboundary flooding; Testbed #2: Southern Europe: heatwaves, drought and wildfires; Testbed #3: Northern Europe: convective storms and flash flooding; and Testbed #4: Eastern Europe: flooding and landslides.

Each WG will be managed through a set of a logical, interconnected Tasks (T), each linked back to the Action's objectives and shown in parentheses '[ ]'. The five cross-cutting WGs are described as follows:

WG1: Setting the capability landscape: Sources of multi-hazard predictability

Research tasks and activities: WG1 will set the capability landscape for ANTICIPATE, exploring and mapping the potential of multi-hazard predictions across Europe. WG1 will take an interrelated, process-based effort to build a new, common understanding of multi-hazard interdependencies, mechanisms and causes and their potential sources of predictability on the extended-range forecasting timescale across Europe. **T1.1** [RCO1] will develop and advance existing protocols for assessing multi-hazard interdependencies, their causes and the influence of large-scale drivers (e.g., the North Atlantic Oscillation). This new knowledge will be applied to case studies of past high-impact multi-hazard events to provide case studies that support education, knowledge exchange and dissemination. **T1.2** [RCO1] will then assess key multi-hazard interdependencies and relate these to extended-range predictions up to 46 days ahead using the ECMWF extended-range ensemble forecasts (ECMWF, 2024). Comparative studies will be performed using large-scale atmospheric weather observation datasets as well as local datasets provided by the participants. **T1.3** [RCO2] will then develop an adaptable and intelligent methodological framework to visualise known and unknown multi-hazard interdependencies, causes and sources of predictability. For this, conditional probability analyses will be used to assess the probability of one co-variable being extreme if another is also extreme. To cope with limited ensemble sizes, this task will focus on large-scale predictors to local extreme events across different regions of Europe. This approach will underpin many of the Action's activities to ensure that new methods and approaches will function as a common language throughout the timeline of the Action.

Capacity-building: WG1 [CbO1-3] will work closely with stakeholders to explore the potential for multi-hazard predictions and their limitations and uncertainties to lay the foundation for next generation of operational MHEWS and improve disaster preparedness. WG1 will work with range of stakeholders including governments, emergency responders and civil protection authorities to explore and share new information on the interrelationships between hazards, their dynamics and drivers, and their spatial and temporal scales. Although implementing an operational extended-range multi-hazard prediction system is out of scope for ANTICIPATE, WG1 will build crucial capacity that can facilitate collaboration between the multi-hazard and weather prediction centres to lay the foundations for operationalisation.

WG2: Linking multi-hazards with extended-range predictions

Research tasks and activities: T2.1 [RCO3] will exploit the knowledge on multi-hazards, their dynamics and drivers and their sources of predictability from WG1 and utilise the ECMWF extended-range ensemble forecasts through the S2S Prediction Project database along with other datasets in the

Copernicus Climate Data Store (e.g., EFAS, CEMS) to characterise, estimate, and predict hazards and their interactions across a range of spatial-temporal dependencies. Analysis will be carried out over the European domain, exploring data and single hazard forecasting services already implemented at scale in Europe. This task will explore the ability of the extended-range models to predict a range of multi-hazard events at varying spatial and temporal scales. This task will again use the testbeds as pilots to identify forecast skill and gaps in the science and capabilities on the extended-range forecasting lead-time. In parallel, **T2.2** [RCO3] will build on the knowledge from T1.2 to foster the use of state-of-the-art multivariate hybrid frameworks that combine non-stationary copulas for high-dimensional interdependence modelling using new AI/ML techniques to replace statistical empirical prediction models. This is important when uncertainty in multi-hazards is challenging to quantify in historical and forecasting data, limiting the applicability of uncertainty quantification for early warnings despite their ability to study causation drivers. ML will be used extend the ECMWF ensembles using information from both coarse- and high-resolution models to build statistical emulators (e.g., Yousefi et al., 2020) for improved prediction harnessing the large amount of forecast data available. Data sources (including impacts identified in WG3) will be used for the development of disaster-specific AI-driven impact-based forecasting technologies. **T2.3** [RCO3,4] will then use the outputs from T2.1 and T2.2 and test a seamless 'Ready-Set-Go!' approach (Goddard et al., 2014) to the multi-hazard predictions, exploring how seasonal forecasts (>30 day forecast lead-time) can be used to provide the 'Ready' multi-hazard monitoring information and early contingency planning, extended-range forecasts (10-30 days) the 'Set' early warnings and alerts, and short-range weather forecasts (up to 10 days) the 'Go!' actions stage. This concept will be used to demonstrate the potential for multi-hazard predictions to emergency responders, governments and the general public to react accordingly to hazardous events.

Capacity-building: As with WG1, WG2 [CbO1-3] will continue to work with stakeholders to share and discuss the potential for multi-hazard predictions and communicate their potential limitations and uncertainties. Multi-hazard predictions will be assessed using defined evaluation protocols for end-users' consultation and validation towards providing tailor-made products in WG4 and facilitating potential further R2O collaborations. Innovation and capacity-building will extend to the exploration of the different multi-hazard interdependencies among a range of events that can lead to increasing disproportionate risks and impacts.

WG3: Multi-hazard impacts and databases

Research tasks and activities: T3.1 [RCO3,4] will gather, catalogue and assess the still uncharted impacts of multi-hazard events using data and information from multiple sources (e.g., national records, sectoral datasets) to help characterise, estimate and predict multi-hazards and integrate relevant exposure and vulnerability data. This task demands close collaboration between researchers and stakeholders. Using the testbeds as pilots, a methodology for quantitatively calculating multi-hazard impacts will be co-developed with the Action' stakeholders using vulnerability curves, impact-based and stakeholder-centred information. To deliver reliable information and support the use of open access, quality-ensured datasets, this task will use observations and reanalysis data, generated by state-of-the-art mechanistic models that are available on the Copernicus Climate Data Store, together with regional and national information provided by the Action's stakeholders. **T3.2** [RCO3,4] will explore the strength of AI/ML hybrid modelling to assess spatiotemporal patterns and evolutions of interdependent hazards and their impacts. There may be a large range of scientific and modelling issues to be dealt with by WG3, especially regarding poorly understood multi-hazard impacts on the local scale. Therefore, this task will explore the use of AI to reduce this complexity and uncertainty in terms of quantitative and modality of data to generate explainable, effective, and applicable impact-based information. AI will be used to explore and extend existing data, measures, and technologies to estimate multi-hazard impacts, spanning spatial-temporal dependencies between different hazards. **T3.3** [RCO3,4] will then explore the potential for the development of a comprehensive database with reported multi-hazards impacts across the pan-European area, ensuring adequate and appropriate data is collected and post-processed to a harmonised format, and supporting frequent data updates as disaster tracking is a highly dynamic scenario. A set of AI-based detecting, post-processing (bias-adjustment & downscaling) and forecasting algorithms will also be identified (supported by WG2). Comparisons and collaboration with conventual course-resolution impact databases (e.g., EM-DAT) will allow for novel techniques to estimate potential impacts by integrating new, localised hazard, exposure, and vulnerability data.

Capacity-building: WG3 [CbO4] participants will work closely with stakeholders and weather prediction services involved in the Action to identify datasets, methodological advances and propose new products (e.g., databases) for understanding the impacts of multi-hazard events on regional, national and

European scales. Stakeholders will be expected to provide input to enable tailoring of these products to their needs and thus maximise the visibility and utility of the Action's products.

WG4: Exploring multi-hazard early warning products for anticipatory actions

Research tasks and activities: WG4 will link the innovative multi-hazard understanding in WG1, the predictions developed in WP2, and the understanding of their impacts developed in WP3 to understand the potential for developing state-of-the-art extended-range multi-hazard predictions and early warnings for improved anticipatory actions. **T4.1** [RCO5] will understand and map the Action's key stakeholder needs and analyse their existing measures, technologies, early warning and response products and systems to investigate their potential to be extended to characterise, estimate and predict multi-hazard events on extended-range timescales. It will engage with an inclusive range of stakeholders in developing a contextual understanding of priorities and experiences that would ensure the development and continuous improvement in the implementation of a multi-hazard early warning system. The analysis will include a focus on existing local measures and regional systems, including the prediction of short-term events and their persistence into the extended-range timescale (e.g., several weeks ahead). The starting point will be well-established national and European warning systems (including nowcasting) and various WMO projects and initiatives. The analysis will provide a comprehensive landscape of spatial-temporal coverage for different hazards of existing services that will help to define later tasks. **T4.2** [RCO5] will then utilise ANTICIPATE's co-design and co-development ethos to develop products that can deliver effect extended-range multi-hazard early warnings for anticipatory actions across spatial and temporal scales. This task will build on the 'Ready-Set-Go!' approach embraced in WG2 and integrate knowledge and ideas from users and stakeholders to best achieve the timely communication and dissemination of multi-hazards predictions and early warnings (e.g., severity levels, impact levels) using clear, simple, and appropriate language across different predictive timescales and with different levels of complexity. In **T4.3** [RCO5], ANTICIPATE will then draw on the unique capabilities, access, and local knowledge and networks of the Action's partners and stakeholders to test and refine the products, ensuring viability of the approach and achieving sustainability and complementarity with existing products and services. This task will connect with and complement existing impact-based assessment services and lay out a roadmap for R2O to guide and support the development of downstream services, offer lessons learnt and good practices, and boost the operational uptake of the proposed products. The four testbeds will be used to demonstrate and test the potential effectiveness of these early warning products and support local capacity-building and potential implementation.

Capacity-building: Identifying potential pan-European scalability a critical component of ANTICIPATE. WG4 [CbO5] will bridge the "last mile" in capacity-building and communication, delivered through an integrated co-design approach and a continuous dialogue between stakeholders. With the Action's partners, including international intergovernmental scientific organisations and UN specialist agencies, national governmental organisations and not-for-profit organisations, WG4 will utilise existing social and anticipatory knowledge and practises to deliver information that communicates multi-hazard information and appropriate actions on predictive timescales (up to 46 days) that are not yet operational.

WG5: Cross-cutting co-design, stakeholder engagement and dissemination

Cross-cutting stakeholder engagement activities: T5.1 [RCO6, CbO1-5] will design and manage ANTICIPATE's engagement and dissemination plan, offering cross-cutting and inclusive co-design and outreach, awareness raising, and capacity building activities with its stakeholders to support ANTICIPATE's activities to improve early warnings that predict multi-hazards, inform earlier decision-making, and enable societal anticipatory actions. In this task, the various activities of the Action will be supported by annual workshops, targeted stakeholder engagement activities, and information activities for the general public including focus groups and demonstrations. The website and social media feeds will include interviews, blogs, articles and online seminars by Action members aimed at the general public. During events, training and educational activities will be organised (e.g., case study workshops and online seminars). The outcomes of these activities will help extract meaningful knowledge related to the full exploitation of breakthroughs from the Action. By including the general public in outreach events, it will target the wider ecosystem and society as a whole, translating complex information to actionable knowledge. **T5.2** [RCO6] will focus on providing multidisciplinary opportunities for education, training and capacity development of YRIs and operational practitioners. The task will focus on STSMs and training schools, targeting multidisciplinary training and knowledge exchange between the multi-hazard and extended-range communities to facilitate the development of enhanced multi-hazard predictions. **T5.3** [RCO6] will then focus on designing mechanisms to facilitate the long-term sustainable

translation of complex information to actionable knowledge for end-users, suggest best practices to address challenges of multi-hazard events, propose priorities for improving modelling and operational forecasting procedures, and facilitate R2O operational uptake. The task will produce guidance and create dialogue across the WGs using utilising the four testbeds as a communication mechanism.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

The Milestones (M) and Deliverables (D) for each of the WGs described in the previous section are detailed below. The timeframe of these activities is illustrated in the Gantt chart in section 4.1.4.

WG	Milestones	Deliverables
WG1	**M1.1** Development of a common understanding of multi-hazard interdependencies, mechanisms and causes and their potential sources of predictability **M1.2** Production of an intelligent methodological framework to visualise known and unknown multi-hazard interdependencies, causes and sources of predictability	**D1.1** Case studies of past multi-hazard events and impacts including narratives and dissemination materials **D1.2** Paper describing the methodological framework
WG2	**M2.1** Assessment and characterisation of the prediction of hazards and their interactions across a range of spatial-temporal dependencies **M2.2** Exploration of AI/ML techniques and impact modelling using hybrid statistical-physical approaches **M2.3** Testing of a seamless 'Ready-Set-Go!' multi-hazard extended-range prediction approach	**D2.1** Report(s) / scientific paper(s) describing the potential of multi-hazard predictions **D2.2** Scientific paper exploring the viability of the 'Ready-Set-Go!' approach
WG3	**M3.1** Analysis of the impacts of multi-hazard events including spatiotemporal patterns and their impacts incorporating AI-based detection and post-processing **M3.2** Exploration of a potential multi-hazard database	**D3.1** Catalogue of the impacts of multi-hazards **D3.2** Trial multi-hazard impacts database
WG4	**M4.1** Quantification of the Action's key stakeholder needs and analysis of their existing measures, technologies, early warning and response products and systems **M4.2** Co-development of products and interfaces to deliver extended-range multi-hazard early warnings for anticipatory actions **M4.3** Testing and refinement of the products ensuring viability of the approach and roadmap for R2O	**D4.1** White paper exploring stakeholder wants and needs from multi-hazard early warnings **D4.2** Multi-hazard early warning product development summary **D4.3** Roadmap for R2O
WG5	**M5.1** Identify the best channels for the dissemination of project results and case studies, including Action website **M5.2** Organise focused annual workshops **M5.3** Design of targeted stakeholder engagement and dissemination activities including a YRI network, online seminars, and videos supported by case study narratives **M5.4** Run focus groups with the general public including case study workshops and demonstrations **M5.5** Organise and run multidisciplinary STSMs and training schools **M5.6** Complete translation and dissemination of information to actionable knowledge for end-users, suggest best practices to address challenges of multi-hazard events, propose priorities for improving modelling and operational forecasting procedures, and facilitate public engagement	**D5.1** Website live **D5.2.1-4** Annual workshops summary **D5.3** Targeted stakeholder engagement activities delivered and summarised as a short report **D5.4** Public engagement activities held and summarised **D5.5.1-4** Annual summaries suitable for public and stakeholders

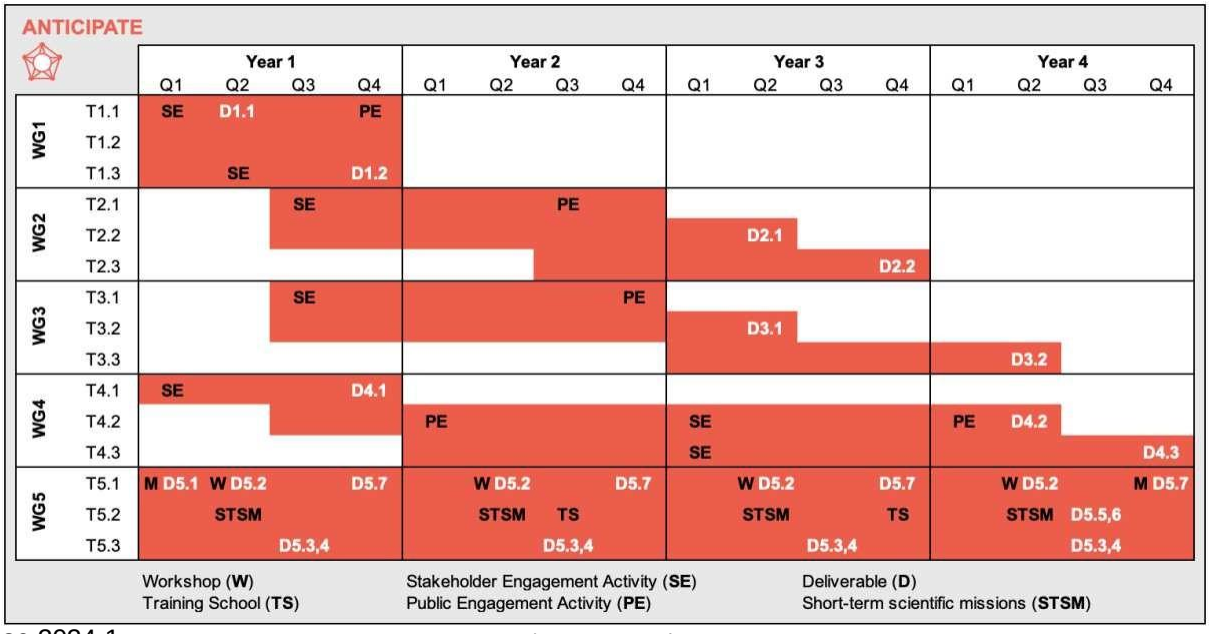
4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

The Core Group will meet online monthly to ensure ANTICIPATE's management, monitor progress and outcomes, and take necessary actions in case of deviations or problems. The MC will then hold meetings ~6 months to track the progress of the Action. The following potential risks have been identified, presented with mitigation plans to overcome them or to minimise their impact:

Description of risk and level	WG	Proposed risk-mitigation measure

Operational risk: Management, administrative or personnel changes **Low**	All	Unanticipated changes in the Action Chair, MC or WGs may slow down work when new staff may need to be trained for networking tasks. The Action Chair and other MC Members are experienced in project management of large international research consortia, which will ensure continuity in staffing as well as administration and management duties. For each WG, ANTICIPATE will have two leads (including one YRI and one senior scientist) for redundancy.
Operational risk: Poor collaboration / coordination between WGs and / or slow progress **High but mitigated**	All	In case of slow or insufficient progress across the WGs, the MC will ask the WG leaders to set priorities for advancing with the WG tasks. Depending on the issue, mitigations may include: invitation to new members with relevant expertise to the Action; creation of a discussion forum on the website to enhance interaction; setting of more regular MC meetings to identify problems and propose solutions; and fostering specific side-meetings between partners during the Action workshops and other activities.
Operational risk: Force Majeure / COVID-19 may Disrupt activities or prevent physical events **Medium but mitigated**	All	The Action includes workshops and training events that ideally will be conducted face-to-face. However, if COVID-19 or a similar 'Force Majeure' occurs, face-to-face dissemination and networking events might not be possible also in the future. Therefore, to overcome this risk, the MC will use online alternatives for workshops and training schools using online meeting tools. To facilitate and accelerate cooperation among the various research teams in the consortium, online teamwork software would be used (e.g., https://miro.com/).
Scientific risk: Dependencies between WGs **Low**	All	Some WG activities are designed to build on each other with the risk that delays in tasks of one WG propagate to other WGs of the Action. However, the WGs are sufficiently stand-alone so that most activities can run in parallel if some activities and deliverables are delayed.
Impact risk: Challenges with stakeholder engagement and involvement **Low**	All; WG5	ANTICIPATE will identify additional stakeholders and end-users and involve them in the networking activities. A potential risk may be the identification and engagement of these stakeholders. However, ANTICIPATE comprises an existing network of partners and stakeholders across Europe that it will use to extend ANTICIPATE's reach. The MC will ask the MC Members to identify specific entities from each of their countries with a high interest in this Action.
Impact risk: Limited interest from the general public **Low**	WG5	The MC will reinforce dissemination activities through the website, social media and dedicated activities. Dissemination materials including multimedia videos, graphics and case study narratives will be communicated to increase visibility and outreach.

4.1.4. GANTT DIAGRAM



References

Boult, V.L., et al. (2022). Towards drought impact-based forecasting in a multi-hazard context. Climate Risk Management, https://doi.org/10.1016/j.crm.2022.100402

Brimicombe, C., et al. (2024) Preventing heat-related deaths: The urgent need for a global early warning system for heat. PLOS Climate, https://doi.org/10.1371/journal.pclm.0000437

Domeisen, D.I.V., et al. (2022). Advances in the subseasonal prediction of extreme events. Bulletin of the American Meteorological Society, E1473–E1501, https://doi.org/10.1175/BAMS-D-20-0221.1

ECMWF (2024). Extended-range forecasts. European Centre for Medium-Range Weather Forecasts (ECMWF), https://www.ecmwf.int/en/forecasts/documentation-and-support/extended-range-forecasts (accessed 16/10/2024)

First, J.M., et al. (2022). Double trouble: Examining public protective decision-making during concurrent tornado and flash flood threats in the U.S. Southeast. International Journal of Disaster Risk Reduction, 81, 103297, https://doi.org/10.1016/j.ijdrr.2022.103297

Goddard, L. et al. (2014). The International Research Institute for Climate & Society: why, what and how. Earth Perspectives, 1, 10, https://doi.org/10.1186/2194-6434-1-10

Golding, B. (2022). Towards the “Perfect” Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication. Springer, https://link.springer.com/book/10.1007/978-3-030-98989-7

IFRC (2020). World Disasters Report 2020. International Federation of Red Cross and Red Crescent Societies (IFRC), Geneva, 378p, ISBN 978-2-9701289-5-3, https://media.ifrc.org/ifrc/world-disaster- report-2020

IPCC (2022). Sixth Assessment Report: Summary for Policymakers WGII. Intergovernmental Panel on Climate Change (IPCC), Geneva, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Krocak, M.J., et al. (2023). Public Information Priorities across Weather Hazards and Time Scales. Bulletin of the American Meteorological Society, E768–E780, https://doi.org/10.1175/BAMS-D-22-0190.1

Merz, B., et al. (2020). Impact Forecasting to Support Emergency Management of Natural Hazards. Reviews of Geophysics, https://doi.org/10.1029/2020RG000704

Reichstein, M., et al. (2024) Early warning of complex climate risk with integrated artificial intelligence. ResearchSquare (preprint), https://doi.org/10.21203/rs.3.rs-4248340/v1

Šakić Trogrlić, R., et al. (2024). Challenges in assessing and managing multi-hazard risks: A European stakeholders perspective. Environmental Science & Policy, 157, 103774, https://doi.org/10.1016/j.envsci.2024.103774

Sengupta, A., et al. (2022). Advances in Subseasonal to Seasonal Prediction Relevant to Water Management in the Western United States. Bulletin of the American Meteorological Society, E2168–E2175, https://doi.org/10.1175/BAMS-D-22-0146.1

UNDRR (2022). Global Assessment Report on Disaster Risk Reduction: Our World at Risk. United Nations

Office for Disaster Risk Reduction (UNDRR), 256p https://www.undrr.org/gar/gar2022-our-world-risk-gar

UNISDR (2017). Sendai Framework for Disaster Risk Reduction 2015-2030. UN International Strategy for Disaster Reduction (UNISDR), 32p, https://www.undrr.org/publication/sendai-framework-disaster-risk- reduction-2015-2030

Vitart, F., et al. (2017). The Subseasonal to Seasonal (S2S) Prediction Project Database. Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-16-0017.1

Vitart, F., Robertson, A.W. (2018). The sub-seasonal to seasonal prediction project (S2S) and the prediction of extreme events. npj Climate and Atmospheric Science, 1, 3, https://doi.org/10.1038/s41612-018-0013-0

Ward, P., et al. (2022). Invited perspectives: A research agenda towards disaster risk management pathways in multi-(hazard-)risk assessment. Natural Hazards and Earth System Sciences, 22, 1487–1497, https://doi.org/10.5194/nhess-22-1487-2022

White, C.J., et al. (2022). Advances in the application and utility of subseasonal-to-seasonal predictions. Bulletin of the American Meteorological Society, E1448–E1472, https://doi.org/10.1175/BAMS- D-20-0224.1

WHO (2022). Climate change is already killing us, but strong action now can prevent more deaths. WHO Press Statement 07/11/2022 https://www.who.int/europe/news/item/07-11-2022-statement---climate-change-i s-already-killing-us--but-strong-action-now-can-prevent-more-deaths#:~:text=Heat%20stress%2C%20when%20the%20body,%2C%20and%20diabetes%2Drelated%20conditions

WMO (2023). Early Warnings for All – The UN Global Early Warning Initiative for the Implementation of Climate Adaptation: Executive Action Plan 2023-2027. WMO, Geneva, 56p https://library.wmo.int/records/item/58209-early-warnings-for-all

Woolnough, S., et al. (2024). Celebrating 10 Years of the Subseasonal to Seasonal Prediction Project and Looking to the Future. Bulletin of the American Meteorological Society, E521–E526, https://doi.org/10.1175/BAMS-D-23-0323.1

Yousefi, S., et al. (2020). A machine learning framework for multi-hazards modeling and mapping in a mountainous area. Nature Scientific Reports, 10, 12144, https://doi.org/10.1038/s41598-020-69233-2