Urban Prediction Project Implementation Plan (2025-2029)

Urban-PREDICT: Predictions, Risk assessments, Early warnings, Data integration, Inclusive governance, Community awareness, and Transformative actions

WORLD METEOROLOGICAL ORGANIZATION

WWRP WORLD WEATHER RESEARCH PROGRAMME

1 Table of Contents

Executive Summary

1. Background and Motivation: Urban areas worldwide are increasingly vulnerable to weather-related hazards due to global climate change and rapid urbanization. This affects people living in diverse urban conditions and with different levels of vulnerability. These hazards include extreme heat, storm surges, heavy precipitation and flooding, wildfires, and deteriorating air quality. The Urban-PREDICT project, as part of the World Weather Research Program (WWRP) Implementation Plan (IP) 2024–2027, and Advancing Weather Research to Reduce Risk to Societies ($AWAR^3E$) principles, to advance urban multi-hazard prediction and Early Warning Systems (EWS). By developing and integrating ultra-high-resolution weather hazard forecasting at application-appropriate spatial scales (ranging from tens to thousands of meters), Artificial Intelligence (AI), and place-specific, culturally relevant data, the project aims to enhance preparedness and response in diverse urban settings.

2. Project Aim: Urban-PREDICT seeks to reduce weather-related risks by combining advanced weather prediction models with community and place-specific insights, including decision-making structures and processes. This will lead to more effective early warning systems and risk management strategies tailored to urban populations.

3. Key Research Objectives: The project is structured into four interconnected work packages (WP):

- **WP1 "Accessibility and Relevance of Information":** Explore context specific early warnings and data availability, actionability, and cultural relevance.
- **WP2 "Prediction and EWS Across Spatial Scales":** Assess the impact of varying spatio-temporal resolutions on hazard prediction accuracy and EWS effectiveness.
- **WP3 "Advanced Urban Modelling and Prediction Capabilities":** Develop and leverage emerging numerical weather prediction models and AI to enhance urban multi-hazard forecasting from nowcasting to seasonal timescales.
- **WP4 "Knowledge Sharing and Capacity Building":** Leverage knowledge and capacity to enable stakeholders (including scientists, policymakers, emergency management and communities) to co-develop the tools and insights necessary for resilient urban EWS planning.

4. Deliverables and Outcomes: Urban-PREDICT will provide:

- Improved accuracy and timeliness of urban hazard forecasting and warning systems.

- Enhanced risk communication strategies including with diverse communities.
- Robust benchmarks for multi-hazard prediction and warning systems.
- Strengthened cross-sector partnerships and decision-making capacities among global and local stakeholders.

A multidisciplinary steering group representing six WMO global regions will oversee the project to ensure scientific rigor and local relevance. Urban-PREDICT Implementation Plan (2025–2029) will be phased through a series of workshops, research initiatives, and collaborations at various geographical scales, including local communities and decision makers. By consolidating research outputs into policy and operational improvements, Urban-PREDICT aims to protect lives, infrastructure, and promote sustainable urban development in the face of evolving weather hazards.

1 Introduction

1.1 Mission Statement

To understand and reduce multi-hazard weather-related risks in urban areas through the integration of ultra-high-resolution[1] and accurate early warning capabilities, prediction models (potentially supported by AI), and observations as well as populations' lived experiences, perceptions, awareness, governance practices and actions for enhanced urban adaptation and resilience, communication and ultimately well-being of diverse urban communities.

1.2 Project overarching question

How can advanced prediction technologies, context-specific practices, and multi-scale approaches enhance the accessibility, relevance, and effectiveness of multi-hazard early warning systems and risk communication in socially diverse urban areas?

1.3 Key Scientific Questions

To achieve the above mission statement, below are the main questions that the project will address in the four focus areas:

A. **ACCESSIBILITY AND RELEVANCE OF INFORMATION**

Question 1:

[1] Ultra-high resolution refers to sub-kilometer and even hectometer scales

How can information and data contributing to the EWS process be available and accessible, culturally relevant, actionable, and place-specific, considering socially diverse urban areas and complex and uncertain weather-related risks?

B. **PREDICTION AND EWS ACROSS SPATIAL SCALES**

Question 2:

What are the roles of spatio-temporal scale required to accurately predict different types of weather-related hazards and provide effective multi-hazard early warnings for diverse urban populations and decision-makers?

C. **ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS**

Question 3:

To what extent can the integration of advanced and emerging physical prediction models, observations, AI technologies, and diverse multidisciplinary urban data enhance prediction and early warning systems in different urban environments (e.g., by improving their ability to capture spatial and/or temporal variability)?

D. **KNOWLEDGE SHARING AND CAPACITY BUILDING**

Question 4:

What capacity is needed to access, analyze, and interpret urban multi-disciplinary data and information, enabling key actors (i.e., scientists, policymakers, practitioners, and communities) to develop accessible, culturally relevant, actionable, place-specific, and co-produced weather-related hazards risk reduction measures?

1.4 Urban-PREDICT Project Background

Urban areas around the world are facing an unprecedented rise in weather-related hazards as climate change and rapid urbanization intensify the risks. Those hazards include extreme heat, heavy precipitation and flooding, wildfire, and deteriorating air quality. At the same time 70% of the world's population will be living in cities by 2050, exacerbating both their risks and the number of people potentially exposed. Increasing evidence highlights the effects of wildfire smoke on air quality (AQ) and human health (e.g., Aguilera et al., 2021; Xu et al., 2023). With more than half the global population living in cities projected to rise significantly, the urgency for effective early warning systems has never been greater. In 2023, the UN Secretary General launched a cross-UN initiative "Early Warnings for All" (EW4All) to ensure that everyone on Earth is protected from hazardous weather, water, or climate events through life-saving early warning systems (EWS) by the end of 2027. EWSs are a proven, efficient, and cost-effective way to save lives and infrastructure and support climate resilience and long-term sustainability. This UN initiative underscores the global commitment to ensuring that every urban community, particularly those most vulnerable, receives timely and actionable weather alerts to mitigate these emerging risks.

The WMO is tasked to co-lead the UN EW4All effort. Building on its legacy of advancing weather and climate prediction through core projects like High-Impact Weather, Polar Prediction, and Sub-seasonal to Seasonal Prediction, the WMO WWRP IP (2024-2027) has recognized that a new focus is needed to address the unique challenges of urban environments. This Urban Prediction Project (Urban-PREDICT) emerged from the understanding that cities face a distinct set of cascading hazards that require a tailored approach. The project is driven by the need to provide ultra-high-resolution multi-hazard predictions and warnings that capture the fine-scale geographical and social variability of urban landscapes—information that is critical for enhancing local preparedness and resilience against hazards exacerbated by climate change.

Moreover, increasing urbanization and changing weather patterns and their compounding effects intensify vulnerability, socio-spatial segregation, and inequality, creating major challenges for climate resilience, mitigation, and adaptation. Addressing these issues requires looking beyond the physical footprint of weather hazards to examine governance systems and relations that influence decision-making. This integrated approach promotes a fairer distribution of knowledge, power, and resources, enabling communities to monitor their environments and reduce unequal exposure to weather-related risks. Research has shown that technical knowledge alone is insufficient; for effective solutions, it must be understood, accepted, and legitimized by all relevant actors (Smith, et al., 2020).

Urban-PREDICT will build upon recent progress in urban weather prediction research community and WWRP projects. The World Meteorological Organization (WMO)-endorsed the Paris 2024 Olympics Research Demonstration Project (RDP), which focused on improving weather forecasting systems at hectometric scales and included an intercomparison of hectometric weather models over the Paris region. This Urban-PREDICT project is specifically aimed to improve urban multi-hazard prediction and warning systems at ultra-high-resolutions, i.e. sub-kilometer and even hectometer scales. Such a high resolution is essential for addressing the heterogeneous nature of urban settings, where variations in infrastructure, socioeconomic conditions, and microclimates can significantly influence the impact of weather events. By leveraging advanced weather prediction, AI-driven big data technologies, and novel observational techniques, the project aims to enhance actionable early warnings that directly benefit densely populated and under-resourced urban areas.

Cities are not only recipients of climate change impacts, but they actively influence regional weather and climate. It is well documented that urban areas create heat islands and contribute to extreme heat (Oke et al. 2017), alter precipitation patterns and regional weather (Bornstein and Lin 2000, Miao et al. 2011, Niyogi et al. 2011, Chen et al 2011b), affect hurricane landfall precipitation (Zhang et al. 2018), and intensify extreme precipitation events (Wu et al. 2019). It is important to further our understanding and modelling of these human–nature interactions at urban scales and how they modify extreme events, which is a unique and critical focus of the Urban-PREDICT Project. Urban-PREDICT will explore the interaction between the land/ocean-atmospheric, environmental, socio-economic, political and institutional factors related to evolving weather risks, in order to enable the development of context-specific ultra-high-resolution urban prediction strategies through combining systematic physical and social sciences studies. These complex datasets are expected to inform local decision making and policy development involving cross-sector capacity building activities and actions rooted in collaboration, co-creation and co-responsibility.

Moreover, the Urban-PREDICT project distinguishes itself by adopting a comprehensive **science-for-services** approach that integrates technical forecasting innovations with robust risk communication strategies. The research will be structured around a series of case studies and demonstrators, which will be a key element of the project's execution. It builds upon the lessons learned from earlier WWRP projects by explicitly addressing the challenges of public engagement and effective warning information dissemination in urban contexts. This integrated strategy—combining cutting-edge ultra-high-resolution weather modelling and prediction capabilities, AI technologies, interdisciplinary research, and social science insights—ensures that weather-related hazard-prediction are translated into clear and actionable warning guidance for emergency managers, policymakers, and the public. In doing so, the project not only enhances urban resilience and safety but also aligns with global mandates such as the United Nation (UN) "Early Warnings for All" initiative, reinforcing WWRP's commitment to reducing risk and building sustainable, climate-resilient cities.

The Urban-PREDICT project will go beyond an interdisciplinary approach, often critiqued for not transgressing disciplinary thinking (Ramadier, 2004), through the involvement of transdisciplinary research teams in selected case studies, as well as non-academic partners and communities. Rooted on complexity and using a transdisciplinary approach, which recognizes the superposition of realities and attempts to confront them (Smith & Jenkins, 2015), the ultimate goal of this project is to understand and reduce multi-hazard weather-related risks in urban areas through the integration of ultra-high-resolution and accurate early warning capabilities, prediction models (potentially supported by AI, and observations as well as population lived experiences, perceptions, awareness, governance practices and actions for enhanced urban adaptation and resilience, communication and ultimately well-being of diverse urban communities.

1.5 Strategic alignment with WWRP Goals

The Urban-PREDICT project is closely aligned with the mission of the WWRP Implementation Plan 2024-2027, which is to advance and promote interdisciplinary weather research that enhances forecast accuracy and reliability from minutes to seasons to reduce disaster risks. It directly contributes to advancing targeted research and the "science-for-services" paradigm by developing ultra-high-resolution forecasting tools that improve the prediction and warning of weather-related hazards in urban areas. It not only enhances the scientific understanding of urban meteorological phenomena but also ensures that research outcomes translate into actionable information for decision-makers and urban vulnerable communities.

Central to the WWRP IP is the AWAR3E (Advancing Weather Research to Reduce Risk to Societies) framework, which outlines guiding principles for integrating scientific innovation with societal needs. This project embodies the AWAR3E principles by: 1) ensuring that stakeholders are well-informed about emerging hazards through improved risk communication and early warning systems; 2) promoting an integrated approach that combines ultra-high-resolution physical and AI-based modelling with social science insights, thus addressing the complex interplay between urban infrastructure, human vulnerability, and extreme weather events; and 3) engaging communities and enhancing capacity building so that knowledge, power, and resources are more equitably distributed, ultimately leading to more resilient and adaptive urban systems. It reinforces WWRP's commitment to reducing disaster risks, supporting equitable climate adaptation, and ensuring that scientific advancements result in tangible benefits for societies facing the challenges of a changing climate.

1.6 Partners and Beneficiaries

The project will benefit institutions, governments, and communities at a range of geographical scales. Throughout a series of case studies and demonstrators, which will be the focus of the Urban-PREDICT project, the beneficiaries are local communities, affected by weather risks and local governments, who will benefit from new data to develop context-specific frameworks and actions oriented to EWS and mitigation.

In addition, potential partners include organizations and research programs within and outside the WMO. The Urban-PREDICT project is expected to contribute to ongoing research across all WMO projects and programs with new datasets, findings and actions from specific demonstrators. These include within the World Weather Research Programme (WWRP), Progressing EW4All Oriented to Partnerships and Local Engagement (PEOPLE), Integrated Prediction of Precipitation and Hydrology for Early Actions (InPRHA) (https://wpo.noaa.gov/inprha/) , High Impact Weather (HIWeather), EW4All and within the World Climate Research Programme (WCRP), My Climate Risk, Digital Earth, Human system, Coordinated Regional Climate Downscaling Experiment (CORDEX), especially CORDEX-URBAN. The project will also generate impactful interactions with INFCOM: Infrastructure Commission (INFCOM)/Services Commission (SERCOM), Global Atmospheric Watch (GAW), GAW Urban Research Meteorology and Environment (GURME), Social and Economic Research Applications (SERA).

In particular, the GURME project has expressed strong interest in collaborating with Urban-PREDICT. This partnership will focus on joint activities under Work Package (WP2) and Work Package (WP4), especially in co-developing reports on the suitability of data sources and modelling approaches for urban-scale prediction and early warning systems, and dispersion modeling in the urban environment. This collaboration will support both technical benchmarking and capacity-building components of the project. The collaboration is aligned with the timeline of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Cities, with the intention that its outcomes contribute directly to that process by late 2026.

Beyond the WMO context, the Urban-PREDICT project will participate from UN dialogues, including those led by United Nations Office for Disaster Risk Reduction (UNDRR), World

Health Organization (WHO) (Beat the Heat project), United Nations Environment Programme (UNEP), and International Organization for Migration (IOM), to offer insights into weather prediction actions in urban areas and to contribute to policy development at an international level.

2 Research Plan

2.1 Objectives

The research activities are structured around four areas of work, interlinking social and physical sciences to achieve the overarching mission of the project. This section highlights the four objectives of the project, which are further explained in the following sections.

A. ACCESSIBILITY AND RELEVANCE OF INFORMATION

Objective 1:

To assess and provide guidance on the accessibility and cultural relevance of diverse urban data (e.g., socio-economic, demographic, geospatial) and information to contribute to an actionable EWS process for place-specific preparedness and response.

B. PREDICTION AND EWS ACROSS SPATIAL SCALES

Objective 2:

Understand the roles of spatial and temporal scale and recommend benchmarks in multi-hazard predicting and providing effective early warnings for diverse urban populations and decision-makers.

C. ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS

Objective 3:

Understand how the integration of advanced physical models, observations, AI technologies, and diverse multidisciplinary urban data can enhance prediction and early warning systems in different urban environments.

D. KNOWLEDGE SHARING AND CAPACITY BUILDING

Objective 4*:*

To explore place-specific, diverse knowledge and capacities among key actors in urban areas to prepare and respond to weather-related risks using data and information.

2.2 Outputs

The four interlinked research areas that structure this project will be managed through four Work Packages (WPs) and develop the following outputs:

A. WP1: ACCESSIBILITY AND RELEVANCE OF INFORMATION

Outputs:

1. Comprehensive framework for case study selection.
2. Report on existing good practice examples and processes across specific case studies
3. Report on the success and failure of existing initiatives and projects across selected case studies
4. Guidance for context-specific EWS, preparedness, and response, reflecting on the findings from the analysis and the outcomes of the workshop.
5. Report on the locally relevant need-based training material in the selected case study areas
6. Publication of an academic paper of the results of place-specific research on information sharing for action in the context of extreme weather conditions

B. WP2: PREDICTION AND EWS ACROSS SPATIAL SCALES

Outputs:

1. Report and/or academic publication on the importance of spatial and temporal scale for various urban hazards, including model performance evaluation and benchmarking.
2. Recommendations for optimal prediction scales for each hazard and type of city
3. Recommendations for future integrated multi-hazard warning system intercomparison studies.
4. Special WWRP Urban Prediction and Warning sessions in international conferences
5. Special Issues with peer-reviewed journal

C. **WP3: ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS**

Outputs:

1. Report on performance evaluation of physics-based AI versus conventional weather prediction models, with reflection on data requirements for effective AI modelling of different hazards.
2. Report on the transferability of state-of-the-art physics-based AI urban hazard modelling systems, considering data and observation gaps, and inherent global inequalities.
3. Research proposals and new partnerships towards the development of enhanced integrated and interactive prediction and EWS in diverse urban areas.

D. **WP4: KNOWLEDGE SHARING AND CAPACITY BUILDING**

Outputs:

1. Report showcasing examples of place-specific knowledge and capacities for preparedness and EWS (including less studied regions of the world)
2. Dashboard with datasets showcasing place specific knowledge and capacities that exist within the case studies.
3. Training material for communities, decision-makers, and practitioners working in urban settings on local good practices for place-specific EWS and preparedness (informed by findings and recommendations across all objectives)
4. Training workshops for key actors

2.3 Outcome

The project is expected to achieve the following outcomes in each of the research areas.

A. **WP1: ACCESSIBILITY AND RELEVANCE OF INFORMATION**

Outcome: Knowledge synthesis and guidance on better accessibility and culturally relevant urban datasets and information to support actionable EWS for place-specific preparedness and response.

B. **WP2: PREDICTION AND EWS ACROSS SPATIAL SCALES**

Outcome: Improved knowledge and recommendations for benchmarking on the role of spatial scale in providing effective multi-hazard early warnings.

C. **WP3: ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS**

Outcome: Enhanced understanding of the role of diverse and emerging models and urban data in hazard prediction and improved ultra-high-resolution urban hazard prediction and EWS capabilities.

D. **WP4: KNOWLEDGE SHARING AND BUILDING CAPACITY**

Outcome: Improved preparedness of policymakers, communities, and practitioners in urban areas to respond to weather-related risks using data and information that are place-specific and result from a dialogue of knowledges.

2.4 Impact

The project will foster and build a dynamic international community of researchers in urban prediction, enhancing global collaboration, knowledge exchange, and capacity-building for urban multi-hazard prediction and early warning systems.

Communities in urban areas will have reduced adverse impacts from weather-related multi-hazard risks as a result of better preparedness and enhanced minute-to-season multi-hazard hazard prediction and EWS, clear risk communication campaigns, and actionable plans.

3 Strategies/Activities for Execution

3.1 General activities surrounding each project objective

The following activities will be carried across the four project WPs:

A: WP1 ACCESSIBILITY AND RELEVANCE OF INFORMATION

Addressing today's complex challenges around early warnings and weather impact analysis requires open, plural and effective use of knowledge provided by diverse disciplinary expertise and should consider local, regional, national, and global contexts. Moreover, it is essential that decision-making around weather data, early warnings and mitigation actions considers the relevance of place-based research. Urban areas represent a diversity of socio economic and cultural backgrounds that should be taken into consideration when developing early warnings and plans for protective actions around weather related multi-hazard risks. This introduces the concept of tailored warnings whereby warnings are personalized for individuals, groups, communities, or sectors.

Urban areas introduce unique challenges around producing tailored warnings for a large and diverse population. A challenge exists around how to personalize information to incorporate user-specific thresholds and in-turn how those tailored warnings are incorporated into user-specific decision-making processes (Potter et al., 2025). Furthermore, questions persist around the effectiveness of tailored or highly personalized warnings at influencing risk perceptions and behavioral responses (Potter et al., 2025, Che et al. 2020).

To understand the specific urban conditions in which weather-related risks are assessed and early warning systems implemented, it is essential to review place-specific literature, drawing on successful and challenging case studies. Therefore, WP1 focuses on the analysis of secondary and tertiary sources, to build an understanding of the relevance of data for the local level and explore how context-specific data sources can better inform capacity building and eventually more impactful decision-making processes.

Additionally, the findings from the literature review will be shared through multi-actor workshops, where scientists, communities, practitioners and decision makers will be represented, to discuss the material and address further information and data that may be required. Local capacities will be evaluated to co-develop the adequate training material to enhance capacity building. Guidance and communication will also be reviewed to co-develop effective ways to share the findings within communities, locally, regionally and globally for a better dissemination of knowledge.

Activities:

1. Comprehensive case study selection framework

A comprehensive framework for case study selection will be developed, considering criteria such as diversity in climate hazards varying levels of institutional capacity and data availability, organizational weakness of communities and institutions, and equitable geographical representation.

2. Literature and policy review

Literature and policy reviews will contribute to identifying practice examples of EWS (considering the diversity of hazards, including those mentioned in Obj. 2), that have had a positive impact in terms of preparedness and response actions. Investigate whether and how warnings were personalized or tailored to the specific needs of the warning audiences.

3. Illustrative case study reviews

- Paris Opening Ceremony convective precipitation and nowcasting.
- Personalized Real-Time Air Quality Informatics System for Exposure-Hong Kong (PRAISE-HK) air pollution and health warning App (https://praise.hkust.edu.hk/)
- Recent floods in South American cities (South of Brazil and River Plate)
- Miami case study: why did the EWS fail?
- Engage decision-makers at specific events in relation to the context; Understand communication to different groups;
- interviews/focus group meetings; engaging communities and policymakers.

Each case study will explore the following:

- Document guidance that has been helpful
- Explore governance structures around good practice examples (EWS)
- Understand the flow and receptivity of information.
- Investigate communication and information dissemination strategies.
- Investigate the needs and thresholds of various warning recipients (e.g., individuals, groups)
- Investigate the usefulness or examples of tailoring the forecasts and warnings to meet various users' needs.
- Explore actions from institutions, communities, etc.
- Evaluate socio-economic and health impacts.

  Identify potential gaps in all the above areas.

4. Multi-actor workshops

Workshops with multiple actors, representing communities, decision-makers, scientists, and practitioners, to share, build trust, disseminate, and evaluate the findings of the literature review, and identify training and data/information needs. Through these workshops we will explore the needs and thresholds of the various actors, communities, sectors present at the workshops to contribute towards a framework for developing tailored warnings. The workshops will enable the development of a "Participation and Co-production Protocol" in the selected case studies. This protocol will specify the management of multi-actor interactions, the integration of local knowledge ("lived experiences") into research processes, the translation of scientific findings for decision-makers (to name a few), and the resolution of expectations and potential disagreements. These, in the light of strengthen the community and institutional organizational structure.

5. **Capacity building evaluation**

Gap analysis for evaluation of available and development of needed training material

6. Citizen science/crowdsourcing

The project will explore opportunities for crowdsourcing and citizen science using the Beneficence Principle and Distributive Justice Principle, and other ethical, legal, and risk frameworks, around the collection of public observations of hazards and impacts during a hazardous, urban event. This will help to build an understanding of the legal and liability implications for collecting public hazard and impact observations for supporting early warning and response. Recommendations will be implemented through WP2 and WP3

7. Guidance and communication

Co-develop guidance for effective data communication and access, and tailoring.

B: WP2 PREDICTION AND EWS ACROSS SPATIAL SCALES

Urban areas are increasingly vulnerable to multi-hazard risks, ranging from extreme air pollution, extreme heat, heavy precipitation, and flooding to cascading weather events. Given the spatial variability of these hazards, the resolution of their prediction may significantly affect the accuracy and usability of early warning systems for diverse urban populations (Yekeen et al. 2020). Accurate and reliable hazard predictions are critical for informing decision-makers and communities to implement timely and effective responses, particularly in heterogeneous urban environments.

For instance, in the Personalized Real-time Air-quality Information and Warning System for Exposure for Hong Kong (PRAISE-HK), ultra-high spatiotemporal resolution of air pollutant concentrations at street-level (~ 10 meters) is required to assess indoor-outdoor exposure and individual mobility and to warn the vulnerable groups such as asthma patients (Che et al. 2020). This is particularly relevant at traffic hotspots, where large gradients in AQ may result in inequalities in population exposure (Etuman et al., 2020; Valencia et al., 2023). In the case of AQ, such spatial variability depends not only on local emissions and atmospheric conditions but also on the interactions between wind and complex urban morphology. The urban background contribution might also be a relevant factor. Understanding these gradients and their main drivers for different hazards and types of cities is key to identifying model and data requirements for their accurate representation. However, there is still a lack of standardized benchmarks and good practices for multi-hazard modelling at different spatial scales. Benchmarks could consist of coarse resolution (or coarse-grained) multi-hazard model predictions, supplemented with observations from selected case studies, to evaluate the performance of high-resolution multi-hazard model predictions.

In addition, with the global push for impact-based forecasts and warnings to make warnings more meaningful and relevant, the inclusion of exposure data (that is, the location of people and assets in relation to the hazard) has been identified as a required data source for setting impact-based warning thresholds. However, as noted in previous and ongoing research, setting impact-based warning thresholds based on exposure may introduce an urban-rural bias, where warnings are issued in areas of higher population density, excluding low-density areas (Potter et al., 2021; 2025). This introduces a need to explore and test the role and influence of exposure data in designing impact-based warnings.

The WG2 aims to address these gaps by exploring the impact of spatial resolution and modelling approaches on hazard prediction. The goal is to provide actionable recommendations and benchmarks for enhancing the effectiveness of multi-hazard early warnings tailored to the needs of urban stakeholders through the following activities:

Activities:

1. **Micro-Review of Literature:** A focused review will examine the spatial variability of key hazards and the impact of model resolution on the accuracy of hazard prediction. Those hazards include air quality, urban heat stress, cold stress and freezing infrastructure, urban heavy precipitation, urban wind, urban flash flooding, and compound and cascading hazards. Case study examples of past urban hazards will be included to provide context. A table documenting a preliminary

analysis of recommended optimal prediction scales for each hazard type will be developed. The review will emphasize the role of both models and observations in understanding hazards across diverse urban contexts.

2. **Model Intercomparison exercise:** This activity will coordinate with WP3 and recommend multiple case studies representing a diverse range of hazards and urban contexts from different geographical regions. This could form the basis of an urban hazard early warning system intercomparison study. The cases will be selected based on the availability of observational data, WWRP endorsed projects, to evaluate models and the presence of engaged communities and decision-makers. The event data library, an output of the WWRP HIWeather Value Chain Project, is one of several key databases that will be checked to identify possible case studies.
    - Approach: Participants (including the extended urban scientific community) will execute hazard prediction models, both conventional Numerical Weather Prediction (NWP) and AI-based and hybrid approaches, at varying spatial resolutions. Models will also vary in their physics settings, downscaling techniques, and input datasets and assimilation techniques.
    - Goals:
        - Assess the performance of different models and configurations for providing urban multi-hazard warnings.
        - Identify the appropriate scales for effective hazard prediction and early warning systems.
        - Develop evidence-based recommendations and open-access benchmarks for ultra-high-resolution urban hazard prediction models.
3. **The role of exposure and vulnerability data in impact-based warning thresholds:** This activity will use a risk-modelling approach using readily available exposure data of assets and vulnerability functions to test the influence of these data in setting thresholds for impact-based warnings. This will build an understanding of the urban-rural bias phenomena in impact-based warning design, within the selected case studies.

By bridging the gaps between model resolution, urban physics parameterizations, hazard prediction, and actionable insights, this project aims to inform the development and deployment of more effective multi-hazard early warning systems in urban environments.

C: WP3 ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS

Over the past two decades, urban physical processes have been increasingly integrated into numerical weather prediction (NWP) models (Liu et al., 2006; Chen et al., 2011; Best, 2005; Bohnenstengel et al., 2011; Lemonsu and Masson, 2002). However, their performance varies significantly across cities (Grimmond et al., 2010), especially struggling in tropical urban regions due to uncertainties in model initialization and physics. Moving from kilometer-scale to hectometer-scale (100 m) NWP offers many benefits for urban hazard modelling, including the ability to provide information at sub-neighborhood scales and a more accurate representation of convective precipitation. However, this transition also introduces new challenges, primarily due to the partial resolution of atmospheric processes such as turbulence. To fully realize the potential of hectometric models, significant work is still required to improve physics parameterizations and effectively incorporate data at this finer scale (Lean et al., 2024). The Paris 2024 RDP intercomparison of urbanized hectometric NWP models revealed substantial model variability, particularly in simulating Urban Heat Islands (UHIs) and their associated heat plumes. While differences in UHI intensity can be linked to urban structure and canopy schemes, the variability of heat plumes suggests that complex interactions between atmospheric processes are treated differently between models. Improving urban hazard prediction accuracy and lead time from nowcasting to seasonal scales remains a major challenge in global NWP modelling.

There is cause for promise in improving NWP-based hazard predictions, with recent advancements in urban physics parameterizations, model resolution, and data availability and density (Lean et al., 2024). Improved data sources include population and anthropogenic heat inventories, satellite-based remote sensing (e.g., for land use, land cover, building information, land surface temperatures, and soil moisture) (Ching et al., 2018; Kamath et al., 2024; Hall et al., 2024), radar precipitation, urban boundary layer field campaigns (Fenner et al., 2024), and intercomparison datasets (Lipson et al., 2024), and emerging data sources include crowdsourced observations and urban-canopy-process modelling datasets that contain a range of realistic urban geometries (Li et al., 2024; Nazarian et al., 2025). These data sources will inform development of parameterizations and facilitate model evaluation, both being crucial for improving NWP-based hazard predictions. Also, NWP advancements have coincided with rapid advancements in AI-based weather forecasting techniques. AI models that have the ability to incorporate a wide range of data sources (e.g., satellite remote sensed products, radar, and crowdsourced observations) have the potential to revolutionize urban hazard early warning systems (EWSs) by improving warning timeliness, accuracy, and accessibility, particularly in data sparse cities.

Crowdsourced and IoT (Internet of Things) observations are a particularly exciting data source owing to their high spatial density, being able to provide data on urban hot spots and rapidly developing storms. However, before operational weather centers can routinely incorporate these observations into the initial conditions of NWP models, further work is needed. This includes establishing minimum quality standards, developing techniques for radiation bias correction of air temperature data (e.g., by referencing nearby long-term in situ observations), and developing data assimilation systems capable of operating at intra-city scales.

Urban hazards exhibit significant spatio-temporal variability, necessitating ultra-high-resolution predictions. While operational NWP models have grid resolutions of several kilometers, research models at hectometer (H)-scale offer finer detail but are computationally expensive. AI presents a cost-effective solution by learning from past predictions to generate emulated H-scale forecasts. AI-based statistical downscaling methods can refine conventional forecasts, while specialized models trained on large-eddy simulations can predict building-scale hazards such as extreme wind and air pollution. Nowcasting, particularly for precipitation, is an area where AI has already been shown to outperform traditional methods. Urban pluvial, fluvial, and coastal flood prediction have benefited from data and computational advances. AI can further enhance real-time urban hazard prediction by integrating physics-based models with observational data. Although significant progress has been made, further validation of data-driven models and verification of results remain essential, especially in data-sparse urban areas.

Digital twins are emerging as valuable tools for urban weather and hazard modelling. Compared to traditional NWP, they emphasize the use of AI, user interactivity, computational efficiency, and seamless integration across the modelling workflow—spanning weather prediction to urban hazard warnings—enabling timely scenario-based assessments. However, AI-based urban EWSs remain in their early stages and require rigorous validation across different hazards and cities. Key challenges include ensuring model generalizability and determining the data volume needed for reliable AI training. Addressing these factors will be crucial for advancing AI-driven urban hazard predictions and guiding future investments in urban observation systems.

Activities:

1. **AI Model Evaluation:** Evaluate the performance of AI-based modelling systems in terms of accuracy, efficiency, new capabilities, and trustworthiness, compared to conventional numerical weather hazard prediction models with advanced urban physics parameterizations and emerging global building datasets. This will build on the insights and benchmarks developed in 2.2 and explore how performance depends on data availability, hazard type, and local conditions.
2. **Utilization of Emerging Datasets in AI:** Review the literature on methods for integrating multiple data sources, including emerging datasets such as crowdsourced and remote sensed observations, into AI model training, and prepare a report with recommendations.
3. **Transferability Investigation:** Investigate the transferability of weather-related hazard predictions from AI models trained on high-resolution computational simulation output with limited temporal and spatial coverage to global urban areas. This includes the validation of models and the role of auxiliary global datasets (e.g., remote sensing) in data sparse cities. AI models that can incorporate a wide range of data sources (e.g., satellite remote sensed products, radar, and crowdsourced observations) and are trained with reliable high-resolution prediction data have the potential to revolutionize urban hazard early warning systems (EWSs) by improving warning timeliness, accuracy, and accessibility, particularly in data sparse cities.
4. **Workshop on AI-based EWSs:** Organize a workshop with end users and experts to assess the current state of AI-based EWSs and present research findings from 3.1 and 3.2.

D: WP4 KNOWLEDGE SHARING AND CAPACITY BUILDING

Urban areas are increasingly at the forefront of the impacts of weather hazards and climate change-related processes, including multi-hazards and longer-term shifts in climate patterns (IPCC, 2021). This is further exacerbated by the increasing concentration of population in vulnerable urban or rural-urban border areas exposed to these impacts, which requires place-specific policy responses for weather hazards preparedness and climate adaptation. This can be achieved by closing the gap between advanced forecasts and useful information provided by, and informing, decision makers at the city and local scales (Jebeile and Roussos, 2023). This can be supported by the establishment of a shared vision for the decision-making processes

(Dilling and Lemos, 2011). The benefits of active knowledge exchange between science policy in generating innovation in adaptation strategies have been highlighted in several studies (Bridges et al., 2024; Goodrich et al., 2020; Guston, 2001). However, these exchanges are more fruitful when conducted through participatory processes involving dialogues between scientists, government agencies, and communities. Such knowledge exchange promotes equity in climate adaptation through the design and co-production of culturally sensitive policies, inclusiveness and mutual learning, and a deeper understanding of the obstacles to efficient adaptation (Foster et al., 2019; Kalafatis et al., 2019; Lemos et al., 2014). In addition, these interactions with local actors across the selected case studies, will contribute to understanding disparities in available data and infrastructures across cities and countries and how such inequalities may limit the adoption and effectiveness of AI-based approaches in lower resourced settings.

In this context, multi-hazard Early Warning Systems (EWS) provide an active initiative implemented on multiple spatial scales to reduce the loss and damage caused by urban multi-hazards. The key components of EWS include: (i) risk knowledge and risk assessment, (ii) monitoring of parameters, which enhance or enable predictions and forecasts, (iii) dissemination of timely warnings, and (iv) preparedness to respond to the disaster (Chaves and Tomas De Cola, 2017; Zambrano et al., 2017). However, only 38% of the countries have multi-hazard EWS with 30% of the world population in the less developing parts of the world uncovered by EWS; the highest coverage being in the Asia Pacific region and the relative absence of any comprehensive capability in Africa (UNDRR, 2025a). If a warning is issued at least 24 hours before the multi-hazard, it can reduce about 30% of the potential damage (WMO, 2022). An effective EWS should consist of multi-hazard warning capabilities, so it has the capacity to issue warnings and communications about multiple hazards through timely coordinated and compatible mechanisms across multiple organizations, and to enable continued monitoring and support immediately after the hazard. Another essential component of an EWS is a place-based and community centered approach to get better buy-ins and to save more lives. There continues to be a large gap in the dissemination of effective information from EWS to vulnerable communities and remote areas due to inequitable access. Therefore, it is critical for EWS to concentrate on enhancing the production, accessibility, dissemination, and usage of risk information. This includes fostering stronger coordination among actors, encouraging innovation, and empowering decision-makers and vulnerable communities to understand, recognize, and address risks effectively and to develop actions for their own protection once the event takes place (UNDRR, 2025b).

Activities:

1. **Desk study:** Conduct a review of studies that document and examine the utilization of place-specific diverse knowledge and capacities for preparedness and EWS and include findings from Objectives 1-3.
2. **Case study selection**: Use a case study approach to explore existing capacities, gaps as well as decision-making processes and governance structures that support co-produced strategies and actions before, during, and after events, informed by Activity 1.2. The project will work closely with WMO's Expert Groups INFCOM and SERCOM to explore early warning protocols and response plans with the municipal authorities in the case study cities.
3. **Existing resources**: Explore existing resources (databases, dashboard, etc.) that are accessible to policymakers, communities and practitioners to understand and support urban resilience.
4. **Gap analysis:** Review of knowledge-user gap studies and recommendations for bridging the gap.
5. **Action research:** Develop detailed urban multi-hazard vulnerability maps of urban areas for wildfires, floods, and extreme heat.
    a. Active community and stakeholder engagement for buy-ins that will result in more resilient communities.
    b. Identify individual parcel-level risks to urban multi-hazards such as wildfires, floods, and extreme heat.
    c. Identify critical infrastructure and response options for shelter and evacuation during multi-hazards such as wildfires, floods, and extreme heat.
    d. Collect primary data through case studies to understand the role of communities and local knowledge in early warning systems and how best to integrate community-based warnings with other warning systems. This will facilitate knowledge sharing between communities and warning services and to support the design of localized and meaningful warnings in urban settings.

3.2 Communications and Outreach

The Urban-PREDICT project will establish consistent communication tools among all involved project member institutions and partners. The project team will develop newsletters, will share links of published material and will update online platforms, showcasing progress of the research, as it evolves. A key priority is to maintain and enhance collaboration with external and WMO internal partners to ensure to reach broader audiences and expand the project findings and outcomes.

A key priority for Urban-PREDICT is to ensure that all communities are acknowledged, and all knowledge is legitimized, therefore, a commitment to inclusivity will guide communication. All activities, workshops, meetings will be carefully set up, ensuring that everyone can participate and share ideas. Where required, adaptation measures will be put in place.

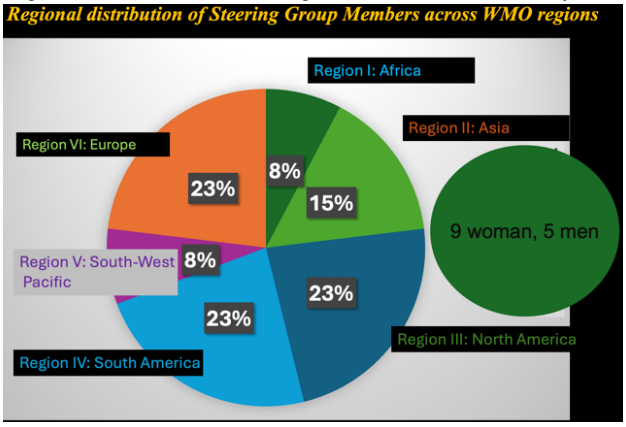
The breadth and international reach of the Urban-PREDICT project requires that careful consideration be given to the specific locations where demonstrator projects are taking place, including local cultures, policies and guidance, as well as local capacities and knowledge. The Urban-PREDICT project will ensure to promote dialogue and legitimization of local practices and cultures.

The project is committed with ethics and integrity. Ethics plays a crucial role in the design and implementation of early warning systems, particularly the use of data and access to sensitive information. We will consult the Institutional Review Board (IRB) or equivalent at the relevant institution for review for research that involves human subjects. The ethical considerations involve ensuring that data is collected, stored, and shared responsibly, with respect for the privacy, security, and wellbeing of human subjects. All access to data stored on the storage drives will have 128-bit encryption so that data is fully encrypted as it leaves and comes into the network via local or remote network access. Thus, data to be collected during the study period can be easily and securely shared with the co-investigators. To further protect the data, strict security measures such as Juniper firewall will be implemented. Sensitive information, especially personal or confidential data, should be handled transparently and with explicit consent from affected individuals or communities. Finally, there should be equitable access to the information provided by these systems for vulnerable populations, ensuring their protection.

4 Governance and Management:

This project comes within the World Weather Research Programme (WWRP) of WMO. It is therefore formally under the overall direction of the WWRP Scientific Committee (WWRP-SSC). The Chairs of the Urban-PREDICT Project Steering Group (SG) reports to the WWRP-SSC through the SSC liaisons to this project.

A Project Steering Group (SG) was established in 2023 and had a face-to-face meeting 17-19 December 2024 in Boulder, Colorado, USA, with an initial task of preparing the project implementation plan. The SG plans to meet annually to review progress and ensure momentum. All other discussions will be via email, regular virtual meetings, and occasionally at international conferences and workshops.



The Urban-PREDICT SG is composed of physical and social scientists with different backgrounds representing six WMO regions: Africa, Asia, North America, South America, South-West Pacific, and Europe. They have a range of specialties: weather prediction model development, urban climatologist, air and water quality, boundary layer meteorology, hydrology, governance, sustainability and climate in cities, societal risk, vulnerability, adaptive capacity, and urban planning policy and economy.

Urban-PREDICT Steering Group members:

Co-Chairs:

Fei Chen, the Hong Kong University of Science and Technology, Hong, Kong, **China**

Soledad Garcia Ferrari, University of Edinburgh, **United Kingdom**

Members:

Lewis Blunn, Met Office, **United Kingdom**

Gabriela di Giulio, University of Sao Paulo, **Brazil**

Sara Harrison, GNS Science, **New Zealand**

Valéry Masson, Meteo-France, **France**

Negin Nazarian, University of New South Wales, **Australia**

Thara Prabhakaran, Indian Institute of Tropical Meteorology, **India**

Shouraseni Roy, University of Miami, **USA**

Andrea Laura Pineda Rojas, University of Buenos Aires, **Argentina**

Gilbert Siame, University of Zambia, **Zambia**

María Eugenia Ibarrarán Viniegra, Ibero-American University Puebla, **Mexico**

Olga Wilhelmi, NSF NCAR, **USA**

Mariano Re, National Water Institute, University of Buenos Aires, **Argentina**

WWRP SSC liaisons to Urban-PREDICT:

Shiguang Miao, Institute of Urban Meteorology, **China**

Volker Lehmann, Deutscher Wetterdienst (DWD), **Germany**

Siham Sbii, Morocco Met Service, **Morocco**

Steering Group members plan to meet monthly online and have an annual in-person meeting supported by WWRP to report and update activities. WP leaders report to SG. In addition, they (or a subset of SG members) will meet at relevant conferences and workshops. The SG members will work with partners to organize workshops, and education and outreach events.

International Coordination Office (ICO):

To support Urban-PREDICT operations and task execution, an International Coordination Office (ICO) will be established. The ICO handles a diverse set of responsibilities for effective project management, collaboration, communication, outreach, and operational efficiency.

HKUST offered to host the Urban-PREDICT ICO, and the WWRP office and the HKUST have been finalizing an agreement to establish the Urban PREDICT project ICO at the Institute for the Environment at the Hong Kong University of Science and Technology.

5 Monitoring and Evaluation and Learning (MEL) tools

Table 1: Summary of the URBAN PREDICT project activities

Objective	Output	Activity	Outcome
	OP1. Comprehensive framework for case study selection	A1. Considerations and criteria for case study selection	Guidance on case study selection criteria, including climate hazards, institutional capacities,

			geographical representation, etc.
O1. To assess and provide guidance on the accessibility and cultural relevance of diverse urban data (e.g., socio-economic, demographic, geospatial) and information to contribute to an actionable EWS process for place-specific preparedness and response.	OP2. Report - containing a list of good practice examples and processes as outlined above	A2. Literature and policy review to identify practice examples of EWS (considering the diversity of hazard), that have had a positive impact in terms of preparedness and action	Guidance on the accessibility and cultural relevance of diverse urban data and information for an actionable EWS process (for place-specific preparedness and response) has been developed
	OP3. Report on the success and failure of cases	A3. Illustrative Case study reviews	
	OP4. Guidance for context-specific EWS, preparedness, and response, reflecting on the findings from the analysis and the outcomes of the workshop	A4. Workshops including multiple actors representing (communities, decision-makers, scientists, practitioners, etc.) to share, build trust, disseminate, and evaluate the findings of the literature review, and identify training needs.	
	OP5. Report on the need-based training material	A5. Gap analysis for evaluation of available and development of needed training material	

	OP6. Publication of an academic paper	A6. Co-develop guidance for effective data communication and access	
O2. Understand the role of spatial scale and recommend benchmarks in predicting and providing effective multi-hazard early warnings for diverse urban populations and decision-makers	OP1. Report and/or academic paper on the importance of spatial scale for various urban hazards, including performance model evaluation and benchmarking, and open access benchmark datasets	A1. Model intercomparison exercise for several case studies selected to cover a diverse range of hazards and cities. A2. Micro review of the literature (on the spatial variability of the hazards and their representation by different hazard prediction models)	Recommendations to improve predicting and effective multi-hazard early warnings for diverse urban populations and decision-makers
	OP2. Table with recommendations for optimized scales for each hazard type of city;		
	OP3. Key Recommendations for Future Intercomparison Projects on Integrated Multi-Hazard Warning Systems.		
O3. Understand how the integration of advanced physical models, observations, AI technologies, and diverse multidisciplinary urban	OP1. Report on performance evaluation of AI vs conventional models reflecting on how disparities of data	A1. Understand how AI-based modelling systems perform (accuracy, efficiency, new capabilities, and trustworthiness)	Enhanced understanding of the role of diverse and emerging models and urban data in prediction and EWS.

data enhance prediction and early warning systems in different urban environments	contribute to efficient AI modelling	compared to conventional numerical weather hazard predictions, building on the insights and benchmarks developed in Ob2. Explore how this performance is dependent on data availability, hazard type, and local conditions.	
	OP2. Report on the state-of-the-art AI hazard modelling system and their transferability considering data and observation gaps and inherent inequalities	A2. Investigate the transferability of weather-related hazard predictions from AI models (i.e., trained on cases of high-resolution numerical weather prediction model data covering a wide range of conditions) to global urban areas, including the role of auxiliary global datasets (e.g., remote sensing)	
	OP3. Proposal for partnership and future research to develop enhanced integrated and interactive prediction and EWS in urban areas.	A3. Workshop with end users and experts to share the findings of the research and gather feedback	
		A4. Investigate the integration of physical modelling, AI techniques, and comprehensive urban	

		data (e.g., digital twins, interactive atlases) to enhance multi-hazard warning systems and inform risk reduction strategies	
OB4. To explore place-specific, diverse knowledge and capacities among key actors in urban areas to prepare and respond to weather-related risks using data and information.	OP1. Report showcasing examples of place-specific knowledge and capacities for preparedness and EWS (including less studied regions of the world)	A1. Conduct a review of studies, policies, and govt and non-governmental plans that document and examine the utilization of place-specific diverse knowledge and capacities for preparedness, resilience, and EWS and include findings from Ob. 1-3.	Policymakers, communities, and practitioners in urban areas are better prepared to respond to weather-related risks using data and information that are place-specific and result from a dialogue of knowledges.
	OP2. Dashboard with early warning systems already implemented at various locations datasets that exist	A2. Explore existing resources (databases, dashboard, etc.) that are accessible to policymakers, communities and practitioners to understand and support urban resilience.	
	OP3. Training material for communities, decision-makers, and practitioners working in urban settings on good practices for place-	A3. Use a case study approach to explore existing capacities, gaps as well as decision making processes and governance structures that	

	specific EWS and preparedness (informed by findings and recommendations across all objectives)	support co-produced strategies and actions before, during, and after events, informed by Activity 1.2.	
	OB4. Training workshops for key interest holders - at least once per year.	A4. Use a case study approach to explore existing capacities, gaps as well as decision making processes and governance structures that support co-produced strategies and actions before, during, and after events, informed by Activity 1.2.	

Theory of Change Narrative

The theory of change framework is used to highlight the causal relationship between the activities under the project and how these would lead to planned outcomes and ultimately a larger impact. By integrating ultra-high-resolution weather hazard forecasting at various scales, impacted by emerging technologies such as AI with context-specific culturally relevant data, the URBAN Predict project aims to reduce weather-related hazards and risks in urban areas to amplify early warnings for all.

The project comes at a time when urban populations are not only expanding but face increasingly vulnerability to weather hazards. Yet, there remains a critical gap between improving ultra-high-resolution weather forecasting whilst simultaneously ensuring that the most vulnerable populations have access to and are able to understand and act on warnings. It is this gap that sets the context of and shapes the purpose of the project. To add to this challenge, is the complexity of urban landscapes, geographically and socio-economically which can influence how extreme weather events impact different sectors and groups.

Subsequently, the project, in line with the WWRP IP seeks to combine both physical and social components as part of a more holistic approach. It combines the need to advance predictions and EWS across spatial scales whilst understanding how advanced physical models integrate with AI, observations and multidisciplinary urban data. Nonetheless, the project goes beyond the physical component by focusing on the accessibility and cultural relevance of diverse urban data actionable EWS processes and how they support preparedness and responses specific to selective places. In doing so, it aims to address the last mile challenges faced in EWS in urban settings.

A cross-cutting theme that runs across the project and aligns with the WWRP AWAR3E Principles highlights the need for mutual knowledge exchange to learn from practitioners, scientists, policymakers and even community representatives. This knowledge can then be leveraged to build capacity and enhance understanding of the multitude of challenges faced in urban settings.

The theory of change diagram thus indicates whether the project is starting from and the objectives it sets out to achieve. The underlying premise is that the accomplishment of these objectives can lead to a wider impact. Through its activities, aligning with the outcomes, and engaging with diverse groups of people the project envisions a larger change - wherein communities in urban areas have reduced adverse impacts from weather-related multi-hazard risks due to better preparedness and enhanced multi-hazard hazard prediction and EWS, clear risk communication campaigns, and actionable plans.

Theory of Change

PRIMARY ACTIVITIES

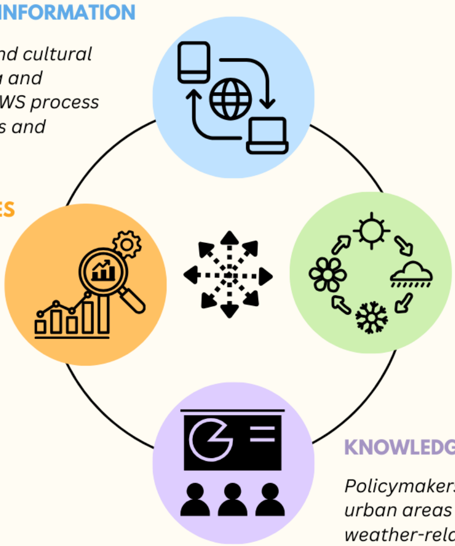
- Literature Reviews
- Identify relevant case studies
- Stakeholder engagement
- Gap analysis
- Training Workshops
- Model intercomparison exercises

ACCESS AND RELEVANCE OF INFORMATION

Guidance on the accessibility and cultural relevance of diverse urban data and information for an actionable EWS process (for place-specific preparedness and response) has been developed.

ADVANCING MODELLING TECHNIQUES AND UTILIZATION OF EMERGING DATASETS

Enhanced understanding of the role of diverse and emerging models and urban data in prediction and EWS.



PREDICTION AND EWS ACROSS SPATIAL SCALES

Recommendations of benchmarks in predicting and providing effective multi-hazard early warnings for diverse urban populations and decision-makers have been developed.

KNOWLEDGE SHARING AND BUILDING CAPACITY

Policymakers, communities, and practitioners in urban areas are better prepared to respond to weather-related risks using data and information that are place-specific and result from a dialogue of knowledges.

IMPACT

To understand and reduce urban weather and multi-hazard environmental risks through the integration of ultra-high-resolution early warning capabilities, prediction models (potentially supported by AI), observations, lived experiences, perceptions, awareness and governance practices, to enhance urban adaptation and resilience, communication and ultimately well-being of diverse urban communities.

6 Implementation Schedule

Activity	2025	2026	2027	2028	2029
Project management					
Establish International Coordination Office (ICO)	√				
Reports					
Project Implementation Plan	√				
Framework for case study criteria	√				
Transferability of state-of-the-art AI hazard modelling systems				√	
Micro review reports		√	√	√	√
Performance evaluation of AI versus conventional models					√
Report on recommendations for weather centers in relation to data vulnerability		√	√		
Research activities					
Identify cities and partners for conducting model intercomparison	√				
Facilitate research proposals and new partnerships	√				
Model intercomparison using conventional NWP and AI models;	√	√	√	√	
Scoping of the AI component of the model intercomparison	√				

Micro-review reports on spatial variability	√	√	√		
conduct the AI component of the model intercomparison,				√	
Review of resilience policies and plans for multi hazard mitigation in selected urban areas	√	√			
Workshops and Special Session Participated and Organized					
Workshop on the current state of AI-based EWSs		√			
Joint webinars/workshops with PEOPLE project to explore overlaps and collaboration across the projects		√		√	
Workshop on assessing strengths and weakness of conventional urban hazard predictions, plans, and policies;			√		
Special sessions on urban prediction and warning systems	√	√	√	√	√
Workshop to inform end users and interest holders the major finding and improved urban hazard prediction and warning capabilities.					√
Capacity Building					
Multi-actor workshops in the selected case study areas exploring inputs from interest holders, communication, and dissemination for actionable EWS		√	√	√	√
Practice and policy reports for locally relevant and actionable monitoring and mitigation strategies across selected case studies				√	√

Training workshops and related resources/material in the selected case study areas.				√	√
Publications					
A special Issue on "urban extreme weather, climate, and air quality" for *Urban Climate*		√			
Publications from the project research activities		√	√	√	√

7 References

Aguilera, R., Corringham, T., Gershunov, A., et al. (2021), Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California, *Nat Commun*, 12, 1493, doi:10.1038/s41467-021-21708-0.

Alam, E. (2023), Factors of cyclone disaster deaths in coastal Bangladesh, *Heliyon*, 9(7).

Berkhahn, S. and Neuweiler, I. (2024), Data driven real-time prediction of urban floods with spatial and temporal distribution, *J. Hydrology*, X, 22, 100167, doi: 10.1016/j.hydroa.2023.100167.

Best, M. J. (2005), Representing urban areas within operational numerical weather prediction models, *Boundary-Layer Meteorol.*, 114, 91–109.

Blunn, L. P., et al. (2024), Machine learning bias correction and downscaling of urban heatwave temperature predictions from kilometre to hectometre scale, *Meteorol. Appl.*, 31(3), e2200.

Bocher, et al. (2021), GeoClimate: a geospatial processing toolbox for environmental and climate studies, *J. Open Source Softw.*, 6(65), 3541, doi:10.21105/joss.03541.

Bohnenstengel, S. I., et al. (2011), Simulations of the London urban heat island, *Q. J. R. Meteorol. Soc.*, 137(659), 1625–1640.

Bornstein, R. and Lin, Q. (2000), Urban heat islands and summertime convective thunderstorms in Atlanta: three case studies, *Atmos. Environ.*, 34(3), 507–516.

Bridges, A., LoPresti, A., Parris, A., and Horton, R. (2024), Advancing urban climate adaptation through knowledge exchange: a case study of New York City, *Urban Climate*, 57, 102100.

Chaves, J. M. and De Cola, T. (2017), Public warning applications: requirements and examples, in *Wireless Public Safety Networks 3*, 1–18, Elsevier.

Che, W., et al. (2020), PRAISE-HK: A personalized real-time air quality informatics system for citizen participation in exposure and health risk management, *Sustainable Cities and Society*, doi: 10.1016/j.scs.2019.101986.

Chen, F., Kusaka, H., Bornstein, R., Ching, J., Grimmond, C. S. B., Grossman-Clarke, S., Loridan, T., Manning, K., Martilli, A., Miao, S., Sailor, D., Salamanca, F., Taha, H., Tewari, M., Wang, X., Wyszogrodzki, A., and Zhang, C. (2011a), The integrated WRF/urban modeling system: development, evaluation, and applications to urban environmental problems, *Int. J. Climatol.*, 31, 273–288, doi:10.1002/joc.2158.

Chen, F., Miao, S., Tewari, M., Bao, J.-W., and Kusaka, H. (2011b), A numerical study of interactions between surface forcing and sea-breeze circulations and their effects on stagnant winds in the Greater Houston Area, *J. Geophys. Res.*, doi:10.1029/2010JD015533.

Ching, J., Mills, G., Bechtel, B., See, L., et al. (2018), WUDAPT: an urban weather, climate, and environmental modeling infrastructure for the Anthropocene, *Bull. Am. Meteorol. Soc.*, 99(9), 1907–1924.

Coen, J. L., Cameron, M., Michalakes, J., Patton, E. G., Riggan, P. J., and Yedinak, K. M. (2013), WRF-Fire: coupled weather–wildland fire modeling with the Weather Research and Forecasting model, *J. Appl. Meteorol. Climatol.*, 52(1), 16–38, doi:10.1175/jamc-d-12-023.1.

Costes, A., Rodier, Q., Masson, V., Lac, C., and Rochoux, M. (2022), Effects of high-density gradients on wildland fire behavior in coupled atmosphere-fire simulations, *J. Adv. Model. Earth Syst.*, 14(11), e2021MS002955, doi:10.1029/2021MS002955.

Dilling, L. and Lemos, M. C. (2011), Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy, *Glob. Environ. Change*, 21(2), 680–689.

Dupont, S., Otte, T. L., and Ching, J. K. S. (2004), Simulation of meteorological fields within and above urban and rural canopies with a mesoscale model (MM5), *Boundary-Layer Meteorol.*, 113, 111–158.

Etuman, A. E., Coll, I., Makni, I., and Benoussaid, T. (2020), Addressing the issue of exposure to primary pollution in urban areas: application to Greater Paris, *Atmos. Environ.*, 239, 117661, doi: 10.1016/j.atmosenv.2020.117661.

Fenner, D., Christen, A., Grimmond, S., Meier, F., Morrison, W., Zeeman, M., ... & Van Hove, M. (2024). Urbisphere-berlin campaign: investigating multiscale urban impacts on the atmospheric boundary layer. Bulletin of the American Meteorological Society, 105(10), E1929-E1961.

Foster, S., Leichenko, R., Nguyen, K. H., Blake, R., Kunreuther, H., Madajewicz, M., and Ravenborg, D. (2019), New York City panel on climate change 2019 report chapter 6: community-based assessments of adaptation and equity, *Ann. N. Y. Acad. Sci.*, 1439(1), 126–173, doi:10.1111/nyas.14009.

Goodrich, K., Sjostrom, K., Vaughan, C., Nichols, L., Bednarek, A., and Lemos, M. (2020), Who are boundary spanners and how can we support them in making knowledge more actionable in sustainability fields? *Curr. Opin. Environ. Sustain.*, 42, 45–51, doi:10.1016/j.cosust.2020.01.001.

Hall, T. W., Blunn, L., Grimmond, S., McCarroll, N., Merchant, C. J., Morrison, W., ... & Best, M. (2024). Utility of thermal remote sensing for evaluation of a high-resolution weather model in a city. Quarterly Journal of the Royal Meteorological Society, 150(760), 1771-1790.

Grimmond, C. S. B., Blackett, M., et al. (2010), The International Urban Energy Balance Models Comparison Project: first results from Phase 1, *J. Appl. Meteorol. Climatol.*, 49, 1268–1292, doi:10.1175/2010JAMC2354.1.

Guston, D. H. (2001), Boundary organizations in environmental policy and science: an introduction, *Sci. Technol. Hum. Values*, 26(4), 399–408.

IPCC (2021), Summary for policymakers, in Masson-Delmotte, V., et al. (Eds.), *Climate Change 2021: the Physical Science Basis*.

Kamath, H. G., Singh, M., Malviya, N., et al. (2024), GLObal Building heights for Urban Studies (UT-GLOBUS) for city- and street-scale urban simulations: development and first applications, *Sci. Data*, 11, 886, doi:10.1038/s41597-024-03719-w.

Lemonsu, A. and Masson, V. (2002), Simulation of a summer urban breeze over Paris, *Boundary-Layer Meteorol.*, 104, 463–490, doi:10.1023/A:1016509614936.

Kalafatis, S. E., Neosh, J., Libarkin, J. C., Whyte, K. P., and Caldwell, C. (2019), Experiential learning processes informing climate change decision support, *Weath. Clim. Soc.*, 11(3), 681–694, doi:10.1175/WCAS-D-19-0002.1.

Kochanski, A. K., Jenkins, M. A., Mandel, J., Beezley, J. D., Clements, C. B., and Krueger, S. (2013), Evaluation of WRF-SFIRE performance with field observations from the FireFlux experiment, *Geosci. Model Dev.*, 6(4), 1109–1126, doi:10.5194/gmd-6-1109-2013.

Lean, H. W., et al. (2024), The hectometric modelling challenge: gaps in the current state of the art and ways forward towards the implementation of 100-m scale weather and climate models, *Q. J. R. Meteorol. Soc.*, 150(765), 4671–4708.

Lemos, M. C., Kirchhoff, C. J., and Ramprasad, V. (2012), Narrowing the climate information usability gap, *Nat. Clim. Chang.*, 2(11), 789–794, doi:10.1038/nclimate1614.

Li, R., Sun, T., Ghaffarian, S., et al. (2024), GLAMOUR: GLobAl building MOrphology dataset for URban hydroclimate modelling, *Sci. Data*, 11, 618, doi:10.1038/s41597-024-03446-2.

Lipson, M. J., et al. (2022), A transformation in city-descriptive input data for urban climate models, *Front. Environ. Sci.*, 10, 866398.

Lipson, M. J., Grimmond, S., Best, M., Abramowitz, G., Coutts, A., Tapper, N., ... & Pitman, A. J. (2024). Evaluation of 30 urban land surface models in the Urban-PLUMBER project: Phase 1 results. Quarterly Journal of the Royal Meteorological Society, 150(758), 126-169.

Liu, Y., Chen, F., Warner, T., and Basara, J. (2006), Verification of a mesoscale data-assimilation and forecasting system for the Oklahoma City Area during the Joint Urban 2003 Field Project, *J. Appl. Meteorol.*, 45, 912–929.

Oke, T.R., Mills, G., Christen, A. and Voogt, J.A., (2017). *Urban climates*. Cambridge university press.

Oskarsson, J., Landelius, T., and Lindsten, F. (2023), Graph-based neural weather prediction for limited area modeling, *arXiv preprint*, arXiv:2309.17370.

Miao, S., Chen, F., LeMone, M. A., Tewari, M., Li, Q., and Wang, Y. (2009), An observational and modeling study of characteristics of urban heat island and boundary layer structures in Beijing, *J. Appl. Meteorol.*, 48, 484–501.

Miao, S., Chen, F., Li, Q., and Fan, S. (2011), Impacts of urban processes and urbanization on summer precipitation: a case study of heavy rainfall in Beijing on 1 August 2006, *J. Appl. Meteorol.*, 50(4), 806–825, doi:10.1175/2010JAMC2513.1.

Nazarian, N., et al. (2025), UrbanTALES: a comprehensive LES dataset for urban canopy layer turbulence analyses and parameterization development.

Niyogi, D., P. Pyle, M. Lei, S. Pal Arya, C. M. Kishtawal, M. Shepherd, F. Chen, and B. Wolfe (2011), Urban modification of thunderstorms: an observational storm climatology and model case study for the Indianapolis urban region, *J. Appl. Meteorol.*, 50, 1129–1144.

Nipen, T. N., et al. (2024), Regional data-driven weather modeling with a global stretched-grid, *arXiv preprint*, arXiv:2409.02891.

Potter, S. H., Harrison, S. E., & Kreft, P. (2021). The Benefits and Challenges of Implementing Impact-Based Severe Weather Warning Systems: Perspectives of Weather, Flood, and Emergency Management Personnel. Weather, Climate, and Society, 13(2), 303-314. https://doi.org/10.1175/wcas-d-20-0110.1

Potter, S., Kox, T., Mills, B., Taylor, A., Robbins, J. C., Cerrudo, C., Wyatt, F., Harrison, S. E., Golding, B., Lang, W., Harris, A. J. L., Kaltenberger, R., Kienberger, S., Brooks, H., & Tupper, A. (2025). Research gaps and challenges for impact-based forecasts and warnings: Results of international workshops for high impact weather in 2022. International Journal of Disaster Risk Reduction. https://doi.org/10.1016/j.ijdrr.2025.105234

Ramadier, T. (2004) Transdisciplinarity and its challenges: the case of urban studies, Futures Volume 36, Issue 4, May 2004, Pages 423-439

Ritchie, H., Rosado, P., and Roser, M. (2022), Natural disasters, data adapted from EM-DAT, CRED/UCLouvain, retrieved from https://ourworldindata.org/grapher/damage-costs-from-natural-disasters.

Smith, H., Coupé, F., Garcia Ferrari, S., Rivera, H. & Mera, W.E.C. (2020a), 'Toward Negotiated Mitigation of Landslide Risks in Informal Settlements: Reflections from a Pilot Experience in Medellín, Colombia', Ecology and Society, 25(1): 19. https://doi.org/10.5751/ES-11337-25011

Smith, H. & Jenkins, P. (2015) Trans-disciplinary research and strategic urban expansion planning in a context of weak institutional capacity: Case study of Huambo, Angola, Habitat International Volume 46, April 2015, Pages 244-251

UNDRR (2025), Early Warnings for All, retrieved from https://www.undrr.org/implementing-sendai-framework/sendai-framework-action/early-warnings-for-all (accessed February 22, 2025).

Valencia, A., Serre, M., and Arunachalam, S. (2023), A hyperlocal hybrid data fusion near-road PM2.5 and NO2 annual risk and environmental justice assessment across the United States, *PLoS ONE*, 18(6), e0286406, doi:10.1371/journal.pone.0286406.

Wu, M., Luo, Y., Chen, F., and Wong, W. K. (2019), Observed link of extreme hourly precipitation changes to urbanization over coastal South China, *J. Appl. Meteorol.*, 58(8), 1799–1819.

WMO (2022), The UN The UN Global Early Warning Initiative for the Implementation of Climate Adaptation, Executive Action Plan 2023-27, WMO https://library.wmo.int/idurl/4/58209

Xu, R., Ye, T., Yue, X., et al. (2023), Global population exposure to landscape fire air pollution from 2000 to 2019, *Nature*, 621, 521–529, doi:10.1038/s41586-023-06398-6.

Xu, R., et al. (2024), Global, regional, and national mortality burden attributable to air pollution from landscape fires: a health impact assessment study, *The Lancet*, 404(10470), 2447–2459, doi:10.1016/S0140-6736(24)02251-7.

Yekeen, S., Balogun, A., and Aina, Y. (2020), Early warning systems and geospatial tools: managing disasters for urban sustainability, in W. Leal Filho et al. (Eds.), *Sustainable Cities and Communities. Encyclopedia of the UN Sustainable Development Goals*, Springer, Cham, doi:10.1007/978-3-319-95717-3_103.

Zambrano, A. M., Calderón, X., Jaramillo, S., Zambrano, O. M., Esteve, M., and Palau, C. (2017), Community early warning systems, in *Wireless Public Safety Networks 3*, 39–66, Elsevier.

Zhang, W., Villarini, G., Vecchi, G. A., and Smith, J. A. (2018), Urbanization exacerbated the rainfall and flooding caused by hurricane Harvey in Houston, *Nature*, 563(7731), 384–388.

Zhang, Y., et al. (2023), Skilful nowcasting of extreme precipitation with NowcastNet, *Nature*, 619(7970), 526–532.

8 Annex A: Table 2: Indicators for the URBAN PREDICT project

WWRP Goal	**Outcome**	**Indicators**
WWRP goal 1: Advance research of the Earth system on time scales from minutes to months, and through a science-for services value cycle approach, enable this research to provide local and regional actionable weather information that is needed for communities to reduce vulnerability to hazards, and advance applications such as renewable energy, agriculture, and health.	Policymakers, communities, and practitioners in urban areas are better prepared to respond to weather-related risks using data and information that are place-specific and result from a dialogue of knowledge.	• Analysis produced from the review of studies that examine the utilization of place-specific diverse knowledge and capacities for preparedness and EWS • Development of a repository or database on existing resources • Number of training workshops/webinars hosted for place-specific EWS and preparedness

WWRP goal 2: Enhance the warning process to account for compounding and cascading risk, and the evolving nature of weather impacts in a changing climate.	Guidance on the accessibility and cultural relevance of diverse urban data and information for an actionable EWS process (for place-specific preparedness and response) has been developed.	• Number of case studies identified and completed/published • Number of workshops completed (online or physical). • Diversity of actors involved and meaningful representation of new communities in these workshops. • Number of papers published/ abstracts submitted on guidance on the accessibility and cultural relevance of diverse urban data
WWRP goal 3: Quantify and reduce uncertainty in predictions on time scales	Enhanced understanding of the role of diverse and emerging models and urban data in prediction and EWS. Recommendations of benchmarks in predicting and providing effective multi-hazard early warnings for diverse urban populations and decision-makers have been developed.	• Number of hazards covered, or models used in the intercomparison exercise? • Number of micro-reviews completed, or the compilation/analysis of results developed

Cross-cutting Development of partnerships and inter/trans- disciplinary communities of practice	Guidance on the accessibility and cultural relevance of diverse urban data and information for an actionable EWS process (for place-specific preparedness and response) has been developed.	Same as above
Cross-cutting Capacity development	Policymakers, communities, and practitioners in urban areas are better prepared to respond to weather-related risks using place-specific data and information resulting from a dialogue of knowledge.	Same as above.