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| WEATHER CLIMATE WATER | **World Meteorological Organization****WORLD METEOROLOGICAL CONGRESS****Nineteenth Session**22 May to 2 June 2023, Geneva | **Cg-19/Doc. 4.3(1)** |
| Submitted by:Chair of theResearch Board,through EC22.V.2023**DRAFT 2** |

**AGENDA ITEM 4: TECHNICAL STRATEGIES SUPPORTING LONG-TERM GOALS**

**AGENDA ITEM 4.3: Targeted research**

# World Weather Research Programme Implementation Plan 2024–2027

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| **Summary** |
| **Document presented by:** Chair of the Research Board to endorse the World Weather Research Programme Implementation Plan for 2024–2027.**Strategic objective 2020–2023:** 3.1 Advance scientific knowledge of the Earth system, 3.2 Enhance the science-for-service value chain ensuring scientific and technological advances improve predictive capabilities, 3.3 Advance policy-relevant science**Financial and administrative implications:** within the parameters of the Strategic and Operational Plans 2020–2023, will be reflected in the Strategic and Operational Plans 2024–2027.**Key implementers:** RB, in consultation with SERCOM, INFCOM and RAs**Time frame:** 2024–2027**Action expected:** adopt the Implementation Plan of the WWRP for the period 2024–2027 through the annex to the present Resolution. |

# GENERAL CONSIDERATIONS

**Introduction**

1. The current Implementation Plan of the World Weather Research Programme (WWRP) was approved by EC-68 in 2016 through [Decision 61 (EC-68)](https://library.wmo.int/doc_num.php?explnum_id=3166#page=193) and is coming to an end in 2023.

2. This document presents a new Implementation Plan of the WWRP for the period 2024–2027, aligning with the draft of the WMO Strategic Plan for the same period, which will be considered for approval by Congress-19.

3. During the period of WWRP’s previous Implementation Plan, 2016–2023, major advances have been achieved in science, community building, research capacity building and stakeholder engagement.

4. Built on the guidance provided by the Research Board in line with the WMO Strategic Plan for 2024–2027 and the United Nations’ initiative Early Warnings for All, the WWRP will embrace a versatile scientific portfolio integrated with the needs of actors representing diverse constituencies.

5. WWRP will continue scientific threads from major projects that are ending, expand into new areas such as hydrology, and tighten the linkage between the WWRP and partner organizations including academia to ensure that the right expertise is available for designing projects and for seeing the projects through to useful outcomes, advancing science to services.

**Expected action**

Based on the above, Congress is invited to adopt the Implementation Plan of the World Weather Research Programme for the period 2024–2027 through Draft Resolution 4.3(1)/1 (Cg-19).

# DRAFT RESOLUTION

## Draft Resolution 4.3(1)/1 (Cg-19)

## Implementation Plan of the World Weather Research Programme for the period 2024–2027

THE WORLD METEOROLOGICAL CONGRESS,

**Recalling**:

(1) [Resolution 45 (Cg-17)](https://library.wmo.int/doc_num.php?explnum_id=3138#page=521) – World Weather Research Programme,

(2) [Resolution 16 (EC-64)](https://library.wmo.int/doc_num.php?explnum_id=5103#page=139) – Sub-seasonal to Seasonal Prediction Project,

(3) [Resolution 17 (EC-64)](https://library.wmo.int/doc_num.php?explnum_id=5103#page=140) – Polar Prediction Project,

(4) [Resolution 12 (EC-66)](https://library.wmo.int/doc_num.php?explnum_id=5155/#page=139) – High Impact Weather Project,

(5) [Decision 61 (EC-68)](https://library.wmo.int/doc_num.php?explnum_id=3166#page=193) – World Weather Research Programme Implementation Plan for the Period 2016–2023,

**Acknowledging** the successful completion of the World Weather Research Programme’s (WWRP) Polar Prediction Project in 2022 and the ongoing work in the Sub-seasonal-to-Seasonal project and High-Impact Weather project, ending in 2023 and 2024, respectively,

**Having considered** [Recommendation 6 (EC-76)](https://meetings.wmo.int/EC-76/_layouts/15/WopiFrame.aspx?sourcedoc=/EC-76/English/2.%20PROVISIONAL%20REPORT%20(Approved%20documents)/EC-76-d03-3(1)-WWRP-IMPLEMENTATION-PLAN-approved_en.docx&action=default) – Implementation Plan of the World Weather Research Programme for the period 2024–2027,

**Having examined** the proposed Implementation Plan of the World Weather Research Programme for the period 2024–2027, as provided in the [annex](#_Annex_1_to) to the present resolution,

**Noting**:

(1) The major advances made in the WWRP since 2016 to enhance science, community building, research capacity building and stakeholder engagement,

(2) The still compelling and urgent need to move our science into the hands of those who need it, using new understandings of how and why people make decisions, in order to reduce their risk, individually and collectively,

(3) That the WWRP plans to continue the scientific threads from major projects that are ending, while expanding into new areas such as hydrology and the urban environment,

**Emphasizing** the value of continued weather research driven by the United Nations Sustainable Development Goals, the Sendai Framework for Disaster Risk Reduction, WMO Strategic Plan 2024–2027 and the United Nations initiative Early Warnings for All,

**Decides to** adopt the Implementation Plan of the World Weather Research Programme for the period 2024–2027;

**Invites** Members to support and contribute to the development of the science plans, launch and implementation of the projects;

**Requests** the Research Board to support the launch and implementation of the projects to enhance weather-related research in support of the WMO Strategic Plan for 2024–2027.

**Requests** the Secretary-General to provide the necessary support for LDCs and SIDS to enhance research for improved service delivery.[Ethiopia]

[Annex: 1](#_Annex_1_to)

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### Annex to draft Resolution 4.3(1)/1 (Cg-19)

**WORLD WEATHER RESEARCH PROGRAMME
IMPLEMENTATION PLAN FOR THE PERIOD 2024–2027**

**EXECUTIVE SUMMARY**

As WWRP enters its twenty-fifth year, people all across our planet face unprecedented extremes in the form of heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence. There is every reason to believe these events will continue to accelerate, disproportionately affecting vulnerable populations. There is a compelling and urgent need to move our science into the hands of those who need it, using new understandings of how and why people make decisions, in order to reduce their risk, individually and collectively.

During the period of WWRP’s previous Implementation Plan, 2016–2023, major advances have been achieved in science, community building, research capacity building and stakeholder engagement. The science of polar prediction was catalysed through the Polar Prediction Project, highlighted by the Year of Polar Prediction (YOPP) that broke new ground (or ice!) on physical processes in the coupled atmosphere-ice-ocean system through analysis of novel observations and the advent of kilometre-scale simulations. Research in the Sub-seasonal-to-Seasonal (S2S) project probed the predictability of the atmosphere out to seasonal timescales and seeded the use of S2S forecasts for applications across a wide range of economic sectors. The S2S project created a high-quality research database for broad use. This galvanized the research community and provided a foundation for collaboration and exploration. The High-Impact Weather project explored the value chain of weather forecasts and created a framework to understand how to reduce disaster risk by uncovering the reasons behind unforeseen impacts of extreme weather.

Built on the guidance provided by the United Nations Sustainable Development Goals, the Sendai Framework, WMO Strategic Plan for 2024–2027, the call for Early Warning and Early Action for all in 5 years by the UN Secretary-General, the WMO Regional Reform as well as the Research Board, the WWRP will embrace a versatile scientific portfolio integrated with the needs of actors representing diverse constituencies. This science is developed and conducted with three principal goals in mind:

• Advance research of the Earth system on timescales from minutes to months and, through the science-for-services value cycle approach, transition 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;

• Revolutionize the warning process to account for compounding and cascading risk, and the evolving nature of weather impacts in a changing climate;

• Quantify and reduce uncertainty in predictions on timescales from minutes to months, increase the understanding of decision-making under uncertainty, and develop effective communication strategies of uncertainty for informed decision-making.

The new plan is the first constructed under the reformed WMO structure. In this plan, we address priorities under the umbrella of science-for-services, guided by priorities in the WMO Strategic Plan (2024–2027), and by a set of principles for Advancing WeAther Research to Reduce Risk to SociEties (AWAR3E), or the Aware principles. These principles require involvement of stakeholders in defining scientific priorities, the communication of useful research results, the training of practitioners, the revolutionization of the warning process, and the collaborations across disciplines needed to address the complex societal challenges.

WWRP will continue scientific threads from major projects that are ending, expand into new areas such as hydrology, and tighten the linkage between the working group expertise with WWRP and partner organizations across WMO, and external to WMO. These science areas will include polar regions, S2S predictions for agriculture, water and energy, integrated hydrology and meteorology to address flooding, and interdisciplinary science to benefit urban communities. WWRP will also work with our early career scientists to help ensure that the next generation of leading scientists is given all the tools and experience they need to continue this vital work. Furthermore, WWRP will spawn a new project aimed at the broad engagement of members of society, so we can understand their priorities, communicate our science and elevate mutual understanding that is needed for successful outcomes from research.

The complexity and breadth of the projects that WWRP will undertake necessitates partnerships with numerous entities within and outside of WMO. First, partner projects will expand the scope of WWRP science, and target specific regional priorities. We will also advance our long-standing partnerships with the World Climate Research Programme (WCRP) and Global Atmosphere Watch (GAW), under the Research Board, as well as grow collaborations with the technical commissions of WMO, and with external partners, particularly operational agencies. Our partners also include representatives of the constituencies who will benefit from the research. These partnerships will ensure that the right expertise is at the table for designing projects and for seeing the projects through to useful outcomes.

### Introduction

The World Weather Research Programme (WWRP) is the World Meteorological Organization’s international programme for advancing and promoting research activities on weather, its prediction, and its impact on society on timescales from minutes to months.

The WWRP mission: The World Meteorological Organization (WMO) WWRP promotes international and interdisciplinary research to provide more accurate and reliable forecasts from minutes to seasons, expanding the frontiers of weather science to enhance society’s resilience to high-impact weather and the value of weather information to users. WWRP aims at Seamless Prediction by increasing convergence between weather, climate, and environmental approaches. WWRP strengthens academic–operational partnerships and interdisciplinary collaboration and enhances the role of early career scientists.

Responding to the need for Earth system science that addresses the increasing societal and economic demand for weather-related information for numerous applications within the context of a changing climate, WWRP has designed a new Implementation Plan that will now guide WWRP activities from 2024 to 2027, in alignment with the WMO strategy for the same period.

Motivated by Long-Term Goal 3 (LTG3) of the WMO Strategic Plan 2024–2027 to advance targeted research by “leveraging leadership in science to improve understanding of the Earth system for enhanced services”, WWRP plans an ambitious agenda to address three WMO strategic objectives.

Strategic Objectives:

3.1: Advance scientific knowledge of the Earth system

3.2: Enhance the science-for-service value cycle [New Zealand] to ensure that scientific and technological advances improve predictive capabilities and analysis, and

3.3: Advance and contribute to policy-relevant science.

WWRP also takes note of the importance of the United Nations’ Sustainable Development Goals for 2030 as a driver of critical weather science and its applications, and recognizes the unprecedented threats to society posed by weather, water and climate-related hazards. Furthermore, WWRP acknowledges the primary goal of the Sendai Framework for Disaster Risk Reduction, which explicitly grasps the interconnectedness of multiple sectors and the need for inclusiveness and a framework of research that emphasizes societal needs and feedbacks to science.

In 2022, the United Nations Secretary-General António Guterres tasked the WMO to draw up a blueprint to ensure that Early Warning Systems reach everyone within the next five years. The Secretary-General stressed the value of early warnings and early action as critical tools to reduce disaster risk and support climate adaptation. With this announcement, the urgency for universal coverage and protection by early warning services is clear and must be prioritized. Closing the early warning gap will require inputs from actors throughout the entire early warning to early action value cycle.

In accordance with the regional Reform of the WMO there is a growing need to forge closer links between the needs and activities of all WMO Regions. Surveys circulated to the Regions have identified several research topics as key research priorities for all Regions, including climate, climate variability and climate change, disaster risk reduction, hydrology, user engagement and impact-based forecasting, aviation, synoptic, mesoscale/microscale and tropical weather prediction. The WMO Research Board (RB) supports the work of WMO research programmes and is instrumental in the implementation of the WMO Hydrological Research Strategy.

Applying the guidance and priorities set by the RB, WWRP will aim to address these higher-level mandates drawing on the expertise of the WWRP community, which includes National Meteorological and Hydrological Services (NMHSs), academia as well as other research centres. The WWRP will embrace a versatile scientific portfolio integrating the needs of actors representing diverse constituencies.This science is developed and conducted with three principal goals in mind.

Principal Goals:

Goal 1: Advance research of the Earth system on timescales from minutes to months and, through the 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

Goal 2: Enhance [New Zealand] the warning process to account for compounding and cascading risk, and the evolving nature of weather impacts in a changing climate

Goal 3: Quantify and reduce uncertainty in predictions on timescales from minutes to months, enhance understanding of decision-making under uncertainty, and develop effective communication strategies on uncertainty for informed decision-making.

The first goal (G1) is built on the science needed to produce weather-related information that serves a variety of decision-making needs for the benefit of diverse communities ranging from megacities to Indigenous populations, including urban and rural environments. It is centred on the concept of communities as the network for connecting people, as well as acknowledging the inherently dynamic character of interactions in a socio-ecological system [New Zealand]. In order to be effective, the information gathered should provide not only the relevant time and space scales pertaining to the weather phenomena, but it should also be co-designed with the stakeholders [New Zealand].

The second goal (G2) is founded on the awareness that our information delivery systems and the practices aimed at protecting people and infrastructure from hazards are not static. The needs of populations are constantly evolving, the nature of risk is changing as climate change advances, urbanization is increasing, and vulnerabilities are [New Zealand] shifting: our warning systems must develop accordingly. Weather science must account for the nonlinear changes in extreme events as socio-ecological systems are affected by climate change [New Zealand], and work with a variety of actors to determine how such changes may require different strategies for effective and universally accessible warnings.

The third goal (G3) underlines the fact that uncertainty is inherent in all weather information due to the intrinsic limits of predictability, limitations of our observing, data assimilation and forecast systems and the spatial and temporal limits of information content itself. WWRP must work on addressing the factors that create uncertainty in forecasts, while also formulating and applying effective strategies for communicating uncertainty through a value cycle approach. Uncertainty is herein reframed as ‘confidence’, and it is the quantification of forecast confidence, and understanding how best to communicate confidence, that is critical for informed decision-making.

The goals outlined above are not meant to be independent; but they each lead to somewhat different guiding questions for the research, as detailed below.

For the first goal (G1), which focuses on weather research to benefit communities, we ask:

* What type of weather information, tailored in which ways, do communities need to reduce their vulnerability to hazards?
* How can vulnerable communities that are exposed to weather and climate-related hazards reduce disaster risk?

These interrelated questions urge us to ponder the perspective of the various actors in diverse communities in different regions in the world. The first question considers weather information that has the greatest impact and includes the sectors of communities that are most precarious and have the highest levels of exposure. The second question probes the need for action based on weather information, which may lead to policy changes, infrastructural improvement and creating and communicating options for protective actions. Communities cannot thrive if vulnerable populations are not attended to, especially, but not exclusively, those in the developing and least developed countries. WWRP will strive for technological and scientific innovation that will improve environmental predictions on a spatial and temporal scale where decisions are made, while also engaging with decision makers to promote effective warnings and communication strategies.

For the second goal (G2) focusing on warnings, we note that much of the information about weather hazards is conveyed in the form of single-hazard warnings. There is clearly a need to revolutionize the warning process, and steps towards significant improvements are outlined in the recently released book from the High-Impact Weather Project, *Towards the Perfect Weather Warning* [<https://link.springer.com/book/9783030989880>]. Warnings must explicitly include vulnerable and diverse communities, and they cannot begin and end with meteorology. Development of warning strategies must be formulated from an integrated perspective (Earth system approach), in which contributions from the social sciences are central. The impacts of meteorological events cascade through different populations in complex ways that are influenced by the evolution of the built environment, in the areas of transportation, housing, and sustainable or, rather, unsustainable practices. The combination of changing extreme events, as our climate state and patterns of daily life change, creates a multifaceted prediction problem, often with impacts that have little or no precedence. We therefore pose the following questions:

* How can WWRP improve weather warnings in the light of compounding and cascading events and the evolving nature of hazards in a warming climate?
* How is urbanization exacerbating the impacts of weather, climate variability and climate change and driving the need for new types of warnings?
* How are the socio-ecological, cultural and economic systems [New Zealand] of rural areas shaping the impacts of weather, climate variability, and climate change, and driving the need for new types of warnings?

The third goal (G3) focuses on uncertainty, and we note that no strategy to reduce disaster risk can ignore the fundamental limitations of Earth system predictability or limitations of the tools used to make predictions. On all timescales relevant to WWRP, new observational, modelling, data assimilation and artificial intelligence and/or machine learning approaches will be critical in identifying and exploiting sources of predictability that will accelerate improvements to weather forecasts. Progress on both questions will require WWRP to partner with a variety of entities within and external to WMO. Furthermore, the users of information must constantly incorporate forecast confidence that is highly variable across prediction lead times, variables and flow dependence. This leads us to ask the following:

* What are the sources of predictability and the improvements to initial conditions and reductions of systematic model errors needed to exploit those sources, from nowcasting to seasonal timescales?
* How can we engage with actors to improve decision-making despite uncertainty?
* Which principles frame [New Zealand] decision-making under uncertainty?

The questions posed for each goal are not meant to be comprehensive, nor can they be addressed entirely by WWRP alone. These questions are indicative of a philosophy and framing of science that combines physical and social science queries. Most of them have been asked before: we already have tools to address these questions; to some degree, we have had them for a long time.

The novelty of these and similar questions lies in transdisciplinary efforts, in the integration of the physical and social science perspectives in an attempt to ask the right questions in the correct manner, and involving the right people in such a way that the resulting research has the greatest chance of having a positive impact.

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### An overarching theme for WWRP

In its early days, WWRP was integrated into The Observing System Research and Predictability Experiment (THORPEX). This gave rise to many of the working group structures that exist in WWRP today to support the science of observations, data assimilation, numerical modelling, ensemble forecasting, and weather impacts on society. THORPEX was succeeded by three WWRP core projects: Polar Prediction, Sub-seasonal to Seasonal Prediction, and the High-Impact Weather Project. These core projects emphasize emerging and critical areas of science to advance weather prediction from minutes to months. The WWRP working groups continue to provide the scientific expertise and important linkages between the research and operational communities.

The heightened importance of connecting science to services and creating the benefits of research both require a value cycle approach, with the increased participation of the actors in using forecast information to develop research requirements. This is what led to the framing described in the introduction to this document – a framing that we feel is timely and essential for the benefits of research to be realized.

Structurally, WWRP seeks to remain agile in order to respond to emerging priorities and new technologies, while also linking the parts of WWRP together more firmly and purposefully under a common umbrella that provides strategic focus. We propose to call this entity the Advancing WeAther Research to Reduce Risk to SociEties (AWAR3E). It is a product of the dual perspectives of disaster risk reduction and Earth system science: it explicitly includes the human dimension and fully embraces interdisciplinarity.

AWAR3E consists of actionable research aimed not only at providing weather information but also going further, to ensure that information is used to attenuate weather impacts on society. The use of the term ‘aware’ also refers to the basic goals of warnings: to inform actors of both the impending threat and the options available in terms of action to be taken in order to mitigate such threat:

* AWAR3E is broader than WWRP alone. It requires partnerships with the WMO Technical Commissions, Research Programmes, Member Services and their Regional Offices as well as a variety of stakeholders
* AWAR3E addresses the need for the public to have greater knowledge of weather impacts on their daily lives, and for action on the part of decision makers aimed at reducing the adverse effects of weather on people and the environment
* AWAR3E also demands that we pay attention to society as a whole, and that we continually remind ourselves of the needs of communities representing all WMO Regions
* AWAR3E is not a project in the traditional sense. It is a rallying point, a motivating force, a set of guiding principles, and a strategic goal against which success can be measured.

The guiding principles of AWAR3E will apply to all WWRP activities and will be used for regular monitoring, evaluation and learning assessments.

Guiding Principles:

1. Ensure that all stakeholders are aware of threats and mitigation efforts

Increase societal preparedness for weather events by enhancing the relevance and interpretability of weather information. We should endeavour to determine whether people are aware of the potential evolution of the situation, or whether they are even aware of the current local or global position, and what could be done to counter adverse developments

A1. Measure of success: evidence that fewer surprises occur, or fewer poor decisions are made due to inadequate information.

1. Be aware of all people and their needs

Developing countries, including the Least Developed Countries (LDCs) and Small Island Developing States (SIDS), are among the most vulnerable to the impacts of climate change. This is due to diverse factors, including geography, location, limited resources and low adaptive capacity. Consequently, WWRP needs to consider all constituencies, particularly vulnerable populations, and to incorporate them into the design and execution of its research agenda to ensure equity as well as the adequate communication of information and knowledge

A2. Measure of success: increased availability of weather research and applications for developing countries, LDCs, and SIDS.

1. Make society aware of our science

Ensure that society is cognizant of the critical role of weather research, and its transition to operations, as the underpinning of information. This opportunity for education is crucial to building trust

A3. Measure of success: evidence that capacity building and training include various groups in society. More frequent public engagement events. Launching of successful citizen science initiatives.

1. Increase awareness of forecasters and decision makers of appropriate data, tools, and techniques

Train the current and future generations on best practices, new technologies, and communication strategies

A4. Measure of success: workshops designed with, and for, forecasters and decision makers to raise awareness of new tools, and provide training to make their work more effective.

1. Ensure that researchers are aware of each other’s work

Eliminate stovepipes by improving the research-to-operations as well as the operations-to-research communication channels. Spread knowledge of what is happening in all relevant institutes and leverage this knowledge to improve prediction capabilities. Incorporate and raise the voices of early career scientists within the community

A5. Measure of success: projects or initiatives started or continued with partners such as the GAW, WCRP, the technical commissions, Member Services, academia, operational centres, and other relevant bodies to raise awareness.

### A Roadmap for WWRP

**Projects**

At the start of 2024, there will remain only one WWRP core project, High-Impact Weather, which is expected to end by the close of 2024. In order to maintain enough versatility to respond to the evolving requirements of the WMO Regions, there is no intention to create a new set of decade-long WWRP core projects. These projects have been valuable for building communities of practice and for pursuing fundamental and applied science in critical topic areas. Partnerships with the WMO Commission for Observation, Infrastructure and Information Systems (INFCOM), the Commission for Weather, Climate, Water and Related Environmental Services and Applications (SERCOM) and Member Services (MS) are required to sustain these achievements. From 2024 onwards, WWRP seeks a more agile project structure, with working groups that are tightly integrated into projects to infuse their scientific knowledge, carry out critical activities for projects, and advance relationships within a community of researchers and practitioners.

The projects chosen for the 2024–2027 period are aimed at addressing the targets set by the Sendai Framework, specifically, to “Substantially increase the availability of, and access to, multi-hazard early warning systems and disaster risk information and assessments to people by 2030” by better understanding disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment (Target 7 [Secretariat] of the Sendai Framework). These projects will also address some of the SDGs – specifically Goal 2 (agriculture), Goal 6 (water management), Goal 7 (sustainable and modern energy), Goal 11 (sustainable cities) and Goal 13 (the impacts of Climate change). In line with the targets of the United Nations Framework Convention on Climate Change, the WWRP project and the AWAR3Eprinciples will acknowledge and support vulnerable communities in adapting to climate change and the associated extreme weather events, taking developing countries, which lack the resources to do so on their own, especially into account.

Projects are expected to integrate [New Zealand] physical and social sciences from the outset. It will be necessary to take an Earth system approach, wherein coupled predictions of different components (atmosphere, ocean, cryosphere, land, hydrosphere and ecosystems) will be needed to produce the information necessary for decision-making. Technical approaches such as artificial intelligence and machine learning (AI/ML) will be needed for an array of purposes ranging from modelling human behaviour, to mining data for predictability signals, to model emulation, and to build ensembles to quantify forecast confidence. Projects will need to explore strategies to utilize exascale computing technology, on computationally and energy-efficient architectures, to achieve the fine spatial resolution, data assimilation, large ensembles and detailed process representation needed to advance science and solutions.

In addition to the High-Impact Weather Core Project, within which the Value Chain, Impact-based-forecasting and citizen science flagship projects will continue through 2024, WWRP will implement three current Research and Development Projects or Forecast Demonstration Projects (RDPS/FDPs) that are anticipated to go beyond 2023.

**Current projects going beyond 2023:**

1. *Aviation Research Demonstration Project (AvRDP) Phase II, expected to continue through 2025*

The aim of the AvRDP Phase II project will develop, demonstrate and quantify the benefits of improvements to forecasts of significant convection and associated hazards for aviation. The project will focus on the end-to-end flight route by defining a series of airport pairs spanning the six WMO Regions, and will place special attention on developing, demonstrating and evaluating advancements in probabilistic forecasting and statistical methods, with a view to helping forecasters and to providing confidence information and other assessments for practitioners in the aviation sector.

*Benefit to Members*

*The International Civil Aviation Organization (ICAO) and other aviation stakeholders will benefit from improved nowcasts of convective weather hazards along the gate-to-gate flight route. The project supports the global air traffic management vision conveyed in the ICAO Global Air Navigation Plan (GANP) over the coming decade.*

1. *Paris Olympics 2024 RDP, expected to continue through 2024*

The objective of the Paris Olympics RDP is to advance research on meteorological forecasting systems at 100 m, or finer, resolution for urban areas, especially related to extreme events in summer, such as thunderstorms and strong urban heat islands, and their consequences. The highlights of the project are field phases in summer 2022 and the 2024 Olympic Games in Paris.

*Benefit to Members*

*Urban communities should benefit from useful, detailed information, to improve thermal comfort and air quality especially during extreme events. The actors and users include forecasters, the public, athletes, security and safety institutions and event organizers.*

1. *Tropical Cyclone Probabilistic Forecast products, expected to continue through 2025*

This is a pilot project of the Global Data Processing and Forecasting System (GDPFS) with the potential to become a Forecast Demonstration Project through 2025. The Tropical Cyclone Probabilistic Forecast Products project (TC-PFP) stems from recommendations by the International Workshop on Tropical Cyclones (IWTC-9) to replace static products (such as the ‘cone of uncertainty’) with dynamic products conveying confidence, to incorporate social science into design, and to encourage access to common and consistent data through a pilot project of the seamless GDPFS. The three phases of TC-PFP will progress from Tropical Cyclones (TCs) track to intensity and structure, and finally to rainfall and storm surge.

*Benefit to Members*

*Regional Specialized Meteorological Centres (RSMSs) for TCs will benefit from better coordination across RSMCs to adopt best practices of a value cycle approach to probabilistic tropical cyclone impacts forecasts. Disaster risk managers will receive information on the impacts of wind and flooding due to TCs in an understandable format.*

These projects each explicitlyrepresent the WMOscience-for-services concept and the Research Board. They are responsive to the drivers outlined in section 1, and each adheres to the AWAR3E guidelines. RDPs and FDPs have a global or regional focus and each project has a Steering Group comprising 8 to 10 scientists in the relevant disciplines, who should come from the WWRP Working Groups and partner entities, from other WMO departments, and potentially from outside WMO if additional expertise is required. The Co-Chairs of RDP/FDPs should ideally be representative of both the physical and social sciences. The Steering Group writes a science plan that lays out science goals, methods, deliverables, strategy for communication of results, and the evaluation approach. The deliverables of the project should be based on the activities proposed in the WWRP Implementation Plan, in line with the key priorities outlined in the WMO Strategic Plan.

WWRP must choose additional projects to round out its portfolio across current and anticipated challenges in prediction capability, guided by the needs of users and communities from all Regions. The existing and new projects should incorporate the value cycle into stakeholder engagement. Here we summarize six new projects that begin or occur within the 2024–2027 time frame ([Annex A](#_ANNEX_A_–) contains further details on the five projects led by WWRP).

**Future projects (2024–2027):**

1. *Research on the southern and northern hemisphere polar regions*

This project will pay special attention to all relevant communities and to improving coupled models for weather impacts in the increasingly ice-free Arctic and climate-change prone Antarctica. In the Arctic and Antarctic novel observations capture the state of the sea ice at high resolution to enable the prediction of fine-scale structures and movements of sea ice that are relevant to coastal populations and their environments. Proposed name: Polar Coupled Analysis and Prediction for [New Zealand] Services (PCAPS).

*Benefits to Members*

*Indigenous communities and coastal populations in the northern and southern hemisphere polar regions will acquire improved services, including transport, fisheries and scientific research. Polar regions are closely linked to changes in our climate and can help us to predict what will occur in various regions of the planet years in advance. Globally, this will benefit users of the Earth system modelling and observations.*

1. *Research on sub-seasonal to seasonal sources of predictability, with a focus on water for agricultural and other environmental applications*

This project will entail the development of products that serve a variety of actors such as the management of water resources and food supplies. Useful information on sub-seasonal to seasonal timescales is underpinned by coupled atmosphere-ocean-land assimilation and prediction systems to monitor the progression of monsoons, clustering of atmospheric rivers, snowpack evolution, and water storage, as well as the resolution of fine-scale processes that capture the cycling of water and dynamics of vegetation. This project may also include phenomena such as drought and wildfires. Probabilistic information is a central component of prediction on this timescale. Communicating with the relevant users and partners and the challenges of communicating warnings for slow onset disasters should be addressed. Proposed name: SAGE: Sub-seasonal applications for AGriculture and Environment.

*Benefits to members*

*Managers of water resources, agriculture, food security and (renewable) energy will derive benefits from improved services on a sub-seasonal to seasonal timescale. Early warnings on sub-seasonal to seasonal timescales could improve decision-making in various sectors.*

1. *Research on the prediction of precipitation and hydrology to focus mainly on the integrated prediction of precipitation and hydrological processes*

This project will focus on the shorter timescales (minutes to days), and the advancement of warning strategies associated with multi-hazards and their interdependencies that affect the water cycle. The integrated precipitation-hydrology prediction problem builds on the goals of the WMO hydrology initiative to ensure that communities are prepared for flooding events of different types, including flooding through interaction with the built environment, freshwater flooding, coastal inundation, and mud or debris flows. Coupling the land and atmosphere (from nowcasting to short-range timescales) Numerical Weather Prediction (NWP) models with the hydrological model would be crucial to advance and accurately initialize the precipitation and hydrological state, and to realistically represent the evolution of uncertainty through the coupled system. This work requires the significant improvement in remotely sensed observations for precipitation estimation, the improvement of observations of the hydrological and soil moisture state, and continued support for ground-based networks for precipitation and stream flow. (Name to be determined)

*Benefits to Members*

*Stakeholders who are vulnerable to flash flooding, fluvial floods and coastal inundation will benefit from improved multi-hazard warnings to be better prepared for flooding events of different types and early warnings.*

1. *Research on urban-scale prediction of weather-related hazards to serve transportation, energy and related sectors to create sustainable cities.*

Urban-scale prediction must deal with existing and novel observations, specifically in the atmospheric boundary layer (ABL), and the subsequent development, application, and evaluation of sub-kilometre modelling techniques to predict spatial and temporal patterns of exposure to the threats of heavy rainfall, heat waves and poor air quality. The project will seek to understand the vulnerabilities inherent among subsets of the population distinguished by income, mobility, age, and minority status. Urban hazard impacts are dominated by variations in vulnerability and often result from cascades of environmental, technological and health hazards. Patterns of transportation and energy use exacerbate and unduly expose the more vulnerable communities, which is an unsustainable situation. While the value cycle is relevant to all projects, this project has the potential to substantially further the objectives of the value cycle (value chain) work within the High-Impact Weather Core Project that ends in 2024. The urban project would advance the concept of digital cities as a companion to initiatives such as Digital Earth and Digital Twins (WCRP). (Name to be determined)

*Benefits to Members*

*Urban communities will benefit from improved high-resolution information for transportation, energy, heat waves and extreme thunderstorms. Members could also contribute to this initiative by means of crowdsourced data and citizen science.*

1. *Public engagement and communication of WWRP science and its benefits*

While differing from the other RDPs and FDPs, this effort is nonetheless a project in its own right. A clear and consistent strategy for communication should be developed, drawing on expertise and networks from early career scientists (Young Earth System Scientists, YESS) and working group members. New connections with educators and experts in the communication of science should also be forged. Scientific communication and public engagement will disseminate the work that WWRP is doing, and provide resources for practitioners, decision makers and the general public for them to meaningfully engage with WWRP science and applications. The project will continue the work of sharing best practices. The project may initiate new components of citizen science. Proposed name: Public Engagement fOr Practitioners, Learners, and Educators (PEOPLE).

*Benefits to Members*

*Best practices will be developed in collaboration with educators (academia), practitioners, decision makers and the public to ensure good, effective communication of science to services.*

1. *Research on improving the nowcasting capabilities in African countries with a specific focus on Geostationary (GEO) satellite data*

The African community has indicated that it is willing and eager to manage its own African Meteorological Satellite Applications Facility (AMSAF), which will operate in Africa, by Africa and for Africa. Building on the AMSAF concept, WWRP hopes to work in partnership on an initiative to facilitate the wider generation and use of satellite-based nowcasting products in Regional Association I (RA I), in support of the better use of existing and emerging observational capabilities. A regional capacity building approach is planned, through which strong NMHSs, or regional climate centres, will become the regional hubs for access to Meteosat Third Generation (MTG) data, create nowcasting products developed by others, as well as develop their own products and later spread these to the surrounding countries in the respective regions. Through such products it would be possible, for example, to track severe thunderstorms, similar to radar products; detect the position of lightning events (Lightning Imager (LI) onboard MTG) and more precisely identify areas of heavy precipitation. This requires a concerted effort across WMO to harness the technology afforded by rapidly updating satellites, short range weather prediction models, as well as AI, to create nowcasting tools in, for, and by Africa. This project may intersect with other efforts related to precipitation prediction to some extent, although, based on geostationary data, precipitation estimations are not of similar quality as rain gauges or radar rainfall estimates. This project will build on knowledge and relationships established through previous projects in the region. Proposed name: Aiding Decision-making in Vulnerable Africa with Nowcasting of ConvEction (ADVANCE).

ADVANCE is anticipated to become a WWRP partner project to illustrate the concept of science**-**for-services. Through engagement with the WWRP its profitable results will be made available to the international community, in particular to developing and LDCs and regions, landlocked developing countries, and SIDS. It is hoped that the project will garner long-term independent funding covering at least three years. The aims of the project are expected to provide much benefit to the WWRP community, for example, through the publication of scientific findings, common exploitation of data, diagnostic tools, software development and training. Partner projects do not need to be led by WWRP, but WWRP should be a true partner of the projects in which it is involved.

*Benefits to Members*

*African members will benefit from better access to, and use of, geostationary (MSG and MTG) data and products for nowcasting of severe weather events, including severe lightning events, to improve early warning systems and their impacts.*

The scientific focus of each project and its projected time frame are listed in Table 1. Timelines for several projects will extend beyond 2027, since we expect to start 2024 with some projects that are already under way. It is therefore likely that by end 2027 some of them will still be ongoing.

In the course of 2027, we will take the opportunity to review our areas of focus to continue the work of WWRP guided by the same general goals. WMO follows the same approach: the goals remain even if the focus areas may differ slightly over time.

**Table 1. Research foci for each of the WWRP projects
that will be active during 2024–2027**

|  |  |
| --- | --- |
| **WWRP Projects****From 2024** | **Research Foci** |
| HIWeather Core Project(through 2024) | Research on the predictability of weather impacts, how stakeholders make decisions and best respond to information on uncertainty |
| Paris RDP (through 2024) | Prediction at sub-kilometre scales, with integrated meteorology and atmospheric composition |
| Aviation RDP-2(through 2025) | Integration of remote sensing observations with numerical modelling to represent deep convection and, at flight level, the associated turbulence and ice water content |
|  TC-PFP RDP (through 2025) | Quantifying and communicating confidence for tropical cyclone attributes and related hazards |
| PCAPS RDP (2024–2028) | Improving process representation in coupled polar models with atmosphere, sea ice, land ice and ocean components; prediction out to seasonal timescales to benefit local populations and regional economies in polar regions |
| SAGE RDP (2024–2028) | Improving sub-seasonal and longer prediction with coupled atmosphere-ocean-land systems; understanding sources of predictability; improving on operational products and their use for agriculture, energy, and water management |
| Urban Prediction RDP(2025–2029) | Exploring observations and modelling at sub-kilometre scales; representing integrated urban-scale processes, including energy and transportation; understanding vulnerability of different population groups to heat and air quality hazards |
| Hydrology and Precipitation RDP(2024–2028) | Understanding the flow of uncertainty, and decision-making, through the integrated atmospheric and hydrological system on timescales of minutes to days; improving short-range information about flash flooding and coastal inundation for disaster risk reduction |
| PEOPLE(2024–2027) | Developing consistent strategies for communication and developing new connections with educators and experts in the communication of science to disseminate the work that WWRP is doing in the area of sensitizing the public on science |
| ADVANCE Partner project (2023–2027) | Improving nowcasting capabilities and tools, focusing on GEO satellite data to enhance short term (0–6h) early warning systems and communication in Africa |

The first four projects have been chosen because they represent different intersections of components of the Earth system: atmosphere-ocean-ice (1), atmosphere-ocean-land (2), atmosphere and built environment (3), and atmosphere-hydrosphere (4). The last two projects were chosen to work specifically with vulnerable populations (PEOPLE and ADVANCE), to involve society in our science and increase awareness of WWRP.

Progress in research projects will require improvements in our ability to provide coupled modelling from minutes to months, including the data assimilation of coupled systems needed to make full use of existing and new observations. Much of the activity in this regard will occur at operational centres, research institutes and universities. The WWRP will play a role in connecting the needs of our Members to co-design the prediction systems and products of the future. Research will be necessary to understand the vulnerability of populations in urban areas, those affected by flooding and coastal inundation, and those for whom drought, or excessive seasonal rainfall, for instance, represents a serious risk for food and water resources. WWRP would suggest that all data generated by the projects should be findable, accessible, interoperable and reusable (FAIR).

**A Structure fit for purpose**

WWRP currently has six Working Groups and one Expert Team:

* Expert Team on Weather Modification (WxMOD) to promote scientific practices in weather modification research through its activities, and the organization of scientific conferences or sessions within a conference on weather modification
* Nowcasting and Mesoscale Research (NMR) Working Group to advance research on nowcasting and mesoscale processes and predictability. It will also promote the implementation of nowcasting systems within NMHSs and among their users, including the use of numerical modelling, predictability, assimilation of high-resolution data and field experiments
* Data Assimilation and Observing Systems (DAOS) Working Group to guide the WWRP in optimizing the use of the current WMO Global Observing System (GOS). DAOS will facilitate the development of data assimilation and observing system methodologies from the convective to planetary scales, and improvement of forecasts with time ranges of hours to weeks
* Predictability, Dynamics and Ensemble Forecasting (PDEF) Working Group to advance dynamical meteorology and predictability research, and their application to ensemble forecasting; promote the quantification of forecast uncertainty and the development of ensemble applications and their transition into operations
* Tropical Meteorology Research (TMR) Working Group to coordinate and advance the research on tropical cyclones, monsoon systems and intra-seasonal tropical variability, to improve the prediction of high-impact weather in the tropics
* Joint Working Group on Forecasting Verification Research (JWGFVR), shared with the WCRP and the Working Group on Numerical Experimentation (WGNE), to advance the development and application of improved diagnostic and verification methods to assess and enable improvement of the quality and value of weather forecasts, including forecasts from NWP systems and climate models
* Societal and Economic Research Applications (SERA) Working Group to advance the science of the social and economic application of weather-related information, provide services, and to review and assist in the development and promotion of societal and economic demonstration projects.

In its effort to create a tight coupling between working groups and projects, WWRP will adopt a matrix structure in which the expertise of working groups is mapped across projects, most of which will function as Research Development Projects. However, WWRP also has partner projects, and we envisage that the ADVANCE project will be added to this list as it will be run in partnership with WWRP, but with external funding. The table below summarizes the projects, with provisional names, and the groups involved.

**Table 2. Current projects (grey) extending beyond 2023, and proposed new projects (pink), with Working Group and Expert Team contributions.**

**See** [**Annex B**](#_ANNEX_B_–) **for List of Acronyms.**

|  |  |
| --- | --- |
| **WWRP Projects****From 2024** | **Working Group or Expert Team** |
| HIWeather Core Project (through 2024) | NMR, JWGFVR, SERA, PDEF, SERA, HAP |
| Paris RDP (through 2024) | NMR, JWGFVR, PDEF, DAOS, SERA |
| Aviation RDP-2(through 2025) | NMR, JWGFVR, PDEF SERA |
|  TC-PFP RDP(through 2025) | JWGFVR, PDEF, SERA, TMR, HAP |
| PCAPS RDP(2024–2028) | JWGFVR, PDEF, DAOS, SERA |
| SAGE RDP(2024–2028) | JWGFVR, PDEF, DAOS, SERA, TMR, HAP |
| Urban Prediction RDP (2025–2029) | NMR, JWGFVR, SERA, PDEF, DAOS, TMR, WxMOD |
| Hydrology and Precipitation RDP(2024–2028) | NMR, JWGFVR, SERA, PDEF, DAOS, TMR, WxMOD, HAP |
| PEOPLE(2024–2027) | All WGs, YESS |
| ADVANCEPartner project(2023–2027) | NMR, JWGFVR, SERA, DAOS, TMR, HAP |

The enhanced focus on hydrology, and the emphasis of precipitation in multiple projects motivate the addition of a working group with expertise in hydrology, precipitation microphysics, and remote sensing of precipitation and land characteristics, including river levels and areas exposed to inundation. The Hydrology and Precipitation Working Group (HAP) will connect with several projects and will lead the Hydrology and Precipitation project (name TBD). WWRP expects that the HAP Working Group will coordinate closely with several other working groups on impacts and the value cycle (SERA), verification (JWGFVR), nowcasting (NMR), data assimilation (DAOS) and other groups as deemed relevant.

The intent of the matrix structure is to create a tighter coupling between working groups and projects, and to provide clearer guidance for working group members about roles and responsibilities. It is evident that some working groups will be connected to most of the projects. Membership of these groups may need to be expanded. Considering their contributions to the projects, the working groups will continue to convene the scientific community, harvest the latest scientific advances, and communicate science through broad networks without overburdening themselves.

Reporting will be predominantly along project lines rather than by specific working groups. Members of working groups will be actively engaged in the projects, which will communicate the cross-cutting linkages across projects, identify important innovations that may benefit multiple projects, and bring together the community, offering perspectives on future directions and best practices within their scientific areas of focus.

The progress of projects should be monitored regularly, with evaluation procedures built into new projects at the design phase. A Monitoring, Evaluation and Learning (MEL) plan could include several mechanisms for monitoring: scientific publications and citations; acquisition of external funding; annual deliverables and outputs, as well as measurement of impact through surveys to stakeholders, feedback in focus groups, and case studies, all guided by the measures of success outlined in the AWAR3E principles.

Projects will also establish connections with specific constituencies, who should also be involved during the design phase in order to define the goals, critical development efforts and milestones of the projects. In accordance with the terms of reference, all projects will have a steering committee comprised of roughly 10 members, mostly from working groups, and may include members from partner entities, representatives of the constituencies that will make use of the science and/or bring additional expertise to the project.

Innovations do not represent a specific project. Rather, this is a reminder that it is the new ideas and technologies that come into WWRP through the working group members and the involvement of early career scientists (YESS) that will fuel future projects. Although it will be important for WWRP to conduct a periodic review of new concepts and technologies, this is a continuous process. This will facilitate the communication of science to the WMO community, and the incorporation of recent advances into projects.

**Partnerships for success**

The complexity and breadth of the projects to be undertaken by WWRP will necessitate partnerships with numerous entities within WMO. Next to each project listed in Table 3 below, we state the preferred partnerships and requirements encompassed by AWAR3E principle 5:

**Table 3. Partners for the research projects listed in Table 1**

| **WWRP Projects****From 2024** | **Partner** |
| --- | --- |
| HIWeather Core Project(through 2024) | SERCOM/Standing Committee on Disaster Risk Reduction and Public Services (SC-DRR) |
| Paris RDP (through 2024) | SERCOM/SG-URB and GAW for air quality prediction |
| Aviation RDP-2(through 2025) | SERCOM/Standing Committee on Services for Aviation (SC-AVI) |
|  TC-PFP RDP (through 2025) | INFCOM/Standing Committee on Data Processing for Applied Earth System Modelling and Prediction & Projection (SC-ESMP); SERCOM (RSMCs) and SC-DRR |
| PCAPS RDP (2024–2028) | WCRP/ESMO and WGNE; EC-PHORS, INFCOM/JET-EOSDE, SC-ESMP, GCW-AG |
| SAGE RDP(2024–2028) | WCRP/ESMO and GEWEX/GPEX, SERCOM/Standing Committee on Services for Agriculture (SC-AGR), INFCOM/JET-EOSDE |
| Urban Prediction RDP (2025–2029) | GAW/GAW Urban Research Meteorology and Environment (GURME) for air quality and urban boundary layer research and SG-URBAN, WGNE, INFCOM/JET-OWR, JET-HYDMON, JET-EOSDE, JET-ABO |
| Hydrology and Precipitation RDP(2024–2028) | WCRP/GEWEX, SERCOM/Standing Committees on Hydrological Services (SC-HYD) and Disaster Risk Reduction and Public Services (SC-DRR), INFCOM/ET-OWR, JET-HYDMON, JET-EOSDE, CoastPredict |
| PEOPLE(2024–2027) | YESS; WCRP (RIfS), WMO/ETR, WMO/Comms |
| ADVANCEPartner project (2023–2027) | African NMHSs; EUMETSAT’s Nowcasting Satellite Applications Facility (NWC-SAF); WMO RA I Regional Office, INFCOM/Space Systems and Utilization Division (SSUD) and Education and Training division (MS/ETR) and SERCOM/Global Multi-hazard Alert System (GMAS) |

Apart from the professional relationships among individual scientists, the mechanism governing such networks will be membership on the steering committee for each project. For instance, the steering committee for AvRDP-2 will consist of five members each from WWRP and SERCOM. The RDPs and FDPs all have these committees to ensure that decisions are co-designed among collaborating groups, and with constituencies at the table.

Steering committees and community advisory groups for new projects will be formed in the year prior to the beginning of the project. Each steering committee will be responsible for writing a project plan, before the launch of the project, based on general concepts that are agreed upon by the WWRP Scientific Steering Committee (SSC) and working groupchairs.

**Interaction between projects and Working Groups**

In a more matrixed, project-oriented focus, the expectations for working groups will be twofold:

Firstly, members will continue to promote engagement of the scientific community, perhaps through the organization of conferences and workshops, or the identification and dissemination of best practices, where appropriate. Working groups will be able to draft position or review papers on topics of current interest, and their members will also serve as WWRP ambassadors in the course of their everyday scientific or operational tasks.

Secondly, members will either serve on the steering committee of a project (see below) or engage directly in project research. Participation in projects may be achieved through the alignment of their goals with the ‘day jobs’ of working group members, or through modest funding obtained by WMO and WWRP to support WWRP projects. It is expected that each project will involve multiple working groups, each of which will contribute to several other projects.

The combined expectation of project participation and scientific engagement will require all working group members to be active contributors and the possible expansion of working group membership beyond ten members in some cases. This is particularly true of the JWGFVR and SERA Working Groups because they will likely be linked to every project. Working group members will be selected on the basis of scientific expertise, regional and gender diversity and their ability to contribute to WWRP RDPs and FDPs.

Projects will be led by a steering committee, whose membership will come from WWRP working groups and partner entities from other WMO departments or, potentially, outside WMO. This committee should include members from relevant communities that will apply the outcomes of the projects to improving their decision-making capacity or to disseminating information to other constituencies.

### Conclusion

The new plan for WWRP builds upon successes of recent and current WWRP activities, while moving weather science closer to society. That means involving stakeholders in research design, informing society of the important work carried out by WWRP, and measuring the value of the results in terms of protecting the health and well-being of the public. This plan comes at a critical time for WWRP to contribute to the United Nations Sustainable Development Goals for 2030. It is also crucial for the United Nations to meet its target of making early warnings available for all within 5 years. This cannot be realized without close coordination of research into the needs of decision makers, and everyone is a decision maker. Such coordination is central to WWRP.

The World Weather Research Programme is committed to harnessing the intellectual power and dedication of its experts to create new knowledge aimed at achieving beneficial outcomes that societies will need in order to thrive despite the mounting and increasingly complex environmental threats in the coming years.

## ANNEX A – Short Summaries of New Projects

# Polar Coupled Analysis and Prediction for Services (PCAPS)

Motivation and link to WWRP IP (2024–2027) and WWRP drivers

Both the Arctic and Antarctic are areas of increasing geo-political, geo-economic and geo-ecological interest. This is driven by the fact that the polar regions are rich in raw materials and natural resources, and the heightened interest stems from opportunities and challenges due to the significant climate change in these regions. The recorded rise in average temperatures is significantly more pronounced than anywhere else on Earth. This change is also drastically affecting living conditions for Indigenous peoples.

Weather in the polar regions results from a complex interplay between numerous physical processes in and between the three major Earth system components: atmosphere, hydrosphere and cryosphere. Improvements in our forecasting capabilities therefore require the development and use of increasingly complex Earth system models to represent all relevant processes with sufficient accuracy. However, more complex models are also much harder to constrain and evaluate due to a corresponding increase in the degrees of freedom in such systems. This calls for continued enhancement of the observing system to inform further model validation and development, and to improve the determination of the initial conditions.

A major finding from the PPP and YOPP has indicated that the key parameters for current conditions and forecast products in the polar regions are mainly surface wind speed and direction, swell height/frequency/direction, cloud conditions, precipitation, visibility and sea ice characteristics. These physical parameters are related to small-scale processes occurring in the BL between the atmosphere and ice-covered ocean/ice-covered land and perhaps also small-scale and high-gradient structures in the ocean. Most of these parameters are rather difficult or even impossible to derive from satellite measurements. It is therefore mandatory to improve operational observations focusing on these variables and on the provision of profile[Secretariat] measurements in the polar boundary layer. This should also include measurements of fluxes of energy, momentum and water between atmosphere, ocean and snow/ice.

To simulate these small-scale processes with greater fidelity, higher resolution numerical Earth system monitoring seems to be a necessary, but, unfortunately, not adequate condition. In order to estimate the origin of model biases or their impact, process-oriented model evaluations are required to take into account the possibility of compensating errors. It also appears to be important to improve the coupling between atmosphere, ocean and ice compartments of the models, especially for data assimilation.

### Scientific questions to be addressed

With this background in mind, there are three, interwoven foci of the project. One crucial aspect is that the needs of stakeholders must drive the science priorities. These needs include improved services for shipping, aviation and travel by land or water. The stakeholders also involve both poles, although with somewhat different priorities. The YOPP Final Summit highlighted the need for accurate surface wind and visibility forecasts in all regions. While prediction of sea ice on timescales of days to months is important over both the northern and southern hemispheres, the expanses of new ice in the Arctic render prediction in that region particularly challenging.

Model development will prioritize processes at the interface of the coupled atmosphere, ocean, ice system, including fluxes of heat, water vapour and momentum. This includes building on the development of high-resolution models capable of resolving complex coastal land and ice boundaries, as well as leads in the ice. Improvement in the treatment of stable boundary layers and the near-surface radiative balance are areas where concerted effort is needed.

The prediction of sea ice requires high resolution to capture leads in the ice, plus dynamically consistent initialization of the ice in a consistent state with the ocean and atmosphere. Recent promising results for sea ice prediction on timescales of weeks to months suggest that rapid progress is possible over the next few years. Operational centres are moving toward kilometre-scale global models and coupled data assimilation, which will likely prove essential to the prediction of ice-related hazards.

The polar observations that underpin prediction tend to be dominated by remote sensing from polar orbiting satellites. However, these observations contain many gaps with regard to observing the boundary layer in polar regions. We envision the development of a tiered surface observing network concept which especially addresses the principal limits and weaknesses of satellite-based remote sensing. This includes the investigation of feasible and cost-effective qualitative extensions of the operational observing technology: ground-based remote sensing, robotic surface and aerial crafts, as well as hardened autonomous surface weather stations and buoys. We also consider the extension of a few permanent observatories for providing long-term multivariate process-oriented measurements, for example, the International Arctic Systems for Observing the Atmosphere (IASOA[[[[1]](#footnote-2)]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en%2DUS&rs=en%2DUS&wopisrc=https%3A%2F%2Fwmoomm-my.sharepoint.com%2Fpersonal%2Fedeconing_wmo_int%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F032f949ace0c43f7bccc9d97a0d57e5b&wdenableroaming=1&mscc=0&wdodb=1&hid=3270659E-4827-444B-BE2A-56B0F2185F58&wdorigin=Sharing&jsapi=1&jsapiver=v1&newsession=1&corrid=36b87b70-e893-4be2-b67d-35c6a4aa347f&usid=36b87b70-e893-4be2-b67d-35c6a4aa347f&sftc=1&cac=1&mtf=1&sfp=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush&rct=Medium&ctp=LeastProtected#_ftn1)). The combined network of surface observations will provide further validation and improvements of critical satellite products such as sea ice age and thickness and snow depth on sea ice. An important outcome of PCAPS would be a cost-benefit analysis of various components of the observing system necessary to define the ‘sustainably observed’ poles.

Building on the YOPP, we strongly support the continuation and extension of the YOPP data portal and the YOPPSiteMIP[[[[2]](#footnote-3)]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en%2DUS&rs=en%2DUS&wopisrc=https%3A%2F%2Fwmoomm-my.sharepoint.com%2Fpersonal%2Fedeconing_wmo_int%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F032f949ace0c43f7bccc9d97a0d57e5b&wdenableroaming=1&mscc=0&wdodb=1&hid=3270659E-4827-444B-BE2A-56B0F2185F58&wdorigin=Sharing&jsapi=1&jsapiver=v1&newsession=1&corrid=36b87b70-e893-4be2-b67d-35c6a4aa347f&usid=36b87b70-e893-4be2-b67d-35c6a4aa347f&sftc=1&cac=1&mtf=1&sfp=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush&rct=Medium&ctp=LeastProtected#_ftn2) activities, the goal of which is to make existing and future data widely available in a user-friendly manner, and mainly for a comprehensive process-based evaluation of models. These evaluations are likely to be conducted through detailed, process-oriented case studies of extreme events (atmospheric rivers, transient warm periods, arctic wildfires, polar lows). There should be a focus on a better quantitative understanding of boundary layer processes, wave-ice-ocean interactions (wave-effects), cloud microphysics (especially mixed phase clouds), aerosols and sea-ice characteristics. We also foresee that new developments in observing technology such as robotic crafts – saildrones, controlled balloons, unmanned aerial vehicles (UAVs) – and ground-based remote sensors will spur on these process investigations.

Desired outcomes

Through the activities of PCAPS, there are many likely outcomes across space and timescales. Improved observation and modelling should provide a better understanding of the Arctic amplification mechanisms through an improved understanding of physical processes in the polar region, especially cloud microphysics, cloud-radiation interaction, and turbulence in the strongly stable, but sometimes also quite heterogeneous, boundary layer over ice (leads, polynyas). We envision a variety of improved services to the diverse group of stakeholders in polar regions that are vital to communities in the region and who add economic value to many countries. Through better initialized predictions, using higher-resolution coupled models, we also foresee improvements in the polar coupled system influencing [Secretariat] to lower latitudes through teleconnections.

### Anticipated and/or needed partnerships

WCRP – provision of process-oriented observations for improving climate models

GAW – arctic wildfires, soil gas exchange between atmosphere and land – thawing permafrost

INFCOM – development of a cost-effective long-term oriented surface-based observing network in the polar regions to strategically complement the satellite-based system, especially taking physical limits of current and future space-based remote sensing methods into account; improving quality and availability of observational products for clouds, snow and ice

SERCOM – this partnership will be essential for the benefits of improved prediction skill of local and regional services to be relayed to a diverse group of stakeholders.

SCAR – Scientific Committee of Antarctic Research [New Zealand]

IASC – International Arctic Science Committee [New Zealand]

### Estimated timeline

This project is envisaged to be a five-year effort running from 2023 to 2027.

# Urban Prediction RDP (Name TBD)

Motivation and link to WWRP IP (2024–2027) and WWRP drivers

Slightly more than 50% of the current global population reside in urban environments. Growth in urban centres will continue. It is projected that this percentage will rise to as much as 70% in the coming decades, resulting in an increasing number of people susceptible to weather-related hazards in urban environments. These complex, heterogeneous environments are particularly susceptible to cascading impacts from individual extreme events such as localized heavy precipitation, heat waves exacerbated by urban heat-island effects, disintegrated air quality, and so on. These potential impacts are evolving further due to the changing climate.

Understanding of the vulnerabilities to subsets of the population is crucial to providing valuable warnings, planning, and ensuring equitable access to usable information. The need for information, warnings, service across various sectors including emergency management, disaster relief, transportation, energy, and various industries such as tourism, also vary. This summary [Secretariat] outlines a project strategy and sets priorities for advancing research for urban scales and environments. The agenda that is required will be inherently interdisciplinary, leveraging a value cycle approach to connect science to valuable services.

### Scientific questions to be addressed

User needs, vulnerability, and impact prediction: urban hazard impacts are dominated by variations in vulnerability and are often the result of compound, cascading effects. Given the varying needs of diverse communities, the integration of user needs and social science will be critical. This project will focus on addressing methodologies for understanding and addressing variable vulnerabilities across urban environments. Such information is critical for setting priorities for other aspects of prediction in the urban environment, and tailoring products and communication to meet the greatest needs and challenges for integrated urban services. Systems for defining and updating key exposure and vulnerability grids will be considered and assessed. Research will be explored to better understand and/or plan for changes in transportation patterns and energy consumption and distribution that could potentially exacerbate exposure of communities that have been identified as particularly vulnerable. Finally, questions about the context in which impact-based forecasts and warnings in the urban environment are most effective will be addressed, and will include the means by which multi-hazard impact and action messaging can be most effectively communicated to induce appropriate action.

Urban modelling and required input datasets: In order to improve prediction of weather impact on urban environments, significant strides in high-resolution modelling will be required. This project will address the need for progress in the state of modelling toward developing and building grey-zone (hectometer) scale applications, including the identification of the widest gaps and starkest needs moving forward. The project will also seek to address the challenge of predictability at such fine scales. In order to support sub-kilometre scale urban prediction, the complexities of urban data that underpin modelling efforts and the establishment of new mechanisms to obtain such supporting data will be studied.

Observations, data assimilation, verification, and validation: This project will focus on the need for atmospheric observations at the appropriate scales for monitoring, model development, data assimilation, and validation. For example, it will ask the following:

* Which novel observations would be needed in order to facilitate progress in urban boundary layer research, and to process level diagnostics and evaluation?
* Which new technologies might or should be explored to expand coverage of observations in the urban environment?
* How can we best exploit observations from less traditional platforms such as those from citizen science, social media, and so forth?
* What novel verification methods might be needed for applications at these scales?

Given the unique nature of the problem, this project will further focus on questions regarding the best use of observation in data assimilation methodologies, including their application to the creation of initial conditions by models and performing online [Secretariat] parameter estimation.

Urban prediction for services: To connect user and stakeholder needs to modelling and observations, this project will focus on phenomena of relevance to the urban environment:

* What are some of the challenges associated with sub-kilometre scale modelling to address predictions of urban rainfall, flooding, and associated mechanisms?
* What are some of the challenges associated with the prediction of spatial and temporal patterns of exposure to threats such as heat and poor air quality?
* Building on the proposals made for digital twins and Digital Earth, how can the concept of digital cities be pursued in order to explore questions arising in hypothetical scenarios in the urban environment, including the assessment of impacts when human interaction with the environment is varied?

### Desired outcomes

The urban project will result in improved state-of-the-science modelling capabilities and recommendations for predictions at sub-kilometre scales. New urban data sets will be made available along with the deployment of new observing systems for the urban environment. Ideally these should be co-designed with users and should create templates for others to follow. There will be better understanding of information-gathering on the distribution of vulnerabilities and how best to utilize such information to produce services of value. WMO members will have improved tools at their disposal for providing relevant data on multi-impact hazards in the urban environment to communities. In order to ensure that urban-scale forecasts, and especially impact-based forecasts and warnings, are translated into tailored services, it is recommended that social scientists should be involved.

### Anticipated and/or needed partnerships

* Close integration of other WWRP projects, bringing various experts from several disciplines (AI/ML, Information System, Ensemble Prediction)
* The GURME project - for air quality and urban boundary layer research
* Study Group on Integrated Urban Services – focus on service delivery for urban complexes
* Joint Expert Teams on Operational Weather Radars (JET-OWR); Hydrological Monitoring (JET-HYDMON); Earth Observing System Design and Evolution (JET-EOSDE); Aircraft-based Observing Systems (JET-ABO)
* Engagement with NMHSs, likely supported by Member Services, to understand their need to improve their communication practices. Strong alignment with the GMAS team needed
* Engagement with ‘boundary’ or brokering agencies to enhance communication to the public and enable feedback to be incorporated into the science
* Involvement of the social scientists and users to produce a collaborative science from the stage of defining the problem to forecast production and dissemination, including data collection and analysis
* Partnering to understand how urban forecasts and information may be combined and applied to other hazards such as landslides, flooding, and volcanic ash fall.

### Estimated timeline

This project is envisaged to be a five-year effort running from 2025 to 2029.

# Hydrology and Precipitation RDP (Name TBD)

Motivation and link to WWRP IP (2024–2027) and WWRP drivers

The number of disasters is on the rise due to higher levels of disaster risk derived from increasing vulnerability and exposure to hazards of diverse origins, particularly weather, climate, and water hazards. Deaths, human displacements, loss of livelihoods, damage to the environment and economic losses are among the major consequences of disasters. Early Warning Systems (EWSs), understood as an integrated system of monitoring hazard, forecasting and prediction, disaster risk assessment, communication, and preparedness activities, can serve as a mechanism to enable individuals, communities, governments and businesses to take timely action to reduce disaster risks.

In March 2022 WMO and the United Nations announced an ambitious target to develop a plan to ensure that EWSs are widely used within the next five years by all people around the world against increasingly extreme weather and climate change. In a similar vein, the WWRP has fixed the advancement and promotion of research activities that facilitate timely and actionable EWSs to effectively inform and influence societal actions, planning, and policy decisions as one of its top priorities.

WWRP recognizes that this ambition rests on the ability to:

* Advance research frameworks on Earth system modelling and high-impact weather prediction that focus on improving integration and interconnectedness throughout the entire early warning to early action value cycle
* Increase our understanding of the many underexplored or unexplored interactions and feedback loops in coupled human and natural systems
* Bring together knowledge from different disciplines (meteorology, hydrology and the social sciences)
* Foster collaboration between research and operations, within NMHSs and beyond, to bring forward effective strategies for uncertainty quantification and communication
* Rethink the warning process, as new approaches to disaster risk assessment emerge, including those targeting the combined assessment of regional multi-hazard interdependencies (compound and cascading hazards) and local vulnerability.

This project will address these challenges as follows:

* It focuses on an integrated and transversal approach to multi-hazards and vulnerability assessments and predictions on short timescales (minutes to days) across the weather and water boundaries for society-tailored disaster risk information
* It aims at improving the scientific interface between weather and hydrological research to define and make available holistic prediction models (storms, floods, landslides), which are major technical components of EWSs associated with hydrometeorological hazards
* Equally important, it seeks to shape EWSs from a social perspective, by developing strategies of disaster risk communication that will be used by communities to reduce their exposure to hazards and increase disaster risk awareness and preparedness.

Hydrology and Precipitation is fully in line with the 2021 WMO Water Declaration, which, in support of the global water agenda and the United Nations Sustainable Development Goals, acknowledges the central role of the water cycle and hydrology in the water-climate-weather continuum. It is also in harmony with the WMO Vision andStrategy for Hydrology and its associated Action Plan which targets eight long-term ambitions for operational hydrology including, “No one is surprised by a flood” and “Science provides a sound basis for operational hydrology”. Finally, it mobilizes the WWRP community to join efforts and create partnerships within the WMO Hydrological Research Strategy 2022–2030, which highlights the priority areas where research is needed to improve the delivery and use of hydrologic data, information and services.

### Scientific questions to be addressed

The project poses the question of how vulnerable communities exposed to weather, climate, and water-related hazards might reduce the risk of disaster. It focuses on advancing hazard predictability (monitoring and modelling), improving hydrometeorological warnings, and co-developing sound communication strategies for decision-making. It brings together a diverse community of researchers, operational forecasters, and stakeholders to ensure that scientific information is communicated in the best possible way and used to reduce the impacts on society despite forecasting uncertainty.

The project is structured around three main themes:

Coupled Earth system modelling (ESM): physics, ensemble prediction, data assimilation, verification. The development of coupled ESM requires integration of data and knowledge on atmosphere, land, and hydrological processes. Challenges still remain in considering how to draw on recent advances in hydrology to improve the hydrological process representations within ESM and NWP models. The project will address the need to advance research on the surface and atmospheric interactions from global to local scales, with a focus on enhancing the modelling of hydrometeorological hazards. By leveraging artificial intelligence and multisource hydrometeorological data, it will address challenges in testing and benchmarking model predictions against observations. It will explore pathways to implementing efficient data assimilation schemes, statistical post-processing, and hydrometeorological ensemble prediction systems (precipitation, streamflow) that can be readily used in real-time operational forecasting.

Socio-hydrometeorology: dynamic interactions and feedbacks between weather, water and people, and citizen science. The project will foster research on the interplay between weather, hydrological and social processes. It will address questions regarding the increasing impact of changing landscapes and human activities on the water cycle across scales. It will consist of advancing research on human-weather-water modelling systems at different resolutions, from global to local perspectives. It will explore the potential of citizen science projects to enhance modelling, risk perception, and communication of hydrometeorological hazards and disaster risk.

Integrating precipitation and hydrology in multi-hazard contexts: hazard dynamics, risk perception, early warning systems and informed decision-making. The project will investigate hydrometeorological hazards associated with high-impact weather and their interdependencies affecting the water cycle (for example, compound and cascading events). It will explore the use of exposure and vulnerability information for multi-hazard impact-based forecasting. It will address the needs of co-designing and implementing robust impact indicators, integrating them into EWSs, as well as enhancing their usability to drive decision-making.

Specific key questions:

* How can we leverage improvements in remotely sensed observations for precipitation estimation and in Earth observations of the hydrological and soil moisture states, with continued support for ground-based networks for precipitation and streamflow?
* How do nowcasting and short-range coupled prediction systems need to advance to accurately initialize the precipitation and hydrological state, and to realistically represent the evolution of uncertainty through the coupled system?
* How can we best identify the problems and formulate potential solutions on integrated precipitation-hydrology research prediction following the current societal needs as well as the goals of the WMO Vision and Strategy for Hydrology?
* What are the main barriers to effectively communicating uncertainty?
* What are the most effective approaches for communicating the potential impact of hydrometeorological hazards?
* How might stakeholders, exposed to flooding events of different types (flash floods, fluvial floods, coastal floods, urban floods), benefit from improved multi-hazard warnings to be better prepared for early warnings and decision-making?

### Desired outcomes

Hydrology and Precipitation will strengthen interdisciplinary research within WWRP and enhance its transdisciplinary nature. It will foster research activities that bring together the weather, hydrology, and social sciences communities that work for, or with, NMHSs and organizations involved in disaster risk assessment and management.

It will advance hydrometeorological prediction systems from the Earth system perspective, with a better coupling of hydrological and meteorological models (integration of runoff and river routing) and robust assessment of improvements. From the operational and services perspective, it will advance ensemble prediction systems in the hydrometeorological context, with coupled and uncoupled systems, improving the way current systems account for multi-hazard interdependencies and communicate forecast uncertainty in different decision-making contexts. By putting a strong focus on disaster risk reduction, the project will foster close ties between hydrometeorological forecasts and practical uses and needs.

By addressing integration, modelling capacities, and knowledge gaps on impact-based forecasting and social vulnerability, the project will directly contribute to the WMO ambition of providing EWSs for society and to the WMO Research strategy for hydrology, in terms of advancing research-to-operations activities on flood forecasting and related services for early warning. For WMO members, EWS will be improved and services at regional, national, and subnational levels will also benefit from integrating weather (precipitation, evaporation) and hydrology (soil moisture, streamflow) knowledge and processes.

### Anticipated and/or needed partnerships

Given the strong component of integrated research in the project (weather-hydrology-society), partnerships with the other WWRP projects dealing with the water cycle and impact-based forecasting will be essential (PEOPLE, Urban Prediction, SAGE). Interactions with the WWRP JWGFVR is important for fruitful collaboration on advanced methods for model output assessments. In the initial years of the project, close collaboration with the ongoing High-Impact Weather Project (HIWeather), which will end in 2024, will also be essential to securing continuity of key achievements (for example, value chain, citizen science).

Coordination of research projects and dissemination of outcomes will be prioritized with topic-related WMO programmes, particularly with the Hydrological Coordination Panel, the Hydrology and Water Resources Programme, and the Disaster Risk Reduction programme, also targeting services-oriented collaborations with WMO SERCOM/SC-DRR.

Linking research activities to national and international organizations, and encouraging the interface between scientific research, policymakers and society will be fundamental. This includes liaising with NMHSs, UNDRR (United Nations Office for Disaster Risk Reduction), GFP (Global Flood Partnership), GEWEX (Global Energy and Water Exchanges project), HEPEX (Hydrological Ensemble Prediction Experiment), and IAHS (International Association of Hydrological Sciences).

### Provisional timeline

The project will start in 2024 for a 5-year duration (2024–2028).

Year 1: Framing and mapping the interactions and specific objectives; defining actions and establishing partnerships

Years 2–5: Project activities and outcomes

# Public Engagement of Practitioners, Learners, and Educators (PEOPLE)

Motivation and link to WWRP IP 2024–2027 and WWRP drivers

Weather and climate-related events are pointing to a rapidly emerging risk profile that requires robust, reliable, and useful information to help reduce risks. The day-to-day weather experiences of the public call for accessible information sources on both short- and long-term time frames in decision-making. The WWRP is well placed to engage and work with people in a focused communication, knowledge, and brokering context.

In this summary [Secretariat] we provide an initial rationale, foci as well as suggested research questions for a project centred on the science of public engagement. Through scientific communication and public engagement, the project will help to disseminate information on the work of WWRP in providing best-practice resources for practitioners and decision makers, and will enable a more engaged interface for the general public to contribute to science and the applications of WWRP.

PEOPLE will be a cross-cutting project that draws on communication and information needs, best practices, and evidence-based science that will be collated and informed by the various science efforts of the other projects, as well as through public engagements with users of weather information, for example. There will be an iterative process between (1) the development of project level communication and engagement within WWRP projects and (2) cross-cutting science on communication and engagement which will be based on the activities within the other projects. Thematic areas may include:

* The role of various knowledge pools (tacit and Indigenous knowledge) adding to WWRP knowledge creation and outputs (for example, Indigenous knowledge use)
* Two-way dialogues and interaction profiling how various communities adopt and provide inputs to WWRP on weather, for instance, modes of effective communication
* Expanding, extending and enhancing citizen science initiatives
* Working with social scientists who can assist in various dimensions of information for users, including behavioural science and communication practices
* Developing a communication and outreach strategy for WWRP.

### Scientific and practical questions to be addressed:

* In which contexts are impact-based forecasts and warnings effective? This question may be included among the urban and hydrology themes, and may also help to inform the GMAS Action Plan for impact and early warning messaging and assessment
* How can multi-hazard impact and action messages be most effectively communicated?
* How do we use different communication approaches for diverse knowledge holders? For example, placing value on Indigenous world views and cultures
* How do various contexts of power and trust influence and shape the outcomes of various communication actions and responses?
* In which ways do emerging communication channels and tools effectively target users (Indigenous knowledge users, industry sectors, youth, donors, to name a few)?
* How can we make more effective use of the creative arts and humanities to promote and inform the critical elements of the science that may be needed for risk reduction?
* What are some of the barriers to effective uptake of information in the various projects, and how can these be overcome?
* What are the opportunities for more effective outreach and dissemination in the various projects, for example, digital engagement and on-line consultation?
* How might citizen science promote more effective engagement and outreach in the various projects?
* What are the user roles, expectations and responsibilities in supporting evaluation?
* With all the above actions, ensuring that the ethics of communication and information-sharing are carefully monitored, prepared and delivered is crucial.

Science questions will be investigated using robust methodologies and research plans co-designed with key users. The appropriate methodologies will be selected according to the research question, taking the contexts and cultures into consideration. Guidance on best practices will be developed in collaboration with educators (academia), practitioners, decision makers and the general public to ensure good, effective communication of the science to services process. Activities will be aligned with other initiatives within WMO, as described in the partnerships section below.

Communication approaches (inreach, outreach) will include speaking directly to people, surveys, websites, social media, and so on. A phased approach will be used where some initial benchmarking assessment of communication needs, gaps, and opportunities will feed into a more expanded set of activities. Evaluation of the project will use the initial benchmark to track progress and impact.

### Desired outcomes

By considering some of the aforementioned issues, themes and questions, WMO members, various users and ‘people’ should gain better knowledge of various critical dimensions of weather, warnings, potential risks and impacts. By exploring various appropriate case studies, experiments, demonstration projects, and by eliciting feedback from the users of weather information, gaps between people and science development should be better understood and narrowed.

In most cases of the weather space, users are not usually consulted in the development and the creation of weather information. By employing a more co-designed approach with users as well as being mindful of local contexts and how these may enable or constrain weather information, the opportunity for the development of useful baselines and identification of gaps between ‘science’ and ‘society’ should emerge. As a result of this project, a more integrated and coherent sense of current use and uptake of WWRP science will be obtained that can then be used to guide future research foci and thrusts.

Finally, by including the co-development of products together with ‘people’ and social sciences, enhanced science measurements, assessments, methodologies and metrics may in turn enhance WWRP science. Engagement with a range of practitioners, educators, and other actors will spawn new and improved service areas and actions, as well as future science questions.

### Anticipated and/or needed partnerships

Partnerships with the other WWRP projects will be crucial to ensuring that appropriate outreach is conducted, communication strategies are developed, and communication and engagement science questions are identified and tackled. The SERA working group will have an important role to play in liaising with the project to ensure that it has effective social sciences inputs and programmatic elements.

* Engagement with SERCOM is important for finding areas of mutual and synergistic activity. In particular, the GMAS Action Plan, and the Standing Committee for Disaster Risk Reduction
* Interaction with WCRP and GAW will identify areas of possible fruitful collaboration
* Engagement with NMHSs, likely supported by Member Services, is important to understanding their needs for improving their own communication practices. Strong alignment with the GMAS team will be needed
* Engagement with ‘boundary’ or brokering agencies (for example agricultural extension services) would enhance communication to the public and enable feedback into the science.

### Estimated timeline:2023 to 2027

Year 1: Benchmarking

Years 2–5: Project activities

# Sub-seasonal applications for AGriculture and Environment (SAGE)

Motivation and link to WWRP IP 2024–2027 and WWRP drivers

Realizing the importance and need to predict high-impact weather events beyond the short range scale, the [Sub-seasonal to Seasonal Prediction Project (S2S)](http://s2sprediction.net/) was launched as a joint project of the World Climate Research Programme (WCRP) and the [WWRP](https://public.wmo.int/en/programmes/world-weather-research-programme) in November 2013 and will continue in 2023. S2S forecasts are increasingly gaining interest among users and are being utilized for decision-making in various sectors and services from agriculture, water resource management, public health to renewable energy. However, incorporating probabilistic S2S forecasts, which are more skilful, into existing decision-making operations is not a trivial matter. Therefore, to generate useful, usable and actionable forecast applications, there is a need to bridge the gap between the user requirement and their feedback, and science teams. Therefore, S2S prediction capabilities should be aimed at enhancing a physical science base for improved forecast development and promoting user interactions and engagements for product co-development. In order to systematically address this, the Sub-seasonal applications for AGriculture and Environment (SAGE) project is proposed with the main foci outlined below:

* To identify and address outstanding challenges in S2S prediction and enhance capacities to realize the potential predictability available in the system
* To identify processes, drivers and modelling strategies in advancing the S2S prediction particularly for extreme weather, and
* To support the application of S2S predictions in various sectors primarily in managing agriculture, water resources, health and renewable energy for enhancing and securing the necessities of life: SDGs, food security, energy and well-being.

These overarching objectives will be addressed under three themes, viz., science, science to services, and policymaking, in line with the primary goals of the WWRP Action Plan for 2024–2027.

### Scientific Questions to be addressed

Considering the need for revamping the S2S prediction of high-impact weather and its seamless application to agriculture, water and energy sector, the following science questions will be addressed in SAGE:

* How to prioritize important processes (teleconnections, physical parametrizations, coupled data assimilation, model resolution, initialization, biases, and so on) to get improved predictions?
* How to improve the skill with new observations and/or new strategy for incorporating observations?
* How S2S probabilistic products are being used, and what is the prospect of being used in untapped areas in decision-making for region-specific extreme conditions in various sectors particularly water, agriculture and energy?
* What are the major research advances and products that have not been adequately incorporated into the operational practices? How should we treat feedback from the industry to science teams?
* What is needed to communicate inherent uncertainty in the prediction and how do we facilitate users to interpret these uncertainties in their decision-making?
* How do we involve users in forecast verification, bias correction, calibration and uncertainty estimation for the optimization of S2S operational products?

### Desired outcomes

SAGE will seek to gain further understanding of predictability sources and teleconnections to predict extreme weather at the S2S scale. WMO Members will have better knowledge of region and season-specific skills, uncertainty and model biases (monsoons, ENSO, heat waves, cold waves, cyclones, and so on). With the active engagement of users, services and WWRP science, the co-developed tailored products and co-designed metrics will be available to evaluate the success of projects and services in agriculture and energy. SAGE will also aim to design and enhance the dissemination of S2S forecasts and their uncertainty, with the needed communication modes to users and producers. Through this project, managers of water resources, agriculture, food security and (renewable) energy will benefit from improved services.

### Anticipated and/or needed partnerships

* Close association with PCAPS and WWRP/WCRP International Monsoons Project Office activities
* Engagement with NMHSs, likely supported by Member Services, to understand their needs for improving their own communication practices. Strong alignment with the GMAS team will be needed
* Close collaboration of SAGE with the other WWRP projects’ working groups or expert teams, JWGFVR, PDEF, DAOS, SERA, TMR, HAP
* Partnerships between SAGE and the other WMO groups WCRP/ESMO and GEWEX, SERCOM/Standing Committee on Services for Agriculture (SC-AGR) and the Study Group of Integrated Energy Services (SG-ENE), and INFCOM/JET-EOSDE.

### Timeline estimate

This project will be launched in 2024 as a 5-year project, after the S2S project has ended.

## ANNEX B – Acronyms



|  |  |
| --- | --- |
| **ADVANCE** | Aiding Decision-making in Vulnerable Africa with Nowcasting of ConvEction |
| **AI** | Artificial Intelligence |
| **AI/ML** | Artificial Intelligence/Machine Learning |
| **AMSAF** | African Meteorological Satellite Applications Facility |
| **AvRDP** | Aviation Research Demonstration Project |
| **AWAR3E** | Advancing Weather Research to Reduce Risk to Societies |
| **ABL** | Atmospheric Boundary Layer |
| **DAOS** | Data Assimilation and Observing Systems |
| **EC-PHORS** | Executive Council Panel of Experts on Polar and High Mountain Observations, Research and Services |
| **ESM** | Earth System Modelling |
| **ESMO** | Earth System Modelling and Observations |
| **ET** | Expert Team |
| **ETR** | Education and Training |
| **EUMETSAT** | European Organization for the Exploitation of Meteorological Satellites |
| **EWSs** | Early Warning Systems |
| **FAIR** | Findable, Accessible, Interoperable and Reusable |
| **FDP** | Forecast Demonstration Project |
| **GANP** | Global Air Navigation Plan |
| **GAW** | Global Atmosphere Watch |
| **GDPFS** | Global Data Processing and Forecasting System |
| **GEO** | Geostationary |
| **GEWEX** | Global Energy and Water Cycle Experiment |
| **GFP** | Global Flood Partnership |
| **GMAS** | Global Multi-hazard Alert System |
| **GOS** | Global Observing System |
| **GURME-GAW** | Urban Research Meteorology and Environment/Global Atmosphere Watch |
| **HAP** | Hydrology and Precipitation |
| **HEPEX** | Hydrological Ensemble Prediction Experiment |
| **IAHS** | International Association of Hydrological Sciences |
| **IASOA** | International Arctic Systems for Observing the Atmosphere |
| **ICAO** | International Civil Aviation Organization |
| **INFCOM** | WMO Commission for Observation, Infrastructure and Information Systems |
| **IWTC-9** | Ninth International Workshop on Tropical Cyclones |
| **JET-ABO** | Joint Expert Team on Aircraft-based Observing Systems |
| **JET-EOSDE** | Joint Expert Team on Earth Observing System Design and Evolution |
| **JET-HYDMON** | Joint Expert Team on Hydrological Monitoring |
| **JET-OWR** | Joint Expert Team on Operational Weather Radars |
| **JWGFVR** | Joint Working Group on Forecast Verification Research |
| **LI** | Lightning Imager |
| **LDCs** | Least Developed Countries |
| **LTG3** | Long-Term Goal 3 |
| **MEL** | Monitoring, Evaluation and Learning |
| **MS** | Member Services |
| **MSG** | Meteosat Second Generation |
| **MTG** | Meteosat Third Generation |
| **NMHS** | National Meteorological and Hydrological Service |
| **NMR** | Nowcasting and Mesoscale Research |
| **NWC-SAF** | Nowcasting Satellite Application Facility |
| **NWP** | Numerical Weather Prediction |
| **PCAPS** | Polar Coupled Analysis and Prediction Services |
| **PDEF** | Predictability, Dynamics and Ensemble Forecasting |
| **PEOPLE** | Public Engagement fOr Practitioners, Learners, and Educators |
| **PPP** | Polar Prediction Project |
| **RA I** | Regional Association I |
| **RB** | Research Board |
| **RDP** | Research Demonstration Project |
| **RIfS** | Regional Information for Society |
| **RSMCs** | Regional Specialized Meteorological Centres |
| **S2S** | Sub-seasonal to Seasonal |
| **SAGE** | Sub-seasonal Applications for AGriculture and Environment |
| **SC-AGR** | Standing Committee on Services for Agriculture |
| **SC-AVI** | Standing Committee on Services for Aviation |
| **SC-DRR** | Standing Committee on Disaster Risk Reduction and Public Services |
| **SC-ESMP** | Standing Committee on Data Processing for Applied Earth System Modelling and Prediction |
| **SC-HYD** | Standing Committees on Hydrological Services |
| **SDGs** | Sustainable Development Goals |
| **SERA** | Societal and Economic Research Applications |
| **SERCOM** | Commission for Weather, Climate, Water and Related Environmental Services and Applications |
| **SG-ENE** | Study Group oN Integrated Energy Services |
| **SG-URB** | Study Group on Integrated Urban Services |
| **SIDS** | Small Island Developing States |
| **SSC** | Scientific Steering Committee |
| **SSUD** | Space Systems and Utilization Division |
| **TC** | Tropical Cyclone |
| **TC-PFP** | Tropical Cyclone Probabilistic Forecast Products |
| **THORPEX** | The Observing System Research and Predictability Experiment |
| **TMR** | Tropical Meteorology Research |
| **UAVs** | Unmanned Aerial Vehicles |
| **UNDRR** | United Nations Office for Disaster Risk Reduction |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **WCRP** | World Climate Research Programme |
| **WG** | Working Group |
| **WGNE** | Working Group on Numerical Experimentation |
| **WMO** | World Meteorological Organization |
| **WMO/Comms** | World Meteorological Organization/Communications Division |
| **WWRP** | World Weather Research Programme |
| **WxMOD** | Weather Modification |
| **YESS** | Young Earth System Scientists |
| **YOPP** | Year of Polar Prediction |
| **YOPPSiteMIP** | Year of Polar Prediction Site Model |

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1. <https://psl.noaa.gov/iasoa/home2> [↑](#footnote-ref-2)
2. <https://www.polarprediction.net/key-yopp-activities/yoppsitemip/> [↑](#footnote-ref-3)