BAMS
Meeting Summary

Enhancing the Value of Weather and Climate Services in Society

Identified Gaps and Needs as Outcomes of the First WMO WWRP/SERA Weather and Society Conference

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What: The Societal and Economics Research Application (SERA) Working Group of the World Meteorological Organization (WMO) World Weather Research Programme (WWRP) organized the first Weather and Society Conference, inviting the weather community to actively engage on critical themes to understand, analyze, and enhance the value of weather and climate services in society. The online conference ran over 2 weeks. Each session focused on a theme, ran for two hours, and included talks and discussion followed by a one-hour poster session.
When: 28 February to 11 March 2022
Where: Online

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Extreme hydrometeorological events are affecting societies, economies, and the environment. Governments, science agencies, the humanitarian sector, emergency managers, and decision-makers face continuing challenges to reduce the risks to citizens and society.

To address these challenges, the Societal and Economic Research Applications (SERA)[1] Working Group of the WMO World Weather Research Programme (WWRP),[2] in close collaboration with the German Weather Service (DWD), the Free University Berlin, and the Hans-Ertel-Centre for Weather Research (HErZ), held the first Weather and Society Conference (https://www.weatherandsociety.de) from 28 February to 11 March 2022. The online event focused on the science for services approach adopted by the WMO to understand, analyze, and enhance the value of weather and climate services in society.

The conference built on the former series of "Weather and Society Integrated Studies" workshops initiated in the United States which aimed to integrate social science into meteorological research and practice (Gruntfest 2017).

The objectives of the conference were to

- discuss and promote all aspects of social and economic research applications along the weather forecast value chain;
- bring people together from the operational meteorological and hydrological services, research, and forecast user communities; and
- identify gaps, needs, and challenges to reducing the risks to citizens and society.

[1] The WWRP Working Group on Societal and Economic Research Applications (SERA) aims to advance the science of the social and economic application of weather-related information and services through reviewing and assisting in the development and promotion of societal and economic-related demonstration projects. SERA has the responsibility for the entire range of time scales and research issues associated with the WWRP. The working group brings the knowledge of how to frame, design, and implement research projects co-designed between physical and social scientists and a range of appropriate actors to achieve more useful information for decision-makers and the public.

[2] The WMO World Weather Research Programme (WWRP) is advancing and promoting research activities on weather, its prediction, and its impact on society. The improvements in science and operational predictions are driven by international cooperation, and in turn, international cooperation in weather science is a unique opportunity to drive sustainable development. As the science is advancing, critical questions are arising such as the potential sources of predictability on weekly, monthly, and longer time scales; seamless prediction from minutes to months; optimal use of local and global observing systems; and the effective utilization of supercomputers. In addition, communication of forecasts, warnings, and their uncertainty, as well as some indication of the impacts of these warnings, raise new challenges for weather-related approaches for the full value chain.

The conference covered various topics in nine different sessions, ranging from impact-based forecasting and warning of extreme weather events to the use of weather

information for civil protection and humanitarian aid to the application of indigenous and local weather knowledge. Over 700 participants registered from 104 countries, while authors from over 40 countries took part in the talks, discussions, and poster sessions throughout the two weeks.

The COVID pandemic has challenged in-person participation in conferences over the last three years. The decision of an online conference allowed the engagement of a broader community and enabled the contribution and participation from across the globe.

Gaps and needs identified in the sessions

The First Mile of weather and climate warning. The concept of the First Mile of warnings is to involve people in the whole warning process and throughout the development and implementation of products and services. It explicitly avoids a top-down approach based on a one-way transfer that assumes that outside experts know better than the actual users of the services.

Gaps identified in this session included the need for improved two-way communication; better, more reliable, and well-maintained equipment; mitigating the potential harm of false alarms by providing information about the warning process and communication of uncertainty; and the value of including all players in the warning process.

The opportunities included combining formal and informal approaches for warnings and using inclusive communication across languages and cultures and word-based and non-word-based approaches, as well as impact-based warnings with other messages such as behavioral advice. Warnings need to combine technologies and communication with partnerships to account for the needs of users based on their requirements.

This leads to the main overarching opportunity to look beyond early warning systems (EWS) to all types of warnings. The social process of warning starts and ends with people and their day-to-day activities, not with a specific hazard or extreme event.

Value chain of early warning systems. This session addressed aspects of effective warning design and production viewed through the conceptual model of the value chain. It included relevant uses of the value chain concept and comparison to a value cycle approach, case study analysis of severe weather events, adaptation strategies, and seamless Earth system prediction. The value chain approach facilitates the understanding of the different relationships, processes, inputs, contributions, outcomes, and operational contexts of each stakeholder in the warning chain from observations to forecasts, warning dissemination and decision-making.

The warning value chain provided a cross-cutting analysis and exposed many of the gaps and issues discussed in greater detail in later sessions. First is the need to increase user engagement to ensure that those at risk are involved in designing the warning system and receive warnings suited to their different needs. Communication of uncertainty in warnings remains a difficult challenge, particularly when early action on a high-impact event is necessary while it is still low probability. The lack of evidence and data on warning response and avoided impacts constitutes a gap for warning evaluation. Such outcomes are very difficult to measure; new methods from social and physical science are needed to quantify missing links and bottlenecks in the information flow to assist warning performance evaluation.

Citizen science and observations. In this session the role and potential of citizen science to contribute grounded data for meteorological research and operations was explored. Contributions ranged from education and citizen science, social sensing via social media, inclusion of communities for risk reduction, bias in impact databases fed by citizens, and data from nonprivate actors.

The gaps identified for upcoming research were (i) the combination of unsolicited (e.g., crowdsourcing) with solicited data (e.g., higher degree of participation) within an open science framework; (ii) the validation of data from social media (e.g., impact data); (iii) the bidirectional information flow and mutual benefits between researchers and citizens; (iv) the added value of citizen science to weather services, the warning chain, and the verification of forecasts and warnings; and (v) the participation bias, i.e., the advantaging/disadvantaging of different groups and demographic profiles in society when collecting data using different methods (e.g., social media, smartphones, time, etc.). Each approach will attract different user groups and therefore be a biased representation of the social impact of an event.

The potential of citizen science and observations to contribute to the weather enterprise was well demonstrated in this session.

Indigenous and local weather knowledge. Indigenous and local weather knowledge are gaining salience in the agendas of policymakers, practitioners, and academia. Yet, these knowledge systems are rarely discussed by the hydrometeorological service community. The presentations in this session chiefly focused on the role and use of indigenous knowledge for addressing communities' needs to respond and adapt to climate change. Another topic presented was the importance of the co-production of knowledge.

The gaps identified by the session included (i) the mismatch between the spatial and temporal scales of national weather services and the perspectives of indigenous and local peoples; (ii) understanding the contexts of indigenous knowledge producers and how it shapes knowledge use and relevance; (iii) the impacts of changing rural and urban landscapes, accelerated climate change, increased severity and frequency of climatic variability; and (iv) the synergic impacts of interacting climatic and nonclimatic processes (e.g., economic, social) on vulnerability, exposure, and natural hazards.

In sum, the discussion highlighted the importance of understanding indigenous peoples' needs for weather information. This is particularly the case in the context of a changing climate and the value of knowledge co-production to address gaps and enhance Western science.

Understanding and advancing the communication and use of weather forecast uncertainty. This session focused on ways to improve understanding of how forecast uncertainty and risk information can be presented to help users to make informed decisions.

Research gaps were identified with respect to (i) the presentation of low probability for severe events to facilitate informed decisions; (ii) the understanding of the people and their behavior when interpreting uncertainty information; (iii) suitable communication methods, channels, and formats best suited to reach different user groups; (iv) methods and approaches to quantify people's understanding and perception of uncertainty; and (v) the institutional arrangements that facilitate the embedding of social science methods and approaches into forecasting and warning chains.

The session highlighted that research on and operational implementation of the communication of forecast uncertainty is topical across the globe. Sharing of best practices and transdisciplinary sociometeorological research efforts across hydrometeorological institutes is warranted.

Impact-based forecasting and warning of extreme weather events. The impact-based forecasting and warning (IbFW) of extreme weather events session demonstrated the breadth of work to develop and enhance IbFW across a range of countries. Despite advances, several research and implementation challenges were identified.

Research gaps included (i) different approaches to implementation and the benefits/disbenefits of them; (ii) the challenge of incorporating dynamic vulnerability and exposure into IbFW and what the term "dynamic" really means in the context of IbFW development; (iii) methods to collect qualitative and quantitative impact and social response data and its use for verification and user evaluation; and (iv) the need to improve understanding of compound events to provide a more holistic and cumulative view of potential impacts.

The developments in IbFW have broadened collaborations, and there is a strong desire and need for increased engagement with users which needs to be supported by integration of social science and new participatory methods. The multidisciplinary nature and broader scope of IbFW also requires institutional arrangements, roles, and responsibilities to be reviewed, to ensure progress and capacity for research and operational implementation.

Use of weather information for civil protection, emergency management, and humanitarian aid. This session focused on the importance of understanding the needs of key users of weather information, such as emergency managers and services, and the provision of effective science advice to provide a user-oriented service.

Collocation of weather services with key users, interagency and multidisciplinary working or advisory groups and embedding social scientists in weather services has been effective in several countries, as demonstrated in this conference session.

Research gaps included (i) how to incorporate social scientists and users directly into these groups and the challenges of such interorganizational partnerships, e.g., working through differences in culture and practices and establishing long-term relationships; (ii) the way in which sharing of uncertainty and probabilities relating to severe weather that has been found to be useful and necessary can be embedded in decision making processes; and (iii) the need to better understand broader contextual factors affecting key users such as environmental drivers, technology advancements, population changes, and the potential for new risk management and roles and responsibility frameworks to embed these requirements.

Estimating and improving the socioeconomic benefit of weather information. The "Weather and Climate Enterprise" exists to observe, model, forecast, and communicate data and information about weather, water, and climate for the benefit of society (Golding 2022). As this conference has demonstrated, the entire weather and climate information process has transformed into a full forecast value chain including the communication, reception, comprehension, use, and valuation of weather and climate information. Thus, estimating and improving the benefit for society requires a comprehensive understanding and joint implementation of the aspects covered throughout all sessions of this conference.

With respect to the actual valuation process, several research gaps were identified: (i) adequate delineation of the actual value chain to be accessed to support efficient choice of method; (ii) the need to identify standardized/universal valuation approaches to foster user-friendly replicability of approaches and portability of results; and (iii) the valuation of nonmonetized/societal benefits of weather and climate information, e.g., to include social and environmental aspects that benefit society.

The broad range of contributions and participants also identified opportunities including (i) the co-design of valuation approaches through inclusion of users as experts in their field, not only in the development and deployment of services, but also in the valuation process and (ii) the provision of standardized tools and universal valuation approaches to the service providers that can enable them to receive evidence on the effectiveness of their services for users and to tackle the matching gaps between services provided and needed.

The Last Mile challenges of seamless weather and climate information. This session addressed the challenges of providing seamless predictions across different time and space scales; data collection systems, including novel methodologies for crowdsourcing data; and models. Despite the multiple technical challenges, the session focused on the needs of users, stakeholders, and decision-makers for information that is continuous and consistent despite the different sources from which the information is generated.

The session was an opportunity to gather both weather and climate services communities which brought multiple perspectives on what is understood as seamless information and highlighted the need for a broad and consensual definition that is promoted within both communities. Diverse talks pointed to how developing effective seamless climate services requires an exploration of how decision and planning time scales map onto weather and climate time scales at the outset; this calls for further research besides additional efforts to elicit critical decision thresholds from the users. There are still research gaps on understanding the barriers and enablers to accessing and utilizing information. These barriers may occur at different regional and temporal scales and acknowledging and understanding them is key to develop services that address end-user needs. Finally, the need for forming and mapping networks of users and providers—the information ecosystem—was deemed critical to build and develop seamless information services that can meet cross-sectoral needs. Further efforts on seamless approaches developed with and for users are essential to improve the relevance, quality, and impact of knowledge and services.

Cross-cutting issues

The conference created an environment for a rich discussion about research gaps and needs which can help to inform future research agendas, prioritization, and resource allocation.

The diversity of research gaps across the nine sessions have been grouped into five broad categories (Table 1).

- The need for inclusive user engagement and co-production of knowledge was almost universally identified as being of importance.
- Integration of social and physical sciences remains a challenge and the need for improved collaboration between the different disciplines was identified.
- Improved communication and information flow along the value chain was seen to be a significant gap which includes the estimation, communication, and use of uncertainty information.
- The lack of evidence, knowledge, and data, particularly of indigenous and local knowledge is apparent, and this impedes the effectiveness of the warning process.
- Finally, the need for evaluation and user-oriented verification remains a pressing issue and is critical to demonstrating the benefits of weather services and to ensuring continuous improvement.

Conclusions

The conference was successful in building a rich and diverse science program with contributions from a range of regions and disciplines. A number of research gaps were identified and, while this list needs further validation, it provides an important foundation for discussions about future directions. We advocate for expanding the use of integrated weather and society approaches to help fill in these gaps. The conference's online format enabled people from across the globe to contribute and participate. An in-person conference in alternating years should consider hybrid formats and could include tutorial workshops to strengthen the capacity of national hydrometeorological officers and other practitioners. These workshops have proved

Table 1. Common gaps and needs identified across the sessions.

Session	Gaps/Needs				
	Improving communication/ information flow	Inclusion/user engagement/ co-production	Lack of data, knowledge, evidence and uncertainty information	Social/ physical science collab.	Data evaluation/ methodology
The First Mile of weather and climate warning	X	X	X	X	X
Value chain of EWS	X	X	X	X	
Citizen science and observations	X	X	X		X
Indigenous and local weather knowledge		X	X		
Understanding and advancing the communication and use of weather forecast uncertainty	X	X	X	X	X
Impact-based forecasting and warning of extreme weather events		X	X	X	X
Use of weather information for civil protection, emergency management, and humanitarian aid	X	X		X	
Estimating and improving the socioeconomic benefit of weather information		X		X	X
The Last Mile challenges of seamless weather and climate information		X	X		X

to be successful in other contexts (e.g., verification methods workshops) and would enhance and enable progress and pull-through of science into operational society-centered services.

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