BAMS In Box

Tailored Investments Needed to Support Weather, Water, Ice, and Climate Services in the Polar Regions

Machiel Lamers, Gita Ljubicic, Rick Thoman, Jorge Carrasco, Jackie Dawson, Victoria J. Heinrich, Jelmer Jeuring, Daniela Liggett, and Emma J. Stewart

KEYWORDS:
Social Science;
Antarctica;
Arctic

ABSTRACT: The Polar Prediction Project (PPP), one of the flagship programs of the World Meteorological Organization's (WMO) World Weather Research Programme (WWRP), has come to an end after a decade of intensive and coordinated international observing, modeling, verification, user engagement, and education activities. While PPP facilitated many advancements in modeling and forecasting, critical investment is now required to turn prediction science into salient environmental services for the polar regions. In this commentary, the members of the Societal and Economic Research and Applications task team of PPP, a group of social scientists and service delivery specialists, identify a number of insights and lessons that are critical for the implementation of the follow-up program Polar Coupled Analysis and Prediction for Services (PCAPS). We argue that in order to raise the societal value of polar environmental services, we need to better understand the diversity of highly specific user contexts; to tailor the actionability of weather, water, ice, and climate (WWIC) service development in the polar regions through inclusive transdisciplinary approaches to coproduction; to assess the societal impact of improved environmental services in the polar regions; and to invest and provide dedicated funding for involving the social sciences in research and tailoring processes across all the polar regions.

https://doi.org/10.1175/BAMS-D-23-0159.1
Corresponding author: Machiel Lamers, machiel.lamers@wur.nl
In final form 3 February 2024

AFFILIATIONS: Lamers—Wageningen University and Research, Wageningen, Netherlands; **Ljubicic**—McMasters University, Hamilton, Ontario, Canada; **Thoman**—University of Alaska Fairbanks, Fairbanks, Alaska; **Carrasco**—Universidad de Magallanes, Punta Arenas, Chile; **Dawson**—University of Ottawa, Ottawa, Ontario, Canada; **Heinrich**—University of Tasmania, Hobart, Tasmania, Australia; **Jeuring**—Norwegian Meteorological Institute, Bergen, Norway; **Liggett**—University of Canterbury, Christchurch, New Zealand; **Stewart**—Lincoln University, Lincoln, New Zealand

The polar regions are at the forefront of the impacts of global climate change (Stuecker et al. 2018) and are facing a wide range of challenges, including rapidly changing environmental conditions and increasing human activities, such as science, tourism, and shipping. At the same time, these regions have limited infrastructure and rescue services, which signals concern about the associated human and environmental risks (Meredith et al. 2019; Wagner et al. 2020). In response to such concerns, an increasing number of scientists, Indigenous community members, industry, and government stakeholders have advocated over the last decade for improvements to polar weather, marine, and sea ice forecasts to support navigation needs and decision-making for safer aerial, marine, and terrestrial operations (Stewart et al. 2020). Advancements in environmental science and services are typically suggested as key actions to reduce hazard impacts and enhance human and environmental safety (Eicken 2013).

Seeking to address calls for improved polar forecasting services, the World Meteorological Organization (WMO) established the decade-long Polar Prediction Project (PPP) (2013–23). PPP was aimed at promoting cooperative international research to improve weather and environmental prediction services for the Arctic and Antarctic regions (Jung et al. 2016). Research during PPP centered on the Year of Polar Prediction (YOPP) (2017–22), an intensive period of coordinated international activities around observing, modeling, verification, user engagement, and education. As members of the Polar Prediction Project's Societal and Economic Research and Applications (PPP-SERA) Task Team, our role as social scientists and service delivery specialists has been to contribute to a more nuanced understanding of the diverse needs among key users of polar environmental forecasts, as well as to showcase the need for transdisciplinary collaborations and coproduction approaches to ensure long-term societal benefits from improved environmental forecasting abilities.

Now, at the end of the PPP, and as we are moving toward the new Polar Coupled Analysis and Prediction for Services (PCAPS) program, we are reflecting on PPP's achievements in terms of innovations in matching forecasts and services to user needs and on challenges that lie ahead for ensuring that scientific advances translate into salient services. Four key messages stand out:

1) We need to better understand user needs in a diversity of highly specific user contexts.
2) Tailoring actionable weather, water, ice, and climate (WWIC) services for user groups in the polar regions requires inclusive transdisciplinary approaches to coproduction.
3) New or enhanced environmental services generate intended, as well as unintended, societal impacts in the polar regions, which we need to assess.
4) Investments and dedicated funding are needed to involve the social sciences in research and tailoring processes across all the polar regions.

Some of these lessons are common and known to the international weather and climate services literature (e.g., Alexander and Dessai 2019), while others are specific for, or amplified in, polar contexts. In the remainder of this article we argue that these lessons from PPP for tailoring services to user needs should be central to the current PCAPS program and other future research programs on environmental information service development for the polar regions.

Understanding specific user contexts in the polar regions

The conventional approach to producing and delivering WWIC information was established in the early to mid-twentieth century and is still largely followed in the polar regions today. This typically involves providing limited and generalized information, focused on very few meteorological parameters and observations, at discrete intervals, which are for many users not fit for purpose. We argue that the scope of users traditionally considered in polar prediction is too narrow (Stewart et al. 2020). The "one size fits all" approach is particularly unhelpful in the current context of highly diverse users and their specific user requirements in the polar regions.

User groups include cargo shipping and cruise tourism (from small to large vessels), fishing, offshore sectors, aviation, science logistics, military activities, and search and rescue operations, as well as local and Indigenous communities. User groups in the polar regions are relatively small compared to more temperate or tropical regions. The risks polar operators manage and the way they relate to different and extreme environmental conditions, at various temporal and geographic scales, are very context specific. For example, while some maritime sectors, such as Indigenous hunters, resupply ships or expedition cruises, may be actively looking for sea ice, others will be avoiding it (Wagner et al. 2020). Public–private partitioning of WWIC products and services, common in more populous regions, is based on economies of scale, and supported by existing large investments in observational and forecasting capacity. In the polar regions this is not feasible (except for a small number of specific sectors paying for specialized forecasts), which leads to an uneven playing field in terms of service provision. Specialized services require funding or may be developed by commercial actors, which are accessible or affordable for some user groups (e.g., larger-scale commercial or government operations), but not for others (e.g., small-scale fishing or tourism operations, local Indigenous mobilities) (Haavisto et al. 2020). Furthermore, the increased societal sensitivity of historically underrepresented or marginalized groups has exposed inadequacies and provided justification for the importance of tailoring WWIC services to address societal needs.

Challenges to the availability, accessibility, and usability of WWIC services in the polar regions are amplified by a number of factors. Routine and regular weather observations are far sparser in polar regions than at lower latitudes. Locations or types of weather observations that do exist are typically supporting one specific sector (e.g., aviation) and may not be appropriate for other uses. Both providers and users face challenges relating to unreliable telecommunication systems, reduced Internet bandwidth, and fewer options for communication, which represent critical barriers to providing and accessing environmental forecasts and real-time weather information. Users in the polar regions require particular WWIC forecasts, such as sea ice and wind, which may not be available due to lack of observations, skill, or proprietary considerations. In the polar regions, the widespread use and preference for freely available, commercial applications, like Windy.com, vividly illustrates the importance of intuitive visualizations usable at low bandwidth (Blair et al. 2022a). However, diverse users, such as Inuit hunters, fishing vessel captains, and tourism operators, may not always be aware of the inherent uncertainties in forecast products (Jeuring et al. 2020). Available forecast products may be difficult to interpret due to language barriers, technical terminology, or incongruities with tacit or traditional knowledge systems, particularly in the case of Indigenous communities (Simonee et al. 2021).

All in all, the risks of living and working in cold and isolated polar environments are greater than in more temperate areas due to limited emergency response capabilities and more high-impact weather conditions (Blair et al. 2022b; Fox et al. 2023). In these more extreme environments, decision-making of most polar WWIC user groups is strongly based on lived experience and risk mitigation (Lamers et al. 2018; Simonee et al. 2021). WWIC products and services will never replace the need for lived experience, but they are a critical additional information component to support the planning of voyages or the anticipation of risks.

Evaluating and tailoring services toward greater actionability

International cooperation, such as through PPP, have yielded (hemispheric to global) prediction improvements, but tailoring forecasts to user needs and producing actionable services is highly context and scale dependent. International literature on climate services suggests that tailoring WWIC products to the evolving needs and decision contexts of specific user groups requires targeted evaluations of existing services, as well as genuine and long-term collaboration between different scientific disciplines, providers, and the societal actors involved (e.g., Alexander and Dessai 2019; Vaughan and Dessai 2014). Different user groups require focused attention from researchers and service providers to tailor WWIC information and forecast products to their unique needs and requirements, including consideration of use, risk tolerances, specific parameters, spatial and temporal scales, frequency, accuracy, and visual representation. Useable and effective service development requires closer involvement of social science methods and approaches, with a focus on understanding behavioral aspects, institutional links, ethical implications, and acknowledgment of diverse knowledge systems (Findlater et al. 2021; Kettle et al. 2020), all of which support the articulation of the diverse information needs and contexts of polar users and sectors.

The remote locations and mobile character of polar maritime users and Indigenous communities makes processes of evaluating, tailoring, and coproduction services here more costly than elsewhere in the world. Nevertheless, recent research suggests that user-focused improvements to the ways that existing WWIC information is made available could rapidly increase user uptake of that information in polar contexts (Blair et al. 2022a). Communication and service development should be seen as a worthwhile, high-payoff investment in itself. By working together, transdisciplinary research teams can strengthen knowledge-sharing and communications across the user–producer interface and inform tailored development, representation, and distribution of accessible and useable WWIC products and services.

Assessing the societal impacts of new environmental services

Next to evaluating and tailoring the usability of WWIC services for specific user groups, new and enhanced services also generate wider societal impacts with largely unknown implications. Innovations in WWIC services in the polar regions are driven by developments in modeling and prediction techniques, commercial service providers (Haavisto et al. 2020), improved Earth observation satellite systems, such as the EU Copernicus program (Gabarró et al. 2023), the introduction of new communication satellite systems (e.g., Starlink), machine learning and artificial intelligence (AI) (Dewitte et al. 2021), or the integration of weather warnings or forecasts in e-navigation platforms. Such technological advances may be surrounded with societal expectations, including risk reduction for polar operators and communities, safe and sustainable decision-making, and the empowerment of marginalized communities through information services. In reality they may also generate or emphasize societal challenges, including growing informational inequity and disenfranchisement of remote communities, the promotion of unsustainable sectors, or the creation of an illusion of safety resulting from improved forecast services (Haavisto et al. 2020; Lamers et al. 2018). For example, environmental information services may play an important role in the current emphasis in the polar and global shipping sector toward safety, decarbonization, and reducing emissions and fuel use efficiency. However, such services may also increase opportunities for environmentally unsustainable economic activities, such as extractive industries or other activities not governed properly. Research on broader societal impacts also includes analyzing the political and legal economy of information delivery, including forms of private provision or public–private provision (Haavisto et al. 2020).

The wider societal impacts of enhanced WWIC services in the polar regions are currently neither well understood nor systematically analyzed. A substantial transdisciplinary research effort is needed to address these societal impacts. Key questions include:

- What difference can emerging technologies bring to the provision of accurate environmental services on high-impact conditions for societal actors in the polar regions?
- To what extent do improved environmental services contribute to sustainable development in the Arctic region and environmental conservation in the Antarctic?
- To what extent do improved environmental services contribute to the reduction of risk for operators in the polar regions?
- How can environmental services contribute to equity and empowerment in relation to respecting and supporting Indigenous self-determination in research and Indigenous governance systems?

Tailoring investments for science to services translations

We observe a disconnect between the investments made in polar science and technology, including environmental observing and modeling capabilities, and the ability to meet diverse user needs. Researchers and service providers must consider the diversity of users of environmental observations and forecasts, their different expertise in utilizing forecasts, and wide-ranging requirements regarding spatial and temporal scales. To build on PPP, we call for a dedicated interdisciplinary research program that focuses on WWIC information service development, a program in which user needs drive the research priorities and that critically looks into the societal benefits and challenges resulting from innovations in science and technology.

If model improvements are to benefit the intended users, social and communication sciences need a “seat at the table” to work in close partnership at all stages with the modeling and forecasting community. This must be facilitated by proportional investments of funding, resources, and expertise. Social scientists can play a crucial role in engaging with users to understand their needs, evaluating service quality, embedding user needs and service provision in governance and policy frameworks, and contributing to product development by enhancing decision quality, trust, usability, risk communication and mitigation, managing uncertainty, and providing insights into cognitive and behavioral processes of information use. Through established relationships with user groups, social scientists can also create opportunities for direct engagement between users and WWIC service providers to enhance cultural awareness and mutual understanding.

The legacy of YOPP and the PPP will be evaluated based on scientific advancements as well as on the successful translation of science into services and their societal impact. However, as we have argued, the path from science to service is not straightforward, easy, or generalizable. The PCAPS program provides an excellent opportunity for ensuring that previous investments in polar prediction science translates into salient services, user value, and greater societal benefits. To achieve the envisioned societal benefits of improved polar prediction, we need continued investment in social science involvement and transdisciplinary approaches to guide the development and provision of salient WWIC services.

Acknowledgments. We are grateful to the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO) and the International Coordination Office (ICO) of the Polar Prediction Project, at the Alfred Wegener Institute (AWI), for the opportunity to form the PPP-SERA task group and the logistical support over the last eight years (2015–23).

References

Alexander, M., and S. Dessai, 2019: What can climate services learn from the broader services literature? *Climatic Change*, **157**, 133–149, https://doi.org/10.1007/s10584-019-02388-8.

Blair, B., A. M. Gierisch, J. Jeuring, S. M. Olsen, and M. Lamers, 2022a: Mind the gap! A consensus analysis of users and producers on trust in new sea ice information products. *Climate Serv.*, **28**, 100323, https://doi.org/10.1016/j.cliser.2022.100323.

——, M. Müller, C. Palerme, R. Blair, D. Crookall, M. Knol-Kauffman, and M. Lamers, 2022b: Coproducing sea ice predictions with stakeholders using simulation. *Wea. Climate Soc.*, **14**, 399–413, https://doi.org/10.1175/WCAS-D-21-0048.1.

Dewitte, S., J. P. Cornelis, R. Müller, and A. Munteanu, 2021: Artificial intelligence revolutionises weather forecast, climate monitoring and decadal prediction. *Remote Sens.*, **13**, 3209, https://doi.org/10.3390/rs13163209.

Eicken, H., 2013: Arctic sea ice needs better forecasts. *Nature*, **497**, 431–433, https://doi.org/10.1038/497431a.

Findlater, K., S. Webber, M. Kandlikar, and S. Donner, 2021: Climate services promise better decisions but mainly focus on better data. *Nat. Climate Change*, **11**, 731–737, https://doi.org/10.1038/s41558-021-01125-3.

Fox, S., A. Crawford, M. McCrystall, J. Stroeve, J. Lukovich, N. Loeb, J. Natanine, and M. Serreze, 2023: Extreme Arctic weather and community impacts in Nunavut: A case study of one winter's storms and lessons for local climate change preparedness. *Wea. Climate Soc.*, **15**, 881–892, https://doi.org/10.1175/WCAS-D-23-0006.1.

Gabarró, C., and Coauthors, 2023: Improving satellite-based monitoring of the polar regions: Identification of research and capacity gaps. *Front. Remote Sens.*, **4**, 952091, https://doi.org/10.3389/frsen.2023.952091.

Haavisto, R., M. Lamers, R. Thoman, D. Liggett, J. Carrasco, J. Dawson, G. Ljubicic, and E. Stewart, 2020: Mapping weather, water, ice and climate (WWIC) information providers in polar regions: Who are they and who do they serve? *Polar Geogr.*, **43**, 120–138, https://doi.org/10.1080/1088937X.2019.1707320.

Jeuring, J., M. Knol-Kauffman, and A. Sivle, 2020: Toward valuable weather and sea-ice services for the marine Arctic: Exploring user–producer interfaces of the Norwegian Meteorological Institute. *Polar Geogr.*, **43**, 139–159, https://doi.org/10.1080/1088937X.2019.1679270.

Jung, T., and Coauthors, 2016: Advancing polar prediction capabilities on daily to seasonal time scales. *Bull. Amer. Meteor. Soc.*, **97**, 1631–1647, https://doi.org/10.1175/BAMS-D-14-00246.1.

Kettle, N. P., D. Abdel-Fattah, A. R. Mahoney, H. Eicken, L. W. Brigham, and J. Jones, 2020: Linking Arctic system science research to decision maker needs: Co-producing sea ice decision support tools in Utqiaġvik, Alaska. *Polar Geogr.*, **43**, 206–222, https://doi.org/10.1080/1088937X.2019.1707318.

Lamers, M., P. Duske, and L. van Bets, 2018: Understanding user needs: A practice-based approach to exploring the role of weather and sea ice services in European Arctic expedition cruising. *Polar Geogr.*, **41**, 262–278, https://doi.org/10.1080/1088937X.2018.1513959.

Meredith, M., and Coauthors, 2019: Polar regions. *The Ocean and Cryosphere in a Changing Climate*, H.-O. Pörtner et al., Eds., Cambridge University Press, 203–320, https://doi.org/10.1017/9781009157964.005.

Simonee, N., J. Alooloo, N. A. Carter, G. Ljubicic, and J. Dawson, 2021: Sila Qanuippa? (How's the weather?): Integrating inuit qaujimajatuqangit and environmental forecasting products to support travel safety around Pond Inlet, Nunavut, in a changing climate. *Wea. Climate Soc.*, **13**, 933–962, https://doi.org/10.1175/WCAS-D-20-0174.1.

Stewart, E. J., D. Liggett, M. Lamers, G. Ljubicic, J. Dawson, R. Thoman, R. Haavisto, and J. Carrasco, 2020: Characterizing polar mobilities to understand the role of weather, water, ice and climate (WWIC) information. *Polar Geogr.*, **43**, 95–119, https://doi.org/10.1080/1088937X.2019.1707319.

Stuecker, M. F., and Coauthors, 2018: Polar amplification dominated by local forcing and feedbacks. *Nat. Climate Change*, **8**, 1076–1081, https://doi.org/10.1038/s41558-018-0339-y.

Vaughan, C., and S. Dessai, 2014: Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdiscip. Rev.: Climate Change*, **5**, 587–603, https://doi.org/10.1002/wcc.290.

Wagner, P. M., and Coauthors, 2020: Sea-ice information and forecast needs for industry maritime stakeholders. *Polar Geogr.*, **43**, 160–187, https://doi.org/10.1080/1088937X.2020.1766592.