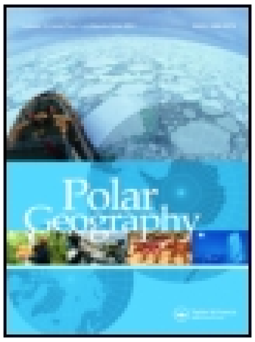

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Toward valuable weather and sea-ice services for the marine Arctic: exploring user–producer interfaces of the Norwegian Meteorological Institute

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ABSTRACT

Recognition is growing that valuable weather, water, ice and climate (WWIC) services for marine, Arctic environments can only be produced in close dialogue with its actual users. This denotes an acknowledgement that knowing how users incorporate WWIC information in their activities should be considered throughout the information value chain. Notions like co-production and user engagement are current terms to grapple with user needs, but little is known about how such concepts are operationalized in the practical context of tasks and responsibilities of National Meteorological and Hydrometeorological Services (NMHS). Based on a series of in-depth, qualitative interviews with a diversity of personnel from the Norwegian Meteorological Institute, we describe the shifting dynamics of interactions between WWIC information providers and maritime stakeholders operating in Arctic environments. Three key challenges are discussed, pertaining to both day-to-day and strategic interactions: (1) the importance of knowing how information is used, (2) the increasing automation of meteorological practices and the growing need for user observations, and (3) the need for bridging research-to-operations gaps. We embed these findings in a discussion on how user–producer interfaces are shaped and transforming through an ongoing negotiation of expertise, changing the roles and responsibilities within particular constellations of co-producing WWIC information services.

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WWIC information services; maritime Arctic; co-production; expertise; servitization; user–producer interactions

Introduction

The marine Arctic is becoming more and more accessible to a wider range of users, including those involved in fisheries, marine tourism and shipping activities. The highly dynamic environments in which these actors operate call for a development of valuable weather, water, ice and climate information (WWIC) services (Dawson et al., 2017; Knol et al., 2018; Lamers, Duske, & van Bets, 2018). It is broadly acknowledged that user engagement is crucial for the development of such services (Hoke, Werner, Goessling, & Jung, 2018). For example, in YOPP (Year of Polar Prediction) it is argued that it is vital to ‘better

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understand what really matters at the end of the forecast chain to those operating in Polar Regions' (Gößling, 2017). Hence, research and development in meteorology and related fields increasingly build on the idea that involving users in a 'co-production' process is a prerequisite for more meaningful services (Bremer & Meisch, 2017).

This recognition goes hand-in-hand with the increasing 'servitization' (Harjanne, 2017) of meteorology from a science that mostly produces and broadcasts data, to a service that informs and advises societal actors. Knowing how users incorporate weather and sea-ice information in their activities should thus be considered throughout the information value chain (Figure 1) (Dawson et al., 2017). This paper explores the dynamics of user–producer interfaces around WWIC information services from the perspective of National Meteorological and Hydrometeorological Services (NMHSs), in the context of the marine Arctic. In doing so, it explores shifting modes and challenges of interactions between 'users' and 'producers' of WWIC information services, from the perspective of the Norwegian Meteorological Institute (MET Norway).

Focusing on how user–producer interactions materialize in an Arctic context is highly relevant, given the growing interest in maritime mobilities in/through the Arctic (Lasserre, 2015; Smith & Stephenson, 2013). This interest is sparked by the effects of human-induced climate change, with the reduction in sea-ice extent as a prominent feature (Jung et al., 2016; Stephenson & Smith, 2015). The Arctic is warming twice as fast as the global average (AMAP, 2017) and some areas might warm up even more dramatically than previously expected. A recent report warns that, in a worst-case scenario, Svalbard could be warming up by 10 degrees towards the end of the century (Hanssen-Bauer et al., 2019). Shipping activity has increased in most parts of the Arctic through the past decade and will grow further. For example, Svalbard has seen an increase in cruise passengers from approximately 25,000 in 2011 to 41,000 in 2016 (Statistics Norway, 2016). Fisheries are also moving northwards due to migrating fish stocks that respond to higher water temperatures (Frainer et al., 2017; Kortsch et al., 2012). Although the extent to which fisheries are moving towards the ice edge is dependent on their economic viability (Misund et al., 2016), early patterns of increased fishing activity in the high North are already becoming visible (Carlowicz, 2018).

While there is growing attention for user–producer interactions around WWIC services (Dawson et al., 2017) the 'producer perspective' has often remained overlooked. Yet, the highly technological and increasingly automated working environment of present-day staff

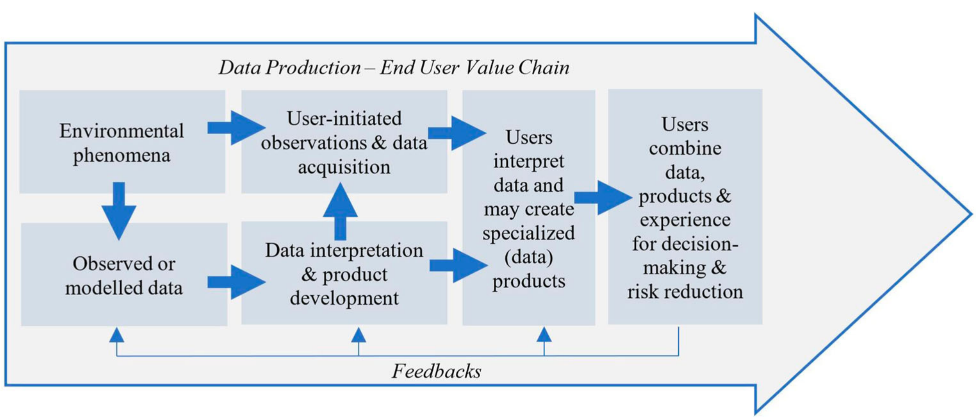

Figure 1. Components of the information value chain.

of NMHSs, from researchers to operational forecasters, strongly influences how relationships between public meteorological institutes and their marine end-users are instigated and maintained.

Based on a series of qualitative interviews with personnel from MET Norway, the paper reflects on the characteristics of such interfaces and describes the driving forces behind the meaningful collaboration of NMHS personnel (research, management and operational staff) and their users to achieve a common goal in a process through which a service gains value. The remainder of the paper is organized as follows. The background section provides the theoretical and practical context of the study, after which the methods section lays out the research process. Then, based on three interrelated challenges that emerged from the interviews, the findings are tied up in a discussion of implications for user–producer interactions and practices of service development around WWIC information in the Arctic. The paper concludes by formulating themes for follow-up research.

Background

Negotiating expertise in user–producer interactions

Ever since Robert Fitzroy was appointed to lead the precursor of the current UK Met Office in 1854 (Moore, 2015), public meteorological institutes have been an authoritative source for weather and climate information – despite at the same time being exposed to never-ending evaluations across all levels of society, ranging from political critiques to social ridicule. Indeed, the weather is everyone's business. Since its inception, the meteorological discipline has therefore been a science with close connections to society (Hunt, 2013). For example, the Norwegian meteorologist Vilhelm Bjerknes, one of the founders of modern weather forecasting, arranged meetings with fishermen in 1930 (Grønås, 2017). Meteorologists' role as experts in understanding the complexities of the atmosphere and the ocean, and their responsibility to provide information about past, current and future metocean conditions to lay users is strongly embedded in the working culture of public meteorological institutes. This authoritative role, however, implies what Daipha calls a problem of expertise: meteorological institutes 'must maintain an epistemic asymmetry between lay persons and themselves in order to appear credible' (Daipha, 2015, p. 169). This asymmetry, however, must dissolve in order to build meaningful relations between users and producers and provide useful advice, but in order to do so, it is necessary to appear credible. For the marine sector though, and likewise for sectors such as aviation and agriculture, a clear-cut division between lay and expert knowledge is difficult to make, as they are strongly depending on and entangled in the dynamics of metocean conditions (Kuonen, Conway, & Strub, 2019). This condition of expertise calls into question the ways meteorological institutes define their various maritime audiences, and how expertise is assumed to be distributed among different groups of maritime users (for example, recreational boaters, expedition cruise operators, fisheries and cargo shipping).

Daipha (2015) continues by discerning three types of users: the general public (citizens and any other user of the freely available meteorological information), customers (who pay for tailored services as agreed in commercial contracts) and partners (governmental institutes and public service suppliers). While the general public often tends to be qualified as lay users, the customers and partners are often acknowledged for possessing a level of meteorological expertise that makes them more proficient in understanding and, therefore, using meteorological information. How marine stakeholders, and the diversity within this group, are perceived in terms of 'publics' can provide a helpful perspective for understanding interactions with these stakeholders and getting insight in the implications for tailoring services to their needs. It can, for example, be argued that marine stakeholders, (including the ones not using paid services) do not fall under the 'general public' of meteorological institutes, as their activities and operational environment are considerably challenging and exposed to metocean conditions, which requires a level of expertise well beyond that of a lay user (Lamers, Duske, et al., 2018). Moreover, their cumulative weather knowledge and their skills of *being in* the weather (Ingold, 2007) arguably might require, or facilitate, a user–producer interface that allows for a more symmetric user–producer relationship that is based on mutually acknowledged expertise. While there is some evidence that such a relationship exists in certain specific local settings (Daipha, 2015; Fulsås, 2007), there has been little research on how expertise on WWIC information is negotiated within user–producer interactions in the maritime Arctic. It is therefore not well understood which challenges might be faced in establishing and maintaining these interactions, and what the implications are of assumptions of expertise for providing WWIC information to different maritime Arctic stakeholders.

Shifting roles in the weather enterprise

Increased interactions between environment and society, resulting from a combination of climatic change and growing socio-economic activity, lead to higher exposure to weather-related hazards and therefore increased vulnerability of both societal stakeholders and the natural environment (Fagan-Watson & Burchell, 2016; Holling, 2001). At the same time, ongoing technological developments in the weather and climate enterprise are taking place, resulting in increased forecast lead times, observations and models at ever higher resolutions, while new communication technologies facilitate the dissemination of and access to weather and climate information on a virtually individual level. Furthermore, public meteorological institutes in most areas do no longer have a monopoly on meteorological knowledge: weather forecasting, and disseminating weather information in particular, has truly become a global 'enterprise' (Thorpe, 2016) of public and commercial organizations, with tailored meteorological information viewed as an economic commodity (Lazo, Morss, & Demuth, 2009). Public meteorological institutes, therefore, face challenges on both organizational and individual levels in terms of prioritizing and framing responsibilities vis-à-vis societal demands, for developing and providing their services.

In attempts toward increased efficiency and service value, NMHSs are motivated to bridge 'research to operations' gaps (R2O) (Serafin, MacDonald, & Gall, 2002), which pertain to a limited uptake of research findings into operational products. Factors increasing R2O gaps that have been identified include a lack of continuous funding, limited communications between research and operational departments or lack of skills to use novel products (Brooks, 2013). Furthermore, interpreting and translating scientific data into information that is valuable for the various audiences of public meteorological institutes has always been a primary task. From a service perspective, however, straightforward provisioning of high-quality information does not suffice and increasingly operational tasks also include providing behavioral advice or, more formally, Decision Support Services (DSS) (Hewitt & Macleod, 2017; Zulkafli et al., 2017). The work of public meteorological institutes has therefore become even more embedded within societal dynamics, as the links throughout the value chain between research, production, operational services and the use of WWIC services are increasingly tight, interdependent and non-linear.

As a result, a distinction between roles of producers and users of weather and climate services becomes rather blurred and contingent on the specific contextual factors shaping up the 'servicescape' (Alexander & Dessai, 2019) of various types of user–producer interaction. For example, operational forecasters do not just produce forecasts, they are users of products and knowledge spilling over from the research departments. Similarly, even researchers take on user roles, as they receive feedback from end-users when collaborating in research projects, and from operational colleagues when discussing how their workflow can be improved. The multiplicity of roles that signifies co-production might complicate the relationships between public meteorological institutes and their different audiences; responsibilities may not always be clear (Jeuring & Becken, 2013), and expectations can be unrealistic. At the same time, a wider variety of interactions is necessary to cope with the complex, interdependent reality of the contemporary weather and climate enterprise.

Even though meteorology has been described as a discipline with very close connections to society, that has always been dependent on user feedback (Fulsås, 2003; Hunt, 2013), co-production and user involvement have in the context of developing WWIC information services only recently received more explicit attention in Arctic contexts (Dawson et al., 2017). The value of co-producing weather and climate services has been conceptualized along various overlapping and interacting criteria. For example, high-quality services are salient, credible and legitimate (Bremer et al., 2019), or actionable and relatable to those involved (Daipha, 2015). Similarly, valuable DSS ideally provide useful, usable and exchangeable information (Dilling & Lemos, 2011; McNie, 2012; Zulkafli et al., 2017). However, to date, conceptualizations of co-production in relation to WWIC services often remain undefined and undertheorized (Bremer & Meisch, 2017). For example, what constitutes co-production and how co-production will be assessed varies depending on which 'lenses' (Bremer et al., 2019) are employed to look at the process. While ongoing scholarly debates and research will advance theories of co-production and quality assessments, there is also a need to connect these debates with practical servicescapes (Alexander & Dessai, 2019) of interaction.

Insight in WWIC servicescapes can provide guidelines along which certain modes and criteria of co-production fit better in one, and less in other contexts. User–producer interactions achieve robustness through continual interaction between fact-finding and meaning-making (Jasanoff, 2010), thereby constantly reshaping the relations between producers and users of those services. This goes particularly for interactions between users and producers in the everyday reality of producing and disseminating WWIC information to, in this case, maritime Arctic stakeholders. Such interactions have been taking shape in multiple ways, from informal day-to-day communications about imminent weather conditions, to formal responsibilities to provide WWIC information for large marine areas.

Serving maritime users in the Arctic

The Norwegian Meteorological Institute is the state-funded national meteorological service with more than 400 employees, underlying the Ministry of Climate and Environment. The institute is organized in five departments (a weather forecasting department; a center for the development of weather forecasting; an observation and climate department; an information technology department; and a research and development department) and has a main office in Oslo in addition to regional offices in Bergen and Tromsø, among others.

With its long history of forecasting for coastal and ocean areas and serving marine industries, MET Norway has always maintained a close connection with maritime stakeholders. While storm forecasting was the primary motivation behind the establishment of the Norwegian Meteorological Institute in 1866, pressure from the fisheries sector led to setting up the meteorological observatory in Bergen in 1903 (Nilsen & Vollset, 2016, p. 15). Fisheries management agencies were soon after its establishment pushing for the expansion of the Norwegian Meteorological Institute's services (Fulsås, 2003).

Despite the increase of maritime activity in recent decades, WWIC information services cater to a relatively small group of stakeholders, when compared to services for, often highly populated, land areas. Forecasting for the marine Arctic is indeed a special case in point:

> public weather forecast information is generally available on an hourly to daily basis for five to ten days in advance, containing routine information about temperatures, winds, and precipitation and warnings or alerts for extreme weather. Marine forecasts are generally less detailed (as they are provided for broad areas) and do not extend as far into the future. (EC-PHORS, 2015, p. 16)

Forecasting for Arctic areas is difficult resulting from a combination of the lack of observations from the region and shortcomings in numerical models, e.g. the representation of certain key polar processes (Jung et al., 2016). There are unique metocean processes in the marine Arctic (e.g. ice-wave interactions), which can only be covered by customized models for the region. Similarly, ice conditions are of core interest to maritime users in Arctic waters. The Norwegian Ice Service is a part of MET Norway and was established in the 1960s. Today the Ice Service produces digital ice charts for the Barents Sea area on a daily basis (Monday to Friday). Additionally, the archive of ice charts can serve as a basis to document changes in sea-ice conditions over the years.

Throughout the 1980s, several of MET Norway's services that were traditionally freely accessible were transformed into commercial products, and a division was formulated between core services on the one hand, and special services on the other. Core services, which fell under the public, non-commercial tasks, included forecasting severe weather events that could put life and property in danger. Special services included, for example, customized products for the offshore industry. The division would become the backdrop for many changes that followed from the developments in the 1980s, and was partly induced by the upcoming offshore oil and gas industry in the North Sea, where companies started to buy customized services from other, public and private, meteorological offices (Nilsen & Vollset, 2016).

The Norwegian Meteorological Institute currently has an international responsibility to provide WWIC information over an area that covers a large part of the Arctic, METAREA XIX (http://www.gmdss.org/XIX.html), which includes ocean areas between Norway and Greenland (Figure 2). Late 2015, the Institute started to run a dedicated Arctic, high-resolution model, which builds particularly on satellite observations (AROME-Arctic). These models are used to generate forecasts on, among others, the public service Yr (https://hjelp.yr.no/hc/en-us/articles/206550539-Facts-about-Yr). Yr is a public forecast service developed by the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation. Yr currently provides forecasts for about 10 million locations around the world and has a special section for ocean and coastal areas. Furthermore, there is a large focus on improving polar prediction efforts; see, for example, research projects such as ALERTNESS (Kristiansen et al., 2018) and the Nansen Legacy (https://arvenetternansen.com/). In sum, the

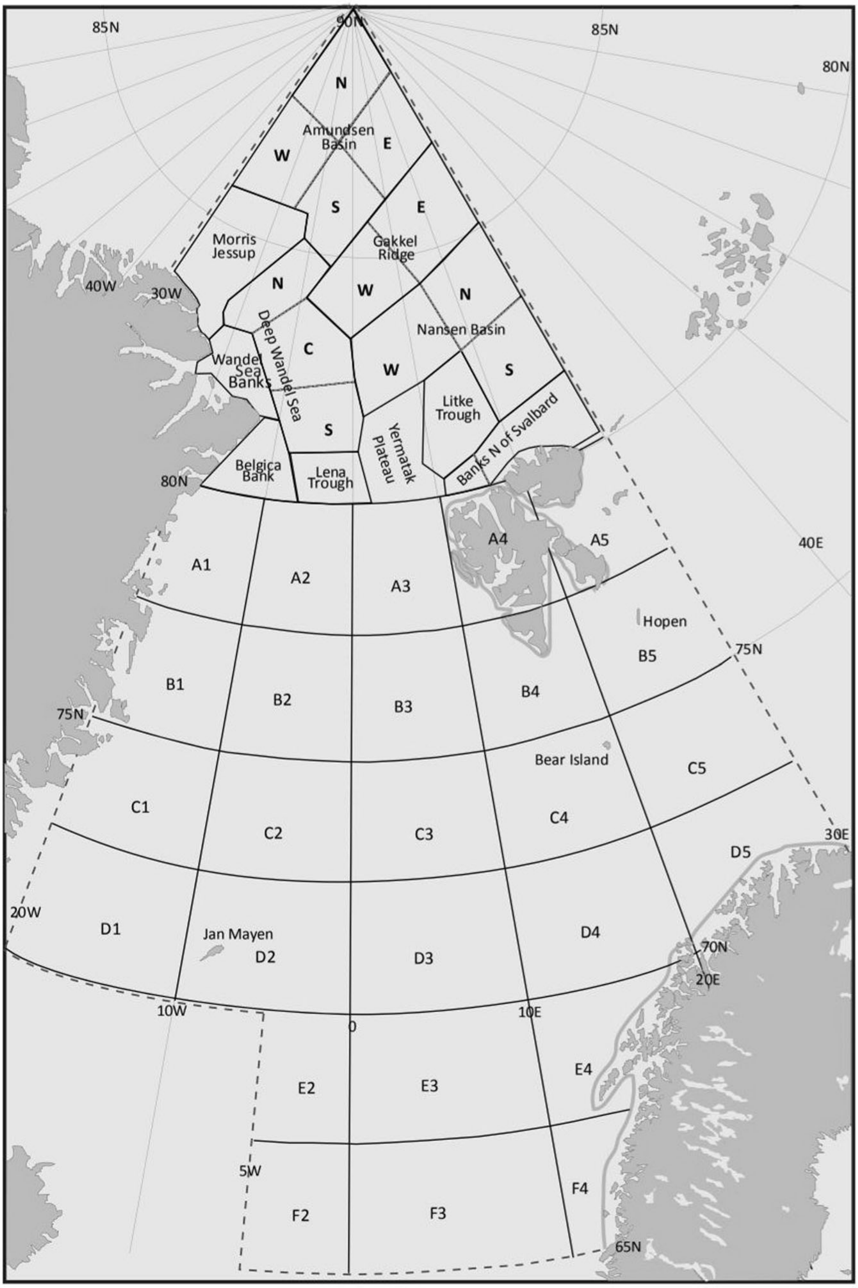

Figure 2. MET Norway area of responsibility for WWIC information, including navigational warnings (METAREA XIX). Source: WMO (2015).

transformation from products to services resulted in a diversification of WWIC information provided by MET Norway, targeting more specifically to various audiences consisting of a general public, a number of customers and various partners (cf. Daipha, 2015). These developments complicate the tasks and responsibilities of NMHS personnel far beyond providing 'accurate' forecasts, and demand for a sensibility toward interactions between producers and users of WWIC information.

Methods

While the previous sections provided a background to analyze user–producer interactions around WWIC services in a transforming Arctic context, the remaining of this paper zooms into a case study from MET Norway. The analysis in the remaining of this paper is based on qualitative methods which we applied to explore perspectives of NMHS personnel about their interactions with maritime users in the Arctic. The focus is on 'mobile' end-users that use the Norwegian Meteorological Institute's *publicly available* services in the marine Arctic (e.g. fishers and cruise ship operators). Hence, the analysis and conclusions do not necessarily apply directly to user–producer interactions around commercial services, or services directed at government agencies.

We carried out nine semi-structured interviews with staff from MET Norway. The interview protocol was developed through iterative discussions between authors. Specific topics were selected during these sessions, and were informed by relevant literature and reports (e.g. Dawson et al., 2017), and the authors' participation in several interdisciplinary stakeholder workshops (the Sea Ice Prediction workshop, Arctic Frontiers 2018 and the SALIENSEAS co-scoping workshop (Lamers, Knol, et al., 2018)). The interviews dug into both operational and strategic modi operandi of tasks and responsibilities for providing WWIC services, discussing topics such as information availability, product development, communication channels and competition/collaboration between WWIC service providers.

Among our interviewees were operational forecasters, sea-ice analysts, researchers, and management staff representing the various divisions and offices. Several of them work partly as operational forecasters and partly as researchers, and most of the interviewees have a long history of employment at MET Norway. Table 1 provides an overview of interviewees.

The interviews lasted between 70 and 100 minutes. They were fully transcribed, and consequently coded and analyzed in qualitative data analysis software (MAXQDA11). Coding of the interview transcripts was done independently by the three authors, while triangulation of the findings occurred by iterative discussions between authors. The findings are also based on an expert group discussion with analysts of the Norwegian Ice Service (underlying MET Norway's research and development department). While these conversations were not recorded or transcribed, the first two authors both took extensive notes during the meeting, which were shared and discussed afterwards.

The research setup benefited from the third author being employed by MET Norway. The expertise of this 'insider' perspective allowed for a mode of collaboration which proved valuable in terms of obtaining institutional support at various organizational levels for conducting the interviews (carried out by the first and second author) and getting access to

Table 1. Overview of interviewees

Interviewee nr.	Gender	Role
1	Male	Management
2	Female	Operational/Management
3	Female	Operational/Research
4	Female	Operational
5	Male	Management
6	Male	Operational/Research
7	Male	Management
8	Female	Operational/Research
9	Male	Management/Research

interviewees. It also allowed for discussions between scientific and practical perspectives and connecting the research findings directly to the everyday NMHS tasks and responsibilities.

Next, the findings from the interviews are discussed along a general discussion of the nature of daily to strategic interactions, followed by a description of three fundamental challenges in maintaining valuable user–producer interactions. Parenthesized numbers behind quotes refer to interviewee numbers as listed in Table 1.

Findings

Engaging in day-to-day and strategic interactions

The diversity of contacts between MET Norway's personnel and their maritime users varies by type, intensity and focus. Day-to-day interactions (typically over the phone, by e-mail, or online) are often initiated by users, either to verify local conditions, to check the development of potential severe weather events, or to discuss the accuracy or correctness of a forecast for a specific location. Strategic interactions have a longer-term perspective than day-to-day interactions. Rather than focusing on the accuracy of a forecast, or the development of particular metocean conditions in a specific location and time frame, strategic interactions focus on the structural improvement of forecasts, or improvements of the formats in which forecasts, or other metocean information are communicated.

The types of day-to-day interactions have changed tremendously over the past decade, and especially since the establishment of Yr in 2007. Until 2015, MET Norway had a special phone line for users, including the general public, that was constantly monitored. Budget cuts and the launch of Yr has made the one-to-one communication style provided by this phone line unfit for contemporary communication strategies which shifted to online platforms. Some of the interviewees argued that this has led to a decreased contact with users, and a declined insight into how WWIC information was used:

> [I]t is many years ago since people actually phoned, but it was very useful for us that they actually did so, we could ask them about the conditions, so we got in a way a confirmation about the correctness of the forecasts, but we don't have that any longer. (2)

On the other hand, feedback and requests are now often sent directly through the Yr platform, and related social media pages on Twitter, Instagram and Facebook. One interviewee said that user input includes up to approximately 500–1000 mails per month, showing that contact certainly has not diminished, but mainly took on another form. Overall, social media has triggered a shift from one-to-one types of communication, to one-to-many communication (Morss et al., 2017). This shift has various important implications for user–producer interactions, which will be outlined in the following sections.

Generally, there is increasing attention for and interest in involving users systematically in the modus operandi of MET Norway. However, strategic user–producer interactions in MET Norway focused primarily at maritime users in the Arctic currently still seem to be fragmentary and lack a systematic organization across its publics. Interviewees say that strategic contact is quite well established with partners, for example through the HALO platform (https://halo.met.no/), through the Yr collaboration and with large customers who pay for tailored services. Things become more ad-hoc when it comes to specific user groups from the general public, which includes many maritime stakeholders. For example, few regular reference group meetings are organized; rather, strategic interactions take shape as ad-hoc attendance of MET Norway representatives at user meetings (e.g. with fisheries or cruise tourism associations), and a sporadic use of user surveys (Gjesdal, Goa, Olsen, & Olsen, 2015) is mentioned by various interviewees. While user meetings appear to be valued by the interviewees, they are not systematically embedded in the organization, but rather initiated on a reactive basis, for example when a group of fishers in a local community uttered their dissatisfaction about systematically inaccurate forecasts. Additionally, it has to be taken into account that the actual maritime end-users of public services are highly diverse, often little organized themselves, and sometimes difficult to reach: 'We tried to make these kind of meetings […]. But it turned out that the logistics were not so easy, we talked to the local organizations but this time they were all far away fishing, so it wasn't possible … ' (7).

We can relate the relatively opportunistic strategic interface between MET Norway and its marine end-users to a relatively new interest of NMHSs in users' contexts in which information becomes 'actionable' (see also Daipha, 2015, pp. 167–172), that is, having value in decision-making processes. This requires a paradigm shift among forecasters and researchers, which appears to be slowly finding its way through the organization. For example, the notion 'science for service' has been taken up, indeed explicitly reflecting a shift towards the servitization (Harjanne, 2017) of MET Norway's research and operational activities. Similarly, one interviewee stated that interactions with users are approached with the idea that ' … the user is always right. The most important thing is that the forecast is not completed before it's understood by the user' (1), implying that the value of services strongly depends on user contexts. In sum, the (potential of) different interactions from day-to-day to strategic levels make for a complex and continuously evolving interface. A picture emerges of a shifting user–producer interface, with differentiating strategies across user groups: relationships with the general public are built on a societal level, while interactions with customers and partners take a more strategic form. The following sections provide a deeper understanding of these dynamics, via a discussion of three key challenges for maintaining meaningful interactions, particularly with Arctic maritime users.

Challenge 1: knowing maritime users in the Arctic and their needs

Although MET Norway has a relatively good knowledge of who the users are that operate in the marine Arctic and use MET Norway's public services, there is relatively little understanding of how, when and where these services are used (see also Gjesdal et al., 2015). These situated aspects of user needs go beyond the widely known issues of bandwidth limitations, low spatial model resolutions of models and unreliability of longer-term forecasts. Indeed, interviewees see room for getting more contextualized insights in the 'use' (Ray & Webb, 2016) of weather and climate information: 'We send out something, and we know nothing about how it is being used, basically. Sometimes we meet users, like fishers, fishers' organizations, in this way we can be in touch with them, but this happens very seldom' (2). The challenge of 'knowing users' thus pertains specifically to an embedded understanding of their needs, and to get deeper insights in what it means to *use* services of MET Norway.

A related aspect pertains to NMHSs employees' awareness of and their underlying assumptions about the skills of users to interpret WWIC information. Here a distinction between different types of 'publics' (Daipha, 2015) becomes visible. Different types of users have different levels of knowing how to interpret WWIC information formats, which make certain types of information suitable for some users, but less for others.

When it comes to maritime users, interviewees discern between different types of users in terms of such skills. For example, one interviewee told that professional users such as fishermen typically know the consequences of weather well, and that they do not need them explained. Other marine users though, especially small leisure boaters in summer, might benefit of knowing the consequences of certain weather conditions. Interviewees see a challenge though to cater for the many different types of user contexts, especially when maritime activity is increasing:

> […] when larger marine areas become accessible, then the needs for forecasts will also increase. […] there are so many foreign captains and officers on board that don't know the conditions in the North Atlantic, and especially around the ice edge, so those are experienced as a big problem, but we have no contact with them. (2)

As a route toward better understanding users and their needs for WWIC services, MET Norway increasingly engages with users through involving them in various research projects, as external experts and partners in product development. While operational forecasters have seen a decline in contact with users, the research department, therefore, has experienced an increase in collaboration with users: 'We need to have a coproduction between the users and the scientists. […] Before we did not want to talk to the end users, that was just a hassle' (1). The increased involvement of users in research and development is a positive development that is valued by most interviewees, but creates several issues related to user–producer interactions in later stages of the information value chain. These will be addressed under Challenge 3.

Challenge 2: automation as blessing and curse

There is an ongoing tension between standardization and differentiation of WWIC information services (see also Knol et al., 2018), between the production of these services and the communication with its users. Standardization tends to go hand in hand with increased automation of the production chain, which should give operational forecasters and sea-ice analysts more time to focus on specific areas where users need information on more detailed levels:

> I am just guessing that there is not many customers that use […]the east part of Greenland; that is not an area we really focus on and we don't do that much detail there, so I think an automatic product would be just as good for that part and we shouldn't spend too much time on that and focus more on the main area. (4)

Automation of WWIC production is also embedded in larger organizational dynamics toward efficiency: '[Currently] you need the forecasters to do all the tasks, and we need to free the time for the forecasters. So, automation is one way of doing that and we have a budgetary stress […]' (5). Furthermore, as one interviewee (5) explains, while MET Norway has to comply with specific international legal requirements about how to provide information for MET area XIX, these requirements could satisfactorily be addressed by automated products in a way similar to those provided through the Yr interface. Hence, an overall tendency toward more automated WWIC products is occurring and is generally perceived as a positive development.

With the automation of products, there is a tendency to automate the communication of WWIC information, which has consequences for user–producer interactions. This has been referred to earlier as a shift in emphasis from one-to-one communication, to one-to-many communication (Morss et al., 2017). An increasingly automated interface, with no interpretation of operational forecasters, presupposes users' expertise in knowing how to use automatically produced information. For example, location-based services risk creating a sense of false accuracy, as exemplified by one interviewee who explains how rather precise, deterministic forecast formats might be interpreted differently than intended by users. Without knowledge of, for example, the model resolution behind such a detailed forecast, presenting WWIC information straight from model outputs to users in a deterministic form, therefore, might create expectations that cannot be met.

Interviewees mention that all feedback on Yr is manually summarized on a monthly basis, to achieve insight into users' needs and desires. User feedback on forecasts has led to development and improvement of the forecast communication, and to possibilities for extended engagement of the public through their individual weather observations. The use of social media, particularly Facebook and Twitter is seen as a good way to communicate with the general public. An 'Editorial Team' – established in 2016 recently and made up of operational forecasters, climate researchers and communication advisors – makes sure that users receive response to their comments and feedback within a certain time frame. However, given that this is typically catering users on the group level, social media channels tend not to be used for individual, detailed requests for information.

Automation of communication modes also affects feedback loops through which public meteorological institutes gain local knowledge and can verify WWIC information in near-real time, based on information that comes from users out at sea. For example, regardless of advances in modelling and accuracy, Jung and Matsueda (2016) found that numerical weather models have lower forecast capabilities in the Arctic compared to other regions due to scarcity of surface-based observations in the Arctic. This can be improved through additional in-situ observations as well as better usage of satellite data (Jung et al., 2016). A number of interviewees in our study confirmed that a lack of in-situ observations is one of the main limitations to modelling weather in the Arctic, as well as for operational forecasters to add value to forecast products, thus reducing their potential value. A similar concern is expressed by interviewees from the Norwegian Ice Service (part of MET Norway); more in-situ observations would be helpful to validate the information from satellites or to adjust ice charts accordingly. For the purpose of weather forecasting, the number of in-situ observations in marine Arctic today is so sparse, that one interviewee believes that just a few new observation sites would give a significant contribution to the numerical models: 'ten would be a good effort, fifty would be very nice, hundred would almost be overkill' (5). Some of the interviewees mention citizen science as one possibility to expand observations. Also, while various vessels already carry instruments and ship-crew make observations or measurements such as releasing weather balloons, expanding the number of participating ships could be encouraged, according to interviewees. However, at the same time, several interviewees notice that the great increase of remote sensing capabilities in the last years already provides very valuable input to sea-ice analysis.

Despite the potential of automated processes such as machine learning, human interpretations are still essential since users request and desire local and detailed information about sea-ice, which otherwise are overlooked:

> We are at a point right now that we have so much satellite information that has been completely unprecedented, ever, and then it is high resolution, and it is just gonna get more. […] I think, combining all these different frequencies could actually allow us to do a lot more automation

> than we have right now. Right now, we just can't have that. We have to have a certain amount of human input, because, it doesn't matter what kind of algorithm you do, it's [for] the geophysical limitations of the sensors and the sea ice, that you actually need that [human] input. (8)

Our interviewees underline the challenging situation where automation of WWIC services requires increased levels of human input in order to become usable information. This situation reflects aspects of the automation paradox (Lyons & Stokes, 2012; van Diggelen, Post, Rakhorst, Plasmeijer, & van Staal, 2014): strong reliance on automated systems decreases flexibility and increases a risk of information overload, which only can be mitigated by human intervention. This implies that in non-standard situations (e.g. severe weather conditions) standardized information and standardized communication channels could lack the 'human factor' that is essential for tailored information needed for decision making in contexts with high uncertainty. In the context of WWIC information services this means that, particularly for Arctic maritime users who are active in extreme, highly dynamic environments, services need to maintain a level of flexibility that balances automated production and standardized communication interfaces with human interpretation.

Challenge 3: research to operations gaps

Operational and research staff within public meteorological institutes such as MET Norway mutually feed from each other's expertise. Successful interactions between forecasting and research departments are therefore an essential basis for providing salient WWIC information services to the various publics of meteorological institutes. However, several occasions of R2O gaps can be identified in the particular context of providing WWIC information services to maritime users, which relate directly to the previously mentioned challenges around user-produced interactions. In general, interviewees are aware of the importance of connecting research activities with operational forecasting responsibilities, 'because [researchers] work on the model and ensemble predictions, but also do validations of the forecasts. So the links between the forecasters and the researchers are important' (5). The mutual dependence of these two core tasks of public meteorological institutes is neatly outlined in this quote:

> … what's equally important is that operations are pushing research to the limit of knowledge […]. The operations [are] not just there as an endpoint, it's also supposed to push research, and that means that there must be a close connection between what is operational […] and what is being developed further by the researchers. (1)

Maintaining successful interactions between research and operations departments is not straightforward though. We highlight two challenging facets in the context of providing WWIC information services to maritime Arctic end-users, as perceived by our interviewees.

First, when it comes to priorities for service improvement through research and product development, we notice diverging perspectives on the urgency and potential of long-term forecast services for maritime users in the Arctic. Recently, (sub)seasonal forecasting has gained much attention (Melia, Haines, Hawkins, & Day, 2017; White et al., 2017) and climate services have proven valuable in various decision-making contexts (Brasseur & Gallardo, 2016). Many research projects on advancing climate services are being funded, including those with a focus on WWIC information services in the Arctic (Jung et al., 2016, see, for example, the ERA4CS program: http://www.jpi-climate.eu/ERA4CS). Interviewees acknowledge the theoretical potential of climate services for maritime activities in the Arctic, but are somewhat skeptical about their current value: 'If it was shown to be reliable, they'd certainly be able to plan something further in advance' (9). Another interviewee adds: 'Long range forecasting in the Arctic – seasonal for three months and longer – is done but we know the quality is not very good' (7). Thus limited reliability of such forecasts confines its usability. Also, long-term forecasts might not be interesting for some maritime sectors, such as fishers, since forecasts with lead times beyond a week or so does not fit their planning timelines.

Particularly, the discrepancy between climate science and providing valuable climate services for operational contexts relates to the inherent uncertainty that lies in the methodologies behind producing long-term forecasts: 'A lot of people don't like to get information about probabilities because they need a [deterministic] answer. I think it's difficult to understand' (3). Probability-based forecasts thus require a certain level of expertise, which many users currently do not possess: 'There is no definitive answer that the next winter will be warmer than the average, with a probability of 61% … it requires understanding from the users … ' (2). Thus, despite the significant resources invested in advancing climate research, perceptions prevail on the operational level of limited potential and interest.

Second, we observe that the increased focus on project-based research facilitates interactions between researchers and maritime users, but tends to skip involvement at the operational level, which has experienced decreased contact with users over the past decade, as described earlier. These diverging experiences highlight how the scope of interactions with users shifted from personal and immediate dialogues, to a context in which *user representatives* become involved in product development.

This shift toward project-based product development in which user representatives are increasingly involved resonates the tendency of user involvement through 'iterative interaction' (Bremer & Meisch, 2017), where users are consulted throughout several phases of a research project. There seems to be a challenge to establish a continuous dialogue between research and operations, especially since users might become less interested in contributing to another research project when the road towards implementation of new products is long and users do not clearly see the results of their engagement: 'There has been a lot of surveys […] and I see that a lot of users have a survey fatigue, and they are not really willing to do that [anymore]' (8).

The imbalance between the number of research projects, the strong demand for user involvement and the (so far) often limited operationally valuable output of these projects point to a challenge of discontinuity in information value chain processes:

> I think this a big challenge for the research institute because it's not only to develop new presentations. You have to put it into knowledge, you have to test it and then expose it to the users whether you like it or not. And for this research to operations [process], but specially the operations pushing research again, we need some core resources. (1)

In other words, project-based research challenges the continuity of research, since once the money is spent during two or three years, often product development stops. This is elsewhere called the 'valley of death' (Barr, Baker, Markham, & Kingon, 2009; Brooks, 2013). Next to financial resources and several other criteria through which organizations can overcome the valley (Buontempo, Hewitt, Doblas-Reyes, & Dessai, 2014), an ongoing dialogue between the research and operational communities is essential (National Research Council, 2000). Along this line, there might be room for closer engagement with operational staff in co-production-based research projects focused on Arctic maritime WWIC information services. Involving operational staff is an essential part of co-production. Not only can they play an important role in validating usability from an NMHS perspective (a.o.t. an end-user perspective). Importantly, operational staff can help establishing strategic collaborations with maritime stakeholders beyond the short runtime of research project and hereby smoothen information value chains toward a seamless process where daily and long-term, strategic, user–producer interactions enhance each other. Based on these findings, the next section discusses implications for NMHSs in negotiating with different maritime publics in the Arctic. These findings inform ways of maintaining user–producer interactions that are valuable for all involved.

Discussion

Negotiating expertise in user–producer interactions: opening up to uncertainty?

The field of meteorology and the various players within it, including public meteorological institutes, continuously deal with the challenge of maintaining authority as a public-science field (see Daipha, 2015). The turn towards user involvement beyond the operational level into research and development is a necessary, but difficult step: it reflects an acknowledgement of the limitations of meteorological knowledge, which is at first sight a risk in terms of losing credibility. It is not surprising therefore that the implementation of a servitization paradigm is taking place in small steps (Buontempo et al., 2014; Harjanne, 2017). Also, it makes sense that engaging users into the modus operandi of NMHSs is currently often product-focused; it has proven successful to focus on improving forecast products and numerical models, on getting observations at higher resolutions and on developing systematic insights in metocean patterns across different temporal scales. This will continue in the years to come, through enlarged calculating power of computers allowing for higher resolution models (Palmer, 2018), or with new satellites sent into orbit (Hanson, Peronto, & Hilderbrand, 2013).

While uncertainty is a major challenge in ‘conveying the message’ of future weather conditions (Frick & Hegg, 2011; Joslyn & Savelli, 2010), translating uncertainty in relatable and actionable information implies a new way of thinking: not only about the epistemic value of meteorological knowledge itself, but also about the uncertainty that is embedded in the processes through which the necessary robustness (Jasanoff, 2010) is achieved to make meteorological knowledge meaningful. It also implies a shifting mode of engaging users (Buontempo et al., 2014), in which climate service science opens up much more to the decision making contexts of their potential users by ‘inverting the relationship linking climate information to climate-sensitive decisions’ (Buontempo et al., 2014, p. 4). This way, co-production of WWIC information services is necessarily based on collaborative learning, in which uncertainty is embraced as a commonality that binds NMHSs and their users. In such a ‘learning’ paradigm, knowledge production is attributed a less deterministic role, and the interaction between scientific facts and meaning-making is emphasized as an ongoing, collaborative process. This implies a more explicit need for a variety of user–producer interactions and creates a space for openly discussing the uncertainties (or ‘ignorances’ (Buontempo et al., 2014, p. 4)), inherent to producing salient WWIC information services.

Co-production and user engagement: bridging gaps in the information value chain

There is a need to more profoundly conceptualize co-production in relation to user–producer interactions for WWIC information services. This is relevant because it provides grips to study meteorological practices beyond the dualistic notions of users versus producers of such services (Bremer et al., 2019). While meteorologists continuously change roles between user and producer of information, various processes – such as the development of technology – reshape the relations between these roles, and challenge these boundaries (Dawson et al., 2017). For example, particularly in the observation-sparse environment of the Arctic, 'ground truth' from users in the field – whether they are automated measurements or annotated visual observations – is an important source of feedback for meteorological institutes, on which they can perform verification measures and eventually improve forecast models. From such a perspective, co-production implies a continuous circulation of information, becoming more robust through iterative interactions between different stakeholders and building accumulated levels of expertise over time (Daipha, 2015).

Parallel to *product* improvement however, the findings of this paper stress the need to intensify the attention for *process* aspects of co-producing WWIC information services. A process perspective enlarges the potential of co-production beyond iterative modes of product development, and allows for an understanding of user–producer interactions that also accounts for ethical, educational and institutional benefits (see also Bremer et al., 2019). Importantly, a process perspective on co-production implies a collaborative focus on meaningful ways of translating the uncertainties inherent in increasingly sophisticated meteorological and climatological models into valuable information.

Furthermore, the interviews reveal that in the context of Arctic WWIC information services provided by MET Norway, a distinction between different publics (Daipha, 2015) is made that relates to different levels of information access across (maritime) sectors. There is a particular challenge to address the potential service gaps for maritime users who need more expert level WWIC information than the general public, but have no financial resources to establish a commercial partnership with MET Norway. Therefore, user–producer interfaces which are becoming too generic toward certain publics risk losing their value for user groups who do not fit with the particular 'public model' of NMHSs (general public, customers and partners). Thus, for public meteorological institutes it remains important to find a balance between standardization and diversification as to avoid any 'expertise' gaps between various interfaces. In the context of this study, special attention seems warranted for maintaining non-commercial relationships with certain user groups (e.g. fishers, recreational boating) who are (increasingly) active in the resource-scarce Arctic waters.

To that end, when maritime users are united in some form, it is easier to become recognized as a distinguished user group that stands out from the general public. A certain level of organization opens up a wider range of possibilities for interactions both on day-to-day and strategic levels. Regular interactions already exist between the Association of Arctic Expedition Cruise Operators (AECO) and the Norwegian Ice Service. How to cater for other user groups and where certain non-commercial services could fit, remains an important point on the agenda. A focus on maritime users in Arctic waters, given the complex environment and skill dependent activities appears to be suitable for further, in-depth exploration.

Automation will provide opportunities for greater production efficiency and will put less strain on the manual capacities of operational forecasters. Our findings point out that the shift toward more standardized and indirect forms of day-to-day interaction with users mostly impacts the operational level. However, increased automation also results in a challenge to find new ways for maintaining dialogues with end-users. While such dialogues can take shape on a strategic level (e.g. user meetings), such systematic interactions are still sparse and might not work or be viable for all types of end-users. It is in the context of the above issues where a more profound inclusion of operational staff might be beneficial to bridge various user–producer gaps. Operational forecasters are already increasingly moving into roles as advisors for specific stakeholders or in the case of extreme metocean conditions (Nilsen & Vollset, 2016; Sivle & Aamodt, 2019). Moreover, and in line with the call for an 'inverted', decision-driven (as opposed to product-driven) approach to catering for WWIC user needs (Buontempo et al., 2014), research projects could benefit from involving operational forecasters and make use of their tangible knowledge and connections with end-users. Generally, it is necessary for NMHSs to capitalize on the dualistic and overlapping roles of users and producers and stimulate continuous dialogues between researchers, operational forecasters and user groups across day-to-day and strategic levels, through a variety of interconnected formats of co-production (Bremer et al., 2019). Only then will the potential of increased automated production of WWIC information become valuable to its full extent.

Conclusion

In this paper, we explored the shifting dynamics of interactions between WWIC information providers and maritime stakeholders operating in Arctic environments. By using the case of MET Norway, we attempted to complement the increasing scholarly interest in user–producer interactions, and studied the thus far often overlooked 'producer perspective' on WWIC information services. We identified three key challenges pertaining to day-to-day and strategic user–producer interactions: (1) the importance of knowing how information is used, (2) the increasing automation of meteorological practices and the growing need for user observations, and (3) the need for bridging research-to-operations gaps.

This study provides a basis for several future investigations. First, it would be fruitful to expand the scope of this study to cover user–producer interactions across public meteorological institutes. This would allow for an organizational comparison and stimulate a sharing of best practices across NMHSs with responsibilities to provide WWIC information in the European Arctic (e.g. DMI, FMI, SMHI and IMO). Second, it would be relevant to analyze and compare the history of meteorologists' relations with diverse maritime sectors, and the objectives behind these interactions. Such a historic comprehension will contribute to structure future relationships with these sectors. As illustrated in this paper, the dynamics of the interactions between MET Norway and the fisheries and cruise tourism sector, for example, have a completely different history and are very dependent on the dynamics and development of each sector, its needs, its role in the larger society, and the expertise of its professionals. Then, thirdly, and connected to this, a systematic study on the experiences of maritime end-users about different formats in which user–producer interactions take place – particularly strategic meetings and involvement in research projects – would help to shape future collaborations, such as sector sector-specific user meetings. On a more practical note, insights in such experiences might help avoid stakeholder fatigue and align user involvement across various research projects. Such insights would be valuable to improve the processes of meaning-making around the development of WWIC services in a rapidly transforming Arctic environment.

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