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Mind the gap! A consensus analysis of users and producers on trust in new sea ice information products

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HIGHLIGHTS

- There is a consensus between producers and users on factors that build trust in new sea ice products.
- An established producer track record and endorsement of products by peers are among prominent factors.
- Automation is seen as a promising trend and does not generate mistrust in users.
- Small-scale highly tailored products for commercial users will drive next-level sea ice services.
- Implementation of already identified enhancement possibilities is key to closing the usability gap.

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ABSTRACT

In the ice-infested Arctic Ocean environment, the uptake of new sea ice services is an important factor in ensuring safe and efficient marine operations. Producers increasingly turn to co-production for user input, similar to the wider field of climate services. This paper asks how the uptake of sea ice information services can be optimized, by gauging the extent to which producers and users already share an understanding of how trust develops toward new products. By adopting a consensus analysis approach, we gain insights about how to balance further investments in knowledge co-production versus change implementation. We chose cultural consensus analysis, a method that produces valid estimates even in small sample sizes. Our survey presented thirty-two propositions based on seven dimensions of trust in weather, water, ice and climate services. The survey was completed by fifty-seven respondents (n = 29 users, n = 28 producers) and revealed a strong consensus model among the two groups about the necessary improvements needed to increase users' trust in new services. Our results suggest that forecast producers for the Arctic region, specifically in the field of specialized sea ice predictions and mapping/charting, share a substantial understanding with users about how trust develops toward new products. We discuss the importance of automation, peer endorsement and perceptions of cost-performance ratio for necessary strategic approaches to help experienced forecast users to trust and adapt products to their specific operational context, and reflect on the costs associated with the use of specialized sea ice services in closing the usability gap.

1. Introduction

Widespread climate-driven loss of sea ice and a simultaneous political opening of Arctic waters to international shipping within a stable institutional framework have made the Arctic more navigable (Buixadé Farré et al., 2014). Fast-changing sea ice conditions may constitute an increase in hazardous situations, which is especially pertinent in the light of growing social and environmental pressures, increasing marine traffic and growing competition for resource access (Eicken, 2013; Meier et al., 2014; Blair and Muller-Stoffels, 2019). For example, the increased mobility of sea ice has increased the frequency of pressure ridges, one of the most hazardous navigational challenges even for powerful ice-

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Practical implications

Access to, and optimal uptake of, salient sea ice information is essential for users who operate in sea ice infested marine environments. Producers of sea ice information services have been making significant efforts to develop useful and usable products in ways that align with demands from users. To date, user surveys have predominantly focused on the technical aspects of product performance and less so on the contextual, socio-technical factors that facilitate the adoption of new products into routine use. As well, there is a need for systemic evaluations of co-production outcomes, in this case as it regards the successful alignment of user and producer perspectives about adoption of sea ice information: Are producers already aware of factors that increase the chances that newly developed products will be used?

The present study measured the extent to which producers and users of Arctic sea ice information agree about the factors that promote trust toward new sea ice information products. Based on a cultural consensus analysis survey of 32 propositions, our study found a strong consensus pattern among users and producers about various trust-building dimensions of peer endorsement, handling, transparency, control, performance, brand and onboarding. Only 2 propositions resulted in different answer sets in the user and producer groups: A proposition probing perceived price-performance ratio and user willingness to pay, and another probing the desirability of transparently communicated uncertainties drew disagreement.

Summary Implications: Products from public entities such as national weather services are currently trusted more by users than those offered by private ones, but this relationship can be mitigated by time and experience with a producer. Well-known, established producers are trusted more than newcomers. Operational routines are important drivers in determining which products are trusted and used. However new services that are co-produced with users, or are recommended by other users, are trusted and more likely to be trialed -this is one way producers can close the usability gap. Users tend to trust automated products, but for continued user trust, human actors will need to keep an important role in the production process, both for solving very complex tasks and for quality-checking. Generally speaking, producers and users do not believe users to be biased against freely available products –most users do not think that free products are of worse quality than commercially priced ones– but service providers should be aware that 45% of users have the perception that there is correlation between higher costs and higher quality. In fact, users indicated that they are willing to pay for high-quality services, while producers did not think this to be the case. Based on our findings, it appears that a breadth of user priorities have already been translated into scientifically tractable questions, waiting to be operationalized through useful products.

Recommendations: Producers of sea ice information services are sufficiently aware of many factors that help to promote trust in new products, increasing the chances of adoption and closing the usability gap. Removing remaining limitations in sea ice services may now be a function of not only improved predictive capacity, but also rethinking institutional (i.e. funding) and regulatory transitions for full operational implementation. We posit the following factors to be vital in the future optimal uptake of sea ice information services:

- transparency in the automation process of ice products;
- making users sufficiently aware of the whole suite of newly available services;
- experimentation and feedback in co-production and product development;
- the ability of National Meteorological and Hydrological Services responsible for Arctic environmental prediction to match their significant investments to improve environmental observations and predictions with upscaled uptake of high quality services.

These are factors that require considerable energy and organization to ensure that already existing, co-produced knowledge is used to facilitate optimal uptake of sea ice decision-support tools.

strengthened cargo ships (Bourbonnais and Lasserre, 2015), as it is difficult to detect until a ship is in contact with it, often causing ships to become beset (Mussells et al., 2017). The vulnerability of marine operators to biophysical risks is compounded by various factors, “including experience and competence, equipment used and technology available (instruments, information and communication technologies), access to knowledge and information, mode of transportation (size and type of vessel), logistical support (emergency response, backup support) and financial resources” (Dawson et al., 2017). The nascent field of ice forecasting therefore offers potential decision support for long-term growth in Arctic operations (Bourbonnais and Lasserre, 2015).

Owing to these emerging pressures, the mapping of sea ice, and nowcasting and forecasting of weather, water, ice and climate (WWIC) conditions in general, are of high-priority for Arctic governments, communities and marine sectors. Much research has explored technological, infrastructural and institutional requirements of developing and disseminating WWIC information in the Arctic region (e.g. Li et al., 2011; Lee et al., 2015; Lovecraft, 2016; Knol et al., 2018; Blair et al., 2020; Haavisto et al., 2020), often with a central focus on user needs (e.g. Dawson et al., 2017; Lamers et al., 2018a; Lamers et al., 2018b; Jeuring and Knol-Kauffman, 2019; Jeuring et al., 2020; Wagner et al., 2020). Several studies have explored the needs of end-users in polar operational marine communities, specifically pertaining to desired sea ice parameters and spatial and temporal scales based on their activities (e.g. IICWG, 2019; Jeuring and Knol-Kauffman, 2019; Wagner et al., 2019). These studies generally frame the line of inquiry to improve knowledge of why user uptake of sea ice information might be poor due to technical aspects, such as user requirements of specific sea ice properties of interest and the limitations of transferring information in the remote Polar Regions due to low bandwidth (see also Tietsche et al., 2020; Wagner et al., 2020; Lamers et al., 2018a).

1.1. Objectives

Our study furthers this line of research about how the usability of sea ice information can be enhanced. However, instead of focusing on specific parameters that need to be brought into alignment with user needs, the objective here is to gauge the extent to which producers and users of sea ice information already share an understanding of the factors that promote trust toward products. To our knowledge, this is the first study of its kind probing *shared* beliefs between producers and users, especially as it regards trust toward new products. Critical reflection among scientists and practitioners is an important step in the co-production or evaluation of climate service development, ensuring its legacy, and to stimulate the sustainability of future service developments (Bruno Soares and Buontempo, 2019). If producers and users have demonstrable shared understandings about what users need, it points to largely effective co-production channels between users and producers, suitable for identifying the problem space. Such reflections (*are we on the same page as our users?*) are a helpful step in determining where to invest skill and resources, to narrow the usability gap: whether it is technologies, infrastructure, co-production or institutional arrangements that need immediate capacity development (*how do we implement the enhancements we already know are needed?*).

Our concern in this study is specifically with 1) the factors that promote trust in products and services, and 2) measuring already existing consensus about trust among producers and users. Following Dawson et al. (2017) we define *producers* as individuals or enterprises that develop, sell or exchange data, information and knowledge with the intention satisfying a real or perceived need of a given *user*, here defined as individuals engaging in polar mobilities that receive such information.

Our study seeks to answer three main questions about sea ice product producers and users:

Q1: What do users and producers consider to be factors that influence the trust necessary for the adoption of new sea ice products (e.g. automated ice charts, sea ice forecasts, seasonal-to-subseasonal sea ice products) as decision support tools for Arctic marine operations?

Q2: Do users and producers agree on the factors that pertain to Q1?

Q3: What does agreement or a lack thereof mean for the future of co-production in Arctic sea ice information services?

In the following sections we explain the conceptual framework and methodology used in our inquiry, describe participants' responses, and evaluate their implications. Finally we discuss recommendations for providing sea ice forecasts to end users with a vested interest in Arctic marine operations.

1.2. Usability of WWIC services and the role of co-production

Optimal uptake of weather or sea ice information, or the adoption of a product or service into routine use, is an important factor in safe and efficient marine operations in the Polar Regions (Stewart et al., 2020). Usable WWIC information products also have wide-ranging societal value from informing resource use to adaptation options in light of climate change and increased economic activities. According to a recent inventory, at least 200 private and public service providers focus on delivering WWIC information in the Arctic region, targeting mainly scientific, commercial and societal user groups; yet developments in this field tend to focus more on the production process rather than on the uptake of information (Haavisto et al., 2020). It is equally important to understand what factors promote or inhibit user uptake of downstream services. The broader climate services literature has been strongly attuned to potential mismatches between the supply and demand of information that precipitates the so-called usability gap (Lemos et al., 2012; McNie, 2012; Briley et al., 2015; Zulkafli et al., 2017), and has, amongst others, contributed to the understanding about how and when co-production approaches can help to bridge this gap (Hegger et al., 2012; Vaughan et al., 2018; Vincent et al., 2018; Bremer et al., 2019; Bruno Soares and Buontempo, 2019; Vincent et al., 2020). Co-production refers to collaborative transformation of information or ideas into products and services (Ostrom, 1996; Alford, 2014; Brandsen and Honingh, 2016), with the aim of producing services that are useful, usable and used (Vaughan et al., 2018). Insights from the co-production approach forwarded by climate services researchers (e.g. Máñez-Costa et al., 2022) are necessary for successful implementation of decision-support tools in high-stake environments, such as sea ice information in Arctic maritime operations and activities (Jeuring and Lamers, 2021). Co-production also needs to be considered as part of a set of factors that affect uptake of decision-support tools by tailoring information to users, and thereby increasing the usability of, and users' trust toward, new services.

1.3. Trust in WWIC services and the role of automation

Knowledge systems for sustainable development–the institutions that effectively harness science and technology for sustainability–manage boundaries between knowledge (what is known) and action (decisions informed by knowledge) in ways that simultaneously enhance the salience, credibility, and legitimacy of the information they produce (Cash et al., 2003). This type of boundary management demands leadership that is transdisciplinary, builds bridges and fosters trust built upon ethical considerations for adaptation researchers and decision-makers (Celliers et al., 2021, Cash et al., 2003). Considerations of these factors is particularly essential for knowledge systems that inform risk decisions and aim to reduce the vulnerability of marine mobility sectors (Thoman et al., 2017).

Risk communication research establishes a wide range of applications for trust (Liu and Mehta, 2020), and trust is generally considered as a key factor in decision making under uncertainty (Baumgart et al., 2008). Research on trust in the context of WWIC information communication tends to centralize perceptions of trustworthiness of information sources (Su et al., 2021). For example, Burgeno and Joslyn (2020), by studying the relative impact of varying levels of forecast accuracy and forecast consistency on public trust, found forecast accuracy to have a stronger positive effect on trust than message consistency. Importantly, a key challenge is to understand how interactions between decision support tool characteristics and trust parameters may affect decision behavior. Research on relations between perceived trustworthiness of information, risk-related psychological determinants (e.g. norms, beliefs, risk aversion) and behavioral outcomes vis-a-vis weather conditions shows how forecast trust is positively related to risk perception and stimulates protective action, given a certain forecast (Losee and Joslyn, 2018). Trust perceptions reflect mechanisms to cope with uncertainty, and emerge from and affect weather warning information exchange and emergency response needs (Cross and LaDue, 2021).

Another factor which might influence the level of trust in WWIC products is to what extent it has been produced by a human (e.g. manually drawn maps, or quality checking) or whether the data stems solely from computer-based methods like models or machine-learning. The latter will be called automated products hereafter, which cover for example satellite derived products. In contrast to automated products, ice charts are drawn by ice analysts and are still widely used in Arctic maritime navigation due to their high resolution and reliability. Satellite products suffer either from a low resolution (>1 km, e.g. AMSR-2) or from ambiguities in the ice type classification (synthetic aperture radar (SAR) images).

Methods have been developed for several years to classify and translate the high-resolution information in SAR images into ice-related quantities (Zakhvatkina et al., 2019, and references therein; Kruk et al., 2020; Boulze et al., 2020). Currently, these methods are being extended to incorporate information from different satellite sources at the same time (Malmgren-Hansen et al., 2021), with the aim to improve the automated ice products and to eventually reach a similar level of detail and accuracy as traditional ice charts. This could provide ice services providers and users with high-quality products with less latency (Jeuring et al, 2020). However, there has been a longstanding debate in meteorology about the lack of trust in, and the usability of, automated products; and whether such issues could be overcome with sufficient evaluation, user feedback, as well as transparency into the role of automated systems (see Pagano et al., 2016 for overview).

Improving environmental prediction services does not automatically translate to societal value, unless it is understood and actually used (Dawson et al., 2017). Here we focus on trust and its determinants as major drivers of sea ice information use in high-stake maritime operational contexts (Blair et al., 2022). Wagner et al. (2020) have shown that in the case of activities near the marginal ice zone, users tend to have a lower tolerance for risk and require more detailed information to maximize their margin of safety, though decision thresholds depend on

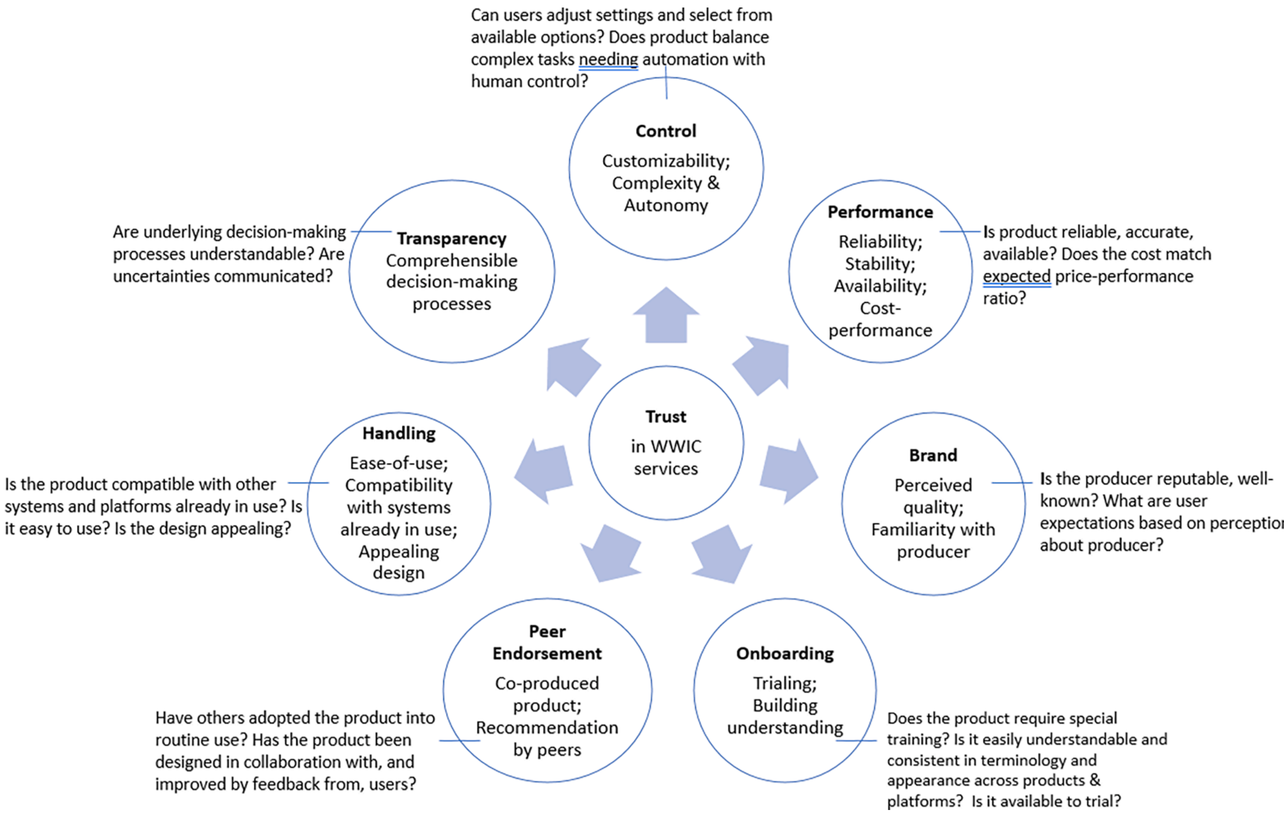

Fig. 1. Potential factors that build trust in weather, water, ice and climate (WWIC) information products. Adapted from Michler et al. (2020).

the type of activity. Thus it is important to minimize ambiguity about the trustworthiness of sea ice information, and to increase understanding of the context-specific factors that influence trust in a product's utility and consequential levels of information uptake.

We rely on a typology of trust in smart products developed by Michler et al. (2020) to consider factors that foster trust in WWIC information products. We chose this framework due to its emphasis on products and technologies that collect, analyze, store, share, combine data about contextual situations, carry out partly or fully autonomous decisions and actions, and have the ability for gathering and learning from additional information, such as user preferences. The framework's emphasis on smart products accommodates the necessary perspectives to explore trust in sea ice information, necessitated by increasing automation trends. Michler et al. (2020) identified seven factors as influential in building trust in smart products: control, performance, handling, brand, onboarding and information, transparency, and security and protection. In our adapted framework (Fig. 1) we omit security and protection because in our extended engagements with users, the question of data sharing and handling most prominently emerged in the context of interoperability between technologies and platforms and not from the perspective of privacy or security. Instead we complement the typology with a factor of our own we call *peer endorsement* to denote the importance of peers by way of recommendation (has it been adopted by others into routine use?) and whether a product was co-produced with users (has it been developed or adapted based on user feedback?). Peer recommendation is an important dimension of trust toward WWIC products (Blair et al., 2022; Rautenbach and Blair, 2021), while co-production approaches can proactively create interaction between producers and users of complex and automated information services (Dawson et al., 2017). If users have a strong relation with a particular producer whose information products they routinely use, they are more likely to trust new products of this same producer (see also Lamers et al., 2018a).

We use this WWIC framework of trust-building factors as depicted in Fig. 1 to take stock of the understanding between producers and users about trust-promoting factors in the sea ice information value chain.

2. Methods

2.1. Cultural consensus analysis

Mariners and the organizations supporting navigation can develop distinctive traits (learned knowledge, modes of interaction), unique mental models and organizational cultures as a result of, and resulting in, practices and social-material contexts (Lemire, 2015; Kuonen et al., 2019; Hederstrom, n.d.). These factors may be reflected in information needs, consensus of information exchanges and a constellation of trust attributions (Lamers et al., 2018b; Blair et al., 2022). We used cultural consensus analysis (Romney et al., 1986; Weller, 2007) to document the variation in and consensus about experiential knowledge that may exist among users and producers of sea ice information products. Cultural consensus theory is a collection of analytical techniques and models that can reveal agreements among a group of people as a reflection of a shared knowledge domain -in our case about the factors that surround trust in, and uptake of, sea ice information products. An advantage of cultural consensus analysis is that a small population of respondents can yield rich observations and data about group- and subgroup-level understandings; revealing sector or discipline-specific views as they may exist among service providers for the Arctic region and the users of their services. Following the establishment of the knowledge domain (see section 2.2), the consensus model is a statistical method that estimates shared beliefs relying on three steps (Weller, 2007):

1. Principal component analysis tests whether the responses are consistent with an underlying shared model for the topics covered in the survey. This consensus is determined by the presence of a single

factor that explains most of the variation in the responses, with a first to second eigenvalue ratio greater than, or equal to, 3.0.

2. A measure of individual competence for each respondent is provided. This so-called cultural competence score is found by testing each respondent's agreement with shared beliefs, using the covariance coefficients. The competence score is derived from the probability (value between 0 and 1) that an informant knows (not guesses) the answer to a question. Competence here refers to the individual's level of knowledge of the specific group-level beliefs (shared knowledge domain) in question.
3. Individual answers to questions are aggregated by weighting the cultural model (what the group holds as true) in favor of respondents with high competence. This produces a set of responses that can be considered as the consensus-based result, an approximation of the collective knowledge of the group.

For data analysis we used the match coefficient method of the formal consensus model in the UCINET software package (Borgatti et al., 2002).

2.2. Questionnaire

Thirty-two dichotomous propositions were presented to both user and producer participants in true/false format and later submitted for consensus analysis. The propositions were carefully compiled to represent a coherent domain of knowledge about the factors that foster trust in users of sea ice products (Fig. 1) drawing on literature (Michler et al., 2020) and extensive interactions in workshops and interviews with end-users during the course of a three-year project (Lamers et al., 2018b; Blair and Muller-Stoffels, 2019; Jeuring and Knol-Kauffman, 2019; Blair et al., 2020; Jeuring et al., 2020; Blair et al., 2022). The survey was made available online and promoted via the authors' email contacts, professional networks including relevant organizations with an extensive membership base, and collaborative online platforms. Recruitment ultimately aimed to engage a sufficient number of participants to satisfy validity criteria for cultural consensus analysis. Adequate sample size ultimately depends on the level of agreement found in a group, and the accuracy with which one hopes to estimate group-level answers to questions (Weller, 2007): At low levels of agreement, about thirty people per group is needed to estimate group-level answers with confidence; while in cases of extremely high consensus, as few as five people may be sufficient. We therefore aimed to recruit around thirty people per group. No personally identifiable information was collected and all procedures were performed in compliance with General Data Protection Regulation guidelines. The research was exempt from ethical clearance as per Wageningen University and Research regulations, and informed consent was obtained at the beginning of the survey.

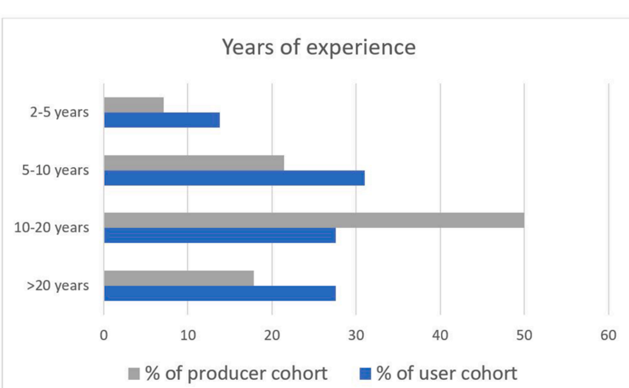

Fig. 2. Respondents' years of experience in field of expertise.

3. Results

3.1. Participant demographics

In total there were N = 57 respondents to the questionnaire, comprised of n = 29 users and n = 28 producers of sea ice services. These numbers proved to be sufficient for the use of consensus analysis after Weller (2007), as the minimum sample size was met based on level of agreement (mean competence scores) and eigen value ratios obtained in the two cohorts (refer to Section 3.2). Fifty-five percent of users indicated they had more than 10 years of experience in their profession, while sixty-eight percent of producers indicated the same (Fig. 2).

Fig. 3 depicts responses to demographic questions in the user group. Most participants had affiliations with the Arctic shipping sector, while passenger shipping (tourism), ice-breaking, piloting and sea ice consultancy were also represented, to a lesser extent. Most users reported familiarity in Svalbard and Greenland waters and nearly half reported regular use of automated sea ice information products. All but two respondents in the user cohort indicated that they use sea ice products onboard vessels for tactical decisions, roughly half indicated use during onshore route-planning activities, and six respondents indicated use while in sea ice.

Most respondents in the producer cohort are affiliated with public service providers, and are involved with research and development activities (Fig. 4). Two-thirds of producer respondents reported that their institution provides automated sea ice products. This supports similar trends reported elsewhere about the increased rate of automation in forecasting services in general (Doswell, 2004; Stuart et al., 2006; Pagano et al., 2016).

3.2. Consensus analysis results

We approach the consensus analysis from two angles. First, we analyzed all participants together as a single cohort in order to test for the existence of a shared knowledge model between producers and users. We refer to this set as the *producers-users cohort*. Second, we analyzed users and producers separately in order to see if the consensus-based answers to any of the propositions are different within the subgroups. We refer to these groups as the *users* and *producers subgroups*, respectively.

We found a strong, coherent consensus model for all scopes of analysis (producers-users cohort, users subgroup, producers subgroup). As indicated in Table 1, the ratio of first to second eigenvalues was greater than 3.0 in all three runs of the analysis. This indicates that our participants agree about the factors that foster trust toward new sea ice products in users. Analysis of the entire response set submitted by the producers-users cohort resulted in a mean competence score of 0.62 (SD = 0.12) and nearly identical results were obtained separately in the users and producers subgroups. The minimum sample size required for consensus analysis at 0.95 validity, in a group where the mean competence score is 0.6; is N = 17 (Weller, 2007), a criterion met by all three cohorts in our analyses. None of the respondents had negative competence scores in any of the consensus models. Negative competencies would signal that a participant responded very differently from others.

The agreement between users and producers was visualized using nonmetric multidimensional scaling (Fig. 5). The visualization is based on the respondent-by-respondent agreement matrix used in the consensus analysis, and it depicts the proportion of agreement between respondents as a pattern of proximities in space. Those who had high levels of agreement with each other are situated close to each other, while those who had high levels of disagreement are scattered proportionally farther apart. The visualization indicates that most producers (blue squares) cluster close and centrally with users (red squares) who have high competence scores. Respondents who are scattered outside the blue oval had lower competence scores. This applies to five producer- and seven user-respondents. While there is strong consensus in

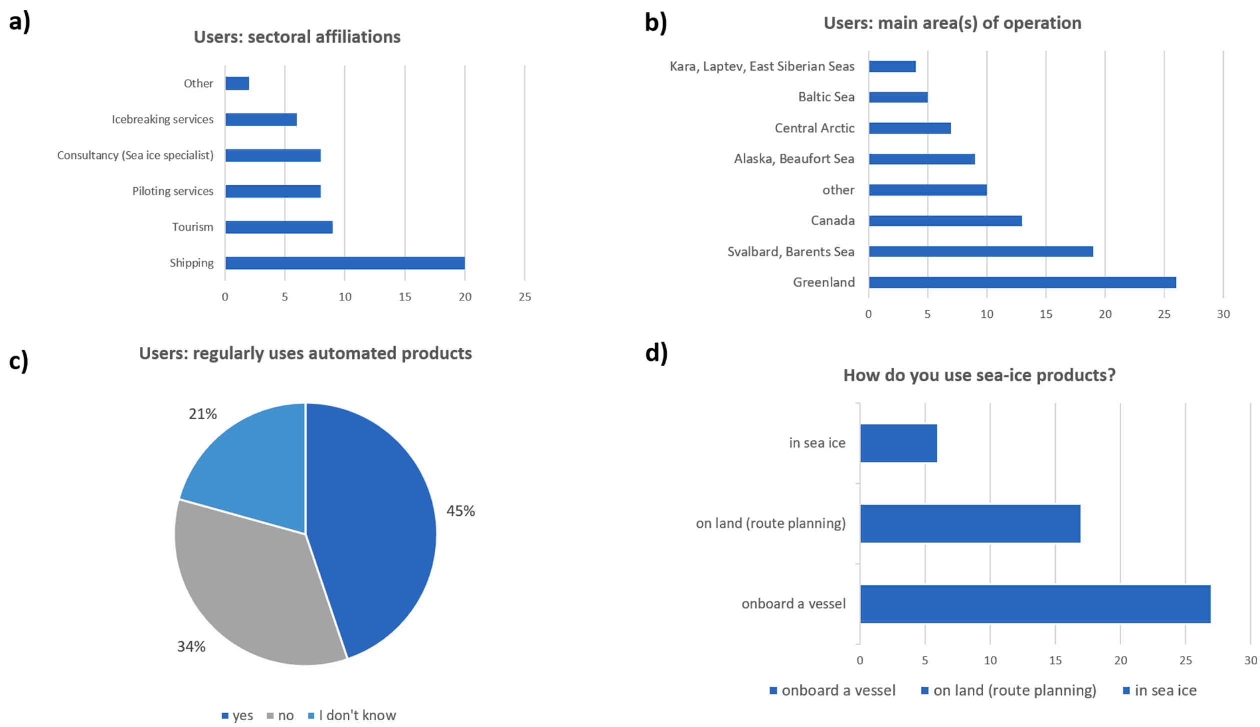

Fig. 3. User demographics. Panel a: sectoral affiliations. Panel b: geographical contexts. Panel c: level of engagement with automated sea ice products. Panel d: routines with sea ice product use.

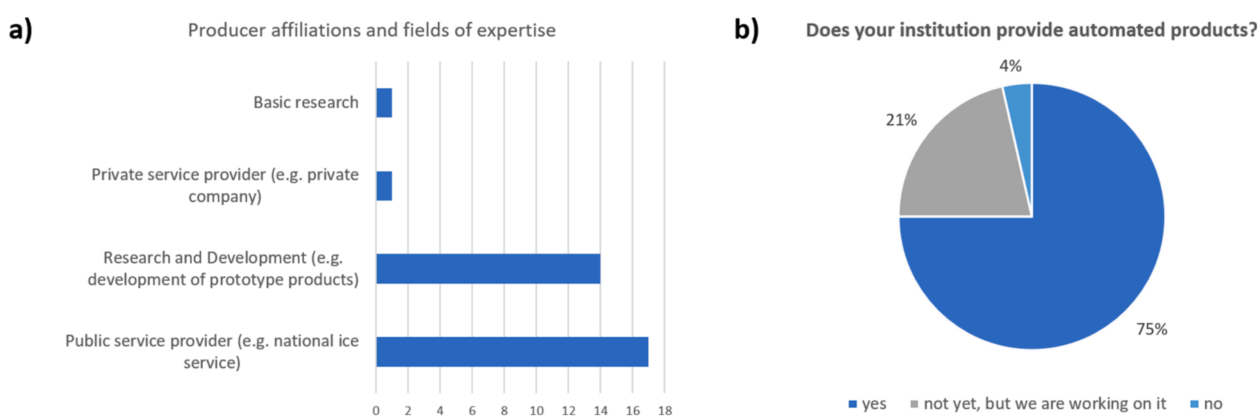

Fig. 4. Producer demographics. Panel a: affiliations and area of expertise. Panel b: prevalence of automated products at respondents' institutions.

Table 1
Consensus analysis, group mean competence scores and eigenvalue ratios of the first to second factors for each study cohort. Here, SD refers to the Standard Deviation.

Scope of analysis:	1st to 2nd eigen value ratio	mean competence (SD)	mean user subgroup competence (SD)	mean producer subgroup competence (SD)	Negative competence scores	conclusions
producers-users cohort N = 57	6.3	0.62 (0.12)	0.6 (1.12)	0.64 (0.11)	none	consensus
users subgroup n = 29	6.3	0.61 (0.11)	———	———	none	consensus
producers subgroup n = 28	6.2	0.63 (0.13)	———	———	none	consensus

the producers-users cohort, the visualization indicates that blue squares (producers) generally cluster above the X axis while red ones (users) tend to cluster below it. This suggests that some of the propositions drew dissimilar answer patterns that were unique to the subgroups.

This hypothesis can be confirmed by studying the level of consensus for every proposition separately. Table 2 lists all survey propositions and the producers-users cohort's consensus-based answers (True or False) as well as the percent of respondents in the two subgroups who gave

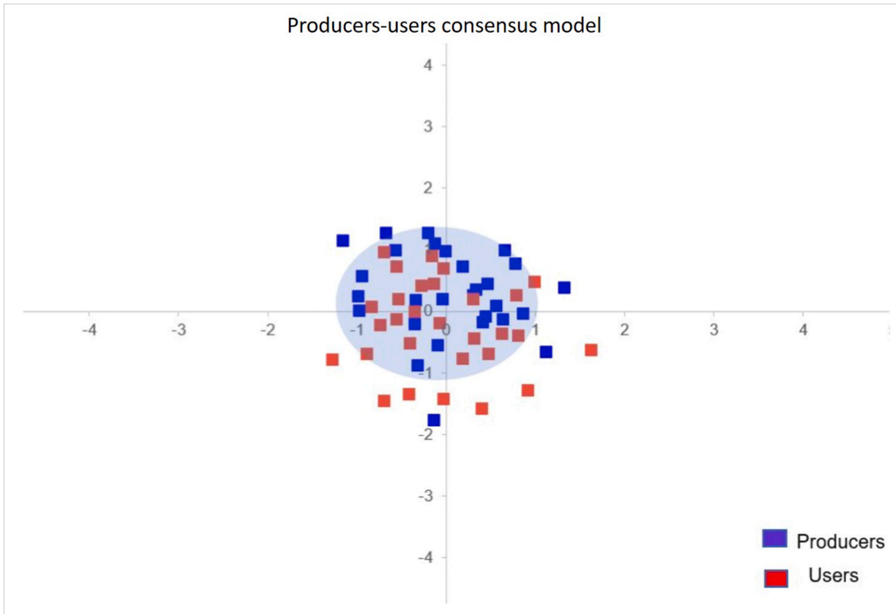

Fig. 5. Nonmetric, multidimensional scaling of agreement in the producers-users cohort (stress = 0.259, N = 57 fulfilling criteria by Sturrock and Rocha (2000) for goodness-of-fit). Blue oval at center encompasses respondents whose competence score was 0.6 or greater. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

matching answers. In all but two cases (propositions 29 and 30) the user and producer subgroups' own consensus models matched the combined producers-users cohort. One of the two propositions that drew disagreement between the two groups probed whether users are more likely to adopt products if they disclose underlying uncertainties, for example via reliability estimates. While the consensus in the combined producers-users cohort is agreement (and 79 % of producers agreed) the user group's consensus-based answer is disagreement with this statement (55 % of users answered with 'false'). In the other case where the two subgroups had different consensus results over a proposition, respondents evaluated the statement "Most users are willing/able to pay for high-quality products". The whole-group consensus is that this statement is false. However, 59 % of users believe this to be true (the consensus in the users-subgroup) against just 36 % of producers.

The rest of the propositions resulted in similar answer patterns in the two subgroups: there is strong agreement that users are capable of understanding automated products, that automated products have the potential to decrease the cost of high-quality services, and that human involvement will continue to be needed both for specifically complex tasks and for quality-checking because users are not ready to trust fully-automated products. Interestingly, most users (66 %) do not believe that automation increases the need for training and support, while producers are split on this issue (50 %). Producer reputation is an important consideration. Generally speaking, products (including commercially priced) from public entities such as national weather services are trusted more by users than those offered by private ones. This can be mitigated by time and experience with a producer: well-known, established producers are trusted more than newcomers. While the proposition that freely available products are likely to be of worse quality than commercial ones elicited disagreement in both groups, it is noteworthy that 45 % of users still agreed with this statement (as did 21 % of producers), which is not an insignificant figure. Products that have been co-produced with users are trusted more than those that were not; and this proposition received 100 % agreement from user respondents -one of only two propositions to do so. Perhaps unsurprisingly then, users are more likely to trust products when recommended by peers and colleagues, and are not at ease being the first to adopt a new service. Whether a product is recommended by a scientist or developer is of consequence to roughly half of users, who agreed that this would generate enough trust to try a new product. Importantly, both users and producers strongly agreed (>90 %) that users are not sufficiently aware of the whole suite of newly available sea ice products.

Operational routines are important drivers in determining which products are trusted and used. Users strongly agree that they tend to stick to proven routines, products and sources (where they access information) and are not at ease with trying out new ones. However when they do so, a trial period is critical and they strongly agree that the full value of new products can only be grasped after a trial period. There was only weak agreement (55 %) that most users need special training to be able to try new products. In terms of trust-generating factors related to design, intuitive layout, color schemes and other features that promote user-friendliness (compatible format, customizable zoom and scroll features) are important considerations, in addition to the use of consistent terminology. There was only weak agreement (55 % users, 54 % producers) that value-added products (such as 'traffic light' or other merged visualizations of diverse datasets) are trusted more than products that depict raw data.

Finally, five propositions (propositions 8, 23, 24, 25, 26) probed a baseline understanding of issues around existing user needs. Responses confirm that there is a need for more sea ice information as currently available products do not offer adequate spatial or dynamic coverage of conditions to support Arctic maritime operations. There was overall consensus that currently available products do not meet a level of quality required by users (accuracy, resolution, update frequency). Interestingly, 34 % of users, but only 7 % of producers *disagreed* with this proposition, suggesting that users may be less dissatisfied with the quality of currently available products than is estimated by producers.

4. Discussion

The results contribute to our understanding of how uptake of sea ice information by users can be enhanced, with an emphasis on the role of trust, and shared views of producers and users of products and services. One limitation in our study stems from the dichotomous true/false format of the survey, a common approach in cultural consensus analysis studies. This format nudges participants who are on the fence or

Table 2
Factors that promote/hinder trust in new sea ice products. The producers-users consensus model is based on the analysis of the entire dataset consisting of all respondents; this consensus model is shown as agreement (check mark = true) or disagreement (X = false) with the propositions. Level of consensus in the users and producers subgroups is measured by the frequency of answers (%) that match the producers-users cohort's answer. Where a subgroup's own consensus-model (consensus analysis including only members of the subgroup) deviates from the producers-users cohort's model, the added icon shows the consensus model specific to that subgroup.

	Trust-building factor	Subtopic	Proposition	Producers-users consensus model	Users subgroup % match	Producers subgroup % match
1	Brand	Perceived quality tied to producer identity	Products from public authorities are trusted more by users than those offered by private producers.	✓	69	75
2	Brand	Perceived quality tied to producer identity	Products developed by new-comers are trusted just as much as products from well-known producers.	×	93	86
3	Brand	Quality	Users are more likely to try a new product if it is recommended by a scientist.	✓	55	50
4	Brand	Quality	A freely-available product is likely of worse quality than a commercial one.	×	55	79
5	Brand	Familiarity	Currently users are sufficiently aware about the availability of new products.	×	90	93
6	Control & Performance	Complexity/Autonomy, Reliability	Users are ready to trust a fully-automated product without quality-check by a human.	×	76	64
7	Control & Performance	Complexity/Autonomy, Reliability	Some complex tasks will continue to need human involvement	✓	93	79
8	Handling	Functionality	There is a need for more animated products.	✓	76	71
9	Handling	Ease-of-use	An intuitive "look and feel" of the new product, such as layout and color, impacts whether users adopt it.	✓	97	93
10	Handling	Ease-of-use	Users trust a new product more if it is presented in simple, basic layout without gimmicks.	✓	76	71
11	Handling	Compatibility and familiarity with existing systems	The format of the product/data files and whether they can be used with existing software (e.g. ECDIS compatibility) impacts the adoption of new products.	✓	90	96
12	Handling	Compatibility and familiarity with existing systems	Users are more likely to adopt a new product if it's accessible in the same place where they access other products already.	✓	97	93
13	Handling & Control	Enjoyment, customizability	An attractive layout and user-friendly features (e.g. ability to zoom and scroll) impact whether users adopt the product.	✓	90	93
14	Onboarding	Building understanding	Users are capable of understanding automated products	✓	69	54
15	Onboarding	Building understanding	Most users need to get special training (e.g. in form of a course) in order to be able to adopt a new product.	✓	55	57
16	Onboarding	Building understanding	Automation increases the need for training & support	×	66	50
17	Onboarding	Building understanding and knowledge transfer	Users tend to stick to proven routines and familiar products and therefore they are hesitant to try new ones.	✓	79	86
18	Onboarding & Performance	Building understanding; Expected performance	Consistent terminology and appearance (e.g. familiar color schemes) across products and platforms increase the chances of adoption by users.	✓	100	100
19	Onboarding & Performance	Trialing; Reliability	Users can fully grasp the value of a new product only after they have used it for a while.	✓	93	89
20	Peer endorsement	Co-production with peers	Users trust a new product more easily if it has been developed in co-production with other users.	✓	100	93
21	Peer endorsement	Peer recommendation	Users adopt a new product more likely if a colleague/peer is recommending it.	✓	93	96
22	Peer endorsement	Peer recommendation	Users are at ease adopting a new product earlier than their peers/colleagues (being the first).	×	62	75
23	Performance	Availability	There is need for new sea ice information products to support Arctic maritime operations.	✓	90	93
24	Performance	Availability	Currently available products meet user needs in terms of scope (spatial coverage, available quantities).	×	69	82
25	Performance	Accuracy	Currently available products meet the user needs in terms of quality (accuracy, resolution, update frequency).	×	66	93
26	Performance	Technical performance	Currently available products adequately convey the dynamics of conditions, such as sea ice drift.	×	86	82
27	Performance	Perceived price-performance ratio; Availability	Automation increases the number of affordable, high-quality products	✓	79	89
28	Performance	Stability & Availability	Bad onboard connection for many users hampers the adoption of new products.	✓	86	86
29	Performance	Perceived price-performance ratio	Most users are willing/able to pay for high-quality products.	×	✓	64
30	Transparency	Comprehensibility	A new product is more likely to be adopted by users, if it discloses underlying uncertainties (e.g. reliability estimates) and capabilities.	✓	×	79
31	Transparency	Comprehensibility	Value-added products (ready-made interpretations e.g. time averages, navigation risk, travel time), are trusted more than products that depict raw data.	✓	55	54
32	Transparency	Regulations	Current regulatory frameworks tend to be favourable for the adoption of new products.	✓	62	61

otherwise neutral on a topic to lean toward agreement or disagreement. We explained to participants that the purpose of the study is to gain an understanding of group-level beliefs about the topics presented. Both users and producers were instructed to answer, to the extent it was possible, from the prevailing perspective about the topics within their respective groups. We acknowledged the difficulty in the dichotomous question format, and asked participants to think about how their peers would respond to each question item. Future studies may focus on in-depth discussions with producer and user groups especially focusing on the few topic areas that drew dissimilar answer patterns. While in this study we made a clear distinction between users and providers, the value chains of WWIC information services are more complex (Dawson et al., 2017; Jeuring et al., 2020). For example, operational forecasters are also users of information and products that are produced by the research departments. Future studies may also explore beliefs, trust and consensus across more ambiguous contexts where provision and use of products overlap. Our results contribute to a range of points for discussion relevant to strategic thinking about present and expected future challenges in the provision of sea ice information products and services.

4.1. Trust in new products and services

Trust in sea ice products and services is built up in practice by using products regularly. Our respondents confirmed the importance of an established track record of trust with producers. However, our results suggest that a constellation of factors together influence users' trust in forecast products, and that producers are aware of these factors. Consistent terminology and standardized visualization across products and platforms are important in fostering trust – and this was confirmed by both user and producer cohorts with unanimous agreement.

Importantly, we also confirmed that users trust the expertise of their peers when it comes to which products should be adopted into operational routines, and this trust is also reflected in the reported prestige of co-produced products. A recent comparative study of commercial and recreational coastal resource users in South Africa and New Zealand (Rautenbach and Blair, 2021) also found that recommendation by peers is important for the uptake of marine meteorological products for both recreational and commercial user groups. Our respondents' preference for, and indicated trust in, public entities is aligned with previous studies that showed high pubic trust in (for example) Environment Canada (Silver, 2015), and the national weather services of New Zealand and South Africa (Rautenbach and Blair, 2021). This indicates that users value the standardized and established best practices that are followed at National Meteorological and Hydrological Services (NMHSs), and place trust in the competency of their products and services.

4.1.1. Potential impacts of automation

Automated products are seen as valuable complements for users, by both users and producers. They agree that users are capable of understanding automated products. This is a basic prerequisite to further pursuing the direction of development of new automated products. Both groups expect benefits in terms of decreased costs for high-quality products, without increased need for training and support. Regarding training and support, producers are indifferent, which could either mean that producers underestimate users' capabilities or that producers are more careful due to their better understanding of the product type and the related challenges. Whether the automation process of ice products is sufficiently transparent for users to grasp or whether further evaluation is needed about user demand for training and support is an important question. If automated products do not require special training and support, this would help to onboard users and foster trust in the new products (Michler et al., 2020).

Irrespective of the benefits of automated products, both groups also agree that human actors will keep an important role in the production process, both for solving very complex tasks and for quality-checking. Especially the user group sees human supervision as important, as highlighted by this comment left on our survey by a user respondent:

> "[…] Automation is important but close human supervision is necessary and confirming this information with local sources to improve the data delivered."

4.1.2. Cost-performance perception as a trust-promoting factor

Beliefs about the potential cost of different types of sea ice information, and the willingness to pay for certain services appears related to product usability. Users say they would be willing to pay for high-quality products while public service providers tend to think that sea ice information should be available for free as much as possible. This duality may exemplify a tension that is signifying the contemporary landscape of weather and climate information services, with a wide variety of business models (Rogers et al., 2021). What is the public role of NMHSs, where are the boundaries of public services? Especially for national meteorological institutes, who often primarily have a public responsibility to contribute to safeguarding life and property, navigating modes for expert-level service provision (which sea ice information services arguably are) is closely tied to debates about justification for investing public money. The Arctic user context differs considerably from those found at lower latitudes in that the absolute volume of potential public users is relatively low, simply due to the area being sparsely populated. Decisions on who will be able to access which information, and to whose needs the sea ice service portfolio is tailored need to take into account the wider context of Arctic service provision across public–private partnerships, and what positions NMHSs responsible for Arctic environmental prediction need to take in order to fulfil their public responsibilities. In that light, justification of significant investments made in large-scale initiatives to improve environmental observations and prediction (e.g. Copernicus) may be challenged by limited possibilities for upscaled uptake of high quality services built on top of such initiatives, if commercial services turn out to be the only viable business model. This way, the potential of the enormous increase in high quality data remains largely unused.

That said, current expert-level information needs that can push the service quality to the next level may come from the private sector (cruise tourism, global shipping) who are exploring the boundaries of safe maritime operations in the Arctic. Successful small-scale and highly tailored collaborations with commercial users may result in next-level services that can be upscaled and spill over into the public realm. Similarly, if NMHSs stay away from catering to private sector needs, they may be missing out on important income and knowledge that can be used for improvement of public products and services.

A related issue is the risk of a too-polarized distinction between free services catered to the general public on one hand, and commercial, tailored services for specific user niches on the other. High levels of expertise and congruent specialized maritime user needs may not match with what is publicly available. Especially 'small scale' users with low resources may not be served by a service format that discerns between the general public (free info) and expert users (able to pay) (Jeuring et al., 2020). This may be a particular challenge in the high-stake Arctic environment where the daily life of local communities is strongly shaped by the extreme conditions, including sea ice conditions (Cooley et al., 2020).

Cost-benefit perceptions may be affected by the inherent relationality of environmental information and the beliefs behind what usability means from either producer or user perspectives. High quality services are only translated in high usability, given a specific user context, regardless of the service being paid for or freely available. Exemplary for this is the response patterns to the survey item "A freely-available product is likely of worse quality than a commercial one". While both users and producers have consensus that this statement is untrue, it is worth noting that 45 % of users marked this as true. This can be explained by the simple observation that users most likely relate to information quality based on how it matches their own specific needs and evaluations of saliency, while producers may assess quality in terms of how it caters for needs across several user contexts.

4.1.3. Co-production and peer endorsement of products

In line with the climate services literature, our results suggest that users in the European Arctic are convinced by the greater levels of trust and usability of co-produced ice products. This is remarkable given the relative newness of the field. While peer recommendation and co-production are considered an important factor in enhancing usability, our results also make clear that experimentation and feedback is considered important as part of product development, as users make clear that they would not want to see a product that is not accurate or that discloses underlying uncertainties or reliability estimates. This could very well be related to the importance of experience and the lack of transferability of digital products in the remote Arctic ocean environment, where navigators have to be pragmatic with regard to product use (Lamers et al., 2018b). Captains and navigators are used to making their own decisions and will not take a sea ice product for granted, while producers think that they need to show such kind of information in order to be transparent and on the safe side.

For example, a survey comment left by a user respondent reiterated the value of peer-recommendation for new products, but warned that in any case, personal experience is the determining factor:

> “[…] For years it has been seen how the delivery of ice information has improved, to adopt new software it is necessary to confirm with experience that the information presented is accurate or very close to reality. Using a software recommended by a colleague should be evaluated until you know that it is reliable.”

4.2. The last mile for sea ice services

Much is known about what sea ice parameters maritime operators currently use, and would like to see being provided in the future. From consistent feedback from 10 years of studies into the spatial and temporal scales that marine users require for sea ice and iceberg information (Wagner et al., 2020), it appears that a breadth of user priorities have already been translated into scientifically tractable questions, waiting to be operationalized through useful products. Our findings confirm this status, and it may be the case then, that in the field of specialized sea ice information, co-production efforts have yielded sufficient knowledge about user priorities. This would mean that bridging the remaining usability gap in sea ice services may now be a function of not only improved predictive capacity, but also rethinking unconducive funding mechanisms for full operational implementation. Institutional (e.g. funding) and regulatory transitions that accommodate the implementation of what we know is vital to effective co-production that may result in meaningful knowledge use and decision-support for society (Lahsen and Turnhout, 2021; Arnott et al., 2020). Thus, to deliver on the promise of co-production as a facilitator to cover the last mile to successful user uptake requires careful shifting of emphasis from a continued examination of misalignments in supply/demand to the implementation of enhancements based on what is already known. In climate services development the emphasis for more interaction and co-production between producers and users is ever-present with the goal of closing the usability gap (e.g. Lemos et al., 2012). Yet in order to surmount this challenge, it seems that sea ice information and forecast development faces a set of pressing next steps, overcoming technical as well as wider societal and political obstacles, to implement the wealth of information about user needs that is already known.

5. Conclusions and recommendations

Mapping sea ice and communicating the information via usable products is a challenging endeavor: it is at once challenging technological and scientific frontiers, while it also demands ever-evolving stakeholder engagements to align the goals and resources of institutions with user priorities. In our study we prioritized insights about the extent to which user engagements have yielded understanding in producers about the factors that promote trust in new sea ice information products. Using a consensus model approach, we found that producers and users are in agreement about the necessary improvements needed to increase users’ trust in new services.

Our results showed that both users and producers emphasize the importance of producer reputation, trial period, peer-recommendation, co-production with users, user-friendly design, consistent terminology and ensuring that users are aware of the full range of already available products. Producers and users agree that users have a positive attitude toward automation and feel confident that it is a positive force for better products and services, though they foresee that users want continued human involvement for optimal trust. In spite of an overall strong consensus model between producers and users, there was disagreement around whether users are willing to pay for high-quality products, and whether they want products to disclose underlying uncertainties.

Based on our findings we propose that, for the foreseeable future, a number of questions will continue to be important determinants in narrowing the usability gap for sea ice information products: 1) whether the automation process of ice products is sufficiently transparent for users to grasp; 2) whether users are sufficiently made aware of the whole suite of newly available sea ice products; 3) whether experimentation and feedback is an integral component of co-production and product development; and 4) the ability of NMHSs responsible for Arctic environmental prediction to match their significant investments in large-scale initiatives to improve environmental observations and prediction with upscaled uptake of high quality services.

Going forward, efforts to mitigate the misalignment between the goals and resources of institutions and user priorities via time-managed co-production projects need to be re-imagined. There is a need for increased consideration of the funding mechanisms required for full operational implementation of service improvements, including international coordination of the funding landscape and adequate platforms and programs to link expert knowledge. Not unlike the ‘last mile’ challenge in climate change adaptation (Celliers et al., 2021), considerable energy and organization is needed to ensure that existing useful information for sea ice services provision is implemented to fully profit from co-production and to facilitate practical uptake of decision-support tools.

CRediT authorship contribution statement

Berill Blair: Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Andrea M.U. Gierisch:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Jelmer Jeuring:** Investigation, Writing – original draft, Writing – review & editing. **Steffen M. Olsen:** Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Machiel Lamers:** Conceptualization, Investigation, Funding acquisition, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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