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Editorial: The state of knowledge from operational ice service perspectives: previous and future mandates

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Editorial on the Research Topic
The state of knowledge from operational ice service perspectives: previous and future mandates

Sea ice and iceberg services hold a unique and critical position at the interface of maritime activity, science, and policy in ice encumbered areas all around the world. They are the authoritative sources of sea ice and iceberg information and their role requires the use of non-traditional observations, satellite sensors, and local knowledge to translate complex cryospheric observations into practical information so those operating in these areas can make informed decisions using the most representative and relevant environmental information.

Polar and sub-polar regions have been experiencing rapid changes, shifting from stable ice regimes to more dynamic seasonal ice conditions. At the same time, satellite coverage has improved significantly over the past decade, and we expect the satellite coverage to increase with faster processing capabilities in the future. It is therefore essential for sea ice services, the research community, and third-party product providers to strengthen their collaboration to help meet current and future sea ice monitoring challenges and fully exploit emerging technologies.

The Research Topic The State of Knowledge from Operational Ice Service Perspectives: Previous and Future Mandates brings together thirteen diverse contributions from national ice services and innovative research focused on developing fit-for-purpose products for operational use. The papers also examine how national ice services and their products must evolve to meet emerging societal and environmental challenges.

The intent of the Research Topic is twofold: first, to document existing ice service practices and mandates, including future plans, across national services; and second, to

explore how recent scientific advances in remote sensing, modelling, forecasting, and data integration may support and complement these services. As human activity, including shipping, fisheries, tourism, offshore resource exploration, and research operations, increases across the Arctic, Antarctic, and seasonally ice-encumbered areas, the demands on sea ice services have expanded well beyond their historical roots in basic ice charting. The articles in this Research Topic provide an overview of these shifting responsibilities and technologies.

Several contributions examine the evolution and historical foundations of operational services. The long-term institutional perspective is presented in the paper, *The International Ice Charting Working Group: the first twenty-five years* by Falkingham, which chronicles the development of international coordination, standards, and shared practices since the IICWG's founding in 1999. This highlights how collaboration across nations has strengthened operational reliability and user confidence. At a national scale, *The MET Norway Ice Service: a comprehensive review of the historical and future evolution, ice chart creation, and end user interaction within METAREA XIX* by Copeland et al., provides an overview of the Norwegian ice operations servicing a wide range of users in Arctic waters, including tourism operators, research vessels, fisheries, and search-and-rescue services. In the Baltic, *Information on operational sea ice products and current and future activities of the German ice service* by Aldenhoff and Holfort, presents how operational workflows integrate satellite data, observations, and archive digitization to maintain consistent and timely products. *The Finnish Ice Service, its sea-ice monitoring of the Baltic Sea and operational concept* by Eriksson et al., describes the parallel evolution of the Baltic and European services, each shaped by specific regional environmental regimes and mandates, navigational demands, and long traditions of shipping support for operators working in and around sea ice.

Antarctic operational needs are presented in *Southern Ocean ice charts at the Argentine Naval Hydrographic Service*, by Scardelli et al. that highlights the importance of accurate charting for navigational safety in Antarctic waters. A complement to the Argentine operations is the *Multi-band SAR intercomparison study in the Antarctic Peninsula* by Salvo et al., which demonstrates how multi-frequency radar datasets are necessary to detect icebergs and complex sea-ice features under challenging conditions, emphasizing the importance of a system-of-sensors for regional monitoring.

A common thread through these reviews is that institutional experience built over many years, together with expert analysis and local knowledge, remains essential. Satellite and sensor data frequently contain ambiguities that require skilled interpretation, and ice services increasingly rely on analysts to ensure that information produced for operations remain accurate and representative. As national services integrate more advanced processing pipelines and adopt new sensors, there is a growing interest in semi-automated production methods, while balancing consistent quality and preserving the integrity of long-term ice chart records, particularly where ground-truth data are limited.

Several research contributions explore emerging capabilities that support sea ice automation and forecasting. Higher resolution satellite data are enabling more refined classification methods, while machine learning techniques show promise for operational automation. *Sea ice recognition for CFOSAT SWIM* by Liu et al. evaluates small-incidence-angle CFOSAT waveforms and demonstrates effective machine-learning approaches for distinguishing sea ice from open water. For sea ice concentration, *Multisensor data fusion of operational sea ice observations* by Wang et al. presents a framework that integrates synthetic aperture radar (SAR), optical, and *in situ* datasets to improve the consistency and reliability of operational products, illustrating how diverse sensors can be combined within one workflow.

Forecasting capabilities in this Research Topic present advancements. The paper *Greenlandic sea ice products with a focus on an updated operational forecast system* by Ponsoni et al. demonstrates how modern coupled ocean–sea-ice modelling and data assimilation approaches are becoming increasingly relevant for ice operations. The Wang et al. paper, *Improving short-term forecasts of sea-ice edge and MIZ around Svalbard*, describes the development and tests of a method to improve short-term forecasting of the sea-ice edge and marginal ice zone around Svalbard, demonstrating clear operational benefits for real-time decision support. For the Antarctic, *SIPN South: six years of coordinated seasonal Antarctic sea ice forecasting* by Massonet et al. summarizes a coordinated multi-model forecasting effort, highlighting both advances and challenges in seasonal prediction. Together, these works capture the accelerating push toward tactical and short-term forecasting and the integration of predictive tools into operational workflows. They also show how improvements in multi-sensor products, along with the use of non-traditional observations for sea-ice classification and forecasting, are helping to shape how future services can be supported.

Human activities in ice encumbered waters are further explored across two papers, reflecting the growing importance of operational guidance for vessel design and route planning support. Studies on polar class shipping accessibility, from the papers Vlietstra et al. analyzes *A decade of sea-ice variability to assess changes in polar-class vessel accessibility north of the Bering Strait* and Liu et al. reviews *Ship-performance models and ice-routing algorithms for Arctic navigation, emphasizing the influence of sea-ice conditions*, present how thinning ice, shifting ice edges, and more variable seasonal patterns influence routing strategies, operational risk, and user expectations for more specialized and tailored ice information.

The thirteen contributions in this Research Topic present a small subset of work being done in a field that is undergoing a significant transition, driven by changing user requirements, advances in automation, expanded observational capabilities, and new forecasting tools. While national sea ice services are adopting semi-automated workflows to meet evolving user needs, they, and the research community working on developments to support these services, reaffirm the importance of expert interpretation and regional knowledge that remain critical for services providing information for safe navigation. Future mandates of national ice services will extend beyond routine ice charting to include more parameters in ice charts, risk-informed decision-making, probabilistic forecasting, and may include the integration of autonomous systems for *in situ* data

collection. As climate change reshapes global sea ice regimes, deeper collaboration across scientific, operational, and policy communities is essential. By combining long-standing operational experience with emerging methodological advances, this Research Topic provides a timely basis for guiding the future development of sea ice services.

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Conflict of interest

The authors declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declared that generative AI was not used in the creation of this manuscript.

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