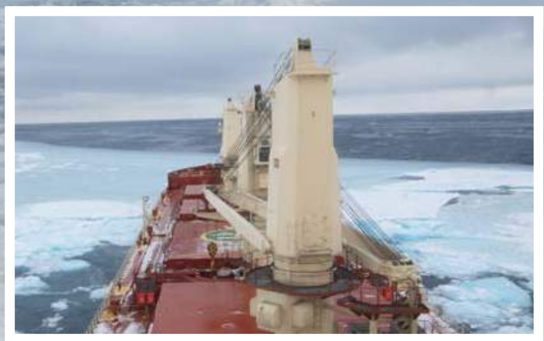
WWRP/PPP No. 5 - 2017

Navigating Weather, Water, Ice and Climate Information for Safe Polar Mobilities



WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER RESEARCH PROGRAMME

WWRP/PPP No. 5 - 2017

NAVIGATING WEATHER, WATER, ICE AND CLIMATE INFORMATION FOR SAFE POLAR MOBILITIES

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WORLD METEOROLOGICAL ORGANIZATION

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at:
http://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html.
Acronyms may also be found at: http://www.wmo.int/pages/themes/acronyms/index_en.html.

WWRP Polar Prediction Project
For related documents refer to http://polarprediction.net

Cover page photos kindly provided by J. Dawson, E.J. Stewart and Meet the North

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EXECUTIVE SUMMARY

The Polar Prediction Project (PPP) was conceived and initiated in 2012 by the World Meteorological Organization (WMO), through its World Weather Research Programme (WWRP), in response to rapid environmental change in the Polar Regions. The primary goal of the PPP is to advance scientific knowledge such that society, both within and outside of the Arctic and Antarctic, may benefit through applications of improved weather and climate services. This includes improved understanding and prediction of physical parameters and the ways people use the available information. To this end, the Polar Prediction Project Societal and Economic Research and Applications (PPP-SERA) working group was established in 2015.

This report represents the foundational work of PPP-SERA and aims to explore how weather, water, ice and climate (WWIC) information is currently being used and produced in the Polar Regions, by whom, and for what reasons. The report also identifies, frames and articulates important areas of research related to the use and provision of environmental prediction services that should be prioritized and further developed during, and beyond, the Year of Polar Prediction (YOPP, 2017-19).

The concepts of information *value chains* and human *mobilities* are used in this document to conceptualize the complex interaction between the production and use of environmental prediction information. This approach facilitates: (a) the exploration of WWIC-related risks that affect physical movement of people, goods and services between places (i.e. mobilities); (b) an examination of the demand for, and production and mobilization of, WWIC knowledge and information that can inform user decisions (i.e. value chain).

We identify that WWIC information provision occurs through a variety of actors, from formal state institutions, to private and community-based organizations, to Indigenous and local knowledge obtained by a range of individual actors or groups, positioned in an increasingly complex value chain of information provision and use. The constitution, functioning and implications of these increasingly complex WWIC information value chains are currently not fully understood. Value chains used to describe linear processes whereby WWIC information was transferred directly from providers to users. Today, users not only consume WWIC information but they also co-produce data, information, and decisionmaking products. This has largely been facilitated by technological advancement and improved communications via the Internet, which promotes a decentralization of WWIC information services. Consequently, it is difficult to discern whether or not user needs are being adequately identified and addressed by providers and whether WWIC services are adding value to users.

Our analysis indicates that human activities and mobility sectors operating in the Polar Regions vary widely in size and scope, and are diverse in terms of operational contexts and practices. Despite the challenge of mapping the temporal and spatial dimensions of human activities in the Polar Regions, due to a paucity of consistent information, we discuss relevant characteristics and future prospects of a range of distinct mobility sectors including: (a) commercial transportation (shipping and aviation); (b) tourism: (c) fishing; (d) resource extraction and development; (e) community activities; (f) government activities and scientific research. Most activities are on the rise and human activities in the Polar Regions are becoming increasingly diversified. Users appear to be increasingly dependent on specialised WWIC information services and technology needed to access these. More detailed, specialized and near-real-time weather and climate services are required to provide relevant information for a diversity of contexts and practices. While higher-quality WWIC information and greater resolution of data is necessary for some, it is insufficient for all. There is no 'one-size-fits-all' data product needed to assist the variety of users. Furthermore, the existence of more and

improved WWIC information does not necessarily mean that it will be used. For WWIC data to be valuable and used, they must be trusted, easily understood, accessible, and packaged for easy transmission to remote areas with limited Internet bandwidth.

There is also a need for systematic documentation regarding particular uses of existing WWIC information services, and thus more work is needed to collect data necessary to situate human activities and their mobilities within their spatial-temporal contexts and decisionmaking practices.

To respond to these knowledge gaps, we identify that in-depth qualitative and quantitative research is needed which explores: (a) user information needs, behaviours and preferences; (b) the relationship between users and providers of WWIC information, including the co-production of services; (c) factors that enable or constrain access to, or provision of, WWIC information services; (d) infrastructure and communication needs.

PPP-SERA, and social scientists involved in research that focuses on the Polar Regions more broadly, can contribute to addressing some of the knowledge gaps outlined in this document. We have compiled an initial database of sources for WWIC information that is of relevance for different user sectors and across different regions, and we envision broader and ongoing contributions to this effort. We also identify a need for categorization of users, decision factors, services sought and providers tailoring products for specific mobilities. This will highlight the complexity and interconnections between users, providers and decisionmaking contexts across the Polar Regions.

The Polar Regions are undergoing dramatic environmental changes while seeing a general growth and diversification of human activity. These changes imply that WWIC services not only need to respond to rapidly transforming environmental parameters, but ought to be salient in the diverse contexts in which users engage with them. While it is still largely unknown how WWIC information services are currently being used, and to what extent they influence decisionmaking and planning, improved access to, and quality of, WWIC information is considered as significant for reducing the risks related to human activities in dynamic polar environments.

1. INTRODUCTION

The Arctic and the Antarctic Peninsula have been warming at a higher rate than any other region in the world (see e.g. Graversen et al., 2008; Vaughan et al., 2003) resulting in profound socio-economic consequences (Emmerson and Lahn, 2012). The prospects of warming regimes causing continued decline of sea ice are propelling expectations of growth in marine mobile activities, such as shipping, tourism and fisheries. For example, it is expected that the Arctic will attract economic investments in excess of $100bn in the coming decade (Emmerson and Lahn, 2012). It is claimed that we are transitioning from experimental shipping activities (Brigham, 2010) to a more routine use of polar marine environments (Hillmer-Pegram and Robards, 2015).

At the same time, there is growing concern about the risks involved in increased human activities in the Polar Regions (see Table 1.1). Various reports of maritime incidents in both the Arctic and the Antarctic region are calling for stricter regulations (e.g. the Polar Code) and stronger capabilities with regard to maritime safety and search and rescue (SAR) (Liggett et al., 2011; Dawson et al., 2014; 2016; Marchenko, 2014; Jabor 2014). The effects of climate change in the Polar Regions are wide-ranging and include coupled physical events of relevance to polar maritime sectors, such as fast-ice formation and breakup with the potential of episodic iceberg calving events in the coastal zone, ice-shelf collapse, extreme weather events combined with icing, and the opening and closure of coastal leads under anomalous atmospheric conditions. In addition, the marine insurance industry – whose collaboration is essential to the commercial viability of polar maritime activities – holds a host of safety and navigational concerns (Marsh, 2014; Ghosh and Rubly, 2015; Jóhannsdóttir and Cook, 2015).

Table 1.1. Examples of environmental changes and risks for human activities in the Polar Regions

Environmental change	**Examples of safety risks**
Changing sea ice conditions	Changing patterns of freeze up and break up, lengthening of the open water season, and increased accessibility
Seasonality	Changing weather and ice conditions can affect seasonality, opportunities for marine operations and local transportation, and also influence the timing of safe transportation and resupply to both Arctic communities and Antarctic research stations.
Extreme weather events	Increasing likelihood of more severe impacts from extreme weather events (e.g. stronger storms and precipitation events) due to the disappearing ice cover, resulting in higher waves, coastal erosion and icing that affects marine operators and communities
Low visibility and other environmental factors	Risk of damage for equipment and human life near airfields and during start and landing due to fog, or while travelling on snow or ice
Thawing permafrost	Damage to (mobility related) infrastructure, increasing risk of avalanche and landslides

It is widely recognized that, to realize the prospects and expectations of polar marine sectors in safe ways, there is a great need for user-specified weather, water, ice and climate (WWIC) information services in the Arctic (Eicken, 2013; Knapp and Trainor, 2013; 2015; WMO WWRP PPP, 2013; EC-PHORS, 2015; WMO/WCP, 2015). The Arctic Council's Arctic Marine Shipping Assessment (AMSA) (Arctic Council, 2009) advised countries to facilitate the planning for and operation of safe shipping activities by improving their investment in collecting and maintaining high-quality hydrographic, meteorological, and oceanographic data, which would also be imperative for safe navigation (Brigham, 2010). However, it remains unclear what WWIC services are needed to facilitate the expected increases in marine activities in polar waters due to climate change and other socio-economic factors. It is also unclear what information needs to exist and how WWIC services may differ among the wide variety of actors operating in different polar contexts, how existing information services are used, and how the utility of such services can be enhanced.

Polar Regions

The Polar Regions are defined in different ways, for different purposes. A common definition includes the areas poleward of 66.6 degrees latitude (i.e. Arctic and Antarctic Circles) (see Figure 1.1), where the sun continuously remains visible above the horizon on the summer solstice and below the horizon during winter solstice. However, institutionally, the Antarctic Treaty System, the group of states that collectively manage human activities in the Antarctic, defines its land and ocean territory as south of 60 degrees southern latitude. Both Polar Regions can also be defined by their unique bioclimatic thresholds, such as the tree line and the zone of continuous or discontinuous ground permafrost in the northern hemisphere; the equatorward extent of sea ice in both the Antarctic and Arctic; or the Antarctic convergence in the south.

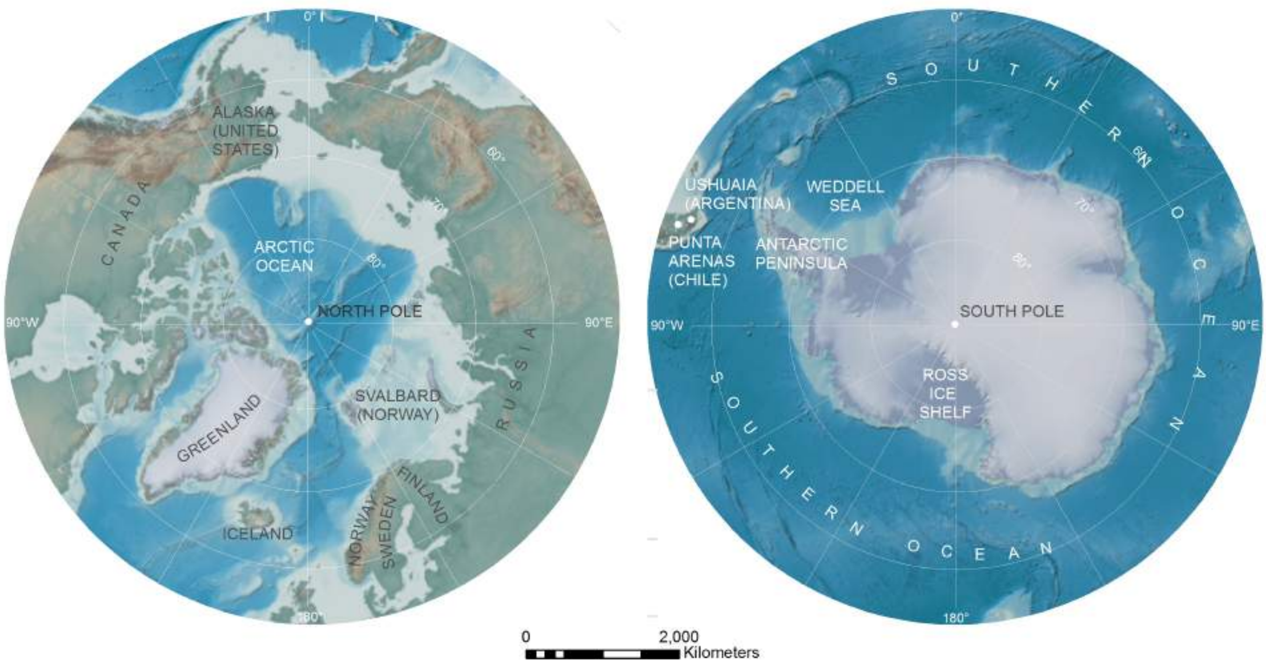


Figure 1.1. Map of the Arctic and Antarctic Regions

The Polar Prediction Project (PPP)

The Polar Prediction Project (PPP) was conceived and initiated by the World Meteorological Organization (WMO) in 2012 through its World Weather Research Programme (WWRP) in response to certain trends observed in the Antarctic and Arctic regions and related concerns about human or environmental safety. Observed trends include:

- Growth in resource development, transportation, tourism, other industries and research activities in the Polar Regions such that more people, economic activities, and infrastructure are becoming exposed to conditions that affect safety, health, mobility, and productivity.
- Changes in the global climate system that may affect future weather patterns and, in some situations, already have compromised the reliability of traditional and experiential knowledge used by members of Indigenous societies and polar communities to deal with WWIC related hazards.
- A limited ability to observe and predict polar weather, sea ice, waves, and related physical environmental phenomena in the Polar Regions relative to other parts of the world.
- Improvements in the ability to predict and forecast weather in many mid-latitude regions will be limited until we better understand polar weather and climate.

The primary goal of the PPP is to advance scientific knowledge such that society, both within and outside of Polar Regions, may benefit through applications of better WWIC information and improved services. Although realizing this goal depends upon achieving an improved understanding, characterization and modelling of atmospheric, oceanic, and land surface processes in Polar Regions, the PPP acknowledges in the first of its eight objectives the parallel need and challenge to translate scientific success into societal value (WMO Science Plan, 2013; WMO WWRP PPP 2016). In this context, and for the purpose of this report, societal value is defined as enhancing opportunities while reducing human risk.

1.1 Polar Prediction Project – Societal and Economic Research and Applications (PPP-SERA) Working Group

Meeting the challenge to ensure societal value from scientific efforts demands the application of social and interdisciplinary science to better understand WWIC-related decisionmaking and communication processes that underpin scientific actions. It also requires improved methods to evaluate impact and to measure social and economic value across a wide spectrum of potential users across a range of cultural, social, political, economic and geographic contexts. Towards these ends, the PPP established a special committee of social and interdisciplinary researchers and service practitioners in 2015. This initiative led to the official establishment of the Polar Prediction Project’s Societal and Economic Research and Applications (PPP-SERA) working group.

The working group held an inaugural meeting in Ottawa, Canada in 2015 (WMO, 2015), a second meeting in Christchurch, New Zealand in 2016 (WMO, 2016; Thoman et al., 2017), and a third meeting in Fairbanks, Alaska in 2017. The task of the PPP-SERA involves defining, developing and promoting a collaborative research programme to complement meteorological and oceanic science activities in PPP (such as modelling and forecasting), much of which will be undertaken around its Year of Polar Prediction (YOPP), a concentrated period of intensive observation and modelling activities from 2017-2019 followed by an extended period of analysis and research through to 2022.

The main interest of the PPP-SERA is in understanding human behaviours and decisionmaking processes to identify the need for and utilization of WWIC prediction services. This document represents a foundational contribution of the PPP-SERA working group.

1.2 Purpose and Framing of the Report

The purpose of this report is twofold:

1) Scoping how WWIC information is currently being used and produced for the Polar Regions, by whom, and for what reasons.
2) Identifying, framing and articulating important areas of research related to the use and provision of environmental prediction services that could be prioritized and further developed given available capacity, resources, and interest during, and beyond, the YOPP.

The report is framed with the assumption that improving environmental prediction services will not automatically lead to the enhancement of societal value. That is, the utility of an environmental prediction product only has value if it is understood and actually used. For example, it is plausible that the development of some of the most sophisticated, innovative, and precise prediction tools may never lead to any enhancement in societal value if they are too complicated for users to interpret, if they are too expensive to justify local purchase, or if their resolution is too high for electronic transmission across the Polar Regions – an area with limited communications infrastructure.

Thus, this report is purposefully focused on the complexities that exist among the social, economic, political, and cultural relationships and ties among people, communities, institutions and enterprises. This includes scientists observing and modelling the cryosphere, the climate, and the atmosphere; the institutions and operators involved in data interpretation and the development of environmental predication products; the several million Indigenous and non-Indigenous inhabitants of the Arctic; and those temporarily working in or visiting either Polar Region; but it also extends to people, places and organizations situated well beyond the Arctic and Antarctic that influence activities and have interests there, or are affected by polar activities and conditions.

To conceptualize the complex interaction among stakeholders involved in the production and use of environmental prediction information, and to frame this document, we rely on two foundational concepts: ***value chain*** and ***mobilities.***

The concepts of value chain and mobilities are explained in the following section and are used throughout the document to:

1) Explore patterns and characteristics of WWIC-related risks that affect physical movement of people, goods and services between places.
2) Examine the demand for, and production and mobilization of, WWIC knowledge and information (scientific, traditional, experiential) that can inform user decisions, for example when to safely travel, conduct particular activities and take precautionary or protective actions.

This approach aims to enable a better understanding of user needs and how WWIC information can be enhanced through the application of improved observation and prediction, which in turn, we hope will translate into improved outcomes and societal benefit.

1.3 Defining Value Chain

A value chain is defined here as the process by which organizations (whether governmental or commercial sector) add value to a product (in this case WWIC information). The WWIC information value chain recognizes the value of activities required in the production and use of information. It represents the cycle of a common information product, with the activities undertaken by different actors and organizations in the chain. These activities can be both primary value activities, related to aspects of the chain that are the core information product (e.g. data creation, information generation and knowledge application) and supporting value activities, related to aspects of the chain that assist the core information product (e.g. storage, processing and distribution).

A value chain perspective to WWIC is useful as it provides a context to understanding the complex array of information provision in which individual actors seldom operate independently. In fact, most WWIC information providers function as one piece of a larger network of information producers, providers and users. Thus, there is a need to better appreciate some of the complex interactions and interlinkages such entities have among each other and ultimately with the users they serve. Figure 1.2 defines several specific functions, sources and flows of information that are typically undertaken or delivered by one or more organizations in the operation of formal WWIC services, from the environmental phenomenon at stake, to various forms of observed or modelled data, to interpretation, to information uptake, and finally to decisionmaking.

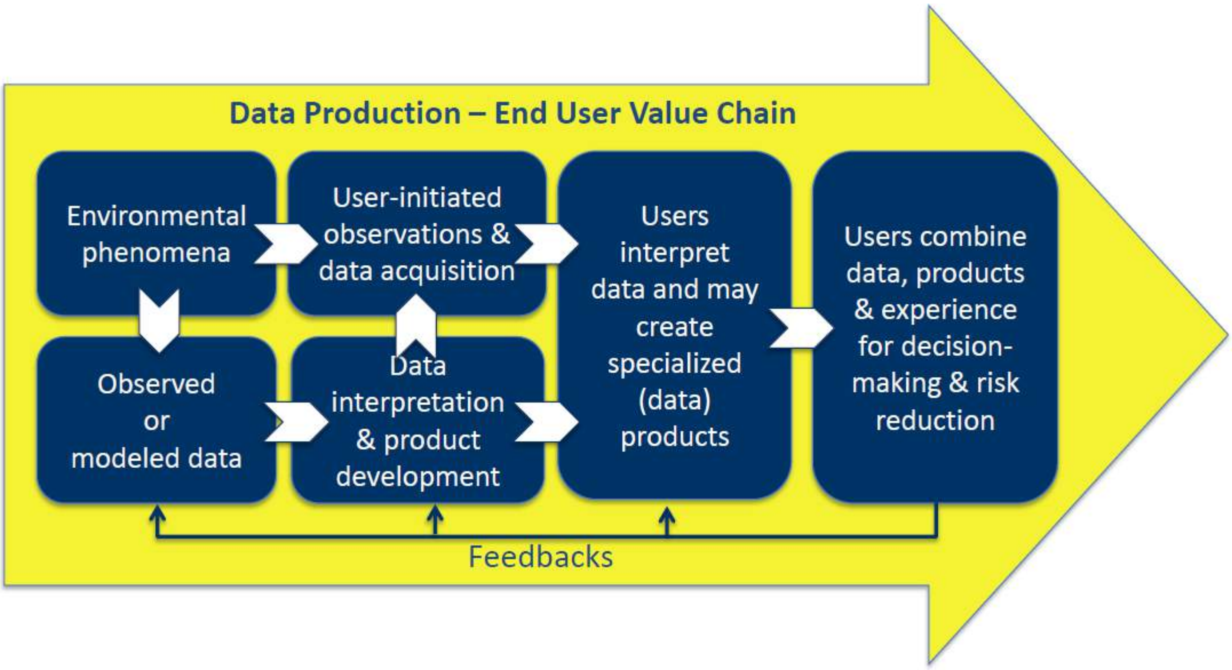


Figure 1.2 Components of the value chain (after WMO, 2015:15; Dawson, 2016)

1.4 Defining Mobilities

Polar environmental prediction services are essential for individuals living or working in Arctic communities or in Antarctic research stations, largely because they facilitate the safe and efficient movement of people, goods and services between places. We draw on the concept of mobilities following Sheller and Urry (2006) who define mobilities broadly as the movement or flow of people or information and/or knowledge.

Mobility is a naturally integrating and organizing concept, whether used in everyday conversation or in academia. Taken literally, it is most frequently used in reference to the ability to physically move between two points. The objects in motion could be people, animals and plants, raw materials, manufactured goods or a host of other things including ice, water and atmospheric phenomena (e.g. storms). When viewed more as a metaphorical social construct, mobility captures a broader range of transfer, including virtual travel, movements of capital, changes in social status or class, or exchanges of technology, images, ideas, opinions, knowledge and information.

Sheller and Urry (2006) describe what they call the mobility paradigm, or mobility turn, which emerged and coalesced in the 1990s and early 2000s from academic contributions in anthropology, cultural studies, geography, migration studies, science and technology studies, tourism and transport studies and sociology. The mobility paradigm offers the distinct way of viewing the world where mobilities become the primary objects of interdisciplinary research and investigation, countering prevailing notions of mobility as a secondary or generic and static process, quality or characteristic (Faulconbridge and Hui, 2016; Sheller and Urry, 2006).

In the Polar Regions mobility is a fundamental concept both from the perspective of individuals such as residents and visiting scientists and from the perspective of relevant industries such as tourism, fisheries, resource development, and maritime trade and transport. Local residents in the Arctic regularly travel between and around communities to visit friends and relatives and to access country and subsistence food sources, with the latter applying particularly to Indigenous residents. Researchers engage in field studies traveling from various points to others and engaging in weather-dependent field operations. In addition to their own necessary mobilities, individuals living in communities across the Arctic or scientists living more temporarily in the Arctic and Antarctic also rely on the mobility of goods and services from other areas to the poles in order to survive. Maritime transport in both Polar Regions for re-supply is now an essential service. Resource exploration and development in the Arctic and fisheries and marine tourism in both poles are also examples of the various forms of mobility occurring across the Polar Regions today. The availability and utility of accurate and relevant WWIC prediction services to local residents, researchers and industry stakeholders are fundamental for local and regional mobility and in many instances can mean the difference between life and death.

1.5 Navigating this Report

The report provides discussion of: WWIC-information providers for the Polar Regions (Chapter 2); human use and activities trends in the Polar Regions, including a discussion of the types of WWIC information key sectors use and why (Chapter 3); and the identification of knowledge gaps and research needs that are focused on improving the societal value of WWIC prediction products and services (Chapter 4).

2. WEATHER, WATER, ICE AND CLIMATE INFORMATION PROVIDERS

2.1 Introduction

Throughout the report, we define information ***providers*** as individuals, groups, organizations or enterprises that develop, hold, share, sell or exchange data, information and knowledge with the intention of influencing a belief, decision or behaviour, or otherwise satisfying a real or perceived need of a given ***user***. We define ***users*** as individuals engaging in polar mobilities that receive (or are targeted to receive) WWIC information via providers.

In order to identify the providers of WWIC information in the Polar Regions a selection of available peer-reviewed literature, reports, inventories and surveys of WWIC service providers in Polar Regions were compiled and reviewed, including recent assessments by the EC-PHORS Services Task Team (2015) and Duske et al. (2016).

2.2 Overview of Information Providers

At first glance, it seems a rather uncomplicated task to identify and characterize the providers of WWIC information in Polar Regions. However, these providers are distinguished by their varying mandates or purpose, size and scope, activity, geographic coverage or focus and longevity. For simplicity, in Table 2.1 we distinguish four general types of formal WWIC information and knowledge providers: Government agencies, private sector enterprises, academic or scientific institutions, and non-profit or community-based organizations (See Annex 1 for a more extensive list of providers).

Table 2.1. Examples of WWIC information and knowledge providers

	Arctic-focus	**Antarctic-focus**	**Transpolar-focus**
1) Government agencies	• Environment and Climate Change Canada (ECCC) • Finnish Meteorological Institute (FMI)	• Antarctic Mesoscale Prediction Project (AMPS) • British Antarctic Survey (BAS)	• Arctic and Antarctic Research Institute (AARI) • National Oceanic and Atmospheric Administration (NOAA) • National Center for Atmospheric Research (NCAR)
2) Private sector enterprises	• Ice Advisors • Seaice.dk • IceBreakerNet • Martech Polar	None identified	• PolarView • GlobalWeatherLogistics • AccuWeather • The Weather Company • UGRIB.US

3) Academic or scientific institutions	• Arctic Portal • Northern Sea Route Information Office • Nansen Environmental and Remote Sensing Center (NERSC) • Arctic Research Consortium of the United States (ARCUS) • International Arctic Buoy Programme (IPAB)	• Southern Ocean Observation System (SOOS) • Scientific Committee on Oceanic Research (SCOR) • Global Cryosphere Watch (GCW) • Antarctic Meteorological Research Centre (AMRC) • Byrd Polar and Climate Research Center • The SCAR READER Project	• SeaIcePortal.de • IICWG International Ice Chart Working Group • International Council for Science (ICSU) • Sea Ice Prediction Network (SIPN) • Climate and Cryosphere (CliC) • Climate Data Operators (CDO) • National Snow and Ice Data Center (NSIDC)
4) Non-profit or community-based organizations	• Sea Ice for Walrus Outlook • Local Environmental Observer Network (LEO Network)	None identified	None identified

2.2.1 Government agencies

National Meteorological and Hydrometeorological Services (NMHSs) and National Ice Services (NISs) have historically formed the backbone of WWIC research, development and service provision in both the Arctic and Antarctic. These are large government organizations (dozens to thousands of staff[a]) mainly funded through public taxation with several having organizational origins dating back to the late 1800s. Their primary mandate is public safety and the protection of important infrastructure and assets. The home countries of these agencies control territory in the Arctic (Arctic Council members: Canada, Denmark, Finland, Norway, Russia, Sweden, the United States), hold territorial claims in the Antarctic (Argentina, Australia, Chile, France, United Kingdom, New Zealand, Norway), or operate bases in either Polar Region. In recent decades, transnational programmes such as the European Union's Copernicus effort provide services and information delivery. Coordination is achieved through international agencies, such as the WMO and the International Maritime Organization (IMO), through which certain agencies take on the responsibility of providing basic information services for particular regions (e.g. METAREAS (GMDSS, 2017)), or via less formal but no less effective working partnerships, such as the International Ice Chart Working Group (IICWG). In addition to their coordination function, organizations within some international agencies may also act as service providers (e.g. the WMO's Global Cyrosphere Watch).

[a] Though not all work to produce knowledge and services strictly for Polar Regions.

2.2.2 *Private sector enterprises*

Private sector providers form another important group. More heterogeneous than government agencies, for-profit enterprises operate under a commercial mandate within a competitive market to serve particular sets of clients with tailored and often proprietary data, information, knowledge and advice. A few companies that offer global weather services (e.g. AccuWeather (2017a), the Weather Company (2017)) are as large as NMHSs but most are small to moderate in size (<50 staff) and have flourished since the advent of widespread and relatively cheap access to computing and telecommunication infrastructure and services, most significantly since the nearly ubiquitous adoption and use of Internet technologies. In some cases, they have been spun out of government or academic R&D programmes and investments, for example Polar View (2017), which provides sophisticated satellite-based data and analysis services in the Polar Regions to clients ranging from government agencies to individual hunters requiring near real-time ice-edge information (see Box 2.1).

Further, small-scale efforts driven by individuals, or small groups of enthusiasts, such as GRIB.US (2017) provide software or tools to extract custom GRIB[b] weather files.

Polar View

Box 2.1. Polar View (http://www.polarview.org/)

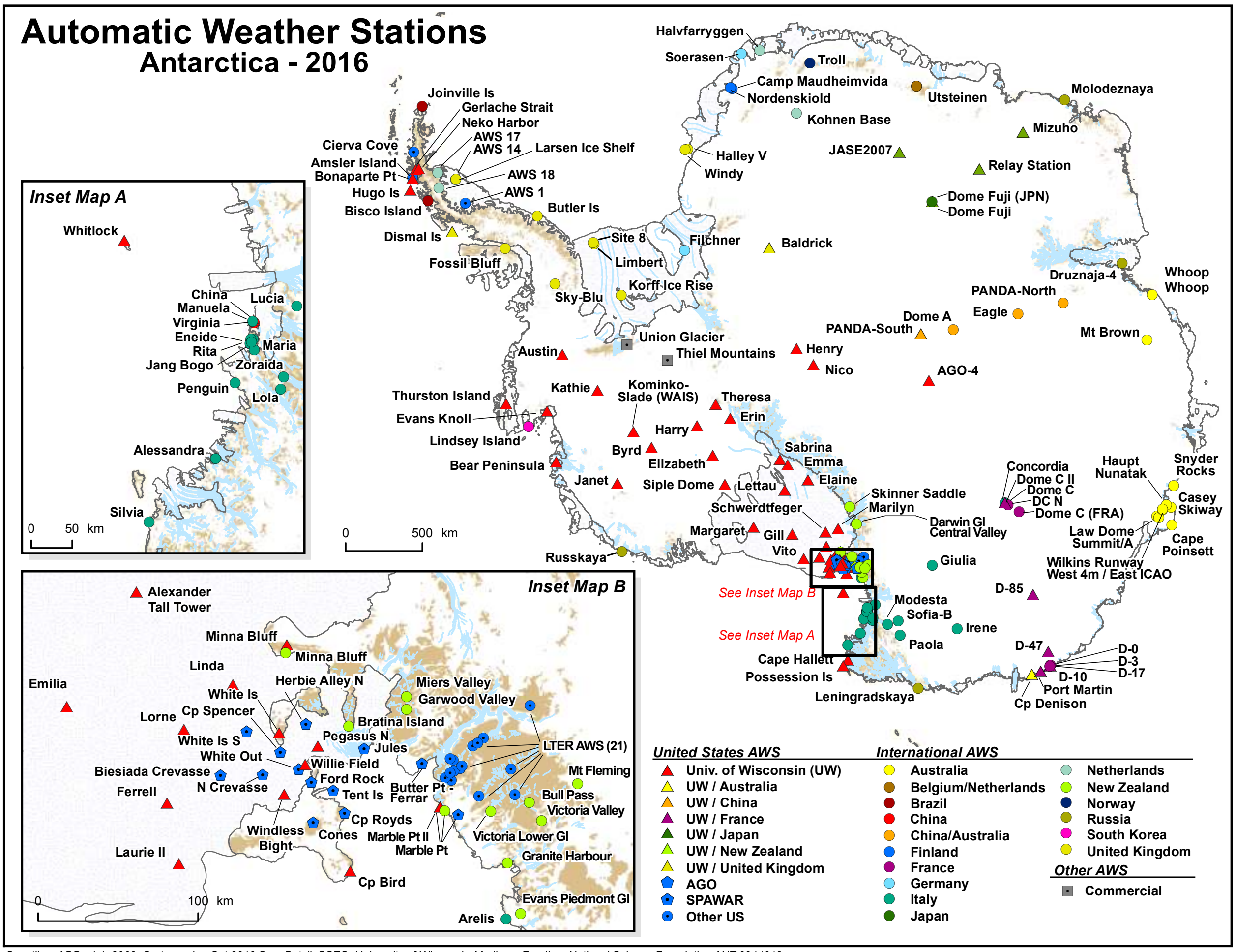
Potential users of remotely sensed information in the Polar Regions have a bewildering array of Internet-based options, but many are governmental or academic institutions that are not geared toward specific user sectors. Polar View is an international provider of remote sensing information and products for Polar Regions. Polar View originated as a project supported by the European Space Agency (ESA) and the European Commission, with participation from the Canadian Space Agency, and in 2011 transitioned to an incorporated company. Polar View targets natural resource extractive industries, tourism, shipping and fishing interests. Cognizant of the severe limitations of communication that are common in polar regions, Polar View makes publicly available a set of remote sensing products, including low bandwidth options, as well as specialised cryosphere-related services for a fee. Free data include Moderate Resolution Imaging Spectroradiometer (MODIS) and Synthetic aperture radar (SAR) products, ice extent and concentration analyses and iceberg data. Specialized services include sea-ice thickness analyses and all manner of ice forecasts.

2.2.3 *Academic or scientific institutions*

Academic and scientific research institutes are also providers of WWIC information and knowledge, though less directly and often as a by-product of the pursuit of new science and understanding (e.g. the Alfred Wegener Institute based in Germany, Gateway Antarctica based at the University of Canterbury in New Zealand and the Australian Antarctic Climate and Ecosystems Cooperative Research Centre, or the National Snow and Ice Data Center (NSIDC) at the University of Colorado in Boulder). Meteorological research groups also offer WWIC

[b] GRIB is a format commonly used by meteorological services to share and transfer files containing meteorological data.

information in support of a range of government-sponsored forecasting services. Examples include the Byrd Polar and Climate Research Center's Polar Meteorological Group, which developed the Polar Weather Research and Forecasting Model that now feeds into the Antarctic Mesoscale Prediction Model (AMPS) and provides weather and sea ice information with a focus on the Ross Sea region; the Antarctic Meteorological Research Center at the University of Wisconsin-Madison, which maintains a comprehensive observational network of Automatic Weather Stations across the Antarctic continent (see Figure 2.1); and the National Center for Atmospheric Research (NCAR), which is federally funding by the US National Science Foundation (NSF) and is primarily based in Boulder, Colorado.



Coastline: ADD v4.1, 2003; Cartography: Oct 2016 Sam Batzli, SSEC, University of Wisconsin-Madison; Funding: National Science Foundation ANT-0944018

Figure 2.1. The location of Automatic Weather Stations (AWS) in Antarctica (AMRC, 2017)

While individual projects may involve only a few scientists, focus on narrowly defined problems, and be undertaken at very localised observation or research sites, they are sometimes conceived within or absorbed into larger programmes, such as the International Polar Year (IPY) or the Year of Polar Prediction (YOPP). In best-case scenarios, there is a successful transfer of knowledge from shorter term (often < 5 years) research conducted by these institutions into operational applications and services that lead to the sustainability of observation and prediction systems that can be relied upon by decision-makers. Increasingly, the success of research funding proposals is at least partially predicated on demonstrating that designs inform socially relevant questions, benefit and involve local populations or stakeholders, have potential commercialization or operationalization prospects, and adopt open data frameworks

2.2.4 Non-profit or community-based organizations

Providers are not restricted to those housed within government agencies, commercial ventures, or academic institutions. Fewer in number and often smaller in size, non-profit or community-based monitoring networks and organizations also develop and deliver important information to those affected by WWIC conditions (Johnson et al., 2015; Kouril et al., 2016). Many are initiated, supported or maintained through academic and government-funded partnerships that serve both scientific and pragmatic needs, employing a range of locally autonomous, collaborative, or eternally driven approaches (Kouril et al., 2016). Examples include the Sea Ice for Walrus Outlook (Arctic Portal, 2017) in Alaska (see Box 2.2), the Arctic Eider Society's Community-Driven Research Network (AES, 2017), the Local Environmental Observer Network (LEO, 2017), SmartICE (2017), and other locally run programmes such as the Clyde River Weather Network (CRWN, 2017).

Box 2.2. Case of the 'Sea Ice for Walrus Outlook' in Alaska

The Sea Ice for Walrus Outlook (SIWO) (Arctic Portal, 2017) is a product designed specifically to assist Alaskan walrus hunters and communities in the northern Bering and southern Chukchi Sea regions during the spring hunting season. Walrus (*Odobenus rosmarus*) are a primary food source and culturally critical to the Yupik and Inupiat communities of the region. The Outlook provides detailed information on present sea-ice conditions and expected changes and a generalized weather forecast for the upcoming week. The outlook was developed in 2010 in a collaborative effort between the National Oceanic and Atmospheric Administration (NOAA), the University of Alaska and the Arctic Research Consortium of the U.S. (ARCUS) in conjunction with Alaska Native sea ice experts and the Eskimo Walrus Commission. Following the first season's outlooks, feedback from the communities was critical to refining the outlooks. Hunters emphasized the value of high resolution satellite imagery in their planning, and as a result annotated graphics are now included as a routine part of the outlook. The community review also noted the importance of social media in information dissemination and in limitations in Internet communications due to low reliability and low bandwidth constraints. In 2013, the Alaska Sea Ice Program within the National Weather Service Alaska Region assumed operational production of the SIWO. The outlook is produced weekly starting in April and continues until sea ice clears the southern Chukchi Sea region, typically sometime in June. Sea ice analysts and meteorologists provide ten-day sea ice and weather forecasts, with an emphasis on winds and sea-ice conditions and expected changes. Feedback and input throughout the season are provided by western Alaska walrus hunters. The outlook is promoted through a Sea Ice for Walrus Facebook page and hosted online by the Study for Environmental Arctic Change (SEARCH) and includes both text and graphics. A low bandwidth option for accessing the outlooks and automatic email delivery are also available.

Some data providers, such as the Polar Data Catalogue (PDC, 2017) (see Box 2.3) and the Arctic Portal (2017), offer a service that integrates data and information provided by many disparate sources. Since funding, voluntary contributions and partnerships are usually not fixed or permanent, the services enabled through non-profit or community-based organizations are subject to the same issues of long-term stability and viability as academic institutions.

Box 2.3. Polar Data Catalogue (https://www.polardata.ca/)

The Polar Data Catalogue (PDC) is a searchable database of metadata and data that describes and provides access to data and information produced by Arctic and Antarctic researchers. Launched online in 2007, the PDC contains thousands of datasets, satellite images, and links to other polar data archives for use by scientists, decisionmakers, and the public (for a recent review see Church et al., 2016). The PDC metadata records follow ISO 19115 (North American Profile) and Canadian Federal Geographic Data Committee (FGDC) standard formats to facilitate discovery and exchange with other data centres. Data and metadata contributors to the PDC are required to follow best practices guidelines as described by Friddell et al. (2014).

The scope of the research in PDC covers a range of disciplines, from natural sciences to policy to health and social sciences, the latter facilitated in part through partnership with the ArcticNet Network of Centres of Excellence and access to its research holdings. The PDC collection contains over 2,500 metadata entries (as of March 2017) and 2.8 million data files. While there is a definite emphasis on Canadian and Arctic information, PDC holdings describing research from other countries and Antarctica are increasing in number as links become established with international portals (e.g. Circumpolar Biodiversity Monitoring Program, Conservation of Arctic Flora and Fauna; Arctic Data Centre, Norwegian Meteorological Institute; National Institute of Polar Research, Japan; British Antarctic Survey; National Snow and Ice Data Center, United States; Alaska Ocean Observing System; Global Cryosphere Watch portal; Australian Antarctic Data Centre and others).

Recent PDC activities include extension of interactive data visualization capacity for specific ocean and ice datasets, and careful consideration of how to acknowledge, archive, and protect contributions from Indigenous Knowledge (IK) systems and sources. Continuous engagement and participation of Indigenous people, for instance through dialogue at the 2015 Polar Data Forum (http://www.polar-data-forum.org/) and other meetings, will be essential to ensuring proper treatment and inclusion of IK into the PDC.

PDC offers at least a few possible opportunities for the World Meteorological Organization's Polar Prediction Project (PPP) and Year of Polar Prediction (YOPP) that may enhance the visibility, relevance and legacy of the programme. A review of existing PDC holdings will provide an immediate inventory of potential collaborators and users of research produced through PPP and YOPP. The many monitoring, modelling and social science-related datasets expected to result from PPP and YOPP activities would be welcome additions to the PDC, though storage constraints may limit submissions to metadata descriptions. Finally, and perhaps most relevant to the PPP-SERA component of the programme, PDC could be an interesting case study and partner in new social science research that examines the use of data catalogues/portals and the societal value of data, information, and knowledge contained therein to support decisionmaking.

2.2.5 The role of Indigenous and local knowledge

The majority of WWIC providers offer formal services defined by the presence of an overt mandate (i.e. legislated, officially sanctioned, institutionalized or commercialized), an organized structure and source of resources, and technologically-enabled means of disseminating science-based information to a targeted user base. While these are very important sources of WWIC information, they co-exist with another critical source of understanding weather, water, and ice that is not generally accessible through publications, data portals, or formalised WWIC services-Indigenous and local knowledge.

Indigenous and local knowledge is accrued through long-term observation and lived experience, in other words by 'doing'. This knowledge is typically held and shared by those with considerable experience with a given occupation, practice, lifestyle or activity. Over the past decade, Indigenous knowledge of safe ice and weather conditions has received considerable academic attention (Aporta, 2002; Nichols et al., 2004; Rees et al., 2008; Laidler, et al., 2009; Bartsch et al., 2010; Krupnik et al., 2010; Maynard et al., 2010; Gearheard et al., 2013). Such knowledge is shared both orally and through joint participation in activities. It is very rich and specific to a given location, time of year, and activity, and is often accumulated through many generations of practice and knowledge sharing.

Such in-depth local knowledge, however, is not restricted to members of Indigenous societies. It is also prevalent among individuals engaging regularly in activities sensitive to WWIC conditions, such as ice road haulers, base managers, deep field scientists, tourism itinerary planners, expedition guides and ship captains. While this type of knowledge is informal, it is often vital and sometimes lifesaving relative to science-based sources in local decisionmaking (see the " Community activites" section in Chapter 2).

2.3 Information Provision via the Value Chain

The provider landscape has been presented above categorically but, in reality, individual information providers seldom operate independently or linearly. Rather, they operate within the value chain framework outlined in Chapter 1 (Figure 1.2). Thus, there is a need to better appreciate some of the complex interactions and interlinkages such entities have among each other and ultimately with the users they serve. The service production component of the value chain defines several specific functions, sources and diverse flows of information that are typically undertaken or delivered in the operation of formal WWIC services.

In some cases, such as with NMHSs, most of the main functions identified in the information value chain outlined in Figure 1.2 are represented, or contained, within one single organization. For example, observations are processed, analysed and used in global and regional atmospheric, ocean and coupled models to predict future states, which are then shared within a given NMHS or NIS to produce textual, graphic, and audio forecasts and services for dissemination to end users.

Even where these functions are centralized within a single organization, there is great reliance on information from other sources-in effect even a primary WWIC provider, such as an NMHS, is also a large user of upstream data and information. For example, weather and ice analyses and forecasts depend heavily on high-quality satellite observations which are typically managed by and acquired from space agencies (e.g. European Space Agency) or their commercial arms, affiliates, and partners (e.g. MDA (2017), access to Radarsat data from the

Canadian Space Agency). In many cases, users, for example in aviation and shipping, are also providers of observations. Aircraft measurements (AMDAR (2017)) and ship-based ice and weather reports are shared via the WMO Global Telecommunication system and make significant contributions to a relatively poorly observed polar environment.
Further across the value chain, for instance when NMHSs produce forecasts of future weather and climate conditions, outputs from multiple modelling systems can be combined (e.g. probabilistic forecasts produced by the North American Ensemble Prediction System (NAEFS) (Candille, 2009) or the North American Multi-Model Ensemble (NMME) (Kirtman et al., 2014). Outputs from the European Centre for Medium-range Weather Forecasting (ECMWF, 2017) global model are used by many NMHSs and private sector providers to develop specialized products and services or to complement and interpret outputs from their own systems. As well, the advancement of observation, modelling, and data processing systems depends in large part on linkages to academic, government and commercial research institutions which may design, test and develop components for the next generation of WWIC forecasts, products and services.

Finally, the entire value chain is supported by a host of essential non-WWIC services. For example, media and broadcast services help WWIC providers reach communities and public audiences. Secondary disseminators then help individual providers to extend their reach to larger or underserved user audiences (e.g. observations and forecasts carried globally through the WMO World Weather Watch (WWW, 2017)). Increasingly, social media services are an important source of WWIC. In theory, this link in the value chain should permit the translation of scientific or technical information into actionable knowledge in communications prepared in official and local languages and dialects, however, a cursory review of NMHS activities suggests that this is rarely sustained in practice. Information and Communication Technologies (ICT) allow WWIC information providers to both receive upstream data and disseminate their information products to downstream providers and end-users. While important to all WWIC prediction systems, they are particularly relevant in Polar Regions where satellite coverage and communication bandwidths are limited.

2.4 Examples of Current WWIC Products and Services

Mobility-related decisions among residents, workers and visitors to the Polar Regions primarily concern movements within or between communities to facilitate employment, social, cultural and recreational pursuits, and in the case of the Arctic also between residences and the locations of various subsistence activities, including hunting, fishing, and berry gathering. Travel might be taken on foot, snowmachine, dogsled, boat, truck or automobile and will involve accessing or crossing roads, paths/trails, open or frozen river, lake and ocean waters. These factors affect decisions with respect to route choice, trip duration, stopping points along the way, and a variety of protective measures (e.g. cancel or defer trip, take GPS, pack extra provisions, etc.). Observations and near to short-term (hours to a few days) forecasts or warnings of weather, water and ice conditions (e.g. storms, visibility, wind, temperature, precipitation, water levels, waves, ice coverage, thickness/quality, movement) would seem to be most relevant, based on the WWIC products disseminated by NMHSs and other providers serving this user group. For example, standard public forecast products are available for remote Arctic locations, such as Tiksi, Russia, from Roshydromet, the official NMHS of Russia, BarentsWatch for Norway, and from AccuWeather – a large private-sector provider –, are shown in Figure 2.2, Figure 2.3 and Figure 2.4. Longer-term forecasts might be useful in planning activities, for instance when and where certain species might be present for hunting or gathering.

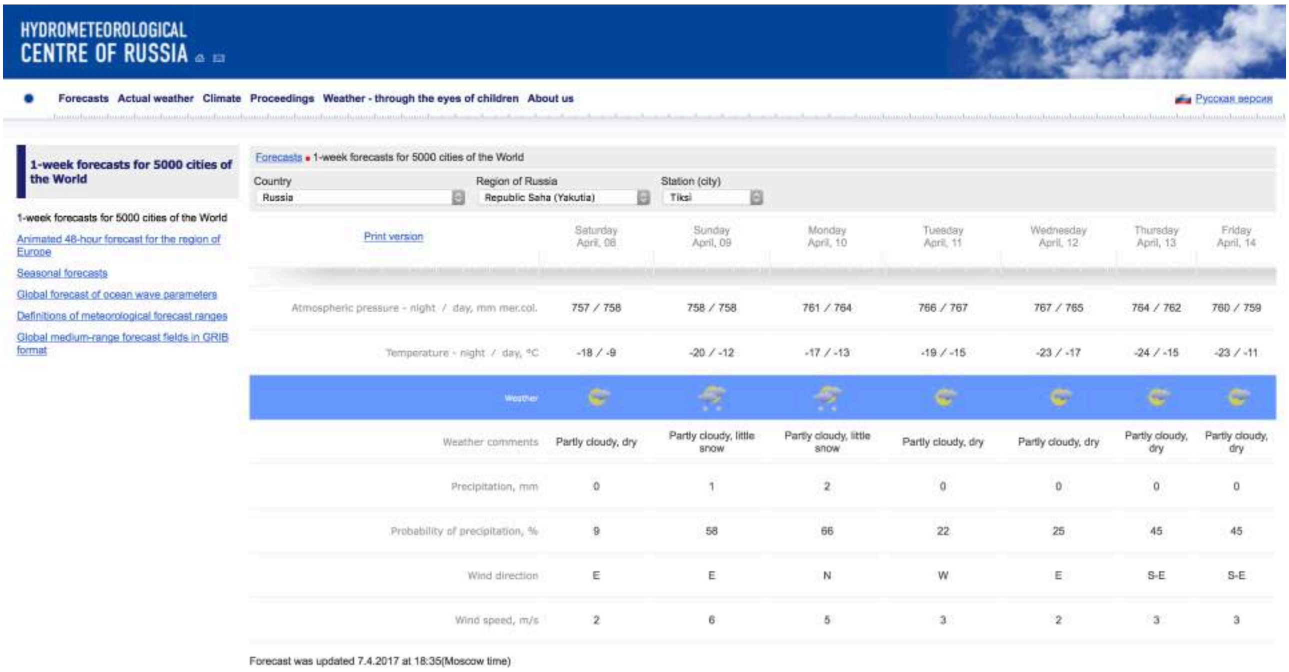


Figure 2.2. Example forecast products for Tiksi, Russia from English version of Roshydromet website (Hydrometeorological Centre of Russia, 2017)

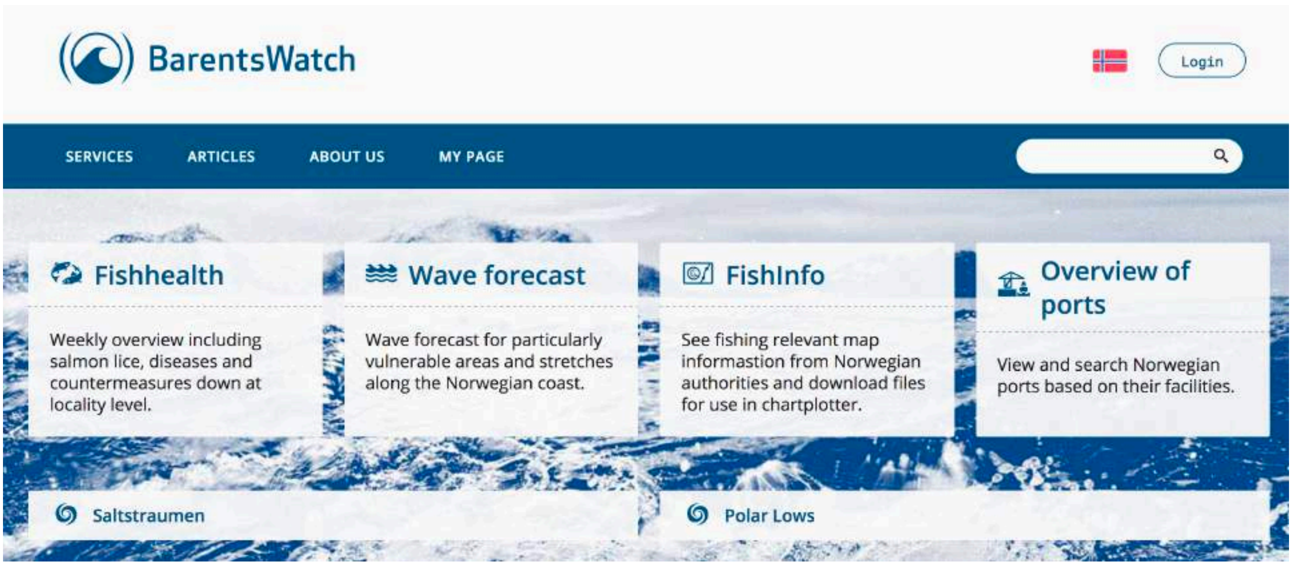


Figure 2.3. Example forecast products for Norway (BarentsWatch, 2017)

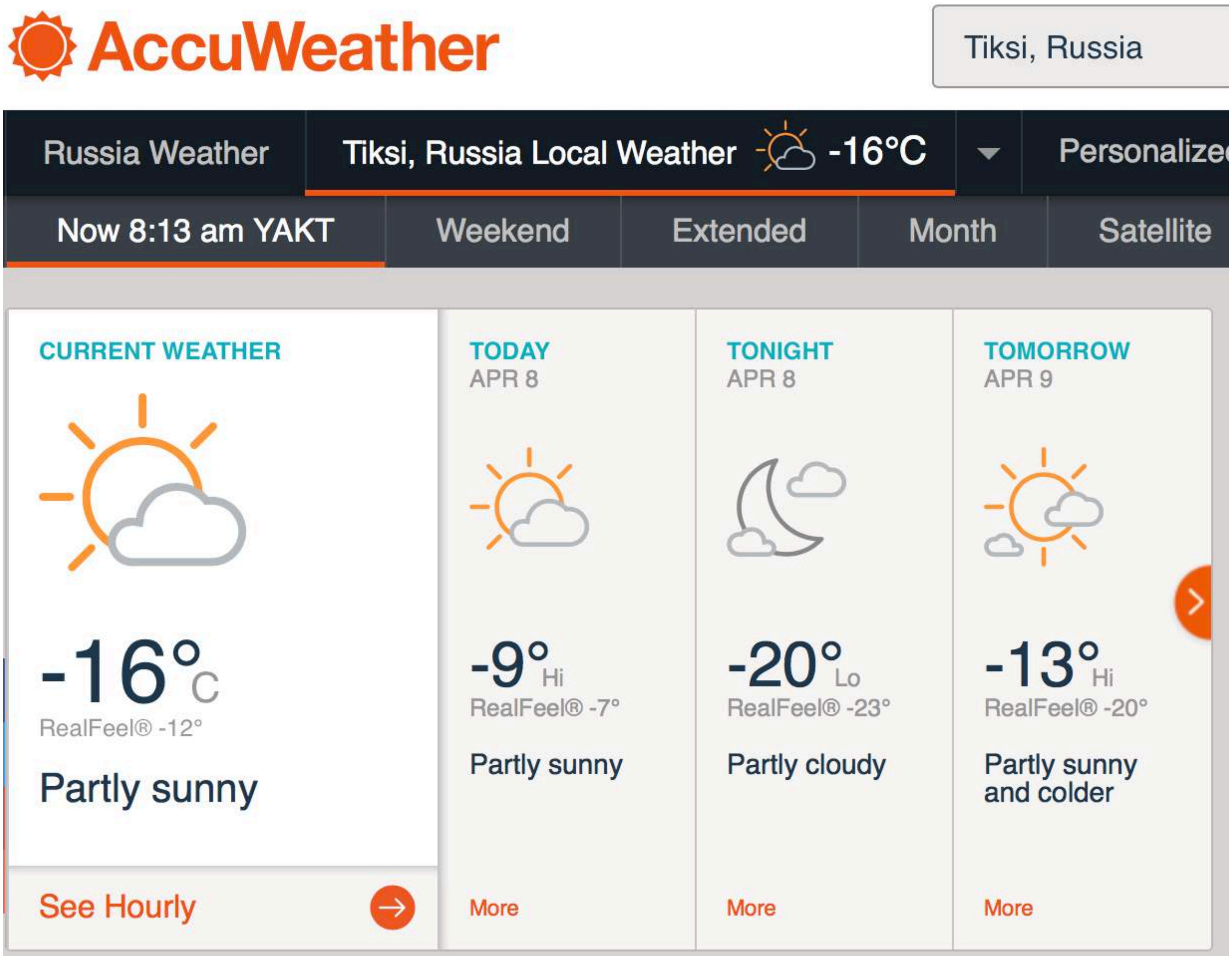


Figure 2.4. Example forecast product for Tiksi, Russia from AccuWeather (2017b)

Different providers sometimes offer somewhat conflicting forecast information (Note the contrasting expectations for temperature over the first few days of the forecast in Figure 2.4). Competing sources of information are particularly troubling if they contest the expected likelihood, timing, duration or intensity of severe weather events such as this example warning product issued by Environment Canada for Clyde River, Canada (Figure 2.5). Agencies issuing such information also face the challenge of communicating to a very diverse public, who may not understand certain terms or recommended actions as intended by the provider (e.g. blizzards) or where the criteria for issuing certain warnings may not relate to the activity or mobility-related decision (e.g. visibility threshold). In other cases, for example, information may be presented in a form that is not readily discernible to many members of the intended general public audience (see for example Figure 2.6 which displays a water-level forecast).

*** Mar 16, 2016 09:08Z ***
WWCN16 CWNT 160908
BLIZZARD WARNING
FOR THE QIKIQTAALUK AREA
ISSUED BY ENVIRONMENT CANADA
AT 5:08 A.M. EDT WEDNESDAY 16 MARCH 2016.

BLIZZARD WARNING FOR:
=NEW= CLYDE RIVER.

==DISCUSSION==

BLIZZARD CONDITIONS WITH POOR VISIBILITY IN SNOW AND BLOWING SNOW
ARE EXPECTED OR OCCURRING.

BLIZZARD CONDITIONS THIS MORNING IMPROVING THIS AFTERNOON. A
DISTURBANCE TRACKING NORTHWARDS ACROSS BAFFIN BAY IS BRINGING STRONG
NORTHWESTERLY WINDS RESULTING IN NEAR ZERO VISIBILITIES IN BLOWING
SNOW TO THE CLYDE RIVER AREA. WINDS GUSTING AT TIMES TO 80 KM/H ARE
CREATING BLIZZARD CONDITIONS WHICH WILL PERSIST THROUGH THE MORNING
HOURS. CONDITIONS ARE EXPECTED TO IMPROVE THIS AFTERNOON AS THE
DISTURBANCE PULLS AWAY FROM THE AREA.

TRAVEL IS EXPECTED TO BE HAZARDOUS DUE TO REDUCED VISIBILITY.
PROTECT YOURSELF FROM WIND, COLD AND DISORIENTATION BY STAYING
SHELTERED, INDOORS OR WITH YOUR VEHICLE. IF YOU MUST TRAVEL, KEEP
OTHERS INFORMED OF YOUR SCHEDULE AND DESTINATION AND CARRY AN
EMERGENCY KIT AND MOBILE PHONE. PLEASE CONTINUE TO MONITOR ALERTS
AND FORECASTS ISSUED BY ENVIRONMENT CANADA. TO REPORT SEVERE
WEATHER, SEND AN EMAIL TO STORM(AT)EC.GC.CA OR TWEET REPORTS TO
(HASH)NUSTORM.

HTTP://WEATHER.GC.CA

END/PASPC

Figure 2.5. Weather warning product issued by Environment Canada for Clyde River, Canada (ECCC, 2016)

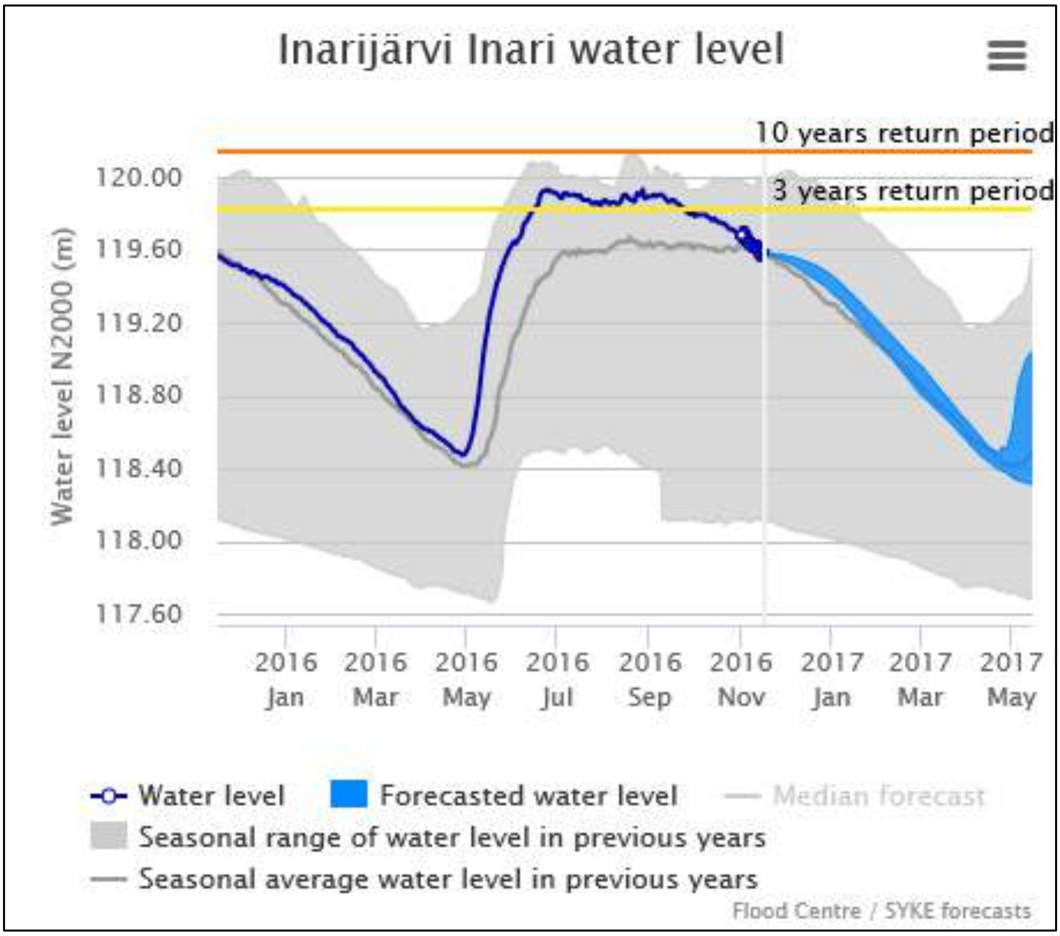


Figure 2.6. Example of a hydrologic forecast product for northern Finland (Finnish Environment Institute, 2016)

2.5 Conclusion

While an exhaustive review of WWIC products is beyond the scope of this document, it is possible to examine examples within broad sets of users or decisionmaking problems to appreciate how users are being served. The following general WWIC information users or application areas are consistently referred to in the literature (Duske et al., 2016, Gråbak et al., 2016, EC-PHORS Services Task Team, 2015), each having a range of mobility-related challenges: public (residents/households, workers, visitors); marine transportation (shipping); tourism (cruise ships, land-based); fisheries; resource extraction (oil and gas, minerals); aviation; and government and scientific research operations (search and rescue, military, local/regional).

Each of these user groups, and in fact the many specialized niches within these groups, have different WWIC information needs that are largely a function of: (a) sensitivity and exposure (i.e. related to mode and medium of travel) and (b) the temporal scale of potential mobility-related decisions and actions (i.e. short, medium, long-term; tactical, operational, strategic). These aspects affect the content of the WWIC product or service needed (e.g. surface weather, river, wave, ice; observations, analyses, forecasts, climatologies) as well as the choice of relevant variables and attributes (e.g. warning criteria; spatiotemporal precision; spatial coverage; accuracy; uncertainty characteristics; timing and frequency; range) offered by providers. They also affect the desired format (e.g. text, audio, graphical, symbols and codes) and preferred or available means of communication (e.g. radio, television, Internet, multi-media, etc.).

This section illustrates that WWIC information provision occurs through a value chain that includes a variety of actors, from state institutions, to private and community-based organizations, to Indigenous and local knowledge. The focus for many formal WWIC providers has been on the information production side of the value chain while less attention has been placed on end user utilization, needs and communication. In some instances, it is assumed that the production of data will automatically lead to utilization and enhanced social value. However, weakness or misunderstandings at any point within this chain can prevent value from actually accruing. Furthermore, rapid technology development and related 'big data' challenges have additionally strained the value chain of WWIC information provision, which again focuses attention on data development and interpretation instead of on end users' data needs. The constitution, functioning and implications of WWIC information value chains are currently not well studied, let alone fully understood. It is difficult to discern whether or not user needs are being adequately identified and addressed by providers and thus the extent to which current WWIC services are producing value to society is not clear.

3. WEATHER, WATER, ICE, AND CLIMATE INFORMATION USERS

An inventory of human activity trends in the Polar Regions was established as a foundation for understanding each user group's unique mobility challenges and associated environmental information and prediction needs (see Duske et al., 2016; Gråbak et al., 2016; EC-PHORS Services Task Team, 2015). The inventory provided here distinguishes human activities by the following primary sectors: (a) commercial transportation (shipping and aviation), (b) community activities (local residents), (c) tourism, (d) fisheries, (e) natural resource activities, and (f) government and research operations (search and rescue, military, science missions)[c]. It is recognized that many of these information users may fit within several sectorial categories created here and even flow between categories over time.

Mapping human activities and mobilities in the Polar Regions is a challenging task (Freeman, 1976; Hughes et al., 2011; Pertierra et al., 2017). There is no consistent set of data on human activities, let alone human mobilities, within any subregion of the Arctic or Antarctic, making it difficult to develop regional comparisons, characterize pan-Arctic trends, or predict future trends with much confidence. To deal with data challenges we have drawn upon data sources that are available and used a range of case studies to illustrate human mobility trends across several key subsectors. As a result, it is possible that not all activity trends are fully captured here.

3.1 Commercial Transportation (Aviation and Shipping)

Generally, marine and airborne transportation underlie many different human activities in the Polar Regions, primarily due to the remoteness of these regions from major population centres in the lower latitudes and the reliance on transportation in all forms as a necessary facilitator for human mobility and human activities at the Poles. This section is primarily focused on commercial transport, but it is noted that the same issues detailed here may apply to shipping and aviation that supports tourism, fisheries, resource extraction, and government and research activities, which are discussed in greater detail below.

3.1.1 Aviation

Aviation[d] has been a mainstay of polar transportation for more than seventy years. Its appeal was immediate due to the long distances and unpractical nature of other types of transportation, such as rail or road. Thus, the year-round ability to rapidly move large amounts of cargo and people by air has played an important role in the "modernization" of Polar Regions.

Weather is notoriously challenging in the Polar Regions, with frequent low cloud ceilings, poor visibilities due to fog and rapid changes being commonplace. While modern aviation activities worldwide are less weather-impacted than in the past due to significantly improved technologies, the Polar Regions have not benefitted to the same extent by infrastructure modernization programmes. Both governmental and non-governmental providers produce

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[c] Government and Research Operations has been divided into two sub-sectors in the summary of activities (Table 3.2).
[d] International transpolar overflight aviation is not considered here.

specialized short-term aviation forecasts for both surface airport and inflight conditions. The variable nature of polar weather (Nakashima et al., 2012) means forecasts are generally reliable only up to about 48 hours.

The long-term changes occurring in polar environments bring a variety of risks and opportunities for aviation in the Polar Regions. Increasing demand for search and rescue activities necessitate increasing aviation activities, sometimes in dangerous flying conditions. Surface-related changes will also have important consequences for aviation activities in some polar areas. In recent years, communities and other activities that are dependent on stable sea ice for seasonal airstrip construction on snow and ice (e.g. Little Diomede, Alaska) have had very short (or no) such season, greatly increasing the time required and cost of the shipment of goods and services. At some small communities, seasonal and permanent airstrips are unusable during spring thaw and autumn freeze, and a changing environment will potentially impact the timing, frequency and duration of thaw/freeze cycles. The timing of the transition from wheeled to ski-equipped aircraft (and back again) for some activities is likely to change. In the Antarctic, aircraft activity is almost entirely limited to the austral summer, although night flights in winter have been trialled and are likely to become more common in the future. It is also noteworthy that access to some field sites is highly limited even during the austral summer period, with soft snow conditions preventing access after late November or early December (e.g. access to the Mars Oasis, Alexander Island). Sea-ice runways in the Antarctic are equally susceptible to change as they are in the Arctic, and airfields constructed on shelf ice are vulnerable to degradation and require significant maintenance or relocation when the ice shelf becomes unstable. Similarly, as the case of British Antarctic Survey's Halley VI Research Station has shown, even if a station is located on an ice shelf, some level of unpredictability remains. Located on the Brunt Ice Shelf, the Halley VI station is currently being relocated further inland after a large crack appeared c. 17 km north of the station in October 2016, interrupting ongoing research programmes and incurring additional costs as the station will be closed down over the winter for safety reasons (BAS, 2017).

3.1.2 Shipping

Various types of shipping mobilities can be distinguished in the Arctic and Antarctic. These include passenger ships (from local ferries to larger distance movement of people), bulk and container ships, oil and gas tankers, offshore supply and service ships, container ships, cruise ships and fishing vessels. In the Arctic, the extraction of mineral and hydrocarbon resources is a major driver for shipping activity (Sander et al 2016; Dawson et al. 2017a). The cost of cargo transport by air is much higher than by ship and thus, whenever possible, cargo is moved by sea within the Polar Regions (Lasserre and Têtu, 2015).

Of the total 11.066 ships that were detected via AIS in the Arctic in 2014, a large part was concentrated in the North Atlantic region. Only a small part transited completely through the Arctic (Eguíluz et al, 2016). While Arctic shipping is dominated by internal and destinational traffic, there is an increasing interest in transpolar international trade by sea via increasingly ice-free shipping routes between the North Atlantic and the Pacific Oceans (see Lasserre and Têtu, 2015; Pizzolato et al., 2014; 2016; Smith and Stephenson, 2013; Mussells et al., 2017). There are two main routes for trans-Arctic shipping today: the Northwest Passage following the coasts of Norway, Russia and Alaska (a major part of the Russian section is called the Northern Sea Route) and the Northeast Passage, running along the northern coast of Canada and Alaska.

Sea ice across the pan-Arctic has shifted from a predominantly thick perennial sea ice that was difficult to navigate to a regime of younger, thinner, more seasonal sea ice regime (Parkinson, 2014; Comiso, 2012; Maslanik et al., 2011). Between 1979 and 2013, there was a long-term average increase of pan-Arctic melt season length by five days per decade (Stroeve et al., 2014), which has led to increases in the shipping season and has improved navigability and access to the once fabled trade routes of the Northwest Passage, the Transpolar Route and the Northeast Passage (see Figure 3.1 for an overview of shipping density in the Arctic in 2011). In the Antarctic, sea ice extent is decreasing in some areas, in particular the Antarctic Peninsula, and increasing in most other areas (primarily in East Antarctica) (King, 2014), posing its own challenges for marine transportation and re-supply of bases. The upwelling of warm water under the ice shelves thins and weakens them from below (Pritchard et al., 2012)[e], which has implications for shipping by affecting ocean currents, iceberg calving events and including potentially also the dramatic collapse of ice shelves, such as happened to Larsen-B in 2002 (see e.g. Scampos et al., 2004).

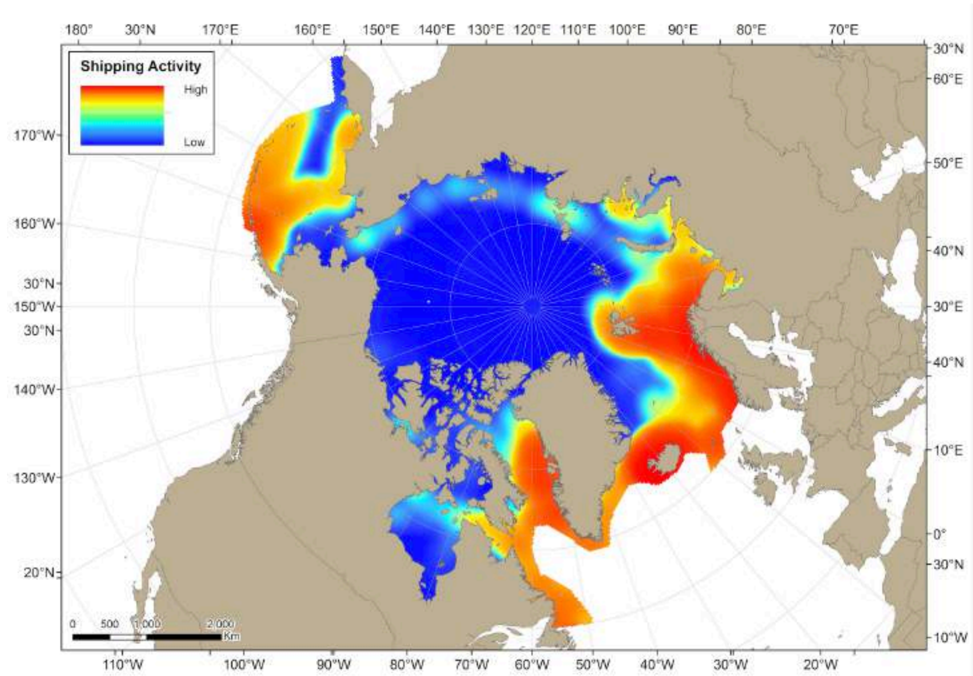

Figure 3.1. Ship traffic density in the Arctic for 2011 (Low = 0 ships/10km^2; High = 99 ships/10km^2) (exactEarth AIS data)

3.1.3 Expected future trends

Environmental changes are likely to continue to impact inflight aviation conditions. In particular, changes in the seasonality and potential intensity of low level icing can also be expected from a variety of sources, including decreasing sea ice coverage, warming air temperatures and increase lower atmospheric moisture. Changing ice conditions will also likely lead to increased fog intensity in some areas and will challenge ice-based landing areas.

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[e] This, in turn, reduces their buttressing effects and speeds up the velocity of glaciers in the interior (Rignot et al., 2014).

Thawing permafrost and warmer summers will continue to impact landing strips across the Polar Region.

It is anticipated that there will be a seasonally sea ice-free summer (sea ice extent < 1.0 million km^2) realized in the Arctic by the mid-21st century (Wang and Overland, 2012; Massonnet et al., 2012) that will lead to increased maritime traffic (Figure 3.2). This is likely to lead to increased navigability and open-water-season length for shipping activity in the Arctic and in particular will lead to increased trade via the Northern Sea Route (NSR) and the southern route of the NWP (e.g. Smith and Stephenson, 2013; 2015). However, a reduction in ice concentration and thickness could increase the risk to ships transiting Polar Regions due to increased hull penetrating ice bergs and bergy bits compared to larger ice islands of the past that are easier to navigate. Furthermore, the perception that the Polar Regions are becoming increasingly accessible could lead to a premature increase in activity and the entrance of new and inexperienced ship operators in the region (see Stewart et al., 2007; Pizzolato et al., 2014; 2016; Dawson et al., 2016; 2017a).

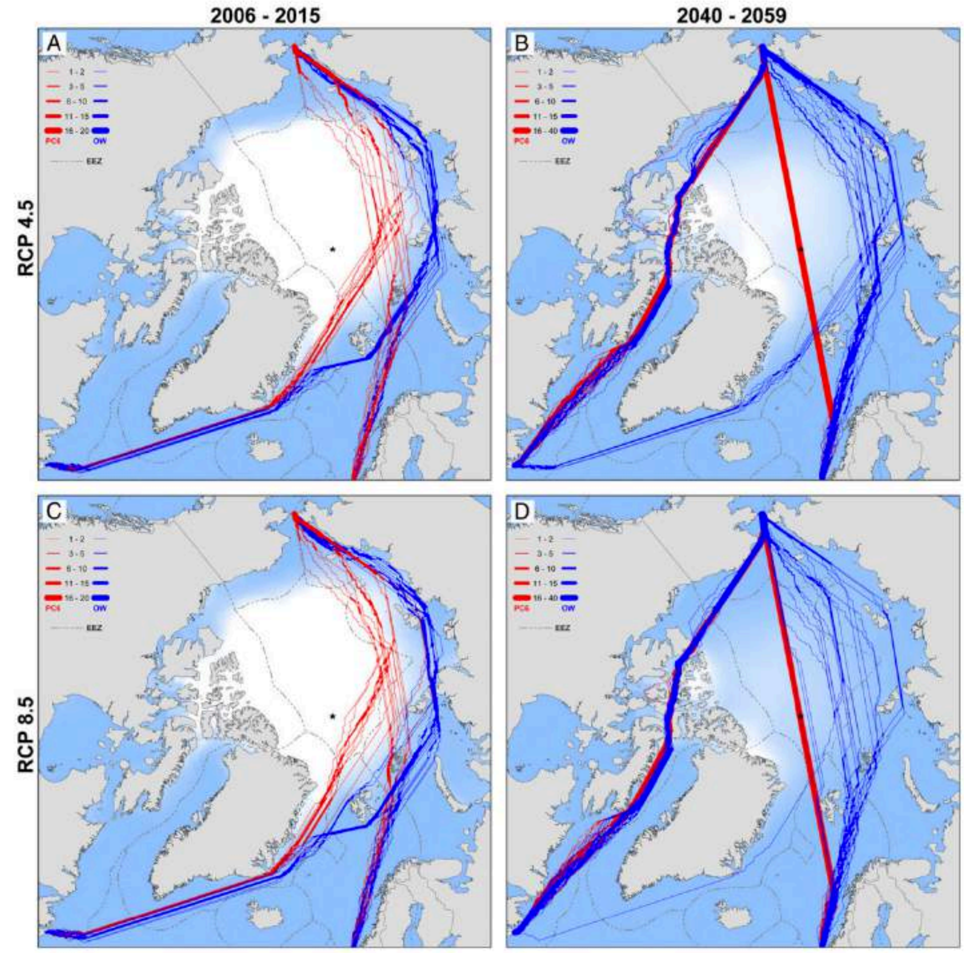

Figure 3.2. Projected future shipping traffic for a medium-low radiative forcing – RCP4.5 (A, B) and high radiative forcing – RCP 8.5(C, D) for the 2050 time period compared to 2006-15 baseline period. The blue line represents projections for an open-water vessel (not ice-strengthened), and the red line represents projections for Polar Class 6 (ice-strengthened) vessels. (Smith and Stephenson, 2013: E1193)

3.2 Community Activities

Arctic hamlets and Antarctic research stations are strongly dependent on aviation and marine transportation for bulk delivery of cargo and long distance movement of people. The seasonal restrictions on marine transportation, and uncertainties in delivery schedules with both marine and aviation shipping, have profound impacts on these communities (Arctic Council, 2009; Berman, 2013; Pizzolato et al., 2014) and in general increases their vulnerability. For example, in the Canadian Arctic, a year's worth of fuel must be delivered during the comparatively short open water season. Failure in the delivery of food stocks or medical supplies, whether by marine or aviation, creates significant hardship and even life-threatening situations (e.g. in the case of medevac aircraft grounded due to weather). Changing ice conditions, and the potential for increased shipping which also brings new prospects for science and economic development, there is also enhanced concern over environmental impacts and safety (ASMA, 2009; Howell et al., 2009; Stephenson and Smith, 2015; Stewart et al., 2015).

While larger-scale Polar transportation mobilities are important for connecting and supplying remote communities, the remainder of this section focuses on the activities associated with daily community life in the Arctic at the level of the individual. Throughout this section, when we refer to Arctic communities, we do so according to the definition outlined by Rasmussen et al. (2014: 428) to include "political, social, and cultural linkages", while Arctic settlement "refers to physical and territorial factors". Therefore, settlements can range from small remote villages or hamlets, to regional centres that act as administrative hubs for government and services, to large urban cities. Within settlements there are diverse communities based on shared cultures, ethnicities, interests, experiences, or values, and individuals may belong to multiple communities at once. This reference could thus also include communities that are formed through interactions within long-term research stations, industrial development sites, or government initiatives based in the Arctic or Antarctic; however, these are covered within the respective sections (see also Government and Research Operations in this chapter).

Small, remote settlements tend to consist of predominantly Indigenous communities, which maintain strong ties to land- and marine-based subsistence activities as part of the mixed economy (Poppel and Kruse, 2009; Harder and Wenzel, 2012; Larsen and Huskey, 2015; BurnSilver et al., 2016), and thus engage in unique mobilities. Indigenous peoples have survived and thrived in Arctic regions for generations, and while many (even very remote) communities are interconnected with the global economy they also continue to be closely connected to seasonal cycles of harvesting country foods (AMAP, 2009; Donaldson et al., 2010; ICC, 2015; Fondahl et al., 2015). This includes gathering (e.g. berries, mushrooms, roots) in the terrestrial environment, hunting and fishing in both terrestrial and marine environments, and reindeer husbandry (Rees et al., 2008; Rattenbury et al., 2009; Bartsch et al., 2010). Such activities occur as part of cultural and family practices, to support dietary needs and preferences, or as part of local commercial enterprises (e.g. adventure tourism, sport hunting or fishing, ecotourism, arts and crafts, reindeer herding) (AMAP, 2009; Donaldson et al., 2010; Nilsson and Evengård, 2015; Berner et al., 2016; Kenny and Chan, 2017). All of these activities depend on transportation, which in turn is defined by the activity and by the time of year. Hunting/gathering areas can range from a few to hundreds of kilometres away, and are accessed typically by snowmachine, all-terrain vehicle (ATV), or open motor boat. Movement between communities is also important, and takes place using the same modes for subsistence, as well as commercial small aircraft operations. Movement on foot is also common, such as after arrival at the hunting/gathering site. In support of these kinds of travel, much attention is paid to weather conditions and extreme events, seasonal trends, wind direction and strength, sea ice and lake/river ice formation and break-up processes, ice thickness and stability, floe edge position, snow and rain fall, cloud and fog conditions, and marine tidal cycles (Aporta, 2002; George et al., 2004; Nickels et al., 2005; Gearheard et al., 2006; 2010; Meier et al., 2006; Ford et al., 2008; Druckenmiller et al., 2009; Weatherhead et al., 2010; Laidler et al., 2008; 2009; 2011; Eicken et al., 2014). Therefore, nuanced weather, water, and ice indicators are all considered in particular place-based contexts to inform community mobility decisions around travel destinations, timing and safety.

In order to prepare for land-based, sea ice, or water travel, it is common for residents to consult weather forecasts (on radio, TV, or Internet), to look at available satellite imagery, and/or tide tables, among other sources (Meier et al., 2006; Ford et al., 2008; Laidler et al., 2008; 2011; Gearheard et al., 2010; ICC, 2014). However, significant importance is placed on local/Indigenous knowledge derived from long-term observation and experience that includes intergenerational knowledge transfer and information gained from informal, often inter-personal knowledge sharing networks. These networks link individuals, family members, and community members in person, over the local radio, via short-wave radio or satellite phone while travelling. GPS technologies are increasingly used as navigational aids, especially for younger or less experienced hunters and travellers (Aporta and Higgs, 2005; Ford et al., 2008; Durkalec et al., 2014), but in assessing travel safety Indigenous and local weather, water, and ice indicators (and tools, such as a harpoon to test ice thickness) are predominantly relied upon to make decisions on the fly[f]. Nevertheless, Elders and experienced hunters worry that the younger generations may not be spending enough time on the land, water, or ice to be learning these indicators[g] (George et al., 2004; Aporta and Higgs, 2005; Ford et al., 2008; Laidler et al., 2008). Concerns have also been expressed in relation to observed environmental changes, and greater uncertainties associated with rapidly changing weather events, ice dynamics, and increasingly unreliable traditional indicators (George et al., 2004; Gearheard et al., 2006; Ford and Pearce, 2012; Durkalec et al., 2014; Alessa et al., 2015). Because of this, some communities have begun to initiate their own community-based monitoring programmes to track weather and ice conditions in locations and at scales that are most relevant to local decisionmaking (Mahoney et al., 2009; Druckenmiller et al., 2009; Gearheard et al., 2010; Alessa et al., 2015; Johnson et al., 2015; Kouril et al., 2016) (see Box 3.1; also see "Non-profit or community-based organizations" section in Chapter 2).

It remains unclear to what extent WWIC information is sought out or used in making community level decisions, or through what access channels in what circumstances. Access to services and products furnished by providers outside of the communities is often limited by bandwidth and by the age/technical capacity of the computer. Some providers offer data via sophisticated dynamic interfaces which are inaccessible to most community users. WWIC services are rarely tailored to address locally relevant indicators, at appropriate spatial and temporal scales. Therefore, the emphasis in available literature is more on documenting local and Indigenous knowledge to link to or improve potential WWIC information products, than on the use of current products and services.

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[f] It is worth noting that exactly the same techniques are being used by small 2-4-person field parties travelling in Antarctica.

[g] Again, the same is the case in Antarctica, where safety concerns now limit the work and recreation activities of summer and overwintering staff at research stations.

Box 3.1. The Inuit and their reliance on sea ice

Inuit, the Indigenous peoples whose homelands stretch across the circumpolar Arctic, are known as maritime people, their lives, culture, and identity inextricably tied to the sea and free movement over sea and sea ice (ICC, 2014). Therefore, Inuit have traditionally relied on marine mammals as sustenance (primarily seals, whales, walrus), although caribou, fish, small game, migratory birds and collecting berries and certain plants also provided important dietary diversity. Living and hunting/gathering in Arctic coastal zones, the formation of landfast sea ice is considered a seasonal extension of the land (Krupnik et al., 2010; Gearheard et al., 2013). Travel on landfast sea ice, and at times moving/multi-year ice, is most important for Inuit mobilities. In fact, the sea ice represents a "highway", a platform for travel, whereby "[l]ife in the Arctic is dependent on movement, and sea ice is integral to this movement" (ICC, 2008: 3). Traditionally sea ice travel enabled connectivity, communications, and survival for generations of Inuit, and it remains of tremendous importance in today's northern lifestyles and livelihoods (Krupnik et al., 2010; Gearheard et al., 2013; ICC, 2014).

Travel on land plays a significant role, too, primarily during winter when it is frozen, snow-covered and lakes and rivers are frozen. As there are hardly any roads connecting Arctic communities, flying between communities to visit friends or relatives or for work is common. However, some still make long snowmachine, boat, or dog team journeys between communities or to hunting locations, traveling over land and sea.

Photo above: Hunters waiting and watching for seals at the edge of a polynya, outside of Cape Dorset, Nunavut (© G. Ljubicic (2005)).

While the importance of these local sources of information are acknowledged as critical to arriving at a complete understanding of the local context, a real challenge remains in integrating these sources into the weather forecasting process (Eicken et al., 2009; Lovecraft et al., 2013; Druckenmiller et al., 2015). There are several points of intersection. The first is near real-time use, which involves efforts to ingest surface data measurements directly into weather forecast models to help initiate them. Functionally, however, the capacity of a single datum to affect a model is very limited. Of greater utility is the potential of surface observations to be utilized directly by forecasters for spot verification. The second is in support of longer term efforts to validate models, by comparing model output to specific observations. This can lead to identification of biases that could be addressed in future model revisions (e.g. capturing the strong surface-based radiation inversion that occurs in the winter). The third is for end-users to provide specific information about thresholds defining go/no-go decisions, weather parameters of interest, specific temporal or spatial scales that are of more use, and forecast locations that are more important, such as, hunting areas. This last aspect is complicated because there are distinct seasonal aspects associated with most activities (e.g. it is of little use to issue a forecast oriented around berry-picking in January). This applies to shifts in mobility forms, such as from snowmachine to ATVs.

Language considerations are critical in relation to conveying WWIC information at the community level. In many cases, there is an Indigenous linguistic context to descriptive terms for features or processes in the landscape, which does not readily translate (Huntington et al., 2002; Laidler et al., 2008; 2011; Gearheard et al., 2013; Eicken et al., 2014). This can lead to confusion when going back and forth between English and other languages, including Indigenous languages and dialects. Another consideration is communication amongst disciplines; in some cases the same term can mean different things, leading to potential misunderstandings even when working in a single language such as English.

3.2.1 Expected future trends

During the first half of the 20th century, mobilities generally decreased across Arctic Asia and North America, with nomadic, seasonal and recourse dependent mobilities changed as permanent settlement was encouraged or mandated by national governments. However, mobility has been on the rise in the past several decades, within and between communities, and inside and outside the Arctic, while the overall demographic trend in the Arctic is outmigration from smaller communities to urban areas, with an increasing divide between centres and the periphery. In particular, there is a trend, though not the same everywhere, for women to leave and men to stay, creating a gender imbalance (Rasmussen et al., 2014). Shifts in mobilities also include, in North America, shifts from using dog teams to snowmachines in the late 1950s-1960s with great implications on travel distance, timing, and assessments of safety on the sea ice (ICC, 2014). In Antarctica, dog teams were routinely used for research expeditions into the 1980s but were prohibited by the Protocol on Environmental Protection to the Antarctic Treaty, which came into force in 1998.
There have been reports from northern communities about increasing injuries related to environmental changes in the Arctic, but there are still major gaps in our knowledge of factors contributing to land-based injury and trauma in the North (Durkalec et al., 2014), and whether some of these relate to lack of accurate, up-to-date or appropriate WWIC information (also see Clark et al., 2016).

Community connections, to the environment or among people within communities are also being transformed by increasing moblities of goods and services. Imported foods are gaining importance in the Arctic, but in some areas, like Norway, interest in, and demand for, local food is rising (Rasmussen et al., 2014). The growing reliance on imported foods is likely to be linked to, both as a cause and effect, the increasing costs of food, transportation and engaging in hunting and harvesting activities in remote Arctic communities. Weather conditions that delay shipments of food (air or ship) often result in spoiling of perishable items, which stimulates the move towards cheaper, unhealthy food sources when relying on market foods (Rautio et al., 2014). Similarly, climate change in the Arctic is resulting in the degradation of permafrost, reduced snow and ice cover, and extreme weather conditions (e.g. floods and storms), which affects harvest from fishing and hunting, the health of animals, options for traditional preparation and safe storage of food, and the nutritional status of Indigenous people who depend on traditional foods for subsistence (Rautio et al., 2014). Small-scale tourism, related to increased cruise tourism or more local outfitters, as well as research activity (community-based, ship-based, and remote field camps) is growing (Rasmussen et al., 2014), with the importance of Inuit knowledge for a wide range of Arctic research being increasingly highlighted (ICC, 2014). The number of full-time hunters are decreasing but their uptake and use of technology (especially GPS) in support of hunting is increasing despite diverse opinions on the utility of GPS and different approaches to its use by different age groups (ICC, 2014; ICC, 2008; Aporta and Higgs, 2005). Increasingly, hunters look up sea-ice conditions on the internet before travel (ICC, 2014; ICC, 2008). Overall, an increase in the use of social media for sharing information of all kinds, including traditional and environmental information has been noted in the Arctic (Larsen and Fondahl, 2015; Rasmussen et al., 2014; ICC, 2014; 2008), along with the greater use of modern communication devices to stay in touch with family or for safety purposes when out on longer hunting trips (e.g. two-way radios, satellite phones, mobile phones).

3.3 Tourism

Total tourism numbers in the Polar Regions has increased over the past decade but continues to fluctuate annually. The overall number of tourists visiting the Arctic is greater than the number of tourists visiting the Antarctic, however, tourism in represents the primary and largest commercial activity in Antarctica (see Figure 3.3). Visitation across the Arctic varies dramatically by country, with the United States (Alaska) and Norway (Svalbard) by far attracting the highest number of visitors annually (see Figure 3.4 and Figure 3.5). Other Arctic tourism locations include the Canadian Arctic, the Russian Arctic, Iceland and Greenland.

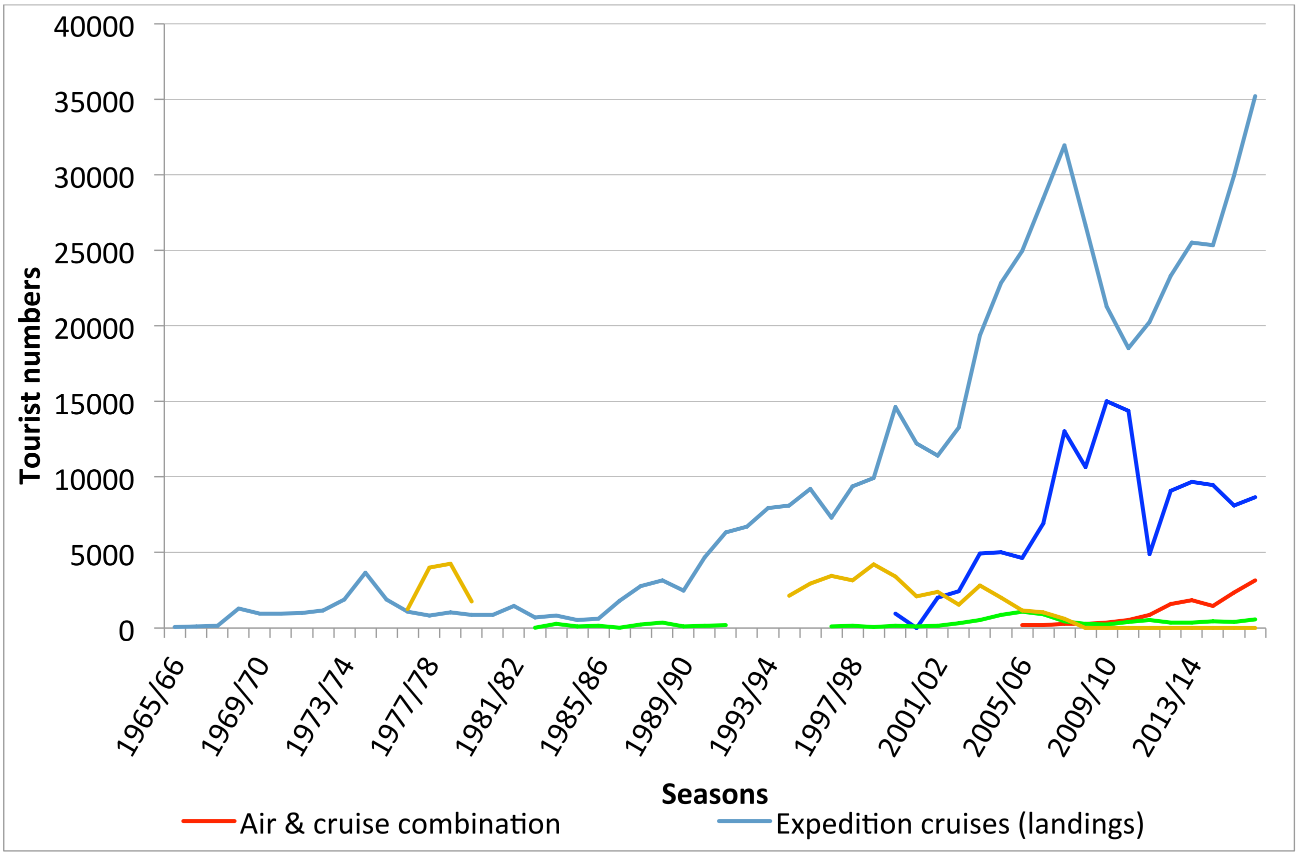

Figure 3.3. Antarctic tourism numbers (based on data obtained from IAATO, 2017)

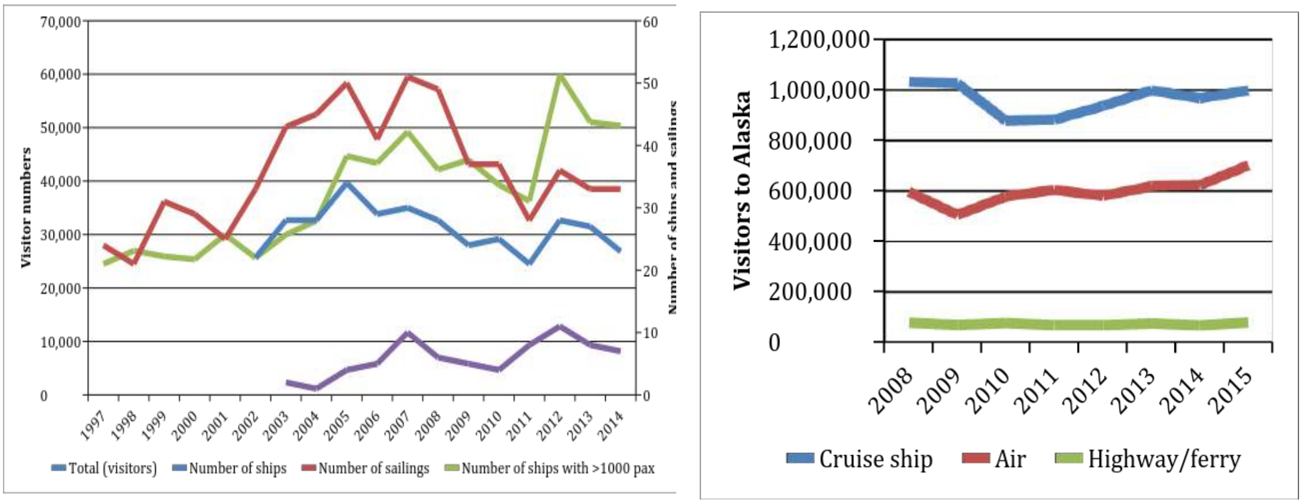

Figure 3.4. (Left) Number of visitor arrivals by road, sea or air in Alaska (AVSP, 2016); (Right) Number of cruise tourists, cruise vessels and sailings to Svalbard (AECO, n.d.)

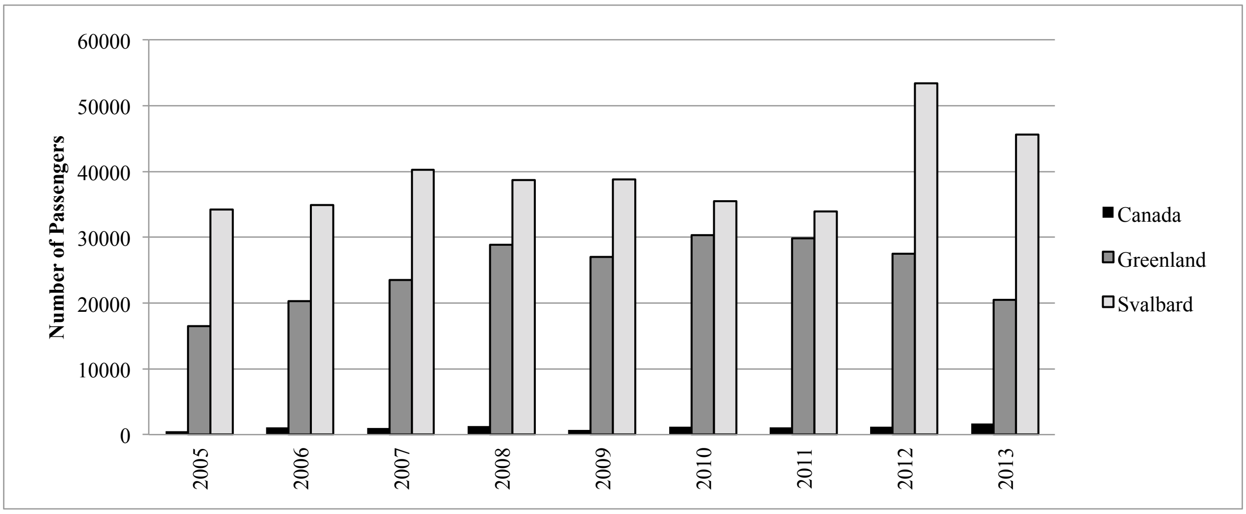

Figure 3.5. Cruise Passengers in the Arctic (Canada, Greenland, Norway) (Dawson et al., 2017c)

Tourists engage in a variety of land based and marine activities while visiting Polar Regions (see Table 3.1). The various kinds of land-based tourism activities are often labelled as "adventure tourism" and include a variety of sports and more physically demanding activities such as hiking, climbing, skiing, snow-shoeing, running marathons, etc. In both, the Arctic and the Antarctic, adventure tourists continue to challenge themselves with solo expeditions or endeavours that test their mental and physical endurance (Stewart and Liggett, 2016). Those activities are viewed with some concern by policy makers, especially in the Antarctic, due to their great risks and the potentially complex search-and-rescue operations required should anything go wrong (USA, 2007). Tourists in both Polar Regions frequently visit historic monuments and local communities – be it resident communities in the Arctic or research stations and refuges in the Antarctic. On land, mobility types include a wide range of multi-terrain vehicles (some of which are the same as those shown in Figures 3.4 and 3.5 above), including various types of snowmachines, and movement by foot or skis. Consumptive tourism, i.e. hunting or fishing, is only undertaken in the Arctic as the 1991 Protocol on Environmental Protection to the Antarctic Treaty prohibits any kind of mineral-resource extraction, other than for purely scientific purposes (Maher et al., 2011), and the Convention on the Conservation of Antarctic Marine Living Resources strictly regulates marine-resource extraction, with recreational fishing activities not being permitted by the International Association of Antarctica Tour Operators (IAATO).

Despite land-based tourism opportunities, most tourism to the Polar Regions is ship-based supported by air travel. Ship-based tourism is dominated by cruise vessels, with many of the same vessels operating both in the Arctic and Antarctic (see Table 3.1) (Lück et al., 2010). Cruising without landing anywhere (also referred to as "cruise-only" tourism) is less common than expedition cruising, which regularly lands passengers in areas of interest to land-based tourism activities (Stewart and Liggett, 2016). Increasingly, private and commercial yachts, i.e. ships with a capacity of up to 12 passengers are also visiting the Polar Regions (Johnston et al., 2017).

Table 3.1. Advertised tourism activities in the Polar Regions

(Adapted from Dawson et al. (2017b) and Lamers and Gelter (2012))

Country	*Kayaking or rafting (river and sea)*	*Wildlife viewing*	*Cultural heritage tours*	*Diving and snorkeling*	*Zodiac and sailing tours*	*Hunting and fishing*	*Fjord cruises*	*Aurora australis/ borealis*	*Cruise and yacht*
Russia	X	X	X	X		X			X
Finland	X	X		X	X	X			X
Norway		X	X	X	X	X	X	X	X
Iceland	X	X		X		X	X	X	X
Alaska (USA)	X	X	X	X		X		X	X
Canada North	X	X	X		X	X		X	X
Greenland	X	X	X	X	X	X	X	X	X
Antarctica	X	X	X	X	X		X		X

Over 98 per cent of Antarctic tourism is ship-based (see IAATO, 2016), and more than 90 percept of all tourists visiting Antarctica pass through Ushuaia, the most southern port of Argentina en route to the Antarctic. Once in the Antarctic, the majority of tourism activities are focused at a relatively small number of landing sites along the Antarctic Peninsula (Bender et al., 2016). The majority of Antarctic tour operators belong to the International Association of Antarctica Tour Operators (IAATO), which aims to "promote the practice of safe and environmentally responsible private-sector travel to the Antarctic" (IAATO, 2016). Antarctic tourism is highly concentrated in the Northwestern part of the Antarctic Peninsula, as highlighted in Figure 3.6.

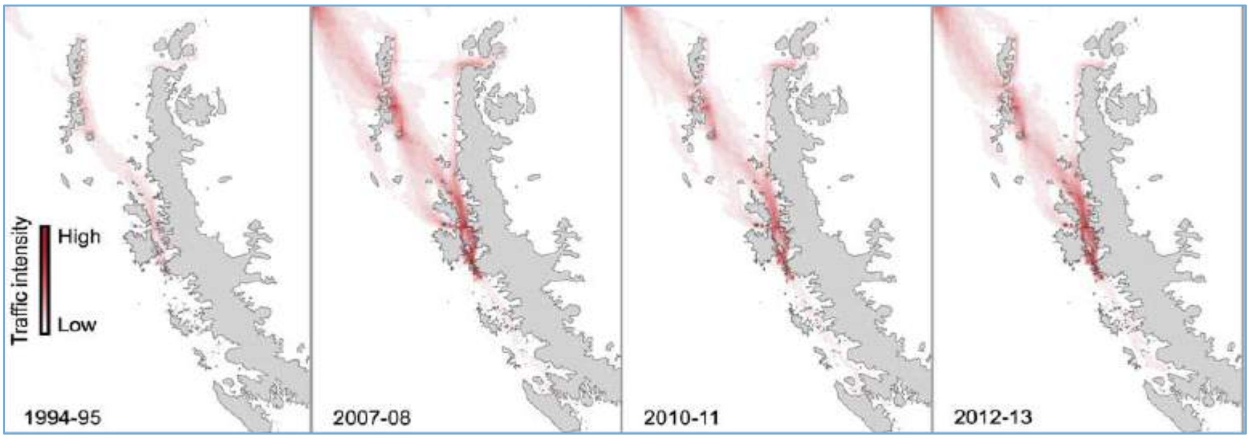

Figure 3.6. Traffic intensity due to tourism in the Antarctic Peninsula [N.B. The darker the shade of red in this figure, the greater the intensity of tourism in this region] (Bender et al., 2016: 3).

Self-regulatory organizations such as IAATO for the Antarctic and the Association of Arctic Expedition Cruise Operators (AECO, 2016b) for the Arctic also play an important role in managing some of the risks associated with tourism (Dawson et al. 2014, 2016, 2017c; also see Box 3.2). For example, IAATO's bylaws require cruise vessels venturing into ice-strewn Antarctic waters have to have an experienced Ice Pilot or Ice Master on board (IAATO, 2009).

3.3.1 Expected future trends

In both Polar Regions, dramatic changes in sea-ice extent and thickness and in particular diminishing sea-ice cover in the Arctic and around the Antarctic Peninsula region (see e.g. Meredith et al., 2016; Stroeve et al., 2014) allow tour operators to move into even higher latitudes and to extend the lengths of their operating season from earlier in the spring into later in the summer (see e.g. Tejedo et al., 2014; Bender et al., 2016). However, visiting the Polar Regions at the very beginning of a cruising season does not come without its risks as the sinking of the MV Explorer in Bransfield Strait in 2007 has highlighted (Republic of Liberia, 2009; Stewart and Draper, 2008).

In Antarctica, at least in part due to recent changes in IMO regulations that now requires anyone operating in the Antarctic to use light-marine fuel oils only (IMO, 2011), cruise-only tourism (i.e. generally vessels carrying over 500 passengers) has declined and is not expected to regain the same popularity as prior to 2007/8. In the Arctic, the presence of large cruise vessels continues to grow. Land-based tourism has not undergone any significant changes over the 30+ years of its operation and is likely to dramatically change in the future as it taps into a niche market of adventurous and fit individuals with a significant disposable income. Continental overflights in the Antarctic are unlikely to feature in the future, but novel products such as the recently offered aurora flights from New Zealand or new adventure-tourism products may gain in popularity. Air-cruise combinations are also expected to increase further. Finally, small-scale and non-commercial tourism, including private yacht expeditions and record-setting expeditions are the fastest growing sector in recent years, and this trend is likely to continue (see Johnston et al., 2016).

Box 3.2. Arctic Expedition Cruising

Expedition cruise tourism is the most common form of cruising in the Polar Regions and is characterized by small vessels (between 20 and 500 passengers), shore landings and exploration using rubber boats, quality environmental and historical interpretation of biodiversity, landscapes, historical remains and current use, remote and exclusive wilderness experience (i.e. the one boat at one bay at any one time principle), minimal environmental and social impact, human safety and flexibility due to dynamic weather and sea ice conditions. Expedition cruising started in the Antarctic with Lars-Erik Lindblad, and the building of the M/V *Lindblad Explorer* in the late 1970s, a tailor-made expedition ship for exploring ice-infested Antarctic waters (Headland, 1994; Lamers et al., 2008; Stonehouse, 1994). The so-called Lindblad model of expedition cruising travelled with the operators to other remote marine destinations, like the Galapagos Islands and the European and Canadian Arctic. To safeguard the mentioned principles in times of growth and spread expedition cruise operators collaborate in two industry associations, the Association of Antarctica Tour Operators (IAATO) and the Association of Arctic Expedition Cruise Operators (AECO, 2016a; Lamers et al., 2012; Haase et al., 2009).

Arctic expedition cruise operators make use of a variety of environmental information sources and instruments for decisionmaking. For example, operators use on board instruments like barometers and barographs, information services like GRIB files or ice charts, and communication tools like internet, Iridium satellite telephone, VHF radio. Their use is integrated in complex operational practices that predominantly depend on the experience of captains and expedition leaders, and their ability to communicate, for several reasons (Duske, 2016). First, internet connectivity is very weak in high latitude marine settings, which makes heavy data formats are difficult to download particularly for smaller sized expedition cruise vessels. This foregrounds the use of Iridium telephone and VHF for communication with company headquarters and other expedition cruise vessels in the vicinity about weather and sea ice conditions. Second, GRIB weather files are not very predictable at high latitudes with limited verification from local weather stations. As one expedition leader explains: “If you use a local GRIB file they don’t provide details and they don’t show the coastal effect, so I have to do it myself”. Third, the risk categories used in ice-charts typically do not necessarily correspond with the practice of expedition cruising, whereby the sea ice is not avoided but used as an attraction, including the biodiversity living on and around it. Fourth, various information sources are not readily available, for example ice charts from the Norwegian MET service are not available during the weekend when captains and expedition leaders rely on raw satellite imagery. Captains and expedition leaders know from experience what information source is useful at any one spatial-temporal context, including various national and private meteorological and sea ice services. Fifth, climate change is making navigation in Arctic waters more unpredictable.

Photo above: The icebreaker ‘Kapitan Khlebnikov’ visiting Pond Inlet, Canada (© E.J. Stewart (2010).

3.4 Fisheries

Reflecting the existence of some of the world's most productive fisheries, there are a range of commercial, community and science-based fishing activities occurring in the Polar Regions. Commercial and science-based fishing (including whaling) is conducted in both the Arctic and the Antarctic[h] (see also Box 3.3) while subsistence and other small-scale fishing operations are restricted to the Arctic regions.

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established in 1982 with the objective of conserving Antarctic marine life (CCAMLR, 2016) and as a result, the Commission is the source of significant information on fishing activity trends in the Southern Ocean (see Figure 3.7). According to CCAMLR (2016) the fisheries of the Antarctic and Southern Oceans currently target Patagonian toothfish (*Dissostichus eleginoides*), Antarctic toothfish (*Dissostichus mawsoni*), mackerel icefish (*Champsocephalus gunnari*) and Antarctic krill (*Euphausia superba*).

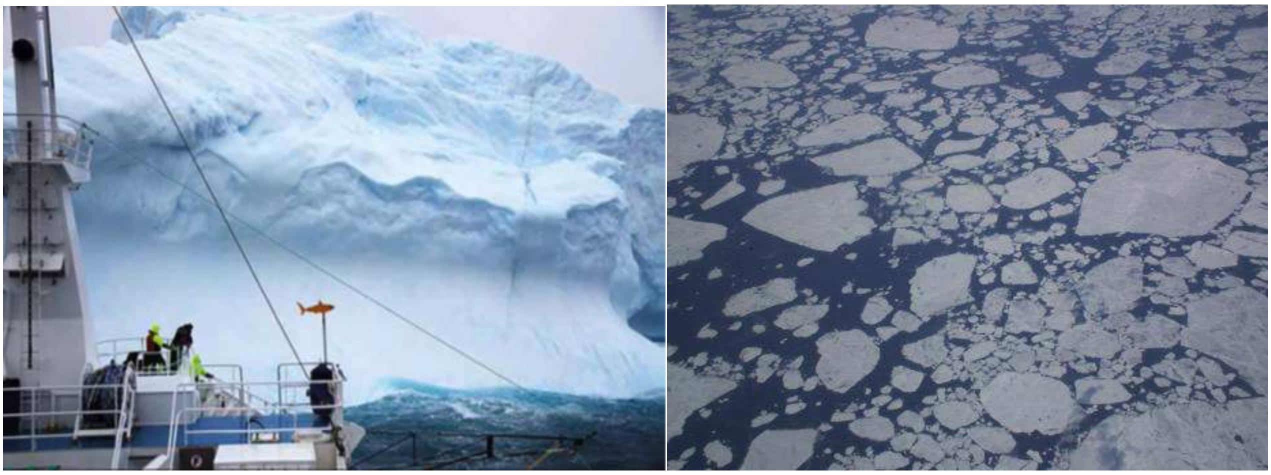

Figure 3.7. (Left) Fishing operations in the Ross Sea, Antarctica (Sanford, 2016); (Right) Pack ice in the Ross Sea providing a challenge for fishing (© D. Liggett, 2015)

In contrast, 59 marine fish species are targeted by industrial fisheries in the Arctic Ocean and adjacent seas (Christiansen et al., 2014). There are all bony fishes (*Actinopterygii*), and the reported fishing areas concentrate in the Bering and Barents Seas, in Baffin Bay around the west coast of Greenland, and around Iceland and the Faroe Islands, with very little reported fishing activity in the Canadian Arctic or the wider Arctic Ocean (see Arctic Council 2009; Figure 3.8). These fishing activities take place at different scales. In the Northeast Atlantic, large trawlers spend up to several weeks fishing far off the coast and all the way up to Svalbard. Along the Norwegian mainland, coastal fisheries prevail on small vessels with limited crews (e.g. 2-3 persons per vessel). Both categories are very dependent on reliable and accessible information, as weather circumstances can change rapidly, in particular in the winter season with the occurrence of Polar Lows.

[h] In the Antarctic, whales are only taken for research purposes. Commercial whaling per se does not occur in the Antarctic.

Box 3.3. Sanford's Antarctic Fishing Operations

Starting as a family business in Auckland in 1881, **Sanford Limited** is New Zealand's largest integrated fishing and aquaculture business devoted to the harvesting, farming, processing, storage and marketing of quality fish. One of Sanford's target species is the Antarctic toothfish (*Dissostichus mawsoni*). Toothfish are a highly prized species and are sought after in restaurants and high-end markets worldwide. The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) governs all fishing activity in Antarctic waters, and uses a precautionary approach to manage the Antarctic toothfish fishery. Catch limits are agreed using decision rules that ensure the long-term sustainability of the fishery (CCAMLR, 2015). In 2015, the precautionary catch limit for Antarctic toothfish was 3,044 tonnes with 97% of the catch limit being met, although it remains unclear about the extent of illegal, unreported and unregulated (IUU) fishing vessels in this region (CCAMLR, 2015).

In 2015, 14 fishing vessels from six nations operated in the Ross Sea Antarctic fishing grounds (CCAMLR, 2015), and Sanford operated two of these ships (Sanford, 2016). Typically the fishing starts in early December and finishes in January or February depending on ice conditions. According to the skipper of Sanford's San Aspiring fishing vessel, "one of the greatest challenges of the fishery has always been the Antarctic sea ice. It quickly gained its own moniker – the Great White Monster" (Sanford, 2016). Clearly, the effect of sea ice has a major influence on fishing operations in the Antarctic including restricting or denying access to preferred fishing grounds and hampering fishing operations, with consequences for catches and time spent fishing (CCAMLR, 2015). Sanford's skipper goes on to explain "timing of trips is critical; the ice only lets vessels in for three months of the year and we need to be heading home by early March or risk getting frozen in for winter" (Sanford, 2016). The 2015 season was the third most 'constraining' season, with 24% of the fishing grounds clear of ice, after the 2001 season (17%) and the 2008 season (18%). In contrast, the 2014 season was considered a 'good' ice year with 71% of the fishing grounds clear of ice (CCAMLR, 2015). With the benefit of a long association of operating in the Ross Sea, Sanford's draws on "experience" as well as "high resolution satellite images and ice data to help us navigate in this harsh challenging environment" (Sanford, 2016). Jack Fenaughty, an eminent polar fish scientist and science advisor to the Marine Stewardship Council, commented that operators of fishing businesses in the Antarctic need "real-time data" because the season is so short, and forecasted data too far into the future is not useful. He also confirmed that skippers rely most heavily on past experience, and that weather data are used as one of many inputs in fishing operator's decisionmaking processes (See also CCAMLR, 2015; Sanford; 2016).

Photo above: Two New Zealand vessels transiting the Ross Ice Bridge (© J. Fenaughty (2012))

Figure 3.8. Fishing vessel activity in the Arctic (Arctic Marine Shipping Assessment, 2009: 77)

Small-scale subsistence fisheries among Indigenous peoples do occur in the Canadian Arctic or the Arctic Ocean (Berkes, 1990). From 1950-2006 subsistence catches for a range of species accumulated to about 950,000 tonnes (Zeller et al., 2011), which is very small compared to commercial fishing operations (Christiansen et al., 2014). Unlike the Southern Ocean, fishing in the Arctic only occurs up to the ice-edge (not in the ice-pack), and generally operations take place in locations that are completely or seasonally ice-free (or in places with low ice concentration). Consequently, Arctic fishing is somewhat "opportunistic in nature" (Arctic Council 2009: 77).

3.4.1 Expected future trends

While environmental considerations, such as sea ice, have prevented the expansion of most Arctic krill fisheries (Nicol and Foster, 2003), Nicol et al. (2012) indicate that Antarctic krill fisheries are on the rise again. In the Antarctic, the commercial krill fisheries were established in the early 1970s, when they saw a quick dramatic increase (Nicol et al., 2012), which governments responded to with the establishment of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). Largely stable for a couple of decades, krill fishing recently started becoming more popular again, and the demand for krill is likely to further increase as improved technologies allow catches to be processed more quickly and as krill is in greater demand for use in the production of a wide variety of products, such as feed for farmed fish or nutritional supplements (ASOC, 2016; Nicol et al., 2012).

Climate change has a range of implications for the fishing sector, particularly with regard to ocean warming and loss of sea ice. Fisheries may move poleward into previously unexploited areas of polar waters (Christiansen et al., 2014). Furthermore, regulatory actions, such as the recent consensus at the CCAMLR meeting in 2016 to establish a Marine Protected Area in the Ross Sea, the largest Marine Protected Area, needs to be approved in the Antarctic to date.

Antarctic and Patagonian toothfish fisheries are likely to continue to suffer from a certain level of illegal, unreported and unregulated fishing activities, simply due to the high value being associated with toothfish. Between 2007 and 2012, the average price for imported toothfish to the ten most active countries in the toothfish trade increased by over 60%, although the overall volume traded decreased[i] (Grilly et al., 2015). Conversely, the extensive Antarctic toothfish fisheries are also thought to contribute to an increase in the number of Adélie penguins, which occupy the same ecological niche in the Antarctic marine foodweb as toothfish (Ainley et al., 2017). As main tourism attractions, Adélie penguins could potentially encourage more tourism operators to visit the Ross Sea.

3.5 Resource Extraction and Development

There are a range of resource extraction activities taking place across the Polar Regions, including energy production (renewable and non-renewable) and mining. The 1991 Protocol on Environmental Protection to the Antarctic Treaty, which forms a key component of the Antarctic Treaty System (ATS), bans all activities related to mineral resource exploitation in the Antarctic. Consequently, in the Antarctic only renewable energy generation exists as a form of resource development[j]. By contrast, the Arctic exhibits a multitude of natural resource extraction and development activities, often including the interplay of resource production, traditional activities and public services.

The US Geological Survey has estimated that 30 per cent of the world's undiscovered gas, and 13 per cent of the world's undiscovered oil is located in the circumpolar north (Gautier et al. 2009). Most of the region's oil reserves are in Alaska, while Russia holds large natural gas reserves. About 75% of Russia's estimated offshore hydrocarbon resources are located in Arctic regions, which accounts for 22-27% of global offshore resources (Luszczuk et al 2016). Some of these resources are becoming more accessible due to improved technologies as well as through climate-induced changes in sea-ice cover and extent. However, technological challenges are persisting – especially in areas with (seasonal) sea-ice. The costs to operate in the offshore Arctic waters are high and environmental concerns are large (Luszczuk et al 2016; Knol and Arbo 2014).

The large economic value of both on-shore and off-shore resources, the location of most resources within national jurisdictions, and the large multinational corporations involved have generated interest and investment in finding solutions to challenges of exploration and extraction of hydrocarbon and mineral deposits in the Arctic. For example, there are large mines in the Arctic producing nickel, zinc and other ores, as well as oil and gas fields off the coast of Norway, Arctic Russia, and the US (Arctic Council, 2009).

[i] The authors acknowledge that due to illegal, unreported and unregulated fishing activities, data discrepancies may exist (see Grilly et al., 2015).

[j] One could argue that bioprospecting also constitutes a form of resource exploitation in the Antarctic but it is sufficiently small-scale, and intrinsically linked to Antarctic research activities, to allow for it to be ignored in this document.

Figure 3.9. Wind turbines on Ross Island, Antarctica, providing power to the US McMurdo Station and the New Zealand Scott Base (© D. Liggett, 2014)

The type of mobility associated with exploration and extraction of natural resources is largely determined by its location either 'on' or 'off' –shore, as well as by the offshore solutions that are chosen (the degree to which pipelines are used). Both onshore and offshore activities generate marine transport. The bulk transport of extracted commodities such as oil, gas and minerals represent a significant portion of total Arctic marine transportation in terms of the volume of cargo transported according to Arctic Council (2009), and this is set to increase in the future. By necessity, the shipping takes place during the ice-free season or in the ice-free locations of the Arctic (such as the Norwegian Arctic and parts of the Russian Arctic). In other mining regions, some bulk cargo is stored on-land during the winter and spring necessitating the use of land-based transport.

3.5.1 Expected future trends

Northern resource development will only occur if outputs are expected to be profitable. The Arctic is a high-cost operating region, and this will remain unchanged. Costs will remain high as resources are at great distances from their intended markets and are located in remote and sparsely populated regions with an environment that is not conducive to development. However, while climate warming might facilitate access, environmental conditions may remain unpredictable, with the implication that the cost of future development may actually increase. Development of natural resources in the Arctic will continue as a central component of Arctic economies, but production is likely to occur in regions of lower cost (e.g. where infrastructure already exists, where regulation is conducive to operations, and where rich deposits of resources exist). Economic activities outside the traditional resource economy will become increasingly significant. For example, diversification into the realms of tourism, electronics and finance are already being recognized for their economic development potential (Larsen and Fondahl, 2015).

3.6 Government and Research Operations

In the Arctic, government and research vessels (including icebreakers) undertake surveying, oceanographic research, vessel escort in ice, salvage, pollution response, naval and military exercises, and search and rescue operations (Arctic Council, 2009; Dawson et al., 2017a). An increasing number of icebreakers and research vessels have been conducting geological, geophysical, oceanographic, and environmental research activities throughout the central Arctic Ocean related to establishing the limits of the extended continental shelf (Arctic Council, 2009), and increased economic interests in the region.

In the Antarctic, government activities are dominated by research, building and maintenance of research stations and any activities in support of research. The latter can include the use of the military, private companies or national operators to provide transport to and from the Antarctic, the erection and maintenance of field camps and field bases, and air, land and sea support of these field camps from the main research stations. Research and research support in the Antarctic is generally characterized by a high level of cooperation between different states. Those Antarctic programmes with sufficient motivation or funds may utilize cutting-edge and high-cost technologies to ensure the safety of personnel and the efficiency of operations. Similarly dependent on the availability of governmental, or in some cases private (c.f. the Belgian case), funding, a few National Antarctic Programmes have begun a process of "greening" their stations and started installing more environmentally friendly technology to generate electricity (see the example in the previous section) or built wastewater treatment plans (see e.g. McMurdo Station). Such station improvements are in line with greater environmental awareness and a greater focus on environmental impact assessments, largely due to changing global attitudes towards natural environments as well as the constraints imposed by the 1991 Protocol on Environmental Protection to the Antarctic Treaty, which entered into force in 1998.

Personnel regularly overwinter at Antarctic research stations, which brings along its own challenges and results in Antarctic stations representing small-scale communities that engage in some of the activities that are also present in Arctic communities (at least as recreational activities and cultural endeavours are concerned).

Search and rescue (SAR) mobilities can be air-, marine- and land-based in the Arctic (Canadian National Search and Rescue Secretariat, 2016). Incidents in the Arctic are increasing due to changing weather and ice conditions, limited SAR assets, and the vast geographic areas needing coverage (Clark, et al., 2016). Implementation of the Polar Code (IMO, 2017) and other initiatives such as the 'Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic' (Arctic Council, 2011) and the 'Agreement on Cooperation on Oil Pollution Preparedness and Response in the Arctic' (Arctic Council, 2013) are promising multi-lateral approaches to dealing with increasing probabilities of Arctic incidents.

Figure 3.10. (Left) The US McMurdo Station and (Right) New Zealand's Scott Base, both on Ross Island, Antarctica (© D. Liggett, 2014)

In the Antarctic, National Antarctic Programmes employ a variety of modes of transport to move personnel and cargo to and from Antarctic research stations and field camps. These modes of transport include ship-based transport, which in some regions of the Antarctic (e.g. the Ross Sea) necessitates the use of an icebreaker to maintain a channel that can then be used by cargo ships, and air transport. Flights to the Antarctic include, to a great extent, landings on ice runways and, to a much smaller extent, landings on hard-rock runways. Currently, Antarctica only has three operational hard-rock runways, which are all in the Antarctic Peninsula, although a fourth one is currently being built by the Italian Antarctic programme in Northern Victoria Land. Local and regional transport options include helicopters, small aircraft (e.g. Basler), land-based or permanent-ice-based vehicle transport (e.g. by Hägglunds, snowmachine, ATV, tractor trains, etc.), and human-powered transport (including using skis or bicycles for recreation transport). For any type of mobility, weather is still one of the key challenges that results in increased risk and cost (see section on commercial transport).

Figure 3.11 (Left) A resupply vessel docking at the ice pier at McMurdo Station, Antarctica; (Right) A ski-equipped LC-130 operated by the US Air Force on Pegasus Airfield, Antarctica (© D. Liggett, 2014)

3.6.1 Expected future trends

In the Arctic, the Canadian National Search and Rescue Secretariat (2016) indicated a range of factors that will influence future SAR activities in the Arctic including: the anticipated increase in frequency of extreme weather events requiring changes to the deployment of SAR resources; increased commercial and tourist activity will demand a deeper awareness of the requirements and responsibilities for successful SAR in that region; the development of new technologies (such as the international Medium Earth Orbit Search and Rescue System), together with supporting regulation, will present opportunities for improving SAR through enhanced communications, detection, and so forth. Conversely, new technologies have the potential to create a false sense of security amongst the general public, and this, in combination with a loss of land-based knowledge, increases the potential for SAR incidents.
In the Antarctic, over the past decade, states have shown a renewed interest in increasing their presence on the continent by expanding their facilities or adding new stations or camps. A number of states have recently joined the Antarctic Treaty System (e.g. Mongolia, Kazakhstan, Iceland), and other states such as Malaysia, Iran, Thailand and Turkey are working towards increasing their profiles in Antarctic Research. Thus, there is likely to be continued and increased international research and government activity in the region. For example, there has been a push for undertaking research further afield – e.g. the New Zealand Antarctic Programme has begun extending the perimeter of its operations in the Ross Sea region and has commenced establishing field camps e.g. on the Siple Coast. Furthermore, "night flights" in the austral winter, formerly only reserved for medical emergencies/evacuations which require the pilots to fly and land a plane wearing night-vision goggles, are now also planned as an activity to be undertaken on a semi-regular basis by the US and New Zealand Antarctic programmes.

3.7 WWIC Information Needs

All of the various activity sectors outlined here require WWIC information albeit at different scales, timeframes and resolutions. Each sector requires focused attention in order to tailor data products for their unique needs and requirements. However, there are some universal understandings related to many user groups in the Polar Regions:

- A desire exists for real-time observations and related products (e.g. short-term forecasts). The operational shipping seasons are short, and weather conditions can change quickly, real-time or near-real-time data are essential for operators in any sector outlined here to make risk-reducing decisions.
- Sometimes an indication of data directionality (e.g. is the wind increasing or decreasing, or is it from the West or the East) is most useful.
- Operators and community members rely heavily on past experience, and WWIC data are just one piece of information used in their decisionmaking process.
- Communicating data simply, efficiently, and effectively is very important. For example, too much data can become a problem for operators or residents. There is a need for increased attention to the communication of data products.
- Effective data interpretation is essential. The availability of very sophisticated and technical weather data is useless if an operator cannot understand it.
- Nuanced WWIC indicators that are based on local and Indigenous knowledge need to be better communicated to – and documented by – service providers in order to identify

potential scales, thresholds, and frequency of products that could be better tailored to user needs.

- Wind is one of the most important weather variables for navigation in Polar Regions (i.e. in terms of extreme events, rapid movement of ice, etc.), and there is a lack of good wind prediction and forecasting tools.
- It is challenging for data users to stay current with new weather data portals and products. Users may prefer a single information source for WWIC information but this is not the current convention.
- Ice data in the Antarctic are lacking compared to what is available for the Arctic.
- The limited communications infrastructure and, in particular the limited bandwidth available for Internet transmissions, is a challenge when trying to access data.

3.8 Conclusion

This section provided a description of WWIC-related mobility issues and challenges for several socio-economic sectors and groups of people living, visiting and working in Polar Regions. All of the challenges are to some degree attributable to the harsh, demanding and changing aspects of the physical polar environment, but many are also exacerbated or complicated by a growing demand for resources, associated increased levels of activity, and greater access to and use of new technologies. Users generally exhibit a greater dependency on technology but require specialized services due to the breadth of contexts and practices involved.

While the affected actors are numerous and wide-ranging (e.g. individual Arctic residents, cruise-ship operators, petroleum industry managers, scientific expedition logistics coordinators, etc.), all of them make decisions that involve some consideration and understanding of WWIC conditions. For instance, any activities involving maritime mobility would benefit from real-time ice data that extended to include information on ice thickness as well as ice extent. Here, information on wind direction and strength is of great importance.

Table 3.2 provides a summary of human activities in the Polar Regions, including weather and ice needs. The table distinguishes between different types of activities, their dominant forms of mobility (foot, plane/helicopter, ship/yacht, land-transport by vehicle, or mixed), the scale (local, regional, national, international, cross-scale) at which each activity cluster operates and gives an indication of the current trend (increasing, neutral, decreasing, or unknown) characterising each activity cluster. While this summary offers a high-level overview of human activities and mobilities in the Polar Regions, it is only to be taken as a guideline due to the paucity of actual accurate data on human activity trends.

Table 3.2. Human activities and environmental information needs in the Polar Regions

Legend:

Trend	3 - increasing	Mobility (dominant mobility shown in table)	F	Foot	Scale	L	Local
	2 - neutral		A	Airplane/Helicopter		R	Regional
	1 - decreasing		S	Ship/Yacht		N	National
	0 - unknown		LT	Land transport (by vehicle)		I	International
			ST	Sea-ice transport (by vehicle)		C	Cross-scale
	empty - activity not occurring		M	Mixed (at least three of the above)			

		Arctic			Antarctic			WWIC Information	
		Mobility type	**Trend**	**Scale**	**Mobility type**	**Trend**	**Scale**	**Weather**	**Ice**
Tourism	Consumptive tourism (hunting, fishing)	M	2	L				1	1
	Adventure tourism	M	3	C	M	2	C	1	1
	Cruise tourism	S	3	C	S	3	C	1	1
	Air-cruise tourism				A; S	3	C	1	1
	Yachting	S	3	R	S	3	R	1	1
	Air-borne tourism	A	0	I	A	1	I	1	1
	Business tourism	M	3	L					
	Visiting friends and relatives	M	2	L					
	Other forms of tourism	M	0		M	0			
Fishing	Krill and crustacean	S	0	R	S	0	R	1	1
	Antarctic high-end (Toothfish)				S	3	R	1	1
	Arctic high-end (e.g. cod, salmon, etc.)	S	0	R				1	1
	Whaling (scientific and commercial)	S	0	R	S	0	R	1	1
	Small-scale commercial fisheries (e.g. using the ice as platforms)	S	0	L				1	1
	Subsistence fishing	S	2	L				1	1
Resource extraction and development	On-shore resource exploration	LT; A	3	L				1	1
	Off-shore resource exploration	S; A	3	R				1	1
	On-shore resource extraction (oil, gas, minerals)	LT; A	3	L				1	1
	Off-shore resource extraction (oil, gas, minerals)	S; A	2	R				1	1
	Farming and agriculture	F; LT	3	L				1	
	Reindeer herding	F; LT	0	R				1	
	Subsistence hunting	F; LT	2	L				1	1
	Energy generation (fossil-fuel, geothermal, hydro, wind, solar, nuclear)	LT	0	L	LT	0	L		

Construction	Heritage restoration	M	0	C	LT; S	3	C	1	
	Asset construction (bases and other infrastructure)	LT; A	0	R	LT; S	3	R	1	
	Other construction activities	M	3	R	M	3	R	1	1
Commercial transport	Commercial shipping	S	3	I			I	1	1
	Commercial land-based transport (by road or rail)	LT	0	R				1	
	Commercial air-based transport	A	3	I				1	
Government activities	Military activities (including research support)	M	3	C	M	3	C	1	1
	Icebreaking	S	3	R	S	0	R	1	1
	Surveillance	S; A	0	C	S; A	0	C		
	SAR/Emergency services	S; A	0	R	S; A	0	R	1	1
	Surveying/Charting/Mapping (hydrographic and terrestrial)	M	0	R	M	0	R	1	1
	Social services (including health service)	LT	0	L				1	1
Community activities	Private boating	S	2	L				1	1
	Private land-based transport (car, snow-machine, ski, etc.)	LT	0	L	LT	0	L	1	1
	Private transport on sea ice (snow-machine, ski)	ST	0	L	ST	0	L	1	1
	Private air-based transport	A	0	R				1	1
Research*	Community-based research	LT; A	2	L	S; A	0	L		
	Urban-based research	LT; A	0	L					
	Land-based remote fieldwork	LT; A	0	R	LT; A	3	R	1	
	Marine remote fieldwork	S	0	R	S	3	R	1	1

**This could be government-sponsored, NGO-sponsored, research for commercial purposes, or research funded by other non-governmental entities.*

4. THE PROVIDER-USER INTERFACE: GAPS, PRIORITIES AND A RESEARCH AGENDA

4.1 Introduction

PPP aims to improve the availability, reliability and user-friendliness of WWIC forecasting in the Polar Regions and beyond. PPP-SERA has been tasked with the definition, development, and promotion of a collaborative research programme that complements physical science activities in PPP. Work within PPP-SERA will have an intensive research and observation period during the YOPP Core Phase from 2017 to 2019, but will extend beyond that Core Phase and be relevant indefinitely.

In the previous chapters of this document, we have attempted to identify and analyse the actor-scape of WWIC information service users and providers in the Polar Regions, organized by the activities of various actors. As we have shown, WWIC information is important in addressing user needs in the context of a changing climate and in supporting critical services (e.g. community re-supply, resource harvesting) and preparedness for the environment (e.g. SAR, emergency response to environmental disasters, safe navigation in shipping and aviation, and national security). Generally, we observe a mismatch or incongruence between the WWIC information currently provided, and the ways in, and extent to which, WWIC information is used and or is needed by various actors and sectors.

This section further identifies key research gaps and priorities related to the challenges facing both WWIC information providers and WWIC information users, and proposes a research agenda to fill key knowledge gaps. While some of these identified knowledge gaps are likely to be addressed during YOPP, we encourage other scientists with a background in polar research to continually contribute to the research agenda outlined in this section.

4.2 Mobility Patterns and Trends

Human activities and mobility sectors vary widely in size and scope, and are diverse in terms of their spatial-temporal context of operation and practices. Some travel occurs across vast geographic areas while others only cover small areas. It has been claimed that the Polar Regions are in a phase of transition from experimental shipping activities towards a more routine use of polar marine environments (Arctic Council 2009). To assist in this transitional phase, there is an urgent need for enhanced WWIC information services addressing physical events with relevance to marine sectors, such as around freeze and breakup of fast-ice, iceberg calving, extreme weather events and icing.

It is unclear what WWIC information services are needed to facilitate the execution of plans for extending marine activities in the Polar Regions, including shipping of people and goods. More work is needed to collect and process data necessary to map these mobilities in terms of their spatial and temporal characteristics. Since most activities are on the increase, and a greater dependency can be observed of users on technology, more detailed, specialised and instant weather and climate services are required for a greater diversity of contexts and practices. However, since most activities, and their related mobilities, currently tend to be small-scale and specialist, it can be questioned whether large investments in specific WWIC services are justified in all cases.

4.3 Risks, Risk Perceptions and Challenges

There are key risks and opportunities related to human activities in the Polar Regions. Risk generally refers to the probability and the consequences of an adverse event. As a measure for hazard (Keiler, 2004), risk represents "a situation or event where something of human value (including humans themselves) has been put at stake and where the outcome is uncertain" (Rosa, 1998: 28). Further work needs to be done to understand the nature and consequences of these risks in dynamic polar environments, including their relationship with safety, security, sovereignty, cultural and environmental sustainability, economic development, communication, empowerment of marginalised groups, and human health. Risks result from exposure to direct biophysical changes and indirect socio-economic effects resulting from biophysical risks (increases in shipping activity). Risks tend to be compounding in the sense that they emerge from a combination of multiple factors, including the absence or failure of adequate response mechanisms.

Moreover, static and top-down approaches of assessing hazards, exposure and risk have been, and still are, dominant. However, risks, uncertainties and opportunities are dynamic, entail agency, adaptive capacity and social learning by the groups involved and should encompass a temporal scale (Student et al., 2016). Vulnerability and resilience of actors to biophysical risks is co-determined 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.

Work is also needed to understand how risks are dealt with in practice by various mobile actors, such as how are risks perceived and decisions taken in times of uncertainty by different actors. For example, traditional hunting and subsistence activities rely on stable and predictable sea ice conditions. With the latter being adversely affected by climate change and becoming more dynamic and unstable, members of Indigenous communities are forced to seek out new hunting grounds. Competence and experience is a key factor in the safe conduct of activities across all actors operating in dynamic polar environments, regardless of whether these are local communities or ship operators. A pertinent issue emerges with new actors or operators entering these environments. How can we ensure that they have sufficient experience or access to the best information to make sensible decisions? For example, planning is typically done well in advance of any consideration of sea ice or weather and is based on experience, which is something that new entrants do not yet possess to the same extent as "old hands". This, in turn, increases the operational risks arising from involving new entrants.

4.4 WWIC Information Use

Improving access to, and quality of, climate relevant information is particularly pertinent to mobile actors and sectors operating in remote and dynamic polar marine environments, as it is in moving through such environments that relevant and reliable information services reduce the vulnerability of marine mobility sectors (Thoman et al., 2017). We have seen that the growth and diversity of activities in the Polar Regions call for more detailed and specialized WWIC information services to be salient in the diversity of contexts and practices in which users engage. There seems to be a greater dependency of users on technology. Individual users of WWIC information in the Polar Regions are insignificant when viewed in the context of a global economy, but they are far from insignificant when considering socio-cultural aspects, ethics and costs related to search and rescue. Their activities are accompanied by a greater risk compared to other groups in the world because of the remote and dynamic environment they operate in.

How information services are used and how they influence specific relevant decisionmaking and operational practices is largely unknown. Different end-users seem to have very different needs and capabilities with regard to WWIC information services, depending on their objectives, modi operandi, experience or available technologies. Situating WWIC information within the overall framework of what is being done is important. Climate services may play a minor role in the decision-making process, e.g. compared to experience, Indigenous and local knowledge or regulations. Better information is necessary for some but insufficient for all; just because it exists does not mean it will be used.

A wide range of WWIC information is available but, out of the array of available information, only a small subset of services is being selected by individual users, usually based on familiarity, convenience and accessibility (free of cost). The use of WWIC information services tends to be routine and, despite some inadequacies, users are coping with what they have and use the services in a confirmatory sense, i.e. in an attempt verify their own perceptions or decisions that are based on experience or well-established practices. Moreover, the mere availability of information or the fact that actors access certain information do not say much about if and how this information is actually used in decision-making. For example, it is known that ship operators are required to download particular datasets for meeting the IMO's SOLAS regulations, instead of, for actual use.

Improving the ability to predict and forecast weather and sea-ice conditions in the Polar Regions depends on improving our understanding of how marine mobility sectors use such information in planning and operations. Marine mobility sectors are highly vulnerable to climate change, whereby the main marine vulnerabilities in Polar Regions arise from sea ice and iceberg dynamics, rough seas (e.g. high waves, strong winds) and icing. These vulnerabilities, however, do not materialize independently; rather, they emerge through interactions between users, a range of user characteristics (e.g. experience, ship-type, communication technology) and environmental factors. For example, accessing weather and climate information in the Arctic or Antarctic environment is challenging due to limited internet accessibility. Therefore, there is a need for research that considers the context in which marine activities in the Polar Regions are undertaken and WWIC services are used, including their different interests, constraints, abilities, routines and decision-making contexts. In other words, for WWIC services to become more salient, they will have to be tailored more precisely to decision practices of different users, not only in terms of content, but also in terms of format and interface (Thoman et al., 2017).

4.5 WWIC Information Value Chain

When compared to other parts of the world, the Polar Regions face a limited ability to observe and predict environmental conditions such as weather, sea ice, waves and related physical environmental phenomena (Eicken, 2013; Inoue et al., 2013; WMO WWRP PPP, 2013). Those development needs are currently addressed in large internationally coordinated initiatives for improving the observations, modelling, forecasting and integration of weather and climate information in, and for, the Polar Regions, including the Copernicus Climate Change Service (C3S), Polar Prediction Project (WWRP-PPP), Polar Climate Predictability Initiative (WCRP-PCPI), and the Sub-seasonal to Seasonal Prediction Project (WCRP-WWRP-S2S). From a meteorological services perspective, there is potential in using these combined resources to improve our understanding and prediction of Arctic and Antarctic processes in a seamless weather-to-climate context. There is a need to harmonize production and service along the value chain, allowing the seamless use of observation and forecasting at sub-seasonal to climate time scales. Moreover, the potential of these efforts for enhancing user-specified climate services for local communities, public and private sector organizations in the Arctic and the Antarctic are currently not realized.

The increasingly complex WWIC information value chain has to be understood better. Worldwide, WWIC information value chains no longer describe linear processes from producers and providers of information to end-users. The commencement and growth of the internet has formed a clear divergence point in the decentralization of WWIC information services among a wide range of actors, acting as users and providers at the same time. In the Polar Regions, centralized and top-down weather and climate services are still dominant. However, here we also see decentralized forms of information collection and provision by and for specific user groups, with data quality that cannot always be guaranteed by the traditional state-based institutions (e.g. community-based monitoring).

Currently, the implications of differences between end-user characteristics and user needs are largely unknown and not taken into consideration in the development or enhancement of weather or sea- ice forecasts (Thoman et al., 2017). A key question is how WWIC services can be co-produced with end-users, especially as transdisciplinary work and feedback systems are concerned. During the last decade, climate adaptation researchers and policy makers have realized that, in order to enhance the saliency, along with the credibility and legitimacy of climate information (Cash et al., 2003), co-producing knowledge and knowledge systems with users of this knowledge would be crucial (e.g. Hegger et al., 2012).

Successful co-production depends on a range of conditions, including early involvement of a broad representation of end-users in a joint problem definition (co-scoping), clearly defined roles and tasks, the availability of sufficient time and resources as well as the inclusion of contextualised (space and time specific) end-user perspectives (Hegger et al., 2012). So far, these ideas and conditions for knowledge co-production have been primarily applied to community-based and research-driven projects, while the potential for co-production approaches of larger information service providers, such as national weather and climate service providers, has received less attention.

The societal implications of this decentralization trend for various actor groups in the Polar Regions are largely unknown (Lamers et al., 2016). For example, to what extent does the emergence of big data utilization, community-based approaches and private services for specialised needs lead to the empowerment of particular users. Further, the increasing availability of environmental information systems may contribute to an illusion of safety, resulting in risks that may not have taken in the past.

4.6 Research Agenda

4.6.1 Understanding WWIC use in various human activities in the Polar Regions

There is a need to identify and categorize relevant human activities and mobilities in the Polar Regions, and to engage in in-depth systematic and sector-specific analyses to characterize and synthesise what is currently known about these activities, the kinds of WWIC used or identified as necessary to support decisionmaking at different spatial and temporal contexts. Currently, no comprehensive information is available on human activities in the Polar Regions. We encourage research, industry, and government efforts to develop approaches to effectively and systematically identify and track the diverse activities taking place in the Polar Regions. We also need to work with key representatives of the various sectors to identify and better understand what WWIC services are needed to support these activities, and facilitate any potential emergency responses.

We need to improve our collective understanding of human activities in the Polar Regions, their related mobilities, WWIC needs and decisionmaking behaviours.

To address the aforementioned knowledge gaps, we recommend the following work to be undertaken:

- Extensive descriptive research collating trans-regional information and statistics on human activities in the Polar Regions across all sectors, but with a particular focus on tourism, fishing, the transport sector, research activities and community-based activities.
- A survey of key actors to understand the breadth of 'information user needs'.
- Assessments of information needs for WWIC services among different user categories.
- Ethnographies detailing decisionmaking processes among actors in the Polar Regions and their use of WWIC-related information.

Furthermore, to understand decisionmaking by actors, we need to gain a better understanding of:

- Risk perception
- Factors affecting decision-making
- Factors that might constrain, as well as facilitate, opportunities (including legal and political issues)

4.6.2 Providers and the coproduction of WWIC services

As this report indicates there is a need to (a) improve our understanding of the kinds of WWIC services already used in different sectors; (b) learn more about the diversity of WWIC indicators used for experiential navigation within different the sectors; (c) assess the potential for WWIC services to improve their representation at the appropriate scale, resolution (spatial and temporal) and frequency that are needed by different actors in different sectors.

We need to better understand how salient WWIC services can be provided or coproduced.

In response to these needs, we require detailed descriptive research cataloguing the different types of WWIC-service providers and their characteristics as well as original research that assesses:

- Ways that providers tailor their information to specific users (including what strategies are used).
- Factors that might prohibit, or limit, responsiveness to users in institutional providers.
- Types of services providers could offer in an ideal world as opposed to services providers can realistically offer in a resource-constraint world.

4.6.3 The Provider-User Interface: The salience and effectiveness of WWIC services

There is a paucity of research on the provider-user interface and on the usefulness and effectiveness of WWIC services despite the obvious need to tailor products or formats to specific user needs and assess the relative levels of success in this respect. Firstly, work is required to explore user preferences for certain sources or formats of information and to assess the kinds of interface characteristics or channels for accessing WWIC information that users find more useful or challenging.

Furthermore, the relevance, accessibility, ease of use, and effectiveness of communication of current WWIC forecasts or modelling products should be evaluated taking into account the perspectives of target users. We also need to learn what makes particular kinds of information, or particular kinds of providers, trusted sources by users. On a practical level, we encourage the development of additional opportunities and mechanisms for user feedback of data services/technologies offered by providers.

We need to identify ways to accurately assess the usefulness and effectiveness of WWIC services from diverse perspectives.

To respond to these knowledge gaps, in-depth qualitative and quantitative research is needed which explores:

- Kinds of data/information actually and routinely consulted by users.
- Access and interface characteristics users find useful, or not, in the delivery of WWIC services.
- What makes particular providers trusted sources for users.
- User preferences for sources/formats over others (technological, trust, etc.).
- Institutional, legal or other factors that may constrain access to or provision of WWIC services, and how this impacts provider ability to respond to user needs and feedback.

Furthermore, it is essential to understand the role of local observations, citizen-science and operational forecasters, which is increasingly recognized as contributing important WWIC information. These groups are often considered as 'users' but the boundary between 'users' and 'providers' of WWIC forecasting is no longer dualistic or clearly defined. Consequently, we should address the following questions:

- To what extent can WWIC information and forecasts be co-produced?
- What infrastructure and communication pathways are needed to connect, say, community-based or research-driven monitoring with larger formalised WWIC-service providers, such as national weather, water, ice, and climate service providers?
- What new language may better reflect the reciprocal and interconnected nature of "users" and "providers" of WWIC information and identify contributions appropriately?
- To what extent is there the potential for an increasing inequality between, or empowerment of, different user groups?

5. CONCLUSION

This report has highlighted what information on human activities and decisionmaking in the Polar Regions we have access to, but more importantly, what information we are currently lacking. It is beyond doubt that, in order to improve environmental forecasting services in the Polar Regions, we need to better understand user needs. This in turn requires a better grasp of the scale and scope of human activities in the Polar Regions, and the characteristics and mobilities of individual actors.

We have also identified four main categories of WWIC service providers and have shown that the boundaries between users and information providers are becoming blurred. Users of WWIC information are increasingly interested in tailor-made products that may not necessarily be available on the market. Consequently, some users may take it upon themselves to fill that gap and enter the realm of service providers. This implies that we are entering a new era of WWIC service provision, and we need to understand the altered dynamics of provider-user interactions to be able to deliver effective and successful environmental forecasting for the Polar Regions and beyond. The blurring between information providers and users also means that not all forecasting products and services available are likely to be quality-assured. Even more importantly, while this new era of pluralist and multimodal interactions between providers and users of WWIC services opens new opportunities for enhanced forecasting services, it requires additional research to ensure the effectiveness and societal value of these new developments. We need to understand what actors actually need in support of decision-making, why they choose certain services over others, what formats for information provision they prefer, and how they develop trust in information providers.

The Societal and Economic Research and Applications subcommittee of the Polar Prediction Project, and scientists involved in research that focuses on the Polar Regions more broadly, can contribute to addressing some of the knowledge gaps outlined above and in the preceding chapters of this document. From a practical perspective, we encourage the utilization of geospatial and other data mapping to make WWIC information available graphically. We have already compiled an initial overview of WWIC information providers, which we envision will be made available online. We invite others to contribute further information to this database. While these last two points represent ideas for applied tools that we are unlikely to have the capacity to develop solely within PPP-SERA, we can work on a schematic of users, decision factors, services sought, and providers tailoring products for specific mobilities, to try to highlight the complexity and interconnections between users, providers, mobilities and decisionmaking across the Polar Regions.

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ANNEX I

LIST OF PROVIDERS

The following lists serve as examples for various kinds of providers for data, information, knowledge, structure, etc. The following lists are not intended to be exhaustive. The categorization of the following lists (national service providers, polar research operators, etc.) is impossible to be descriptive.

Part 1 – National Service Providers
These different organizations are part of the national structure and deliver data and information to decision-makers of various levels, the public and for scientific research.

AARI	The oldest and largest Russian research institute in the field of comprehensive studies of Arctic and Antarctica.
AEMET	Spanish Meteorological Institute
AFMA	Australian Government agency responsible for the efficient management and sustainable use of Commonwealth fish resources on behalf of the Australian community.
APRI	Austrian Polar Research Institute
Arctic Voyage Planning Guide	By Canadian government [Canadian Government Fisheries and Oceans], building a strategic planning tool for all vessels that travel through the Canadian Arctic.
AWI	Alfred-Wegener-Institute. One of the 16 national research centres in Germany.
BAS	British Antarctic Survey
BEAC	Forum for intergovernmental and interregional cooperation in the Barents Region; Including IBS – International Barents Secretariat.
BSH	Bundesamt für Seeschifffahrt und Hydrographie, Germany. German Maritime and Hydrographic Agency, Federal Government's provider of maritime services.
Bureau of Meteorology	Antarctic Meteorological Centre at the Australian Station, Casey, Antarctica
CAA	Chinese Arctic and Antarctic Administration
CIS	A division of the Meteorological Service of Canada in the Department of Environment, - mission is to provide the most timely and accurate information about ice in Canada's navigable waters - provide direct access to ice and iceberg information.
CMA	Chinese Academy of Meteorological Science
Danish Ice Service	The Admiral Danish Fleet is responsible for the Danish Ice Breaking Service and ice information for the Danish Waters.
DLR	DLR is the national aeronautics and space research centre of the Federal Republic of Germany.
DMC	Direccion Meteorologica de Chile (Chilean Meteorological Service)
DMI	Danish Fleet: Danish Ice Breaking Service and ice About half of the total DMI activities are related to the Forecasting Services Department while the activities of the Research and Development, Observation, Data Processing and Data Base Departments amount to about 10%, 20%, 5% and 5% respectively.
ECCC	Environment and Climate Change Canada

EMHI	Responsible for the sea ice information service in Estonia. The service is, in particular, intended to meet the needs of international and Estonian shipping services. Service is also given to all other activities, where sea ice information is required: fisheries, coastal and harbour activities, meteorological forecasting and climatology.
FMI	On 1 January 2009 physical oceanography in Finnish Institute of Marine Research (FIMR) was amalgamated with Finnish Meteorological Institute (FMI), and chemical and biological oceanography with Finnish Environmental Institute (SYKE). With these rearrangements Finnish Ice Service, responsible for the sea ice information service in Finland, became a part of FMI.
Ice Desk	National Weather Service Forecasting Office, Anchorage, AK, USA; NOAA; National Weather Service Ice Desk (Anchorage, AK).
Ice Logistics Portal	Baltic Sea Ice Services - Ice Logistics Portal
IMGW	The Ice Service is provided by the Institute of Meteorology and Water Management, Maritime Branch (Instytut Meteorologii Gospodarki Wodnej, Oddzial Morski – IMGW OM), Hydrological Forecasting Office in Gdynia). It covers Polish waters. Ice services are provided for all marine activities (fisheries, navigation, drilling and harbours).
IMO	The Icelandic Meteorological Office provides all sea ice information services in Iceland.
IPEV	Institut Paul Emile Victor - Institut Polaire Français - to operate in the Arctic or Antarctic polar regions, subarctic and subantarctic zones where remote locations and harsh climate justify specially adapted technological approaches.
Italian AF	Italian Air Force
JMA	Japan Meteorological Agency
KOPRI	To undertake a world-class programme of scientific research, survey and long term observations addressing key issues of global or fundamental importance that require access to the Arctic/Antarctic or related regions.
LEGMA	Provides the national sea ice service
LHMS	Klaipeda Department of the Lithuanian Hydrometeorological Service - analyses and collects data (e.g. from CMR)
Met Service NZ	Meteorological Service New Zealand
met.no	Norwegian Meteorological Institute
Meteoinfo.ru	Russian Hydrometrological Centre for Weather Forecasts
NAIS	A joint initiative of the U.S. National Ice Center (NIC), including the International Ice Patrol (IIP), and the Canadian Ice Service (CIS) that has grown out of the long-standing cooperation between the two organizations. The primary objective is to provide a better ice information service to users by reducing the potential for confusion caused by multiple, overlapping products coming from different sources. A secondary objective is to gain greater efficiency by reducing duplication of effort by the two services.
NCEP	National Center for Environmental Prediction (USA)
NIC	Through the collective efforts of three Federal Government agencies: the National Oceanic and Atmospheric Administration (NOAA), the United States Navy (USN), and the United States Coast Guard (USCG), manpower and fiscal resources are contributed and used in the collaborative operation of the National Ice Center (NIC).
NIPR	National Institue of Polar Research - Serving as Japan’s key institution for scientific research and observation in Polar Regions, Serving as a leader in implementing Antarctic+Arctic monitoring programmes, As a center for cultivation of researchers.
NMEFC	China's National Marine Environment Forecast Centre
NOAA	National Oceanic and Atmospheric Administration, USA

Norway Ice Service	Norwegian Ice Service, provided by MET Norway; provision of ice charts and other data.
Norwegian Coastal Administration	The main task of the Norwegian Coastal Administration Ice Service is to inform vessels about the ice situation in Norwegian waters from the Swedish border to Kristiansand including the Oslofjord.
Norwegian Polar Institute	Norsk Polarinstitutt is Norway's central institution for the mapping and practical and scientific investigations on Svalbard and Jan Mayen, in the Arctic waters and in the Antarctic. The institute is organized under the Norwegian Ministry of the Environment. The institute has roots back to 1906. The head office is located in Oslo (moves to Tromso in 1997). In 1993 and 1994 the activity was expanded with offices in Longyearbyen and Tromsш. The institute also runs a research station in Ny-Elesund, Svalbard, and the summer-stations Troll and Tor in Dronning Maud Land, Antarctica.
NSIDC	Supports research into our world’s frozen realms: the snow, ice, glaciers, frozen ground, and climate interactions that make up Earth’s cryosphere. NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere.
PRIC	Polar Research Institute of China
RANNIS	The Icelandic Centre for Research (RANNIS) supports research, innovation, education and culture in Iceland. RANNIS cooperates closely with the Icelandic Science and Technology Policy Council and provides professional assistance in the preparation and implementation of the national science and technology policy.
SAO	China's national ice service, including services as Qingdao Marine Forecasting Observatory (QMFO).
SIOS	Svalbard Integrated Observing System
SMARA	Sea ice information services in Argentina are provided by the Argentine Navy Meteorological Service (SMARA) of the Naval Hydrographic Service.
SMHI	Responsible for the sea ice information service in Sweden since 1930. SMHI provides ice information for the Swedish icebreakers and international shipping through the National Maritime Administration, the Royal Swedish Navy and the general public and media.
SOA	State Oceanic Administration (China)
Swedish Polar Research Secretariat	The Swedish Polar Research Secretariat is a government agency that promotes and co-ordinates Swedish polar research. This includes following and planning research and development, as well as to organize and lead research expeditions to the Arctic and Antarctic regions.
USCG	United States Coast Guard (USCG) (contribute to the NIC)
USN	United States Navy (contribute to the NIC)

Part 2 – Polar Research Operators

The following organizations are conducting research in the polar realms, but are not part of a national framework but belong either to international bodies, scientific organizations

ACE-CRC	ACE-CRC - Australian Antarctic Climate and Ecosystems Cooperative Research Centre - provide governments and industry with accurate, timely and actionable information on climate change and its likely impacts.
ADC	The overarching purpose of the Arctic Data Committee is to promote and facilitate international collaboration towards the goal of free, ethically open, sustained and timely access to Arctic data through useful, usable, and interoperable systems.
AOOS	Plays a crucial role in terms of data generation and provisioning for the Alaskan area -- gather and provide data and information that provide understanding about the status of Alaska's marine ecosystem for better decisionmaking.

CMR	Centre of Marine Research - its observations are sent to LHMS
e-navigation	e-navigation is a Strategy developed by the International Maritime Organization (IMO) to bring about increased safety of navigation in commercial shipping through better organization of data on ships and on shore, and better data exchange and communication between ships and the ship and shore.
ECMWF	ECMWF - European Centre for Medium-range Weather Forecasts. An independent intergovernmental organization supported by 34 states, located in Reading, UK.
ESA	European space Agency
ETSI	Expert Team on Sea Ice
EUCOS	Additional observations over northern Polar Regions - EUCOS is the ground-based or non-satellite observing system designed for EUMETNET Members to serve the needs of the Forecasting (incl. general numerical weather prediction) and Climate Programmes and those of the Members over Europe.
EUMETNET	EIG EUMETNET is a grouping of 31 European National Meteorological Services that provides a framework to organize co-operative programmes between its Members in the various fields of basic meteorological activities.
GCW	GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere. GCW includes observation, monitoring, assessment, product development, prediction, and research.
GEOSS	This 'system of systems', through its Common Infrastructure (GCI), proactively links together existing and planned observing systems around the world and support the need for the development of new systems where gaps currently exist.
GIPPS	Global Integrated Polar Prediction System
IABP	The participants of the IABP work together to maintain a network of drifting buoys in the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes including support to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) Programme.
IASOA	Contributing observations and research based on pan-Arctic atmospheric observatories - to advance coordinated and collaborative research objectives from independent pan-Arctic atmospheric observatories through (1) strategically developing comprehensive observational capacity, (2) facilitating data access and usability through a single gateway, and (3) mobilizing contributions to synergistic science and socially-relevant services derived from IASOA assets and expertise.
IIP	The mission of the International Ice Patrol is to monitor the iceberg danger in the North Atlantic Ocean and provide relevant iceberg warning products to the maritime community.
IPAB	The Participants of the WCRP/SCAR International Programme for Antarctic Buoys (IPAB) work together to maintain a network of drifting buoys in the Southern Ocean, in particular over sea ice.

Part 3 – Knowledge Exchange Platforms

Following organizations serve the purpose to inform the public or limited parties with information, but not in a scientific way but rather for knowledge exchange and decisionmaking.

Arctic Centre	Arctic Centre is a national and international hub of information and centre of excellence that conducts multidisciplinary research in changes in the Arctic region.
Arctic Portal	A comprehensive gateway to Arctic information and data on the internet, increasing information sharing and co-operation among Arctic stakeholders and granting exposure to Arctic related information and data.

Arctic Web	Arctic Web is a Danish organization that was founded in 2013 and is funded by the Nordic Council of Ministers. It started off by trying to create a tool for cruise ships to do their obligatory risk assessments.
ArcticNet	Strong scientific understanding and systematic observations of the changing world ocean climate and ecosystems shall underpin sustainable development and global governance for a healthy ocean, and global, regional and national management of risks and opportunities from the ocean.
Barents Portal	A tool for publishing environmental data, strengthen cooperation in ecosystem based management. Few weather/ice data mainly data on pollution etc.
CNNRO	"the facilities and know-how that make northern research possible in Canada". To advance the collective interests of Canada’s northern research infrastructure operators through coordination, outreach and joint action in order to help them achieve excellence in technical and logistical support individually and as a network.
Cryosphere today	A web space devoted to the current state of the cryosphere
EU Arctic Forum	The Arctic Forum Foundation functions as an independent, non-profit platform and bridge builder for Arctic-focused actors in politics, science, civil society and business. Through its three pillars - the Arctic Economic Forum, the EU Arctic Forum, and the Science Policy Forum, the foundation utilizes its extensive network to ensure impacts in decision-making and efficient cooperation.
Fishnet	Fishnet ltd owns and operates Russia's leading seafood portal http://www.fishnet.ru/ for the Russian speaking seafood professionals and http://www.megafishnet.com/ for English speaking fish market players.
Gateway Antarctica	Contributes to increased understanding and more effective management of the Antarctic and the Southern Ocean by being a focal point and a catalyst for Antarctic scholarship, attracting national and international participation in collaborative research, analysis, learning and networking. Engineering in extreme environments.
MeerEisPortal	MeerEisPortal.de (German language) or SeaIcePortal.de (English language) provide satellite observations of sea ice concentration in the Arctic and the Antarctic since its launch in April 2013.
Nautical Institute	The Nautical Institute is an international representative body for maritime professionals involved in the control of sea-going ships. We provide a wide range of services to enhance the professional standing and knowledge of members who are drawn from all sectors of the maritime world.
Northern Sea Route Information Office	The official legitimation for travelling the NSR has to be applied for here
Polar Portal	Danish Arctic research institutions present updated knowledge on the condition of two major components of the Arctic: The Greenland Ice Sheet and the sea ice.

Part 4 – Data Exchange Platforms

The following organizations provide more in-depth, more targeted information about polar environments and conditions than part 3. Users can partly access the data for free, partly it is for professional or commercial use. National/State agencies have been covered in part 1, although a strict line between both (national/private) can often not be drawn precisely, and also governmental or institutional agencies may have commercial interests.

AccuWeather	Private Weather Information provider (online)
Aker Arctic	Aker Arctic offers clients development, design and testing services. In addition, the company also markets and sells complete ice-going ship projects.

AOV	A companion application [of the ARMAP], the Arctic Observing Viewer (AOV), displays "data collection sites" - with higher-resolution locations and details for individual towers, boreholes, vegetation plots, weather stations, stream gauges, and other instrumentation sites.
Arctic Services	Arctic Services is a joint initiative by companies and institutions in the Akureyri region, in the north of Iceland. The main objective of Arctic Services is to promote the high service level and infrastructure available for those involved in exploration, oil search and mining in the Arctic region.
BAID	A paid data platform for barrow area
Baltice	SAR and AVHRR output of FMI - Sea ice info in Baltic region
BSIS	Online information of the Baltic Sea Ice
First Arctic	We act as a strategic partner in the remote and hard-to-reach areas, where oil and gas companies and other natural resources industries are making significant investments. However, when considering operating in these remote areas, an in-depth local knowledge is a prerequisite.
GINA	Geographical Information Network of Alaska - GINA is a mechanism within the University of Alaska (UA) for sharing data and technical capacity among Alaskan, Arctic, and world communities.
GlobalWeatherLogistics	Sea Ice Forecasting and Logistics "specialise in monthly and seasonal sea ice forecasts ... (with) over 25 years of experience in Arctic and Antarctic weather research and forecasting.
High Altitude	High Altitude Polar Sailing and Yachting -- At High Latitudes, we work with adventurous yacht owners and charterers who wish to experience the ultimate in sailing. Our expert team, veterans of hundreds of polar expeditions, prepare you and your boat to safely navigate well outside tradition cruising grounds. Backed by our hard-won knowledge, we'll safely introduce you to some of the most remarkable destinations on the planet.
IBNet	IceBreaker-Net: a distributed traffic information system for icebreakers. IBNet works over mobile connections and utilizes satellite images, weather and ice forecasts for presenting and predicting the changes in the ice conditions. By combining ice condition information with real-time sea traffic information, IBNet offers valuable background information for coordinating the icebreaker fleet. IBNet also provides statistics reports that enable follow-up of how the icebreaker fleet has operated and provides tools for controlling and improving the service level of the icebreakers.
Ice Advisors	Ice Advisors is a winter navigation service company jointly owned and operated by the Finnpilot Pilotage Ltd (Finnpilot) and the Arctia Shipping Ltd. Finnpilot Pilotage Ltd and Arctia Shipping Ltd are owned by the State of Finland.
iceplan.org	'to serve as a resource where people can find projects on a variety of topics in the cryosphere, as well as keep track of which groups will be in the field and when, to allow for shared data collection and enhanced collaboration'.
INMARSAT	A British satellite communication company
Master Mariners of Canada	The Company of Master Mariners of Canada continues to be a recognized and respected organization, representing the interests of Canadian shipmasters and senior deck officers, from which advice and guidance will be sought. Maintain a high and honourable standard of ability and professional conduct of the officers of the Canadian Merchant Service.
NAFO	Northwest Atlantic Fisheries Organization is an intergovernmental fisheries science and management organization that ensures the long-term conservation and sustainable use of the fishery resources in the Northwest Atlantic.
Nord Norge	Tourism website for Northern Norway

NSRA	Federal State Institution "The merchant shipping code of Russian Federation", to organize navigation in the water area of the Northern sea route.
OWM	Open Weather Map (open access)
PFS	Polar Field Services, a woman-owned small business and an employee-owned company, delivers full-cycle project management, facilities support and logistics services to customers in remote locations. We have been helping researchers, the National Science Foundation and other government agencies succeed in the Arctic since 1999.
PolarView	Polar View is the world's leading organization for the provision of operational, satellite-based monitoring of the Polar Regions and the cryosphere. (Paid service)
Prescient Weather	Prescient Weather (Paid weather data service). Available at: http://www.prescient weather.com/
RWS	Dutch Weather/Water service: Rijkswaterstaat/Waterdienst - Information and Warning Centre - Daily ice information reported in Baltic Sea Ice Code.
Sea Ice Index	Sea Ice Index - Data represent Arctic-wide monthly sea ice extent, concentration, and anomalies, as well as climatology.
Seaice.dk	Website with access to raw sea ice images
StormGeo	Commercial supplier of information - play a role for operational information services.
Weathernews	Weathernews Inc. is 'the world's largest private weather service company' headquartered in Japan with offices across the world.
Windyty	Wind map and weather forecast for kiters, surfers, pilots, sailors and anyone else. Worldwide animated weather map, with easy to use overlays and precise spot.

Part 5 – Policy and Organizational Institutions

Sometimes subordinate to research institutions, these listings are also relevant for decision making and active research agenda

Arctic Corridor	The Arctic Corridor is a new cross-border economic area as well as a transport and development corridor. It links the Baltic region with the deep-water ports around the Arctic Ocean, oil and gas fields and the Northern Sea Route to the west.
Arctic Waters Safety Committee	The purpose of the Arctic Waterways Safety Committee is to bring together local marine interests in the Alaskan Arctic in a single forum, and to act collectively on behalf of those interests to develop best practices to ensure a safe, efficient, and predictable operating environment for all current and future users of the waterways.
ARCUS	Arctic Research Consortium of the United States aims 'to identify and bring together the distributed human and facilities resources of the Arctic research community—to create a synergy for the Arctic in which each resource, when combined with others, can result in a strength that enables the community to rise to the many challenges facing the Arctic'.
CNR	The National Research Council (CNR) is the largest public research institution in Italy, the only one under the Research Ministry performing multidisciplinary activities.
COMNAP	Council of Managers of National Antarctic – international organization that brings together its Members, who are the National Antarctic Programmes (organizations that have responsibility for delivering and supporting scientific research in the Antarctic Treaty Area on behalf of their respective governments and in the spirit of the Antarctic Treaty). 30 National Antarctic Programme Members (e.g. AWI) - National Antarctic Programmes (signed in Antarctic Treaty) can apply for membership.

CSA	The Chamber of Shipping of America (CSA) represents U.S. based companies that own, operate or charter oceangoing tank, container, or dry bulk vessels engaged in both the domestic and international trades and companies that maintain a commercial interest in the operation of such oceangoing vessels.
IMO	International Maritime Organization: The United Nations specialised agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.
JCOMM	Worldwide marine meteorological and oceanographic communities are working in partnership under the umbrella of the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology, in order to respond to interdisciplinary requirements for met/ocean observations, data management and service products.
NDPTL	Within the framework of the Northern Dimension Policy, the Northern Dimension Partnership for Transportation and Logistics (NDPTL or Partnership) was established in October 2009, and is one of the four existing partnerships of the Northern Dimension.
PCPI	Polar Climate Predictability Initiative - counterpart to PPP on multi-seasonal timeframe, aims to address these questions by bringing together the different relevant elements of the World Climate Research Programme (WCRP) and working with external partners. It will be led by SPARC and CliC, core projects of the WCRP, and will be a component of the "Cryosphere in a Changing Climate" Grand Science Challenge.
WWRP	WWRP advances society's ability to cope with high impact weather through research focused on improving the accuracy, lead time and utilization of weather prediction.

Part 6 – Science and Research Portals

This summarises projects, initiatives, programmes, that are relevant for polar research and also provide data within scientific networks, although end-products for the end-user are not yet available

AOS	Arctic Observing Summit - is a high-level, biennial summit that aims to provide community-driven, science-based guidance for the design, implementation, coordination and sustained long-term (decades) operation of an international network of Arctic observing systems.
APECS	An international and interdisciplinary organization for undergraduate and graduate students, creating opportunities for the development of innovative, international, and interdisciplinary collaborations among current early career polar researchers as well as recruiting, retaining and promoting the next generation of polar enthusiasts.
Arctic Dialogue	An initiative founded by the Alfred-Wegener-Institute for Polar and Ocean Research with the aim of counselling policy makers. Info is coming from scientists at the Alfred-Wegener-Institute for Polar and Ocean Research but also other partnering research institutes.
Arctic Horizons	Bringing together members of the Arctic social science and indigenous communities to reassess the goals, potentials, and needs of these diverse communities and ASSP within the context of a rapidly changing circumpolar North.
Arctic Science Partnership	An extensive Greenlandic-Danish-Canadian research collaboration, bringing together the world's leading Arctic scientists.
Arctic-Sea-Ice.net	Forum about Arctic sea ice
Barents Watch	Their main focus is the marine territory just off the coast of Norway. They only provide synthesized information and don’t produce information themselves.
CliC	Climate and Cryosphere - Close coordination of related activities of CliC and its working groups - encourages and promotes research into the cryosphere and its interactions as part of the global climate system.
Climate Risk Analysis	Available at: www.climate-risk-analysis.com; “a small research company working on risk quantification and data analysis of extreme climate or weather events”

Commission for Basic Systems (CBS): Integrated Observing Systems	Facilitating the improvement of polar observing systems; Commission for Basic Systems (CBS) are related to the development, implementation and operation of integrated systems for observing, data processing, data communication and data management, and to the provision of public weather services, in response to requirements of all WMO Programmes and opportunities provided by technological developments.
Cryocity	The study of processes occurring in the cryosphere, with special emphasis on continental snow and the Arctic and Antarctic ice sheets.
EfficienSea2	Further interesting is a project of the Danish Maritime Authority called EfficienSea2. The overall aim is to enhance safety, efficiency and sustainability of maritime traffic through increased connectivity.
EPB	The European Polar Board (EPB) is an independent European Organization of Directors and Managers of the major European National Polar Programmes.
EU-PolarNet	EU-PolarNet - connecting science with society - From 2015-2020 EU-PolarNet will develop and deliver a strategic framework and mechanisms to prioritise science, optimise the use of polar infrastructure and broker new partnerships that will lead to the co-design of polar research projects that deliver tangible benefits for society.
GODAE Oceanview	Development and implementation of the intensive modelling campaign (ice-ocean). Scientists leading the scientific development of the major ocean analysis and forecasting systems for generating real-time operational ocean forecasts, hindcasts and reanalysis.
IARPC	IARPC (Interagency Arctic Research Policy Committee)
IASC	International Arctic Science Committee -- planning of YOPP for northern Polar Regions. To pursue a mission of encouraging and facilitating cooperation in all aspects of Arctic research, in all countries engaged in Arctic research and in all areas of the Arctic region.
IASSA	The International Arctic Social Sciences Association is governed by an elected eight-member Council and a General Assembly consisting of all members having paid their membership.
ICARP	Vision: Strong scientific understanding and systematic observations of the changing world ocean climate and ecosystems shall underpin sustainable development and global governance for a healthy ocean, and global, regional and national management of risks and opportunities from the ocean.
ICE-ARC	Is a programme funded by the European Union’s 7th Framework Programme. It is a 4 year project that started on the 1st January 2014, and will look into the current and future changes in Arctic sea ice – both from changing atmospheric and oceanic conditions. We will also investigate in a robust way, the consequences of these changes both on the economics of the area, and social aspects such as on Indigenous peoples.
Iceland Ocean Cluster	Iceland Ocean Cluster - The Iceland Ocean Cluster’s mission is to create value and discover new opportunities by connecting entrepreneurs, businesses and knowledge in the marine industries.
ICES	The International Council for the Exploration of the Sea is a global organization that develops science and advice to support the sustainable use of the oceans. ICES is a network of more than 4000 scientists from over 350 marine institutes in 20 member countries and beyond.
ICSU	The International Council for Science is a non-governmental organization with national scientific bodies (122 Members, representing 142 countries) and International Scientific Unions (31 Members).
IICWG	Coordination of operational ice services - formed in October 1999 to promote cooperation between the world's ice centers on all matters concerning sea ice and icebergs.
IOC	Intergovernmental Oceanographic Commission of UNESCO

ISAC	International Study of Arctic Change - Observing, understanding, responding to change – a programme that provides a scientific and organizational framework, establishes new synergies, promotes obs, modelling, links, collaborates.
MOSAiC	Gathering data from and around the drifting observatory to improve coupled models and coupled data assimilation, and for ground truthing of satellite data.
NAEFS	North American Ensemble Forecast System - A joint project involving the Meteorological Service of Canada (MSC), the United States National Weather Service (NWS) and the National Meteorological Service of Mexico (NMSM).
NERSC	An independent non-profit research institute affiliated with the University of Bergen in Norway.
OSI-SAF	OSI-SAF - Ocean and Sea Ice Satellite Application Facility, a processing center
PEEX	The Pan-Eurasian Experiment is a multidisciplinary climate change, air quality, environment and research infrastructure programme focused on the Northern Eurasian particularly Arctic and boreal regions.
PSTG	Polar Space Task Group is supporting the exploitation of satellite data (“satellite snapshot”) - provide coordination across Space Agencies to facilitate acquisition and distribution of fundamental satellite datasets, and to contribute to or support development of specific derived products in support of cryospheric and polar scientific research and applications.
S2S	Sub-seasonal to Seasonal Prediction Project - Sub-seasonal to seasonal aspects of polar predictions - To improve forecast skill and understanding on the sub-seasonal to seasonal timescale with special emphasis on high-impact weather events.
SAON	Coordination of Arctic Observations - support and strengthen the development of multinational engagement for sustained and coordinated pan-Arctic observing and data sharing systems - not doing research themselves.
SCAR	Planning of YOPP for southern Polar Regions - SCAR meets every 2y, secretary: Scott Polar Research Institute in Cambridge, England
SCOR	Scientific Committee on Oceanic Research, to help address interdisciplinary science questions related to the ocean. SCOR was the first interdisciplinary body formed by ICSU. SCOR's name was later changed to "Scientific Committee on Oceanic Research" to reflect its more permanent status.
SIPN	Sea Ice Prediction Network - Networking scientists and stakeholders to improve sea ice prediction in a changing Arctic -- Coordinate and evaluate activities to predict sea ice; Integrate, assess and guide observations; Synthesize predictions and observations; Disseminate predictions and engage key stakeholders.
WCRP	WMO’s World Climate Research Programme is to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. The two overarching objectives of the WCRP are to determine the predictability of climate; and to determine the effect of human activities on climate.
WGSIP	Encouraging institutions with prediction capability to use initial conditions that take advantage of the new available data from YOPP to rerun some sub-seasonal and seasonal predictions - develop a programme of numerical experimentation for seasonal-to-interannual variability and predictability, paying special attention to assessing and improving predictions.
YESS	Community. Community platform among young researchers from around the world. Self-sustained structure to enhance communication between grad schools and institutes.

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LIST OF WWRP POLAR PREDICTION PROJECT PUBLICATIONS

1. WWRP Polar Prediction Project Science Plan, (WWRP/PPP No. 1 - 2013).

2. WWRP Polar Prediction Project Implementation Plan, (WWRP/PPP No. 2 - 2013).

3. WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP), (WWRP/PPP No. 3 - 2014).

4. WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP) Version 2.0, (WWRP/PPP No. 4 - 2016).

5. Navigating Weather, Water, Ice and Climate Information for Safe Polar Mobilities (WWRP/PPP No. 5 - 2017).

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