Linking Arctic system science research to decision maker needs: co-producing sea ice decision support tools in Utqiaġvik, Alaska

Nathan P. Kettle, Dina Abdel-Fattah, Andrew R. Mahoney, Hajo Eicken, Lawson W. Brigham & Joshua Jones

To cite this article: Nathan P. Kettle, Dina Abdel-Fattah, Andrew R. Mahoney, Hajo Eicken, Lawson W. Brigham & Joshua Jones (2019): Linking Arctic system science research to decision maker needs: co-producing sea ice decision support tools in Utqiaġvik, Alaska, Polar Geography, DOI: 10.1080/1088937X.2019.1707318

To link to this article: https://doi.org/10.1080/1088937X.2019.1707318

Published online: 30 Dec 2019.

Submit your article to this journal

Article views: 4

View related articles

View Crossmark data
Linking Arctic system science research to decision maker needs: co-producing sea ice decision support tools in Utqiaġvik, Alaska

Nathan P. Kettle\textsuperscript{a}, Dina Abdel-Fattah\textsuperscript{a}, Andrew R. Mahoney\textsuperscript{b}, Hajo Eicken\textsuperscript{a}, Lawson W. Brigham\textsuperscript{a} and Joshua Jones\textsuperscript{b}

\textsuperscript{a}International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA; \textsuperscript{b}Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA

\textbf{ABSTRACT}

Improving situational awareness and crisis response are key priorities in reducing potential risks associated with sea ice and environmental-related hazards in the Arctic. This research explores the opportunities and challenges associated with leveraging arctic system science research to coproduce sea ice decision support tools. The research is based on information derived from a coastal radar operated as part of university research in Utqiaġvik, Alaska as well as decision context analysis from 12 interviews with marine operators and responders, subsistence users, and service providers. Findings revealed a diversity of information preferences and needs, decision thresholds, capacities, and constraints. A sea ice notification framework is presented, which illustrates how near-real time observations can be integrated into existing trusted notification systems. Key challenges to using Arctic system science research to support decision maker needs include the logistics of operating and maintaining near-real time observations. Innovative partnerships and informal networks may be especially important in overcoming these challenges.

\textbf{ARTICLE HISTORY}

Received 11 March 2019
Accepted 17 December 2019

\textbf{KEYWORDS}

Co-production; sea ice hazards; Arctic; decision support; Utqiaġvik

\textbf{Introduction}

The Arctic environment poses unique challenges to safe maritime operations, including hazards associated with extreme weather and sea ice (Eicken & Mahoney, 2015). This is especially the case for the growing number of vessels passing through the Northwest Passage, Bering Strait, and waters near Utqiaġvik, Alaska (Smith & Stephenson, 2013). In light of increased demands placed on those responsible for maritime and coastal emergency response, planning, and enforcement, there is a need to improve situational awareness and decision support on weather- and sea ice-related hazards (Deemer et al., 2018; Scott, 2017; USCG, 2019).

Developing tools that support decisions and align with user preferences, capacities, and needs is a key priority in the Arctic (Knapp & Trainor, 2015; Thoman et al., 2017). Knowledge co-production is an action-oriented approach to develop information that is relevant, credible, and usable (Miller & Wyborn, 2018). This approach includes attention to how user needs may be addressed via their fit within broader socio-ecological systems, including how information interplays with user knowledge and knowledge systems, the application of...
information in decision making, and level of interaction (Cash et al., 2003; Lemos, Kirchhoff, & Ramprasad, 2012). Research on decision contexts in the Arctic highlights a diversity of sea ice-related information uses, preferences, and needs for maritime operators and subsistence users (Dawson et al., 2017). Assessments also reveal factors impeding information availability and use, including lack of environmental data at sufficient spatial and temporal resolutions and limited internet connectivity (Hughes, 2012; Knapp & Trainor, 2015). Understanding the full spectrum of requirements associated with operations and planning for both decision makers and service providers is required for advancing actionable science and sea ice prediction services that meet operational needs, preferences, and institutional mandates. The emergence of local monitoring systems that supplement national-level weather and hydrometeorological observations and forecasts exacerbates the lack of a comprehensive decision-support framework (Knol et al., 2018; Thoman et al., 2017).

This paper explores the decision contexts for maritime operators, responders, subsistence users, and service providers in the North American Arctic in order to identify the challenges and opportunities of leveraging local monitoring systems, which were initially designed to advance arctic system science, to develop decision support tools. Drawing upon information derived from a coastal radar operated as part of university research in Utqiaġvik, Alaska, we explore how such research tools may be developed into a sea ice hazard communication system. Within a system science framework, this includes the interconnections across boundaries within academia and practice, including sea ice geophysics, Indigenous knowledge, and social science (Hieronymi, 2013).

**Literature review**

**Arctic maritime hazards, decision making, and information use**

Sea ice and extreme weather pose significant risks for Arctic maritime activities, including shipping, tourism, subsistence, and emergency response (Dammann, Eicken, Mahoney, Meyer, & Betcher, 2018; Eicken et al., 2011, 2018). Collision with multi-year ice can damage hulls, ice pressure can affect maneuverability, and snow depth can reduce vessel speed (Kubat, Fowler, & Sayed, 2015; Timco, Gorman, Falkingham, & O’Connell, 2005). For subsistence hunters, landfast ice break out, episodes of anomalously high rates of ice drift, and shoreward ice convergence events are among the most concerning safety risks (Eicken et al., 2018). These hazards coupled with the high costs of polar operations contributed to the adoption of and amendments to the Polar Code, which provides international safety codes for polar maritime operations (Brigham, 2017).

Arctic maritime operators and subsistence users mitigate potential risks through operational, tactical, and strategic decisions that are sensitive to sea ice conditions (Christiansen, Fagerholt, Nygreen, & Ronen, 2007; Druckenmiller, Eicken, George, & Brower, 2013). Operational decisions include determining ship speed, ship loading and unloading times, and environmental routing problems, which influence time and fuel costs. Tactical decisions include adjustments to fleet size and mix, fleet deployment, routing, and scheduling. Tactical decisions such as determining the ice-free seasons for schedules are especially sensitive to weather and sea ice, as is the risk of launching summer routes prior to ice free conditions or missing potential ice-free shipping days (Lasserre & Pelletier, 2011). Strategic planning decisions include port choice and design, ship design, fleet design and mix, and shipping lanes (Christiansen et al., 2007). Some data, information, and observations are available at
different spatial and temporal scales in the Arctic to support decision making, including scientific observing networks and Indigenous knowledge (Eicken, Lovecraft, & Druckenmiller, 2009; Lovecraft, Meek, & Eicken, 2013; Pearce, Ford, Willox, & Smit, 2015). Although Indigenous and local knowledge plays a central role in supporting sea ice-sensitive decisions, rapid climate change can challenge its reliability and predictive skill (Weatherhead, Gearheard, & Barry, 2010).

Research on Arctic maritime operator awareness and use of sea ice-related information highlights a wide range of application (Table 1). Information on ice edge location, concentration (areal fraction), ice type (including age), thickness, drift velocity, and ice roughness (ridging) is among the most commonly used. No studies were identified that examined decision contexts and information use for search and rescue (SAR) operations in the US, though some research has discussed information use among Canadian Coast Guard icebreaker captains and subsistence hunters (Aporta, Gearheard, Laidler, & Kielsen Holm, 2010; Timco et al., 2005). Information is accessed, shared, and disseminated via radio, cell phone, data portals, electronic delivery, and social media. There are several challenges to information availability and access in the Arctic, including limited internet and the time it takes service providers to receive, process, and communicate near-real time conditions to end-users (Lamers, Duske, & van Bets, 2018). Organizing online data in ways that align with Indigenous ways of knowing is desired among subsistence hunters to increase usability (ACCAP, 2008).

Several weather and sea ice information needs remain unmet for Arctic maritime operators, which vary across stakeholder groups (Table 2). Common information needs across multiple groups are provided below given that several studies summarize needs for multiple stakeholder groups. Needs included improved nowcasting and forecasting of ice edge location, concentration, ice type, and thickness, more accurate information on wave height and wind direction and speed, and integrated satellite, meteorological, and oceanographic data (Eicken et al., 2011; Hughes, 2012; Hutchings & Bitz, 2005; Timco et al., 2005). Near real-time data with high spatial resolutions are also desired given that sea ice conditions can rapidly change in the Arctic (Deemer et al., 2018; George et al., 2004). Improved coordination among scientists, decision makers, and service providers was identified as key to increasing the relevance and usability of information (Knapp & Trainor, 2013).

### Table 1. Assessments of Arctic maritime operator awareness and use of weather and sea ice information.

<table>
<thead>
<tr>
<th>Assessment(s)</th>
<th>Stakeholder(s)</th>
<th>Key Finding(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(AOOS and ACCAP, 2013)</td>
<td>Scientists, decision makers, service providers</td>
<td>Quantified sea ice information use and sources</td>
</tr>
<tr>
<td>(Andreassen et al., 2011)</td>
<td>Scientists, decision makers, service providers</td>
<td>Webinars and internet are effective ways to access sea ice information</td>
</tr>
<tr>
<td>(Druckenmiller et al., 2013)</td>
<td>Inupiat subsistence hunters</td>
<td>Many environmental variables are used, which are obtained from local observations and experience, traditional knowledge, surveys, and satellites</td>
</tr>
<tr>
<td>(Eicken et al., 2009)</td>
<td>Subsistence hunters</td>
<td>Many environmental variables are used, which are obtained from local observations and experience, traditional knowledge, surveys, and satellites</td>
</tr>
<tr>
<td>(Hughes, 2012)</td>
<td>Shipping, oil/gas, researchers</td>
<td>Forecasts useful for strategic planning to assess potential climate impacts on economic sectors</td>
</tr>
<tr>
<td>(Lamers et al., 2018)</td>
<td>Arctic expedition cruise companies</td>
<td>Ice charts checked daily if available; limited internet impedes information access and sharing</td>
</tr>
<tr>
<td>(Timco et al., 2005)</td>
<td>Canadian Coast Guard icebreaker captains</td>
<td>Information is obtained from multiple sources; Information use includes multi-year ice, ice pressure, ice concentration, and ice ridging; images are desired</td>
</tr>
</tbody>
</table>
Several Arctic weather and sea ice-related information needs also remain unmet for service providers, such as the National Weather Service (NWS) Alaska Region (Kettle, 2018). These needs relate in part to the Arctic’s vast geographical expanse that creates logistical and financial challenges to comprehensive data collection efforts by single agencies and organizations. Innovative formal and informal partnerships are increasingly supporting data collection and analyses efforts to improve weather and sea ice forecasts, including federal agency partnerships with industry and local communities (Raye, 2015). The demand for more near-real time information on sea ice may increase with climate change given the potential for increases in vessel traffic in the Arctic.

### Decision support tools and systems

Decision support refers to efforts that seek to improve decision outcomes through the increased access and use of information (Moss et al., 2014). Decision support tools refer to science-based products, such as databases, maps, or reports, which assist decision makers display, integrate, and analyze information (Gibson et al., 2017; Moss, 2016). Decision support systems refer to the broad array of knowledge frameworks and actors involved in the production and use of tools, including decision makers, service providers, and researchers (Moss, 2016).

There is a wide range of decision support tools and systems to support weather and climate-sensitive decisions across multiple contexts, including climate adaptation planning and conservation management and policy (Moss et al., 2014). Spatial scales of tools span from local to global, and temporal scales can range from near-real time to long-term planning (Gibson et al., 2017). Tools can assist with data integration and visualization or provide insight into potential consequences of management actions. Across the Arctic, these weather and sea ice tools include spatial marine planning, oil and gas disaster planning and response,

---

### Table 2. Summary of needs assessments for weather and sea ice information in the Arctic.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Stakeholder(s)</th>
<th>Key need(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Andreasen et al., 2011)</td>
<td>Scientists, emergency responders, service providers</td>
<td>More collaboration between scientists and decision makers; greater awareness of existing data, information on data validity and reliability; research driven by management concerns</td>
</tr>
<tr>
<td>(Arctic LCC, 2013)</td>
<td>Resource and land managers</td>
<td>Information on sea ice mapping, trend analysis, and forecasting</td>
</tr>
<tr>
<td>(Hutchings &amp; Bitz, 2005)</td>
<td>Scientists</td>
<td>Sea ice forecasts at different time scales to develop local products; more community engagement to develop tools; integrate local observations into pan-Arctic monitoring systems; ice hazard or break out capability; high resolution maps of ice extent, concentration, and roughness</td>
</tr>
<tr>
<td>(Hughes, 2012)</td>
<td>Shipping, oil/gas, researchers</td>
<td>Higher resolution data desired; information on sea ice concentration, ice edge, ice type, ice drift, deformation, thickness</td>
</tr>
<tr>
<td>(Johnson et al., 2014)</td>
<td>In/uit subsistence hunters</td>
<td>Multiple specific information needs on sea ice and current information off the coast of Utqiagvik; near-real time tracking of sea ice drift</td>
</tr>
<tr>
<td>(NOAA, 2011)</td>
<td>Scientists</td>
<td>Stakeholder input to create actionable information; metrics to measure the impacts of products on stakeholders</td>
</tr>
<tr>
<td>(Timco et al., 2005)</td>
<td>Captains of ice-class vessels</td>
<td>Sea ice radar images integrated with meteorological and oceanographic data; user friendly tools; localized information on multi-year ice and large-scale ice features</td>
</tr>
<tr>
<td>(Tivy &amp; Petrich, 2016)</td>
<td>Industry, Canadian Coast Guard icebreaker captains</td>
<td>Information on ice concentration, ice type, ice thickness, ice pressure, ice deformation and drift, break/freeze-up, open water season length, floe size; observations in high use areas; now-casting tools; data integration; local information on multi-year ice and large ice features</td>
</tr>
<tr>
<td>(Wagner, 2017)</td>
<td>Polar tour operators</td>
<td>Reliable internet to increase availability of existing data</td>
</tr>
</tbody>
</table>
and subsistence hunting. Tools are often underutilized given temporal or spatial mismatches between products generated and decision maker needs, lack of stakeholder trust and relevance, inadequate inclusion of local knowledge, and limited capacity to access and use developed tools (Gibson et al., 2017). Within rural Indigenous cultures, additional challenges include the exclusion of Indigenous knowledge, communication, and response approaches in the context of western emergency response frameworks.

Knowledge co-production

Research has shown that knowledge co-production – the collaborative process between researchers and decision makers to develop and generate science – increases the usability of science in decision making (Miller & Wyborn, 2018). An extensive body of literature outlines several principles of supporting effective collaboration between researchers and decision makers, including engaging stakeholders in the problem definition, formulation of research questions and design, data collection and analysis, and dissemination (Dilling & Lemos, 2011; Lemos & Morehouse, 2005). Capacities to support co-production include scientific and local knowledge, training on collaborative research approaches, long-term and pre-existing relationships between the research team and practitioners, commitments of time and funds, and motivations for producing actionable science (Kerkhoff & Lebel, 2015).

Decision context assessments are a foundational element of knowledge co-production and the development of usable information and tools (Parris, Garfin, Dow, Meyer, & Close, 2016). These assessments have revealed a wide range of decision maker needs, information uses across multiple response and planning windows, barriers to information use, and capacities across sectors and regions (Lackstrom, Kettle, Haywood, & Dow, 2014). Challenges common to co-producing decision support tools include mismatched terminology between scientists and stakeholders, unrealistic expectations of products for decision making, user fatigue, sustaining tools, unmet expectations, designing tools to meet the needs of multiple user groups, and tradeoffs among credibility, salience, and legitimacy (Briley, Brown, & Kalafatis, 2015; Swart et al., 2017). In the Alaskan Arctic, providing sufficient funds and time is required, given the long time periods necessary for developing actionable knowledge, the high costs of travel, historical legacies of distrust, and time to bring together western science and Indigenous and local knowledge (Kettle, 2019; Robards et al., 2018).

Methods

Utqiaġvik, Alaska

Utqiaġvik, Alaska represents an ideal location to examine the opportunities and challenges of leveraging near-real time observations of sea ice, which were initially designed for arctic system science research, to co-develop decision support tools. First, there are multiple maritime operators and responders in the region interested in improving situational awareness, including tug and barge operators, subsistence hunters, and emergency responders (United States Coast Guard (USCG), North Slope Borough SAR, volunteer SAR) as well as service providers seeking to increase the usability of sea ice information. Second, there is a natural choke point of maritime activity whereby vessel activity is concentrated close to Point Barrow. Third, several SAR events have occurred in the region in the past decade, which could benefit from improved access and availability to sea-ice information (Eicken et al., 2018).
Fourth, there are several long-term data sets, some of which have been available in near real-time, and other targeted observations for detecting and tracking sea ice and ocean currents. These include information from Inuit knowledge, satellite remote sensing, coastal radar, in-situ autonomous instruments and manned and unmanned airborne surveys (Eicken et al., 2018). Fifth, the Utqiagvik labor force includes technically skilled individuals who may be called upon to perform routine maintenance on arctic system science observations.

The Utqiagvik coastal sea ice radar system (CSIRS), which represents the primary data for co-developing sea ice tools in this paper, was installed in its current form in 2007, though prior versions have operated intermittently since 1977 (Mahoney, Eicken, & Shapiro, 2007; Mahoney et al., 2012; Shapiro & Metzner, 1989). It is currently mounted on one of the tallest buildings (22.5 m above sea level) in Utqiagvik. The current radar configuration is a Furuno FAR2117X-band system, operating at 25 kW with a 2.44 m open array antenna, which is able to detect favorably oriented sea ice features out to a range of 11 km. Images are recorded every four to five minutes and data packages of four images are sent to the University of Alaska Fairbanks every 20 min, from where the radar can be remotely operated. Data are orthorectified to a uniform square pixel size of 21.5 ± 0.5 m and georeferenced to an accuracy of ±1 pixel (Mahoney et al., 2015). The CSIRS was initially designed for research and has been used to identify and evaluate environmental contributions to sea ice breakout events, compare the direction and magnitude of ice drift to observations from an ice profiling sonar, and validate instantaneous ice drift dynamics (Jones et al., 2016; Mahoney et al., 2015). It has detected several sea ice motion events in the coastal zone, including breakout, convergence, and high speed anomalous motion (Mahoney et al., 2015). Radar images have supported SAR activities and maritime navigation (Figure 1).

Comparisons between automated and manually detected ice-floe trajectories and velocity fields indicates minimal error in the dislocation vectors (Rohith, Jones, Eicken, & Kambhamettu, 2013). Radar-derived ice velocity data have also been compared with ice-tracking data from a bottom-moored upward-looking sonar and found to agree within a root-mean-square error of 0.12 ms⁻¹ (Mahoney et al., 2015), as well as community-based ice observations provided by Inupiaq sea-ice experts. It is not possible to detect potentially hazardous sea ice events with images from 1977 to 2007, given the limited spatial resolution, image quality, area covered, and gaps in coverage (Mahoney et al., 2012).

Figure 1. Timeseries of CSIRS radar images tracking an 29 April 2014 sea ice break out event in Utqiagvik, Alaska. Images were provided to the North Slope Borough SAR by the University of Alaska Fairbanks. Panel: (a) illustrates the start of the breakout; (b) the progression of the breakout while people were still on the ice (yellow star shows reported location); (c) reversed motion of the ice back towards the shore after successful recovery of all people and equipment.
Data collection and analysis

Semi-structured interviews were used to understand user needs and capacities within the context of socioecological systems. A list of 16 potential participants was generated based on recommendations from the NSB local SAR coordinator, USCG and NWS, as well as a snowball sampling technique. Interviews \((n = 12, 75\% \text{ response rate})\) were conducted from March – April 2018 and included subsistence hunters \((n = 4)\), climate service providers \((n = 4; \text{NOAA/NWS Alaska Sea Ice Program and Weather Forecasting Office, Arctic Environmental Response Management Application, ERMA})\), and USCG land- and field-based staff \((n = 4; \text{information technology, SAR coordinator, vessel captains})\). Interviews were transcribed and coded for themes relating to information preferences and needs, use of sea ice information, decision thresholds, barriers and opportunities for creating decision support tools, challenges to access and availability, and information needs. Feedback from this set of interviewees provides key insights into the relevant stakeholders and communication systems involved in the development and use of a sea ice decision support system in Utqiaġvik (Espejo & Reyes, 2011).

Assessment of decision contexts

The decision context assessment provides insights into weather- and sea ice-sensitive decisions and operational environments as well as information use, preferences, decision thresholds, and needs for service providers and decision makers. Below we discuss the decision contexts of these operators, responders and service providers, with attention to how these contexts relate to the development of a decision support tool based on the CSIRS data.

Subsistence hunters

Subsistence hunters detailed multiple examples of how Inupiat knowledge, passed down through the generations and learned through experience and instruction, provided insight into sea ice and oceanographic conditions that were used for planning and response. For example, open water darkens the underside of overlying low clouds creating ‘water sky’ which can be used to detect an open lead from afar, while the cold surface of multi-year ice can create mirages, making such ice appear taller and visible to the trained observer from greater distances (Nelson, 1969). Also, the color of the water and watching flight patterns of waterfowl can be used to forecast potential changes in the weather (Interviewee 7). Decisions on when, where, and how to hunt safely are made based on the interaction of multiple observations, such as wind, currents, and sea ice. These findings are consistent with detailed surveys of Inupiat observations and knowledge of sea ice environments (Gearheard et al., 2006; George et al., 2004; Johnson, Eicken, Druckenmiller, & Glenn, 2014).

Some thresholds were identified for the speed of ice movement, size of ice floe, and stability of shorefast ice with specific regard to after freeze up, during break up, and boating season within the 6 km domain of the sea ice radar (Jones et al., 2016). For example, breakout events were considered when there was seaward movement of the land ice edge after a minimum of seven days of ice stability. The minimum size and speed were 0.2 sq. km and \(0.6 \text{ ms}^{-1}\), respectively (Joe Leavitt, personal communication, 2014). However, some thresholds were based on experience and feel, rather than quantitively expressed, and others were dependent on additional environmental conditions.
Western science-based information, such as satellite images and weather model outputs, are accessed and used by some younger subsistence hunters to supplement Inupiat knowledge, particularly if it is easily accessed on mobile devices (e.g. windy.com). Social media is often used to share information about weather and sea ice conditions, though several older hunters received this information via in-person interactions. Coarse spatial resolution and lack of near-real time data were consistently identified as a concern and need, respectively, by nearly all interviewed subsistence hunters, likely related to the rapid nature of changing waters surrounding Utqiagvik (Norton & Gaylord, 2004).

Some subsistence hunters and local SAR responders in Utqiagvik were familiar with the CSIRS data. For example, a whaling captain discussed how the CSIRS radar provided a live feed to track the movement of a 2014 break out event, which stranded several hunters on the ice (Figure 1). Recommended improvements to the CSIRS included locating a new similar radar at Point Barrow (northeast of Utqiagvik), a location that would provide observations extending further out to sea. An extended range is also desired as hunters often venture beyond the range of the radar and the current radar range does not extend significantly beyond where hunters can already see. Radar data were perceived to be especially useful if it incorporated data on other environmental conditions, such as currents and wind. Additional information needs include the speed and direction of ocean currents at different distances from the shore, especially for currents that extend beyond onshore observations and prior experience. At the same time, there are perceived limits and vulnerabilities to depending on western science and derived information products while on the water and sea ice, including minimal (or no) access to data, limited internet bandwidth, the reliability of information, and the challenge of obtaining information from a multitude of distribution portals for the parameters of interest (ACTFTIA, 2017; Gearheard et al., 2006). For example, subsistence hunters may have access to mobile phone services that only require minimal data (e.g. texting) offshore in Utqiagvik, but cannot reliably access images quickly. As stated by a subsistence hunter, ‘We have to make our decisions just like that, but we don’t use gadgets. I don’t have a radar out there. I only have what I know (Interviewee 1)’.

United States Coast Guard

The USCG District 17 seeks to ensure the safety, security, and stewardship of the Alaska maritime region and compliance with the Polar Code (USCG, 2019). Weather and sea ice conditions influence several aspects of USCG Arctic operations, including routing and dispatch for response to confirmed vessels in distress, tactical maneuvering, and seasonal and long-term planning. The USCG uses several types of environmental-related variables to support decisions, including sea ice (floe size, concentration, thickness, location of ice edge), atmospheric visibility, and ocean currents. Thresholds for weather, sea ice, and environmental conditions, relating to operational and planning decisions, varied based on the vessel classification and type.

Some weather and sea ice information are provided by USCG field units to support operational and tactical decisions, such as ship-based weather stations and radars. While ship-based radars are capable of detecting ice, they remain poorly suited to provide decision-support information because of the lack of interoperable data acquisition and sharing networks (Kotovirta, Karvonen, von Bock und Polach, Berglund, & Kujala, 2011). Land-based units support operational planning via the synthesis of multiple sources of information and relay of information summaries and directives to field units. NOAA products are among
the most frequently used information sources among land-based units, as they provide multiple sources of data that are trusted and relevant. For example, Arctic ERMA (a tool developed for oil spill response) is used in daily briefings to show the ice edge as it is easy to display and commanders are familiar with the tool (Merten, Winters-Staszak, & Kinner, 2014). Other information sources include transiting boats, the National Ice Center, US Navy, and windy.com. USCG interviewees were not familiar with the CSIRS radar, though several USCG interviewees expressed interest in near-real time radar data at Point Barrow and across the Arctic more broadly.

Accessing multiple sources of information at a single location is desired, such as extracting information on air and water temperature, wind speed, ice concentration, and current speed for specific geographic coordinates through a graphical user interface. Land-based units desire information that is packaged and quickly digestible, especially maps with overlaid data. Data formats such as .csv, .kml, or .shp are a preferred mode of data download, as it could be easily integrated into existing USCG systems.

There are several challenges to the availability and access of weather and sea-ice related information in the Arctic and along the North Slope. For example, the USCG Search and Rescue Optimal Planning System, which provides guidance on search radii and plausible trajectories for drifting targets of a SAR operations, has limited environmental data in the Alaskan Arctic. Although several global and regional numerical weather models that include the Arctic are publicly available, USCG SAR operations in the Arctic rely on two global models for currents (Global HYCOM NAVY and Global HYCOM NCEP) and winds (GFSNEP and NAVGEM), compared to other locations in the conterminous US or Gulf of Alaska, which may have 10 or more models available (Interviewee 9). Firewalls and cybersecurity concerns also contribute to limited data access, such as the need to access some information from a standalone terminal not connected to the network. Bandwidth is also a challenge for communication between field and land-units. Data packages must be kept small (~120 kB) for better transmission, which makes imagery difficult to deliver. Further, there are several additional sources of non-weather and environmental data (e.g. location of boats for enforcement actions) that compete for bandwidth.

The National Weather Service

The NWS provides weather, water, and climate data, forecasts, and warnings for the protection of life and property and enhancement of the national economy (NOAA, 2019a). The NWS Alaska Region produces several sea ice-related products to support decision making throughout Alaska waters, including at Utqiaġvik. The Alaska Sea Ice Program (ASIP) produces several routine products, such as the daily Sea Ice Analysis (concentration and stage), daily Sea Surface Temperature Analysis, Monday/Wednesday/Friday issued five Day Sea Ice Forecast and Sea Ice Advisory, and monthly issued 3-month Sea Ice Outlook (Heim & Schreck, 2017). Products are created by analyzing several resources, including satellite observations, ice analyst experience and knowledge, local currents and bathymetry, buoy data and local observations, drift models, and seasonal experimental models. The NWS Fairbanks Weather Forecasting Office (WFO), and all NWS coastal WFOs, provide marine watches, warnings, and advisories for coastal and offshore waters relevant to maritime situational awareness. Special Marine Warnings may be issued for short duration marine thunderstorm winds, strong winds, hail, waterspouts or ashfall. When conditions near an Alaska coastline may become dangerous owing to a sea ice event, a Special Weather Statement may be issued
to alert coastal communities of the possibility for a sea ice shove to impact the coastline. In addition, mention of changing sea ice conditions, or an ice push on shore, may be included in the Sea Ice Advisory product or may be included in the discussion section of a Coastal Flood Warning. NWS national mission policies and procedural directives and formal instructions specify what and how activities must be performed (Table 3). Regional Supplements augment standard procedures relevant to individual regions.

ASIP forecasters expressed a high level of interest in enhancing decision support for coastal communities that would address user-specific needs and key priorities, including knowing more about how different decision makers use sea ice information and how to improve existing notification systems. The NWS 2019–2022 Strategic Plan also highlights the NWS evolving to connect timely observations, forecasts, and warnings to life-saving decisions at the local, state, tribal nation, and federal levels (NOAA, 2019a). There is also a desire to network with local communities to disseminate products more effectively, increase data availability, and bring together Indigenous and local knowledge into operations (Scott, 2017; Interviewee 6). Forecasters within the ASIP are familiar with CSIRS data and use observations as inputs into products, especially given the paucity of near-real time sea ice data in the Alaskan Arctic. The primary opportunity to use CSIRS data in NWS products are integrating data into existing products, such as the Sea Ice Advisory.

### Arctic ERMA

Arctic ERMA is a web-based mapping application designed to provide historical, current, and forecasted data to support oil spill and other emergency response efforts (Merten et al., 2014). The majority of data are publicly available, including information on weather, oceanography, natural hazards, and sea ice extent and concentrations; other data is only available to federal partners (e.g. Automatic Identification System ship tracking). Recent improvements to Arctic ERMA include providing data in a polar stereographic projection to overcome shortfalls in terms of fidelity of area and directional information associated with Mercator Projections. Relevant data produced by universities can be uploaded into ERMA. If webservices are not available for uploading data, standard UPSG is preferred, as it can be transformable using the standard tools that the GDAL provides. The USCG is mandated to use Arctic ERMA as a tool to guide response efforts; however, encrypted data (e.g. locations of USCG ships and helicopters) cannot be uploaded to non-Department of

### Table 3. NWS Directives and instructions relevant to developing sea ice tools from university-based data. Directive numbers are provided in parenthesis (NOAA, 2019b).

<table>
<thead>
<tr>
<th>NWS Directive/Instruction Title</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>New or Enhanced Products and Services (10-102)</td>
<td>Procedures for implementing experimental products or making substantial changes to existing products</td>
</tr>
<tr>
<td>Capabilities and requirements decision support process (10-103)</td>
<td>Process for evaluating NWS needs and improving operations and services</td>
</tr>
<tr>
<td>Alaska Region Supplement (09-2004)</td>
<td>Augment NWSI 10-204 procedures to meet the needs of Alaska Region customers and maintain national consistency</td>
</tr>
<tr>
<td>Alaska Region Supplement (01-2001)</td>
<td>Augment NWSI 10-303 procedures for communicating &amp; disseminating procedures for the Alaska Region</td>
</tr>
<tr>
<td>Alaska Region Public Weather Service Products (04-2001)</td>
<td>Augment NWSI 10-310 procedures for coastal marine forecast services</td>
</tr>
<tr>
<td>Special Marine Warnings (10-313)</td>
<td>Guidance for Special Marine Warnings</td>
</tr>
<tr>
<td>Ocean and Great Lakes Ice Services (10-330)</td>
<td>Description of ASIP and required products</td>
</tr>
<tr>
<td>Transition of research and development projects into operations (80-8)</td>
<td>Defines how the NOAA Administrative Order policy for governing transitions is implemented in the NWS</td>
</tr>
</tbody>
</table>
Homeland Security (DHS) systems (USCG, 2018). This circumstance prevents USCG datasets coming into the ERMA common operational picture.

**Sea ice decision support system**

Findings from the decision context analysis have implications for the design of sea ice tools based on emerging research-derived, arctic system science data generated from universities and community-based observations, which is of disproportionate importance in the Arctic (Griffith, Alessa, & Kliskey, 2018). Figure 2 illustrates how CSIRS observations can be integrated into a hazard information communication framework, which builds on the maritime domain awareness testbed in Utqiaġvik, to meet the needs of multiple users (Eicken et al., 2018). System features include multiple actors and boundaries, computation and processing, information flow, signal (threshold) detection, and communication (Hieronymi, 2013).

Sea ice observation data are transmitted, processed, and archived using procedures that enable rapid data transfer across a common grid (e.g., .rec, png,.kmz, GeoTiff files), including both GIS- and web-ready formats. Ice hazard threshold detection for breakout, convergence, and high-speed anomalous motion events are automatically detected in near-real time based on exceedance values identified by subsistence users in Utqiaġvik (Jones et al., 2016). The automated detection procedures were validated based on a comparison between the number of events automatically detected and manually observed from the radar animations between 2007 and 2016. Automatic detection for the convergence and break-out events were 80% (the majority of errors were false positive) and 100% accurate, respectively. The accuracy of high-speed events was not detected given the challenges associated with manually observing the speed of ice movement.

Processed data are integrated into trusted local and national response networks, including a near-real time data feed into Arctic ERMA and ice hazard events as an observation in the NOAA/NWS ASIP Sea Ice Advisory. Near-real time conditions and hazard event detection could also be integrated into non-agency online data portals, such as the Alaska Ocean Observing System (AOOS) that could enable stakeholders to receive email or text message notifications that conditions have changed, based on individually defined threshold values. Embedding notifications within Arctic ERMA and AOOS may also enable the integration.

**Figure 2.** Sea ice decision support system for Utqiaġvik, Alaska.
Conclusions

Observations from Arctic system science research hold significant potential to enhance maritime domain awareness and support weather- and sea ice-related sensitive decisions. Opportunities to realize this potential are enhanced via iterative interactions across the science-practice interface to increase the relevance, credibility, and usability of science (Miller & Wyborn, 2018). For this research, a decision context assessment provided insight into a diversity of decision maker and service provider information needs, priorities, and constraints relevant to developing a sea ice decision support system based on information derived from a university-operated coastal radar in northern Alaska (Figure 2).

The sea ice decision support system addresses multiple stakeholder priorities identified in the literature review (Table 2) and interviews. Significantly, the development of the system was grounded in stakeholder priorities and management concerns, including a desire to improve the dissemination of sea ice information, enhance maritime domain awareness, and improve safety (USCG, 2019). For example, the sea ice hazard tools allow for the augmentation of observations and forecasting models in the data sparse Alaskan Arctic. This system has the potential to enhance NWS Alaska Impact-Based Decision Support Services (IDSS) to support meeting everyday decision needs of core partners at local, state, federal, and tribal levels (NOAA, 2019a). Additionally, the system provides near-real time tracking of sea ice conditions in a high use area, including sea ice break-out capability (Hutchings & Bitz, 2005; Tivy & Petrich, 2016). The system was also created collaboratively among researchers, service providers, and decision makers (Andreassen, Itchoak, Krutikov, & Trainor, 2011; Knapp & Trainor, 2015).

At the same time there are several challenges to leveraging local monitoring systems in the development of decision support tools in the Alaskan Arctic. The logistics of operating and maintaining near-real time data products present a significant challenge to sustaining decision-relevant observations in the Arctic, especially given the extreme environmental conditions and high costs of conducting science in the Arctic (Mallory et al., 2018). Western-science observations intended to provide near-real time data support require stable internet connectivity and power to receive and transmit data, which can limit potential locations of observations systems. There are also challenges associated with the reliability of tools, as observation systems often require regular service and maintenance, which often require long-term funding mechanisms that extend beyond the life of individual research grants (Swart et al., 2017). These challenges underscore the difficulties in meeting the needs articulated by subsistence users and USCG staff to extend the radar’s range beyond 10 km and install a radar station near Point Barrow – a site only 16 km away from Utqiagvik but without reliable power or internet.

Innovative partnerships will likely serve key roles in building capacities to overcome challenges associated with sustaining local monitoring systems, integrating observations into national-level weather and sea ice decision support tools, and improving safety (NOAA, 2014). This includes securing funding and partnerships beyond research-based grants and supporting end-to-end expenses to enhance opportunities for supporting sustained decision support tools in the Arctic (NAS, 2017). Informal and ad hoc networks may be especially
important in resource constrained environments for fostering cross-level interactions (univer-
sities, federal and state agencies, corporations, organizations, communities) to build
trust, increase access to data and information, and reduce financial costs (Goldsmith &
Eggers, 2004). This could include networking with Native Corporations and other local
enterprises to secure access for citing and powering observation systems and funding for
power and internet. Partnering with other federal agencies in local communities may also
help sustain observations, such as the Department of Energy’s Atmospheric Radiation
Measurement program, which operates an atmospheric radar system in Utqiaġvik with
more than twice the range of the CSIRS. With some additional data processing this radar
system could provide usable data to the community and operators in the region (Eicken
et al., 2018). Network leaders are likely required to initiate partnerships, attract funding
opportunities, and increase effectiveness (Provan & Kenis, 2008).

**Acknowledgements**

The authors would like to thank all the interviewees who participated and supported this project,
including subsistence hunters from Utqiaġvik, Alaska, USCG District 17, Alaska Region NWS, Arctic
ERMA, AOOS, and university scientists. The views contained in this document are those of the
authors and should not be interpreted as necessarily representing the official policies, either expressed
or implied, of the DHS nor NOAA.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This material is based upon work supported by The Arctic Domain Awareness Center at the Univer-
sity of Alaska, U.S. Department of Homeland Security (DHS) [grant number 2014-ST-016-ML0002-
04] and a grant from NOAA [grant number NA11OAR4310141]; Climate Program Office; Science
and Technology Directorate.

**References**

from https://cpo.noaa.gov/sites/cpo/RISA/ACCAP%205YearReport.pdf


workshops-and-reports/


Hughes, N. (2012). *Assessment of current monitoring and forecasting requirements from users and international providers of services*. Tromsø: Arctic Climate Change Economy and Society.


