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The Potential Contribution of Sustained, Integrated Observations to Arctic Maritime Domain Awareness and Common Operational Picture Development in a Hybrid Research-Operational Setting

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Abstract

Increased maritime activities and rapid environmental change pose significant hazards to Arctic maritime operators and coastal communities. Major categories of hazards discussed in this white paper include (1) technological hazards (amplified by natural hazards and challenging environmental conditions), including threats to life, vessels and infrastructure, (2) natural hazards that present a direct threat to maritime activities, including presence of sea ice, icing conditions, extreme weather and ocean state, (3) natural hazards that present a direct threat to coastal communities and infrastructure as well as human activities, including coastal storms, hazardous shorefast and drift ice conditions, coastal flooding and extreme weather events. We outline a framework for the development of a common operational picture (COP) in the context of maritime domain awarenees (MDA) relevant for Arctic coastal and offshore regions. A COP in these regions needs to consider threats not typically part of the classic MDA framework, including sea ice, threats emanating from slow-onset hazards and other factors. An environmental security and MDA testbed is proposed for the Barrow region of northern Alaska, building on research and community assets to develop a hybrid research-operational framework that addresses major challenges to MDA and effective emergency response in Arctic regions.

Introduction and Rationale

Recent increases in Arctic maritime activities and offshore resource development in conjunction with rapid climate change have increased the exposure of coastal communities and infrastructure to environmental and technological hazards (Brigham, 2014; Pizzolato et al., 2014; Eicken and Mahoney, 2015). Herein we recommend several measures to mitigate the risk of these hazards and exercise these risk-reduction measures in a testbed system. These measures include rapidly delivered *in-situ* and remotely sensed sensor data that are distributed on a common grid using open standards, active engagement with end users to determine needs and preferred methods of operation, and the use of existing tools to provide situational awareness, such as desktop GIS and web mapping systems like the National Oceanic and Atmospheric Administration's (NOAA) Arctic Environmental Response Management Application (Arctic ERMA; Merten, 2013; Merten et al., 2014).

The binding agreements on Search and Rescue and Oil Spill Response recently adopted by the Arctic Council (2011, 2013) highlight the need for an effective, cooperative emergency response framework. The Arctic Council's Emergency Prevention, Preparedness and Response Working Group (EPPR WG), and the newly established Arctic Coast Guard Forum, are key entities to enhance emergency response capacity by scaling up or coordinating national efforts at the pan-Arctic level. Efforts to date have focused on emergency preparedness and response in terms of trained personnel, assets, protocols and frameworks (EPPR, 1998; Arctic Council, 2013; EPPR, 2014). For the time period 2015-17 key goals or themes to be addressed by EPPR WG include, among others, an International Exercise under the auspices of the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic, a project on Prevention, Preparedness and Response for Small Communities, and development of a Database of Arctic Response Assets. EPPR WG is also beginning to address activities focused on Search and Rescue which has come under the EPPR purview. Relevant for the Arctic Observing Summit 2016 (AOS), is EPPR's examination of the use of Unmanned Aerial Systems in Arctic Response Activities (Merten, EPPR Presentation in Anchorage, AK, 2015), as well as its designation of Arctic ERMA as an EPPR pilot project (Arctic Council, 2015).

Many parts of the Arctic that could be impacted by a maritime disaster are remote and lack local response assets and infrastructure. At the same time, the increase in maritime activities may outpace the deployment of assets dedicated to enhancing Arctic or maritime domain awareness (MDA). This includes instrumentation and hardware to monitor the physical and ecological environment and the type and extent of human activities related to hazards and vulnerabilities in the region. In light of such potential shortfalls, environmental data collected in the context of sustained observations of Arctic change can play an important role in providing environmental intelligence (Sullivan, 2015) that contributes to MDA. A recent study in the U.S. Arctic showed that such sustained observations in the marine environment are conducted by an array of different entities. U.S. federal agencies account for about one fifth of all observations, while the academic research community account for about one third, with the remainder being conducted by industry and foreign nations (Lee et al., 2015).

The impacts of rapid climate change have resulted in an array of major natural hazards, many of them associated with slow onset, such as permafrost thaw (Ravens et al., 2012; Barnhart et al., 2014), that threaten coastal communities and infrastructure. Rapid onset hazards are typically better tracked and prepared for than slow onset hazards, leaving a gap in the response and adaptation capacity and challenging the classic picture of MDA in the Arctic. This problem will be considered in more detail below.

The current and future requirements of MDA and the status of sustained Arctic environmental observations raise an important question that guides our white paper: In the event of an emergency or a disaster (such as an oil spill from a pipeline or vessel, a vessel accident requiring evacuation and rescue, an ice break-out or push event putting people and infrastructure at risk, or a coastal storm with threats emanating from flooding, wind or ice action), how can a response effort best draw on research resources, specifically observing assets and data streams that contribute to sustained observations of Arctic environmental change? Given the breadth and depth of this problem, we will focus our discussion on the coastal Arctic Ocean and marginal seas where the presence of ice represents a major hazard. Relevant operations that need to be considered in this context include shipping, subsistence activities by local communities, resource development, and tourism. We include a discussion of increased exposure to storms, coastal erosion and flooding as key environmental hazards, that in turn also enhance existing technological hazards. Drawing on a case study in the North American Arctic we identify promising approaches and next steps in bridging gaps between the research and EPPR communities, in particular in providing a common operational picture (COP) that informs MDA in the context of emergency response.

Maritime Domain Awareness and Common Operational Pictures in Arctic ice-covered seas

Traditional definitions couch MDA in terms of understanding and tracking any aspect of the maritime domain that could impact the security, safety, economy or the environment of a particular region or nation (Department of Homeland Security, 2005). In this context, the maritime domain encompasses the seas, coasts, and associated waterways and the activities therein. In most applications the focus of MDA is on vessels or anthropogenic threats or to a lesser extent ocean state and weather conditions (e.g., Department of Homeland Security, 2005; Bruno et al., 2010). At high latitudes, there are a number of major environmental hazards and threats associated with the presence of ice in the ocean, often in combination with hazardous weather or strong ocean currents (Eicken and Mahoney, 2015).

These environmental hazards have a disproportionate importance in the Arctic. First, they may amplify the risks associated with technological failure or human error in a remote environment, and therefore require advances in MDA research and technology specific to the Arctic maritime domain. Second, changes in sea-ice extent and seasonality are major drivers in enhancing coastal erosion and flooding and threatening the livelihood of Arctic coastal communities (Ravens et al., 2012; Barnhart et al., 2014). Third, such changes are also driving other slow-onset hazards such as permafrost thaw. While changes in sea ice, seasonality and permafrost are not part of the classic definition of MDA (Department of Homeland Security, 2005), we regard them of comparable importance to hazards of the first type because of their disproportionate importance in the Arctic. At the same time, emergency response frameworks may not be effective in addressing these latter two types of hazards in the Arctic (see discussion by Huggel et al., 2015 and Eicken and Mahoney, 2015), which may further increase exposure and vulnerability of communities over time.

Hence, for the framework and case study discussed below, we focus on the following types of hazards: (1) technological hazards (amplified by natural hazards and challenging environmental conditions), including threats to vessels and infrastructure with the potential for loss of life and property as well as oil spills from vessels and hydrocarbon exploration and production, (2) natural hazards that present a direct threat to maritime activities, including presence of sea ice, icing conditions, extreme weather and ocean state, (3) natural hazards that present a direct threat to coastal communities and infrastructure as well as human activities, including coastal storms, hazardous shorefast and drift ice conditions, coastal flooding and extreme weather events. We recognize a fourth type of hazard, i.e., slow-onset hazards that threaten coastal communities and infrastructure, such as through sustained reductions in summer ice extent, decreased stability and presence of shorefast ice or permafrost thaw. While detailed consideration of such hazards is outside of the scope of this white paper, we recognize that they may greatly amplify the impact of other hazards considered here and can drive short timescale catastrophic events (Cutter et al., 2008). Hence, we will provide recommendations relevant to consideration of slow-onset hazards in the context of MDA.

Necessary advances in Arctic MDA include development of robust approaches to vessel detection using standard remote sensing or acoustic techniques (Bruno et al., 2010), tracking systems such as the Automated Identification System (AIS), or inversion of high-frequency ocean radar data (Statscewich et al., 2014). At the same time, information about the state of the environment is needed to inform the development of a common operational picture (COP), identify hazards – including slow onset hazards threatening coastal communities and industry infrastructure, and support vessel detection and tracking. Here, we focus on development of interoperable data sources for use in COPs and briefly explore how to foster integration of relevant data obtained in the context of sustained Arctic observations. As a case study, we consider a subregion of the North Slope of Alaska, centered roughly on the town of Barrow, located at the boundary between Chukchi and Beaufort Seas (Fig. 1).

A case study at Barrow

The Barrow region and North Slope of Alaska are the setting for a range of activities in the maritime domain relevant in the context of this white paper. To the West and East are oil and gas leases, with the Beaufort Sea leases slated both for exploration and development. Maritime traffic typically hugs the coast at the Barrow peninsula, both to minimize distance and to avoid ice often lingering well into summer towards the North. Recent years have seen increased tourist traffic, both in terms of small-craft adventure tourism and larger cruise ships. By number, the greatest proportion of vessel traffic is associated with subsistence hunters from Barrow and neighboring communities who harvest marine mammals and fish in the region. At the same time, the community of Barrow and surrounding regions have experienced increasing threats to community infrastructure and well-being from coastal erosion, flooding and extreme weather events (Gearheard et al., 2006; Brunner and Lynch, 2010). This combination of high level of maritime activity and the range of environmental hazards and potential impacts on the community make this an ideal location to explore various aspects of MDA and COP development in a hybrid research-operational setting.

Barrow is also home to a large number of long-term terrestrial and marine research projects (Norton, 2001). This includes a strong presence by federal, state and local agencies and broad range of U.S. and international universities and research institutions. Significantly, there is also an increasing interest in research at Barrow among non-Arctic nations. The Iñupiat population in the region has a long, well established history of sharing insights from Traditional Environmental Knowledge (TEK) and providing essential support and collaboration on research projects. Indeed, this history includes a number of major research efforts that would not have succeeded without the involvement and assistance of local experts. The remoteness of the location – the nearest U.S. Coast Guard (USCG) base in Kodiak is some 1500 km distant – and challenging environmental conditions put significant emphasis on expertise and assets within the local community. Such assets could include sensor systems currently deployed for long-term studies of environmental change and related research but potentially relevant in the case of emergency response.

Standard approaches to development of a COP (such as Shahir et al., 2014) typically employ an approach that draws on a variety of datasets to determine whether the potential for an *engagement*, *rendezvous* or *anomaly* exists. An *engagement* is the first stage of the evaluation process and occurs when a vessel is brought to within a specified distance of a hazard, which may be another vessel. If a potential engagement is identified, then a second stage of evaluation assesses the potential for an actual *rendezvous,* which conforms with a specific preidentified scenario. If such a scenario is deemed a risk to people, a vessel or infrastructure then it is classed as an *anomaly* and a third stage is initiated in which a decision-maker needs to be involved to take action. The problem in Arctic regions is that a lack of environmental intelligence can compromise MDA and prevent the establishment of an accurate COP, thereby curbing the effectiveness of prevention or response efforts. The ice entrainment and drift of a fuel barge in the eastern Beaufort Sea past Barrow and into Russian waters in the winter of 2014/15 serves as an example of this problem (CBC News, 2015). Moreover, the short-term, event sequence-based approach to COP establishment does not necessarily apply to slow-onset hazards and will require further research into whether and how the classic COP framework can be applied to slow-onset hazards. While this is somewhat beyond the scope of this paper, we recognize the importance of this issue and include it in the recommendations for the Arctic Observing Summit to consider.

In the context of this study, developing data sources and operator knowledge to inform a COP includes the following steps and prerequisites: (i) identification of available sensor system capabilities and relevance to response scenarios; (ii) integration of these data streams into a common reference framework; (iii) automated or supervised evaluation of the potential for engagement, rendezvous or anomaly with potentially hazardous outcomes. To illustrate the scope of step 1, Table 1 shows key capabilities and constraints of selected research sensor networks for the Barrow region. These include: remote sensing data downlinked and processed by the Geographic Information Network of

Alaska (GINA; gina.alaska.edu) at the University of Alaska Fairbanks (UAF), serving both researchers and the National Weather Service; Synthetic Aperture Radar data obtained through the Alaska Satellite Facility; an HF ocean radar (Statscewich et al., 2014); an ice radar (Eicken et al., 2011); unmanned aerial systems deployed by the Alaska Center for Unmanned Aerial Systems Integration (ACUASI); and Iñupiaq ice experts contributing to a seasonal ice zone observing network (Eicken et al., 2014). A capabilities assessment such as this can help identify potential gaps as well as guide the integration of different data streams.

Integration and automated evaluation require that the COP builds on rapid data processing, appropriate distribution methods and flexibility to accommodate a variety of data streams and use cases. Data processing should focus on transferring the raw data quickly from the acquisition point transforming it into an information product on a common grid. Distribution channels must make use of the right networks and transfer protocols while allowing data to be either pushed or pulled as necessary. At the same time, the underlying framework needs the flexibility to allow integration into a variety of systems and for use cases requiring limited bandwidth, alternative projections, scalability, symbol styling, and attribute querying. Stakeholder engagement confirmed that USCG District 17 (Alaska) gravitated towards two major categories of COP interfaces: Desktop GIS systems and Web Map systems. Building on GINA's resources, a demonstration system was developed to provide data sets and data feeds via open standards such as OGC Web Mapping Services (WMS), KML, GeoJSON, and standardized map tile interfaces as endpoints for distribution. Such interoperable feeds would be at the core of an operational system that could provide a relevant COP.

A range of system integration approaches have been identified or scoped out. These include the Alaska Ocean Observing System's (AOOS) Arctic Data Integration Portal (portal.aoos.org/arctic), and an integrated system of systems (ISOS) approach currently under development by the Arctic Domain Awareness Center (ADAC; adac.hsuniversityprograms.org/centers-of-excellence/adac) led by University of Alaska Anchorage. However, a fundamental challenge remains in bridging the research-to-operations gap. This problem is amplified if research infrastructure is to be relied upon for operations and emergency response. To circumvent this challenge, it will be critical to form partnerships between the research community and key entities charged with providing information for emergency response. Additionally, any approach must draw on technology and infrastructure that is well integrated into local, national or international response networks. Here, the State of Alaska Division of Homeland Security and Emergency Management (AKDHSEM) is of particular relevance, in particular in terms of its emergency response guide for small communities (AKDHSEM, 2014) which would need to integrate information about MDA and COP relevant to community-level first responders. For the maritime domain, the Marine Exchange of Alaska (MXAK) is an important potential partner, in particular in the context of the shorebased Automated Identification System (AIS) infrastructure the MXAK has built up in recent years and with respect to the information provided to mariners at the local level.

For the present case study in the North Slope region, but also potentially Arctic-wide, NOAA's Arctic ERMA (Merten et al., 2014) is of particularly relevance. As outlined in Fig. 1, Arctic ERMA is already capable of integrating many types of relevant baseline datasets as well as operationally relevant environmental information such as ice charts or radar data. It also capable of interfacing with local and traditional knowledge (Merten et al., 2014). At the same time, it is the tool of record to be used by USCG and other responders in the management of oil spill response and restoration. The application resides on federally accredited, secure infrastructure, but is also able to use cloud-based computing services to address higher demands and portability during major response efforts. Potential next steps in further advancing the utility of Arctic ERMA as an integrative framework would include further interaction with the research community (see also AOS 2016 white paper by Lovecraft et al., 2015) to help define priorities of variables to be observed and more effective integration of dynamic, near-realtime information relevant for MDA and decision support into the ERMA framework. The interface between Arctic ERMA and community-level response may also require further consideration, e.g., in the context of community response guides (AKDHSEM, 2014).

The availability of a common reference framework, computational infrastructure and a core set of data streams could open the door for a broader evaluation of other resources and datasets that would enter into and substantially enhance development of a COP. The North Slope of Alaska and in particular the Barrow region are an ideal location to further explore and test such approaches, given both the level of maritime activity and the wide array of data collected in the region for environmental change research. Indeed this process has already been started following an incident in which data products from a radar system operated by UAF at Barrow for coastal ice research (e.g., Druckenmiller et al., 2009; Mahoney et al., 2015) contributed to a successful search and rescue operation after the detachment of a section of landfast ice (Fig. 2). This radar system is now generating near-real time information on ice velocity near Barrow, which is shared with USCG District 17 and others through a web interface and datafeed maintained by GINA. There is also potential to expand this capability using data from an atmospheric radar system operated in Barrow by the U.S. Department of Energy's Atmospheric Radiation Measurement North Slope Site (DOE-ARM; www.arm.gov/sites/nsa/C1).While the DOE-ARM radar has been installed to obtain data on atmospheric precipitation and other climate variables, a first assessment indicates that the system may also be of potentially great value in providing information on ice movement and hazards (Fig. 3).

Towards an Environmental Security and MDA Testbed to evaluate the accuracy, relevance and impact of sustained observations and prediction systems on operations and response capacity

Effective integration of different sensor systems and translation of research activities and findings into improved operations will also have to draw on numerical models. For the scenario considered here, this will most likely be some type of coupled ice-ocean model (e.g., Zhang et al., 2012) with atmospheric forcing derived from reanalysis for hindcasts or weather prediction systems for forecasts. Such work would be conducted in partnership with NOAA's Arctic Testbed. The NOAA Arctic Testbed goals are to improve marine, weather, climate and sea ice forecasting decision support capability to meet expanding needs in the Arctic, in particular through evaluation and improvement of new modeling and data acquisition approaches, drawing on agency partners and the broader research community (Petrescu, 2015). We propose that significant advances in Arctic MDA could be achieved through the expansion of the testbed approach and implementation of a comparable effort. A North Slope Arctic MDA Testbed (NSAMDAT) would provide a proving ground for new sensor technology, automated observation systems, new modeling and process parameterization approaches as well as different data fusion and integration methods. The Barrow region is ideal for such a testbed because of the multitude of sustained observing activities and associated data sets, relative ease of access, variety of environmental and operational hazards encountered in the region, and the support and interest of the local community such efforts.

A further potential benefit of such a testbed would be the availability of datasets, infrastructure, data product reference frameworks and on-site support that would greatly increase the efficiency and potential impact of any individual sensor deployment, data acquisition or field experiment. Some of the work planned as part of the ADAC effort, such as validation of coupled ice-ocean models for tracking of oil spills or improvement of coastal erosion and flooding models (Ravens et al., 2012; Ravens and Allen, 2012) would help provide a framework to evaluate the impact of specific types of measurements or observations on the accuracy and utility of predictions feeding into a COP and MDA system. Hence, such a testbed would also play an important role in helping identify, calibrate and refine guidance from stakeholders and decisionmakers on the types of observation and modeling efforts needed to meet their most pressing demands.

A challenge in this context is to ensure that available information and data sets are both shared in near-realtime with all relevant agencies and entities from the local to the (inter)national level, and that they are furthermore archived so as to be available for retrospective analysis, an important part of the testbed approach.

Recommendations and Potential Action Items

We conclude that sustained observations and data sets obtained as part of research efforts tracking Arctic environmental change can play an important role in informing planning and bolstering capacity for emergency response in maritime settings. Specific next steps and recommendations for consideration in the context of the Arctic Observing Summit and Arctic Council Working Group process include the following:

(1) Implement a framework for an MDA Testbed on the North Slope of Alaska that serves federal and state agencies, the national and international academic research community, local stakeholders – in particular partners in CBONs (see AOS white paper by Alessa et al., 2016) – and others interested in building capacity and increasing effectiveness of emergency response. Such a framework would include concepts and designs to bound the effort, a web-based portal and data and information service, and

formal and informal agreements on contributions and collaboration between testbed partners and outside participants.

(2) Survey and interview potential operational users to establish operational requirements and preferences. Use the outcomes of these interactions to set priorities for data feed development and COP softwares to be supported.

(3) Conduct a survey of potentially relevant data sources, partners and contributors for such a testbed centered on the Barrow region. Explore to what extent platforms of opportunity provided by industry can be utilized in testbed implementation (see also Thematic Working Group #3 for Arctic Observing Summit 2016).

(4) Explore the utility of such a testbed concept in fostering international coordination and collaboration, e.g., by implementing a testbed in transnational or international waters, in particular Bering Strait, where increasing vessel traffic and other constraints (Huntington et al., 2015) lend further urgency to such an approach.

(5) Explore the potential value of Arctic ERMA in providing a framework for integration of datastreams, model output and other relevant information, both at the national and international level, tying into plans by the Arctic Council EPPR WG to draw on Arctic ERMA at a broader scale.

(6) Arrange for a field exercise that builds on table-top exercises and both draws on and evaluates key aspects of an environmental security and MDA testbed on the North Slope of Alaska. A key goal for such an exercise would be to improve data and information product availability for key partners from the local to the national level, including but not limited to North Slope Borough Search and Rescue and Barrow Rescue Base, AKDHSEM, MXAK, USCG, NOAA Office of Response and Restoration, Alaska Clean Seas and others tasked with emergency management and response.

(7) Promote broader exchange between the EPPR, local and national response and research communities on how to enhance emergency response efforts by drawing on research resources, datasets and dedicated information products.

(8) Develop a research plan that identifies effective ways of expanding classic MDA and COP concepts to address challenges posed by slow-onset hazards that are typically not well addressed in a rapid-onset hazard response framework.

References

Alaska Division of Homeland Security and Emergency Management, 2014. Alaska emergency response guide for small communities. Electronic document, https://www.ak-prepared.com/SEOC/Documents/Alaska%20Emergency%20Response%20Guide

%20for%20Small%20Communities%202014%20Final.pdf (retrieved 24 Jan 2016)
Alessa, L., Williams, P., Kliskey, A., Beaujean, G., Ward, H., Ungott, J., Ungott, E., 2015. Incorporating community-based observing networks for enhanced preparedness and responses to marine Arctic critical events. Arctic Observing Summit, 15-18 March 2016, Fairbanks, AK.
Arctic Council, 2015. Arctic Environmental Response Management Application. Report to the 9. Ministerial meeting in Iqaluit, Canada, April 24-25 2015. Arctic Council Secretariate, online resource, http://hdl.handle.net/11374/400 (retrieved 28 Jan 2016).
Arctic Council, 2013. Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic. Arctic Council, 230 pp, http://www.state.gov/r/pa/prs/ps/2013/05/209406.htm
Arctic Council 2011. Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic. Arctic Council, 18p., http://library.arcticportal.org/1474/
Barnhart, K.R., Overeem, I., Anderson, R.S., 2014. The effect of changing sea ice on the physical vulnerability of Arctic coasts. Cryosphere 8, 1777-1799.
Brigham, L. W., 2014. Environmental and economic security challenges in a changing U.S. maritime Arctic*Rep.*, 24 pp, Hoover Institution; http://www.hoover.org/research/environmental-and-economic-security-challenges-changing-us-maritime-arctic
Brunner, R.D., Lynch, A.H., 2010. Adaptive governance and climate change. University of Chicago Press, Chicago.
Bruno, M., K. W. Chung, H. Salloum, A. Sedunov, N. Sedunov, A. Sutin, H. Graber, and P. Mallas, 2010. Concurrent use of satellite imaging and passive acoustics for maritime domain awareness, paper presented at Waterside Security Conference (WSS), 2010 International, IEEE, 1-8
CBC News, 2015. NTCL barge that drifted to Russia is on its way home; online resource, retrieved 6 Nov 2015, http://www.cbc.ca/news/canada/north/ntcl-barge-that-drifted-to-russia-is-on-its-way-home-1.3170595
Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb, 2008. A place-based model for understanding community resilience to natural disasters, Global Environm. Change 18, 598-606.
Department of Homeland Security, 2005. National Strategy for Maritime Security: National Plan to Achieve Maritime Domain Awareness. Department of Homeland Security, Washington, DC, 33 pp.
Druckenmiller, M.L., Eicken, H., Pringle, D.J., Williams, C.C., Johnson, M.A., 2009. Towards an integrated coastal sea-ice observatory: System components and a case study at Barrow, Alaska. Cold Reg. Sci. Tech. 56, 61-72.
Eicken, H., Jones, J., MV, R., Kambhamettu, C., Meyer, F., Mahoney, A., Druckenmiller, M.L., 2011. Environmental security in Arctic ice-covered seas: From strategy to tactics of hazard identification and emergency response. Marine Technol. Soc. J. 45, 37-48.
Eicken, H., Mahoney, A.R., 2015. Sea ice: Hazards, risks and implications for disasters. In: Ellis, J., Sherman, D. (Eds.), Sea and ocean hazards, risks and disasters. Elsevier, Oxford, pp. 381-401.

Eicken, H., Kaufman, M., Krupnik, I., Pulsifer, P., Apangalook, L., Apangalook, P., Weyapuk, W.J., Leavitt, J., 2014. A framework and database for community sea ice observations in a changing Arctic: An Alaskan prototype for multiple users. Polar Geogr. 37, 5-27.

Emergency Prevention Preparedness and Response (EPPR), 2014. EPPR Working Group Meeting Final Report. Seattle, WA, 32pp.; http://arctic-council.org/eppr/wp-content/uploads/2010/04/December_4_2014_Seattle_USA.pdf

Emergency Prevention Preparedness and Response (EPPR), 1998. Field Guide for Oil Spill Response in Arctic Waters. Environment Canada, Yellowknife, NT Canada, 348 pp.

Gearheard, S., Matumeak, W., Angutikjuaq, I., Maslanik, J., Huntington, H.P., Leavitt, J., Kagak, D.M., Tigullaraq, G., Barry, R.G., 2006. "It's not that simple": A collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in Barrow, Alaska, USA, and Clyde River, Nunavut, Canada. Ambio 35, 203-211.

Huggel, C., Stone, D., Eicken, H., Hansen, G., 2015. Potential and limitations of the attribution of climate change impacts for informing loss and damage discussions and policies. Climatic Change 133, 453-467.

Huntington, H. P., and ten others, 2015. Vessels, risks, and rules: Planning for safe shipping in Bering Strait, Mar. Policy 51, 119-127.

Lee, O., H. Eicken, G. Kling, and C. Lee (2015), A Framework for Prioritization, Design and Coordination of Arctic Long-term Observing Networks: A Perspective from the U.S. SEARCH Program, *Arctic*, *68*(5), 76-88.

Lovecraft, A.L., Meek, C., Eicken, H., 2015. Data Portals as Institutional Bridges: Connecting Scientific Observations to Stakeholder Needs in Sea Ice Social-Environmental Systems. Arctic Observing Summit, 15-18 March 2016, Fairbanks, AK.

Mahoney, A.R., Eicken, H., Fukamachi, Y., Ohshima, K.I., Simizu, D., Kambhamettu, C., MV, R., Hendricks, S., Jones, J., 2015. Taking a look at both sides of the ice: Comparison of ice thickness and drift speed as observed from moored, airborne, and shore-based instruments near Barrow, Alaska. Ann. Glaciol. 56, 363-372.

Merten, A. (2013), New Tool for First Responders in the Arctic: Arctic ERMA, *Witness the Arctic*, *Spring 2013*(2), www.arcus.org/witness-the-arctic/2013/2/article/19951

Merten, A. A., Z. Winters-Staszak, and N. E. Kinner, 2014., Incorporating Traditional Knowledge and Subsistence Mapping into the Arctic Environmental Response Management Application, International Oil Spill Conference Proceedings, vol. 2014(1), 1512-1523.

MV, R., Kambhamettu, C., Jones, J., Eicken, H., 2013. Extracting quantitative information on coastal ice dynamics and ice hazard events from marine radar digital imagery Transact. Geosci. Rem. Sens. 51, 2556-2570.

Norton, D. W., 2001. *Fifty More Years Below Zero: Tributes and Meditations for the Naval Arctic Research Laboratory's first Half Century at Barrow, Alaska*, University of Alaska Press, Fairbanks, AK.

Petrescu, E., 2015. Arctic Testbed. http://www.testbeds.noaa.gov/events/2015/workshop/presentations/tue-petrescu-atb.pdf

Pizzolato, L., Howell, S.E.L., Derksen, C., Dawson, J., Copland, L., 2014. Changing sea ice conditions and marine transportation activity in Canadian Arctic waters between 1990 and 2012. Climatic Change 122, doi:10.1007/s10584-10013-11038-10583.

Ravens, T. M. and Allen, J. 2012. Modeling Storm-Induced Inundation on the Yukon Kuskokwim Delta for Present and Future Climates. Presented at the AGU Fall Meeting, San Francisco, CA, Dec. 2012.

Ravens, T.M., Jones, B.M., Zhang, J.L., Arp, C.D., Schmutz, J.A., 2012. Process-Based Coastal Erosion Modeling for Drew Point, North Slope, Alaska. J Waterw Port C-ASCE 138, 122-130.

Shahir, H. Y., U. Glasser, N. Nalbandyan, and H. Wehn, 2014. Maritime Situation Analysis: A Multi-vessel Interaction and Anomaly Detection Framework, paper presented at Intelligence and Security Informatics Conference (JISIC), 2014 IEEE Joint, 24-26 Sept. 2014, 191-199.

Statscewich, H., Roarty, H., Smith, M., Page, E., Glenn, S., Weingartner, T., 2014. Enhancing Arctic Maritime Domain Awareness Through an Off-Grid Multi-sensor Instrument Platform. Mar Technol Soc J 48, 97-109.

Sullivan, K. (2015), Statement from Dr. Kathryn Sullivan on NOAA's Fiscal Year 2016 Budget Request, edited, p. 2, NOAA, Washington, DC; http://www.noaanews.noaa.gov/stories2015/20150203_statement-sullivan-noaa-fiscal-year-2016-budget-request.html

Zhang, J.L., Lindsay, R., Schweiger, A., Rigor, I., 2012. Recent changes in the dynamic properties of declining Arctic sea ice: A model study. Geophysical Research Letters 39; L20503, doi:10.1029/2012gl053545

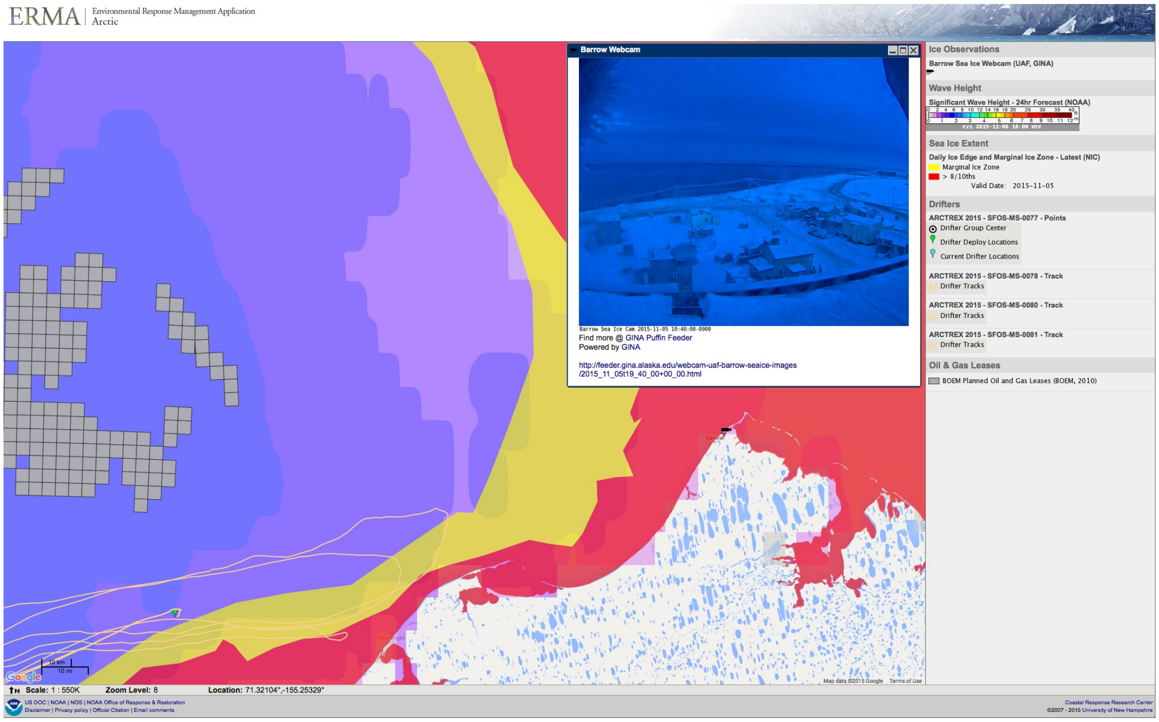

Fig. 1: Map of the Barrow region and part of the North Slope of Alaska, as seen in NOAA's Arctic ERMA interface. Out of a larger number of variables, key locations, such as oil and gas lease areas, ice conditions on 5 Nov 2015 based on NOAA National Ice Center ice charts, sea state (24-hour forecast of wave height), trajectories of surface drifters released in September 2015 and an image of the Barrow Sea Ice Webcam showing new ice forming nearshore with some open water and thicker young ice further offshore. The camera also captures atmospheric riming conditions.

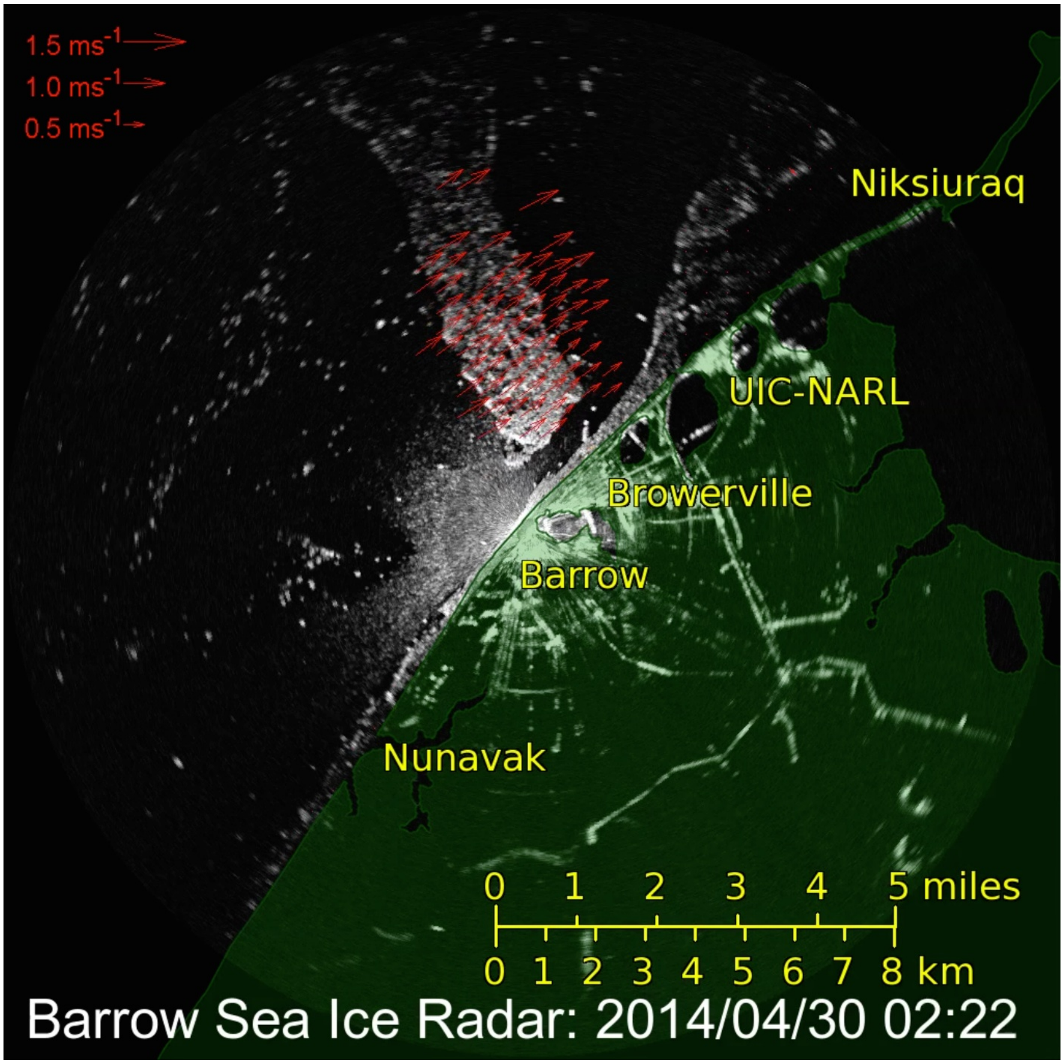

Fig. 2: Ice movement in association with shorefast ice break-out event tracked by UAF X-band sea ice radar at Barrow, Alaska. Velocity vectors are superposed on the backscatter image and have been derived in near-realtime based on analysis of sequential radar imagery (MV et al., 2013). Note the ice floe derived from the break-out event moving back towards shorefast ice between Browerville and Niksiuraq.

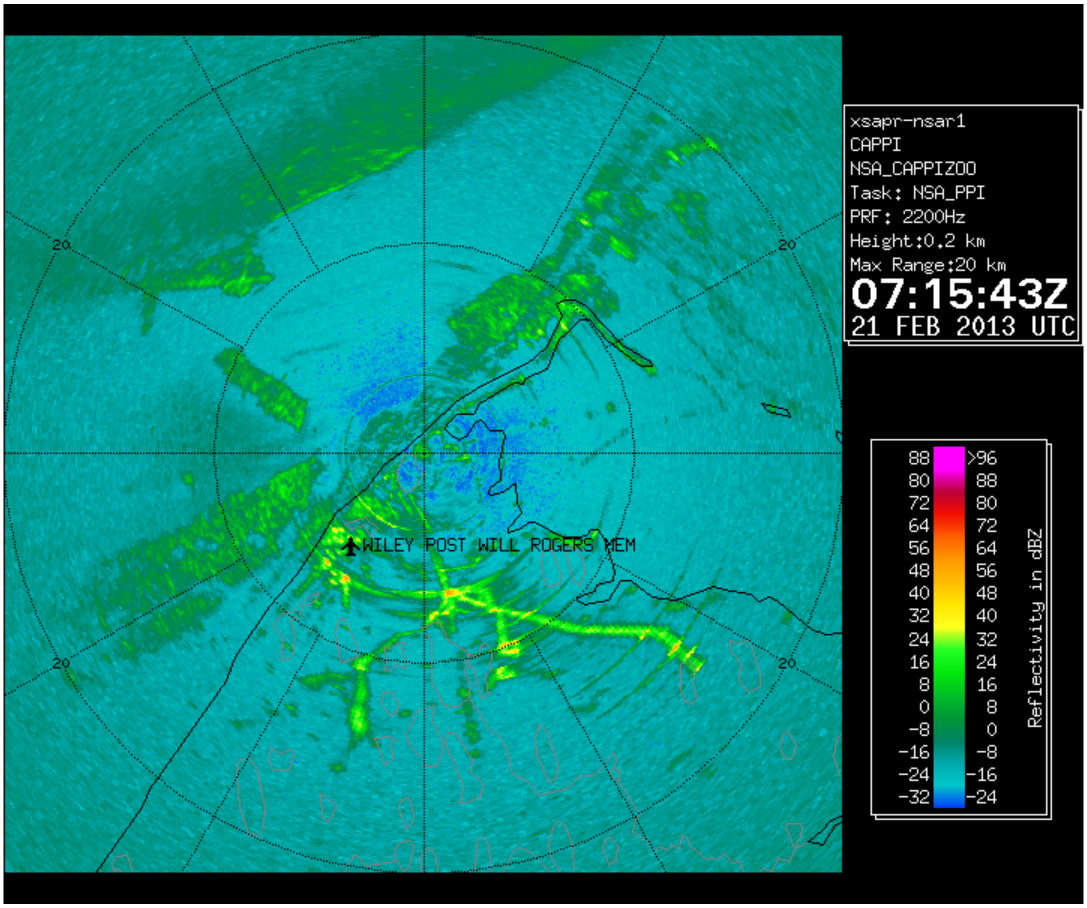

Fig. 3: Radar backscatter image from low-elevation horizon scan by DOE-ARM X-band precipitation radar system. The scene shows ice conditions comparable to Fig. 2, with a fragment derived from the break-out event visible between the shorefast ice in the South and the offshore pack ice in the North. Range of image is twice that of scene shown in Fig. 2, such that inner circle (radius c. 10km) corresponds to area covered by ice radar in Fig. 2.

Table 1: Capabilities of UAF research program components for the Barrow/North Slope of Alaska region relevant for COP applications.

UAF Arctic Sensors Capabilities Matrix									
		Satellite				Radar		UAS	HUMAN
		Optical			SAR	HF	Ice Radar	ACUASI	Local obs
Category	**Factor**	High Res	Med Res	Low Res		5 MHz	10 GHz	Med Weight	Local
Environ-mental	Day	√	√	√	√	√	√	√	√
	Night	X	X	!	√	!	√	√	√
	Clouds	X	X	!	√	√	√	!	√
	Water vapor	√	√	√	!	√	√	√	√
	Precipitation	√	√	√	√	√	!	√	√
	Winds	√	√	√	√	√	√	√	√
	Configurable sensor	√	√	√	√	X	X	!	n/a
	Oper'g Temperatures	all year	all year	all year	all year	Jul - Nov	all year	all year	√
	Ice/snow/water differentiation	√	√	√	√	X	!	√	√
Range	Current range from coast	n/a	n/a	n/a	n/a	50-200 km	10 km	100 Miles	n/a
	Maximum range from coast	n/a	n/a	n/a	n/a	200 km	50-70 km	?	n/a
EM Inter-ference	Proximity	√	√	√	!	!	X	!	n/a
	Radiation/Induction	?	?	?	?	!	√	!	n/a
Comm's Link	Minimum bandwidth	?	?	?	?	Iridium	wifi	900MHz	n/a
	Optimal bandwidth	?	?	?	?	Fiber optic	Fiber optic	Iridium	n/a
Proces-sing Times	Quick look avail.	<20min	<20min	<20min	<20min	√	5 - 30 min	√	√
	Full Product in <12 h	√	√	√	X	√	√	√	n/a
	Full Product in >12 h	√	√	√	√	√	√	√	n/a
Infrastruc-ture	Electric power source	Onboard	Onboard	Onboard	Onboard	RPM	power grid	Onboard	n/a
	Duration of power	Years	Years	Years	Years	all season	constant	20+ hrs	
	Maintenance free	√	√	√	√	X	n/a	X	X
Data Costs	Acquisition costs	High	High	High	High	Low	Low	Low	n/a
	Distribution/Licensing	?	?	?	?	?	?	n/a	n/a
	No Cost	?	?	?	?	publ dom	publ dom	?	n/a
Detection	Vessel	√	√	√	√	√	√	√	√
	Landfast Ice Edge	√	√	√	√	X	√	?	√
	Surface Current - Water	X	X	X	X	√	X	X	?
	Surface Current - Drift Ice	X	X	X	!	X	!	X	√
	Ice Breakout Event	X	X	X	X	X	√	X	√
	Ice Cover					X	√	√	√
	Ice Surface Topography					X	√	!	√
	Ice Thickness					MSB	X	X	√
	Water Pooling on Ice					X	X	√	√
Ice Coverage	100% coverage	√	√	√	√	X	√	√	√
	50% mixed	√	√	√	√	X	√	√	√
	0% coverage (open water)	√	√	√	√	√	√	√	√

Legend
√ = Capable
! = Varying capability
X = No capability
n/a = Not applicable
? = Need further info