Arctic Domain Awareness Center (ADAC)

A DHS Science and Technology Office of University Programs,

Center for Maritime Research

Current State of Science for Arctic Marine Oil Spill

A Literature Synthesis in support of

Arctic-Related Incidents of National Significance

Workshop

"Coping with the Unthinkable"

...an Arctic maritime oil spill"

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Preamble

The Arctic Domain Awareness Center at the University of Alaska in partnership with the Coastal Response Research Center (CRRC) Center for Spills and Environmental Hazards at the University of New Hampshire is sponsoring a workshop addressing a future fictitious Arctic-related Incident of National Significance (an Arctic IoNS). This workshop, "Coping with the unthinkable…an Arctic maritime oil spill" hosted at the University of Alaska Anchorage from 23-25 October 2017, seeks to understand current baselines in research and shortfalls of existing technologies and capabilities in responding to an Arctic oil spill.

The outcomes from this Arctic IoNS workshop are to identify research questions to investigate which can lead to solutions for shortfalls in technologies and capabilities discovered at the workshop.

This Literature Review seeks to help workshop participants understand the existing body of literature regarding current technology relevant to Arctic oil spill response (including gaps in those technologies that can represent the starting point to the workshop discussion).

With Arctic sea-ice diminishing, the probability of trans-Arctic shipping is becoming ever more a reality (while realizing the current numbers of such transits remain low). Arctic maritime destination tourism is already a fact and likely to increase. In the coming years, diminishing Arctic sea ice increases the probability of use of Canada's Northwest Passage and other established Arctic maritime routes. As maritime traffic increases, the risk of accidental release of oil or refined oil products in Arctic waters also increases.

Accordingly, the need for updating and further developing Arctic oil spill response plans and strategies is growing. Needs are also increasing to improve collaboration in pooling and sharing resources in an Arctic oil spill response (which is particularly important given the high cost of spill response capabilities).

The "Coping with the unthinkable…an Arctic maritime oil spill" Literature Review herein seeks to compile oil spill modeling and statistics, review response strategies and emerging technologies, examine decision support systems and policies, and account for logistical, environmental, and medical concerns in the event of an Arctic oil spill.

This Literature Review acknowledges logistics of response for an Arctic oil spill is an under-researched topic. Reliance on existing logistical commercial capabilities is potentially sufficient for on or near shore oil spills, but such reliance in responding to an oil spill out at sea in the environmentally sensitive Arctic Ocean may prove to be an unacceptable risk to the spill response community.

The current literature examining the best response approach to an Arctic oil spill includes three main strategies: mechanical recovery, in-situ burning, and dispersal. The concentration of ice in the area of spilled oil is important in establishing the efficacy and safety of each of these methods. Research is also emerging which examines bioremediation strategies for oil contamination. This process seeds the contaminated area with oil-consuming microbes, either naturally adapted or genetically altered to degrade high oil concentrations. Testing of unmanned aircraft technology also produces promising results potentially applicable to an oil spill scenario in the form of real-time surveillance, or even application of herding agents and subsequent ignition.

In addition to the diversity of response strategies, the coordination and collaboration of nations, government agencies, industry, and research institutions will also become paramount in the efficient removal of oil from the environment. Several nations and multiple tribal entities border the Arctic Ocean, and the location of the region presents operational and transportation difficulties. Existing operational frameworks and decision support systems currently in place are likely insufficient to fully respond, as well as desired, in a major offshore oil spill in the Arctic.

The harsh weather conditions associated with the area create medical and operational challenges that are subject to change regularly. Exposure to cold water and cold temperatures can create medical emergencies for responding personnel, and storms and seas can create an unsafe working environment. Since the survival of personnel is the highest priority in any response scenario, measures and strategies need to be in place to account for all weather scenarios to ensure the safety of these personnel in the field.

The following is a literature review and synopsis organized by focus area. Each synopsis provides a brief explanation and/or abstract of the article. A full text database of all available articles can be accessed here:

https://drive.google.com/drive/folders/0BytFVuw1QfWTOXl1Y1RlXzNZV00?usp=sharing

The Author and contributors to the "Coping with the unthinkable…an Arctic maritime oil spill" Literature Review, hope the following pages provide workshop participants the needed information to assist their own preparation for this important gathering of researchers, operators, and officials to study a problem, we collectively hope…never happens.

ADAC, University of Alaska Anchorage, 9 October 2017

Oil Spill Modeling and Statistics

1. *Dynamic fugacity model for accidental oil release during Arctic shipping (Memorial University of Newfoundland, Afenyo et al. 2016)*

Abstract:
Improved understanding of ecological risk associated with Arctic shipping would help advance effective oil spill prevention, control, and mitigation strategies. Ecological risk assessment involves analysis of a release (oil), its fate, and dispersion, and the exposure and intake of the contaminant to different receptors. Exposure analysis is a key step of the detailed ecological risk assessment, which involves the evaluation of the concentration and persistence of released pollutants in the media of contact. In the present study, a multimedia fate and transport model is presented, which developed using a fugacity-based approach. This model considers four media: air, water, sediment, and ice. The output of the model is the concentration of oil. (Surrogate hydrocarbons—naphthalene) in these four media, which constitutes the potential exposure to receptors. The concentration profiles can subsequently be used to estimate ecological risk thereby providing guidance to policies for Arctic shipping operations, ship design, and ecological response measures.

2. *Dynamic resource allocation to support oil spill response planning for energy exploration in the Arctic (Rensselaer Polytech Institute, Garrett et al. 2017)*

Abstract:
A mixed—integer linear program is proposed to model the dynamic network expansion problem of improving oil-spill response capabilities, to support energy exploration in the Arctic. Oil spill response operations in this region can be hampered by a lack of existing infrastructure, limited pre-positioned response equipment, and the possibility that response equipment might not arrive in time to mitigate the impact of a spill because of a distance and infrastructure limitations. These considerations are modeled by two inter-related constraint sets with the objective of minimized total weighted response time for a set of potential oil spill incidents. One constraint set determines how to dynamically allocate response equipment and improve the infrastructures necessary to stockpile them within a network of response sites. The other set determines how to utilize this stockpile to respond to each task necessary for an incident by scheduling the equipment to complete tasks. These task completion times are subject to deadlines, which, if not met, require costlier follow-on tasks to be scheduled. Subject matter experts in the United States (U.S.) Coast Guard and major Oil Spill Response Organization (in the context of oil spill response logistics) support energy exploration initiatives in the U.S. Arctic assessed the model, its assumptions, and data requirements.

3. *Preparing for the unprecedented – Towards quantitative oil risk assessment in the Arctic marine areas (University of Helsinki, Nevalainen et al. 2017)*

Abstract:
The probability of major oil accidents in the Arctic seas is increasing alongside with increasing maritime traffic. Hence, there is a growing need to understand the risks posed by oil spills to these unique and sensitive areas. So far, these risks have mainly been acknowledged in terms of qualitative descriptions. We introduce a probabilistic framework, based on a general food web approach, to analyze ecological impacts of oil spills. We argue that the food web approach based on key functional groups is more appropriate for providing holistic view of the involved risks than assessments based on single species. We discuss the issues characteristic to the Arctic that need a special attention in risk assessment, and provide examples how to proceed towards quantitative risk estimates. The conceptual model presented in the paper, helps to identify important risk factors and provide a template for more detailed risk assessments.

4. *A dynamical systems perspective for a real-time response to a marine oil spill (Marine Pollution Bulletin, Garcia-Garrido et al. 2010)*

Abstract:
This paper discusses the combined use of tools from dynamical systems theory and remote sensing techniques and shows how they are effective instruments, which may greatly contribute to the decision-making protocols of the emergency services for the real-time management of oil spills. This work presents the successful interplay of these techniques for a recent situation, the sinking of the Oleg Naydenov fishing ship that took place in Spain, close to the Canary Islands, in April 2015.

5. *Estimates of Oil Spill Dispersion Extent in the Nearshore Alaskan Beaufort Sea Based on In-Situ Oceanographic Measurements (Alaska Department of Environmental Conservation, 2007)*

From the Abstract:
"This report describes analyses designed to estimate the distance and direction an Oceanic oil spill could travel during each of the two primary circulation regimes found in the near-shore Beaufort Sea: 1) under landfast ice during winter and 2) in open water or partial ice cover during summer. … The analyses comprise our best estimate of particle displacements over short time periods based upon in-situ oceanographic data from the North Slope. Results allow us to place approximate bounds on the distance an oil spill could traverse during each of the primary circulation regimes. Primary findings include the following. 1) Over the 2-day to 12-day time frames considered here, displacement of an oil spill will be relatively small during the landfast ice period (tens of kilometers) and relatively large during the open water and drifting ice period (hundreds of kilometers). 2) Advection in the summer is highly dependent upon the wind speed and direction. 3) In both seasons, transport of oil in the alongshore (east west) direction is greater than transport in the cross-shore (north-south) direction."

Decision Support and Operational Policy

6. *Alaska Clean Seas Technical Manual Volume 1 (ACS Vol. 1 2008)*

From the Foreword:
"This tactics manual is the first volume of three manuals that make up the *Alaska Clean Seas Technical Manual,* providing ACS member companies with a unified response plan for spills in the North Slope oil fields, both onshore and offshore… both agency and industry felt that industry should develop a unified North Slope response plan under the auspices of Alaska Clean Seas… This manual contains descriptions of the tactics that Alaska Clean Seas can use to respond to a spill."

7. *The Evolution of Applied Geographic Information Systems for Oil Spill Response in California: Rapid Data Dissemination for Informed Decision Making. (Muskat 2014. Proceedings of the 2014 International Oil Spill Conference)*

From the Abstract:
"Computing technology has advanced to the point where it is now standard practice to employ complex Geographic Information Systems (GIS) within the Incident Command Post (ICP). Simultaneously, field data collection has been migrating to mobile computing applications, which output GIS files that are quickly displayed for real-time situational awareness. From the initial emergency response through clean up and sign-off much data with a spatial component is generated and many disparate data sets are collected. More efficient data integration, management and visual analysis affords Incident Commanders and Section Chiefs the ability to make informed and timely planning, operational and strategic decisions."

8. *Oil Pollution Research and Technology Plan (Interagency Coordinating Committee on Oil Pollution Research (ICCOPR 2015))*

"Scope and Use of the Plan: This OPRTP provides a basis for coordinating research to address oil pollution issues in the U.S. It is primarily directed at Federal agencies with responsibilities for conducting or funding oil pollution research, but can serve as a research-planning guide for industry, academia, State governments, research institutions, and other nations. Research, in the context of the OPRTP, includes both basic and applied studies that are considered as peer-reviewed and published as well as studies reported in the "grey literature," which is publically available scientific literature that has not been peer reviewed." pg. 28

9. *Recommended Practice for a Common Operating Picture for Oil Spill Response (OGC 2015)*

Abstract:

This architecture report is part of The International Association of Oil & Gas Producers and IPIECA Oil Spill Response - Joint Industry Project (IOGP–IPIECA OSR-JIP) to produce a recommended practice for GIS/mapping in support of oil spill response and for the use of GIS technology and geospatial information in forming a "Common Operating Picture" to support management of the response. Interoperability seems to be at first a technical topic, but in fact, it is about organization. Interoperability seems to be about the integration of information. What it is really about is the coordination of organizational behavior. The Oil Spill Response Common Operating Picture (OSR COP) project seeks to facilitate the coordination of organizational response to any oil spill in the future.

10. *Offshore oil spill response practices and emerging challenges (Memorial University of Newfoundland, Li 2016).*

Successful oil spill response often hinges on the coordination of several organizations, which must pool resources and efforts in order to complete tasks beyond the capabilities of any single organization. Though models exist for oil spill response planning, a more holistic approach that integrates characterization, assessment, simulation, optimization, and geomatics' analysis techniques would account for and include detailed complexities associated with oil spills.

With the increased likelihood of an oil spill in the Arctic, the concerns of an organized and holistic collaboration become still more complex, due to adverse weather conditions, and a lack of regulatory processes for oil spills in some countries in the region. Thus, a scientifically supported decision-making framework requires much more research and attention to support oil spill response. History makes us aware of the economic, environmental, public health, and community impacts of oil spills.

Decision support systems are guidelines that frame decision-making and inter-organization coordination for disasters like tsunamis, floods, and fires. The authors here strongly suggest the research to implement a decision support system for an oil spill disaster, especially for Arctic countries.

11. *TRL Definitions for Oil Spill Response Technologies and Equipment (Panetta & Potter 2016)*

Description:
The objective of this project is establish a uniform and objective means to determine the level of maturity of a new technology, and when it is ready for use in the field. Technology Readiness Levels (TRL) are used extensively in the aerospace and defense communities. This project will take this existing framework and define the simulated and intended environments, as well as the operational systems for anticipated oil spill response scenarios. It will be accomplished via the following tasks:

Task 1. Review TRL definitions from the Oil and Gas Industry, NASA, the Department of Defense and Department of Energy and develop draft Spill Response TRLs Task 2. Assemble working group and disseminate first draft of Spill Response TRLs Task 3. Organize and hold workshops (in person and via electronic means) Task 4. Develop new TRLs and categorize various spill response technologies Task 5. Provide appropriate reports.

12. Circumpolar Oil Spill Response Viability Test (EPPR 2017).

Abstract:
The purpose of this circumpolar Arctic response viability analysis is to understand the potential for different oil-spill response systems to operate in the Arctic marine environment. The EPPR Working Group commissioned this study of oil spill response viability for the circumpolar Arctic region, co-sponsored by Norway, the United States, and Denmark. DNV GL and Nuka Research and Planning Group, LLC conducted the study under contract to the Norwegian Coastal Administration and the U.S. Bureau of Safety and Environmental Enforcement.
This analysis estimates how often-different type of oil spill systems could be deployed in the Arctic based on defined operational limits and compares these to a hindcast of met ocean data.

13. Improving Safety in the US Arctic (Joint Forces Quarterly, Roscoe et al. 2014)

Increased melt in the Arctic is bound to drive an economic boom, which will likely increase tourism, natural resource exploration and exploitation, and shipping. The risks associated with this kind of activity in the area include a variety of oil spill scenarios such as a small oil spill in the Chukchi or Beaufort Seas, a large oil spill from a drilling operation, or a large oil spill from a tanker operation. To address these stressors, the Arctic Council, an international body of Arctic nations, penned an Arctic SAR agreement that was signed by the U.S. Secretary of State in May 2011. The agreement is the first legally binding instrument to accelerate cooperation between arctic nations.

The Department of Homeland Security is the primary Federal agency responsible for the safety of the Arctic with the Coast Guard as its operational arm. The DHS offers defense to support the safeguarding of human life, the environment, critical infrastructure, and property. Currently, the nearest Coast Guard air station to the Arctic is in Kodiak, 820 miles from Barrow, Alaska's northernmost population. When considering disaster response logistics, it would take 4 hours in a fixed wing aircraft to reach Barrow.

Strategically positioning Search and Rescue (SAR) infrastructure in key locations in the U.S. Arctic would decrease response times by significantly reducing transit distances, which is why Barrow was identified as an ideal location. Despite its advantages as a key location for SAR support assets, Barrow's central North Slope position creates significant logistical challenges due to a limited road network and port access. No roads link Barrow to the rest of Alaska, which prevents ground shipment of supplies, and the lack of a deep-water port requires extensive use of small landing craft and fuel barges to deliver supplies to the mainland. Given weather impacts, Barrow's primary line of communication is by aviation from either Anchorage or Fairbanks. Furthermore, the U.S. needs additional icebreakers as we only have the fewest out of all arctic nations at two. Constructing additional icebreakers would allow: continued Antarctic presence (scientific research and McMurdo resupply); arctic presence (enforcement of vessel routing regimes, compliance with safety, security, and environmental laws/treaties, freedom of navigation; response to vessels in distress, SAR, protecting against potential pollution); Arctic Research/Thule Air Force Base resupply/Flex—support to the NSF, resupply of Thule; and an option to flex to any location in case a crisis or emergency arises. If the U.S. wants to continue to play a role in developing the arctic, additional resources such as icebreakers, response guidelines, response equipment, and proper training will need to have funding appropriated by members of congress.

14. *An evaluation of oil pollution prevention strategies in the Arctic: A comparison of Canadian and U.S. approaches (University of Washington, Thorsell et al. 2016)*

Abstract:
While the Arctic is often described as a cohesive region, there is great regime diversity across Arctic states. What factors influence regime diversity in the Arctic and how does that diversity impact users and coastal states? Recognizing the Arctic regime as the intersection of overlapping governance systems, this research compares two regions: the Northwest Passage, Canada and the Bering Strait, USA, applying principles of Most Similar System Design (MSSD). The two regions are parts of a common waterway, now more accessible because of diminished sea ice. The paper explores the similarities and differences between the two oil pollution control regimes and investigates the relationship between prevention and response measures in each regime. The Canadian oil pollution control regime is characterized by a large number of measures designed to prevent spills; while the U.S. regime features measures intended to assure adequate response to spills. States most able to develop a preventative framework are those with strict legal authority and sovereign rights over their maritime regions. Moreover, states whose national identities are strongly tied to particular regions may be more likely to enact protective measures. The U.S. is dependent on international pollution control instruments in the Bering Strait given the shared jurisdiction of the waterway. The Government of Canada operates in accord with its claim the Northwest Passage are internal waters and has enacted a unilateral pollution control regime. These differences underscore that, absent broader international agreements than exist at present, Arctic waters are likely to remain a patchwork of regulatory regimes.

15. *Flexibility in maritime assets and pooling strategies: a viable response to disaster (Mileski, J. P., & Honeycutt, J. 2013).*

This journal discusses viable responses to maritime disasters and the concept of maritime asset pooling. This article was written because the authors believed that disaster implementation usually focused on solutions and resources regarding to land. The authors highlight a conceptual model on how to prepare for a disaster. The first dimension of the model is identifying the nature of the disaster, is it a natural or manmade/terrorist disaster? Preparation for both of these natures is very different from one another, and depending on the marine location, some vessels may be more equipped to handle one over the other. The second nature is the nature of the responder…is the entity government or privately owned. The government usually excels in coordination but lacks in speed of response due to relying on supplemental assets to be activated, where private owners usually excel at speed and response time but lack in organization and management. The final dimension is the nature of the recipient. Is the recipient an individual citizen or an enterprise such as the government? Individuals may have immediate needs such as food, water and medical care whereas an enterprise may be looking at repairs to infrastructure to mitigate any further losses. The article identifies flexibility in a disaster plan as being a key factor and suggest the use of a concept called marine time asset pooling. This concept is where all available assets are brought together from various owners and managed under a designated supervisor for optimal application.

16. *Cooperation among Stakeholders for a Preventative and Responsive Maritime Disaster System: The Mitigation of an Arctic Wicked Problem (Ghoram, L. C. 2015)*

The purpose of this article is to communicate flaws regarding international cooperation for disaster response. The authors make clear that as the Arctic waters open, maritime traffic will increase; presenting disaster opportunities, challenges, and triggered disputes between competing countries or organizations. One author adds that developing plans and techniques to best manage these Arctic risks require action and cooperation locally, nationally, and internationally. One review by the authors suggests there is a relative lack of good ship charts, communication systems, and other navigational aids for mariners. Furthermore, emergency response is critically limited by the lack of infrastructure, travel distance, weather, and harsh operating conditions. The article continues by explaining the different political frameworks for each Arctic nation; or otherwise contingencies and international cooperation. The authors show that the variety of policies makes disaster response difficult to accomplish with the involvement of multiple countries. The authors have recognized, in various articles, conflicting and competing values in the management and organization of nations. Currently, there is no central authority for enforcement of policy or cooperation in the Arctic. However, one author suggests that cooperation in a maritime disaster is important because one party may not have full knowledge and resources to resolve the situation. To begin the implementation of a disaster plan, the authors advise firstly designating a response manager. The article concludes its four-part plan by explaining that a uniform safety procedure is imperative across multiple levels to prevent future disasters.

Detection

17. *Remote Sensing Guide to Oil Spill Detection in Ice-covered Waters (Watkins, et al. 2016)*

From the Executive Summary:
"This guide was developed with the operational user in mind for assessing and selecting appropriate remote sensing technologies and deployment platforms for oil spill detection and surveillance in ice-covered waters. At this time, the prevailing state of knowledge about remote sensor performance is largely based upon field experience gained in temperate climate spills and experimental tests conducted utilizing intentional spills in various ice conditions. This existing body of knowledge is applied to provide the user with a tool to assess the potential performance of various types of sensors against representative oil in ice distributions commonly occurring in the Arctic. The sensors included are those commercially available at this time that have demonstrated performance in one or more of the oil in ice distributions. The sensors are grouped according to possible deployment platforms (e.g., ice surface, aircraft, vessels, etc.) since the availability of each platform will be a major determinant for the successful use of each remote sensing system." Pg. 5.

18. *Detection of Oil On-In-and -Under Ice (Pegau, et al. 2016)*

From the Executive Summary:
"Using the Beaufort Sea as a benchmark location, in a field environment almost all oil will be on the melting ice surface during the summer months, making below ice methods not applicable (N/A). On-ice activities are also N/A throughout these months due to safety considerations, leaving only airborne methods. Airborne radar systems will have difficulties in fall or spring when the ice is generally too warm and conductive. Provided there is sufficient light from above, under ice optical methods can detect oil under ice, in the interior of ice (when encapsulation thickness is relatively small compared to the oiled area), and on top of thin ice. FP is possible for oil on new and young ice (with minimal snow cover). IR should work with oil on top of the ice during the early part of the ice season as long as there is enough daylight to create detectable temperature differences (October and early November). IR utility should return in spring with increasing sunlight." Pg. 16.

19. *Detection and Quantification of Oil Under Sea-Ice: The View from Below (Wilkinson et al. 2015)*

Abstract:

Traditional measures for detecting oil spills in the open-ocean are both difficult to apply and less effective in ice-covered seas. In view of the increasing levels of commercial activity in the Arctic, there is a growing gap between the potential need to respond to an oil spill in Arctic ice-covered waters and the capability to do so. In particular, there is no robust operational capability to remotely locate oil spilt under or encapsulated within sea ice. To date, most research approaches the problem from on or above the sea ice, and thus they suffer from the need to 'see' through the ice and overlying snow. Here we present results from a large-scale tank experiment, which demonstrate the detection of oil beneath sea ice, and the quantification of the oil layer thickness is achievable through the combined use of an upward-looking camera and sonar deployed in the water column below a covering of sea ice. This approach using acoustic and visible measurements from below is simple and effective, and potentially transformative with respect to the operational response to oil spills in the Arctic marine environment. These results open up a new direction of research into oil detection in ice-covered seas, as well as describing a new and important role for underwater vehicles as platforms for oil-detecting sensors under Arctic sea ice.

20. *Development of a fluorescence polarization submersible instrument for the detection of submerged heavy oil spills (Bello, et al. 2012).*

Abstract:

Spills of Group V heavy oils are a concern because once spilled heavy oils will immediately sink to the bottom and can harm wetlands, beaches, and marine life. Recently, we developed a new tool-fluorescence polarization (FP) - for locating heavy oil deposits. The method relies on the observation that heavy, viscous oil fractions exhibit polarized fluorescence while the ubiquitous fluorescence background characteristic of chlorophyll and hemic compounds do not. The basic FP measurement entails exciting the fluorophore with polarized light and observing the intensities of the emission polarized perpendicular and parallel to it. Heavy, tarry oils containing higher molecular weight poly-nuclear aromatic hydrocarbons fractions exhibit strong FP. The development of a remotely operated, submersible FP instrument will be presented, as well as testing results of the instrument in a simulated spill set up by the US Coast Guard at the National Oil Spill Response Research and Renewable Energy Test Facility (OHMSETT). The FP instrument utilizes a laser (532 nm) to excite the oil matrix. A small refracting telescope with variable focus is employed as the front optics and used to focus the laser beam and to collect the polarized fluorescence from the sample at a standoff distance. An embedded computer resides inside and controls the various operations such as autofocusing of the telescope and data acquisition. The embedded computer also allows autonomous or remotely controlled operation. FP along with phase sensitive detection combines to provide excellent sunlight rejection, thus allowing the use of the instrument during daylight hours.

21. *Locating Oil Spills Under Sea Ice Using Ground-Penetrating Radar (Bradford, et al. 2008).*

Abstract:
The accelerating level of interest in arctic oil and gas exploration was demonstrated in the overwhelming response to recent lease sales in the Alaskan OCS region. As development increases, the potential for accidental oil spills in the arctic marine environment increases. The need for reliable systems to detect oil trapped in a range of ice conditions remains at the forefront of continued efforts to improve response to ocean spills.

22. *Assessing the Potential to Detect Oil Spills in and Under Snow Using Ground-Penetrating Radar (Bradford et al. 2010).*

Abstract:
With recent increased interest in oil and gas exploration and development in the Arctic comes increased potential for an accidental hydrocarbon release into the cryosphere, including within and at the base of snow. There is a critical need to develop effective and reliable methods for detecting such spills. Numerical modeling shows that ground-penetrating radar GPR is sensitive to the presence of oil in the snow pack over a broad range of snow densities and oil types. Oil spills from the surface drain through the snow by the mechanisms of unsaturated flow and form geometrically complex distributions that are controlled by snow stratigraphy. These complex distributions generate an irregular pattern of radar reflections that can be differentiated from natural snow stratigraphy, but in many cases, interpretation will not be straightforward. Oil located at the base of the snow tends to reduce the impedance contrast with the underlying ice or soil substrate resulting in anomalously low-amplitude radar re- flections. Results of a controlled field experiment using a helicopter-borne, 1000-MHz GPR system showed that a 2-cm-thick oil film trapped between snow and sea ice was detected based on a 51% decrease in reflection strength. This is the first reported test of GPR for the problem of oil detection in and under snow. Results indicate that GPR has the potential to become a robust tool that can substantially improve oil spill characterization and remediation.

23. *State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill (Leifer et al. 2012)*

Abstract:
The vast and persistent *Deepwater Horizon* (DWH) spill challenged response capabilities, which required accurate, quantitative oil assessment at synoptic and operational scales. Although experienced observers are a spill response's mainstay, few trained observers and confounding factors including weather, oil emulsification, and scene illumination geometry present challenges. DWH spill and impact monitoring was aided by extensive airborne and space borne passive and active remote sensing.

Oil slick thickness and oil-to-water emulsion ratios are key spill response parameters for containment/cleanup and were derived quantitatively for thick (> 0.1 mm) slicks from AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) data using a spectral library approach based on the shape and depth of near infrared spectral absorption features. MODIS (Moderate Resolution Imaging Spectroradiometer) satellite, visible-spectrum broadband data of surface-slick modulation of sun glint reflection allowed extrapolation to the total slick. A multispectral expert system used a neural network approach to provide Rapid Response thickness class maps.

Airborne and satellite synthetic aperture radar (SAR) provides synoptic data under all-sky conditions; however, SAR generally cannot discriminate thick (> 100 μm) oil slicks from thin sheens (to 0.1 μm). The UAVSAR's (Uninhabited Aerial Vehicle SAR) significantly greater signal-to-noise ratio and finer spatial resolution allowed successful pattern discrimination related to a combination of oil slick thickness, fractional surface coverage, and emulsification.

In situ burning and smoke plumes were studied with AVIRIS and corroborated space borne CALIPSO (Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation) observations of combustion aerosols. CALIPSO and bathymetry LIDAR data documented shallow subsurface oil, although ancillary data were required for confirmation.

Airborne hyperspectral, thermal infrared data have nighttime and overcast collection advantages and were collected as well as MODIS thermal data. However, interpretation challenges and a lack of Rapid Response Products prevented significant use. Rapid Response Products were key to response utilization—data needs are time critical; thus, a high technological readiness level is critical to operational use of remote sensing products. DWH's experience demonstrated that development and operationalization of new spill response remote sensing tools must precede the next major oil spill.

24. Detection of Oil Slicks using MODIS and SAR Imagery (Hu et al. 2006).

“Hu et al. (2003) used MODIS 250-m resolution data to detect and monitor oil spills in a turbid lake in Venezuela. After removing clouds, two images per week were obtained at no cost. The detection was possible because the high turbidity of the lake water provided a "bright" background where the highly light-absorbing oil films could be visualized. In the oligotrophic ocean, the water background is also dark, making oil detection difficult. However, Hu et al. (2009) showed that when MODIS imagery contained sun glint (i.e., specular reflection of the solar beam), high contrast was found between oil slicks and the background water. The contrast is not due to the difference in optical properties of the oil film and the water (as evidenced by the lack of contrast in other glint-free images), but due to the oil-modulation of the surface capillary waves - the same principle for SAR measurements. Indeed, the ability of visible imagery (including those from space shuttle photos) over sun glint regions to serve as effective radar signals was recognized decades ago and demonstrated recently using satellite imagery (Chust and Sagarminaga, 2007). However, its routine application has been difficult due to lack of near-daily data. The free availability of MODIS daily data for the global oceans makes it possible to implement a cost-effective means for oil spill monitoring." Page 22.

Response

25. North Slope Borough Science Advisory Committee Oil Spill Response Review (NSB SAC 2011)

The North Slope Borough Science Advisory Committee completed a review of oil spill response technology with respect to the removal of oil in offshore arctic areas in the presence of *transitional ice*, such as spring rotting fast ice, spring break-up broken ice, and fall freeze-up ice. This report provides a thorough background on previous research findings and current oil spill response abilities, but also includes specific recommendations for preparing for an Arctic oil spill in the near-shore Beaufort Sea in spring and fall ice conditions.

Though oil spill response tactics have been tested and refined to operate under conditions of transitional ice, there is room for expansion of these tests to include all possible permutations of ice, weather, and spill conditions. In addition to the knowledge gaps and room for further testing, this report also outlines the necessity of a vast increase in port infrastructure, including the addition of icebreakers, ice class tugs and barges, oleophilic brush skimmers, boom upgrades, and the replacement of Exxon Valdez Oil Spill equipment.

Though research has shown promising results in the use of dispersants as well as herding agents, insufficient human health, biologic, and toxicological data is currently available to ensure the safety of using these agents. Therefore, the SAC recommends that these agents should not be used in the near-shore Beaufort Sea. Rather, since herding agents may be very helpful for the improvement of in-situ burning practices, further research should be explored in order to better understand how these agents might affect the environment. In-situ burn practices are currently the best way responders can remove oil from the water—especially under transitional ice conditions—therefore these practices need to be improved in their efficiency and effectiveness.

26. Oil Spill Response Mechanical Recovery Systems for Ice-Infested Waters: Examination of Technologies for the Alaska Beaufort Sea (Nuka 2007)

State regulations require that the Alaska Department of Environmental Conservation regularly "review and appraise technology applied at other locations in the United States and the world that represent alternatives to the technologies used by plan holders in their oil discharge prevention and contingency plans". Therefore, this review, prepared by Nuka Research and Planning Group examines a wide variety of mechanical systems designed to recover oil spilled in water, and analyzes their appropriateness and reliability for the conditions of the Alaska Beaufort Sea.

In analysis of arctic skimmer technology, this report suggests testing ice-capable skimmers not currently stockpiled in Alaska to be tested in the Beaufort Sea, most specifically the Lamor LRB. Further, UCSB is developing novel skimmer surface concept, and therefore the report suggests close attention as this work develops as it may enhance oil recovery by as much as 50% and may allow responders to tailor the skimmer surface to the presence of sea ice. Though ice-processing technologies have been developed and tested, none has yet been used in the Beaufort Sea. The report strongly suggests testing one or more ice processing in the Beaufort, but warns that they may not be appropriate for shallow areas due to their dependence on large vessels for deployment. The report also strongly recommends the practice and testing of ice management techniques in the Beaufort Sea. Such practices could expand the operating window for oil recovery under higher ice concentrations.

The authors conclude, after extensive review of oil spill response, that the emphasis among researchers is on non-mechanical recovery, and therefore agencies such as ADEC that favor mechanical recovery must continue to expand research and advocate for the development of new technologies. Further, since conditions are highly variable in ice-cover and weather, a wide variety of mechanical recovery technology will best prepare for an oil spill in the Beaufort Sea.

27. *Scale-up Considerations for Surface Collecting Agent Assisted in-situ Burn Crude Oil Spill Response Experiments in the Arctic: Laboratory to Field-Scale Investigations (UAF, Bullock 2017).*

In-situ burning has been identified as a possible response to rapidly controlling oil when spilled in icy waters. Surface collecting agents ("herders") have also been tested in order to collect oil and aid in-situ burning. Little is known about the efficacy and net environmental benefit of these techniques, and how they will benefit the environment in comparison with other response techniques. Therefore, researchers tested herder formulations with different oil types and conditions to address these knowledge gaps and gain an understanding of their efficacy in oil spill response. They used a multi-scale approach to address how scalable these approaches and results can be.

This experiment was extremely effective under the conditions of the Arctic North Slope crude oil in cold fresh waters with ~10% ice cover. The three different scales analyzed showed a very strong experimental scale correlation, and found no negative impact of ice cover on burn efficacy. The authors conclude that herding agents to thicken oil followed quickly by ignition can allow oil spill responders to quickly and successfully remove oil from the water, even under icy conditions.

28. *Aerial Application of Herding Agents to Advance In-Situ Burning for Oil Spill Response in the Arctic: A Pilot Study (University of Alaska Fairbanks, Aggarwhal 2017).*

In-situ burning (ISB) has performed very strongly in the removal of oil from water. This has been an accepted response strategy for decades, though it requires mechanical collection of oil in order to achieve a minimum oil thickness of >2 mm in order for in-situ burning to work. In the Arctic, this strategy becomes a challenge, where ice and weather can prevent the mechanical booms from maneuvering, or even being deployed at all. Furthermore, there is significant risk associated with weather, temperatures, ice, and darkness of the Arctic, and deploying personnel can be too dangerous. These authors conducted a field-scale study to understand the efficacy of an aerial ISB operation. This option, if effective, could increase response time, maximize safety of personnel, and would be possible in the presence of sea ice.

The field-scale aerially operated burn tests yielded a burn efficiency ranging from 59% to 94% for the gravimetric approach, and 73% to 84% for the conservative aerial imagery approaches. These are promising results, and establish the efficacy of aerially applied herders for in-situ burning. This efficacy in the presence of ~10% ice also establishes that this is a practice that can aid in the event of an Arctic oil spill. The authors conclude with the suggestion of using helicopters as well as UAVs (unmanned aerial vehicles), as well as the suggestion of redundancy of herder application, ignition systems, and video collection in order to increase the probability of successful ISB.

29. *Testing and evaluating low altitude unmanned aircraft system technology for maritime domain awareness and oil spill response in the Arctic (NOAA, Jacobs 2015).*

This article provides context for the use of unmanned aircrafts in the event of an oil spill in the Arctic, and may be quite helpful in the process of weighing options during IoNS. The Puma was the UAS tested in the Arctic for this publication, and would assist particularly in the event of an oil spill through its surveillance capabilities. The use of a UAS like the Puma in an oil spill could support operations and decision making in real-time.

Furthermore, the article offers operational assessments of the Puma under the harsh conditions of the Arctic and includes suggestions for improvements that may be helpful. Such suggestions include expanding the UAS flight envelopes for high wind and icing, improving platform recovery processes, and maximize data gathering for flying over international waters. These suggestions may provide fodder for future research questions and areas of interest to the IoNS workshop in order to improve operations support in the event of an Arctic oil spill.

30. State-of-the-science of dispersants and dispersed oil (DDO) in U.S. Arctic Waters (Kinner et al. 2017)

From the Introduction:
"Chemical dispersants were employed on an unprecedented scale during the Deepwater Horizon oil spill in the Gulf of Mexico, and could be a response option should a large spill occur in Arctic waters. The use of dispersants in response to that spill raised concerns regarding the need for chemical dispersants, the fate of the oil and dispersants, and their potential impacts on human health and the environment. Concerns remain that would be more evident in the Arctic, where the remoteness and harsh environmental conditions would make a response to any oil spill very difficult. An outcome of a 2013 Arctic oil spill exercise for senior federal agency leadership identified the need for an evaluation of the state-of-the-science of dispersants and dispersed oil (DDO), and a clear delineation of the associated uncertainties that remain, particularly as they apply to Arctic waters.

The National Oceanic and Atmospheric Administration (NOAA), in partnership with the Coastal Response Research Center (CRRC), and in consultation with the U.S. Environmental Protection Agency (EPA) embarked on a project to seek expert review and evaluation of the state-of-the- science and the uncertainties involving DDO. The project focused on five areas and how they might be affected by Arctic conditions: dispersant effectiveness, distribution and fate, transport and chemical behavior, environmental impacts, and public health and safety. "

31. Short state-of-the-art report on oil spills in ice-infested waters (SINTEF Materials and Chemistry, SINTEF 2006).

Oil spilled in icy water can severely complicate clean-up efforts. Oil ice interactions can have a number of different outcomes, depending on the ice cover, type of oil spill, drift, time of year, etc. For example, oil can be absorbed into snow, melt into brine channels in the spring and become encapsulated in the ice, become pumped underneath the ice wherein it pools, drift with the current independent of the ice, become trapped in ice rubble, or pool to create fissures through multi-year ice.

The current responses to oil spill are mechanical recovery, in-situ burning, and dispersal. Mechanical recovery is an appropriate response strategy in seasons of the Arctic in which ice is not present. In icy water, however access to the oil becomes extremely limited, and the maneuverability of the machines becomes compromised. Some winterization strategies of mechanical skimmers were tested in the 1970s and 1980s, and, in 1992, a review of oil-in-ice recovery was published by the Canadian Petroleum Association. In this publication, the authors evaluated the potential of seven oil removal principles. The principles with high development potential for oil removal on ice were rope skimmers and combination skimmers. The MORICE (Mechanical Oil Recovery in Ice-infested Waters) project was initiated in 1995 and finalized in 2002, which developed a recovery unity that separates oil from ice with a heated enclosure. On a small scale, this unit showed promise, but would need to be scaled up for a larger spill in offshore conditions.

Dispersants, though effective in emulsification of oil slicks in other parts of the world, vary in their efficacy based on a wide variety of factors such as seawater temperature, seawater salinity, and oil weathering. Due to this variability, dispersants may have limited application in oil spills in icy waters.

Lastly, in-situ burning can be particularly suited for the removal of oil from the surface of sea ice. Oil slicks in the water require mechanical herding in order to achieve a minimum thickness for burning, however herding surface agents show promise into a new means of in-situ burning.

32. *Crude oil spills in the environment, effects and some innovative cleanup biotechnologies (University of Nigeria, Onwurah et al. 2007)*

This article reviews innovative cleanup biotechnologies and addresses potential areas of further research and development. Biodegradation is one of the primary mechanisms of ultimate removal of oil from the environment. The natural process of microbe biodegradation could possibly be accelerated by seeding contaminated areas with bacteria adapted to a high percentage of petroleum hydrocarbons. The success of using these microbes would depend on their ability to compete with the native microbial population, and their ability to adapt to or tolerate the physic-chemical environment. Another method of accelerated biodegradation is with "super bugs", or microorganisms that are genetically engineered to degrade oil. Though these biotechnologies have very promising results in trials, the concept of seeding an area with non-native microbial communities requires rigorous research and understanding of the after-effects on the entire ecosystem.

33. *Isolation and degradation potential of a cold-adapted oil/PAH degrading marine bacterial consortium from Kongsfjorden (Crisafi et al. 2016)*

In the aftermath of an oil spill, one form of bioremediation involves seeding the polluted area with hydrocarbons-degrading bacteria. The success of such a bioremediation process hinges on the microbial communities' tolerance for the new physico-chemical environment. Specifically, temperature is one of the most important factors that can determine the success of such a bioremediation strategy. Thus, the authors of this article examined the success of isolating a cold adapted oil degrading marine bacterial consortium. By collecting bacterial samples from the area in front of Kronebreen glacier in Svalbard, the bacterial communities were assuredly cold adapted. The samples were immediately inoculated in growth medium supplemented with oil in order to stimulate hydrocarbons degradation potential. The authors tested hydrocarbons degradation at 4°C and 15°C and detected almost 80% total percentage hydrocarbon degradation at 4°C and 90% TPH at 15°C. These findings confirm the potential of bioremediation in the Arctic, though authors urge further research and development to understand the genetic and physiological features of the strains studied to expand their application.

34. *Environmental Security in Arctic Ice-Covered Seas: From Strategy to Tactics of Hazard Identification and Emergency Response (Eicken et al. 2011).*

Abstract:
Environmental change and increasing industrial activity in the maritime Arctic require strategies to adapt to change and ensure safe operations. This problem has been defined at the broader strategic level. We evaluate key aspects of environmental security in ice-covered waters, focusing on tactical and operational information needs, which have received less attention. Monitoring of environmental hazards and effective emergency response in sea-ice environments require high-resolution data of ice hazard distributions (e.g., multiyear ice, landfast ice break-out and ice push events), ice movement and deformation as well as ice characteristics and dynamics relevant to emergency response. We have developed a prototype coastal observing system at Barrow, Alaska that addresses such information needs. Local experts combine imagery obtained from a marine X-band radar with a digital controller with data from on-ice sensors (ice thickness, ice and water temperature, sea level) and assessments of potentially hazardous ice conditions. Digital imagery and data are processed and disseminated in near-real time. Using a combination of image processing approaches (optical flow, Lucas-Kanade tracker), ice velocity fields, floe trajectories and boundaries of stationary ice are derived automatically. Early onset of hazardous events is detected through Hidden Markov Modeling, providing potential decision-support in operational settings. We evaluate the utility of the system and strategies towards integration with broader emergency response efforts.

35. *Spill Response in the Arctic Offshore (Potter et al. 2012).*

Abstract:
As attention turns to the Arctic as an important source of oil and natural gas, the industry is taking proactive steps to develop modern tools and technology to ensure effective solutions are available to handle a potential spill. The region presents unique challenges and it is important to continue to establish best practices for exploration and production. Responding to an oil spill is challenging under any circumstance, but arctic conditions require additional environmental considerations. This series of fact sheets discusses the challenges posed by handling a spill in arctic conditions and the technologies being developed to respond to such an event. In some cases, techniques have been modified from standard response techniques for marine conditions based on years of research. Others have been recently developed.

Oil and Sea Ice

36. *Oil Entrainment and Migration in Laboratory-Grown Saltwater Ice (Karlsson et al. 2011).*

Abstract:
With increased interest in economic development of Arctic resources and waterways, understanding the fate of oil spills in the presence of sea ice becomes crucial for successful spill response and remediation efforts. The authors performed a series of laboratory experiments to analyze the entrainment and upward migration of oil (Alaska North Slope Crude and synthetic oil) through sea ice as a critical process constraining the timing and strategy of response to oil spills in ice. It was found that oil is entrained into the pore network of growing sea ice and confined to the region near the growing interface where the porosity is above 8 to 15%. This assessment of a minimum entrainment and migration porosity provides a bound on the movement of oil through the microscopic pore network of sea ice. The volume of ice that oil can permeate this way depends on the porosity profile of the ice, which is a function of the temperature profile and bulk salinity profile. Based on these laboratory measurements and consistent observations from past experiments, the authors hypothesize that stratified oil entrainment takes place if the porosity exceeds a threshold. In addition, oil is able to entrain narrow channels (<2 mm diameter) near the ice–water interface. While the contribution of channel entrainment to the total oil content of the ice is very small, oil in channels appears to be important during the melt season.

37. *2006 Svalbard Experimental Spill to Study Spill Detection and Oil Behavior in Ice (US Dept. of the Interior 2006).*

Summary:
This project encompassed three research areas related to improving the level of understanding of and response to accidental spills in ice:
1. Remote sensing: detection and mapping of oil under ice;
2. Oil in ice, fate and behavior; and
3. In-situ burning evaluation.

The experiment was designed around the concept of a controlled oil release under ice with sufficient surface area, volume and film thickness to permit measurements at a realistic field scale. A volume of 3,400 liters of Statfjord crude oil was successfully released on schedule, and fully contained within a skirt inserted through the ice. Divers measured the oil film thickness distribution under the ice using a specially developed probe. Monitoring of the oil under the ice was achieved with a combination of divers and through-the-ice video cameras. The spill was effectively removed through in-situ burning on the ice. The following summary highlights key results, conclusions and recommendations within each of the three research areas.

38. Behavior of spilled oil—Current practice/operational and technology constraints and opportunities (National Petroleum Council (NPC 2015))

This article contains a section wherein the authors describe how oil interacts with ice, and the possible configurations of oil in, on, and under ice. To quickly summarize (see pages 3-6 for more detail), oil trapped underneath ice will usually be contained until spring melt due to the rough underside of sea ice. Oil can travel up natural brine channels in sea ice, and depending on the thickness of the sea ice, may migrate all the way to the surface of the ice, or through the bottom 10—20 cm of ice. In the spring, as the ice melts, this vertical migration accelerates and causes oil to pool on the ice surface, making it more available to spill responders.

When oil interacts with snow, it is absorbed and combined which can keep the oil from spreading, and is easily managed by shoveling, but cannot be burned. When oil is trapped in ice leads and fissures, it can be contained, depending on the amount of ice cover. In other words, the degree of containment will increase as the amount of ice cover grows. Oil spilled on or under ice will move with the ice drift, and currents must be greater than 0.3 knots in order to move oil under ice that is not moving.

In open ice conditions, oil and ice can move at different rates and directions due to contrasting wind and currents. Multi-year ice is more capable of storing and containing oil than first-year ice, and has fewer brine channels for vertical migration.

39. Inter-annual variability and long-term changes of atmospheric circulation over the Chukchi and Beaufort Seas (Journal of Climate, Wu et al. 2014)

This publication provides background on the Beaufort gyre, sea ice, and atmospheric circulation over the Chukchi and Beaufort Seas.

Abstract:
The Beaufort Sea high (BSH) plays an important role in forcing Arctic sea ice and the Beaufort Gyre. This study examines the variability and long-term trends of atmospheric circulation over the Chukchi and Beaufort Seas using the ECMWF Interim Re-Analysis (ERA-Interim) for the period 1979-2012. Because of the mobility of the BSH through the year, EOF analysis is applied to the sea level pressure (SLP) field in order to investigate the principal patterns of BSH variability. In each season, the three leading EOF modes explain nearly 90% of the total variance and reflect a strengthened or weakened BSH centered over the western Arctic Ocean (EOF1), a north-south dipole-like SLP anomaly (EOF2), and a west-east dipole-like SLP anomaly (EOF3), respectively. These three EOF modes offer distinct influences on local climate in each season and have different connections with the large-scale climate variability modes in winter. In particular, the second principal component (PC2) associated with EOF2 in the autumn exhibits a tendency toward high-index polarity significant at the 5% level, and is related to strongly reduced sea ice extent. Further, the authors have detected significant anticyclone trends among

surface wind fields associated with a strengthened BSH during summer and autumn, but significant cyclonic trends associated with a weakened BSH during early midwinter, consistent with significant trends in SLP gradients between western Arctic Ocean and the adjoining landmass. Comparison with forced trends of surface winds from various simulations from the IPCC Fifth Assessment Report (AR5) indicates that summertime changes in atmospheric circulation cannot be explained by natural external forcing or lower boundary forcing and may instead be attributable to external anthropogenic forcing.

40. *Estimating Arctic sea-ice freeze-up and break-up from the satellite record: A comparison of different approaches in the Chukchi and Beaufort Seas (Johnson and Eicken 2016).*

Abstract:
The recognized importance of the annual cycle of sea ice in the Arctic to heat budgets, human behavior, and ecosystem functions, requires consistent definitions of such key events in the ice cycle as break-up and freeze-up. An internally consistent and reproducible approach to characterize the timing of these events in the annual sea-ice cycle is described. An algorithm was developed to calculate the start and end dates of freeze-up and break-up and applied to time series of satellite-derived sea-ice concentration from 1979 to 2013. Our approach builds from discussions with sea-ice experts having experience observing and working on the sea ice in the Bering, Chukchi and Beaufort Seas. Applying the algorithm to the 1979–2013 satellite data reveals that freeze-up is delayed by two weeks per decade for the Chukchi coast and one week per decade for the Beaufort coast. For both regions, break-up start is arriving earlier by 5–7 days per decade and break-up end is arriving earlier by 10–12 days per decade. In the Chukchi Sea, “early” break-up is arriving earlier by one month over the 34-year period and alternates with a “late” break-up. The calculated freeze-up and break-up dates provide information helpful to understanding the dynamics of the annual sea-ice cycle and identifying the drivers that modify this cycle. The algorithm presented here, and potential refinements, can help guide future work on changes in the seasonal cycle of sea ice. The sea-ice phenology of freeze-up and break-up that results from our approach is consistent with observations of sea-ice use. It may be applied to advancing our understanding and prediction of the timing of seasonal navigation, availability of ice as a biological habitat, and assessment of numerical models.

41. *Assessing trend and variation of Arctic sea-ice extent during 1979-2012 from a latitude perspective of ice edge (Xia et al. 2014).*

In this article, the extent of summer sea ice is observed in the Arctic. Sea ice covers vast portions of the Arctic Ocean and the trend of diminishing sea ice is evaluated from the years 1979-2012. Using data from the National Snow and Ice Data Center, the authors examine the latitudinal ice extent. The most evident decline is in the Chukchi Sea from August to October.

Incidence Reports

42. 1942 (Campbell et al. 1977)

In the eastern US coastal area, torpedoed tankers released 484,200 tons of oil.

43. 1967 (Green & Cooper 2015)

In Scilly Isles, UK, the supertanker The Torrey Canyon, originally built to carry 60,000 and enlarged to carry 120,000 tons hit a reef, spilling 25-36 million gallons.

44. 1972 (Shriadah 1998)

In the Gulf of Oman, South Korean supertanker, Sea Star and Brazilian tanker, the Horta Barbosa, collided, spilling 35.3 million gallons.

45. 1974 (Wang et al. 2001)

In Chile, the supertanker Metula released roughly 47,000 tons of light crude oil and over 3,000 tons of heavy crude oil into the ocean, which washed on the shores of Tierra del Fuego.

46. 1976 (Gundlach et al. 1978)

In Spain, the tanker Urquiola struck a submerged object and began to release cargo from the bow as it approached La Coruña. As the vessel attempted to leave the harbor due to the threat of explosion and endangering the town, it grounded again and further ruptured bow tanks. After two hours, the vessel exploded. An estimated 200,000 barrels of oil polluted the Spanish coast.

47. 1978 (Mille et al. 1998)

In France the tanker Amoco Cadiz grounded onto the North Brittany Coast, releasing 223,000 tons of crude oil. Within about two weeks, nearly the entire cargo load had been released into the marine environment.

48. 1979 (Kodemir et al. 2007)

In Trinidad and Tobago/Barbados the tanker Atlantic Empress released 276,000 tons of oil.

49. 1989 (Exxon Valdez Oil Spill Trustee Council, 1994)

In Prince William Sound, Alaska, the tanker Exxon Valdez released 41,639 m^3 of crude oil into the Prince William Sound and the Gulf of Alaska.

50. 1991 (Bolognesi et al. 2006)

In Genoa, Italy, oil tanker Haven exploded and sank, spilling 45 million gallons into the Mediterranean.

Logistical and Medical Considerations

51. Responding to Oil Spills in the U.S. Arctic Marine Environment (Ocean Studies Board 2014)

Abstract:
The risk of a serious oil spill in the arctic is escalating due to potential increases in shipping traffic and oil and gas activities. To provide an effective response effort in challenging Arctic conditions--and minimize impacts on people and sensitive ecosystems--a full range of oil spill response technologies is needed. This report assesses the current state of science and engineering regarding oil spill response in Arctic waters and identifies key oil spill research priorities, critical data and monitoring needs, mitigation strategies, and important operational and logistical issues.

52. Field guide for Oil Spill Response Strategies in the Arctic (Arctic Council, EPPR 2017).

The Emergency Prevention, Preparedness and Response (EPPR) is a working group of the Arctic Council. In 2017, they published the second edition of the Field Guide for Oil Response in Arctic Waters (first edition published in 1998). This guide is designed to aid in the decision process and the selection of response strategies that are practical and appropriate in the event of an Arctic oil spill. The field guide provides specific response strategies that are tailored to a vast variety of conditions of an oil spill in the Arctic region.

This is an incredibly comprehensive guide that specifies when it is appropriate to use herding agents, dispersants, in situ burning, and mechanical recovery, based on the season, ice conditions, weather, and a variety of other factors. This tool will be helpful in designing a real-time response strategy for an oil spill simulation such as that in IoNS 2017.

53. Guide to Oil Spill Response in Snow and Ice Conditions in the Arctic (Arctic Council, EPPR 2015).

Another publication from the Emergency Prevention, Preparedness and Response working group of the Arctic Council that presents a plan for preparing for an oil spill incident in the Arctic as well as response strategies. This guide does not consider response strategies to deal with Arctic oil spills in summer open water conditions, as it is specific to snow and ice conditions. As we prepare for the event of an oil spill in the Arctic, we need to have a process for weighing environmental trade-offs that is thorough, streamlined, and rigorously backed by scientific data. Such preparedness will maximize the use of limited time windows following a spill event.

Certain challenges specific to significant ice concentrations are as follows: ice can limit the effectiveness of mechanical containment and recovery; ice can limit and challenge the detection of oil; maritime response strategies may be useless under icy conditions. Risk associated with darkness and temperatures of the Arctic must also be taken into account and frequently assessed in order to prioritize the safety of personnel above all else. At the same time, the presence of ice can augment the window of time available for burning and dispersant application, by essentially preserving oil.

54. *Preventing Morbidity and Mortality among Arctic Oil Spill Response Workers (EPPR 2012)*

This is a presentation for the EPPR, presented by Dr. George A. Conway, MD from the National Institute for Occupational Safety and Health U.S. Centers for Disease Control and Prevention and outlines the specific concerns of oil spill response workers in the Arctic. These concerns include: performance of respiratory protective and other gear in very cold conditions; and informing response workers naïve to working in Arctic conditions of hazards such as frostbite and hypothermia, how to manage these hazards, and assuring adequate preparation. This presentation serves to develop adequate training protocol and equipment preparation for the responders to an Arctic oil spill.

55. *Occupational safety and health of arctic disaster and oil spill response workers (Int J Circumpolar Health, Conway et al. 2013).*

Abstract:
There is currently very little in the scientific literature on the topic of worker safety and health in oil spill response in the Arctic, other ice-covered waters, and in very cold surface environments. Instead, issues of detection, mechanical recovery, and the in-situ burning of oil products are the main areas of emphasis in Arctic oil spill response research. Therefore, the purpose of this project, approved by EPPR in Oslo, October 21, 2011, is to conduct research, develop guidelines, and recommend effective measures to prevent morbidity and mortality among oil spill response workers in the Arctic environment. This project will conduct research on oil spill response operations to identify the hazards that oil spill response workers may encounter, suggest strategies to either control or eliminate those hazards, and provide information to public health responders deployed to protect oil spill response workers. This international, collaborative project is intended to improve regional operational capabilities to protect Arctic oil spill response workers by

providing information to enhance safety and health practices during an oil spill response. The information developed during this project will include preparedness tools that will assist governments and agencies in identifying and controlling hazards that may be encountered by workers responding to an oil spill in the Arctic. The primary output, intended as a supplement to the Arctic Council's ''Field Guide for Oil Spill Response in Arctic Waters'', and other EPPR preparedness and response products, will represent a significant contribution to the understanding and control of the unique hazards that exist to workers responding to an oil spill in the Arctic. The information will serve to guide operational planning and response by the indigenous peoples of the Arctic and the eight member nations of the Arctic Council.

Ecological Impact

56. *Marine mammal distribution and abundance in the Northeastern Chukchi Sea, July-October 2008-2010 (Chukchi Sea Environmental Study Program (CSESP 2010)).*

In the summer seasons of 2008, 2009, and 2010, a group of marine mammal observers and Inupiat communicators conducted observation cruises along transects in the Chukchi sea in order to gain a better understanding of the ecological communities found within these areas of offshore drilling interest. These observers sighted pinnipeds the most frequently, while whale sightings were rarer. Ringed seals, spotted seals, bearded seals, walruses, and bowhead whales were the most common observed marine mammal species observed. This baseline data provides background information on marine mammal species to be considered in the event of an Arctic oil spill. See Table 2 on page 21 for Species Composition and Number.

57. Bowhead and gray whale distributions, sighting rates, and habitat associations in the Eastern Chukchi Sea, Summer and Fall 2009-15, with a retrospective comparison to 1982-91 (Arctic, Clarke 2016)

Line-transect aerial surveys conducted in the eastern Chukchi Sea provided observations to gain an understanding of bowhead and gray whale distributions and habitat associations in the late summer and fall of 2009-2015. Bowhead and gray whales were sighted July-October, in all observation months. Observations show that Bowhead whales use the eastern Chukchi Sea for migrating between the Bering and Beaufort Seas, having the highest sighting rates in shelf/trough depth zones.

Observations indicate gray whales use the eastern Chukchi Sea to feed on benthic amphipods, and prefer to select coastal habitats in the summer and shelf/trough depth zones in the fall (September and October).

58. Environmental impacts of shipping in 2030 with a particular focus on the Arctic region (Dalsøren, S. B. 2013)

As the sea ice in the Arctic region continues to deplete, there will be an increase in ship traffic. Unless restrictive measures are placed on shipping regulations, an increase in emissions is expected. Emissions are changed due a concentration difference of short-lived pollutants such as NOx, SOx, CO, NMVOCs, BC and OC. In this study, researchers compared the High and Low scenarios for 2030 models to investigate the potential changes in pollution levels due to the increase in Arctic traffic.

Emissions in the Arctic will see a primary increase during the spring and summer months where there is less ice coverage.
Increases in emissions will not only negatively affect the health of those exposed, but also speed up the melting process of the Arctic. As the melting increases, the production of methane that is trapped within the ice will also increase. According to the study, NO2 changes will be directly found on the shipping paths with an increase from 10% to 60% in Coastal Regions and as much as a 200% increase in the pristine regions of the Arctic. In surface ozone, production there is a projected 10%+ increase in the Arctic Oceans. Sulfate levels could increase upwards of 50% in the Arctic Region in the months of operation. If these rates increase as projected, the Arctic may be a candidate as an Emission Control area, especially related to the extreme increase of NOx.

Additional Readings

59. *New trans-Arctic shipping routes navigable by midcentury (Smith 2013).*

Trends in diminishing Arctic sea-ice extent predict even greater declines in the coming years. With declining sea-ice, access to this region increases for shipping routes and therefore ship navigation in the Arctic becomes a topic of great importance. At this point, little is known about how the projected changes in sea-ice will affect the viability of ship navigation. Therefore, the authors of this publication applied numerical transportation analysis to projected sea ice thickness and concentration datasets. The authors conclude that the Northwest Passage has the lowest historical navigation potential, but will become much more navigable by 2040. A great number of factors may limit Arctic shipping; however, the authors predict greatly increased access and navigability in the next few decades.

60. *Regional atmospheric patterns and the delayed sea-ice freeze-up in the western Arctic (Kent State University, Ballinger 2015).*

Abstract:

The western Arctic sea ice cover has dramatically changed since the late 1970s, particularly the timing of the autumn freeze-up. While atmospheric dynamic and thermody- namic processes associated with synoptic-scale weather patterns largely impact the onset of regional ice formation, linkages between the sub seasonal occurrences of these patterns, across inter-annual to multidecadal time scales, and the freeze-up are not well understood. This manuscript takes a synoptic climatological atmospheric pattern (AP) classification approach to evaluate the role of warm season-dominant (i.e., May-October) mean sea-level pressure (MSLP) and 1000–500 hPa thickness APs, derived from daily NCEP/NCAR reanalysis fields, on the passive microwave-derived freeze-up dates for the marginal Beaufort/Chukchi Seas and western Arctic Ocean from 1979 to 2013. Analysis of the respective classifications' frequencies and their relationships to the freeze-up reveals that approximately one-third of freeze-up variance may be explained by early/middle warm season Beaufort Sea High surface pressure pattern frequency changes. A similar amount of freeze-up variance is explained by the occurrence of mid-warm season dominant thermal patterns, either earlier or later than their predominant season. Both results suggest that pattern changes may be associated with changing ocean–atmosphere heat exchanges affiliated with lengthened periods of melt conditions.

61. *Constructing Arctic Security: an inter disciplinary approach to understanding the Barents region (Hossain et al. 2017).*

Abstract:
The field of Security Studies traditionally focused on military threats to states' survival, however, since the end of the Cold War the concept of security has widened and individuals and communities have gradually become viewed as appropriate referent objects of security: Multifaceted challenges facing communities at the sub-state level are increasingly regarded as security threats, including their potential to cause instability for the larger society, thus affecting states' security. In the Arctic region, a central challenge is that inhabitants are exposed to multiple non-traditional and non-military threats resulting from environmental, economic, and societal changes, which can be understood as threats to human security. We argue that a comprehensive approach to human security overlaps with the concept of societal security, and must therefore consider threats to collective identity and the essential conditions necessary for the maintenance and preservation of a distinct society. We see the human security framework as a suitable analytical tool to study the specific challenges that threaten the Arctic population, and in turn the well-being of Arctic societies. Therefore, we argue that utilizing the concept of human security can promote societal security in the context of the Arctic, and in particular, its sub-regions, for example, the Barents region.

62. *Will the United States Be Able to Respond to an Arctic Disaster? (Texas A&M University at Galveston n.d.)*

Between March and September of 2012, 4.57 million square miles of arctic sea ice melted. Under this melted ice, USGS estimates 13% of the world's undiscovered oil and 30% undiscovered gas is located. Issues arctic nations are facing include national sovereignty, commercial shipping, oil and gas exploration, endangered species and military operations as well as an increase in Arctic traffic and activity. In 2013, Mileski and Honeycutt published the Arctic Disaster Response Framework, which is dependent on three dimensions of response; nature of disaster, nature of responder, and nature of recipient. The nature of disaster includes the dimension of casualties and ecological impact such as in the case of an oil spill. The responder will usually be the US Coast Guard, which has the ability to deploy cutters, aircrafts and boats from the headquarters in Kodiak. Assisting responders may include the Army, having cold weather training and an aviation presence, Air Force, having a Polar System of high frequency military satellite communications about 65° N and aviation presence, and the Marine corps who are trained in arctic operations but have no operations out of Alaska. The Navy does not have ice hardened vessels or training in arctic operations. The US has two icebreakers, one heavy and one medium. It is estimated that with the increase in Arctic traffic there will need to be a minimum of six heavy and four medium icebreakers.

63. *National Roundtable on Arctic Emergency Preparedness: Report of Proceedings (Emergency Preparedness Roundtables n.d.)*

This is a report that goes over the outcomes of the regional roundtables held in each of Canada's three territories in the fall of 2013 with regard to Canada's preparedness in the Arctic. The themes of the discussions are as follows: the flexibility of northern communities need to be recognized, the local needs and abilities for emergency management should be stressed instead of concentrating on visitors to the region, the frequency of emergencies in increasing, the ability to respond to these incidents has not matched the increase in the incidents, and each territory has their own approach to emergency management. It is believed that the Northern residents are often overlooked in these situations and it had come to the attention of this forum to focus the discussion on them. Although you can never be one hundred percent prepared, the council turned the discussion towards how to increase the North's preparedness if an incident were to arise. The outcome of this roundtable was to reinstate the Joint Emergency Preparedness Program to full capacity. This program helps train and encourage skill development throughout communities about, emergency response.

64. *A root cause analysis for Arctic Marine accidents from 1993 to 2011 (Kum, S., & Sahin, B. 2015).*

Abstract:
The aim of this paper is to investigate the marine accidents/incidents, which are recorded by Marine Accident Investigation Branch (MAIB) as occurring north of 66°33′ in the years from 1993 to 2011 to reveal their causes by using root cause

analysis. Due to the global warming, increase of ice melt in North Pole is expected in the future. In the further years, number of vessels and shipping traffic will dramatically increase in the Arctic region. Thus, navigation will become more difficult in the Arctic Region. Consequently, to guide the vessels navigating in this region, an analysis of the previous marine accidents/incidents occurring in the Arctic region is required to improve the safety. Therefore, Root Cause Analysis (RCA) is proposed to clarify the causes and prevent the future incidents from happening. As an empirical study, fault trees of collision and grounding for the Arctic Region is constructed. Fuzzy Fault Tree Analysis (FFTA) is applied to this problem in order to propose a recommendation to reduce the occurrence probabilities. Risk levels of each factors determined by expert consultations. In this study, Accident to Person is found as the most observed incident. Negligence/careless of injured person has the highest priority for root causes of marine accidents. In order to combat this phenomenon, scientific results of this study can open up a dialog between lawmakers and shipping companies those aim to decline incidents. Furthermore, it is assumed to contribute representatives developing crew training manuals and competence requirements as well as opening Arctic navigation training centers.

65. Shared situational awareness in emergency management mitigation and response (Harrald, J., & Jefferson, T. 2007).

Abstract:
The US is replacing its historical federalist concept of emergency management where primary responsibility resides with state and local governments and their emergency management and first responder resources for coordinating emergency response and recovery, supported by the resources federal government (coordinated by FEMA) with a homeland security national response system where response to events is controlled by DHS using a military command and control model. This model assumes that those controlling and coordinating the response and recovery would attain and maintain an accurate, shared common operating picture and situational awareness. The objective of this paper is to discuss why the transfer of this concept from its safety and combat origins to the complex, heterogeneous emergency management structure of the United States would be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness would be easily achieved, are doomed to failure.

66. *Supporting Critical Multi-Organization Collaboration during Response to Catastrophic Events (Harrald, J. R., & Jefferson, T. I. 2007).*

Abstract:
The past two years have shown both the power of nature and the complexity of preparing for and responding to extreme events such as earthquakes, tsunamis, hurricanes/typhoons, and floods. These events, and future catastrophic events, will require coordination and collaboration between multiple government and non-

government organizations across national and state borders. This collaboration will require the discipline necessary to share common processes and procedures, and the agility to improvise plans and actions as situationally required. Information technology must be used to create an “eRegion”, enabling the shared situational assessments and adequately supporting the collaborative, distributed decision making to produce required decisions and future action plans. The role of information technology in developing these capabilities is discussed in the context of two seismic scenarios, the US New Madrid Seismic Zone, and the Adriatic Seismic region.

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