



**ARCTIC DOMAIN
AWARENESS CENTER**
A DEPARTMENT OF HOMELAND SECURITY CENTER OF EXCELLENCE

Arctic Domain Awareness Center (ADAC)

A DHS Science and Technology Office of University Programs,

Center for Maritime Research

Hosted by the University of Alaska

ADAC Current Programing Summary



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Figure 1 ADAC Photo, Pt Barrow Alaska, June 2019

An Introduction to the Arctic Domain Awareness Center (ADAC)

The Arctic Domain Awareness Center (ADAC) is a U.S. Department of Homeland Security (DHS) Science and Technology (S&T) Office of University Programs (UP) Center of Excellence (COE) in Maritime Research.

ADAC supports the U.S. Coast Guard (USCG) and other DHS maritime missions in order to improve capability for Arctic search and rescue, humanitarian assistance, disaster response, and security. This includes efforts to “enable the decision maker” across those mission sets.

A core part of the ADAC mission is to continue to foster the next generation of scientists and engineers devoted to the discovery, development, and improvement of technologies and applications for Arctic Maritime Domain Awareness, Response, and Resilience. ADAC provides mentorship opportunities to student Fellows, presently at different stages in their studies, to ensure their successful transition to the Homeland Security Enterprise workforce once they graduate.

ADAC’s programmatic research format aligns research projects to the DHS Funding Opportunity Announcement’s (FOA) six overarching themes. These are:

- Maritime Risk, Threat Analysis, and Resilience Research;
- Maritime Domain Awareness (MDA) Research;
- Maritime Technology Research;
- Integration of Science and Engineering with Maritime;
- Integrated Education.

ADAC Objective and Purpose.

The U.S. Department of Homeland Security, Science and Technology’s University Programs (DHS S&T UP) established ADAC in summer 2014 to research and provide a scientific basis to address the challenges faced by USCG and other DHS maritime missions in the Arctic region.

ADAC’s principal customer is the USCG. ADAC investigates capability shortfalls and gaps, and orients research activity to support the USCG mission needs. The particular areas that ADAC seeks to assist the USCG are related to missions in support of Arctic search and rescue, humanitarian assistance,

disaster response, and security matters. While oriented to the USCG's Arctic mission needs, ADAC also seeks to support other DHS maritime mission needs in the Arctic.

As U.S. Coast Guard lead U.S. Federal On-scene Coordination (FOSC) in time of maritime crisis, ADAC's research that supports other federal agencies that report to USCG FOSC leadership is also of value. Chief among these other U.S. Federal Agencies is the National Oceanic and Atmospheric Administration (NOAA).

As a university-hosted research venue, ADAC supports student education. Through the Center's Fellows Program, ADAC provisions student research, internships, and entry into the Homeland Security Enterprise.

ADAC's approach is to align the Center's research agenda with U.S. national, DHS, and USCG Arctic strategies and strategy implementation plans. ADAC notes existing strategies may change, and DHS strategy for the Arctic remains in development. As the U.S. national, DHS, and USCG Arctic strategies adapt and develop over time, ADAC will seek to conform Center research endeavors appropriately.

ADAC's corresponding vision, mission and strategy remains unchanged:

Vision: The DHS Center of Excellence provides networked and mission-focused support to the USCG Operator in the High North. ADAC strives to become a National Center of Arctic maritime research.

Mission: ADAC's mission is to develop and transition technology solutions, innovative products, and educational programs to improve situational awareness and crisis response capabilities related to maritime challenges posed by the dynamic Arctic environment. ADAC seeks to accomplish this mission through an inclusive approach.

Strategy: ADAC will conduct a parallel effort over five lines of major collaboration with DHS S&T UP and USCG in order to:

- Investigate, develop, resource, and initiate new research.
- Execute approved research work plans that are appropriately detailed and resourced.
- Successfully integrate university student Fellows into the Homeland Security Enterprise workforce.
- Transition sufficiently mature research to meet customer acquisition needs and commercialize as appropriate.
- Adapt Center activities, management, and communications to continue to learn and collaborate with an array of Center partners, and continue to suitably expand the reach of ADAC across U.S. and Canada to include Arctic government, military and security operators, researchers, and industry partners.

Current ADAC Funded Research projects¹

Mitigating the Damage to Arctic Copepods from Surface Oil Spills: When to Apply Dispersants

¹ Note: Current refers to either Year 7 carryforward or Year 8 approved workplan



Project Investigators: Dr. Christoph Aeppli, Dr. David Fields.

Lead Institution: Bigelow Laboratory for Ocean Sciences, East Boothbay, Maine.

Supporting Team: Erin Beirne and Maura Niemisto, Bigelow Laboratory for Ocean Sciences.

Project Description:

Abstract.

While dispersants are a highly efficient and proven tool for oil spill response in sub-Arctic and Arctic environments, there is concern about negative impacts on *Calanus* spp. copepods, which are critical zoo planktonic organisms in the Arctic food chain. This concern is based on laboratory experiments that place the animals in a homogenous solution of oil and dispersants. However, such an experimental design does not allow for the vertical movement of copepods and may overestimate the potential toxicity for the copepods. Investigators will conduct a series of laboratory experiments to allow research on the impacts of dispersed oil on vertically migrating copepods. The main hypothesis of this project is that in the ocean, Calanoid copepods can spatially separate themselves from surface oil spills during portions of their developmental cycle. Therefore, they might be exposed to much lower concentrations and for much less time than has been assumed based on previous laboratory studies.

Summary of Project Accomplishments

This project addresses two key research questions: (i) what is the impact of an oil spill, *with* and *without* dispersant, on copepods that are able to move vertically in the water column, thereby potentially avoiding the oil? (ii) Are there times in the year (stratification of the water column) when the impact of dispersant application on copepods is minimal? In order to address these questions, the research plan focused on the following three objectives:

- **Objective 1:** Determine whether *C. finmarchicus* copepods actively and effectively avoid oil or dispersants in mesocosm experiments (Phase I of this project, Year 6)
- **Objective 2:** Investigate how dispersants influence the exposure of subsurface animals to oil products (Phase II, Year 6).
- **Objective 3:** Determine how water column stratification and light influence the contact between copepods and oil (with and without dispersants) (Phase III, Year 7)

In the first phase of this project, researchers constructed a custom-made copepod observation tower and optimized the videography and water sampling systems. The 2-m vertical water columns were equipped with video cameras to quantify the number of copepods at three depths using infrared (IR) light. The use of IR light allows the team to conduct experiments in the dark. This was essential since the vertical movement of copepods is triggered by visible light. Furthermore, the copepod towers were equipped with temperature and light sensors, as well as sampling ports at 5 horizons for water sampling and subsequent analysis of polycyclic aromatic hydrocarbons (PAHs).

After completion of the copepod towers, the project team first ran control (i.e., no-oil) experiments with wild-caught copepods. Copepods of the species *Calanus finmarchicus* were collected at approx.

100m depth in the Gulf of Maine during their seasonally non-dormant states, which is roughly between April through October. Once collected, these copepods were kept in the laboratory for approximately one month. Within all control experiments, researchers maintained 85-100 copepods within view of the cameras throughout the experiments, indicating that there was not significant mortality within this time frame. Copepod distribution remained at a stable vertical distribution during control conditions,

Researchers then conducted experiments with fresh oil and observed copepod behavior. Researchers then evaluated data collected from the experiments. The copepod reacted to sub-lethal levels of oil, and a significant decrease of copepods was observed throughout the water column.

The second phase of the project focused on experiment to test the influence oil/dispersants on copepods in the water column. As expected, the addition of dispersants significantly increased the oil concentrations in the water column. As a result, the copepods reacted faster and to a greater degree to the oil addition. The top of the water column was depleted by > 95% at the end of five hours. At lower depths, a pulse of copepods was observed traveling down the water column. Accompanying experiments showed that the pulse of oil led to copepod deactivation, which makes copepod sink in seawater. These copepods were able to recover in clean seawater. The implication for field application of dispersants is that a pulse of oil likely leads to copepods sinking to depths with lower oil concentrations, where these animals can recover. If these animals recover completely (which has not yet been tested), the dispersant application would only lead to a temporary effect on a copepod population. The combined results of Phase I and Phase II experiments were synthesized as a manuscript for submission to a peer-reviewed scientific journal.

Experiments were conducted to test the influence oil/dispersants on copepods in a stratified water column. To this end, researchers equipped the towers with a circulating cooling plate fueled by a water chiller to cool the water column from below. An incandescent red light hangs just above the water surface to warm from the top. Seven temperature-loggers were distributed through the tower at 25cm intervals to collect continuous light and temperature data. Using this setup, experiments were conducted with dispersed and non-dispersed oil. The stratification led to a decreased advection and diffusion of oil compound between the top and bottom water column, which led to low oil concentrations throughout the experiments. This is a realistic scenario for an oil spill in summer conditions, where the warm top water column is separated from the cold bottom water column. Apparently, this barrier between the top and bottom water column was passable for copepod, as an increase in copepods was observed in the lowest water column depth in our experiments. The implications from this observation are that impacts of dispersant application in a stratified condition is limited to the top water column, and that copepods can escape to lower, cleaner water depths, where they can recover. The results of this investigations were written up as a manuscript for publication in a peer-reviewed scientific journal.

Bibliography of Project Related Publications Accomplished by Team

Manuscript is now in development. With an estimated submission to publication in August 2021.

Overall outputs for the entire project include:

- Technical Report: Creating a report with all the results of this research for USCG and DHS S&T UP.

- **Write Manuscripts for Peer-Reviewed Publications:** Researchers are in the process of producing two peer-reviewed scientific publications from this project, where all the results from this project will be described and discussed: (i) Do copepod avoid oil? (ii) The effect of surface oil and dispersed oil on vertically mobile copepod.

Transition Approach.

ADAC and Project team is committed to ensuring the results of this fundamental research will be useful for the USCG and DHS mission and is oriented to support USCG-led spill response for decisions making in dispersant application. Transition is straightforward:

- Completion of comprehensive knowledge product (Technical Report) to provide to U.S. Coast Guard Project Champion. ADAC and Project Investigators will iterate and coordinate Knowledge Product with Project Champion and Project Champion designated advisors as desired and directed, to include providing a summary users guide.
- As discussed, ADAC and Project team will conduct a structured inquiry to the Alaska OSRO and the response community to discuss how to make the findings widely available to response decision makers, advisors, dispersant experts, and the general response community. ADAC and research team will also advance peer-review journal submissions to inform the scientific and spill response community.
- ADAC will host all products produced on the Center's website aligned with both the Project and the Center's electronic library.
- The final project technical report, as well as the scientific publication resulting from this research, will provide scientific data about the extent and timing the use of dispersant could impact a key player in the Arctic food web, useful to FOSC decision making.

Relevance to USCG and Public Good

The rising demand for petroleum products has led to an increase in oil drilling in the sea as well as in shipping using ocean waterways. Over the past 50 years, oil spills have become a major environmental concern. With the decreased ice coverage in the Arctic and sub-Arctic, there has been a substantial increase in trans-Arctic shipping and renewed interest in Arctic oil and gas exploration. This poses a growing risk for oil pollution in the Bering and Beaufort Sea and raises concern about its impact of Arctic food webs. The opening Arctic Ocean has increased interest in the Northern Sea Route and the Northwest Passage. Transits through the Bering Strait are already growing from 220 transits in 2008 to roughly 500 per year in recent years. This increased shipping brings the inherent risk of oil spills. This risk comes not just from oil tankers, but from the heavy fuel oil that all ships carry. In addition to increased shipping, Arctic oil exploration is expected to increase. Current estimates suggest that 30 billion barrels of not-yet undiscovered oil lie in the U.S. Arctic. While the oil exploration in the Chukchi and the Beaufort Seas came to a temporary stop in 2016, the U.S. Congress recently opened Area 1002 in the Arctic National Wildlife Refuge (ANWR) for oil exploration. Extracted oil from these sites would be transported through the trans-Alaskan pipeline to Port Valdez in the Gulf of Alaska, where it is loaded onto tanker ships and shipped for refining. Dispersants are an effective tool, but research indicates dispersants can also make things worse. A recent comprehensive literature review argued that dispersants potentially especially useful in the Arctic since they can be deployed by airplanes in remote location. Through breaking up oil into droplets (< 100 um), dispersants fulfill two primary functions: they increase the surface area of the oil, which enhances the biodegradation rate, and they displace oil from the water surface and dilutes

it into the water column. New types of dispersants (e.g. Corexit 9500) are considered less toxic than crude oil alone and have been suggested to have minimal effects on marine life. However, recent studies of Corexit and chemically dispersed crude oil provide evidence of its toxicity for *Calanus* spp. copepods and other planktonic species dispersed oil can be ingested by planktonic species and pose a risk for these marine organisms.

Among the biological components of marine ecosystems, planktonic organisms are particularly vulnerable to crude oil pollution. More than 90 percent of the biological processes in the ocean are due to planktonic organisms. Therefore, any attempt to assess the ecological impact of oil spills in marine environments requires a good understanding of the effects of crude oil pollution on planktonic communities, as well as a clear understanding of the organism's natural vertical distribution pattern and their behavioral response to chemical pollutants.

A critical research aspect of this project is: *Calanus spp. are essential Arctic species*. Copepods (0.5-5 mm) are the most numerically abundant multicellular zooplankton in the water column. They are a primary consumer of microalgae and are a major food source for young fish and krill, which also serve as prey for higher trophic levels. Lipid-rich copepods of the *Calanus* species are a critical foundation species that provides an energy-rich food source for higher trophic level organisms in boreal and high latitude regions. These copepods serve as a primary source of energy to consumers such as herring (*Clupea harengus*), mackerel (*Scomber scombrus*), capelin (*Mallotus villosus*), and sand lance (*Ammodytes* spp.). These species are in turn prey for top predators including groundfish, tuna (*Thunnus thynnus*), marine mammals, and many seabirds. Copepods often dominate the gut contents of wild-caught larval fishes. Since *Calanus* spp. plays such a crucial role in sub-Arctic and Arctic ecosystems, oil-related impacts would likely have important consequences for coastal and shelf ecosystems of the North Pacific, the North Atlantic and northern littoral seas (such as the Bering, Chukchi and Beaufort Seas) and of the Arctic Ocean proper.

A key facet of the research is identifying and understanding *knowledge gaps related to oil toxicity for Arctic copepods*. Most crude oil toxicological studies on plankton have been conducted using water-soluble fractions of crude oil, or individual dissolved petroleum hydrocarbons. However, petroleum is present in the water column in both dissolved and particulate forms (i.e. crude oil droplets) after a crude oil spill in the natural environment. Plumes of small crude oil droplets generated by wind and waves or by treatment with chemical dispersants are frequently observed after crude oil spills. These dispersed oil droplets can be transported down the water column and serve as a reservoir of dissolved oil hydrocarbons that can affect copepods. Furthermore, these droplets can be in the same size spectra of the food for many zooplankton species, and there is evidence that they ingest crude oil droplets suspended in the water column.

The existing literature on copepod toxicity is very useful and provides knowledge of toxic effects when copepods and dispersed oil are brought together. In these studies, copepods are exposed WAFs or CEWAFs at constant concentrations for hours to days to assess toxicity. While these studies provide toxicity information at discrete concentrations, they likely overestimate that actual toxicity of the oil to copepods in the field for two reasons: First, these studies do not allow copepods to avoid hydrocarbons by vertically migrating. It is currently not known, whether such an avoidance behavior of copepods occurs. Second, existing studies do not allow to account for the vertical hydrocarbon gradients of oil or dispersed oil. Especially during the critical copepod developmental time of lipid accumulation in early summer, the water column is often stratified, which might separate oil from

copepods. It is currently not known, whether this stratification is an effective barrier between oil and copepods.

Photo-enhanced toxicity of dispersed and burned crude oil to Arctic mussels.

Project PI: Dr. Patrick L. Tomco



Supporting Team:

Colin McGill, UAA Chemistry Department

Katrina Counihan, Alaska Sea Life Center

Phoebe Zito, University of New Orleans

Lead Institution: University of Alaska Anchorage

Project Description:

Abstract.

This project studied the direct effects of oil, dispersants, and in-situ burning, along with photo-enhanced effects, on several physiological, biochemical, and metabolic aspects of a cold-water species of mussel (*Mytilus trossulus*). Sunlight-exposed oil is potentially more toxic to aquatic organisms than non-weathered oil, yet there remains little information on what effects (if any) dispersants and in-situ burning have on bay mussels in the arctic environment when exposed to sunlight, which in the summer months is continuous. This study sought to determine if dispersed oil or herded/burned oil are more toxic to bay mussels than oil alone and if these effects are more pronounced during periods of long sun exposure. Researchers also sought to determine the changes in chemical composition of Alaska North Slope (ANS) crude oil as it is exposed in each of these scenarios. Since these concentrations that marine life would be exposed to during an oil spill are realistic, these results are applicable to management decisions on the use of recovery methods.

Summary of Project Accomplishments

A principal question this research seeks to resolve in support of U.S. Coast Guard decision makers leading spill response in Unified Command to an Arctic maritime is: *Disperse or Burn? Is one strategy more toxic at different times of year due to sunlight?* Despite some of the benefits dispersants and *in-situ* burning appear to have in oil spill mitigation, opinions on the utilization of these strategies are polarized, and the issue requires careful consideration and study. The presence of continuous sunlight in the summer months potentially confounds existing knowledge of the seasonal toxic effects that these treatment strategies pose in comparison to no action.

Accordingly, the goal of this project is to understand which response method (dispersants vs *in-situ* burning) has a greater effect on Arctic mussel toxicity and whether the extreme seasonal differences in sunlight cause each response strategy to be more toxic in the summer than in the winter.

In order to complete the baseline to the most current levels of understanding, Project investigators completed the following:

Student Training: Two graduate students and two undergraduate students were recruited, and their projects are now complete.

- *Phase 1:*
 - Task A: Obtained approved State of Alaska Department of Fish and Game aquatic resource permit for hand collection of *Mytilus trossulus* in Resurrection Bay.
 - Task B: Obtained approved hazardous waste disposal and chemical safety approval.
 - Task C: Constructed 15 exposure chambers. Each capable is suitable for safely containing 50 mussels in 5L seawater and containing oil in the event of a spill.
 - Task D: Collected >750 mussels from Resurrection Bay suitable for exposure assessment. Transported to exposure chambers.
 - Task E: Successfully acclimated test organisms to exposure chambers. Recorded data on mortality. Ensured 50 mussels per exposure chamber are acclimated.
 - Task F: Successfully collected burn residue from 3 small-scale controlled in-situ burns.
 - Task G: Exposed collected mussels to 5 conditions: seawater, dispersant, oil, dispersed oil, and burned oil) under 3 light regiments. Organisms were harvested on the defined time intervals and dissected with the tissues archived, masses recorded, and recordings of mortality rates.
- *Phase 2:*
 - Task A1: Successfully performed 6 physiological and biochemical assays on archived tissues at ASLC: Hydrogen peroxide formation, RNA: DNA ratio, Cytochrome P450, Heat Shock Protein, Superoxide dismutase, and Micronuclei.
 - Task A2: Statistically compared physiological and biochemical data between treatments, across time, and between individuals. Counihan to evaluated and provided quality control for the data.
 - Task B1: Successfully perform 3 physiological and biochemical assays on archived tissues at UAA: TBARS, ATP/ADP ratio, and caspase 3/7.
 - Task B2: Statistically compared physiological and biochemical data between treatments, across time, and between individuals. McGill to evaluated and provided quality control for the data.
- *Phase 3:*
 - Task A: Successfully collected NMR spectra from tissue extracts.
 - Task B: Determined metabolic profile present in tissues based on database matches.
 - Task C: Statistically compared metabolite profiles between treatments, across time, and between individuals. Project investigator Tomco evaluated and quality control the data.
- *Phase 4:*
 - Task A: Obtained necessary instrument time permissions for 180 Orbitrap MS samples
 - Task B: Successfully determined dissolved organic carbon concentrations in water samples
 - Task C: Successfully collected spectrofluorescence and Orbitrap MS data from water samples.
 - Task D: Statistically compared DOC, spectrofluorescence and Orbitrap MS data between treatments, across time, and between replicates. Zito to evaluated and provided quality control for the data.

- **Phase 5:**

Currently, project personnel are in the process of summarizing findings and identifying appropriate peer-review journals for submission. Team members Counihan and Zito will lead the manuscript preparation and submission aspects to peer-reviewed scientific journals (i.e. *Aquatic Toxicology*, *Environmental Science and Technology*). PI Tomco will work with ADAC and USCG Project Champion (outlined below) in synthesizing data to meet USCG needs and satisfying reporting outcomes as required by the program. Team member McGill and graduate students will assist in all aspects of reporting and manuscript preparation.

Relevance to USCG and Public Good

Oil and gas drilling have been occurring in Alaska since the 1950s, and additional lease sales are planned for Cook Inlet and the Beaufort Sea (State of Alaska, 2017). As regions in the Arctic continue towards reduced and ice-free marine environments, offshore drilling in that area is anticipated to increase (State of Alaska, 2014). As petroleum development increases in the Arctic, so does the risk of major oil-spill. Oil spills can have a devastating effect on the marine environment and chemical dispersants and in-situ burning are supposed to mitigate that effect. Dispersants are pre-authorized for use in certain regions around Alaska and other areas gain authorization on a case-by-case basis (State of Alaska, 2014).

The use of dispersants and in-situ burning are also authorized on a case-by-case basis. Dispersant application and in-situ burning were conducted on a small scale after the Exxon Valdez spill, approximately 40% of the oil moved onto Prince William Sound beaches, and five years later, two percent of it remained. Dispersants were widely used during the Deepwater Horizon spill allowing microbial remediation to occur in deeper water, and in-situ burning removed oil slicks on the surface.

The toxicity of dispersed or burned oil to marine organisms can differ from untreated oil. The dispersion of oil is supposed to allow natural degradation such as evaporation, photochemical oxidation, microbial degradation, dissolution, adsorption and sedimentation, to occur more rapidly, but it may also increase the bioavailability of oil to marine species.

There have been a few studies on the toxicity of dispersants or dispersed oil to Arctic/Subarctic species. Testing performed at temperatures found in the Arctic with copepods and Arctic cod found that both species were more sensitive to physically dispersed oil than chemically dispersed oil. The physiological responses of bay mussels (*Mytilus trossulus*) to oil, dispersant and dispersed oil in Subarctic conditions were investigated by members of our research team recently, and mussels exposed to non-dispersed oil experienced greater negative physiological impacts than mussels exposed to dispersant or dispersed oil.

Furthermore, there is a lack of knowledge on the toxicity of burned oil to Arctic/Subarctic species. Burned oil from Deepwater Horizon was higher in density with an increased concentration of asphaltenes and pyrogenic polycyclic aromatic hydrocarbons. Additional research is required to determine the impact of burned oil on Arctic and Subarctic marine species.

Bay mussels are ideal for monitoring programs. They are ubiquitous, sessile organisms that bioaccumulate pollutants through filter-feeding. They are an integral component of coastal ecosystems

and an important food source for both wildlife and humans. It has been determined that *Mytilus trossulus* is a distinct species from *Mytilus edulis* and is the species present around Alaska and other northern cold-water coastal environments. Bay mussels would be easily sampled for cost-effective monitoring programs in the case of an oil spill. Therefore, *M. trossulus* was selected for use in this project because it is a cold-water species of commercial, subsistence and ecological importance in both the Arctic and Subarctic.

Photo-enhanced toxicity of crude oil is real, and mussels inhabit the photic zone. Photo-enhanced toxicity, (i.e. the increase in toxicity associated with the presence of sunlight), of oil and dispersed oil has been identified in many studies over the past 20 years to various marine species.

An oil spill in Arctic regions during the summer would expose oil to sunlight for 24 hours per day and may result in significant photo-enhanced toxicity. In both ice-associated and open water conditions, whenever oil is exposed to the surface, the presence of sunlight may be a confounding variable affecting the weathering of oil and our understanding of efficient oil recovery in the Arctic.

Once petroleum enters the environment, it can undergo many chemical and physical changes making it difficult to analyze. In order to overcome these limitations, utilization of advanced analytical techniques to characterize samples to determine optical and molecular-level composition is critical to advance understanding of the effects. The research team finds it imperative for informing spill response contingency plans and monitoring programs to assess these variables. Project investigators believe it is reasonable to expect Arctic and Subarctic conditions to be unique in their exposure scenarios when compared to temperate climates, and the exposure scenario (and toxicity) of each spill response may be different in summer (continuous light) compared to winter (limited to continuous darkness).

Accordingly, research efforts are potentially the first in a series of future integrated research studies with the goal of understanding tradeoffs between spill response strategy, chemical exposure, and toxicological impacts in Arctic and Subarctic conditions.

The Outcome/output of this research project is to provide a knowledge product publishing the research conducted, analysis, conclusions and recommendations. The published works will include peer-reviewed scientific article(s). The results of this project will be helpful in advancing decision support systems for mitigation efforts during future oil spills to protect our natural resources in the Arctic and subarctic.

Translating toxicity data generated in mesocosms into policy decisions and criteria for recovering spilled oil requires not only controlled experiments conducted under simulated realistic scenarios and complex data analysis; it also requires a “global perspective” cost/benefit weighing. We will create a weighted Pugh concept selection matrix (decision matrix, example in Table 1). This will be a wide characterization of project personnel’s scientific opinions from several narrower bands of individual in-depth expertise. This synthesizes a selection process that can be useful as a decision tree input which can be useful for industrial entities. Project personnel will perform concept selection and identify relative criteria weights (e.g. X, Y, and Z in associated table) and, based on the results, identify a perceived significance rank of each criteria/strategy pairing.

Bibliography

Currently, project personal are in the process of summarizing findings and identify appropriate peer-review journals for submission. The research team will develop two manuscripts for peer review in addition to program knowledge product.

Transition Plan.

ADAC and Project team is committed to ensuring the results of this *fundamental* research will be useful for the USCG and DHS mission, and is oriented to support USCG-led spill response for decisions making in dispersant application. Transition is straightforward: Completion of comprehensive knowledge product (Technical Report) to provide to U.S. Coast Guard Project Champion. ADAC and Project Investigators will iterate and coordinate Knowledge Product with Project Champion and Project Champion designated advisors as desired and directed, to include providing a summary users guide.

ADAC and Project team will conduct a structured inquiry to the Alaska OSRO community for suitability of research application in a commercial context. ADAC and research team will also advance peer-review journal submissions to inform the scientific and spill response community. ADAC will host all products produced on the Center's website aligned with both the Project and the Center's electronic library. The final project technical report, as well as the scientific publication resulting from this research, will provide scientific data about the extent and timing the use of dispersant could impact a key player in the Arctic food web, useful to FOSC decision making.

The major scope of this project is to develop knowledge products to advance our broad understanding of the environmental toxicology of petroleum, chemically-treated petroleum, and weathered chemically-treated petroleum exposure. Transition will be conducted by the research team and in compliance with ADAC Research to Transition Process. As outlined in the "Key Stakeholder Engagement Plan", research team will work with USCG HQ Project Champion to ensure knowledge products are of interest, useful and disseminated widely to USCG, and HQ USCG Project Champion designated points of contact that support USCG led unified command for oil spill response. Additionally, Research team will contact relevant federal agencies including the EPA and NOAA to provide further briefings on research findings. Research team will provide full range of research products to ADAC's web portal and any further research destination as determined by the HQ USCG Project Champion. In addition to the providing the full published report to USCG and ADAC posting, the research team will submit summary of research, analysis and findings for peer review scientific journal. Findings will be disseminated throughout the research community as presented orally or through poster at either Alaska Marine Science Symposium or Alaska Oil Spill Technology symposium in fall 2020 / spring 2021. The PI and Research team will also seek to participate either as a panelist or poster demonstration at the Clean Pacific conference and the International Spill Conference in 2021. Researchers will also coordinate via ADAC leadership to NOAA in providing a briefing to NOAA Scientific Support Coordinators, as well as briefing Environmental Protection Agency (EPA) for research to support pollution response.

Marine Induced Polarization Methods for the Detection and Mapping of Oil in an Arctic Marine Oil Spill – Ruggedized Field Kit Production and Testing



Project Investigator: Dr. Socolofsky, Texas A&M University

Project supporting researchers:

Kari Walker, Induced Polarization Associates

Art Wright, Safety & Environmental Coordinator, Induced Polarization Associates

Nathan Lamie, Lead Engineer/Facility Operator, CRREL (U.S. Army Corps of Engineers)

Additional Key Project Team members:

Mike Williamson, Chief Scientist, Induced Polarization Associates

Kevin Hand, Project Planning and Reporting, Induced Polarization Associates

Joseph Radler, Technical Scientist, Induced Polarization Associates

Todd Stedman, Software Scientist, Induced Polarization Associates

Lead Institutions: Academic: Texas A&M University, College Station Texas; Industry: Induced Polarization Associates, Seattle, Washington

Program Description:

Abstract.

Federal on-scene spill response need remote sensing tools to detect and map oil in the open-Arctic ocean, broken ice fields, and oil under and in ice. Marine Induced Polarization (Marine IP) has proven an effective tool to detect hydrocarbons in fresh, brackish, and seawater at all ocean depths including in the seafloor, and current research is underway assessing the performance for Marine IP's suitability in Arctic environmental conditions. ADAC Program Year 6 research tests performed at the Cold Regions Research and Engineering Laboratory (CRREL) demonstrated the importance for the Marine IP field kit to be more compact and resistant to the effects of temperature, as well as vibration and jarring during transport and setup. Based on investigations conducted in ADAC Program Year 6, researchers assess the field kit needs to be redesigned to be a turn-key system that is easy to transport, set up and deploy by trained personnel, and the software interface and functionality needs to be redesigned to guide a user through the steps needed to collect data using the Marine IP system.

This research effort will leverage the previous Marine IP oil under ice detection research to inform the design, build, and delivery of an Arctic-ready, rugged Marine IP field kit for transition of the Marine IP technology into operational use.

As such, based on the assumption of concurrence of USCG Project Champion, investigators seek to build on the original planned outcome of providing knowledge products as the goal of this project, to now expand the research approach to conduct an additional investigation within Program Year 7:

Phase 1 – Re-design, build, and test an Arctic-Ready Marine IP System – Hardware.

Phase 2 – Re-design, test, and deploy user-friendly software for the Arctic-Ready Marine IP System.

The outcome of this research will be one Arctic-Ready Marine IP System with a re-designed interface and data visualization software package, to augment the transition of the Marine IP technology into the hands of the USCG.

Summary of Project Accomplishments

ADAC Program Year 6

Phase 1: Phase 1: Re-design, build, and test an Arctic-Ready Marine IP System – Hardware and Firmware. Designed test plan for open water tests. Outlined functionality and feasibility of Marine IP hardware design and engineering for specific testing.

Research Task 1. Design Arctic-Ready Marine IP System – Hardware.

Research Task 2. Build Arctic-Ready Marine IP System – Hardware.

Research Task 3. Designed a Marine IP cable for investigation of oil in simulated ice conditions – the Ice Cable. The new design of the Ice Cables differs from the standard Marine IP cables in that they are much shorter, the electrodes are significantly closer together, and the electrode pods and protective casings have been shortened to allow the desired electrode spacing. The cable, electrode pods, and electrode casings were designed to accommodate these requirements. Special considerations were also made to account for working in extreme cold-weather environments. Researchers examined and selected cable and electrode components conducive to subfreezing temperatures to minimize common issues such as brittleness, inflexibility, and in some cases, signal degradation.

Phase 2: Construct, integrate and test Marine IP Open Water Cables.

Research Task 4. Constructed and tested a primary and spare cable for investigation of oil in water depths from 1 to 35m in open water conditions – the Open Water Cable. The design swath width of survey area for this cable was targeted to be 20 meters and the minimum depth resolution was targeted to be one-half a meter. The Open Water Cables were each constructed at a length of 180 m, and the measurement portion of this length is 52 m. Each Open Water Cable has two transmitter electrodes and six receiver electrodes, as seen in the diagram below.

Two types of cable were used to construct the Open Water Cables in order to test for the optimal cable to be used for future cable builds. Long lengths of multiconductor cable are long-lead-time items to order, and some delays were experienced in the availability and shipping of the cable materials. Open Water Cable #1 (OWC #1) was constructed from Power/Signal 4206 multiconductor cable (sourced from MacArtney Inc. in Houston, TX), and was completed 29 July 2019. Open Water Cable #2 (OWC #2) was constructed from custom Power/Signal multiconductor cable (sourced from Mercury Wire Products, Inc. in Spencer, MA), and the construction of the cable was completed 5 December 2019.

Research Task 5. Integrated the Open Water Cable into the researcher-developed control system. The Marine IP topside system consists of a Topside Control Box, Universal Power Supply connected to either ship AC mains or a portable generator, two 12v DC sulfur glass-mat batteries, a signal routing wire harness interfacing the Topside Control Box with the cable. The Topside Box components include a transmission (TX) waveform generator powered by the 12V batteries, an external battery patch panel, isolated receiver analog front end and a computer-controlled Data Acquisition System (DAS)

synchronized by the onboard computer. Operator control and is provided via standard computing peripherals (keyboard and mouse or other pointing device) and a monitor displaying a Graphical User Interface tailored for visualizing Marine IP data.

Research Task 6. Conducted Open Water Cable beach tests at Seattle Golden Gardens Park on Puget Sound, Washington to verify proper operation of the transmit/receive electrodes of both cables in a marine environment. OWC #1 was beach tested on 9 August 2019 and OWC #2 was beach tested on 5 December 2019.

Phase 3: Conducted open water testing.

Research Task 7. Conducted field tests in Puget Sound to test and demonstrate system mobilization, baselining procedures and deployment from a 54-ft vessel of opportunity. On 15 October 2019, a survey was performed to test the deployment of the Open Water Cable. OWC #1 was used for this testing. To increase the sensitivity and dynamic range of the Marine IP system, four baselines (i.e., ambient background) measurements were performed before and after data collection at the Eagle Harbor survey transects.

Field testing confirmed reliable operational performance of all Open Water Cable components and interface with the Topside Control Box, showing expected electrode connections, signal reception from each receiver electrode pair (i.e., a “channel”), no grounding faults within the system, and minimal electromagnetic interference from the ambient environment.

Research Task 8. The team conducted field trial to demonstrate performance of wide-area assessments identifying presence/absence of hydrocarbons. The field trial was conducted on 13 December 2019 at Eagle Harbor, WA, aboard a vessel of opportunity, the Kvichak 54’ catamaran Defender 4.

Phase 4: Constructed, integrated, and tested Marine IP Ice Cables; investigated target signatures.

Research Task 9. Constructed and tested a primary and a spare cable for investigation of oil in simulated ice conditions. To study the capabilities of Marine IP for mapping oil contaminants under and within ice, researchers constructed the Ice Cable designed during Research Task 3, optimized for the dimensions and environment of the CRREL GRF Concrete Basin.

Research Task 10. Integrated the Ice Cable into the researcher developed Topside Control system. The Marine IP topside system consists of a Topside Control Box, Universal Power Supply connected to either ship AC mains or a portable generator, two 12v DC sulfur glass-mat batteries, and a signal routing wire harness interfacing the Topside Control Box with the cable. Researchers also took some of the lessons from the field deployments in Research Tasks 7 and 8 by constructing hardened, more portable cases for the computer peripherals. The previously used mouse was replaced with a trackball mouse to provide more control and precise movement on a pitching vessel deck during field operations. A monitor and keyboard were integrated into a field-case for faster deployment.

Research Task 11. Conducted Ice Cable beach tests at Seattle Golden Gardens Park on Puget Sound, Washington to verify the integrity of the cable jacketing and potting and ensure proper operation of the transmit/receive electrodes of both cables in a marine environment.

Research Task 12. Researchers conducted investigations of IP signatures for targeted petroleum following the signature study plan defined in the Test Plan for Marine IP Target Petroleum Signatures for IP signature investigation. Pursuant to accomplishing this task, the lab testing environment was iteratively optimized, and a systematic series of tests were designed to characterize the effects of changing ambient conditions on marine IP signatures for specified oils. While carrying out this task, the team uncovered some key differences between the electrical properties in field measurement environments and those found in the implemented laboratory test apparatus for characterizing spectral signatures of materials.

Phase 5: Conducted ice tank testing at CRREL.

Research Task 13. Conducted baseline measurements at the CRREL facility. For the CRREL simulated ice tests, a baseline configuration was established, and measurements recorded in advance of introducing petroleum to the CRREL GRF. The baseline measurements characterized the effects of inductive responses due to the physical properties of the CRREL GRF, as well as any signal artifacts, noise, or distortion due to the boundary conditions imposed by the presence of the solid ice and other ice-water interactions.

Research Task 14. Conducted final testing at the CRREL facility. The research objective of this portion of the field program was to gain an understanding of both the capabilities and limitations of Marine IP for detecting and mapping oil under and encapsulated within the ice. Oil was introduced into the ice tank environment in coordination with CRREL test procedures and in accordance with the agreed research test plan shown in Research Task 13. The study design included six test regions and seven scenarios within the CRREL GRF.

Research Task 15. Research team conducted data analysis, interpretation, and developed preliminary results. Prior to the extensive system testing in the laboratory and the field both in Seattle and at CRREL, it was hypothesized that, in addition to the known role of providing a baseline dataset for comparison to the oil under ice measurements, an along-line system baseline could also be subtracted from the oil under ice measurements in order to increase the resolution and sensitivity of the Marine IP system. However, it has been determined that a baseline subtraction is not feasible in post processing due to artifacts in the signal, and so the baseline measurements will continue to serve their known purpose of comparison analysis.

Research Task 16. Determined and documented preliminary engineering design specifications for integration of Marine IP with AUV operations using information and lessons learned during Phases 2 and 3. The research team drafted a preliminary integration analysis for the Marine IP system deployed as a payload module aboard an AUV or ROV. This analysis is based on a set of high-level requirements identified by the team during field operations in 2020 as well as additional research into the current state-of-the-art in AUV instrumentation packages and modules.

During ADAC Program Year 7, the Marine IP Topside Control Unit, signal generator, power management system, data acquisition and real-time visualization software were re-designed to be suitable for deployment by the U.S. Coast Guard led, Federal on-scene spill responders.

Transition Approach.

ADAC and Project team is committed to ensuring the results of this research will be useful for the USCG and DHS mission and is oriented to support USCG-led spill response for decisions through the use of Marine IP in characterizing the ocean and shoreline environment. ADAC and Project Investigators will iterate and coordinate Knowledge Product with Project Champion and Project Champion designated advisors as desired and directed. Key to the transition is providing a knowledge product (a comprehensive technical report) which accompanies the prototype to the designated HQ USCG Project Champion that can be used to promote the further development of this technology; with the technology being transitioned to the commercial market.

ADAC and Project team will conduct a structured inquiry to the Alaska OSRO community for suitability of research application in a commercial context. ADAC and research team will also advance peer-review journal submissions to inform the scientific and spill response community. The research team will also apply to present the technology at relevant academic conferences such as Clean Pacific, Clean waterways, and the International Oil Spill Conference. ADAC will host all products produced on the Center's website aligned with both the Project and the Center's electronic library.

The goal of this research is to produce an Arctic-Ready Marine IP System that can be used in the field to enhance situational awareness by the USCG, DHS and other agencies relating to oil released in open or ice-laden water. Upon completion of the project, the System will be provided to DHS and interested industry partners for onward decision in transition destination.

With lessons learned from this first step, the re-design, build and deployment of an Arctic-Ready Marine IP detection system has been identified as the next critical step of transition for use by the USCG and other spill responders; aiding the US government in responding to emergencies and not only gaining further understanding of the wide applications of Marine IP technology, but also making the technology more accessible, is the strategic project goal.

As an extension from the original research plan from ADAC Program Year 6, this additional research will leverage what was learned in Program Year 6 and further the initial design parameters and engineering for applications of Marine IP with an autonomous underwater vehicle (AUV) to investigate under a solid-ice covered ocean surface is an additional important step in future utility for responding agencies.

Future transitional efforts should include the complete integration of Marine IP onto multiple fully autonomous marine vehicles, thereby providing scale coverage over a wide area and aid in oil migration/pattern forecasts. Marine IP technology can then provide detection, mapping, and migration information for oil under ice or in other scenarios where solutions currently do not exist.

Relevance to USCG and Public Good.

Induced polarization has been used on land for many years and has been more recently adapted for the marine environment - resulting in a very efficient application of the technology. Under an inducing voltage, charge is "adsorbed" (adsorb form on the surface) onto certain materials. When the inducing voltage is removed, a time-delayed charge release can be measured similar to a capacitor bleeding off charge.

In modern induced polarization systems, this reaction is typically measured as a time delay or phase-shift between transmitted and received signals. The frequency at which the maximum phase-shift occurs has been shown to be diagnostic of the specific materials being polarized. Marine IP has the capability to work in a broad range of environments, from full ocean depth to as shallow as 1-meter depth. Induced polarization system research has yet to be applied in the Arctic.

Such investigations may prove useful to help minimize the effects of spilled oil in the Arctic marine environment, and assist U.S. Coast Guard led, Federal on-scene spill response needs. In particular, Marine IP may significantly contribute to remote sensing tools to detect and map oil slicks in the open-ocean, broken ice fields, and oil under ice. The below illustration depicts oil in an ice field off the coast of Canada and a schematic of various oil-ice scenarios that can occur.

When an oil spill occurs under ice, the oil collects on the bottom side of the ice and then becomes encapsulated as the ice grows and can infiltrate into brine channels, thereby complicating the ability to detect oil in these environments. During the melt season, the oil will migrate through the expanding brine channels, drawing the oil to the surface of the ice. Wind-driven sea ice formation and mixing in affected coastal polynyas will further complicate the cleanup effort.

These freeze-melt mechanisms and natural processes driving sea ice evolution can significantly increase the cleanup difficulty and the duration of the environmental impact of the spill. Therefore, the ability to detect and map the extent of oil below the ice and in mixed or broken ice is critical to the spill response effort.

Marine IP has demonstrated consistent potential to detect hydrocarbons in fresh, brackish, and seawater sediments. During ADAC Program Year 6, measurements were collected at CRREL in conditions simulating oil under ice, encapsulated within ice and in open broken ice, representing the first tests of Marine IP in simulated Arctic conditions. Preliminary results have shown indications that Marine IP has detected oil under ice at CRREL.

The science behind the technology is environmentally safe, proven and well understood, and with additional research, the capability to apply this technology to the problem of detecting oil within and under broken sea ice is a very strong possibility. Planned investigations will help forward the extent to which the technology proves valuable to detect and map an Arctic oil spill in and under broken or mixed sea ice. Further investigations will seek to determine suitable deployment vehicles for Marine IP (such as remotely operated vehicles/ autonomous underwater vehicles (ROVs/AUVs)). Accordingly, planned research seeks to understand the ability of Marine IP to contribute to characterizing the behavior of an Arctic oil spill, and therefore contribute to conducting an effective response.

Overall Outcomes for the entire project include:

- *Informing Oil Spill Response community of suitability of Marine IP for detecting and potentially characterizing contamination of hydrocarbons in Arctic waters, to include characterizing oil in partial ice formations as well as under pack ice. Included in the analysis is providing insights to preferred deployment mechanisms and ability to enhance planning for deployment of spill response mechanisms.*

- *Informing marine AUV community* (including ADAC and the Center's Long Range Autonomous Underwater Vehicle project team) of additional understanding gained about the suitable design parameters for potential downstream integration of Marine IP.
- *Informing Oil Spill Response community of suitability* of Marine IP to detect and delineate contamination of seafloor sediments,
- *Providing* a knowledge product report and accompanying prototype to the designated HQ USCG Project Champion that can be used to promote the further development of this technology; with the technology being transitioned to the commercial market.

Oil Spill Modeling for Improved Response to Arctic Maritime Spills: The Path Forward



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Project Description:

Abstract.

As examined during an ADAC 2017 maritime oil spill response workshop, the Arctic region is projected to realize more maritime shipping and natural resource development. Accordingly, the probability of more and larger spills, particularly of petroleum, is increasing the need for response-relevant computer modeling. The National Oceanic & Atmospheric Administration (NOAA) Office of Response & Restoration (ORR) provides scientific support to the U.S. Coast Guard (USCG) Federal On-Scene Coordinator (FOSC) during oil spill response. One principal product NOAA ORR supplies is decision support models that include: predicting the path and future location of the spilled oil; characterizing the habitats and species at risk (including humans) and the extent to which they must be protected; and analyzing the potential performance of various clean-up alternatives.

NOAA ORR has access to multiple environmental models useful to characterize an Arctic spill response, including several specific for ice conditions (such as ADAC's Arctic Oil Spill Modeling). The rising risk of an Arctic oil spill increases the urgency to identify the current state-of-the-art models and the potential for integration across current and emerging environmental models. Accordingly, this research investigation will create a knowledge product, as guided by a Project Core Team, Workshops and expert Working Groups, to assist future USCG-led spill response communities in strategizing new investment in model development and associated integration.

Accordingly, the Oil Spill Modeling for Improved Response to Arctic Maritime Spills, the Path Forward project provides a structured approach to solicit expert advice to develop such a strategy as driven by USCG FOSC core needs in an Arctic oil spill response. The project began with the formation of a project "Core Team" (membership consists of ADAC center representative, University of New Hampshire Coastal Response Research Center (CRR), Center for Spills and Environmental Hazards

(CSE), Headquarters USCG Maritime Environmental Response (HQ USCG MER), USCG Pacific Area (PACAREA), USCG District 17 (USCG D17), Alaska Department of Environmental Conservation (ADEC) and NOAA ORR). This core team developed a list of needs/questions that Arctic response models should address.

These served as guideposts to focus all the project's efforts. Subsequently, the project developed and executed a workshop and established 4 expert Working Groups to produce stakeholder consensus on approaches to Arctic response modeling that yield more accurate results with clear uncertainty bounds in response timeframes. Working Group topics include Oil and Ice Interactions at the Meter/Sub Grid Scale, Oil and Ice Interactions at the Kilometer+ Scale, New and Existing Technologies for Observing Ice and Informing Models, and Visualization/Uncertainty. Another workshop will be held to compile the information gathered from these Working Groups. The final Knowledge Product will recommend what new components/sub-models should be developed and validated and how best to coordinate further modeling efforts to aid a USCG-led FOSC in an Arctic maritime oil spill response.

Summary of Project Accomplishments

Guided by a research management team with exceptional professional standing in the community of oil spill response, The objective of this project is to identify the: current state-of-the-art Arctic maritime oil spill response modeling, potential integration of these models, and specific needs to be addressed to obtain models that will be functional and effective in the response time scale to advance the FOSC's decision making during an incident and improve the experience gained from exercises and drills. The focus has been on making models that consider the complications unique to the Arctic (e.g., ice, adverse weather, international waters, and lack of response equipment) that make response modeling particularly challenging. Accordingly, the project consists of 6 phases.

Phase 1: Formation of Project Core Advisory Team.

Phase 2: Meeting of the Core Team and Key Agency Stakeholders to Determine the Needs of/Questions Addressed by Response Models to Facilitate FOSC Decision Making During Arctic Oil Spill Response.

Phase 3: A Three-Day Workshop on Arctic Maritime Spill Response Modeling.

- Once the list of needs/questions guideposts created in Phase 2 was completed and accepted by the Core Team, the Project PI began developing a 3 day comprehensive workshop, organized via a Workshop Organizing Committee. The Project Team conducted the Arctic Maritime Spill Response Modeling workshop in Anchorage, AK on 3-5 December 2019. There were 49 attendees from both the U.S. and internationally. The workshop included a mix of presentations on the different models available for oil spill response in the Arctic and included a range of oil spill modeling and ice modeling experts. In addition to presentations, three different breakout group scenarios were discussed including: a well blowout under ice, a pipeline spill under land fast ice, and a large vessel spill of combinations of oil in the shoulder season (during fall as ice is developing).

Phase 4: Working Groups on Specific Response Model Components/Criteria (Draft of Knowledge Product Sections).

- Following the 3-Day spill response modelling workshop, the Project PI facilitated the formation of Working Groups with help from the project Core Team. Working Groups include the following topics:
 - Oil and Ice Interactions (Meter/Sub Grid Scale)
 - Oil and Ice Interactions (Approximately Kilometer + Scale)
 - New and Existing Technologies for Observing Ice and Informing Models
 - Visualization/Uncertainty

The last two phases occurred in ADAC's Program Year 7.

Phase 5: Conduct a Two-Day Workshop to Review Working Group Drafts and Integrate Feedback into an Initial Knowledge Product.

- In order to facilitate the development of a final knowledge product, the Project PI and Organizing Committee developed a final workshop held in November 2020. Due to the COVID-19 pandemic, the event was reformatted as a three-day virtual event held on 16, 23 & 30 of November 2020 as three hour virtual sessions. The goal of the three-session workshop, conducted on Zoom in November 2020, was to vet and integrate working group findings. The Project PI leveraged deliberations from the four Working Groups to stimulate collaboration and consensus on a pathway forward for Arctic oil spill response modeling, including acceptance of standards, assumptions, algorithms and approaches to solve a variety of issues. The workshop was designed to maintain the open channel of communication among responders, scientists and modelers started at the first workshop and continued during the Working Groups. This workshop was essential to ensure that the final product is consistent and cohesive, especially because multiple groups will be working on the topics. The workshop also allowed responders to be sure that the proposed products are useful and that suggested model developments will conform to key criteria that fulfill the decision maker's needs. This workshop consisted of report outs from the Working Groups and feedback from the stakeholders (e.g., NOAA ORR, USCG, Core Team, and Project Champion).

On Day 1 of the workshop (November 16), 78 people participated. Each of the working groups presented their objectives, findings, recommendations, and research needs identified. Participants asked questions about the findings and conclusions and made suggestions regarding modifications. Detailed notes on each presentation and the ensuing discussion were posted on the CRRC/CSE website along with the slides from each group. Overall, the groups' findings and recommendations were well received by the scientists and responders attending.

The two subsequent days were by invitation only as attendees were developing final recommendations and research needs. Discussion on November 23, when 34 people participated, centered on data assimilation for oil spill models, ice modeling and observational needs/scale of outputs, under ice roughness/storage capacity, oil migration. Discussion on November 30, when 28 people participated, focused on data assimilation for oil and ice models, visualization and uncertainty implementation of CEOMIO Table, and refinement of research needs.

Phase 6: Creating and Submitting the Final Knowledge Product (in progress):

- The Project PI is in the process of drafting and finalizing the final knowledge product: *Oil Spill Modeling for Improved Response to Arctic Maritime Spills: The Path Forward* as a comprehensive report, providing reviews and conclusions, addressing the following:
 - A review of the current state-of-the-art on oil spill response modeling for Arctic Maritime oil spills;
 - A framework for an integrated response modeling suite to address oil spills under ice, in leads, in the MIZ and for 3/10 to 8/10 ice cover, etc.;
 - Recommendations and conclusions for addition of sub models on response technologies;
 - Recommendations and conclusions on incorporation of natural resource and food security protection, and Traditional Ecological Knowledge into models; and
 - Detailed recommendations, conclusions and scopes of work on needed modeling research to fill gaps identified during the project. The Project PI will develop the content and outline of the final knowledge product with reviews and coordination by the Core Team and Project Champion, CAPT Trego. Following coordination of/concurrence with the overall outline, the Project PI will draft the associated final knowledge report, and plan to complete it within three months after the second workshop. Once drafted, the Project PI will send it to the Project Champion, Core Team, OC and Working Group Co-leads for edits. Once this level of coordination is accomplished, the Project PI will send it to ADAC for coordination. Within one month of receiving ADAC's comments/edits, the Project PI will submit the final knowledge product to ADAC, the Core Team and Project Champion Captain Trego. Once the report is submitted and promulgated, the Project PI and ADAC will coordinate a corresponding peer-review journal article.
 - The master's thesis and senior honors thesis successfully defended by ADAC Fellows Megan Verfaillie and Jessica Manning, respectively, are the backbone of the Knowledge Product reviewed by the Core Team and submitted to ADAC on or before August 20, 2021. The contents of the Knowledge Product will also serve as the basis for a peer reviewed publication on the state of the art of Arctic oil spill modeling and the research needs to improve predictions of movement of oil in ice infested waters. This paper, along with the journal article on uncertainty in model prediction published during Year 7 will be the major contributions to the literature for the AMSM project.

Bibliography of Project Related Publications

- Manning, J.; Verfaillie, M.; Barker, C.; Berg, C.; MacFadyen, A.; Donnellan, M.; Everett, M.; Graham, C.; Roe, J.; Kinner, N. Responder Needs Addressed by Arctic Maritime Oil Spill Modeling. J. Mar. Sci. Eng. 2021, 9, 201. <https://doi.org/10.3390/jmse9020201> (peer reviewed)
- Kinner, N. Arctic Maritime Spill Response Modeling (AMSM) Workshop Report. (2019) Arctic Domain Awareness Center (ADAC). Center for Spills and Environmental Hazards

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Transition Plan.

Principal transition plan is to create a Knowledge Product to support USCG led Federal on- Scene Maritime Environmental Response in an Arctic context. The Knowledge Product is almost completed and will be submitted on or before August 20, 2021. In addition, a new transition activity was funded for the AMSM project for Year 8 of ADAC. The project team will facilitate an expert working group starting in early September 2021 to determine the exact data feeds from the existing ice forecasting models and services that will be input into the existing U.S. oil spill models (e.g., NOAA's GNOME) to predict the trajectory of oil in ice. Discussions with NOAA modelers has already started to outline the specific topics for consideration among the experts. Once the individual data feeds are determined, coding will occur to get the necessary information from existing ice models/services in the correct format to ingest into the oil spill models. Finally, a tabletop exercise will be conducted to test the speed and seamlessness by which the ice inputs are feed into the spill models and the reliability of the subsequent oil trajectory outputs. The result of this effort will be a modification to GNOME that will allow NOAA to provide better predictions of where oil will move in ice infested waters, helping USCG make more informed decisions. In addition, the CEOMIO table will be tested to gauge its utility in providing detailed information to FOSCs on sources of uncertainty associated with the model predictions during spill response.

The Knowledge Product and corresponding peer-review journal article will be promulgated across USCG, ICCOPR, and NOAA and via the ADAC and CRRC/CSE networks. The knowledge gained from this project will be directly transferable to HQ USCG Maritime Environmental Response, NOAA ORR and its Emergency Response Division (ERD) team, which is represented on the Core Team. This is important because NOAA ORR is responsible for providing scientific support to USCG during maritime incidents, so its oil spill modeling must be fully adapted to the varying and unique conditions in the Arctic. The Project PI also anticipates that much of the knowledge gained and consensus reached will be used by the private sector and other government agencies within and outside of the U.S., as well as NGOs. Many proprietary models exist (e.g., SIMAP) for use in the Arctic during spills, it is likely that they will also benefit from the consensus approach to modify their oil spill response modeling products, as needed.

Relevance to USCG and Public Good.

ADAC and the Project Team note it is imperative that effective models be available for use during oil spills. Oil spill response modeling may be used as the basis to respond to numerous questions that an FOSC may need answers for during a spill response. For example, the modeling outputs may be used to predict the trajectory or path and future location of the oil slick. This information is also valuable in determining whether there are habitats or species that may be at risk from oil exposure or contamination and the extent to which habitats or species can/must be protected. Modeling during response may also be used to estimate oil weathering - the physical changes that result when oil is released into the environment. Decision makers may use response modeling to inform stakeholders and the public about the location of the oil slick. Further, response modeling is useful to predict/evaluate the performance/ success of various response alternatives (such as mechanical equipment, in situ burning and dispersant application). Understanding response needs, particularly

those of the FOSC and associated response Unified Command, balancing evolving technologies with realistic response capabilities, ensuring data access and integrating forecasts and analysis into operations are all areas for consideration in spill response modeling (CRRC, 2008). Effective response modeling must consider availability and standards for data access, needed time/length scales of meteorological/ocean data, and non-transport modeling needs (i.e., wave or water level forecasts for salvage operations). In addition, the model must consider biological metadata in order to integrate consideration of natural resources with fate and transport forecasts (CRRC, 2008). Spill response modeling has been a focus of UNH's CRRC and its sister center the Center for Spills and Environmental Hazards (CSE) since 2006 when this team facilitated a workshop for NOAA ORR on "Innovative Coastal Modeling for Decision Support: Integrating Physical, Biological and Toxicological Models.

CRRC and NOAA ORR facilitated a Spill Modeling Summit in June 2007 that concluded a Working Group was needed to move ahead. From 2008 to 2011, the Oil Spill Modeling Working Group (OSMWG), consisted of 30 modelers, responders and scientists who had the common goal of developing new 3D algorithms. OSMWG subgroups created associated working documents on topics such as spreading, water in oil emulsification, time-length scales, as well as a matrix of existing models that included dispersants, skimming, in situ burning and booming. The matrix included the inputs and outputs on fate, transport and biology, and the gaps in the models with respect to these processes.

In the wake of the Gulf of Mexico Deepwater Horizon spill, four GOMRI consortia have focused on modeling: Consortium for Advanced Research on Transport of Hydrocarbons in the Environment (CARTHE), Dispersion Research on Oil: Physics and Plankton Studies (DROPPS), Gulf of Mexico Integrated Spill Response Consortium (GISR), and Center for Integrated Modeling and Analysis of Gulf Ecosystems (C-IMAGE). Numerous publications and model advancements have resulted from the efforts of these consortia and some of GOMRI's independent grants-funded projects. Coincident with these efforts, federal agencies such as BOEM (Bureau of Ocean Energy Management) and BSEE (Bureau of Safety and Environmental Enforcement), Environment Canada (EC) and Fisheries and Oceans Canada (DFO)/U.S. Environmental Protection Agency's research have resulted in model advancements. Concurrently, modeling work has been funded through the American Petroleum Institute (API), and Oil and Gas Producers. The sum of these efforts has resulted in numerous modeling advancements, but there have been few efforts to coordinate their findings and their impact on oil spill response modeling.

Several global ocean and ice models (e.g., NWS, EUROGOOS) and oil spill trajectory and weathering models (e.g., GNOME, ADIOS, SINTEF OWM) exist that can be applied to spills in the Arctic. A few of these are actually coupled trajectory and weathering models. Among existing models, the Oil Spill Contingency Response (OSCAR) program developed by SINTEF is an advanced software tool used to predict the fate and transport of spilled oil in ice-covered waters. In addition, the Russian State Oceanographic Institute model "Spill Mod" predicts spreading of oil in between fixed ice floes (Afenyo, Veitch, & Khan, 2016).

An effort put forth by the International Association of Oil and Gas Producers (IOGP) in support of the Arctic Oil Spill Response Technology- Joint Industry Program (JIP) is working to improve Arctic trajectory and fate models (French-McCay et al., 2017). Olason et al. (2016) advanced oil spill trajectory forecasting models by introducing new sea ice rheology's and validation techniques. ADAC

is currently transitioning its Arctic Oil Spill Modeling (AOSM) project, which provides an analytical model, designed to estimate the spread of oil released in an ocean environment under ice due to a well blowout, ruptured pipeline or among ice due to a ship grounding. AOSM is currently in transition to NOAA's General NOAA Operational Modeling Environment (GNOME).

Arctic oil spill response models must also quantify the uncertainty of their outputs to better guide decision-making. Furthermore, in a crisis response, modeling must be done in the relatively short time scale, aligned to rapid decision-making windows that are dictated by emergency oil spill response, while addressing the unique complications of ice, adverse weather, international waters, and lack of response equipment

The project team has comprehensively sought to identify the current state-of-the-art Arctic maritime oil spill response modeling, potential integration of these models, and specific needs to be addressed to obtain models that will be functional and effective in the response time scale to advance the FOSC's decision making during an incident and improve the experience gained from exercises and drills.

The investigators formed a core group of multi-disciplined experts who examined the limitations of current spill modeling for the Arctic and structured a workshop to establish a comprehensive campaign formation of Working Groups related to establish improved understandings in specific response model components/criteria determined for future modeling. The findings from these groups will be used to draft sections of the Knowledge Product that will be developed and integrated into the final Knowledge Product.

The investigators have successfully collaborated with Arctic-oriented maritime spill response modeling communities as well as responder perspectives from both USCG and Alaska Department of Environmental Conservation. In addition, researchers have examined potential Arctic spill scenarios (well blowout under ice, pipeline spill under shore fast ice, and a large vessel spill of combinations of oil in the shoulder season) and answered questions related to: responder needs that can be addressed by modeling, limitations of ice in response modeling, observational gaps, and potential updates needed for existing algorithms and process understanding. Working groups are now underway in advancing understanding of oil-in-ice interactions, new and existing technologies for filling data gaps for modeling, and how to improve visualization and uncertainty when communicating model results.

Arctic Ice Conditions Index (ARCTICE)



Project Investigators: Dr. Jifeng Peng, University of Alaska Anchorage.

Project supporting investigators:

Dr. Shawn Butler, University of Alaska Anchorage; Dr. Jinlun Zhang, University of Washington; Kelsey Frazier, University of Alaska Anchorage. Sam Cheung, U.S. Coast Guard Research & Development Center (RDC). U.S. National Ice Center and Canadian Ice Services.

Lead Institution: University of Alaska Anchorage.

Project Description:

Abstract.

In collaboration with USCG and other government agencies, the ADAC team is developing Arctic Ice Condition Index (ARCTICE). In this project, the team is focused on the ice laden waters of the Bering, Chukchi and Beaufort Seas (corresponding to the U.S. Arctic Extended Economic Zone (EEZ)). The project produces an easy-to-understand numeral to communicate ice conditions that are relevant to the capabilities of an individual vessel. This index will be available for current and future ice conditions, providing forecasts from 72 hours up to 1 month in advance. Based on completed and transitioned Great Lakes ICECON investigations, proposed research will result in providing marine operators a transition destination ready access to this information, in particular the U.S. National Ice Center (USNIC) and the Alaska Ocean Observation System supporting vessel captains and officers in route planning and in determining associated risk with traveling through a particular region in the Arctic Waters.

Similar to the completed project creating ICECON for the Great Lakes region, ARCTICE research, guided by the USCG-led “council of experts” will create a visualized decision support product, a numeric index that combines marine vessel size, gross tonnage and hull strength polar classification to contrast against current and forecast ice of the planned route of sail, to provide USCG and shipmasters improved safe passage insight in Arctic ice laden waters. In order to achieve improved usefulness and utility, ARCTICE will include an inclusive and iterative process principally with meteorological, marine traffic, and safety experts.

In order to provide vessel masters environmental data to create an ARCTICE decision support tool, the decision support will leverage existing (and will be able to select between) available sea-ice characterization models. It is important these factors include and model (forecast) available Arctic region ocean current, sea-ice presence, thickness, movement and ridging factors.

Accordingly, project researchers plan workshops and seminars (using distant technologies as appropriate) in coordination with USCG D17 to collaborate with ice and maritime transportation experts. These experts are from a range of organizations including (but not exclusive to): NOAA, the U.S. National Ice Center, the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), USCG RDC, USCG D17, Transport Canada, the Canadian Ice Service, the Finish

Meteorological Institute, and the University of Alaska. Transitioned ARCTICE is planned to publish to U.S. National Ice Center and will be readily to USCG D17 and Arctic mariners.

Summary of Project Accomplishments

In combination with experience from Great Lakes ICECON, extensive research, and customer input, ARCTICE created a mariner decision support tool for vessels principally operating in the U.S. EEZ, specifically the Bering, Chukchi, and Beaufort Sea regions, and secondarily operating in the waters of the North American Arctic. This planned research investigation leveraged guidance from a USCG led Council of Experts and utilized environmental models for sources of ocean currents, sea ice presence, movement, thickness, and ridging. In line with metrics associated with Great Lakes ICECON, Researchers developed ice indices based on the International Maritime Organization's Polar Code "POLARIS amendment" as the communication tool for mariners, providing these indices on a current and forecast basis, with the possibility providing hindcast data as well.

ARCTICE delivered the mariner support tool to a web-based operational destination as determined and coordinated via the planned USCG led, Council of Experts (to include USNIC products and NOAA's Arctic Environmental Response Management Application (Arctic ERMA). This website is hosted by Axiom Data Science and is under construction as part of Year 8 transition activities. The website can be located here (temporarily): <https://adac.portal.axds.co/#>.

After receiving approval for the ARCTICE project in ADAC Program Year 6, the project team developed an initial algorithm using the index method outlined in POLARIS. The POLARIS amendment outlines the relationship between input environmental parameters and the output ice condition numeral as a function of ice class, season of operation, and vessel operational state (i.e., independent operation or icebreaker escort). This method may appear similar to the Transport Canada AIRSS method, but the POLARIS method considers vessel speed/escort operations, as well as seasonal ice decay and ice strength. While escort operations are not currently planned for the US EEZ, the influence of ice decay and strength is an important factor.

The ARCTICE also accomplished the following items:

1. *Provide and confirm the ARCTICE vessel classification index.*

The Polar Code uses the International Association of Classification Society (IACS) Polar Class Unified Requirements and the Finnish-Swedish Ice Class Rules (Baltic Ice Class). The project team has identified the correlation between the Polar Class/Baltic Ice Class and the ABS Ice Class. Researchers also compared the differences in Arctic vessel classification systems established by Polar Code and by American Bureau of Shipping (ABS). Both the Polar code and POLARIS use a Polar Class classification system (PC 1 to PC 7) from the International Association of Classification Societies (IACS). ABS uses Arctic class (A5 to A1); and Baltic ice class (A0 to E0).

The ARCTICE team also surveyed the AIS data available in the Bering, Beaufort, and Chukchi seas. Unique MMSI IDs were pulled for vessel information, allowing the team to better understand the current state of Arctic and sub-Arctic shipping. Looking specifically at July and September of 2017, the team found an overwhelming majority of the vessel traffic had been

freight and towing vessels. Curiously, there were multiple instances of Russian and Chinese icebreakers passing through the Chukchi.

2. *Investigate other national models (in particular, Canadian programs).*

The project team has investigated the Arctic Ice Regime Shipping System (AIRSS) as a regulatory standard for ice condition used by the Canadian authority. It is the basis of the POLARIS in the Polar Code and very similar to POLARIS. The research team also did a review of other national ice charts as they were related to vessel navigation through ice. Output from these nations follows the IMO's guidance in the Polaris amendment of the POLAR code. The team was satisfied that following the Polaris amendment would offer a high degree of interoperability for Arctic mariners and that this was a prudent path to follow in the development of ARCTICE.

3. *Determined suitable environmental factors and developed public access method*

The research team, having established which environmental factors are necessary for the ARCTICE algorithm, investigated available environmental models from which to collect the necessary inputs. Due to the necessity of sea ice partial concentrations from a potential model, and the desire for a high resolution of 1km, HIOMAS was selected as the best option.

Due to bandwidth issues at high latitudes, ARTICE was developed to output in two formats. Namely, .png files to accommodate low bandwidth access users, which will offer low resolution data, enough for vessels to identify whether significant changes to the ice pack have occurred, and whether they need to adjust course. For vessels with a higher bandwidth availability, geotiff output files will be provided for integration with ArcGIS and other software.

4. *Create, and then optimize a forecasted, numeric Arctic ice condition index for Arctic waters*

At the onset of the project, the team included the idea that the forecast would need to be optimized to marry observable ice conditions with the modeled conditions. This was an important learning from the Great Lakes ICECON project. As the team discovered, optimization is not a necessary component. This is due to the methodology employed by the project team. Using the Polaris amendment meant that the process by which the RIO is calculated was vetted by international experts in the area of Arctic vessel/ice interactions. Therefore, the team feels optimization is not a necessary component for this project. Further, the team feels that year 7 tasks, namely the validation of the project output, will prove that the model is accurate and effective in their claims.

The project team created an experimental ARCTICE algorithm using a software program called MATLAB. The algorithm pulls environmental data, as defined above, from HIOMAS, calculates the RIO for a region, and generates the color maps illustrating RIO values for a given vessel polar class.

The project team created ARCTICE visualizations. While the creation of ARCTICE visualizations is a year 7 task (Task 7 in the workplan), the team felt it necessary to graphically output the RIO values. To that end, the team was able to start working ahead on

their tasks. There is still much to accomplish, per the workplan, however important strides have been made in this area.

The research team accomplished the following in Program Year 7:

- *Integrated the index to a visualization tool as an aid to vessel mariner planning and underway activities.*

This research task takes the calculated ARCTICE to display for operator reference. This chart is similar to the ArcGIS map produced by USNIC in connection to the Great Lakes ICECON project. The recommendation from the experts at D17 and USCG HQ was to offer a broad area/low resolution chart, augmented by a limited area/high resolution chart. Options to overlay or do a side-by-side comparison with hindcast data are also included. Further, ARCTICE charts should be accessible by both desktop and mobile web browsers, offering the widest access possible.

- *Automate a forecast numeric Arctic ice condition index for Arctic waters.*

After establishing the numeric ice condition index for Arctic waters based on the POLARIS index from the Polar Code, the ADAC team collaborated with Axiom Data Science to develop computer scripts to automate the process of calculating the ARCTICE index. The scripts automatically obtain input source data from HIOMAS, run the ARCTICE script, generate POLARIS index plots, and publish the plot on a server.

- *Researchers completed coding the ARCTICE algorithm.*

The coding of the forecast numeric Arctic ice condition index for Arctic waters was completed in the first quarter of Year 7. This experimental algorithm was written in the scientific software package MATLAB. The algorithm uses environmental data from HIOMAS, calculates the risk index outcome (RIO) for the Arctic region based on methodology from the Polaris amendment to the Polar Code, and provides output color maps illustrating RIO values for a given vessel polar class.

- *HIOMAS was updated from 8 to 24 ice categories.*

During the development stage, the research team discussed increasing the accuracy of the ARCTICE algorithm using more refined environmental data from HIOMAS. In HIOMAS, there are 8 categories for partial sea ice concentration provided as output. The ARCTICE algorithm received these categories, then linear interpolation was employed to calculate the 12 partial sea ice concentrations the Polaris RIO requires. It was determined that if the 8 categories could be increased, then the error potential from using linear interpolation methods could be reduced the accuracy of the Polaris RIO would be increased. Dr. Zhang agreed that the partial sea ice concentrations in HIOMAS could be enhanced. He completed work to change the partial sea ice concentration output from 8 categories up to 24. Axiom Data Science integrated these changes and updated the HIOMAS model.

- *ARCTICE (based on the 24-ice category input) is automatically calculating RIO plots.*

Once the experimental algorithm was completed, the research team worked with the team at Axiom Data Science to automate the algorithm. This ensures that, as HIOMAS output is

available, the algorithm automatically receives the environmental data, runs its RIO calculations, and generates output plots. The algorithm is currently running on Axiom servers and providing output for validation efforts in the third quarter. The algorithm was updated to use the 24-ice category input once data from the new model was available in the third quarter.

- *The project team created ARCTICE visualizations.*

While the initial test of ARCTICE visualizations was accomplished in year 6, the research team completed this task in year 7 in the second quarter. This included expanding the output to provide plots for 12 separate ice classes (Polar Class: PC1, PC2, PC3, PC4, PC5, PC6, PC7; Baltic Class: 1a super, 1a, 1b, 1c, and no class).

- *RIO plots are available for 1 month in advance.*

Once the project team integrated the index into a visualization framework, the team then ensured the output RIO plots would be available in both a now and forecast format. Frequency of these plots are currently available for: current day, 1-147 days, 14 days, 21 days, and 28 days in advance. Examples of these now and forecast plots for a PC5 class vessel are shown below, and all other RIO plots for vessel classes are available upon request.

Transition Plan.

Overall, the ARCTICE transition seeks to replicate the transition planning used for Great Lakes ICECON from research to an operationally relevant tool. For the Great Lakes ICECON, the ADAC team established the ICECON algorithm and collaborated with Axiom Data Science to automatically obtain input source data, run the script, generate ICECON plots, and publish the plot at a server. USCG is able to download the ICECON plots direct from the server. In addition, through an agreement with USNIC, the ICECON plots are also transferred to USNIC to add to USNIC's USCG D9 support data folder. This approach of using a third-party to run the script to generate ICECON plots and to only host the generated plots at USNIC is recommended by USNIC.

For ARCTICE, while noting the USCG led Council of Experts will direct the transition focus and overall destination, the research team notes that a similar approach is desired. The ADAC team will work with Axiom Data Science to establish the operation for ARCTICE script and pursue an agreement with USNIC to host the generated ARCTICE data. In addition to USNIC, the Alaska Ocean Observing System based in Anchorage potentially serves as an alternate or replication of a USNIC destination. In addition to directions and guidance received from USCG D17 and other Council of Expert members, transition planning will need to account and gain input/product feedback from Alaska-based mariners who comprise the bulk of the maritime traffic in the U.S. Arctic waters. The research team has also discussed this topic with USCG D17 during the project feasibility study last year and was recommend by D17 to develop a mobile app for ship-based ice observation data collection on CGC Healy (similar to the mobile app for and the data-collection practice of D9 in the GL ICECON project). This practice of data collection does not require separate missions by USCGS Healy.

Relevance to USCG and Public Good

Year to year and decade-to-decade, marine vessel traffic in the Arctic regions of the Bering, Chukchi and Beaufort Seas is increasing. The rise in vessel traffic is highest in summer months but is also increasing in the summer “shoulder seasons” of spring and fall, and there is even a rise in winter related traffic, due in part from the establishment of Liquefied Natural Gas (LNG) in Arctic Russia, transiting the Chukchi and Bering Sea regions year round. Commercial interests are now exploring the feasibility of an Alaska North Slope LNG operation to carry LNG via ship to markets in lower latitudes. Marine vessels operating in the ice-laden waters within the U.S. Exclusive Economic Zone (EEZ) of the Bering, Chukchi and Beaufort Seas in the Arctic face a number of challenges.

These challenges include long distances between ports of call, communication shortfalls, increasingly difficult to predict weather, limited infrastructure, limited U.S. Coast Guard and other search and rescue forces, and a unique safety challenge to assess how to navigate complex sea ice. Currently, there are limited planning tools to support mariner route and decision-making in sea ice conditions. A real-world example was the USCG D17 rescue of the 36 ft. “*Altan Girl*” inadvertently locked in Chukchi Sea ice in July 2014². Specifically, there is no method to communicate the relative risk due to sea ice conditions and related to specific vessel classes.

The ARCTICE project leans on the research methods developed in the Great Lakes ICECON project. Great Lakes ICECON is a decision support tool combining vessel class with nowcast and forecast, lake ice conditions. Great Lakes ICECON forecasts up to 120 hours into the future and uses circulation and ice models developed by NOAA’s Great Lakes Environmental Research Laboratory (GLERL). Great Lakes ICECON accounts for icebreaker activity and its impact via nowcasts and forecasts. In parallel with the development of Great Lakes ICECON, the research identified and adopted a vessel classification system to define a number of vessel classes and the ice-capability of ships in those classes (in terms of ICECON). The ICECON system supports USCG to provide guidance and appropriate decision support to Great Lakes marine vessels (for a given class) planning a given transit. ADAC researchers have previously delivered a Beta version of Great Lakes ICECON for integration to USNIC and are currently in progress in adapting prior feedback and the current winter season, lake ice associated environmental data to refine and deliver the finalized version.

In order to ensure the safety and security of Arctic vessels, personnel, and the environment, the development of a high resolution, Arctic Ice Condition Index (ARCTICE) is warranted to support Arctic

There are numerous methods for communicating sea ice conditions and each Arctic nation has their own system. Russia and Canada, for example, both have systems to take ice conditions and translate those conditions into the relevant risk of transit based on a vessels’ particular class. Translating between Russian and Canadian systems can be challenging as each nation uses a different ice condition scale and a different vessel classification method. Following the adoption of the International Maritime Organization’s “POLARIS amendment” to the IMO Polar Code, those communication tools are starting to migrate to a uniform methodology. While the IMO has no existing or planned international enforcement privileges, the IMO Polar Code is seen as a “best

practices” guide, many nations require that vessels comply with the code as it reduces the potential risks of death, environmental contamination, and excessive search and rescue support.

The POLARIS amendment to the IMO Polar Code is based on vetted ice condition processes from the Canadian AIRSS system, the Russian Ice Certificate concept, and additional inputs from other coastal administrators. The IMO offers a Polar Certificate to crews that train on, and comply with, the Polar Code. Therefore, crews on vessels traveling on Arctic routes will most likely have a Polar Certificate and will be familiar with the ice condition communication regime outlined in POLARIS. Based on the successful completion of Great Lakes ICECON, researchers proposed an Arctic version of ICECON. Arctic ICECON, called ARCTICE, focuses on those Arctic regions that are most relevant to USCG mission and their waterway management concerns: the Bering, Chukchi and Beaufort Sea areas within the U.S. EEZ. The ADAC team researched the subject and completed a report describing the feasibility of ARCTICE (submitted to USCG on 20 July 2019) based on the available science and information gained from the Great Lakes ICECON project. The study assessed the properties and associated differences between sea and lake ice. As this project is the transition from the Great Lakes to the Arctic Ocean, references were reviewed to establish baseline knowledge of the new challenges ARCTICE would need to address. Sea ice strength is relative to its thickness, stage, and temperature. Brine channels play a key role in the relative strength as well. Operators need to understand how these elements will affect their ability to navigate through water with sea ice.

This research also helped the team better understand both U.S. and international sea ice models. There are many operational and experimental Arctic Sea Ice models, including U.S. Navy Global Ocean Forecast System (GOFS), NOAA Global Real-Time Ocean Forecast System (RTOFS), NOAA-ESRL Coupled Arctic Forecast System (CAFS), Canadian Global Ice Ocean Prediction System (GIOPS), and High-resolution Ice-Ocean Modeling and Assimilation System (HIOMAS), which was developed at Arctic Domain Awareness Center. After careful consideration of each of these models, the project team intends to use HIOMAS for its higher resolution (2-km, pan-Arctic).

Arctic Vessel Monitoring Geofencing/Alert Awareness



Project Investigators: Dr. Shawn Butler

Supporting Team:

Dr. Marcus Boyd, University of Maryland

Joshua House, University of Maryland

Rob Bochenek, Axiom Data Sciences

Lead Institution: University of Alaska Anchorage (UAA)

Abstract.

This project seeks to extend the Arctic Vessel Monitoring Geofencing/Alert Awareness project, initially funded in ADAC Program Year 5, by providing enhanced command and control features that improve on the original goals of monitoring and alert awareness developed for the unclassified Marine Exchange PACTRACS system (which is a commercial mariner application). As CG OneView 3.0, is USCG’s determined common operating picture, which now displays both terrestrial and satellite AIS data, there is a need for a geofencing/alert awareness application that supports Coast

Guard planning and command and control decision making tasks which easily integrates into CG OneView.

In addition, new geofencing capabilities could be implemented with the research outcomes developed in the Arctic Domain Awareness Center's project *Arctic all-Hazards GIS Platform*. The Geofencing/Alert Awareness project oriented to USCG CG OneView in ADAC Program Year 6 focused on the development of requirements and application design.

The objective of this project in Program Year 7 was to extend both CG OneView and develop an initial ADAC geofence/alert notification application that would provide better geofence management and improved alert notification for Coast Guard users. The specific objectives for Year 7 were to:

- Develop an application that would allow Coast Guard users to create new geofences, find existing geofences from a database of geofences, modify one or more of the geofence attributes, and reuse or create altered copies of geofences. Finally, users must be able to delete no longer needed geofences.
- Develop an application that allowed users to create geofences that followed shorelines, and easily define the geofence distance from the shoreline, by specifying the number of nautical miles from the shoreline.
- Implement additional features that help improve planning tasks and operational response to vessels crossing geofences such as:
 - Alert operators when a vessel has crossed a geofence
 - Detect vessels that are approaching (i.e., likely to cross if the vessel doesn't change heading) but have not yet crossed a geofence.
 - Use color to show when a vessel is approaching (yellow)/crossing a geofence (red) so that operators can instantly see the geofence and vessel that is approaching/crossing.
- Develop an application that could easily integrate into the CG OneView Architecture.

Summary of Project Accomplishments

Through a select team of experienced computer information systems architects and working with U.S. Coast Guard stakeholders in Alaska and Virginia, the research team is developing a CG One View prototype following a modified *agile* software engineering development cycle. Since the two primary objectives of this project is 1) to produce a working prototype that meets user requirements and 2) can be integrated into CG One View with minimal effort, then the two primary stakeholders are the coast guard users at the Anchorage Sector and the CG One view technical integrators.

The USCG D17 Sector Anchorage has committed to working with the project team in prioritizing and reviewing geofencing functionality as it is developed. Researchers expect to show end users incremental functionality as frequently as every two weeks once the foundation is developed. Based on their feedback, investigators will update the parameters and implement their requested changes. The agile software development process supports the flexibility that a software developer needs to ensure that the final product is very close to what the user needs.

The CG One View technical developers agreed with the investigation team during coordination meetings in Program Year 6 in confirming '*continuous integration*' as the preferred process to

ensure minimum integration issues during transition. Continuous integration ensures that the developers frequently integrate new features to minimize the possibility that the two software baselines (CG One View and Geofencing) diverge as software changes. A continuous integration process will result in a product that can become part of CG One View without major modifications, ideally quickly getting the capability into the hands of those that need it most.

Key Accomplishments in 2019 and 2020 include:

- (PACTRACS geofencing) Developed new PACTRAC geofencing and push notification alerts per the initial project objectives.
- (PACTRACS geofencing) Identified established environmentally protected areas where application of the geofencing tools should be pre-populated in the software.
- (PACTRACS geofencing) Developed web accessible tool to request AIS generated alerts or reports for agencies and other authorized stakeholders. The tool is located on a newly created public website at www.alaskageofence.org.
- (PACTRACS geofencing) Investigator discussions with stakeholders highlighted the need for a communications tool to explain how the geofence tool works. Accordingly, we developed a stop-motion graphic animation to explain functionality and important applications in Alaska marine waters that can be found at <https://vimeo.com/418261996>. The educational video is posted on the www.alaskageofence.org website.
- (CG1V geofencing) Developed more than 120 functional geofencing requirements for CG OneView. Most of the functional requirement will result in 3-4 additional sub-requirements once development begins.
- Coordinated with the CG OneView program office to obtain the technical information necessary to develop an application that can integrate with CG OneView. As CG OneView was designed to allow third-party developers to contribute applications, geofencing will be the first application attempting to do so.

Key Accomplishments in Program Year 7 (July 2020 – June 2021)

1. The project team developed an application that can create geofence polygons that can be shaped to follow geographical land features such as shorelines and bathymetry contours.
 - a. The geofences can be created to follow nautical miles distances from shorelines and include 3 layers of geofence to indicate ships that are: approaching a geofence, ships that are exceptionally close to crossing a geofence, and those that have crossed a geofence.
 - b. Users can copy, modify, or delete an existing geofence.
 - c. The geofence application can communicate with CG OneView so that geofences can be displayed within the CG OneView Operations display
 - d. Users can define geofence alerts and are notified when a vessel crosses a geofence boundary.
2. The project team worked with the CG OneView Developers to implement and fine tune a messaging system between the geofence application and CG OneView. The messaging system allows geofence users to manage geofences and changes are communicated via the messaging system to the CG OneView operational display.
3. The project team met with USCG Anchorage Sector to demonstrate the application's geofencing capabilities and received positive feedback on the application as well as

additional requirements that users would like to see added to the application. Although several additional requirements were captured, some of the more urgent requirements were:

- a. The ability to share geofences within the Coast Guard.
 - b. Fine grained alert management. For example, alert only on vessels with specified attributes such as vessels exceeding a specific tonnage.
 - c. Integrate with the Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) database
 - d. The ability to create dynamic geofences
4. The project team worked closely with the CG OneView developers to ensure the application could integrate into the CG OneView suite of applications with minimal modifications.
- a. The project team followed CG OneView documentation and continuously tested the application interfaces with CG OneView.
 - b. The project team developed an initial set of documentation that will accompany the application when it is transferred to the Coast Guard.

Transition Plan.

The primary output of the project is new software capable for integration to USCG's CG OneView. The research team will incorporate the new software into USCG hosted to CG OneView/Homeland Security Information Network (HSIN) parallel to completed PACTRACS developments.

Since a version of the project will also be completed using the Ozone Widget Framework and coordinated with the CG OneView project office, the transition of the enhanced features should be relatively straightforward. Although this project will be using a slightly different version of the Ozone Widget Framework, conversations with the CG OneView project office indicated that the differences between the two architectures would be minor. All software and documentation will be turned over to USCG for inclusion into the next planned version/edition of CG OneView.

As the geofencing application was being developed, the project team worked closely with the CG OneView lead developer to ensure that the project team developed a messaging system that could communicate within the CG OneView Architecture. This was tested frequently and demonstrated to Anchorage Sector May 12th, 2021. The Lead Software developer anticipated that the application would be able to integrate with CG OneView within 30 days, or sooner, after final delivery. The ADAC application team documented the application as they progressed working with the lead CG OneView developer.

Relevance to USCG and Public Good

The ADAC geofencing project completed in Program Years 5 and 6 by the Maritime Prevention and Response Network and the Alaska Marine Exchange resulted in a geofence/alert capability for static and dynamic targets available for USCG access via the PACTRACS system operated by the Alaska Marine Exchange. This capability is also available to other members of the Alaska Marine Exchange and supports the mariner community across Alaska and the U.S. Arctic region. The parameters and needs developed for this previous project coupled with mission needs solicited from the Anchorage Sector, 17th Coast Guard District during year 6, identified a significant number of additional operational needs for geofencing to fully support Coast Guard CG One View planning and operational activities. Informing the baseline of new CG One View investigations is the completed work that has

been incorporated into the Alaska Marine Exchange PACTRACS application which supports safety and maritime domain management for mariners.

The early stage of investigations collected US Coast Guard's geofencing mission needs and develop an integration strategy with the All Hazards Web GIS (AHWG) application and CG One View. The project team has evaluated the All Hazards Web GIS application to determine how geofencing might be integrated with the AHWG application, and what additional development is necessary to have a functional geofencing capability. In addition, researchers developed geofencing mission needs, and requested additional baseline needs from the CG One View program manager. In addition to the USCG functional geofencing mission needs, it is essential that we sufficiently understand the CG One View architecture and design parameters so that researchers can seamlessly integrate into CG One View when the project is complete.

While the original plan was to establish Geofence within PACTRACS that supports USCG D17 and Alaska/Arctic mariners, in accordance with Project Champion direction, researchers received the Program Year 6 added the task to accomplish a duplicate process within USCG CG One View. This includes the establishment of the Ozone Widget framework to develop basic geofencing capability to allow static geofence and conducted test notification and alerts with agencies and coastal communities, which have successfully monitored sensitive areas such as marine mammal sanctuary in remote islands in the Bering Sea. The team has also accomplished dynamic alerts that can monitor vessels underway. The PACTRACS edition of the project team has developed, refined and implemented PACTRACS alerts process to include visual alerts in addition to Email alerts, useful for marine system watch-standers, to include USCG D17 command and control personnel who monitor PACTRACS in the USCG D17 Command Center.

Accordingly, ADAC investigations have completed the PACTRACS software developments, while the USCG CG One View edition developments have been prepared in support of HQ USCG CG One View program manager, as coordinated by the HQ USCG Project Champion. During ADAC Program Year 6, the project coordinated with CG One View technical developers to identify key components of the current CG One View system architecture that will allow the geofencing prototype to integrate with CG OneView Components. One of the key objectives of this project is to deliver a prototype that can be relatively easily integrated with CG One View. In coordination with the CG One View technical developers we will use the year 6 geofencing design and mission needs as the baseline to begin development of the Geofencing prototype.

Alaska and Arctic Maritime Communications and Connectivity Analysis (AAMC&CA)



Project Investigators:

Dr. Doug Causey, University of Alaska Anchorage

Dr. Mark Ivey, Department of Energy

Mr. Jason Roe, USCG (Ret)

Lead Institution: University of Alaska Anchorage

Project Description:

Abstract.

This project provides a comprehensive review of mariner communications and connectivity mission needs for the Alaska and the U.S. Arctic Extended Economic Zone (EEZ), with a particular focus on the Arctic (based on near, mid-term, and long-term time horizons). The investigation will take a sequenced and iterative approach, beginning with a comprehensive literature review, the establishment of a Core Advisory Team, and the development of detailed working groups. These phases will inform and drive the development of a detailed qualitative market survey, which will serve as the primary data-gathering stage in which key stakeholders will identify gaps and shortfalls related to maritime connectivity needs in their respective regions, industries, and communities. The culmination of the latter phases will inform an expert assessment, leading to the creation of a draft knowledge product, which will be assessed and finalized through a final capstone workshop. The principal focus of this planned series of investigations is to review current-to-long term mission connectivity needs, and to assess current and emerging technologies in order to derive an expert-driven comprehensive knowledge product.

Summary of Project Accomplishments

- Completed Phase 0: Conducted a virtual conference with HQ USCG Project Champion, USCG Stakeholders and USCG technology developers.
 - Alaska and Arctic Maritime Communications and Connectivity Analysis Project Investigators held the project virtual conference and project kickoff meeting on 2 February 2021. The meeting was attended by the Project Champion and included representatives from DHS S&T OUP, USCG 5PW, CG-761, CG-926, D17; Sandia National Labs, Arctic Slope Regional Corporation (ASRC) Federal Mission Solutions, Alaska Chadux Corporation, Marine Exchange of Alaska, Ukpeaġvik Iñupiat Corporation, Alaska Ocean Cluster, National Oceanic and Atmospheric Administration, and Alaska Ocean Observing System.
- Completed Phase 1: Conducted a Comprehensive literature review.
 - ADAC Student Fellows Rachel Lewis and Tristan Goers completed the first draft of the literature review. AAMC&CA Project Investigators edited the document and sent onward to Sandia National Labs and Arctic Slope Regional Corporation (ASRC) Federal Mission Solutions for further content additions. The AAMC&CA literature review can be found at: https://arcticdomainawarenesscenter.org/P30_AAMCCA
Note: The Literature Review is intended as a project working document designed to be periodically updated as needed throughout subsequent phases of the project.
- Completed Phase 2: Forming of project Core Advisory Team. Associated with project initiation, the Project Investigator organized a kickoff meeting with HQ USCG designated Project Champion and “Core Team,” which serves to steer the project in subsequent phases.
 - The Project Core Team was formed, and the first meeting held on 22 February 2021. The Core Team includes representatives from Sandia National Labs, Arctic Slope Regional Corporation (ASRC) Federal Mission Solutions, Alaska Chadux Corporation, Marine Exchange of Alaska, Ukpeaġvik Iñupiat Corporation, Alaska Ocean Cluster, National Oceanic and Atmospheric Administration, and Alaska Ocean Observing System. The Core Team has held 6 subsequent meetings (as of 12 July) and continues to meet on a monthly basis, providing guidance and direction to the Project Investigators.

- Completed Phase 3: Engaging the Community: conducted virtual Meetings across the communities of interest. The principal effort of this phase is to determine communications and connectivity needs via Virtual Meetings of the Core Team and Key Stakeholders.
- The Project Team conducted five “Engaging the Community” virtual meetings in each region beginning 29 March ending on 25 June 2021, completing a total of 30 meetings. Meetings were planned for 90 minutes and were supported by AAMC&CA Project partners including Sandia National Labs, Arctic Slope Regional Corporation (ASRC) Federal Mission Solutions, Alaska Chadux Corporation, Marine Exchange of Alaska, Ukpeaġvik Iñupiat Corporation, Alaska Ocean Cluster, National Oceanic and Atmospheric Administration, and the National Weather Service.
- Initiated Phase 4: Established virtual Working Groups. The principal task in this phase is forming and providing onward investigations via Alaskan and Arctic Maritime Connectivity Virtual Working Groups.
- Working Groups include the following topics:
 - Arctic Working Group
 - Non-Arctic Working Group
- Initiated Phase 5: Conducting a virtual (or hybrid) assessment. The principal task in this phase is planning and conducting an Alaskan and Arctic Maritime Communications and Connectivity Analysis Three-Part Virtual (or hybrid) Assessment.

Transition Plan.

Principal transition plan is to create a research knowledge product to support USCG led communications and connectivity modernization efforts. The Comprehensive Research Report and corresponding peer-review journal article will be promulgated across USCG in accordance with HQ USCG Project Champion desires. The knowledge gained from this project will be directly transferable to HQ USCG CG 5PW, CG7 and CG926, in which the project team will seek to be represented on the project Core Team. In accordance with direction from HQ USCG Project Champion, ADAC will also inquire as to suitability of completed knowledge product to potentially support Arctic communications developer as part of the Center’s efforts to connect research activities and outcomes to commercial entities. This includes meetings with industry as described in the overall center management activities, and in particular, ADAC’s Program Year 7 Industry Day.

Relevance to USCG and Public Good.

Communications and connectivity challenges in the maritime regions of the high latitudes has been highlighted as a concern by USCG and other marine operators for many years. As recent as fall 2019, ADAC informal feedback indicated the USCGS Healy steamed into the high Arctic without communications connectivity for several weeks. A significant number of similar incidents are well known across the Arctic mariner community. Outside the polar-regions, the world is increasingly interconnected, enabled by vast investments in telecommunications, both terrestrial and space-based. Meanwhile, Arctic mariners continue to operate in a largely communications denied environment, unable to connect ship to shore or ship to aircraft (and vice versa) for weeks at a time.

Accordingly, As ADAC's mission is to seek solutions that "enable the decision-maker" in advancing Arctic domain awareness, this project is proposed is to take a proven ADAC research method and apply this method in address a known and high priority problem for the USCG.

As identified by the U.S. Coast Guard's 2019 Arctic Strategic Outlook (ArcSO), USCG identifies communication shortfalls as the critical gap in achieving high latitude domain awareness.³

Specifically highlighted in the 2019 ArcSO: "The high latitudes suffer from poor propagation of radio signals, geomagnetic interference, scant landside infrastructure, and limited satellite coverage and bandwidth. Some Arctic communities have cellular phone networks, but these are often constrained by limited coverage, capacity, and reliability. Closing the communications gap is a whole-of-government challenge and will require intensive partnerships across the interagency, industry, and the international community, as well as the State of Alaska and Alaska Native communities. As commercial, recreational, and subsistence-based activities increase, the Coast Guard must also work cooperatively to enhance communications with and between stakeholders."

ADAC's Arctic-focused Incidents of National Significance (Arctic IoNS) workshops conducted in 2016 and 2019 identified shortfalls and gaps in coordinating crisis response operations to cope with workshop scenarios of a disabled cruise ship in Arctic waters (Arctic IoNS 2016) and emergency response for a large coastal region in the aftermath of a large destructive storm (Arctic IoNS 2019). In particular, satellite, cellular, Very High Frequency (VHF) coastal land-mobile radio communications along with associated digital domain awareness capabilities (such as GIS products to visualize the domain of interest) were identified as critical to effect rapid coordination and cited in both the preparatory literature reviews and workshop findings as a routinely identified, yet unaddressed shortfall.

Modern GIS products, enhanced weather and nautical charts, and shipboard cloud-based computing continue to advance. This array of improved aspects that advance domain awareness all require modern, technologically advanced data connectivity, which is largely denied in the high latitudes. As the USCG seeks to extend its reach beyond its vessel platforms operators will need to routinely leverage unmanned and autonomous, high resolution imagery, and multi-spectrum sensor technologies with increasingly demanding connectivity requirements. Accordingly, USCG platforms operating in the high latitudes should seek modern communications and connectivity technologies to meet these demands by investigating technological advances for the most suitable near-term and long-range solutions.

While, acknowledging the USCG will address certain current shortfalls with near-term commercial-off-the-shelf solutions, there is value in studying and assessing needs for some short-term, and multiple mid-to-longer term horizons in order to support USCG Leadership's ability to plan and program processes that field next generation capability. In order to address technological horizons that

³ https://www.uscg.mil/Portals/0/Images/arctic/Arctic_Strategic_Outlook_APR_2019.pdf

closely align with USCG Arctic operational needs, innovative and new technologies should be researched, needs clearly defined, and corresponding solutions rationally identified and suitably presented to lower costs, increase reliability, and reduce risks for follow-on systems. Based on the growing number of operating vessels and international competition in the Arctic, and the ultra-low bandwidth and utter unreliability of existing connectivity systems, the strategic importance of closing these critical gaps will only continue to grow.

Development of Propeller Driven Long Range Autonomous Underwater Vehicle (LRAUV)



Project Investigators: Ms. Amy Kukulya, Dr. Jim Bellingham (WHOI), Mr. Brett Hobson (MBARI)

Lead Institutions: Woods Hole Oceanographic Institution (WHOI) and Monterey Bay Aquarium Research Institution (MBARI)

Supporting Team: Brian Kieft, Ben Raanan (MBARI), Daniel Gomez-Ibanez, Noa Yoder, Amanda Besaw, Ryan Govostes, Steven Seeberger, (WHOI),

Abstract.

The Propeller Driven LRAUV System is a proven helicopter-portable platform, with corresponding communications buoys which functions as a multi-mission capable system in Open Ocean or under-ice. Through designing, fabricating and testing two platforms, two sets of sensing capabilities and three communication and navigation buoys, the LRAUV project team is providing a suitable deployment package to support USCG-led Arctic oil spill response and associated incidents of national significance (IONS). In sum, the ADAC LRAUV project, led by WHOI and MBARI, creates a rapid response solution to incidents occurring in the maritime environment, and increases situational awareness by characterizing the undersea and under-ice conditions of ocean surroundings, autonomously, and capable at great distances from first responders in an Arctic maritime crisis.

Increasing level of commercial marine activity in high latitudes creates an ever-growing risk of oil spills in ice laden waters. Characterizing oil spills in remote and austere Arctic locations is a daunting challenge to the U.S. Coast Guard. Through 7 years of focused research and engineering, the LRAUV team at WHOI and MBARI have taken the original baseline Tethys Autonomous Underwater Vehicle (AUV), created by a team at MBARI ten years ago, through a significant re-design effort, and have developed and fabricated a specialized portable long-range Arctic-capable Tethys platform equipped with oil sensors, new software and navigation systems.

Through seven years of investigations, in addition to creating (1) an under-ice capable LRAUV, the project team has (2) provided demonstrations of the LRAUV survey capability, (3) created a simulator for establishing Standard Operating Procedures (SOP) related to AUV oil spill deployments, (4) designed and created three communications and navigation agnostic Arctic buoys, (5) designed and fabricated exchangeable nose sections with communications and homing capabilities and a mechanical retrieval and docking capability for ease of shipborne handling and recovery as well as docking for extended periods of time to extend mission duration, (6) completed a review of a reduced cost design for USCG leveraging additive manufacturing; (7) demonstrated LRAUV system in extensive open water tests in real world oil seeps in Santa Barbara Channel California (8) tested LRAUV in fresh water under ice in northern New England (9) demonstrated helicopter portability

through a USCG Jayhawk helicopter demonstration (10) Exercised over-the-horizon missions out to the continental shelf (11) Ran 11+ day science mission testing new anomaly detection and front tracking capabilities (12) filed a provisional patent on the technology and capability (13) developed a backseat CPU capability for sensor and behavior development at WHOI and beyond (open-architecture) (14) developed drivers for inertial navigation and Norbit multibeam integration on a newly implemented ROS backseat (15) Completed redesign and testing of a new, more rugged antenna for open ocean and under-ice and (16) 65% through building a the second LRAUV platform, Stella.

In ADAC Program Year 7, the LRAUV System team's research agenda was focused on fabrication tasks associated with completing the second platform, development of additional software for improved operator-system interface and backseat development, conducting investigations of detailed testing to ensure the platform and communication systems perform in accordance with technical specifications, and expanded under-ice tests to evaluate LRAUV System's performance in cold air/water environments similar to the Arctic. The research agenda also included advancing manufacturing of LRAUV, producing testing documentation and familiarization of USCG personnel and furthering WHOI operators to expand the project into a Center of Expertise for USCG in LRAUV System operations in accordance Project Champion direction.

Specifically, the team worked extensively on system testing of the base platform with a focus on developing user-friendly capabilities for planning, testing, mission development, and furthering navigation capabilities for mapping (LBL) and docking/homing (USBL) in local Cape Cod waters. Additionally, the team procured and is integrating a Norbit multibeam for acoustic detection of oil and gas droplets in an open water and under-ice environment as well as mapping applications. The team worked to develop user friendly software interfaces as well as a 'backseat' capability for autonomy software development needed for new mission behaviors and sensor integration. The team is developing a software simulator in order to be able to 'simulate' missions of LRAUV using the entirety of the system payload as well as real world environmental models (introducing ice models, wind, currents, etc.). This software simulation is also supported by outside funding led by MBARI in order to more rapidly advance its implementation across the LRAUV fleet.

In follow-up to the successful design and engineering accomplishments of the project, in project year 7, ADAC and LRAUV project team continued an additional research and engineering program to (1) advanced collaboration and partnering with the HQ USCG Project Champion designated USCG designated POCs in operating and testing the platform as well as in local districts in New England, (2) work to further and simplify fabrication of an additional LRAUV (spanned over Program Year 6-8), (3) conduct Arctic-readiness tests in local Cape Cod waters, (4) designed and fabricated an additional sensor capability to LRAUV in order to create a multi-mission capable LRAUV including a multibeam and inertial navigation system.

As of 30 June, 2021. the LRAUV project team has provided USCG a state-of-the-art capability in long range Arctic oil spill detection and characterization via an easily deployable package (air, land or sea), advanced Project Champion designated USCG POC AUV competency, created additional LRAUV mission capability to add multiple facets of marine environmental characterization, and conducted extensive platform testing in cold weather conditions to ensure USCG is provided a suitably evaluated LRAUV System. We did not, however, get to test the system under extensive ice or in high latitude conditions due to limitations in travel related to Covid-19.

In parallel to technical development to deliver the LRAUV System to support USCG, ADAC and the research team is conducting investigations for commercialization of the System with industry.

Summary of Project Accomplishments

The goal of this project remains to create an operational system prototype that the USCG can use for characterizing spills in ice-covered ocean environments. ADAC, WHOI, and MBARI focus in advancing LRAUV System will provide and demonstrate a prototype system consisting of two advanced platforms and three Arctic Buoys feasible and suitable for production. Outcomes of effort will provide a commercially available off-the-shelf sensor package that is AUV ready, and turnkey for Arctic seafloor and under-ice mapping. Predicting and monitoring environmental hazards in the Arctic remains an outstanding challenge for under-ice surveys. Our approach builds on proven AUV technology and expands its capability by adding the latest COTS sensor technology for creating 3D maps. Although the current workplan does not include a camera system to augment the acoustic measurements for imaging ice, oil contrast or seafloor features, we strongly recommend adding a visible measurement system in follow-on project years/funding. The power of this technology for investigation of oil spills in open water or under ice remains largely unexplored, but sample data shows strong potential for oil mapping and detection capabilities in the future (Wilkinson, 2007, 2015, Maksym, 2014). The team is also tracking newer, smaller, more effective oil detection sensors and is looking for follow on funding to test and implement on the ADAC platforms in order to keep up with cutting edge COTS capabilities in a time of crisis.

The team achieved several successful underwater docking and undocking missions to a transponder during testing in Woods Hole as well as successful docking under-ice by LRAUV using the Arctic buoy and micromodem system with implementation of reverse thrust and undocking. The team developed and tested firmware for buoys for subsurface capabilities, conducted further evaluation of COTS sensor packages, developed tools and procedures for LRAUV Build-2, and evaluated end of life parts and LRAUV system for improvements and manufacturing. The team successfully conducted cold weather testing of the entire system and made necessary changes to improve reliability and ruggedness (gear box, antenna, and software and designed and integrated a lifting bail system for launch and recovery from a helicopter. The team completed ordering of all year six funded build-2 mechanicals and sensors. Researchers also were able to receive all outstanding parts despite major shutdowns and delays of shops and services affected by COVID19. The team also integrated a multibeam system for seafloor mapping, in water detection of particles and potentially oil submerged under-ice. A concept of operations was developed by the research team for a USCG helicopter demonstration. The team also built a LRAUV in a box, Proxima, for rapid software development.

The ultimate goal is a fly away capability with rapid response for oil spills, sunken ships (etc.), pipe leaks, seafloor mapping, habitat monitoring, measuring soundscapes (weather, whales, etc.), long-range ship less surveys, open ocean, fresh water and under-ice capabilities over-the-horizon data relay, 24/7 operator response.

Key Accomplishments in Program Year 7:

- Tested and demonstrated the LRAUV System's ability to navigate relative to a three- buoy/transponder gateway system using USBL. The vehicle can dock and undock itself with improved gains and newly

intergraded reverse thrust

- Integrated a more advanced docking algorithm that increased our docking rate. Next steps are to run docking/undocking sequences for several days to obtain successful percentage of docking
- Integrated more advanced scientific sensors (Seabird CTD with integrated DO)
- Polaris navigation and communications system testing are complete
- Data from all missions has been evaluated and data is archived with operator notes
- Ran freezer tests on whisker box to complete Arctic readiness tests with the docking nose.
- Technical competency of the base LRAUV vehicle at WHOI is complete. New capabilities and sensors are being developed and outreach of its capabilities is underway with USCG and the oil spill response community
- Picked and launched Polaris from a USCG Jayhawk helicopter in Woods Hole (April)
- WHOI is fabricating a second platform, Stella with multi-mission capability and can operate and develop and manufacture LRAUV in house at WHOI which is 65% complete
- Added a new bulkhead (9th) connector for an additional sensor (multibeam)
- Added backseat CPU for easier software and sensor development
- Redesigned the antenna. Tall for open ocean and stubby for under-ice and fully tested.
- Completed a successful mission from shore to the shelf and back home (without a ship). We completed a 265 km mission with 8 days of battery left in the tank.
- Patent filed.
- Completed mechanic and electrical design of new mapping payload. System is currently being assembled for testing.
- Developed plume tracking algorithm (to be tested in Y8)
- Developed onboard simulation mission for plume tracking testing
- Built second docking nose module with upgraded cold weather gear box
- Developed modular nose configurations (Docking, Mapping, Short-Science)
- Developed new, lighter helicopter lifting bails
- Developed >20 new software behaviors for docking, undocking, no surfacing, new sensor configurations, etc.

System Evaluation and Fabrication: Creating LRAUV Platform #2: Stella. The WHOI/MBARI team conducted a full system evaluation, inclusive of auxiliary gear and buoys, in order to review low cost

manufacturing and design improvements for Build-2 and future builds in YR6 and implemented changes in YR7 to the platforms. The team has continued to use PDM tools consisting of Autodesk Vault, Basecamp, Slack and WHOI Roundabout for tracking current and future inventory and allowing time and cost savings for Build-2 ordering and manufacturing. Autodesk Vault enables revision control on drawings and documentation related to the build. With these tools in place, WHOI has all mechanical drawings as well as ordering information for the entire LRAUV platform in a secure and controlled environment as well as a BoM template for tracking current and future builds. Build instructions were drafted in year 6 and that effort continued through Y7 to make manufacturing of LRAUV a more efficient and economical endeavor.

All vehicle parts were ordered and organized in the WHOI Scibotics lab in bins labeled per assembly. Through Y7 the team worked diligently documenting how to build up with photos, diagrams, drawings and notes/instructions all captured and secured in Basecamp.

The team at WHOI worked on updating the electrical drawing package and is an ongoing effort that will continue into Program Year 8. This effort is a slow and methodical hands on evaluation of the current vehicle and spiral development process in order to update project materials provided by MBARI. We are also working to make the vehicle more modular (inside and out) so we can move around payloads such as the sonar more efficiently.

Additional Accomplishments

1. The team achieved successful underwater docking and undocking to a transponder during testing in Woods Hole.
2. The team conducted a ship less operation 'over-the-horizon' mission from Woods Hole to the shelf break and back. The vehicle was able to navigate back using a cookie crumb waypoint driven mission in order to avoid small islands, shoals and rock piles.
3. Added a new bulkhead (9th) connector for another sensor add-on (multibeam)
4. Ran a 440 km mission with new front tracking software tracking salt intrusions up the shelf break. Showed reliability of LRAUV as an autonomous adaptive sampling vehicle! (with NSF funding)
5. We modified one of three buoys for optimal docking and have a kit to change buoys frequencies between high and low depending on mission objectives
6. Team built relationships with New England USCG and performed a successful Jayhawk pick and launch demonstration. Polaris was dropped from 5 feet and ran a successful mission.
7. Stella, platform 2 is 65% complete
8. Developed drivers and backseat capability for inertial navigation and multibeam sensors
9. Further developed PDM tools and procedures for LRAUV Build-2 using Vault, Basecamp and WHOI Roundabout. Released all mechanical drawings
10. Began created models of the vehicles and systems to make future designs easier to modify

11. Continued to evaluate end of life parts and LRAUV system for improvements and manufacturing.
12. Internal battery charger system was redesigned to be more efficient and also increases battery capacity. A new, more robust antenna design was completed and five new antennas were built and tested.
13. Backseat computer for more versatile control of sensor integration/new behaviors was implemented. Integration on Polaris and Stella is complete. ROS development underway and continues into YR8
14. CTD and DO sensors were updated on Polaris and Stella with new bracketry and less power draw.
15. Multibeam was integrated on the backseat. Next steps are water testing.
16. Created operator/mission documentation and checklists available through the Dash
17. Filed a patent.
18. Built a vehicle in a box (Proxima) for rapid software and system/sensor testing
19. Updated Plume tracking algorithm
20. Developed onboard simulation mission for oil spill testing
21. Developed four different nose configurations (mapping, docking, under-ice and slow science)
22. Further developed WHOI operational DASH for operating LRAUV from inside WHOI

Key Publications (peer reviewed):

- Project investigators have under-ice and oil spill technology manuscripts underway (leveraging field reports from summer 2019 and winter 2020). The team has one peer reviewed paper published in the IOSC proceedings.
- Conmy, R.N., L. DiPinto, A. Kukulya, O. Garcia, D. Tulis, D. Sundaravadivelu, M. Gloekler, A. Hall, E. Fischell, D. Gomez-Ibanez (2021) Advances in underwater oil plume detection capabilities. International Oil Spill Conference Proceedings: Vol. 2021, No. 1.

Transition Plan.

ADAC and LRAUV project team seek an integrated approach as desired by HQ USCG Project Champion to acquire and develop additional LRAUVs commensurate with USCG mission needs. In accordance with DHS S&T UP-ADAC Grant Terms and Conditions, LRAUV Intellectual Property (IP) rights developed under this project remain jointly held between ADAC, WHOI and MBARI. According to the DHS S&T Terms and Conditions, DHS and USCG may leverage this IP royalty free to acquire and construct additional LRAUVs to USCG and other DHS maritime mission needs.

ADAC is ready to support HQ USCG Project Champion planned transition pathway.

LRAUV System likely represents the most commercially marketable investigation conducted under the ADAC cooperative agreement. In parallel to technical development to deliver the LRAUV System to support USCG, ADAC and research team will conduct investigations for commercialization of the System with industry as the Center's flagship development to commercial engagements over the course of Program Year 7 as outlined in the management section of this workplan. Accordingly, Center management and Project investigation team will seek to showcase LRAUV system, to include ADAC's planned event to host Alaskan and Arctic maritime industry leaders, response organizations, Oil Spill Response Organizations (OSROs), maritime shippers, Arctic cruise industries, first responders, Arctic oriented non-profit groups, State of Alaska and U.S. Federal departments and agencies and National Laboratories in a two day Symposium designed to increase visibility of a variety of Arctic Domain Awareness technologies, to include ADAC research endeavors, seeking to strengthen connections, collaboration and partnering between these communities, and to explore or initiate commercial transition pathways for ADAC completed/completing research.

Following the LRAUV's testing plan, and completion of data relay devices, the overall system will be TRL 7/8 and ready for production. Depending on DHS S&T and USCG acquisition desires, project team relays WHOI and MBARI have around-the clock technical expertise available if any such need arises. This technical support covers hardware, software, design, fabrication, specialty application, and operations expertise.

WHOI has a history transitioning technology to operational use, especially with the U.S. Navy. WHOI uses a variety of transition methods tailored to the nature of the challenges associated with the transition. Factors influencing the nature of transition include technological maturity, complexity of operations, availability of investment for 'hardening' of systems, market prospects, and more.

Relevance to USCG and Public Good

The LRAUV is suitable to shore-launch (whether on land or on ice pack) and recovery. A small boat can be used to tow the vehicle between a harbor entrances, or the vehicle can swim itself from shore without the need of a vessel as shown during the Santa Barbara field trials in 2019. LRAUV is also deemed helicopter transportable to remote areas and the team will pursue options to test launch and recovery of the platform in YR7. The fabricated vehicle is approximately 230 lbs. and is possible to be carried by 2-3 personnel for short distances. LRAUV can operate in shallow (2 meters) to continental shelf range depths (300 Meters). The baselines Tethys system occupies the design space intermediate between underwater ocean gliders and the current generation of propeller driven AUVs such as the commercialized REMUS family of AUVs developed at WHOI. Existing ocean gliders (propeller-less) such as the Teledyne Webb Slocum, the Scripps Spray, and Kongsberg Sea glider have a sufficient operational range to achieve the desired range goals needed by USCG. However, they do not have the payload capacity or power to carry the chemical and biological and mapping sensors that are required and cannot operate at higher speeds without redesign. Typical gliders operate at speeds of about 0.3 m/s and utilize a power source equivalent to 1W of energy with minimal power consumption.

In contrast, existing propeller-driven AUVs such as those manufactured by Hydroid, Bluefin, OceanServer, and Teledyne Gavia consume more power, resulting in a shorter endurance. These commercial propeller-driven systems can operate for a period typically up to 24 hours at speed of 1.5 m/s, and providing ranges of less than 130 km. These AUV's, such as the REMUS-600, can

extend their 24-hour range by greatly increasing the size and weight by adding additional battery packs and achieving 3-4-day ranges. As a result, LRAUV is uniquely capable in its combination of payload capacity, range, and endurance for remote under-ice oil detection.

Mission-level control of the LRAUV is achieved by using an architecture called 'state-configured layered-control'. This is an improved variant of the layered control architecture developed by Dr. Bellingham (1991) and implemented on vehicles ranging from Webb gliders to the Dorado AUVs (the first asset deployed during Deep Water Horizon). State-configured layered control supports autonomous adaptive operations for long periods. The software building blocks of the system are behaviors, or control laws, that can be combined to accomplish tasks. These control laws are conditionally connected to the AUV to complete missions that are more complex or respond to certain contingencies. For example, vehicle software is able to detect faults in critical components and respond appropriately, greatly improving the reliability of the AUV. In some cases, through configuration changes, the Tethys may continue a mission after a component failure. For example, depth control of the submersible is a redundant system. If the elevator actuator fails, the vehicle can continue to control depth by shifting internal weight.

Operators interact with the vehicle via an Iridium satellite link in remote areas or via Wi-Fi or cellular in near shore zones by recovering data snippets in near real-time and sending new mission commands to the vehicle as desired. Communication with the vehicle is possible when it surfaces and interpreted at operator-determined intervals. As part of the LRAUV ADAC program, LRAUV can now remain submersed and communicate acoustically to a network of gateway buoys. The radio relay is similar to what exists on LRAUV and consists of RF, Iridium, WIFI and cellular.

More than ten years of development of a web-based operator portal for the LRAUV has been developed, which includes a display of science and engineering data. This portal, known as the Dash, is available via MBARI's networked infrastructure and is now also available within WHOI enabling reliable backup from either portal to command control. On a secure portion of the site users can access a command interface and a variety of utilities, such as an alert page that operators can configure to send mission data via email or mobile phones based upon certain criteria. Prior research has established a design, created operating and navigation software, investigated the range of capabilities associated with critical components, implemented a systems integration plan, and conducted successful field-tests to validate research. The Dash also contains a map for easy tracking of where the vehicle has surveyed. Forward-facing data is publicly available on the web.

In addition to a completed fabrication and integration of the Arctic/oil science payload, project team has provided a completed augmented AUV simulator and test scenarios addressing high-risk elements, including navigation and sensing systems, demonstrating oil-spill following capabilities in Alaskan waters. The completed LRAUV operator simulator (with sea ice geographically situated in Alaska's Cook Inlet), integrates software-modelling code from ADAC's Arctic Oil Spill model (to include oil plume modeling). This simulator is a baseline tool for research and development task to support orientation, training and mission rehearsal for LRAUV operators.

LRAUV has undergone ocean field trials to verify that top-level systems, as well as science sensors contained in the platform nose section: (SeaOwl Ecopuck, CTD (Conductivity, Temperature & Depth), PAR (Photosynthetic Active Radiation (Light)), Optode (optical measurement), and ADCP's (Acoustic Doppler Current Profiler)), and have been found fully functioning in accordance within planned

parameters. LRAUV now has two nose sections. The small nose contains all of the sensors listed above. The second 'large' nose contains the same sensors but with the added DUSBL (homing array) and dynamic docking (whisker box) system.

AUV navigation crucial system usefulness to USCG led decisions. LRAUV has multiple modes of navigation to mitigate complex environmental conditions and changing scenarios to include:

1. A GPS system built into the Tethys antenna will routinely obtain GPS fixes when the vehicle surfaces. If surfacing is not possible Arctic buoys can provide ground-truthing via acoustics;
2. The vehicle will dead-reckon using a Doppler sonar to measure velocity relative to the bottom, and a compass for heading;
3. An Ultra-Short-Base-Line (USBL) acoustic system will measure range and direction to a transponder/buoy acoustically, marking interesting sites for revisit by the vehicle.
4. LBL navigation with two or more buoy transponder systems for aided navigation allowing for triangulated fixes.

In order to complete an Arctic capable oil spill deployment package, project team designed and constructed Arctic Communication buoys, oriented to an "agnostic" communications design allowing for other industry AUV's such as REMUS to be able to share this capability. These communication buoys include long baseline (LBL) and ultrashort baseline (USBL) systems, ACOMMS, Wi-Fi, RF, Iridium, and thermistor capability. LBL allows for long range (up to 10 Km per buoy using traditional low frequency acoustics at 10 kHz), while USBL allows for short range (<500 meters) homing and docking for recovery under ice or in open water. The project team is currently working on improving the USBL by leveraging Navy program development in 360-degree hydrophone array technology. This technology as enabled ranges in excess of 1 km. The buoy system will also allow for data transfer from the LRAUV back to Command Control Center via Iridium for over the horizon communications. In order to transfer data in a format that can be visualized by the receiving party, a software compression is included in the buoy development. These buoys are critical to enable LRAUV to operate as a "system" to effect characterization and communication of an Arctic oil spill, under sea ice, to USCG led unified command.

Advancing LRAUV further, project team designed, implemented and conducted initial testing of a platform WHOI micromodem known as "Umodem" to include advanced navigation capabilities inclusive of LBL and USBL systems.

The Umodem team at WHOI developed new firmware to allow the buoys to be used as transponders. In sum, Umodem, USBL and whisker box are new hardware and software capabilities provided to LRAUV to assist with under ice navigation and docking, but also provide a useful capability for launch and recovery in high seas when it is not possible to approach the vehicle in close ranges.

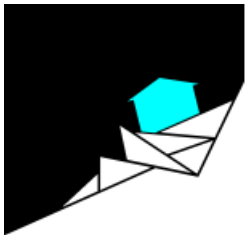
Additionally, when Autonomous Underwater Vehicles (AUVs) are strategically equipped with multiple sensor technologies, including cameras and sonar, they are capable of remote detection and analysis of oil under sea ice. This approach is known as search, map and classification.

Test data illustrates that AUV's remain the most mature tool for the search, map, and classification procedures routinely performed in seafloor analysis and similar methodology can be effectively

applied to under-ice anomaly detection. Beyond the need for rapid detection of oil and gas in the Arctic, based on discussions and conclusions from several Center-led workshops, ADAC and the LRAUV project team notes the important utility for small AUV platforms with a variable endurance range of hours to weeks capable of mapping the seafloor for the purpose of bathymetric surveys and anomaly detection to include leaking pipelines and infrastructure.

The project team's investigations have determined, multibeam sonars are capable of providing a high-resolution swath map with precise readings of hard structure as well as water column oil and gas detections (see figures below). Multibeam sonars are well suited as systems for mapping the seafloor or underside of ice. Accordingly, in order to create a multi-mission capability to LRAUV, the project team PI's, will research, procure and integrate a multibeam sonar system for use on portable AUV platforms as well as a complimentary echosounder sonar.

Arctic Facilities and Infrastructure Environmental Change Risk Index



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Abstract.

As the Arctic region is exposed to the impacts of climate change, increased coastal erosion, and more frequent precipitation, structures once protected by shore-fast ice and securely anchored in permafrost are now exposed to an increasingly dynamic and adverse environment. The imminent threat of infrastructure failure has the potential to cause significant environmental harm and disrupt socioeconomic stability and food security of U.S. Arctic residents. Recognizing that i) the Arctic is experiencing the most dramatic impacts from climate change on the planet; ii) there is a prevalence of ageing oil and other infrastructure constructed upon increasingly unstable permafrost coastlines and riverine landscapes; and iii) there has been multiple small to large scale infrastructure failures documented in the Arctic over the past decade.

This project responds to these concerns as expressed by U.S. Coast Guard (USCG) District 17 to provide an environmental risk index oriented to Arctic coastal regions as a decision support tool to assess environmental impacts to coastal facilities and infrastructure that are under the purview of USCG inspections. This research will focus on conducting a coastal facilities and infrastructure engineering risk analysis along western and northern Alaska. The study will draw experts from a range of disciplines and utilize a collaborative set of workshops and smaller standing working groups to solicit expert opinion that will be used to derive data to apply to models, and test, and deliver an “Arctic facilities and infrastructure environmental change” risk index. The project team will actively seek to coordinate with relevant international Arctic scientists, engineers, and other stakeholders to share and co-develop approaches that are mutually beneficial to those similarly challenged by Arctic environmental change.

The project primarily focuses on bulk oil/fuel containers and pipelines, and piers, docks, and platforms in permafrost coastal and riverine landscapes of the Bering, Chukchi and Beaufort Seas. . Analysis uses appropriate qualitative and quantitative approaches for the data being used and questions posed with attention to uncertainty. Products inform responders and inspectors of the current and predicted future structural integrity of those facilities, and the bearing capacity, stability, and susceptibility to erosion of the surrounding/ supporting landscape. The research effort will produce three products: a comprehensive Arctic facilities and infrastructure environmental change knowledge product, an operationally relevant Arctic facilities and infrastructure environmental change risk index, and an Arctic inspector and responder structural environmental impacts training guide. Due to IRB and CAPO required reviews, the project start was delayed until 3 June 2021.

Summary of Project Accomplishments

DHS approved the workplan on 24 March 2021. CAPO informed the team the same day that the project could not start until IRB approval, with a follow-on CAPO approval was obtained. This process took quite a bit of time, and the project team did not obtain CAPO approval to commence work until 3 June 2021. Since that date, the team has been hard at work.

Initiation and onward conduct of engineering analysis.

The team has initiated this process during core team meetings and will continue work on this milestone in year 8. Continues to form the framework and conduct engineering analysis on the principal research questions.

Formation of Project Core Advisory Team and Project Evaluation Team

Comprehensive Literature review and establishment of project communications schedule

The core team has been working to develop the comprehensive literature review from public and academic sources. Per CAPO requirements, sources did not include interviews or discussions with those outside the listed project team members, and were strictly limited to academic journal databases, and public facing websites for local, state, and federal entities. The team established a cloud-based database system to collect documents and websites relevant to the project. Further, the core team has drafted a table of contents and task allocations for moving the literature review forward.

Transition Plan

As discussed in Project Phase 8, the Comprehensive Research Report and corresponding peer-review journal article will be promulgated across USCG and ADAC networks. The knowledge gained from this project will be directly transferable to USCG Facilities Inspections and Maritime Environmental Response, which are to be represented on the Core Team. The Project development team anticipates that much of the knowledge gained and consensus reached will be used to manage facilities inspections schedules, inform inspectors as to the severity of observed environmental changes, and predict expected future condition of USCG supporting infrastructure and Regulated Facilities.

Relevance to USCG and Public Good

Characterizing Arctic region environmental change is an important and growing researched topic. Understanding larger scale impacts of environmental change in coastal Arctic Alaska has a number of existing studies conducted by University of Alaska Anchorage, (specifically, the UAA College of Engineering), the University of Alaska Fairbanks (specifically the UAF College of Engineering and Mines and the Institute of Northern Engineering), the Alaska District of the U.S. Army Corps of Engineers, the Denali Commission, State of Alaska Department of Environmental Conservation, and the Barrow Area Information Data Base (BAID) coastal monitoring project supporting the State of Alaska's North Slope Borough, principally developed by the University of Texas El Paso.

Existing research and modeling efforts have characterized and modelled regional coastal erosion and vulnerability to storm surge and associated flooding from storms, oriented to several low-lying regions in Western and North Slope Alaska (Yukon-Kuskokwim River delta, Norton Sound and the region around Utqiagvik and Barter Island Alaska).

Review of existing published research has not determined any associated suitable, fine scale characterization of environmental risk to Arctic coastal region bulk storage facilities or infrastructure in coastal areas that may be at risk to degradation of coastal erosion or permafrost thaw.

Due the extraordinary logistics and associated costs of travel to remote/off road system rural Alaska facilities and the short summer season to safely conduct inspections, USCG regulated facility inspectors are challenged with completing necessary critical inspections of potentially hazardous coastal facilities (such as fuel storage tanks) on an annual basis. Other operational and response personnel are routinely challenged with evaluating and mitigating the additional risk associated with a rapidly eroding and increasingly unstable coastal landscape across the U.S. Arctic.

As a generalization, most of Alaska's Arctic Coastal regions contain soils that are vulnerable to erosion. Until recently, permafrost was frozen hard and solid year-round and provided a sturdy and stable substrate for building facilities, infrastructure, and coastal communities. As Alaska, and in particular, the Alaskan Arctic are now increasingly subjected to rapid and dynamic change, those changes are having sustained, significant, and increasingly detrimental impacts upon tundra, underlying permafrost, and coastal areas. As Permafrost degradation and coastal erosion continue, the bearing capacity and load stability of the ground surface will continue to substantially decrease. These rapid changes because increasingly larger shifts in the ground surface that destabilize foundations, thereby negatively impacting their structural integrity.

There is a need to increase the fidelity of operational planning and risk mitigation strategies by supporting existing area familiarization and local knowledge with an increased technical

understanding of key environmental processes contributing to rapid change and instability, providing operators with greater detail of expected on scene conditions and a clearer picture of associated risks. Due to the transportation challenges in accessing the remote coastal regions of the U.S. Arctic for routine facilities inspection, there is need for increased technical understanding of the rapidly changing Arctic coastal environmental conditions as it relates to coastal erosion, permafrost degradation, and associated infrastructure instability. Advancing knowledge products and providing risk indexes to inform inspections and response operations, should help U.S. Coast Guard inspectors identify more vulnerable facilities reducing risk of catastrophic failure, while also providing USCG disaster response operators increased understanding for corresponding environmental mitigation activities.

As the dynamic Arctic environment exerts a multitude of forces upon remote infrastructure, it is advantageous for safe and efficient operations to understand, calculate, and predict those forces and forecast their associated impacts upon the structural integrity of effected facilities. Developing a comprehensive guide outlining associated precursors of an incident, methods for failing structure identification and triage, and methods for closely monitoring change will greatly assist the triage and scheduling of the most at-risk facilities. More frequent inspections of only the most at-risk facilities/structures and less-frequent, periodic inspections of lower risk locations will maximize USCG resources and reduce unnecessary risks to inspection teams, and in light of on-going concerns from the Coronavirus, such efforts will also reduce risk of exposure of indigenous communities to communicable diseases.

The principal outcome of the project will be a comprehensive assessment and public document on the approaches to, and solutions for, improving risk mitigation and operational decision-making for USCG facilities inspections and response operations. The long-term goal is to establish a credible and useable framework for categorizing Arctic infrastructure and facility status and calculating risk of future failure based on the various erosion, permafrost, and facilities engineering conditions that routinely occur in the Arctic. If such a risk framework can be available for use by government entities such as USCG, it will be useful scheduling the frequency of facilities inspections, and identifying the most at-risk locations. If/as USCG was interested in advancing the Environmental Risk Index to higher level of technology readiness, ADAC and the research team are at the ready to support additional investigations via ADAC's Basic Ordering Agreement (BOA).

**Remote Unmanned Aircraft System (UAS) Inspection
and Response Team Development in the Bering Strait Region**
Project Investigator (PI): Jessica Garron, International Arctic

Research Center (IARC), University of Alaska Fairbanks (UAF)

Lead Institution: University of Alaska Fairbanks

Project Supporting Researchers: Mr. John P. Henry (Native Village of Unalakleet (NVU)) Alaska and Ms. Margaret Hall (Model Forest Policy Program (MFPP), Priest Lake, Idaho).

Project Collaborators: U.S. Coast Guard District 17, Sector Anchorage and Pacific Northwest National Laboratories, to be confirmed.



Abstract

Conducting required rural area key infrastructure testing for safety compliance across Alaska (in particular, Western Alaska) is a time and resource challenge for the U.S. Coast Guard (USCG). Normal USCG processes require USCG inspectors to physically fly from home station to remote regions to conduct hands and eyes on tests. Integrating remote sensing tools, such as unmanned aircraft systems (UAS), into the operational environment of remote, sparsely populated, western Alaska has the potential to increase the efficiency of USCG infrastructure inspection missions, while supporting the expansion of community Science, Technology, Engineering and Math (STEM) capacity. To demonstrate this integration concept, project investigators designed a program to train a set of UAS pilots, (equipped with U.S. manufactured UAS platforms) in the Bering Strait hub community of Unalakleet, Alaska, to conduct infrastructure inspections, specifically oil-containing infrastructure, and emergency response (ER) actions in support of local and/or regional crisis. The major components of the investigations are to train approximately eight pilots within Unalakleet to safely operate UAS and become certified under the FAA Part 107 rule; to co-produce infrastructure inspection protocols (IIP) and emergency response (ER) flight protocols with members of the Native Village of Unalakleet, the USCG (specifically, USCG District 17, Sector Anchorage and the core project team). Planned investigations will determine the feasibility of the expansion of the program, statewide, potentially (and ultimately), nationwide; and to disseminate lessons learned to a broad audience of non-technical and technical stakeholders. This work will be conducted over the course of an 18-month period and employ a combination of remote delivery and face-to-face methods of execution. The critical outcome of this program will be a research knowledge product of the investigations for USCG consideration as well as a set of trained pilots and flyable UAS staged in the Bering Strait region, prepared to efficiently support community and USCG maintenance inspection and emergency response needs if/as desired by USCG or facility.

Summary of Project Accomplishments

Project Coordination: The project was established among all institutions and sponsors during November and December of 2020 following the overarching coordination methodology of all ADAC projects. Throughout this time, the tools and methods of communication for the lifecycle of the project were identified and agreed upon by the project core team during preliminary coordination meetings. Included in this program establishment phase was the development and execution of a remote kick-off meeting with sponsors and HQ USCG Project Champion, CDR Chad Thompson, and the establishment of reporting protocols for the project team. The establishment of this project follows the overarching methodology of all ADAC projects, with additional communication requirements imposed by the current Coronavirus 2019 (COVID-19) pandemic.

This work included the iteration, coordination and associated implementation of the project workplan, and the establishment of contractual and reporting mechanisms for all members of the research team. Subsequent coordination efforts included:

1. Kick-off meeting with HQ USCG Project Champion
2. Identify Webinar and Synchronous Instructional Tools
3. Conduct team coordination meetings

4. Prepare and participate in ADAC Quarterly reviews, Customers and Partners Roundtables, Annual meetings and write Semi-Annual, and Annual Reports

UAS Pilot Training and Certification: To develop the community-based Unmanned Aircraft System (UAS) response team, a set of potential UAS pilots needed to be identified and engaged in the community of Unalakleet. The steps to identify potential UAS pilots for program participation centered on a recruitment webinar, an application for participation, and an on-line 8-week training program held synchronously over Zoom. A set of operational aircraft outfitted with EO sensors was purchased to begin general protocol development and in preparation of delivery to Unalakleet once the pilots have achieved their Part 107 certification from the FAA.

UAS instructors will teach all aspects of the operational aircraft to the pilots as part of the hands-on portion of the UAS training program. All participants in the project will train on the same aircraft to allow for additional data collection, regional support of community pilots, and aircraft specific data processing protocol development. Hands-on pilot training will include general practice flights, and test flights for protocol development and is scheduled for ADAC PY 8. Resulting accomplishments from this line of activity include:

1. **Development and Delivery of Kick-off/Recruitment Webinar**
2. **Acquisition and training of Pilots in use of UAVs, Sensors and Software.**
3. **Development of General Protocol for UAS Flights and Data Processing (in-progress)**
4. **Identification of Pilot Teams**
5. **Delivery of Remote UAS Pilot Training**

Coproduction of Infrastructure Inspection Operational Protocols: This work pairs 33 CFR 154 regulated bulk fuel facility integrity inspection requirements and State of Alaska (18 AAC 75) guidelines for reservoir/tank farm infrastructure inspections, with UAS operations, via the co-production of an operational, infrastructure inspection protocol. Data collection, processing and delivery requirements for providing UAS-captured data for infrastructure assessment is being co-produced among the pilots and the project team, using information gathered during testing in Fairbanks and training in Unalakleet. This effort is underway, on schedule and scheduled for completion in the early months of ADAC PY 8.

Transition Activities:

The transition plan for this project is focused on a comprehensive dissemination of knowledge products and research findings for journals, and other practical measures to help communities and other agencies assess the utility of this approach for remote area use of UAS for inspection purposes.

The project team is currently disseminating the results of the program through monthly presentations or publications about the project to academic, operational and non-technical audiences, and through ADAC/DHS reporting mechanisms. The project team is also in the process of

creating a model or “road map” for succinct UAS program creation for remote communities in partnership with USCG Sectors. The model is comprehensive and inclusive of lessons learned from ground zero to an up and running program with challenges of working remotely and in different cultures. This Knowledge Product contains the tangible components of UAS pilot job description, standard operating procedures for an overarching program, flight-specific checklists, and data management solutions. These transition efforts will continue throughout the lifecycle of the project and be concluded holistically at the project’s cessation at the end of ADAC PY 8.

Relevance to USCG and Public Good

Project research methods were designed to answer the question, *what opportunities exist to train local observers to provide quality information to support local infrastructure inspections and emergency response actions?* To address this question, the project research methodology is a sequenced set of coordinated and collaborative activities that incorporate USCG inspection requirements, provide rural regional UAS pilot training, coproduce routine inspection and emergency response protocols for UAS operations, and conduct UAS data collections by vetted and approved local citizens in rural Western Alaska. Key to this methodology is information dissemination about the project to a wide variety of stakeholders ranging from lay audiences to specialized technical teams, and to determine the feasibility of expanding the program to other rural communities or USCG Sectors across the nation. The aim of this methodology is to meet both the community objectives of Unalakleet and mission objectives of USCG by using remotely sensed data sets for local and regional decision-making.

ADAC Workshop and Exercise Programming

Arctic-related incidents of National Significance (Arctic IoNS) Workshops

In 2016 ADAC’s inaugural Arctic-related Incidents of National Significance (Arctic-related IoNS) workshop was hosted at the University of Alaska, Anchorage from 21-22 June 2016. The Arctic IoNS workshop planning commenced in early March 2016, and from the onset was an endeavor purposely planned as a Canada-U.S. forum. ADAC center leadership facilitated the planning and conducted the Arctic-related IoNS workshop with select expert Arctic operators and researchers from both Canada and the United States. The workshop was built around operator defined problems from a work group comprised of CCG, CAF, USCG, National Oceanic and Atmospheric Administration (NOAA) and Alaskan Command members. This "Arctic IoNS Work Group" leveraged USCG District 17 led Tabletop Exercise NORTHWEST PASSAGE, held in Anchorage, Alaska, on 13-14 April 2016. The scenario used in USCG NORTHWEST PASSAGE, was a disabled cruise ship in the Beaufort Sea near the extended Canada-U.S. border. USCG Exercise NORTHWEST PASSAGE provided the Arctic IoNS Operator Work Group a forum to derive operator concerns and a clear understanding of "under-researched" areas relevant to operator concerns in a maritime mass rescue scenario.

In 2017 ADAC and the University of New Hampshire’s Center for Spills and Environmental Hazards (CSE) teamed to conduct the "Coping with the Unthinkable...an Arctic Maritime Oil Spill" Arctic IoNS workshop at the University of Alaska, Anchorage from 23-25 October 2017. This Arctic IoNS workshop assembled a multi-disciplined team of experts who reviewed relevant baselines of applied research along with existing logistics and response capabilities associated with an Arctic maritime oil spill. The "Coping with the Unthinkable...an Arctic Oil Spill" Arctic IoNS workshop strategically sought

a fresh and targeted approach in addressing a distant offshore Arctic oil spill by reviewing current research and soliciting recommendations from workshop participants. The workshop sought to discern needed capability and technology research questions addressing shortfalls for an Arctic maritime oil spill. These questions will inform a future ADAC hosted funded research solicitation. Such research is sought to provide solutions which support the U.S. Coast Guard's (and other Arctic oil spill responders) preparedness and response.

The Third and most recent Arctic IoNS was the 2019 Arctic Incidents of National Significance Workshop (IoNS). The event was designed and conducted to discover key drivers in the emerging Arctic environment that impact the ability of the US Coast Guard and other stakeholders to conduct safe, secure, and effective operations. This body of knowledge is then used to prioritize gaps and articulate key research questions that can direct future science and technology investments by the Department of Homeland Security's Science and Technology Directorate toward addressing high-priority gaps. The workshops bring together stakeholders from U.S. federal, state, and local government agencies, Alaska Natives and Alaska Native regional corporations, international partners, other Alaska community members, and private sectors into a collaborative event with the science and engineering communities to ensure the quality and relevance of the research questions. The 2019 Arctic IoNS workshop series used a scenario driven by a major storm-driven Bering Sea maritime accident scenario, followed by widespread damage to Western Alaska coastal regions to "stress the system" and highlight shortfalls in "managing a complex Arctic crisis response." ADAC partnered with Sandia National Laboratories to plan and execute the 2019 Arctic IoNS via two parts:

1. The Arctic IoNS 2019 Alaska Native and Rural Arctic "Insights" Community Workshop, 18 – 19 April 2019 at University of Alaska Fairbanks Northwest Campus in Nome, Alaska.
2. The Arctic IoNS 2019 "Stressing the system... managing a complex Arctic crisis" workshop in Anchorage Alaska on 20 – 22 May, 2019.

A fourth Arctic IoNS event entitled Arctic Air was intended to be conducted in Program Year 6 in March 2021 but was delayed due to COVID-19. ADAC Leadership is now in coordination to host Arctic Air in the spring 2022 timeframe. More information including Workshop reports can be found on the [ADAC website](#).

Arctic Medium- and Long-Term Environment (Arctic MaLTE) Workshops

ADAC conducts Arctic-focused Medium- and Long-Term Environment (MaLTE) exercise to understand and address the medium and long-term strategy, policy and planning needs specific to the USCG Arctic mission. The Arctic MaLTE format is ADAC's structured workshop involving select academics, industry researchers, and government officials, who explore medium to long-range challenges comprehensively, from policy, governance, and science & technology vantages. ADAC has conducted Arctic MaLTE events in Program Year 3, 4, 5, 6 and 7. The outcome of the MaLTE workshop is a comprehensive knowledge product which includes workshop analysis and recommendations. The ADAC Program Year 8 Arctic MaLTE workshop is planned for an analytical follow-up from the May 2021 Arctic Maritime Horizons exercise. The purpose of the event is to again gather Arctic minded experts from government, operators, academics, and industry from the international community and the U.S. to conduct a series of short essential information briefs followed by discussions" in breakout groups and returning to the next information brief to collect as much insight in a constrained

timeframe as possible to collaboratively address risk factors to the U.S. Arctic MTS discovered in the May 2021 Arctic Maritime Horizons exercise.

The event assessment will be framed to address operational risks to the future MTS in the Arctic region. Based on the range of possible futures, workshop planners seek to characterize risks to waterways management of the Arctic region MTS. Prioritization of proposed solutions will be made using Delphi protocols. Workshop planners will focus recommended solutions which include improve presence and cooperative activities that if/as implemented, should advance improved safety and security for the Arctic and reduce the corresponding risk.

Overall, ADAC MaLTE workshops are designed to meet medium and long-term strategy, planning and policy problems as determined by HQ USCG (specifically, HQ USCG Senior Arctic Policy Advisor to the Commandant). The planned assessment workshop seeks to advance items of relevance to future horizons through convening leaders and experts to quickly surmise current baselines of organizational strategies, plans, policies, and implementation activities in order to identify shortfalls, gaps, new synergies and convergence opportunities in shared MTS endeavors in the Arctic. The planned assessment is considered a useful approach based on the hypothesis that workshop participants generate many of their most innovative ideas and solutions immediately after being inspired by authentic speakers who provoke imagination and creativity. Accordingly, workshop planners seek to leverage this inspiration to quickly generate ideas/brainstorm via dynamic and focused group collaboration. The outcome of the assessment will be a comprehensive knowledge product that captures pre-assessment planning, workshop proceedings and post event analysis.

As the longer-term compliment to Arctic IoNS, the Arctic MaLTE workshop look towards the 10-20-year time horizon to investigate potential mission needs based on projected technology gaps driven by the anticipated Arctic operational environment. Building from lessons learned in the prior MaLTE workshops from May 2017, March 2018, September 2018, and June 2019, May 2021 ADAC collaborates with HQ USCG 5PW to conduct a future oriented assessment of the maritime transportation system of the U.S. Arctic maritime EEZ.

The most recent iteration of the MaLTE workshop series was the Arctic Maritime Horizon's Exercise 2021 (AMH 21) held from 4-6 May as a hybrid virtual/in-person event. AMH 21 was organized to address policy, plans and initiatives to support HQ USCG and the Coast Guard Enterprise in addressing the 2019 USCG Arctic Strategic Outlook (ArcSO) task to "Advance and Modernize the Arctic Marine Transportation System." Arctic Maritime Horizons Exercise provided an orienting and deliberative plenary forum to set the foundation for participants followed by a 3-move exercise. These activities were constructed to challenge assumptions, gain insights and organize follow-on items of consideration to guide USCG Arctic and Maritime Commerce Strategic Outlook implementation tasks. Further information on the event can be found at the [ADAC Website](#).

The principal outcome of these events is a knowledge product which provides a comprehensive assessment advancing known baseline of the U.S. Arctic EEZ MTS, which will inform policy concerns of HQ USCG SAPA in developing implementation plans associated with USCG's 2018 MCSO and 2019 ArcSO oriented to the region. Key inputs to the literature reviews include Arctic oriented or applicable Committee Maritime Transportation System documents as well as associated Aleutians, Bering Sea, Chukchi and Beaufort Sea Port Access Route Studies (PARS), along with navigation and

waterways management policies and regulatory guidance developed and maintained by HQ USCG be key USCG stakeholder consensus on the approaches to, and solutions for, addressing polar region communications and connectivity shortfalls and gaps. The goal of the assessment is to establish a credible and useable knowledge framework to support USCG decision makers in addressing the implementation plans associated with MCSO and ArcSO, and to inform associated safety and security policies for the region. The final project is anticipated to meet at least TRL-3 threshold requirements.

Arctic Symposium

ALCOM conducted an inaugural Arctic Maritime Symposium (AMS2018) at Joint Base Elmendorf-Richardson 14-16 August 2018. Aligned with Strategic U.S. National Defense and Security Strategies, and DOD Arctic Strategy, AMS 2018 included U.S. Congressional, Federal, State of Alaska, Tribal, and international leaders, along with Arctic subject matter experts from across academia and institutions. With approximately 120 participants, AMS 2018 was oriented as a series of comprehensive panels and engagement activities, which included a ship visit aboard USS MOMSEN (DDG 92). The principal outcomes of AMS 2018 were to inform participants on a wide range of defense and security concerns, while establishing a new network of thought leaders to Arctic security and defense matters. Such a network serves to bridge Arctic-minded professionals across government, public, and private organizations and academia to the defense community on matters of mutual interest in better securing U.S. and like-minded nations' interests in the Arctic.

The second ALCOM-hosted Arctic Symposium (AAS19) was conducted on 13-15 November at the University of Alaska Fairbanks (UAF). An advance Arctic Defense and Security Orientation Executive Session (ADSO-ES) course of instruction conducted by the UAF School of Management was conducted on 12 November as well as an invitational dinner in honor of Alaska Native Leader contributions to security and defense leader Arctic understandings. AAS19 provided ALCOM an opportunity to conduct a series of discussions in support of future engagements and exercises to advance Arctic joint interoperability across the military Services, to include the U.S. Coast Guard, while also increasing whole of government collaboration to better secure U.S. Arctic interests. Additional AAS19 outcomes included advanced discussions to support multinational cooperation among like-minded Arctic nations, and to increased awareness of the unique challenges faced on the "western Arctic" (oriented to and North of the Bering, Chukchi, and Beaufort Seas) contrasted against the "eastern Arctic," (oriented to and North of the Greenland, Norwegian and Barents Seas). Additionally, AAS19 broadened discussions (from the original "maritime" focus of AMS 2018) to strengthen a comprehensive approach to land, sea, and air domains of the Arctic. USNORTHCOM's Arctic missions and associated tasks and requirements established in the U.S. Presidentially approved Unified Command Plan, ALCOM's AAS19 was used as the backdrop and orientation to organize as a composite and complex event consisting of 235 registered participants. AAS19 included multiple plenary sessions, breakout (two separate tracks) of electives and follow-on field activities, principally focused to advance greater understanding, improved networks, and more effective approaches in discerning and developing solutions to address current and emerging concerns to U.S. national interests in the Arctic region. Field activities included the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) Permafrost Tunnel, and the UAF Poker Flat Rocket Range. AAS19 provided ALCOM's senior command, USNORTHCOM, an opportunity to gain convergence in shared understanding and improved unity of effort from across policy and practices via a new and developing network of defense and security-minded

professionals. Such convergence came via a cross agency and multidiscipline approach to advance measures to deter and dissuade potential adversaries, while also protecting, securing, and defending America's citizens, supporting allies and partners, protecting U.S. Sovereign Territory and U.S. National interests. Importantly, AAS19 gained key insights on mutual interests oriented to respective national interests of participating allies and partners. ALCOM and the Arctic Domain Awareness Center, a DHS Science and Technology Center of Excellence in Maritime Research, hosted at the University of Alaska, maintain copies of the reports from AMS18 ASLS19 and AAS19. These reports are located at www.arcticdomainawarenesscenter.org.

Arctic Senior Leader Summit

The inaugural ALCOM Arctic Senior Summit was conducted on 18 January 2019 at Cerjan Hall, National Defense University at Ft McNair, Washington, D.C. This follow-up meeting from the initial AMS 2018 comprised 85 participants and provided an important exchange between a select group of senior DOD and interagency leaders, with key Canadian and NATO Nordic allies and partner representatives who affect U.S. efforts in the Arctic to shape and determine policy, apportion and allocate resources, decide preparedness and response activities, and make operational decisions that affect U.S. interests in the Arctic.

In support of United States Northern Command (USNORTHCOM), Alaskan Command (ALCOM) (a subordinate unified command reporting to USNORTHCOM) hosted a virtual two-day Arctic Senior Leader Summit 2021 (ASLS 21) on 10-11 March 2021. The overall goal of the event was to conduct a meaningful seminar to support senior defense and security discussions on the changing dynamic of the evolving Arctic from a geostrategic, defense, environmental, and economic security vantage. The theme of ASLS21 was Arctic Vistas 21: Understanding challenges, assessing risks, and improving partnerships. With this guiding framework, ASLS21 sought to advance collaboration between participating senior leaders as they assessed challenges and opportunities emerging from a changing Arctic.

ALCOM ASLS is a complement to ALCOM Arctic Symposia, which are organized as 200+ participant multiple-day events which comprehensively seek to orient, educate, and engage participants from the staff through senior leaders on current and emerging aspects on the Arctic from a multidiscipline and multicultural vantage. Arctic Symposia are organized with plenary, breakout tracks and field activities.

To achieve this vision, a diverse group of leaders from across the United States and the Circumpolar North convened to address issues relevant to collective security in the Arctic. Participants included representation from the Alaska Native/Arctic Indigenous community, Department of Defense (DOD), Federal scientific agencies, Alaska State and local government, academia, industry, and foreign armed forces from U.S. allied and partner nations. Participants considered individual perspectives that inform overall Arctic security including but not limited to national defense, Arctic environment, geopolitics, economics, and local community security. ALCOM ASLS 2021 content included aspects on adapting to the direct and indirect impacts of the changing dynamics of the region (thawing permafrost, rising sea level, increasing health risks, altered climatologically events, and increasing

human activity) and their association (and associated impact) to United States, Canada-United States (via NORAD), and NATO allies and partners Arctic trans-Atlantic security interests.

Due to COVID 19, ALCOM ASLS 21 was held as a virtual event, via two partial-day sessions. ASLS 21 Day 1 was a series of panels addressing emerging Arctic defense and security challenges. It featured senior DOD leader keynote speakers and facilitated panel discussions with follow-on roundtable discussions.

ASLS 21 Day 2 was a three-move tabletop exercise conducted as scenario-based decision making to inform senior leaders to challenges, constraints, and opportunities. This follow-on, principally military decision maker event provided participants an opportunity to understand the changing dynamics of the Arctic and the complexities of associated decision-making via a tabletop exercise using fictitious, but plausible scenarios. Using methodologies similar to National Defense University and the U.S. Joint Staff, three varied scenarios of Arctic region security and defense challenges were given. This exercise provided senior military leader orientation and understanding of the complexities of assessing, characterizing, and responding to Arctic crisis. Event information including a conference report can be found on the [ASLS Event Hub](#) on the ADAC website.

Advancing Collaboration in Canada-U.S. Regional Security (ACCUSARS)

Building upon a June 2017 workshop on Security in the Arctic Borderlands Region, the North American Marine and Environmental Security Workshop in September 2018, and the Alaskan Command's Arctic Symposium held in November 2019, NAADSN and ADAC co-hosted a follow-on workshop to focus on specific initiatives that will improve understanding and enhance collaboration between Canada and U.S. Arctic security and defense professionals. The workshop is currently being conducted as series of three virtual events each corresponding with a different region of the North American Arctic.

During the Advancing Collaboration in Canada-U.S. Regional Security (ACCUSARS) I Workshop on 17-18 September 2020, workshop participants developed a practical characterization on the North American Arctic region. Participants defined this region as an important international crossroads where issues of a warming impacts on the environment, international trade, and global security intersect. These discussions reinforced how state-sponsored and commercial actors from around the world seek to share in the long-term benefits of an accessible Arctic. Some of this increased activity in the region has the potential to challenge and potentially threaten U.S. and Canadian sovereign interests, including foreign investment, tourism and scientific research.

Continuing this important Canada-U.S. discussion on Arctic regional security, ACCUSARS II sought to examine the emerging trends in the medium- and long-term aspects in the North American Arctic security environment to create a useful Strategic Foresight Assessment (SFA) oriented to the U.S. and Western Canadian Arctic regions (Alaska, Yukon and Northwest Territories). The virtual event gathered of academics and practitioners from across the region in order to anticipate potential North American Arctic futures. Workshop organizers utilized SFA methods to identify gaps in capabilities and in turn define future risks, challenges and opportunities across Canada and U.S.

NAADSN and ADAC look forward further collaborating with both existing and new existing partners for ACCUSARS III in September 2021 which will focus on a characterization of the Eastern North

American Arctic. Details on the event series including Event Reports can be found on the [ADAC Event Webpage](#).

Arctic Challenges, Innovations and Commerce Expo (C-ICE)

In support of commercializing ADAC and other participating mature and completing research, ADAC central management planned, organized, and facilitated Arctic Challenges, Innovations and Commerce Expo (C-ICE) on 16-17 March 2021 as virtual event. Originally proposed as Strengthening Partners in Arctic Industry (SPAI) Symposium in ADAC Workplans, the event to what was conducted in Program Year 7 in order to promote Awareness Center Technologies, foster academic and commercial research collaboration and partnering and generate new Transition Pathways that support the Arctic response community. While the SPAI Symposium is structured to support a collaborative approach to connect and network the community of science and technology research with industry, it serves as a useful venue to connect completed and completed research with maritime oriented industry for possible commercialization. Similar to Program Year 7, a uniquely titled name for the workshop will be developed and promulgated in Program Year 8. The workshop is planned as a virtual activity.

As the Arctic changes, a current gap lies in the connections between commercial and industry interests, innovative and entrepreneurial minds, and existing opportunities in the region. As a result, existing opportunities often fail to be recognized, or are too difficult to find. In response to this gap, the Arctic Domain Awareness Center's (ADAC) Arctic Challenges, Innovations, and Commerce Expo (Arctic CICE) seeks to explore the networks, resources, and infrastructure needed to enable the commercial entrance of Arctic related products and technologies into the Arctic domain. Drawing from ADAC's vast experience in federally funded operational research and design (R&D), this expo utilizes an interdisciplinary and collaborative approach to foster conversations around Arctic-centered business pressure points, state-of-the-Arctic focused R&D, gap analysis of investment and innovation, and the future of business in the region. Participants will be exposed to the latest hardware, software, and people-ware emerging to advance domain awareness, risk mitigation, exploration, Arctic operations, and overall, Arctic security.

ADAC's Arctic C-ICE took place virtually over a two-day timeframe, March 16-17, 2021. Day one of the conference will consist of both live and prerecorded panel presentations that were accessible via online streaming services, as well as interactive platforms. The topics of the first day provided participants with a foundational understanding of the existing challenges associated with commercializing innovative technologies in the Arctic region, while also highlighting the emerging technologies being developed to tackle such challenges. In particular, the first day of the conference focused on the topics of scientific exploration, risk mitigation, domain awareness, and the current known barriers to business in the Arctic region. Lastly, the first day of the conference concluded with a "Solutions Showcase," in which a variety of existing Arctic technologies (both in development and already finalized) will be displayed in a virtual booth format. Day two of the Arctic C-ICE delved deeper into the challenges discussed on the first day of conference by exploring the ways in which such challenges can be transformed into opportunities. The second day began with plenary discussions regarding the ways in which R&D and entrepreneurship play a role in tackling the challenges of the harsh Arctic domain. These discussions followed with a group tabletop exercise in which all workshop participants will have the opportunity to participate in a "Strategic Doing"

exercise, which teaches people how to form collaborations quickly, direct them towards measurable outcomes, and to make adjustments along the way.

Recordings and event materials are available on the [ADAC Events webpage](#). A follow up event will be conducted in Program Year 8 in the spring 2022 timeframe.

Education Programing

ADAC Workforce Development Program Fellowship Program

ADAC's Workforce Development (WFD) Fellowship Program aims to foster the next generation of scientists and engineers devoted to the discovery, development, and improvement of technologies and applications for Arctic maritime domain awareness, response, and resilience. Participation in the program provides student fellows with both valuable research experience and professional development opportunities, as well as access to DHS and other federal professional forums and networks. Furthermore, the funded fellowship provides students with monthly stipend and tuition support at respective education levels. Fellows are selected to the program based upon a set of criteria established by the DHS S&T OUP Award Terms and Conditions, which include U.S. citizenship, a GPA of 3.3 or higher on a scale of 4.0, the ability to pass a background check, a major in a science, technology, engineering, or math discipline (STEM), and a commitment to seek and gain employment within the HSE or a related discipline for at least one year following graduation⁴. ADAC leadership manages these requirements to ensure compliance and continues to mentor and develop opportunities for each student fellow throughout the duration of their fellowship.

Furthermore, ADAC's WFD Fellowship program's mission seeks to recruit and incorporate minority students, as well as those from underrepresented classifications, in addition to non-minority students.

The objectives of this project were to provide scholarship and professional development opportunities to both undergraduate and graduate students in order to facilitate fulfilling future careers in the Homeland Security Enterprise, or related disciplines. These activities are not only aimed to contribute to the growth of a highly skilled federal workforce, but also to contribute to the capability of the U.S. Coast Guard operator in support of USCG missions in the Arctic.

Students were recruited to the ADAC WFD Fellowship program using ADAC's Fellowship webpage, as well as through ADAC's project principle investigators upon recognition of outstanding performance in an academic setting. In order to apply, students first completed the application on ADAC's website. Applications were then screened and evaluated by ADAC's leadership team using the same criteria required for ADAC's fellowship program (as discussed in the "Abstract" section). Upon acceptance into the program, students were placed either with a project principle investigator, or incorporated as

⁴ Students may defer their employment commitment in order to pursue higher education. In addition, students with veteran status do not need to fulfill the HSE employment commitment.

a primary ADAC team member to assist with Center-related activities, such as event and workshop planning, technical report writing, feasibility analyses, literatures reviews, etc.

In order to track and evaluate the progress of each student, a fellowship “Work Plan” was developed, and/or modified at the start of each semester (Spring/Summer/Fall). The progress of each student was then evaluated with each student’s respective PI (if applicable), as well as ADAC’s Education and Administrative Manager. Each fellow also provided a monthly progress report to the Education and Administrative Manager throughout the academic year. In addition, student fellows attended monthly gatherings with ADAC leadership at the ADAC office, as well as virtually (due to COVID-19). These meetings included regular Center-related updates, mentoring opportunities, and occasional guest presentations.

Throughout their fellowship, students were provided continuous mentoring, coaching, and professional development. This came in the form of participating in research, attending and assisting with the education of ADAC’s workshops and events, as well as assistance with placement into a 10-week summer internship program, such as ASIP (discussed in the following section).

Upon completion of the fellowship program, career assistance and guidance were provided to each student as they either sought employment within the HSE or related discipline. In addition, in many cases, assistance with placement into graduate school programs is also offered.

ADAC Arctic Summer Intern Program (ASIP)

ADAC’s Arctic Summer Intern Program (ASIP) is a comprehensive internship conducted at the University of Alaska Anchorage. ADAC’s ASIP provides students opportunity to visit across multiple U.S. federal agencies with offices in Anchorage, participate in ADAC research conducted at UAA, as well as with ADAC’s research network in Southcentral Alaska, and take part in fieldwork activities throughout the Southcentral region, with a visit to Alaska’s most northern village, Utqiagvik (formally Barrow) Alaska. The objective is to provide an Arctic focused summer internship program as part of the overall ADAC Fellows program oriented for Minority Serving Institutions, under-represented classifications students and other ADAC Fellows as part of the student program’s overall workforce development to prepare undergraduate and graduate level students for entry into the Homeland Security Enterprise.

DHS S&T OUP Cooperative Grant Terms and Conditions require ADAC to develop and conduct two 10-week summer internships for all Center student fellows during their tenure of association with ADAC. Accordingly, ADAC created an innovative Summer Internship program for ADAC fellows and students from underrepresented minorities.

Due to the risks associated with the COVID-19 crisis, ADAC had to cancel its traditional in-person Arctic Summer Internship Program in 2020 and 2021. In its place, the ADAC Team transitioned ASIP into an entirely virtual 10-week summer internship in 2020. With the leadership of the program’s Principle Investigator, Dr. Craig Tweedie from the University of Texas at El Paso (UTEP), and program development coordination by ADAC’s Education & Administrative Manager, Ellee Matthews, ADAC’s new online internship program began on June 2nd, 2020, and ended on August 6th, 2020.

In recognition of the dynamic and complex challenges presented by the Arctic region, the 2020 ASIP program took an interdisciplinary approach to teaching students about the Arctic. In particular, the program emphasized that the Arctic’s challenges are multidimensional, as they are impacted by the current ever-changing characteristics of the Arctic, while also rooted in the region’s vibrant historical,

political, and cultural complexities. As such, the ASIP program covered a compilation of critical topics, ranging from Alaska Native studies to biology.