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Climate Change Impacts and Research Needs for DoD Assets in Alaska's Coastal Regions

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Abstract

Climate change is having major impacts in the Arctic where the retreat of sea ice and warmer temperatures will increase the threat to homeland security along the Alaskan coast, increase the already higher rates of coastal erosion, and increase Arctic shipping, petroleum and mineral exploration, and commercial fishing resulting in an increased need for spill response and search and rescue. The purpose of this white paper is to: (1) present the situation and current state of knowledge, (2) discuss the challenges DoD will face, and (3) identify R&D needs that DoD should address to meet its mission along the Alaskan Arctic coast. The Arctic coastal ecosystem is complex and dynamic, with processes that exhibit a high degree of temporal and spatial variability. There is also great uncertainty in our baseline understanding of Arctic coastal environmental processes and ecosystems because very few studies have been conducted. Several climate change phenomena affect the Alaska coastal environment including change in extent of sea ice, increased effects of storms unbuffered by shorefast ice, flooding, and increased salinity of sensitive coastal ecosystems, permafrost melt, and accelerating erosion due to increased coastal permafrost melt rates (due to warming seas and atmosphere), increased wave energy, increased storm surges, and sea level rise. The change will also affect activities by the Departments and Agencies of Homeland Security, Maritime Safety, and Environmental Protection. It will be necessary to build and fortify **ports and facilities**, conduct more **search and rescue (SAR)** operations, respond to spills and other forms of **coastal pollution**, and mitigate against **coastal erosion.** Indigenous communities must not be overlooked in DoD actions to address coastal climate change along the Alaskan coast. The inherent nonlinear behavior of the system precludes simple extrapolation of current trends as the feedback between climate change and environmental behavior can cause wildly varying response, particularly troublesome because the principal forcing mechanism (ultimately rising sea and atmospheric temperatures) has not been adequately measured nor is it easily quantified by other means (*e.g.*, models; heuristic calculations). Ultimately, action is taken at the local, response level. How uncertainty filters down to local (action) scales is not known, but it must be addressed in engineering practices, deployment of military infrastructure, indigenous community response, and ecosystem health and maintenance. In order to make progress, research must be done to address present gaps in our understanding, including new methods for obtaining relevant data, large field programs to observe present (and past) conditions, and verified numerical models to

predict future coastal change. This report includes 19 recommendations to address specific research needs to fill gaps in our understanding and to develop ways to proceed.

Introduction

Climate change is having a major impact on coastal regions as a result of sea level rise, warming air and water temperatures, and greater storm activity. Nowhere will these impacts be greater than in the Arctic, where warmer temperatures force the retreat of sea ice, consequently increasing accessibility to the land and the threat to homeland security along the Alaskan coast, exacerbating the already higher rates of coastal erosion, and increasing trans-Arctic shipping, petroleum and mineral exploration, and commercial fishing (resulting in increased needs for spill response and search and rescue).

The purpose of this white paper is to: (1) present the situation and current state of knowledge, (2) discuss the challenges DoD will face, and (3) identify R&D needs that DoD should address to meet its mission in the Alaskan coast and the nearshore Arctic.

When constructing the paper, three basic concepts were considered.

- The Arctic coastal ecosystem is complex (*i.e.*, it has many interacting components, water, ice, sediment, shore, air, biota) and dynamic. There are action-reaction links among all of the components. For example, creating some type of access channel and port on the coast will change the local hydrodynamics and that will, in turn, alter coastal erosion and sedimentation patterns and rates. The habitat will be different with some attendant changes in species composition and diversity that will alter the food webs and potentially threaten the traditional sources of protein for indigenous Alaskans. Navigation may also be affected as deposition and scouring alter the sea floor.
- When sea ice is present, coastal processes and human activity are minimal. However, when sea ice is retreating or totally gone there will be high temporal and spatial variability (on daily. monthly, and annual scales) as a function of tides, wind, weather and anthropogenic activity.
- There is great uncertainty in our baseline understanding of Arctic coastal environmental processes and ecosystems because of the lack of research that has occurred in this cold,

remote region of the planet. We are even more uncertain about what will happen as a result of climate change. All of our response activities to climate change on the Arctic coastal environment must be resilient enough to address this uncertainty.

Background

Alaska has approximately 47,000 miles of coastline which is 75% more than the rest of the United States combined (McCammon, 2005). The Arctic[1] regions of Alaska's coast are extensive and mostly consist of inhospitable coastline with relatively shallow water and few natural embayments, yet 80% of Alaska's residents live in coastal communities (Atkinson, 2005). The Arctic Ocean itself is a relatively isolated body of water, only 8.3% the size of the Pacific Ocean, encircled by five nations (U.S., Canada, Russia, Denmark (Greenland), and Norway) and consisting of eleven seas (*i.e.*, Chukchi, Kara, Laptev, Barents, Bering, Beaufort, East Siberian, Baffin, Greenland, Norwegian, and Pechora; Figure 1). It is in this region that the U.S. borders come closest to Russia, China, and North Korea. Indeed, as early as the late 1800s, the Navy established a research laboratory (NARL) in Barrow, AK to provide services to its fleet, particularly submarines (while impassable to ships other than icebreakers, the Arctic seas allow submarines to travel easily between the Atlantic and Pacific Oceans). Until recently, Alaska's Arctic coast has been isolated by ice. This has resulted in minimal interaction between DoD and indigenous communities and their unique and vital culture based on subsistence economy centered on harvesting fish and marine

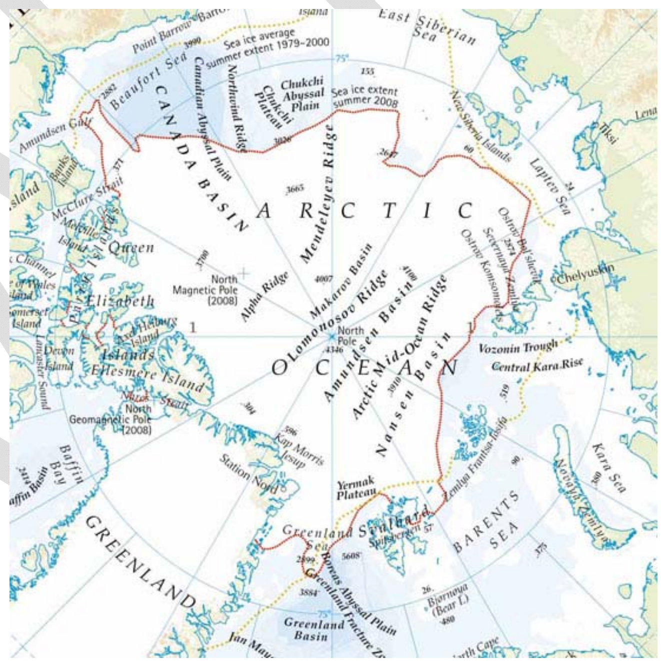


Figure 1: The Arctic Region
(http://www.guardian.co.uk/environment/2008/sep/18/poles.endangeredhabitats?gusrc=rss&feed=global)

[1] The definition of the Arctic used by the Immediate Action Workgroup in its report to the Governor's Subcabinet in Climate Change (Alaska) is used here. The Arctic is the area around the earth's North Pole. The Arctic includes parts of Russia, Alaska, Canada, Greenland, Lapland, and Svalbard as well as the Arctic Ocean. The 10^{0}C (50^{0}F) July isotherm is commonly used to define the border of the Arctic region. https://www.knowledgerush.com/kr/encyclopedia/Arctic/.

mammals. In addition, the coastal ecosystems are typically pristine because there is little shipping activity. For example, a barge travels to the coastal communities along the Beaufort and Chukchi Seas each summer to deliver the next 12 months of fuel to these communities. Whaling is still a community practice with spiritual and economic significance and boats are launched from shore, or directly from the ice, without the benefit of harbors because ice leads (*i.e.*, open water) move and change frequently. With the exception of the Prudhoe Bay and North Slope oil development, there is little industrial development in the Beaufort and Chukchi Seas. As of this writing, claims to jurisdiction are unclear as related to UNCLOS Article 76 (Treadwell, 2009). However, this may change rapidly if petroleum prices increase dramatically, as the U.S. Geological Survey estimates that 22% of the oil and gas reserves worldwide are found in the Arctic (Borgerson, 2009). Russia and Norway are dramatically increasing exports of oil. LNG and LPG are from the Barents, Laptev and Kara Seas. Production is also occurring in the Russian Far East at Sakhalin (Bambulyak and Frantzen, 2009). Many of these products are transported through the Arctic to the Atlantic or Pacific Rim countries including the U.S.

The Arctic is rapidly changing as a result of climate change. For example, the greatest temperature increase globally is in the Arctic (McCammon, 2005). Most broadly, climate change is manifested as an increase in temperature, precipitation and storms. More specifically, the Immediate Action Workgroup (IAWG) of the Alaska Governor's Subcabinet on Climate Change identified several climate change phenomena. All but one (wildfires) affect the Alaska coastal environment and its processes (IAWG, 2009), and include:

- Lack of sea ice
- Change in extent of sea ice
- Increased effects of storms (*i.e.*, surges, wind, and waves) unbuffered by shorefast ice
- Flooding
- Permafrost melt
- Erosion due to flooding or permafrost melt

These phenomena, coupled with higher sea levels and the increased input of sediment in rivers resulting from increased runoff have the potential to create a catastrophic situation along the Alaskan coast just when maritime, oil, gas, and hard minerals development and tourism are growing in the Arctic. Predictive models now indicate that the Arctic may be ice-free in the summer months by 2013 and all year-round by the end of the 21st century (Corell, 2009). For Summer 2008, much of the Northwest Passage through Canada and the passage adjacent to Russia and Norway in the Barents Sea was open water (Figure 2).

A host of U.S. and international committees, conferences, workshops and reports have been evaluating the implications of climate change on Alaska and the Arctic, particularly as they relate to maritime and coastal issues (*e.g.*, Arctic Marine Shipping Assessment, AMSA; Coastal Response Research Center, CRRC; IAWG) and national security (*e.g.*, House Foreign Affairs Committee, NATO, National Geospatial Agency, Arctic Ice Operations, Department of Homeland Security). Research on Arctic Climate Change issues has abounded with many endeavors associated with the International Polar Year (2008-2010). Key U.S. players in these efforts are: DoD, NOAA, U.S. Coast Guard, U.S. Arctic Research Commission, the Alaskan Governor's Subcabinet on Climate Change, the National Science Foundation, and the Minerals Management Service.

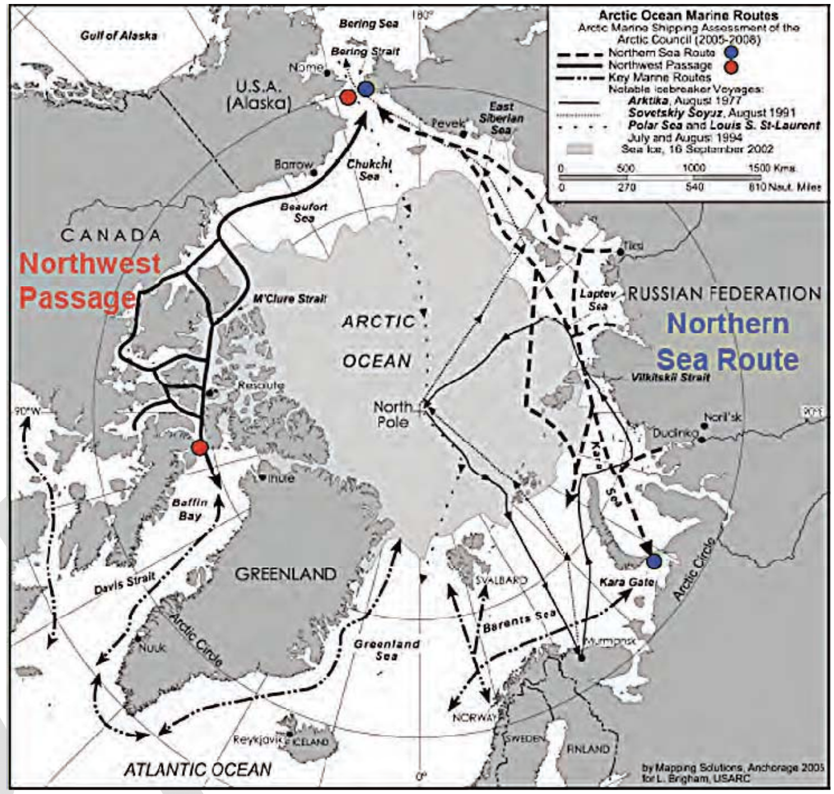


Figure 2. Arctic Marine Routes (AMSA 2005-2006)

Implications of Climate Change

The implications of climate change along the Alaskan coast and within the Arctic can be divided into three major categories:

- Homeland Security
- Maritime Safety
- Environmental Protection

Recent testimony by Mead Treadwell (Chair, U.S. Arctic Research Commission) before the U.S. House of Representatives Committee on Foreign Affairs (25 March 2009) focused on "New Frontiers of National Security" in the Arctic. He noted that the region is particularly important in several ways (Table 1). With respect to operations, the Navy and the Coast Guard will be

Table 1. Important Roles of Alaskan Arctic in the U.S. Security and Well Being (Based on Treadwell, 2009)

Defense	Energy	Environmental/Cultural
• Ground-based missile defense system • Submarine assets move rapidly between Atlantic and Pacific • Potential venue for surface military airlift • Intelligence and telecommunication assets in polar orbit and on ground	• Oil production regions since 1977 • U.S.'s largest reserve of natural gas • Potential for alternative energy source (e.g., gas hydrates, wind, hydro-kinetic, geothermal)	• Helps shield Earth from cosmic rays • Unique ecosystems • Source of 50% of fish consumed in the U.S. • Unique human culture

under increasing pressure to protect the strategically-important Alaskan coast from unfriendly military and terrorist activities. It will be necessary to build and fortify **ports and facilities** from which to supply and service military vessels and equipment. U.S. assets involved in energy production and mineral extraction will also need protection. With increased transpolar shipping, polar tourism (*e.g.*, cruise ships), and fishing (*i.e.*, climate change may warm waters sufficiently to move several major species into the Arctic), the Coast Guard will be involved in more **search and rescue (SAR)** operations. Some of the SAR activities may also involve vessels frozen in place as winter sea ice develops. Incidents of this type have already occurred. Increased shipping activity, energy and mineral development will likely lead to accidents causing spills, exacerbated by cold weather and harsh storms. Spills and other forms of **coastal pollution** will necessitate coordinated response to mitigate impacts on sensitive species. **Coastal erosion** also threatens to pollute the environment as some of the remaining Formerly Used Defense Sites (FUDS), particularly those associated with the Early Warning Radar Systems, are dangerously close to the eroding shoreline.

Many of Alaska's ports must be dredged routinely to allow ships access to channels and docking facilities. Sedimentation rates are high in many harbors (*e.g.*, Anchorage) due to the input of massive amounts of sediment, either transported from rivers or redistributed from the ocean environments (Sheffield, 2005; Oliver, 2005; Churchill, 2005). Increases in the amount of sediment deposition resulting from increased erosion (*i.e.,* due to melting permafrost and flooding) and higher bed loads in rivers entering the coastal zone, mean more frequent dredging will be needed to keep access available. Dredging can injure organisms through smothering or re-suspension of contaminants (*e.g.,* organics, metals). Disposal sites for dredge spoils are typically located within a short distance of the dredged area. However, because of the high energy hydrodynamics in many harbors, the sediment can be readily re-suspended and re-deposition can be a problem.

Ports on Alaska's Arctic Coast

Shipping is the lifeblood of operations in Alaska. Expansion of commercial operations at the Port of Anchorage, Alaska's main port, has also included more space and berths for military rapid deployments (*e.g.,* Stryker Brigade Combat Teams; Sheffield, 2005). In contrast, there are almost no embayments along the Chukchi and Beaufort Sea shoreline to serve as ports of refuge or bases for medium to large Coast Guard and Naval vessels. Dutch Harbor, in the Aleutian Islands, is the closest U.S. harbor with deep water and the nearest U.S. tugs to help in salvage activities are in Seattle (AMSA, 2009). In contrast, Russia, Norway, Iceland and Greenland (*i.e.,* the eastern Arctic) all have several deep water ports in the Arctic, and Canada has a number of ports. Currently, bulk materials such as fuel, building materials, and mining supplies are brought to communities along the Alaskan Arctic coast during the summer on barges (up to 3) pulled by a single tug. The materials are shuttled (*i.e.,* lightered) from the barge to shore using small boats or floating fuel lines and pumps (AMSA, 2009). Approximately 40 small boat harbors (less than 20 *ft* draft; less than 180 *ft* length) have been built by the Army Corps of Engineers in Alaska (Eisses, 2005). Boats used by indigenous communities for fishing are usually much smaller (2-3 *ft* draft; 18-30 *ft* length) and can be launched from the beach, ice, or ramps (many made by the Army Corps of Engineers). The ramps often need protection from the large waves generated during high winds. Maintaining ramps is also difficult because of winter ice along the shoreline and the force of erosion and sedimentation.

Ports of refuge are pre-established locations that can be made available to host ships in distress (*i.e.,* they usually have marine salvage and logistic support capabilities). When a vessel is unable to maneuver, taking on water, or leaking fuel or cargo, it is often best to tow it to the nearest port where it can be safely stabilized under more controlled conditions. Leaving the distressed vessel in the open ocean can subject it to high winds and waves that can cause further damage or even result in sinking. This is usually the least desired course of action during a maritime incident (*e.g.*, the case of the *T/V Prestige*). The *Prestige* was carrying a cargo of heavy fuel oil when it suffered damage to its hull off the coast of Spain in heavy seas on 13 November 2002. The governments of Spain and Portugal refused to offer a port of refuge for the vessel. The ship broke apart 6 days later; releasing approximately 2.5 million gallons of oil. The resulting slick stranded on the coast of northern Spain and France fouling 2,000 miles of shoreline. This spill highlighted the importance of pre-designating ports of refuge and associated protocols to avoid the type of paralysis that resulted from the *Prestige* disaster. In port, appropriate boom can be rigged to contain and recover leaking oil and repairs can be made by salvers in calm harbor waters.

An evaluation should be conducted of the need for, and feasibility of construction of, a port in the Alaskan Arctic that can serve as a base for Coast Guard, Naval, and potentially other military operations as well as a port of refuge. The location and size of such a port will necessitate an analysis of the nearshore bathymetry and coastal processes (*e.g.*, erosion and sedimentation), and plans to address long-term access (*i.e.*, when the sea ice recedes) and stability of the potential sites.

<u>Coastal Erosion</u>

Many of the problems faced by DoD in the Alaskan coastal environment relate to the unique problems of the retreat of the ice pack, the increased water temperatures (which accelerate the rate of coastal permafrost thaw) and the increase in storms and their severity, both exacerbated by sea level rise. Ironically, sea level rise is often not indicated as a problem in the Arctic due to the lack of adequate vertical control and tidal stations needed to detect any rise. Erosion has been a noted problem in the coastal zone of much of Alaska, including the coasts along the Beaufort Sea (North Slope), Chukchi Sea, Bering Sea, and Cook Inlet. The highest erosion rates (on the order of 20 to 30 *m/yr*) have been observed on the North Slope in the vicinity of Teshekpuk Lake (between Drew Point and Cape Halkett; Figure 3). Consequences of coastal erosion include increased risk to infrastructure and indigenous culture associated with local communities (*e.g.*, Lynch *et al.*, 2004), high sedimentation in navigation channels, waterways and sensitive benthic ecosystem habitat, and increased carbon flux to the oceans from coastal tundra, a region previously believed to be a carbon sink (Billings, *et al.*, 1982; Gorham, 1991; Waelbroeck and Monfray, 1997; McGuire, *et al.*, 2000; Jorgenson and Brown, 2005).

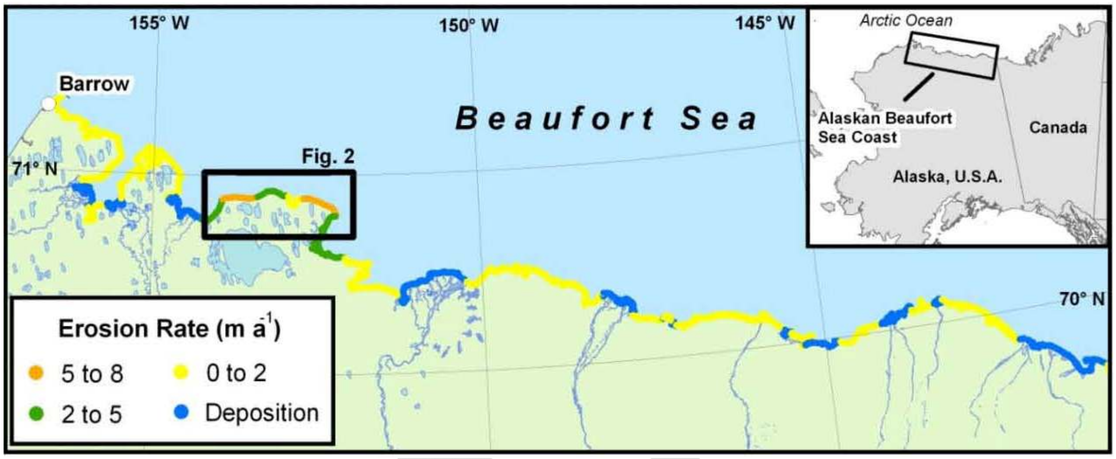


Figure 3. Map of erosion rate on the Alaska North Slope showing the heightened erosion rate between Drew Point and Cape Halkett (erosion rates from period 1950-1980 (approximately) based on data from Jorgenson and Brown 2005. Note: current erosion rates are significantly higher than those shown in the figure. (Map created by Ben Jones, USGS)

The erosion rate in this portion of the North Slope is higher than that in neighboring areas on account of the high ice content of the bluffs, the fineness of the sediment grains found in the bluffs, and the absence of barrier islands (Jorgenson and Brown 2005, Reimnitz *et al*., 1988). Further, in this portion of the North Slope, the erosion rate has been accelerating (Mars and Houseknecht, 2007; Jones *et al*., in press) due to warming of the Beaufort Sea (Steele *et al*., 2008), intensified meteorological conditions, and increasing spatial and temporal extent of open, ice-free water (Stroeve *et al*., 2008).

Coastal erosion has been problematic for coastal villages on the Chukchi and Bering Seas. A number of villages (*e.g.,* Shishmaref and Kivalina) have achieved national recognition as a consequence of their exposure to the coastal erosion threat. In the case of Shishmaref and other coastal villages, the increasing coastal erosion is related to a trend toward less protective nearshore sea ice in October, when the intense Chukchi Sea storms tend to occur. However, the erosion studies of the Chukchi Sea find a significantly slower erosion rate than the fast eroding portions of the Beaufort Sea. Some villages located on the sides of rivers (*e.g.*, Newtok on the Ninglick River) have experienced massive river shoreline erosion which is exacerbated by storm surge and permafrost thaw.

One of the most dramatic coastal erosion mechanisms at work in Alaska is the erosional niche/block collapse mechanism (Figure 4) that is prevalent at some of the fastest eroding locations on the Beaufort Sea. This mechanism is prevalent when the volumetric ice content is very high and when the sediment grains are very small (*e.g.,* silt-sized). Niche erosion occurs when the sea can directly contact and melt the base of the bluff (which is mainly ice) and remove the sediments released. Often the coastal bluff is fronted by a small beach, and thus niche erosion sometimes requires the presence of sufficiently large storm surge. Niche erosion continues until the bluff can no longer support the overburden and block collapse occurs. Typically, the block collapses when the niche grows to about 10 *m* and reaches an ice wedge. A mathematical model of niche growth was developed by Kobayashi (1985) and analysis of the block collapse has been provided by Hoque and Pollard, (2008). Predictive coastal erosion models are under development for a site near Drew Point using the Kobayashi niche erosion model and using an empirical block erosion model (T.M. Ravens, *pers. comm.*, 2009). The model indicates that coastal erosion rates might increase to about 30 *m/yr* by 2045 (from about 13 *m/yr* in the last decade). Another erosion mechanism is retrogressive thaw slump erosion (Hoque and Pollard, 2008). This erosion modality is driven by radiation and convective heating of the bluff face which thaws and slumps into the sea. There have not been any attempts to develop a predictive erosion model for thaw slump. In some cases, coastal erosion appears to be driven by the slumping (*i.e.*, the lowering) of the nearshore zone due to permafrost degradation.

Figure 4. Collapsed block on Alaska North Slope (http://geology.com/usgs/alaska-coastal-erosion)

The recognition that coastal erosion rates have accelerated and are linked to global climate trends has emphasized the need for improved understanding of nearshore processes in the Alaskan Arctic. However, the cold, harsh weather and remote location makes comprehensive nearshore observational programs in the Arctic difficult and funding for such observation has been insufficient. The lack of observations limits quantitative model development.

The nearshore problem in cold climates is closely linked to the presence of ice. In the Arctic Ocean when sea ice covered most of the sea most of the time, the ocean was somewhat buffered from the effects of large storms. Through the years, this buffering shielded coastal regions from much of the wave attack that would have resulted if the ice were not there. However, with the decline in sea ice, the impact of Arctic storms has had a much greater impact on the coastline, ecosystem health, and communities that rely on coastal resources for their livelihood. Prediction of storm impacts is thus closely linked to inter-annual fluctuations of the larger-scale, regional sea ice extent coupled to weather forecasting models. In addition to limiting wind driven waves and currents near the coast, sea ice can transport entrained sediment away from shore when the ice pack moves offshore. Thermoabrasion processes due to ground and shorefast ice can gouge out deep channels in the beach and push sediment along ridges, and may contribute to large scale changes in Arctic sediment balances (*e.g.*, Dallimore, *et al.*, 1996; Are, 1988; Are, 1998).

The presence of ice also impacts sediment transport along the shoreline. Ice within frozen sediment layers bonds the material and provides a measure of resistance to erosion, but also contributes to slope failures on the bluff during thaw periods (*e.g.*, Forbes and Frobel, 1985). Coastal models have been developed that include the effects of thermo-erosional processes based on temperature differences in the sea water and sediment (*e.g.*, Kobayashi, *et al.*, 1999), but are not linked explicitly to process-based models that move entrained sediment and predict the evolution of nearshore bathymetry.

Despite much effort expended in measuring active-layer depths above the permafrost in the Arctic (*e.g.*, Brown, *et al.*, 2000, and many others), limited data exists for the temperature structure of soils and sediments at the waterline, on the beach, or in the adjacent cliffs, dunes, or tundra exposed to wave attack. At the present time, no permanent Circumpolar Active-Layer Monitoring (CALM) sites exist on the beach or close to the bluff edge, due primarily to the risks associated with uncertainty in erosion rates at the shoreline (up to 10's of *m* in a single season). Thus, present leading nearshore morphodynamic models for beach behavior (such as Delft3D; *e.g.*, Lesser, *et al.*, 2004) are limited to heuristic two-dimensional profile evolution models without consideration of thermal processes in sediment transport, and as a consequence, process-based predictions for future change in the Arctic are not yet well developed. To address this problem, improvement is needed in our understanding of how thermal properties and temperature structure on Arctic beaches, bluffs and coastlines are coupled to mechanical sediment transport driven by waves and currents.

Studies related to beach, cliff, and tundra erosion in cold climates should vigorously pursued, ultimately aimed at aiding prediction of coastal profile evolution under dramatically forecasted climate change scenarios, in assessment of flooding risk and inundation associated with coastal profile change, and for improving estimates of the amount of carbon that might be introduced into the sea through long-term changes in Arctic tundra coastlines.

Search and Rescue

The Arctic Marine Shipping Assessment (AMSA) report, released in April 2009, estimates that traffic will increase several fold as the sea ice recedes in the summer opening passages across the top of the world. AMSA notes traffic will include military, cargo, tanker, and fishing vessels and cruise ships. AMSA layered the seasonal ship traffic on a map of the Arctic seas ice extent for July 2004 (AMSA, 2009; Figure 5). This depiction clearly highlights that the eastern Arctic is the most heavily travelled. However, once summer sea ice melts enough to consistently open trans-Arctic navigation through the Bering Strait and if oil and gas development increases in the Alaskan Arctic, the

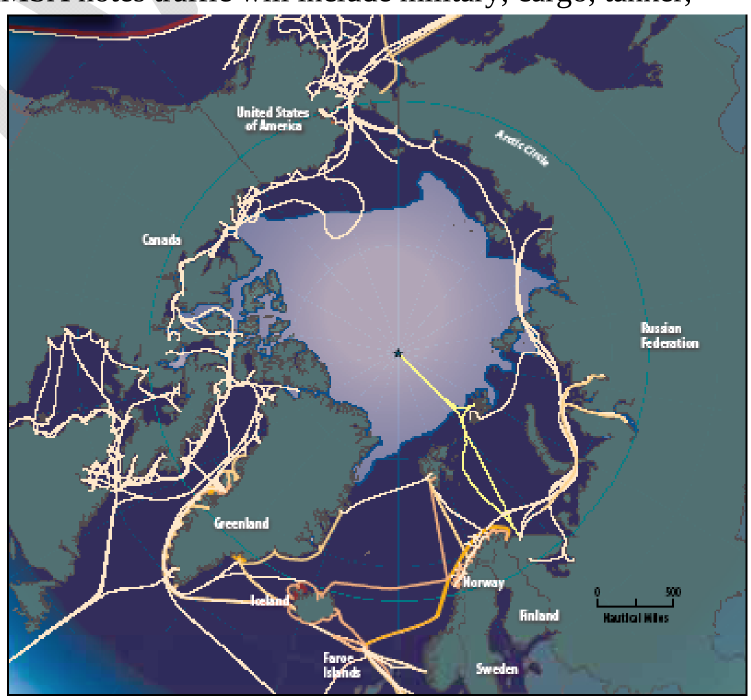
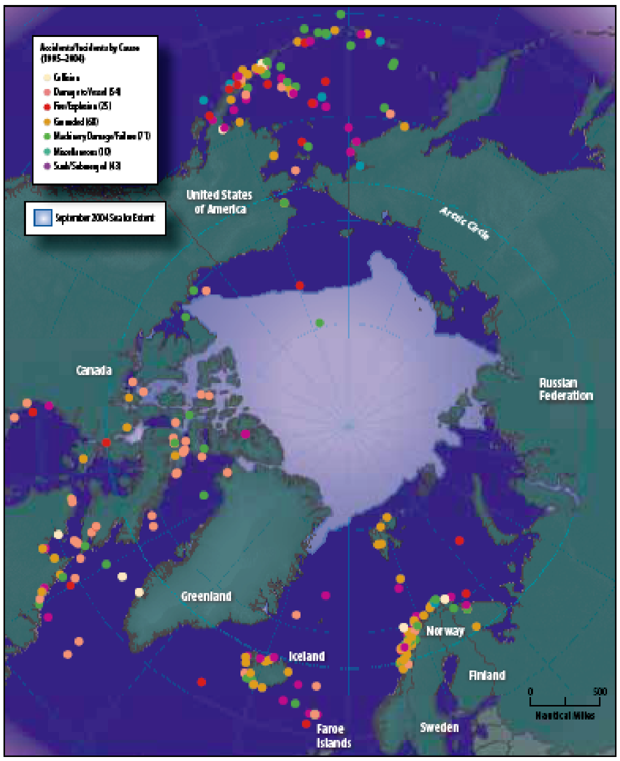


Figure 5. July 2004 Arctic ship traffic (AMSA, 2009 Map 5.6)

western Arctic will likely be just as active. Figure 6 (AMSA, 2009) shows the oil types and locations of the 293 incidents that occurred from 1995-2004. As AMSA notes, the bathymetry of the Arctic is poorly known and there is a dearth of navigational aids (*e.g.*, buoys, weather service reports). A March 2008 workshop sponsored by the Coastal Response Research Center (CRRC), NOAA, U.S. Coast Guard, and the U.S. Arctic Research Commission explored five probable marine incidents that will result from the increased ship traffic including: a cruise ship grounding; an ice-trapped and damaged ore carrier; an explosion on a fixed drilling rig north of Alaska; a collision between a tanker and fishing vessel that results in a large oil spill; and the grounding of a tug towing a barge of explosives in an environmentally sensitive area near the Bering Strait. Each case involved Search and Rescue.



Map 5.7 Arctic shipping accidents and incidents causes, 1995-2004. *Source: Lloyd's Marine Intelligence Unit Sea Searcher Database, Canadian Transportation Safety Board (Marine), Canadian Hydraulics Centre-Arctic Ice Regime System Database.*

Figure 6: AMSA, 2009

When people, vessels, or craft (*e.g.*, airplanes) are in distress or imminent danger, the Coast Guard and DoD (depending upon the situation) provide SAR aid. There is an obvious link between the increasing number of marine incidents in the Arctic and the need for SAR capabilities. Currently, the closest base for major SAR vessels and aircraft is at the U.S. Coast Guard station in Kodiak, Alaska (about 1,000 miles south of Barrow, Alaska). SAR depends upon effective communication, detailed knowledge of the weather (*e.g.*, past, current and future winds, storms), location of sea ice, and navigational aids. In addition, real-time data from ocean observing systems is essential to elucidate sea states, currents, tides, winds, and other air and water conditions (*e.g.*, temperature).

In general, the Arctic is very sparsely instrumented. There are very few buoys deployed by the Alaska Ocean Observing System (AOOS) in the Arctic, almost all of which are concentrated near Barrow (McCammon, 2005). There are also very limited stockpiles of SAR equipment in the Arctic region.

Clearly, if the Coast Guard and Navy are increasing their presence in the Arctic, more navigational aids, weather information, communication capabilities, AOOS data, and the National Weather Service, NWS information must be installed and maintained along with stockpiles of SAR equipment.

<u>Pollution Response</u>

Increased activity along the Arctic coast of Alaska will potentially result in more pollution, including discharges of contaminants from ships (*e.g.,* NO_X, SO_X, VOCs; AMSA, 2009), dredge spoils, spills from offloading cargo, shipboard releases; oil and gas platform releases, and coastal FUDs that may fall victim to coastal erosions. Of these, the greatest potential risk is accidental release of petroleum that can create oil slicks that foul coastlines, smother or coat birds and marine mammals, and harm (*i.e.,* acute or chronic toxicity) marine species (including commercially important and key species in the ecosystem). A spill event triggers an emergency response to stop the release, employ strategies to prevent contamination of sensitive areas (ESI of Arctic Alaska, Figure 7), and recover free product. Stopping the release involves deployment of assets (*e.g.,* salvage vessels) which may not be based in the Alaskan Arctic to stabilize the vessel or equipment at the shore-based facility (*e.g.,* off-loading pipeline). As noted in the sections on Ports and SAR, these types of equipment and facilities are not presently located along the Arctic coast.

The U.S. Coast Guard has an Incident Command System (ICS) that is used during any spills in which it is involved. ICS is practiced annually in every region and includes an organizational structure to formalize response. The U.S. Coast Guard takes the lead in on-scene coordination of spill response. NOAA, the U.S. Fish and Wildlife Service, and other federal and state agencies (*e.g.,* Alaska Dept of Environmental Protection) provide assistance to the Coast Guard. The ICS also includes the Responsible Party (RP) in the decision-making, because of its role in financing clean-up.

Response decisions often have to be made in a very rapid timeframe to protect sensitive species or assets (*e.g.*, fishing/whale stocks/birds are very important to indigenous populations). This means that the Joint Incident Command must have as much relevant information as possible in an easily understandable format (*e.g.*, weather conditions, sensitive species locations, current and predicted spill trajectories, response vessel/equipment predicted types and locations, sea ice location, ice type, and predicted current). This information is lacking in much of the Alaskan Arctic (see section on SAR). There is a new system that the National Response Team (NRT) is considering

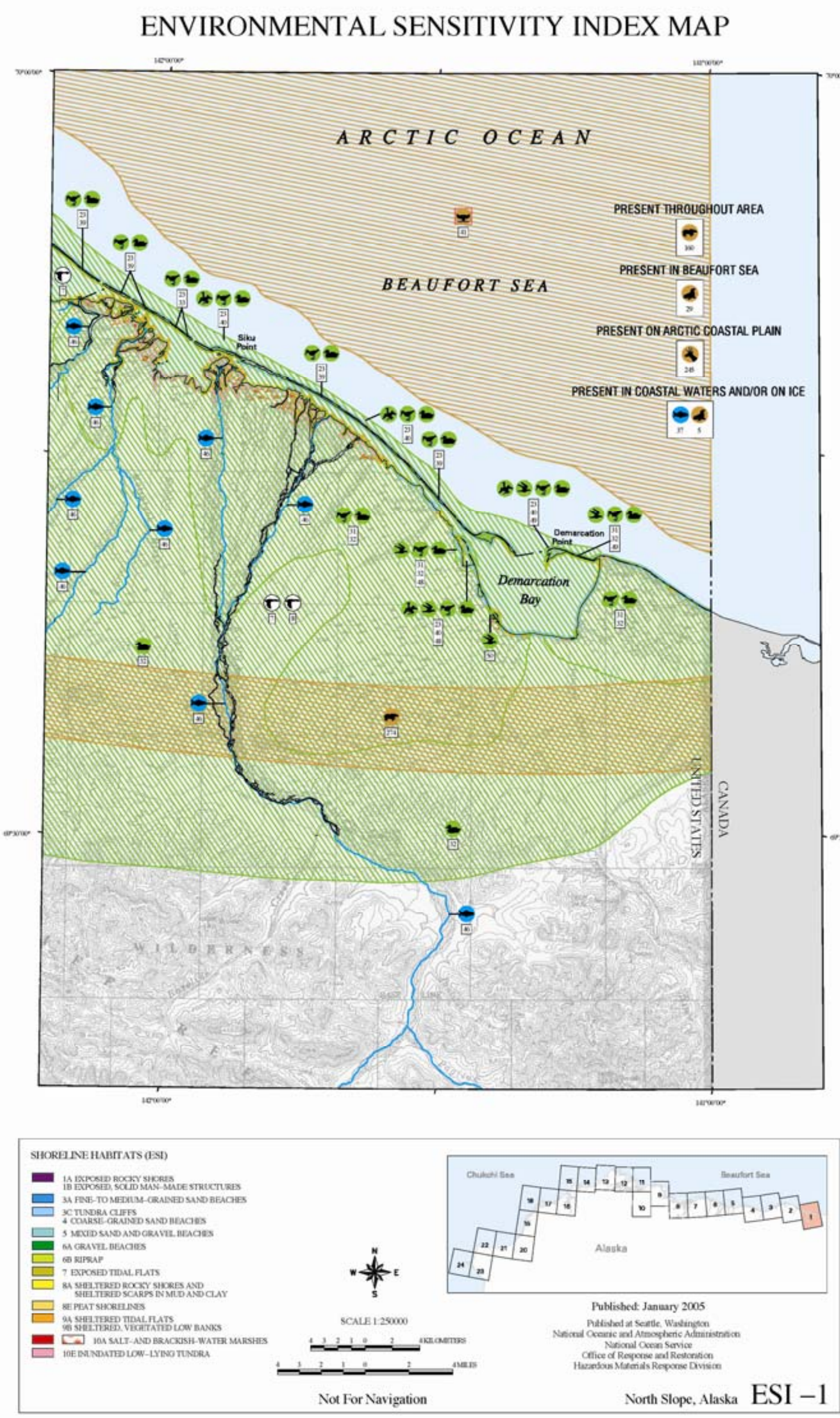


Figure 7. NOAA ESI of Arctic Alaska (www.response.restoration.noaa.gov)

as a platform to supply these data and allow them to be overlaid on a computer to help visualize the complex and multi-faceted data available. The system (Environmental Response Management Application, ERMA) was developed and piloted by CRRC and NOAA. There is interest along some of the stakeholders in the Alaskan Arctic to build a layer on the existing ERMA structure that is able to query and upload data from the North Slope.

Response technologies for oil recovery have been developed for much warmer regions. The effectiveness of booms, skimmer and chemical dispersants in Arctic waters is poorly known. With the thrust to develop offshore oil and gas facilities in the Alaska and Canadian Arctic, the interest in cold water and oil-infested-ice response technology development has increased. Several private sector and governmental organizations are participating in a Joint Industry Program (JIP) occurring in May 2009 in the Barents Sea to test such specialized equipment. Oil released under ice or encapsulated in ice presents even more detection, response, and recovery challenges. The U.S. Minerals Management Service has sponsored some work on these types of technologies, but most are far from being operationally ready.

Little is known about the potential impact of spills on Arctic species (*i.e.*, in the water column, along the shoreline, or on the bottom) from the base of the food chain (*e.g.*, ice algae, phytoplankton) to the top (*e.g.*, carnivorous marine mammals and birds). There are few baseline studies of coastal ecosystems, so even if a spill occurred, there would be a dearth of data to compare with post-spill species types and abundance. It would also be difficult to conduct the mandated Natural Resource Damage Assessment (NRDA) or decide on the best practices for recovery or restoration. Clearly, because of the challenges and inadequacies of cold water/ice spill response equipment and strategies, biota will be impacted. Compounding this problem, the natural degradation (weathering) processes (*i.e.*, evaporation, biodegradation) will be slowed by the cold temperatures and limited sunlight. Hence, everything (habitats and species) will be negatively impacted and restoration will be necessary. Unfortunately, there has also been very little work done on effective restoration strategies for Arctic and subarctic coastal ecosystems.

<u>Human Dimensions</u>

Much has been written about the role of human dimensions in development in the Arctic (Brelsford, 2005; CRRC, 2009; AMSA, 2009; Ritchie, and Gill, 2007). Indigenous people have a very strong culture that is tied extremely closely to subsistence fishing and hunting (*e.g.*, whales, seals, polar bears, and pelagic fish) and spiritual oneness with the natural world. These communities also have a wealth of local knowledge about the coast and the marine environment (*e.g.,* tides, currents, weather, ice movement, species habitat and migration). Any development along the coast by the DoD, Coast Guard or other entities, must be conscious of the importance of these cultures and not negatively impact them. In addition, this local knowledge can supplement and complement knowledge gained in work done by the DoD and others to address issues involving coastal processes.

The Challenge

The response of the Arctic coastal environment to changing environmental conditions involves a complex mix of interconnected processes that interact over a wide range of spatial and temporal scales. The inherent nonlinear behavior of the system precludes simple extrapolation of current trends as the feedback between climate change and geomorphic behavior can cause wildly varying response, particularly troublesome because the principal forcing mechanism (ultimately rising sea and atmospheric temperatures) has not been adequately measured nor is it easily quantified by other means (*e.g.,* models; heuristic calculations). This problem presents significant challenges for scientists, coastal and ocean engineers, environmental managers, military personnel, and political leaders.

Ultimately, action is taken at the local, response level. However, determining what this action should be is heavily dependent on larger scale, longer term regional influences. Thus, forming models for the evolution of, for example, geomorphology of the coastlines requires as boundary conditions regional scale observations or models. These in turn are driven by global climate change scenarios that have very high uncertainty. How this uncertainty filters down to local (action) scales is clearly not known, but is necessary to constrain engineering practices, deployment of military infrastructure, indigenous community response, and ecosystem health and maintenance. In order to make progress, scientific research must be done to address present gaps in our understanding, including new methods for obtaining relevant data, large field programs to observe present (and past) conditions, and verified numerical models to predict future coastal change. Of particular importance are addressing gaps in our knowledge base and data needs listed below.

Data, Research and Development Needs

- Quality nearshore bathymetric data is needed. NOAA data is very sparse and, since it is intended for use in navigation, it may be biased toward reporting "minimum" depth. Also, available bathymetric data may be out-of-date considering the rapid geomorphic change in some areas.
- Geological data is needed (*i.e.*, grain size distribution, ice content, organic content) in nearshore bluffs and in beach sediments (some USGS and other data may exist, but it is not readily accessible).
- Wave generation and propagation must be estimated in seas with ice. Some work has been done on wave dissipation in the Antarctic (Squire, 2007).
- Quality wind field and atmospheric pressure data are needed for storm surge and wind wave models, as well as wave, current, and water level data to calibrate storm surge, current, and wave models (CERB, 2005).
- Regional climate change models that include nearshore temperature projections need to be developed. The regional climate change models should be driven by one or more standard global change scenarios.
- Maps depicting the locations where different erosion mechanisms are at play should be generated.
- Detailed field data from locations at which particular erosion mechanism are active must be obtained along with projections to develop and calibrate coastal erosion models of nearshore air and water temperature, water salinity, solar radiation, and wind under various climate change scenarios. Logistics and equipment/instrumentation may need to be improved in order to acquire this data (*i.e.*, we need comprehensive Arctic nearshore processes field experiments).
- Data obtained should be contributed to various public, online data warehouses, including - but not limited to - the CALM database, the European led Arctic Circum-polar Coastal Observatory Network (ACCO-NET), and Alaskan Ocean Observing System (AOOS).
- An open-source predictive process-oriented model for nearshore sediment transport, coupled to regional meteorological and sea-ice models through predicted wind-driven ocean wave fields, allows for climate change scenarios with multi-decadal time-scales to be considered. Linking wave and circulation models with atmospheric models and

shallow water bathymetric surveys will allow forecasts of increased Arctic storm activity on nearshore profiles, beach erosion, and sediment transport, and provide guidance for engineering practices in an increasingly exposed Arctic coastline. These models can also be linked to flood predictions that include wave-driven set-up, swash oscillations, and storm surge.

- Emergency response assets/supplies/equipment/planning in Arctic regions must be increased, especially in active regions.
- Arctic communications, vessel transit networks, and response management tools should be developed and their coverage expanded.
- Baseline/information data must be collected for Arctic regions for resources or activities that could be affected by potential incidents (*e.g.,* biological, cultural, subsistence, hydrographic, charting).
- Investment must be made in research and development for Arctic spill response.
- Environmental risk assessments and impact assessments must be conducted for the Arctic seas, shipping routes, and ports (multi-layered approach).
- Potential port(s) of refuge must be constructed on the coast using technology developed to suit the rigors of the Arctic environment.
- Knowledge of coastal processes, vessel launching/mooring, and environmental response for the Arctic should be improved through research and development and engagement of the local community, DoD officials, responders, and industry.
- Coastal weather monitoring systems should be expanded, including deployment of more AOOS assets.
- The behavior of potentially spilled materials (*e.g.*, oil) in cold and ice-infested water should be studied to improve existing spill models and lower the uncertainty about its fate and transport *in situ*.
- Local communities and stakeholders should be well-informed about the risks and potential environmental damage and socio-economic impacts that could occur as a result of increased coastal activity resulting from climate change.

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