Acquisition Directorate

Research & Development Center

Verify International Maritime Organization Polar Code Survival Time Requirement

Arctic Search & Rescue Simulation Model

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Homeland Security

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16. Abstract (MAXIMUM 200 WORDS)

The International Maritime Organization (IMO) Polar Code defines the maximum expected time of survival as "the time adopted for the design of equipment and systems that provide survival support. It shall never be less than 5 days" (IMO, 2017, p. 10). This project reviews this requirement by examining six search and rescue (SAR) scenarios within the United States (US) Arctic Area of Responsibility (AOR). The six scenarios vary in scope, location, and season to provide a broad look at the Polar Code requirement under different conditions. The model uses historical vessel track information, SAR response asset siting, and historical weather data to produce a confidence interval containing the expected time a victim in an Arctic maritime emergency might have to rely upon lifesaving appliances (LSA) and survival supplies.

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EXECUTIVE SUMMARY

Maritime emergencies in the Arctic present unique challenges to mariners and Search and Rescue (SAR) response agencies. Ships that navigate Arctic waters transit sparsely populated routes, with limited means for communication, severe weather conditions, and numerous hazards to navigation – primarily ice. Agencies responding to Arctic maritime disasters often have limited or seasonal resources, less permanent infrastructure, and cover vast areas of responsibility (AOR). Due to these realities, the time Arctic distressed mariners wait for assistance is often longer than a comparable emergency taking place at a lower latitude.

The International Maritime Organization (IMO) Polar Code regulates ships subject to the International Conventions of Safety of Life at Sea (SOLAS) and Prevention of Pollution from Ships (MARPOL) operating in Arctic and Antarctic waters. The Polar Code requires that the equipment and supplies required to sustain life in a maritime emergency must be functional in the Polar environment for the maximum expected time of rescue (METR), which the code defines as "not less than five days." The Polar Code requires ship owners to determine the METR through an Operational Assessment but provides only limited guidance on how this assessment is to be undertaken. Additionally, the development of the five-day baseline requirement is not documented. It is likely that many Arctic routes will face a METR that exceeds five days, but there is nothing preventing companies from claiming a five-day METR due to the lack of a standardized, accepted, and repeatable process to calculate METR. A company calculating a METR that is insufficient for a given vessel's route would place their crew and passengers at significant risk.

This project focused on the United States (US) Arctic AOR[1] and developed a simulation model to study six conceivable Arctic emergency scenarios. The model evaluates the scenario response time over several iterations to calculate an interval containing the expected time until response. These six scenarios take place between the months of June to October, range in victim counts from eight to 320, and extend from the Chukchi and Beaufort Seas to the North Pole.

The simulation model incorporates historical traffic patterns, weather data, and seasonal asset siting to run the scenarios and reports the first contact of each asset type to the SAR event as well as the total time it took to recover the last victim from the scene.

The results show that the five-day minimum requirement is adequate in some of the scenarios but would be insufficient in other scenarios. Routes that are beyond the range of response helicopters or rescues involving vessels with significant numbers of persons onboard can expect METR to exceed the five-day baseline. In a joint decision with CG-SAR and Coast Guard District 17, the operational commander for the US Arctic AOR, this study did not examine if the METR baseline of five days should be lowered for some voyages.

Considering the realities this model presents, it is recommended that the Polar Code be updated to include specific requirements and/or methods companies may use to repeatably and consistently calculate METR on their Operational Assessment. This will ensure thorough consideration is applied to Polar routes, that every Polar Ship Certificate METR is evaluated from a uniform standard, and provide sufficient safety apparatus for all persons on board Polar voyages in the case of a SAR incident.

[11] While the US could conceivably assist in an Antarctic SAR case if a US vessel were present, the US does not have a specific SAR AOR in the Antarctic. Therefore, this study focused solely on the US Arctic AOR.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AF	Air Force
AIS	Automatic Identification System
AK	Alaska
AOI	Area of Interest
AOR	Area of Responsibility
AR	Army
AR NG	Army National Guard
ASP	Arctic Sustainment Package
CDS	Climate Date Store
CG	Coast Guard
DHS	Department of Homeland Security
DOD	Department of Defense
EEZ	Exclusive Economic Zone
EPPR	Emergency Prevention, Preparedness and Response
ETR	Expected Time of Response
FSA	Formal Safety Assessment
IMO	International Maritime Organization
kts	Knots
LSA	Life Saving Appliance
MARPOL	International Convention for Maritime Pollution of Ship
METR	Maximum Expected Time until Rescue
MISLE	Maritime Information for Safety and Law Enforcement
NAVCEN	USCG Navigation Center
nm	Nautical Miles
NRC	National Resource Council
NRC	National Resource Center
NSIDC	National Snow and Ice Data Center
NSP	North Slope Burrough
PC	Polar Class
PJ	Para Jumpers
SAR	Search and Rescue
SAREX	Search and Rescue Exercise
SOLAS	International Convention for Safety of Life at Sea
US	United States
USCGC	US Coast Guard Cutter
VOO	Vessel of Opportunity
WMSL	Maritime Security Cutter, Large

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1 INTRODUCTION

Maritime emergencies in Polar regions present unique challenges to mariners and Search and Rescue (SAR) response agencies due to the regions' geography, meteorological conditions, and isolation. Mariners in distress in these areas will often need to wait longer for assistance than a comparable emergency taking place at a lower latitude.

The International Maritime Organization (IMO) Polar Code requires that the equipment and supplies required to sustain life in a maritime emergency must be functional in the Polar environment for the maximum expected time of rescue (METR), which may not be less than five days (Part 1-A 1.2.7). Ship owners are entrusted with determining their vessel's METR through an Operational Assessment of the ship and proposed Polar operating environment (Part 1-A 1.5). The METR evaluated through the Operational Assessment is then used to select the quantity and capability of the Life Saving Appliances (LSA) and survival equipment.

The IMO Polar Code dictates that the Operational Assessment should consider the harsh environment described below in Section 1.1 (Part 1-A 1.5). To perform the Operational Assessment, the Code recommends developing a model to evaluate risk and references the models listed in Appendix 3 of the Revised Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process (MSC-MEPC.2/Circ.12). Appendix 3 describes nine risk assessment modeling methods that range in method from statistical models (Bayesian Networks) to subject matter experts participating in What-If Analysis. The IMO Polar Code does not describe a minimum standard or method required to conduct the Operational Assessment.

This project focused on the United States (US) Arctic area of responsibility (AOR). The project developed a simulation model and tested numerous Arctic maritime emergency scenarios to estimate the response time over several runs to determine the maximum time until rescue and compared these to the five-day baseline requirement. Of note, after discussion with CG-SAR and US Coast Guard District 17 staff[2], this study did not examine or evaluate if the five-day METR should be lowered for some voyages. Given the harsh climate of the Arctic and rapidly variable conditions, it is conceivable that response efforts could be hindered or delayed in any scenario. For instance, if weather conditions prevented a helicopter-based rescue, the arrival of an adequate surface vessel could quickly approach five days even for relatively near-shore, ice-free transits.

1.1 The Arctic

The IMO Polar Code defines Arctic routes as those that fall within the bounds pictured in Figure 1.

[2] Coast Guard District 17 serves as the operational commander and SAR Coordinator for the US Arctic AOR.

Figure 1. Arctic region (IMO, 2017, p. 9).

Within this unique region the Polar Code identifies ten hazards which necessitate the existence of the Polar Code: ice, icing, low temperature, extended daylight/darkness, high latitude equipment malfunctions, remoteness, lack of experience in polar operation, lack of suitable equipment, unpredictable weather, and sensitive environment (IMO, 2017 p. 6-7). Many of these hazards contribute to the probability and severity of a SAR event and inhibit the speed at which agencies can respond.

The US has SAR authority in the waters surrounding Alaska as shown in Figure 2. This project focuses on scenarios that take place in this region, particularly on the section of the Northwest Passage (Figure 4) that passes along the North Slope of Alaska.

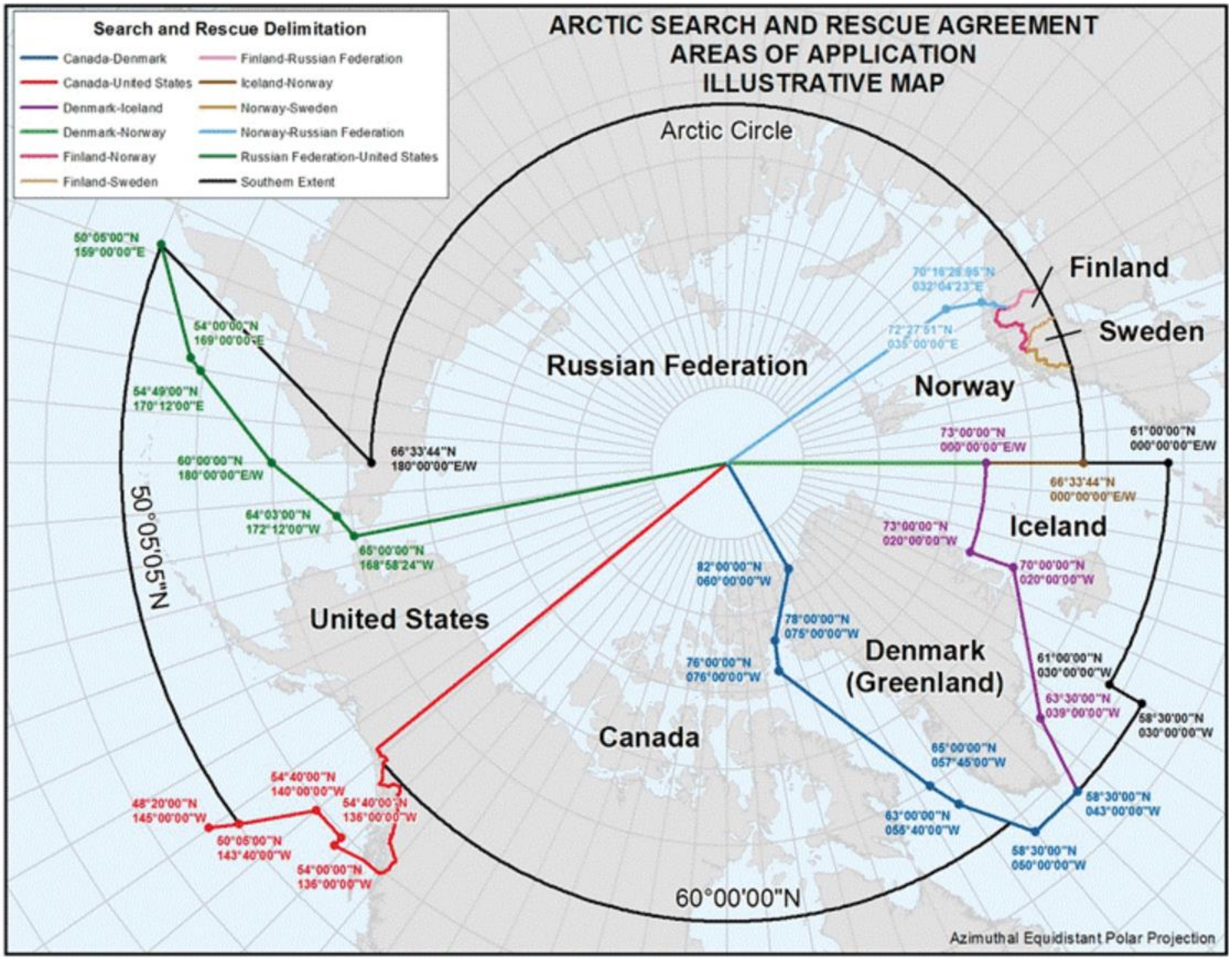

Figure 2. Arctic nation SAR AORs (Department of Homeland Security, 2018, p. 3).

The US Arctic AOR includes portions of the Bering Sea, Chukchi Sea, Beaufort Sea, and Arctic Ocean. "Although winter sea travel is still severely limited because of extensive ice coverage across the region, record low ice extent in recent summers has made seasonal maritime navigation more feasible for longer periods of time" (Department of Homeland Security, 2018, p. 6). Figure 3 depicts the changing ice conditions between July 2022 and December 2022. This project focuses on SAR scenarios in the summer and shoulder seasons (June – Oct) when a Maritime SAR event is most likely to occur.

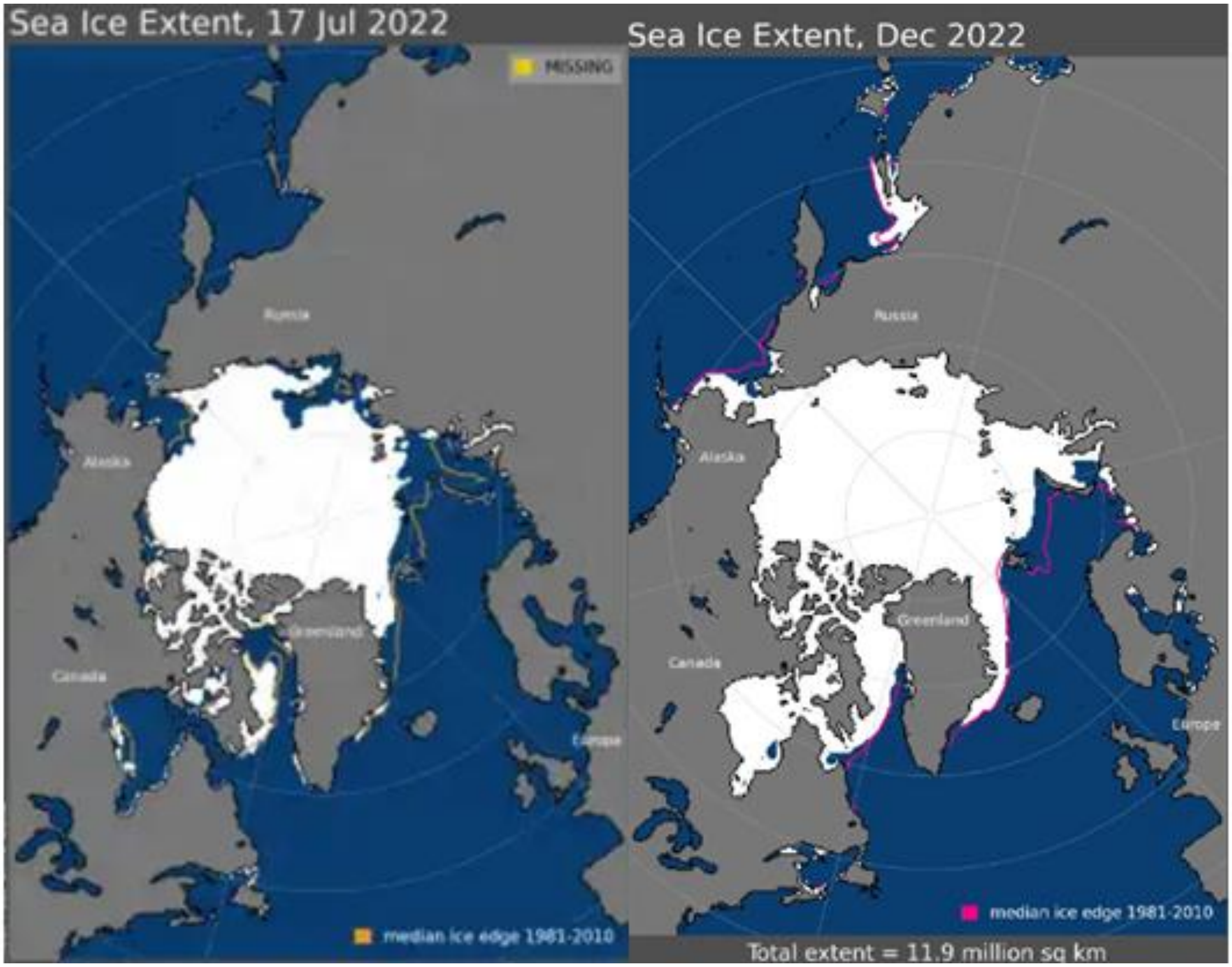

Figure 3. Ice extent in the Arctic (NSIDC, 2022).

1.1.1 Arctic Maritime Traffic

The maritime transit routes of the Arctic vary significantly but, in the US AOR, the transits are primarily in open ocean. There are two main transit lanes in the Arctic, the Northwest passage marked in red and the Northern Sea route in orange and white in Figure 4. There are sporadic trips outside the two transit routes, but they are significantly fewer than the main transit passages (Figure 5).

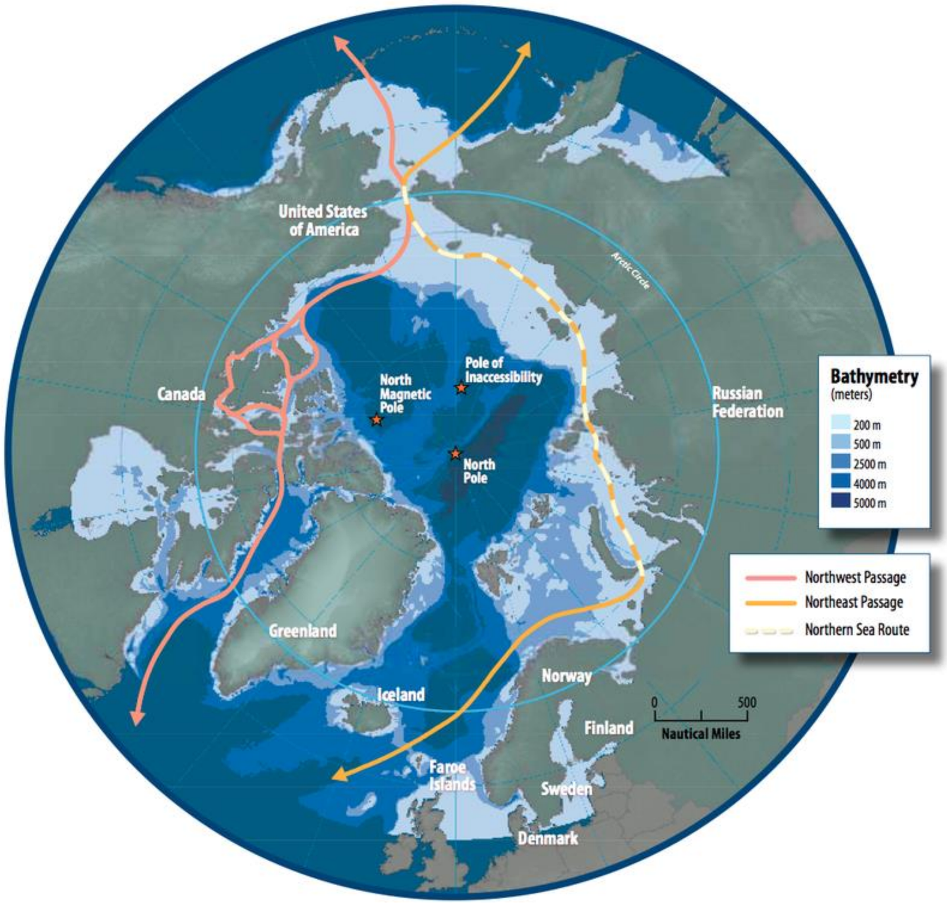

Figure 4. Arctic transit routes (Ellis & Brigham, 2009, p. 17).

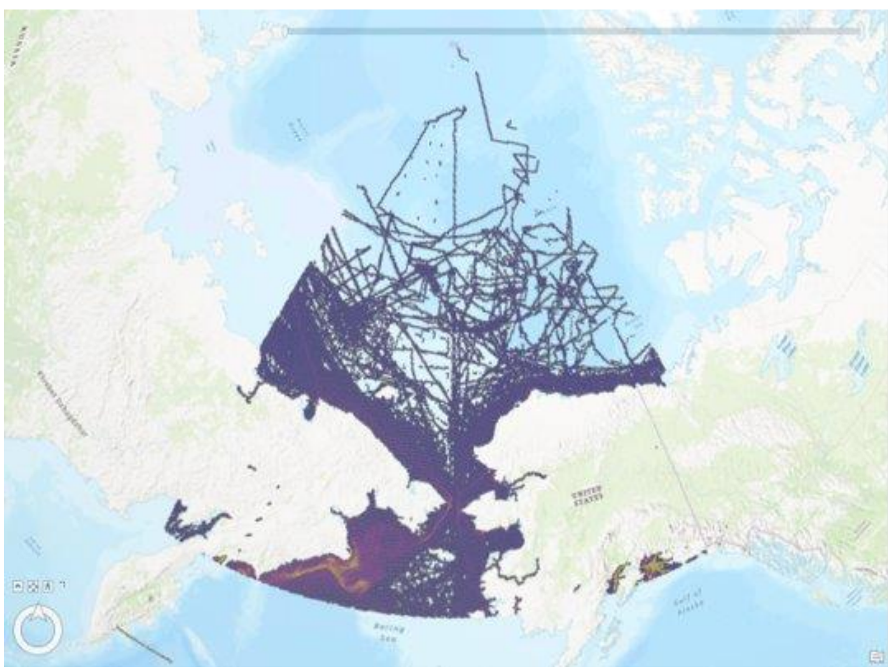

Figure 5. AIS traffic density above 60N.

There is significant vessel traffic south of the Arctic region surrounding Alaska, as seen in Figure 6, and many of responding assets are homebased/ported south of the Arctic region. For that reason, the model includes traffic and units that are located north of 50 degrees.

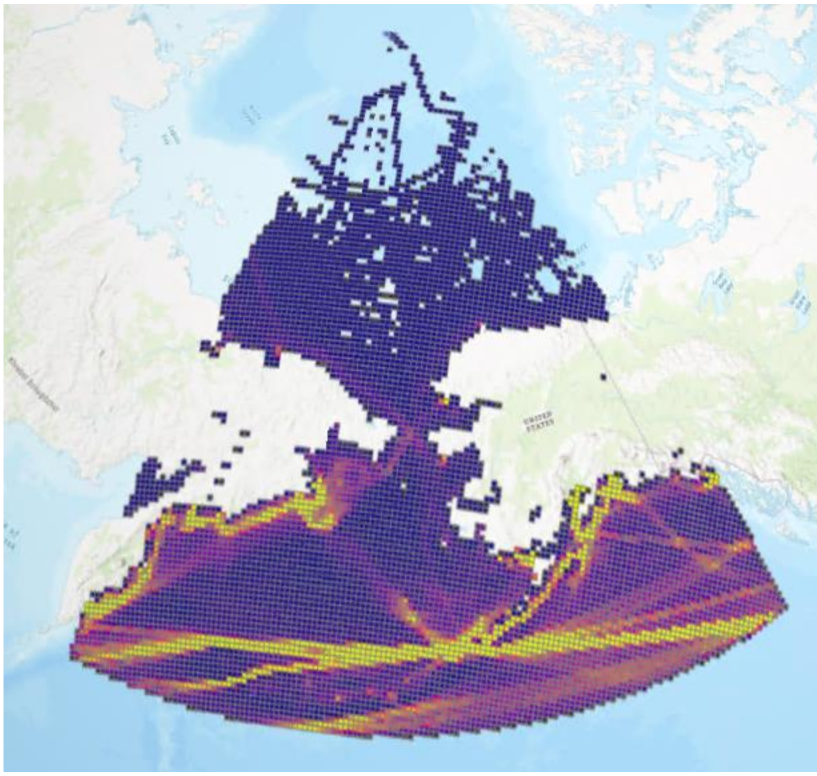

Figure 6. AIS traffic density above 50N.

1.1.2 Arctic Council

The Arctic Council is an intergovernmental council whose mission is to promote cooperation and alignment between nations with claims on Arctic territory. The council includes eight states whose territory abuts Arctic waters: Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the US. The council also collaborates with observer and participant groups, which are not governments with Arctic territorial claims. The council is currently chaired by the Norwegian delegation. This project is to be reviewed by the Emergency Preparedness, Prevention and Response (EPPR) expert group to inform recommendations made to member States of the Arctic Council. The IMO has Observer status on the Arctic Council and will be privy to the results and recommendations of both this report and the EPPR review regarding the IMO Polar Code's METR requirements.

1.2 IMO Polar Code

The IMO Polar Code, in effect since January 1, 2017, regulates ships subject to the International Conventions of Safety of Life at Sea (SOLAS) and Prevention of Pollution from Ships (MARPOL) operating in Arctic and Antarctic waters. The Code includes additional safety measures for ships transiting Arctic routes to account for the increased time a vessel in the Arctic may expect to wait for assistance and explicitly requires that all survival/lifesaving appliances and related equipment "shall be fully operational at the polar service temperature during the maximum expected rescue time" (IMO, 2017, p. 12). The Polar

Code defines the maximum expected time of rescue as "the time adopted for the design of equipment and system that provide survival support. It shall never be less than 5 days" (IMO, 2017, p. 10).

The development of the five-day minimum requirement is not well documented and currently there is sparce guidance, and no enforceable standard, for determining METR (Power et al., 2019). Additionally, finding LSA equipment that is rated for prolonged exposure to the extreme Arctic conditions is difficult and costly, making complying with an accurate METR on a Polar Code Certificate difficult (Power et al., 2019).

2 LITERATURE REVIEW

There have been numerous studies investigating different aspects of maritime activities and emergencies in the Arctic. This section describes the sources that were primarily relied upon to research this topic and inform the underlying assumptions the model was built on.

2.1 National Resource Council Canada

The National Resource Council (NRC) Canada released several Arctic SAR studies that directly confronted the issues differentiating METR in the Arctic and ambiguity in complying with IMO Polar Code regulations. This project was specifically influenced by four of their studies described below.

2.1.1 Evaluating Exposure Time Until Recovery by Location

Kennedy et al. (2013) evaluated the potential exposure time across eight locations within Canada's Arctic AOR. The study considered weather, communications, preparedness, bathymetry, human factors, and assets available when considering the potential exposure time at each location. Surveys were conducted with marine SAR experts and the results were analyzed and consolidated into time intervals (best to worst case) for each location. Four of the eight locations had intervals that exceeded the IMO Polar Code's five-day baseline, the longest of which was over 10 days.

2.1.2 Methodology for Estimating Exposure Time in Polar Regions

Piercy et al. (2019) built on the work of Kennedy et al. (2013) by developing a formula to calculate a time interval for expected exposure time at any location in the Arctic. The formula considers numerous input factors to determine the four formula variables: communication, transit, search, and rescue times. The formula was evaluated on two hypothetical scenarios (one Arctic and one Antarctic). Both scenarios incurred response time intervals that exceeded the IMO Polar Code's five-day baseline.

2.1.3 Gap Analysis of Expected Time of Rescue and Anticipated Performance of Life Saving Appliances in the Canadian Arctic

In 2019, Power et al. considered the IMO Polar Code's requirements regarding LSA. One noteworthy conclusion was that while the LSA was required to be operable in low temperature environments, there was no "guidance to demonstrate that LSA equipment is functional down to Polar Serviceable Temperature and capable of withstanding the environmental challenges whilst providing a survivable environment for the survivors, for the expected time of rescue" (Power et al., 2019, p. 6). Additionally, the report noted that producing LSA for extremely low temperatures is "difficult to achieve…[and] financially challenging as well, due to the relatively low market demand of equipment rated at low temperature" (Power et al., 2019, p. 6).

2.1.4 Incorporating Vessels of Opportunity in Exposure Time Estimates for Polar Regions

Ferrell et al. (2021) extended Piercy et al. (2019) and Power et al. (2019) work by including consideration of nearby vessel traffic when determining the time interval for expected time until rescue. Ferrell et al. relied on historical Automatic Identification System (AIS) data but assumed that a responding Vessel of Opportunity (VOO) had the same characteristics as a primary SAR asset (capacity & speed). Two scenarios were considered in the report, one of which was evaluated to have a VOO closer than a SAR resource 50% of the time which reduced the predicted Expected Time of Response (ETR). The other scenario did not have a VOO in closer proximity than a SAR resource a majority of the time, so the ETR was not affected by the inclusion of vessel traffic. The report concludes that, for some Polar routes, the inclusion of VOOs can have a significant impact on the ETR and should be considered when evaluating response times.

2.2 Search and Rescue in the Arctic

Smith (2017) specifically examined US Arctic SAR capabilities and summarized the response assets available across Department of Homeland Security (DHS), Department of Defense (DOD), State, and Local agencies. Smith evaluated three SAR scenarios and assessed the potential weaknesses in the response network's ability to respond to them. Smith identified weather conditions, and lack of infrastructure/services in northern Alaska (AK) as major factors facing responding agencies operating in the Arctic area.

2.3 SAR Exercises (SAREX)

Numerous Arctic SAR exercises (SAREX) have been conducted to determine the shortcomings that exist in current standards and practices. This project reviewed three exercise reports (2016-2018) sponsored by the University of Stavanger that tested LSA, supplies, communication equipment, and rescue methods in an Arctic environment. The reports repeatedly found shortcomings in LSA equipment's ability to support survival and reiterated the challenging logistics of conducting a rescue in Arctic conditions.

In 2021, this project observed a SAREX on the newly commissioned Polar Class (PC) 2 Cruise Vessel, LeCommandant Charcot, during its trial expedition to the North Pole. Despite significant improvements to LSA equipment and supplies being evaluated, the exercise demonstrated that it would still be very difficult to maintain survivable conditions over a five-day period, with over 20% of participants abandoning the 24-hour exercise before conclusion (Marchesseau, 2021, p. 11).

3 MODEL & INPUT DATA

This project is limited to SAR events that take place in the US Arctic AOR, primarily surrounding the North Slope of Alaska. The model uses historical weather data, AIS vessel traffic data, and limits responding assets to those from the US. While it is likely that in larger and more remote SAR scenarios the US would request assistance from its Arctic neighbors, those assets were not considered in this analysis.

3.1 US Arctic SAR Advisory Panel

This project relied on a group of Arctic and SAR experts to provide guidance on the formulation and focus of the model. The group included representation from CG-SAR, USCG District 17 SAR, USNORTHCOM, USCG District 17 Fisheries, and the Arctic Council. The panel developed six scenarios to test, described in Table 1.

Table 1. Arctic SAR scenarios.

	Date	Vessel Type	# Victims	Location
1	13 August	Cargo Vessel	8	Northwest of Barrow
2	2 October	Research Vessel	25	North Pole
3	15 September	Tanker Vessel	10	Chukchi Sea
4	1 September	Cruise Vessel	300	Northwest Passage
5	2 August	Military Ice Breaker*	137	Arctic Ocean
6	1 June	Commercial Airliner*	320	Arctic Ocean

* Scenarios 5 and 6 involve vessels not subject to the IMO Polar Code, but the results of these scenarios can reasonably be applied to applicable vessels of similar capacities.

The panel additionally provided guidance on limitations and capabilities of vessels and aircraft operating in this region.

3.2 Repast Simphony Arctic Model

Repast Simphony Software was used to develop the model. Repast Simphony is a Java-based open-source agent-based modeling platform that can be used to develop intricate geospatial simulations that incorporate GIS shapefiles. This was particularly useful for modeling the ice extent, coast lines, traffic routes, airport networks and other critical elements required for an Arctic SAR simulation. Figure 7 presents an example of a Repast Simphony simulation where each colored dot represents a different AIS vessel type operating in the project's AOR.

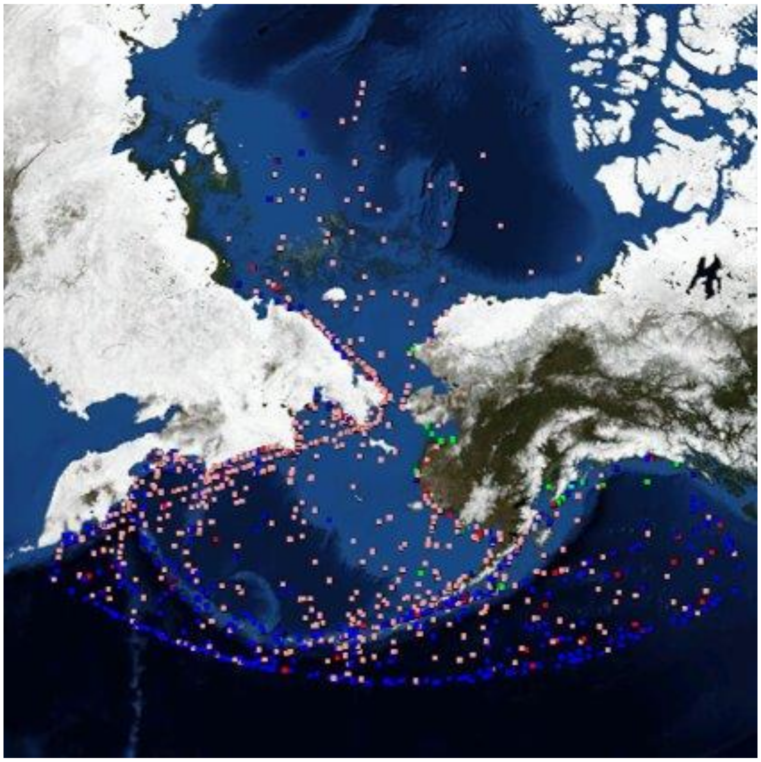

Figure 7. Repast Simphony simulation.

The model developed for this project requires several input files described in Table 2. Every scenario SAR event is preceded by a three-week warm up period to allow the AIS traffic to sufficiently populate the AOR prior to the event.

The model completes its run and publishes its results when the last victim is removed from the SAR event. For every run, diaries logging what took place for every involved agent, every weather zone, and the SAR event are produced in individual text files for each scenario model run[3]. Additionally, the individual run's total and individual asset type response times are recorded in an aggregate CSV file containing the results of every run of a scenario for analysis.

Table 2. Model input files.

File Contents	File Type	Report Description
Weather Probability Distributions	CSV	Section 3.4
AIS vessel Origin/Destination Distributions	CSV	Section 3.3.2
Airport/Airfield locations	CSV	Section 3.6.2.3
Air Assets	CSV	Section 3.6.2
Surface Assets	CSV	Section 3.6.1
Ports	Shapefile	Section 3.5.1
Routes	Shapefile	Section 3.5.1
Weather Zones	Shapefile	Section 3.5.2
Port Zones	Shapefile	Section 3.5.1
Fishing Zones	Shapefile	Section 3.5.4
Ice	Shapefile	Section 3.5.5
Patrol Zones	Shapefile	Section 3.5.3

3.3 AIS Data

One important component of Arctic SAR is the potential for swifter assistance from a VOO. To determine the likelihood of a VOO in the vicinity of a SAR event it was important to determine where and how often vessels usually operate. To accomplish this, the project collected AIS data for ships operating between the latitudes of 50 – 90 North and the longitudes 130 West – 150 East. USCG Navigation Center (NAVCEN) provided three years (2019-2021) of data from both Satellite and Terrestrial AIS.

3.3.1 AIS Data Analysis

The combined Satellite and Terrestrial AIS data included 114,490,900 records associated with 8,811 unique IMO numbers. These records provide information about a vessel (e.g., latitude, longitude, heading, and destination) as a five-minute aggregate of the AIS transmissions for the vessel, allowing analysts to recreate the entire track of a vessel throughout its voyage (R. Roebuck, personal communication, December 9, 2021). However, there are many reasons, particularly in the Arctic, why AIS data may not be available at the standard interval. Therefore, this analysis had to account for less frequent reporting while defining tracks.

[3] One text file is produced for each scenario run for each of the following categories: Air Assets, Surface Assets, VOOs, SAR event, Weather. Each scenario is run 30 times, producing 30 diaries of each type for each scenario. Vessel generation and characteristics, weather, and ice extent vary on each run.

Each unique combination of IMO number and destination (13,487 unique combinations) as reported within the AIS data were evaluated to determine tracks. Adjacent data points (based on time) were required to be within 90 minutes or 45 nautical miles (nm) of each other in order for the data to be associated with the same track. Points that did not adhere to this requirement were considered to be associated with different tracks. A total of 620,881 tracks were initially established following this process. The team evaluated these established tracks to ensure that:

- The track had a total time (from initial to end point) greater than 5 minutes.
- The vessel traveled at least 10 nm (calculated using Haversine distance) between the initial and end points of the track.
- There was a ship and cargo type specified for the track.

Tracks that did not adhere to the above criteria were removed from consideration. A total of 311,063 tracks, associated with 6,889 unique IMO numbers, serve as the basis of VOO traffic.

3.3.2 VOO Vessel Types

The model takes advantage of the way AIS vessels are classified and has 10 vessel types that typically follow the AIS labeled groupings of 10, with a few exceptions. Fishing vessels were numerous and have a distinct loitering behavior, so they are treated as a class of their own. The rest of the vessel types and corresponding AIS codes are depicted in Table 3.

Table 3. Model vessel types.

Vessel Type	AIS Code	Number of Tracks	Number of Unique IMO Numbers*	Average Speed (kts)	Average Capacity
Cargo	70-79	118060	5260	12.1	10.3
Fishing	30	122542	611	5.6	8.9
High Speed Craft	40-49	748	8	8.2	66.9
Other	90-99	5919	122	7.0	21.2
Passenger	60-69	9326	85	11.2	66.9
Reserved	1-19	3355	29	7.0	21.2
Tanker	80-89	15527	510	10.8	8.4
Unknown	0	10514	127	6.5	21.2
Wing In Ground	20-29	189	7	4.8	2
Working	31-39, 50-59	24883	221	5.7	5.1

* Some IMO numbers are associated with multiple different vessel types across the data available. Therefore, the sum of this column will be greater than the number of unique IMO numbers within the data.

Every vessel has an origin/destination, speed, and capacity. The origin/destination is determined from seasonal probability distributions for origin/destinations from the analysis of the AIS data. Each AIS track was mapped to an Origin Port Zone and Destination Port Zone and recorded with its vessel type and season. This analysis produced Port Zone origin/destination probability distributions for every vessel type and season[4].

[4] The model required 40 Port Zone origin/destination probability distributions (four seasons x ten vessel types).

The speed used in the model is generated from a normal distribution centered on the average speed from the AIS data for that vessel type. The data set produced fairly large standard deviations, so every vessel is assured to have a speed of at least 4 kts.

The capacity for each vessel type was determined by analyzing the Marine Information for Safety and Law Enforcement (MISLE) Vessel Population passenger metrics. Six MISLE Vessel Services directly mapped to the AIS vessel types (Cargo, Fishing, Tanker, Passenger[5], Unknown, and Towing[6]). For every vessel type except Passenger, the average and standard deviation of the metric 'Persons in Add[ition] to Crew Qty' was used. For Passenger Vessels the average and standard deviation of 'Max Passengers Allowed' was used. Passenger ships in the model are assumed to be half full so the capacity for victims is half its passenger capacity. The data for every vessel service type produced large standard deviations so every vessel was assumed to at least be able to carry four victims (except for Wing in Ground as described below). The vessel categories Other and Reserved did not have corresponding MISLE categories and were therefore assigned the capacity values from the Unknown MISLE category. Due to the unique design of Wing in Ground vessels and no available capacity metrics, its capacity was limited to 2.

Vessels in the model serve as potential VOOs during a SAR event. When a SAR event is triggered in the model, all vessels are examined to determine if they can reach the SAR event (sometimes prohibited due to ice conditions) and how much capacity for victims they have. The model will route enough of the closest vessels to the SAR event to recover every victim.

3.3.2.1 *Fishing Vessels*

Fishing vessels are a unique agent in the model. They are assigned a fishing coordinate in addition to their origin and destination and linger at this coordinate "fishing" for a period of time. The fishing period is based off the average trip length and standard deviation of all AIS fishing vessel tracks. Again, the standard deviation of this metric was quite large, so all fishing vessels have a fishing period of at least two hours.

Every fishing vessel is assigned a Fishing Vessel Zone (Section 3.5.4) that is selected based on a probability distribution. The probability distribution was created based on the vessel's Origin Port Zone. Fishing zones in closer proximity to the Origin Port Zone are assigned higher probabilities than those further away. All territorial laws are respected, US originating fishing vessels do not fish in Russian Fishing Zone waters and vice versa. Additionally, the US currently prohibits commercial fishing north of the Bering Strait, so the only fishing vessels assigned to those zones originate from the North Slope of Alaska and are considered Native fishing vessels (non-commercial). Once a Fishing Zone is assigned to a vessel, a randomly selected junction (crossing of routes) is selected as the vessel's fishing spot. The fishing vessel departs from its origin port, transits to its fishing spot, lingers until its fishing time elapses, and then completes its route to the destination port.

3.4 Weather Data

Weather is one of the largest factors impacting how fast response assets can arrive on the scene of a SAR event. It is specifically listed as a particular hazard in the IMO Polar Code and affects both surface and air assets. The number of weather factors that the project included in the model was limited by data availability and time. For this study, sea state, wind, and cloud cover were included.

[5] The MISLE category Passenger Vessel was used for both the AIS Passenger and High-Speed Craft Group.

[6] The MISLE category Towing Vessel was used as an equivalent to the AIS Working Vessel Group.

The weather data were pulled from Climate Data Store (CDS) ERA5 Hourly Single Levels data set[7]. The data pull allows users to select the meteorological metric of interest over a period of time and a particular latitude by longitude section. To maintain consistency with the AIS data pull, all weather data were pulled and analyzed from 2019-2021. Data were pulled in 10 degrees by 10 degrees latitude/longitude regions. The area of interest extended from 50 – 90 North and 130 West – 140 East to create 32 distinct data pulls used to calculate the weather metrics. These 32 areas were created as 'Weather Zones' in the model and have an associated probability distribution for each weather metric, by season. The model weather zones can be seen in Figure 8. Weather in the model is updated every four hours according to the model month's seasonal probability distribution for each zone.

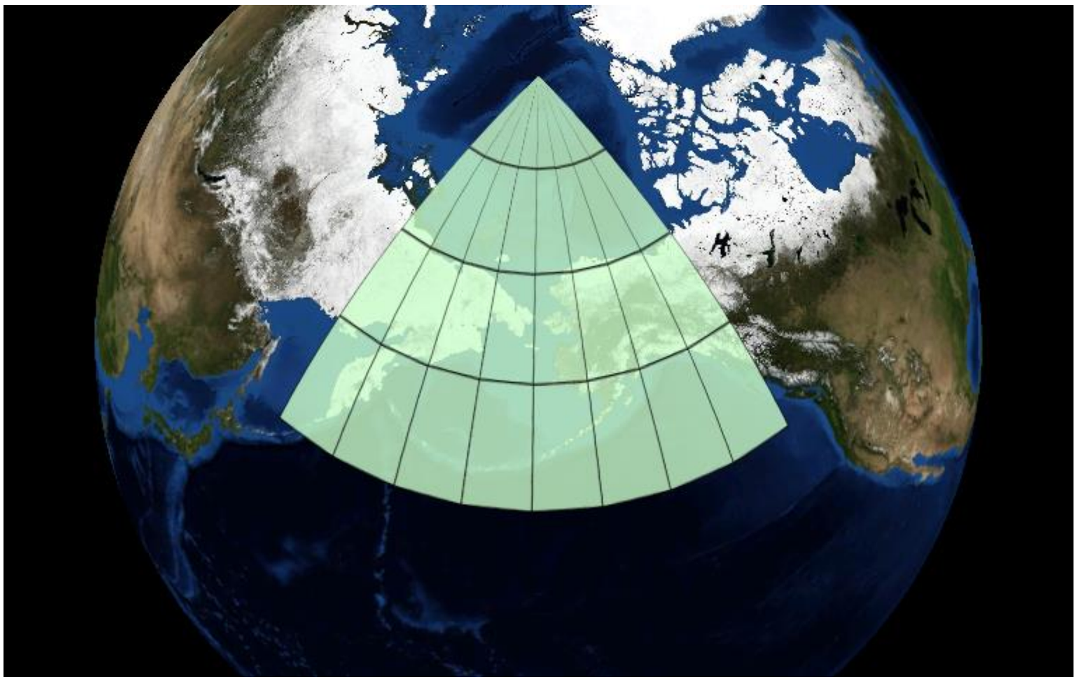

Figure 8. Arctic SAR weather zones.

3.4.1 Sea State

Sea state is used to describe and classify the condition of the ocean surface. The higher the state, the more unsettled the ocean surface and the more likely a vessel's speed will be impacted. The different sea state classifications are described in Table 4.

Table 4. World Maritime Organization sea state classifications.

Sea State	Wave Height	Characteristics
0	0 meters (0 ft)	Calm (glassy)
1	0 to 0.1 meters (0.00 to 0.33 ft)	Calm (rippled)

[7] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form us.eu)

2	0.1 to 0.5 meters (3.9 in to 1 ft 7.7 in)	Smooth (wavelets)
3	0.5 to 1.25 meters (1 ft 8 in to 4 ft 1 in)	Slight
4	1.25 to 2.5 meters (4 ft 1 in to 8 ft 2 in)	Moderate
5	2.5 to 4 meters (8 ft 2 in to 13 ft 1 in)	Rough
6	4 to 6 meters (13 to 20 ft)	Very rough
7	6 to 9 meters (20 to 30 ft)	High
8	9 to 14 meters (30 to 46 ft)	Very high
9	Over 14 meters (46 ft)	Phenomenal

The CDS ERA5 data set provided the significant height of combined wind waves and swell for the entire area and period of interest. The 128 data sets (32 zones x four seasons) were analyzed to create probability distributions for the sea state for each zone/season combination.

All the AIS vessel types, except for Wing in Ground, are modeled to decrease their assigned speed by ten percent in Sea State 5 conditions, twenty percent in Sea State 6 conditions, and ninety five percent in conditions greater than Sea State 6. Wing in Ground vessels are limited to Sea State 2 due to their unique design.

3.4.2 Wind

The wind speed has a direct impact on whether response aircraft can launch on a mission[8]. For fixed wing assets, towing aircraft from the hanger can become hazardous in high winds and rotary winged assets have wind restrictions for starting and stopping the rotor.

The CDS ERA 5 data set provided the ten-meter u and v component of wind[9] in meters per second which was converted to wind speed in knots (Wind Speed = $(u^2 + v^2)^{½} * 1.94384$) for the entire area and period of interest. The 128 data sets were analyzed to create probability distributions for the wind speed for each zone/season combination.

3.4.3 Cloud Ceiling

The cloud ceiling directly impacts whether fixed wing assets can air drop equipment and supplies to the scene of a SAR event. If the ceiling is too low, the SAR event cannot be visualized by the crew and prevents the drop.

The CDS ERA 5 data set provided data on both the Cloud Base Height, which is the height of the lowest cloud layer, and Low Cloud Cover, which is the proportion of the area of interest covered by the lowest cloud levels. When the Cloud Base Height is below the fixed-wing drop limit and the Low Cloud Cover is above 50% the model deems the SAR event obscured to fixed-wing aircraft by cloud cover. The 128 data sets were analyzed to create probability distributions for the cloud ceiling for each zone/season combination.

3.5 ArcGIS Shapefiles

The model relies on shapefiles to help the agents (vessels/assets) navigate the geography of the model. The shapefiles in this project were developed using ArcGIS software. Given the area of interest for this study the

[8] Wind can also impact the speed of surface vessels, but that impact is not considered in this model.

[9] The u-component of wind is the speed of air moving east. The v-component of wind is the speed of air moving north.

WGS 1984 Arctic Polar Stereographic projection coordinate system was used. This projection centers the Arctic and flattens the globe into a 2D representation to facilitate appropriate representation of the region. This project also set a customized Meridian line of 150 which eliminated problems encountered when features (e.g., port zones) crossed the default Meridian line.

3.5.1 Routes, Ports & Port Zones

Surface assets and vessels travel along routes in the model. Analysis of the AIS data did not reveal any definable traffic routes, so a tessellation of routes shapefile was created in ArcGIS to provide vessels with the flexibility to travel the area of interest (AOI) as the AIS heat maps suggest. Additionally, while there are numerous large Ports in the AOI, the AIS data analysis proved that the origin/destination of the track lines was largely evenly distributed throughout the AOI. Aiming to reflect this accurately in the model, a 'Port' was placed every 20 nm along the coastline and ports were grouped into 'Port Zones' to aid in the development or origin/destination probability distributions for the vessels in the model. Figure 9 depicts the model routes with red lines and ports as the yellow circles. Figure 10 shows the grouping of ports into port zones.

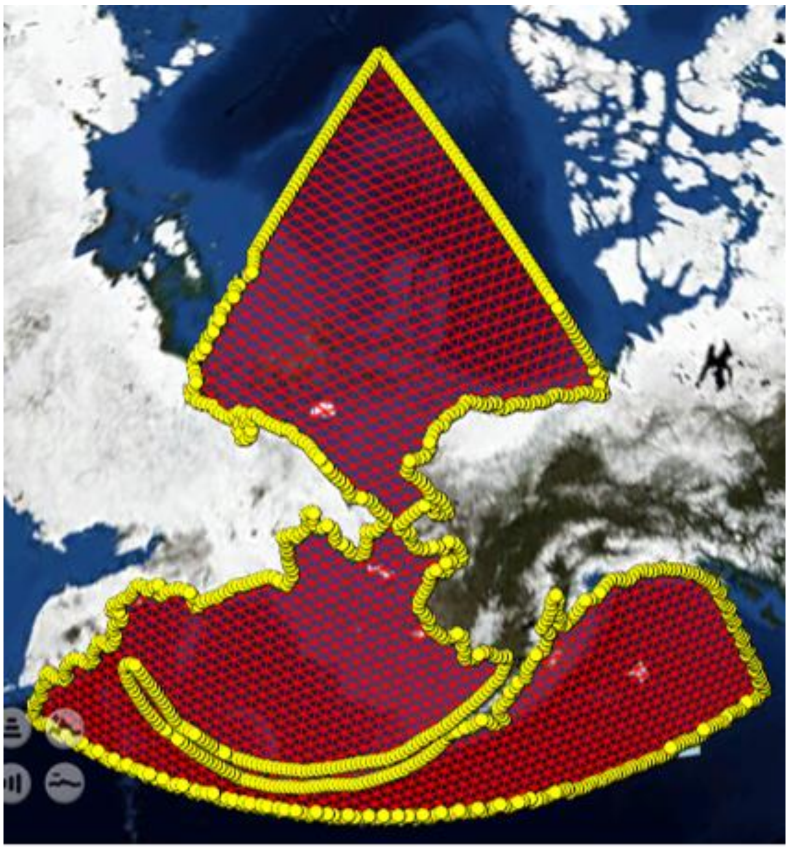

Figure 9. Model ports and routes.

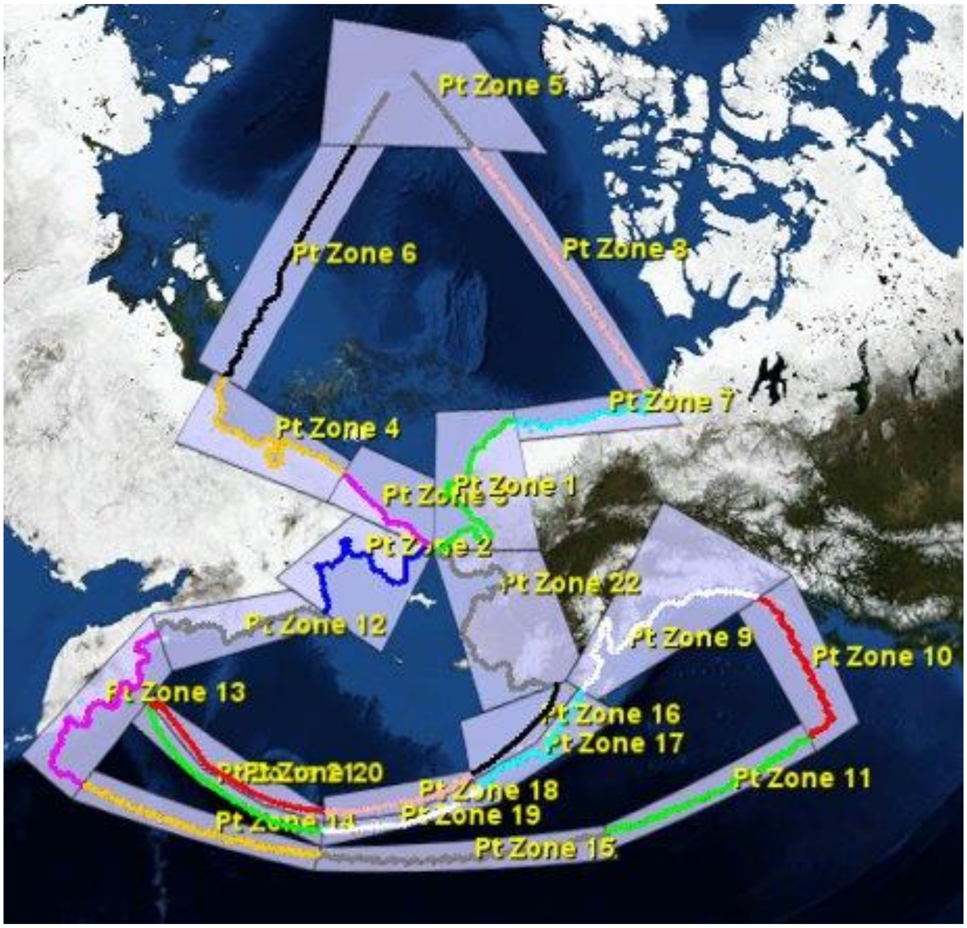

Figure 10. Model port zones.[10]

When a vessel is generated in the model, it is assigned an origin and destination Port Zone based on the Port Zone probability distribution appropriate for the type of vessel and season. Once the origin and destination zones are assigned, a randomly selected port from those zones is selected to serve as the origin and destination of the vessel. The vessel is routed between those points on the shortest path possible, considering distance, ice, and expected weather.

3.5.2 Weather Zones

As previously discussed in Section 3.4, there are 32 weather zones (Figure 8) that are ten degrees of longitude wide by ten degrees of latitude high. Each of these zones has a probability distribution for each season/weather metric combination. For example, there are 128 probability distributions associated with sea state, one for each of the four seasons, for each of the 32 weather zones. The weather in the model is updated every four hours and each weather metric is set according to the appropriate probability distribution for the season/zone.

[10] The gap in ports in Port Zone 5 is due to distortions created in the model at the Pole. To account for this, the affected ports were removed.

3.5.3 Patrol Zones

The surface assets (Section 3.6.1) in the model are assumed to be on patrol when a SAR event occurs. The model has two patrol areas that the assets patrol shown in Figure 11. The northern patrol area is for a CG Ice Breaker on an Arctic patrol. The more southern patrol box is for a Maritime Security Cutter-Large (WMSL) on an Arctic patrol. Assets roam these patrol areas until a SAR event occurs or the asset patrol time expires. These patrol zones are not based on actual patrol tracklines of CG surface assets, but are a general representation of where each asset might operate during an Arctic patrol. While an asset is patrolling in the model, it does not reference any authentic asset patrol data, but instead randomly transits the within the confines of the patrol box.

Figure 11. Model surface asset patrol zones.

3.5.4 Fishing Zones

The fishing zones, in the US Exclusive Economic Zone (EEZ), are loosely based off International Pacific Halibut Commission regulatory areas in Alaska[11]. The zones beyond the US EEZ maintain the general shape of the zones they abut. Some zones are bisected by the 180th meridian. Polygons that overlap the 180th meridian create issues in Repast Simphony models when running intersect queries on them. To prevent this, any zone bisected by the 180th meridian is created using two zones on either side of the meridian, and model queries are run over both.

[11] www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones

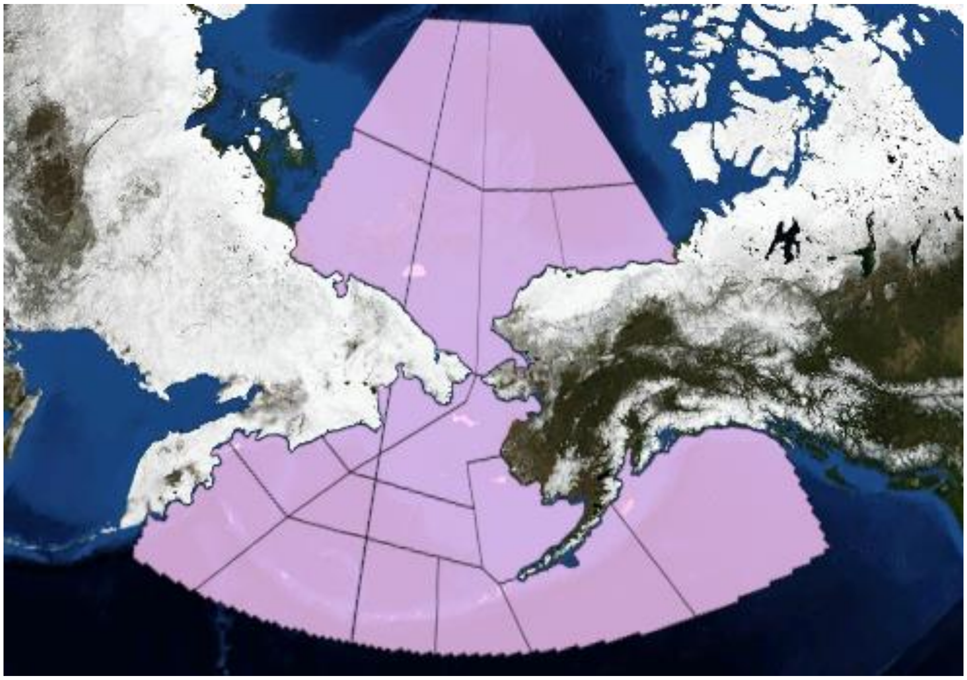

Figure 12. Model fishing vessel fishing zones.

3.5.5 Ice Extent

Arctic ice is particularly known for its variability both throughout and between years. To capture this reality as realistically as possible in the model, the project relied on the National Snow and Ice Data Center's (NSDIC) repository of Arctic Ice Extent Shapefiles. Three years (2019-2021) of mean monthly ice extent shapefiles were loaded into the model. Every time a model run is generated, the year (2019-2021) is randomly selected, and the appropriate month's ice extent shapefile is loaded into the model as seen in Figure 13. This allows the model to have a realistic and seasonally accurate ice extent with variability between scenario runs.

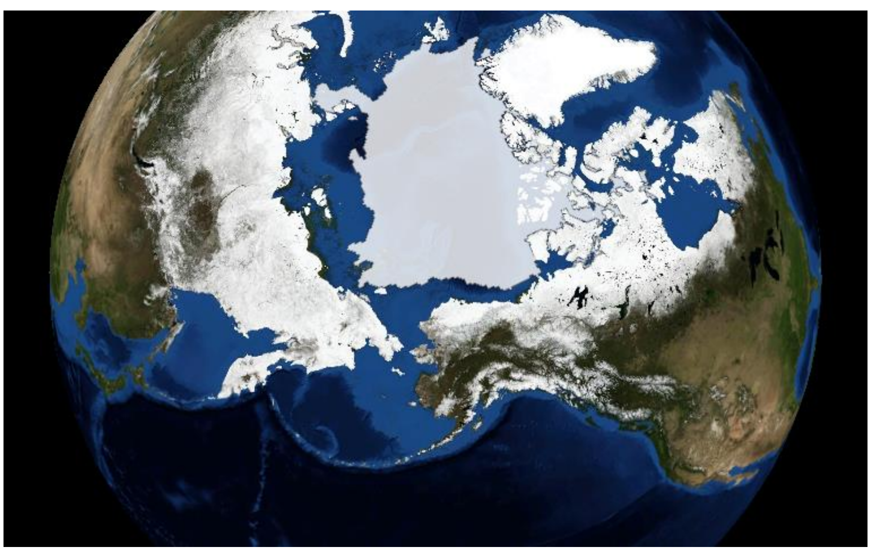

Figure 13. Ice extent shapefile loaded into model.

3.6 Agents

3.6.1 Surface Assets

For nearly every model scenario (except Scenario 5) there are two USCG surface assets included in the response suite, the icebreaking United States Coast Guard Cutter (USCGC) Healy[12] and a WMSL. The model includes response delays for planning, recovering victims, and offloading victims.

The USCGC Healy (Figure 14) is currently the Coast Guard's largest ice breaker. As a research vessel the USCGC Healy routinely operates in the Arctic region. The model adapts Healy's speed for transit through open ocean, ice, and varying sea states.

For the purposes of the model, whose scenarios take place between June and October, Healy is assumed to be patrolling in the Arctic Ocean, without an onboard helicopter, on a scientific support mission.

Figure 14. USCGC Healy.

The WMSL, shown in Figure 15, is the largest and most capable of the Coast Guard's patrol cutters. It has room for two onboard helicopters. For the purposes of the model, a WMSL will be assumed to be on an Arctic patrol in the vicinity of the Bering Strait. The model adjusts the WMSL transit speed for Arctic conditions. The WMSLs are not ice breaking assets, so when a scenario in the model takes place beyond the ice extent, the cutter will approach as close as possible, without breaching the ice extent. If this is within range of the onboard helicopter, the helicopter will be launched to affect the rescue. Otherwise, the cutter will remain on the ice extent edge.

Figure 15. Maritime Security Cutter (WMSL).

[12] The USCGC Polar Star is another available heavy ice breaking asset, but rarely transits north and was not included in the Surface Asset Laydown by the decision of the US Arctic SAR Advisory Panel.

3.6.2 Air Assets

The model includes air assets from the US Air Force (AF), US Army (AR), US Army National Guard (AR NG), US Coast Guard (CG), and North Slope Burrough (NSB) SAR. The air assets included in the model were identified and selected through discussions with the Arctic SAR SME panel but do not represent every possible air asset available in the region. If a scenario has a manageable victim load and is within range, only Coast Guard and NSB assets are considered. However, if a scenario involves a mass casualty event or takes place in an exceedingly remote location, collaboration with the DOD is required and was modeled. When a DOD asset is requested, an additional planning delay is applied to account for the coordination effort required (US Arctic SAR Advisory Panel discussion, personal communication, January 10, 2023).

3.6.2.1 Fixed Wing Aircraft

Both the CG and AF operate HC-130 aircraft in Alaska (see Figure 16). In the model, these aircraft are primarily used to air drop additional supplies to SAR events, but the AF HC-130 can also be used to refuel rotary wing assets to extend their range. In the model, fixed wing aircraft will not launch if wind speeds exceed limitations and will fail to drop supplies if the cloud ceiling over the SAR event is too low. Table 6 displays the fixed wing assets included in the model.

The HC-130s can drop a large variety of supplies to SAR cases to improve the quality of life and impact the length of time victims can survive on scene. These supplies are not guaranteed and are not considered when calculating METR, but they are helpful in understanding the overall risk and survivability of any scenario. Of particular interest is the ability of the AF HC-130 to drop off Pararescue men (PJs) and their Arctic Sustainment Package (ASP) to a scene. These highly trained service members can provide survival and medical assistance and supplement a vessel's emergency equipment with additional Arctic-rated survival gear (Smith, 2017, p. 49).

Figure 16. HC-130 aircraft.

Table 5. Model location for fix winged air assets.[13]

Asset	Location
AF HC-130	Elmendorf AFB
CG HC-130	AIRSTA Kodiak

[13] This table only reflects the fixed wing assets included in the model, it is not a comphensive list of fixed winged assets in the region.

3.6.2.2 Rotary Wing Air Assets

The AF, CG, AR, AR NG, and NSB operate numerous rotary winged assets throughout Alaska (see Figure 17). These assets are most often the quickest way to recover Arctic SAR victims if they occur within the helicopter's range. In the model, rotary winged assets will not launch if wind speeds exceed their limitations. Table 6 summarizes the rotary winged assets included in the model.

Figure 17. MH-60, S-92, CH-47, Bell 412 rotary winged aircraft.

Table 6. Model assumptions for rotary winged air assets.[14]

Asset	Location
AF HH-60	Elmendorf AFB
AF HH-60	Eielson AFB
AR UH-60	Fort Wainwright
ARNG UH-60	Juneau
ARNG UH-60	Anchorage
ARNG UH-60	Bethel
ARNG UH-60	Nome
CG MH-60	Kotzebue FOB
CG MH-60	AIRSTA Kodiak
CG MH-60	AIRSTA Sitka
CG MH-65	WMSLs
NSB S-92[15]	Barrow
NSB Bell 412[16]	Barrow

3.6.2.3 Crew Rest

Many of the scenarios modeled require the air assets to travel vast distances, make transits with multiple stops, and make repeated trips. This level of effort often oversteps the regulations in place for aircrew rest. Crew rest requirements are complicated, situational, and vary by agency. To simplify the model, crew rest was modeled using three criteria: mission time, flight time, and relaunch limits. Mission time is counted from when the air asset is first requested (this time includes the launch and planning delays), the time performing the mission, and the time to end the mission (refuel and offloading delays). Flight time is

[14] This table only reflects the rotary winged assets included in the model, it is not a comphensive list of fixed winged assets in the region.

[15] The NSB S-92 does not perform hoisting rescues. If the S-92 is included in the model it is performing an Air Drop mission unless the rescue is taking place on ice that is thick enough for the S-92 to safely land on.

[16] The NSB Bell 412 does not perform hoisting rescues. If the Bell 412 is included in the model it is performing an Air Drop mission unless the rescue is taking place on ice that is thick enough for the Bel 412 to safely land on.

counted when the air asset is airborne performing the mission. Flight relaunch limits prevent an asset from relaunching if it already has reached a certain level of flight time. The model employs a simplified version of crew rest based closely on CG crew rest regulations.

If an air asset encounters any crew rest limitations in the model, it is placed in a rest status and only continues on the mission once the crew rest requirement is met.

3.6.2.4 Modeled Airport Network

Most of the air assets are located in the southern half of Alaska, and all the SAR scenarios are located well north of the state, well out of range of the majority of the modeled rotary winged air assets. To reach these cases these aircraft must utilize intermediate airports to refuel and take required crew rest along the way. A picture and list of the modeled airfield network are provided in Figure 18 and Table 7, respectively.

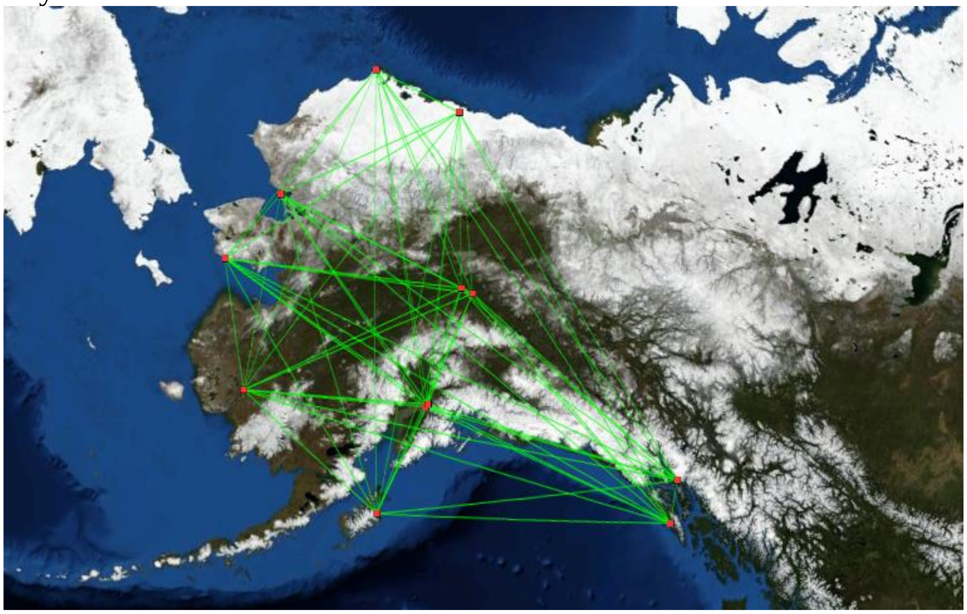

Figure 18. Modeled airfield network.

Table 7. Airports included in the model.

Airport Locations
Anchorage
Barrow
Bethel
Fairbanks
Juneau
Kodiak
Kotzebue
Nome
Prudhoe Bay
Sitka

3.6.3 Vessels

Section 3.3.2 describes the analysis of AIS and MISLE data that informs the creation of the Vessel agents in the model. When an agent is created, it has a unique speed and capacity generated from a normal distribution surrounding the average speed (compiled from AIS data) and average capacity (assessed from MISLE data). A newly created vessel is also provided with a route between an origin and destination port from a probability distribution developed from the AIS data for the type of vessel and time of year.

While some vessels operating in this region have ice breaking abilities, there was no data associated with the AIS data set to indicate the prevalence of this capability. Therefore, all vessels in the model are assumed to be NOT ice – capable and travel on routes that avoid ice. Section 6.2 discusses how these data could be used in future studies to improve the model.

A vessel has the potential to be a VOO in the model if it can reach the event and has capacity for victims. When an event occurs, all vessels are queried to determine how fast they can reach the event and their capacity. The closest (with respect to time) vessels are routed to cover the entire victim load of the event. Once a vessel is classified as a VOO, it makes one trip to the SAR event, drops the victims off at the designated recovery port and then proceeds to its original destination.

4 MODEL SCENARIOS

The Arctic SAR SME panel selected six scenarios to study in this project. The scenarios vary in location, size, time of year, proximity to ice extent, and response suite. The panel determined the responding assets (and agencies) based on the location and number of victims of the SAR event. All but two of the scenarios involve vessels that are subject to the IMO Polar Code. Scenarios five and six involve a military ice breaker and a commercial airliner, which are not subject to the Polar Code. These scenarios were of particular interest to the project sponsor and stakeholders as they are plausible and highly consequential scenarios in the US Arctic AOR and therefore included in this study. For the purpose of evaluating the IMO Polar Code survival time requirement, the results of scenario 5 and 6 can be used as case studies for similarly sized SOLAS vessels in distress under the same conditions.

4.1 Scenario 1

The first scenario involves a Cargo Vessel with a crew of eight persons abandoning ship northeast of Barrow, AK in August. Figure 19 displays the SAR scenario location taking place below the ice extent.

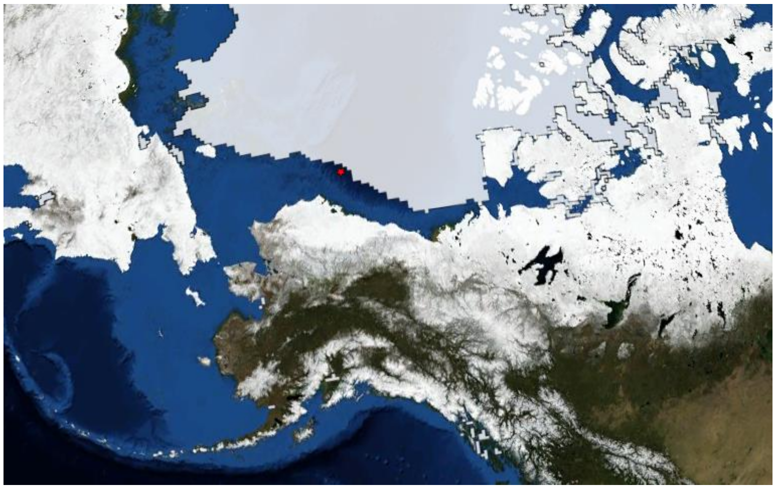

Figure 19. Scenario 1.

Due to the small size and location of this scenario, the responding assets were limited to USCG and NSB SAR response assets.

Table 8. Scenario 1 air asset laydown.

Asset	Location
CG MH-60	FOB Kotzebue
CG HC-130	AIRSTA Kodiak
NSB S92[17]	Airfield Barrow

Table 9. Scenario 1 surface asset laydown.

Asset	Onboard Helicopter
CG Ice Breaker	No
WMSL	Yes

[17] In this scenario, the S-92 is performing an Air Drop mission.

4.2 Scenario 2

Scenario 2 involves a Research Vessel with 25 crew members beset in the ice near the North Pole in October (see Figure 20). This event takes place well within the ice extent. Due to the distance to the SAR location only fixed wing and surface assets were included in the model. This scenario includes in its response assets the 212th RQS Guardian Angel's PJs as part of the air drop package from the AF HC-130.

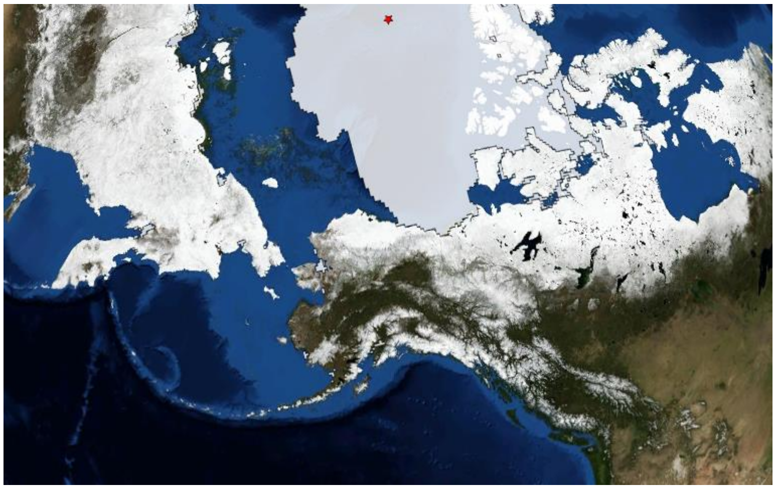

Figure 20. Scenario 2.

Table 10. Scenario 2 air asset laydown.

Asset	Location
CG HC-130	AIRSTA Kodiak
AF HC-130	Elmendorf AFB

Table 11. Scenario 2 surface asset laydown.

Asset	Onboard Helicopter
CG Ice Breaker	No
WMSL	Yes

4.3 Scenario 3

Scenario 3 involves an abandon ship event on a Tanker Vessel in the Chukchi Sea in September (see Figure 21). The vessel has 10 crew members and is south of the ice extent. Due to the size of the scenario, the response suite was limited to NSB and USCG assets.

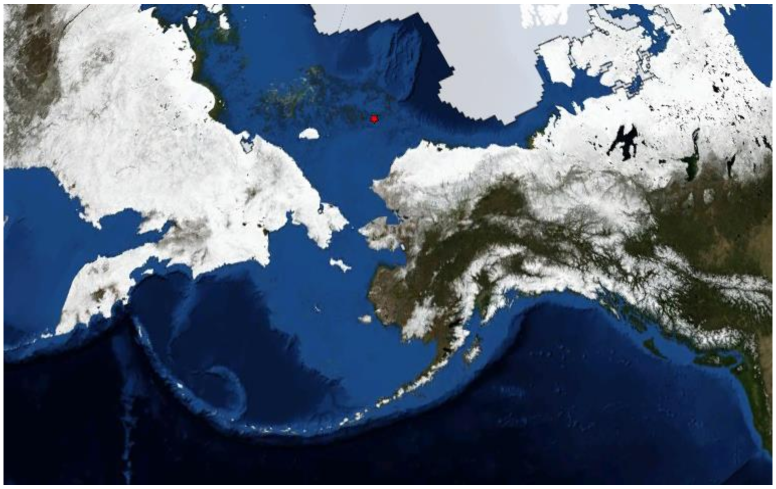

Figure 21. Scenario 3.

Table 12. Scenario 3 air asset laydown.

Asset	Location
CG MH-60	FOB Kotzebue
CG HC-130	AIRSTA Kodiak
NSB S-92[18]	Airfield Barrow

Table 13. Scenario 3 surface asset laydown.

Asset	Onboard Helicopter
CG Ice Breaker	No
WMSL	Yes

[18] In this scenario, the S-92 is performing an Air Drop mission.

4.4 Scenario 4

Scenario 4 is a large capacity SAR event involving a Cruise Vessel with 300 persons abandoning ship northeast of Barrow, AK, in the Northwest Passage in September (see Figure 22). The event is south of the ice extent, but due to the number of victims involves numerous response agencies.

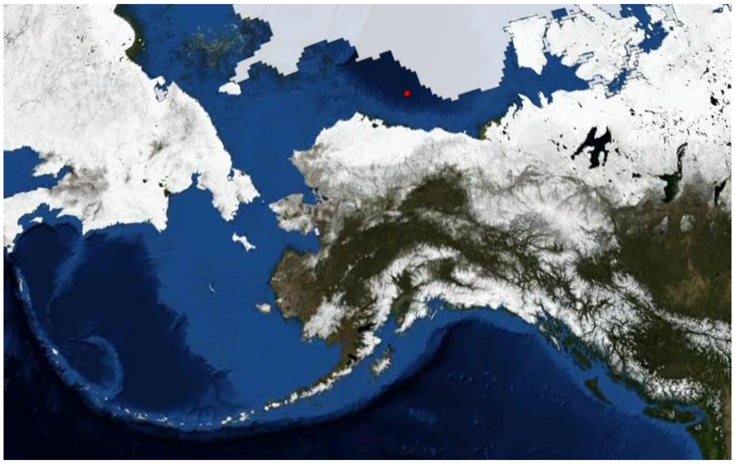

Figure 22. Scenario 4.

Table 14. Scenario 4 air asset laydown.

Asset	Location
CG MH-60	FOB Kotzebue
CG MH-60	AIRSTA Kodiak
CG HC-130	AIRSTA Kodiak
NSB S-92[19]	Airfield Barrow
AF C-130	Elmendorf AFB
AF HH-60	Elmendorf AFB
AF HH-60	Eielson AFB
AR UH-60	Fort Wainwright
AR NG UH-60	Nome
AR NG UH-60	Bethel

Table 15. Scenario 4 surface asset laydown.

Asset	Onboard Helicopter
CG Ice Breaker	No
WMSL	Yes

[19] In this scenario, the S-92 is performing an Air Drop mission.

4.5 Scenario 5

Scenario 5 involves an abandon ship scenario onboard the USCGC Healy in August (see Figure 23). This event takes place north of the ice extent and evaluates the response suite's ability to respond to an event on the ice with no ice breaking asset capability. While a military vessel is not subject to the IMO Polar Code, this scenario tests how long a response to a large SAR event on the ice would take if the USCG does not have an ice breaking surface asset available. Due to the distance of the event from the nearest airport, only fixed wing aircraft and a helicopter that can be refueled in flight are included in the response suite.[20]

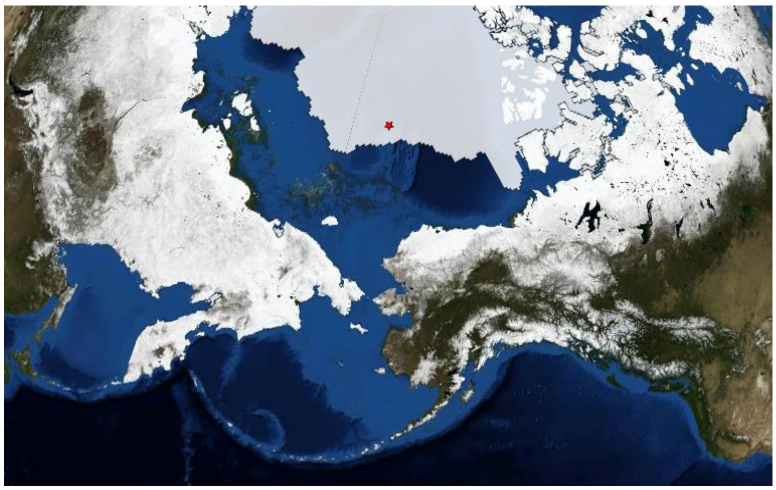

Figure 23. Scenario 5.

Table 16. Scenario 5 air asset laydown.

Asset	Location
CG HC-130	AIRSTA Kodiak
AF HC-130	Elmendorf AFB
AF HH-60	Elmendorf AFB

Table 17. Scenario 5 surface asset laydown.

Asset	Onboard Helicopter
WMSL	Yes

[20] More refuelable rotary winged assets are available in the region, but the SME advisory panel limited the response suite to test results under adverse conditions.

4.6 Scenario 6

Scenario 6 involves a Commercial Airliner, carrying 320 passengers and crew, crashing on the ice in June (see Figure 24). This event takes place north of Barrow. Due to the size, and situation, all agencies are included in the asset laydown. While a commercial airliner is not subject to the IMO Polar Code, this scenario is analogous to a large capacity SAR event on the ice that involves numerous responding agencies.

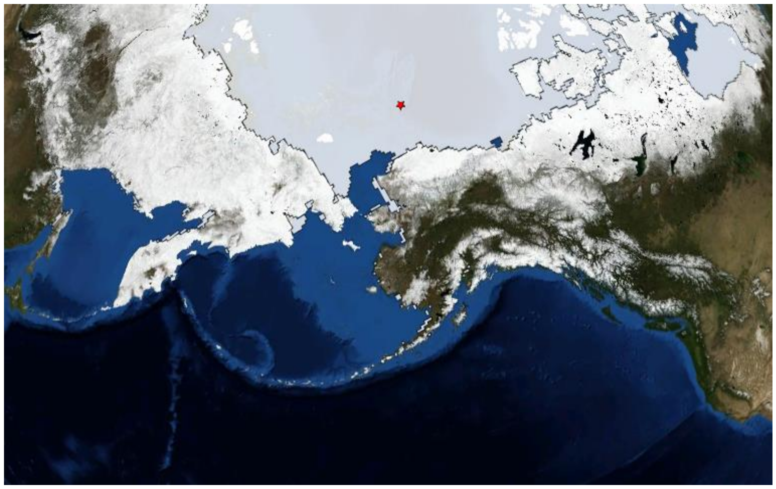

Figure 24. Scenario 6.

Table 18. Scenario 6 air asset laydown.

Asset	Location
CG MH-60	FOB Kotzebue
CG MH-60	AIRSTA Kodiak
CG HC-130	AIRSTA Kodiak
AF HC-130	Elmendorf AFB
AF HH-60	Elmendorf AFB
AF HH-60	Eielson AFB
AR UH-60	Fort Wainwright
ARNG UH-60	Nome
ARNG UH-60	Bethel
NSB S-92	Barrow
Bell 412	Barrow

Table 19. Scenario 6 surface asset laydown.

Asset	Onboard Helicopter
CG Ice Breaker	No
WMSL	Yes

5 MODEL RESULTS

Table 20 summarizes the results of the model from all six scenarios. Each scenario was run 30 times. If the time to complete the rescue exceeded the five day minimum standard in at least one run it was categorized with a METR that exceeded five days.

Table 20. Summary of scenario results.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
METR exceeds five days	No	Yes	No	No	Yes	No

5.1 Scenario 1 Results

Scenario 1 model results did not exceed five days. Most of the model runs had successful Arctic supplies air drops and the CG MH-60s were effective in rescuing the eight victims. In this scenario, the Polar Code baseline METR appears satisfactory.

5.2 Scenario 2 Results

Scenario 2 model results exceeded five days to respond to 25 victims in the vicinity of the North Pole. As this scenario takes place well within the ice extent, no VOOs were modeled to be able to assist in the effort. This scenario relies on a CG Ice Breaker to affect the rescue. In nearly every run, arctic supplies were successfully dropped by the AF and CG HC-130s prior to the end of the case. The AF air drop would include its Arctic Sustainment Package along with the expertise of the PJs which would significantly improve the chances of long-term survival for the victims in this scenario.

In every run, the CG Ice Breaker was on an active Arctic patrol when the SAR event transpired. If this was not the situation, the response time would have been considerably longer. Rerunning the scenario with both surface assets located in Southern AK, nearly doubled the response time average. If the CG Ice Breaker was still in its homeport (Seattle, Washington) or unavailable, then the response time would have been significantly longer. As these response times are particularly long, it is likely that in this situation, SAR coordinators would reach out to international partners to increase the chances of a quicker recovery.

Based on these results, the baseline METR requirement is insufficient.

5.3 Scenario 3 Results

Scenario 3 model results did not exceed five days. Most of the model runs had successful Arctic supplies air drops and the CG MH-60s were effective in rescuing the ten victims. VOOs also were a factor in this scenario, providing assistance in at least one run of the model. In this scenario, the Polar Code baseline METR appears satisfactory.

5.4 Scenario 4 Results

Scenario 4 model results did not exceed five days. Most of the model runs had successful Arctic supplies air drops and the multi-agency rotary winged assets were effective in quickly rescuing the 300 victims. VOOs were a significant factor in this scenario, providing assistance in the majority of model runs. In this scenario the Polar Code METR appears satisfactory.

5.5 Scenario 5 Results

Scenario 5 model results exceeded five days. Scenario 5 is the only scenario examined with no surface asset capable of recovering the victims. In this scenario the WMSL on Arctic patrol travels to the ice extent edge, but if the onboard helicopter is not in range, it cannot assist with victim recovery. The WMSL was able to launch its helicopter and assist in the recovery in less than half of the model runs. The bulk of the recovery was left to the single AF rotary winged asset and recovery times exceeded five days. In this situation, emergency equipment meeting baseline METR standard would not be sufficient to sustain the crew. With newly commissioned polar icebreaking cruise ships, this scenario is applicable to future commercial industry.

5.6 Scenario 6 Results

Scenario 6 model results did not exceed five days to respond to 320 victims north of Barrow on the ice. This scenario relied mostly on air assets to complete the recovery, but the majority of the scenario runs did have contact with the CG Ice Breaker. In this scenario the Polar Code METR appears satisfactory, however it is noteworthy, that a commercial aircraft is not subject to the Polar Code and would likely not have functional survival gear to sustain life for any prolonged duration under the conditions of Scenario 6.

5.7 Summary of Results

Scenarios 2 and 5 resulted in runs that exceed the IMO five-day minimum standard. The results are consistent: vessels with large capacities, or on routes extending beyond helicopter range, will face long recovery times. Rescue times increase if there is no ice breaking surface asset available (Scenario 5). Additionally, any events beset in the ice faced additional delays as transit speed through ice significantly hamper surface vessel intervention.

6 FUTURE WORK

There are countless factors that influence a SAR case in the Arctic. This project incorporates several of the primary elements influencing SAR cases in the Arctic. Several additional elements are described in the following subsections that could be incorporated to improve the model.

6.1 Community Response

The North Slope of Alaska has a robust volunteer network that was not included in this model. “The North Slope of Alaska runs the width of the state…and is the homeland of the Iñupiat people; Alaska natives who comprise around eighty percent of the population and who have always lived their subsistence-hunting culture in the region” (Kiakaha, 2022). These isolated communities have often had to rely on themselves to conduct SAR efforts and have generations of experience navigating the sea ice and the unique Arctic conditions. Including volunteer assets in the model could have significant impact on SAR events that are located closer to the Alaskan coast, particularly in winter months when the ice extent extends to the coastline and fewer governmental assets are available.

6.2 Polar Hull Input

Polar Class (PC) is a designation for a ship with a hull reinforced to handle different levels of ice in polar waters. The classifications range from PC7, summer/autumn operation in thin first year ice, to PC1, year-round operation in all polar waters (International Association of Classification Societies, 2023, p. I1-2).

This project evaluated every unique IMO number generated from the AIS data and queried it to determine which vessels in the data set had a PC hull or equivalent. The search result only uncovered 59 vessels with strengthened hulls for ice. This was not significant enough to meaningfully include in the current model. The PC designations are relatively new (for ships built after 1 July 2007), but as these designations mature and become commonplace, the model can include VOOs with ice capable routes and call upon those vessels to respond to SAR cases in the ice.

6.3 Ice Layers

The ice extent in the Arctic is not uniform. Arctic Ice has different concentrations, depth, and longevity. All these factors affect what types of vessels can transit through the ice, and at what speed. Shapefiles that contain delineations between these ice factors could improve the accuracy of the routing of ships that have ice breaking capability. NSDIC has shapefiles for both ice extent (currently incorporated in the model) and a vector analysis shape file separating the ice into two categories: 1-8 tenths concentration, and 8-10 tenths ice concentration[21]. Additionally, the National Ice Center can produce ice extent accessibility maps based on PC. Combining robust PC data with these shapefiles could have a significant impact on METR for SAR events on the ice.

6.4 Icing

Icing is a significant weather condition in the Arctic. It obstructs both surface and air assets, and when severe enough, icing can be the cause of a SAR event. The CDS ERA 5 data set provided the metric ‘Total Column Supercooled Liquid Water’ which is the amount of liquid water in the atmosphere below 0° Celsius (CDS, main variables description). This metric does not indicate when icing conditions are present but provides a component (supercooled water) necessary for icing to occur. More data would need to be collected to determine if icing conditions were present and at what elevations.

Incorporating accurate icing data would affect vessel speed, aircraft routes, and vessel/aircraft ability to complete a route. Many of the aircraft included in the model have some degree of deicing capability, and conversations with Alaskan aviators indicate that pilots can often avoid icing by flying above/below/around icing conditions (J. Freeman & E. Klynman, personal communication, July 10, 2023).

The model could be updated to reroute aircraft on alternative routes that avoid icing conditions and slow down (or stop) surface vessels that are experiencing icing at sea.

[21] www.usicecenter.gov/products/arcticdata

6.5 Scenario Expansion

The scenarios in this model were limited to the US Arctic AOR, but there is nothing in the model that prevents it from working in other geographic locations with different scenarios. Other Arctic State AORs can be evaluated (or the entire Arctic) by updating the input files (geography shapefiles, assets, VOOs, etc.).

Additionally, the scenarios in the study can be infinitely adjusted. Incorporation of foreign assets and winter scenarios would be of particular benefit as they significantly altered the response suite tested in this study.

6.6 Model Uses for Other Missions

This project focused on SAR in the US Arctic AOR, but the model is not limited by this project's geography, scenarios, or input data. This model can serve as a first step in development of other models to evaluate different mission priorities, such as law enforcement. With adjustments to the movement logic of the response assets (currently set up for SAR), any number of missions can be modeled.

7 CONCLUSION

This project evaluated the response time in six SAR scenarios in the US Arctic AOR and found that two of them exceeded the minimum five-day IMO METR. The model confirms what logically follows: the larger the victim load and the further away from shore-based infrastructure, the longer the METR. This result is consistent with comparable work discussed in the literature review (Section 2). Due to the scale and remoteness of the Arctic, many routes have the potential to become extended duration SAR events.

Currently, the ship owner is responsible for developing an accurate METR. The Polar Code requires owners to conduct an operational assessment to determine the METR value that is identified on the Polar Ship Certificate and used as the requirement for determining the quality and quantity of LSA and survival equipment to be kept onboard. How the owner conducts the OA is not prescribed or regulated by the Polar Code, which means two comparable vessels operating on the same route could produce two different METR values through differences in approach when conducting an OA. The difference in these values could be the difference between survival and tragedy.

This project recommends that the regulations be updated to require operational assessments follow regulated, standardized methodology. This methodology should include in-depth analysis tools to calculate METR (such as simulation models like this one or others described in the literature review), that will reduce inconsistency between operators, and will help ensure that the equipment onboard is more accurately rated for the conditions that may be required of it. Without a unified standard, the possibility of vessels operating with insufficient survival equipment remains high and could cost lives.

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