Master's thesis

NTNU
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Creation of a GIS based Case Study Collection for Marine Accidents and Exercises in the Arctic

Master's thesis in Master Thesis in Cold Climate Engineering
Supervisor: Dr Nataly Marchenko (UNIS), Dr Knut Vilhelm Høyland (NTNU), Per Knudsen (DTU)

June 2022

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ABSTRACT

Arctic sea ice has been experiencing a steady decline in its minimum extent, primarily occurring in September each year, with a current rate of shrinkage at 12% per decade. This diminishing sea ice has facilitated increased accessibility for vessels in the Arctic Ocean, resulting in a surge in ship traffic within these remote and extreme regions. Consequently, it becomes imperative to prepare for potential marine accidents in these areas and learn from past mistakes.

The objective of this project was to develop a user-friendly dashboard interface that serves as a repository of marine accidents and rescue exercises, allowing the user to filter, search, and conduct detailed analysis of these selected cases. At present no such platform to find Arctic specific accident or exercise information exists. Using the capabilities of ArcGIS Online Dashboards and ArcGIS Storymap applications, the project creates a case collection of both 26 accidents and 18 exercises in the Arctic region. These tools were used to provide an intuitive and visually appealing platform to present data along with incorporating various multimedia elements and interactive maps that give a deep dive on each case.

The work aimed to contribute to the broader goal of enhancing maritime safety and accident response strategies along with the education to academics and marine professionals in Arctic specific safety. By providing a platform for accessing and analysing historical accident data, stakeholders can learn from past experiences. The completed project can be used as a learning tool for university students in maritime and safety-related fields or incorporated into existing sites to bring it to a wider audience.

PREFACE AND ACKNOWLEDGEMENTS

This master thesis is part of studies in the Land Track of the Nordic Master in Cold Climate Engineering, which is a joint programme between the Technical University of Denmark (DTU) and the Norwegian University of Science and Technology (NTNU). THe thesis project work was carried out at the University Centre in Svalbard (UNIS) during the spring semester of 2023.
I would also like to thank my three supervisors for their support and help throughout the thesis, Nataly Marchenko of UNIS, Knut Høyland of NTNU and Per Knudsen of DTU. In particular I would like to thank Nataly for all her assistance in the completion of the project and for proposing the project itself. Thanks to my family and friends for the support during the whole period of studies in this masters along with my fellow cold climate students, Tom, Bogdan and Kyle. A special thanks go as well to my third floor hallway 'master of disasters' friends for getting through the long days together.

1 Introduction

Over the last 15 years, marine traffic operating in the Arctic has significantly increased, this is according to research conducted and published by the Arctic Council. The study into unique vessels operating in polar waters revealed that between 2013 and 2019 there was a 25% increase in the overall amount of ships of all types with the majority of these ships being fisheries related at 41%[12]. Additionally, passenger carrying vessels, particularly the large scale cruise liners travelling to Arctic destinations such as the Svalbard archipelago and Greenland showed significant growth. The surge in Arctic tourism has led to an influx of tourists during the summer season visiting small communities and very remote areas of Greenland. The trend is shown in Figure 1 which demonstrates the continuing upward trajectory of visitors to the Arctic regions. In the post-covid era with travel reverting to normal numbers of those travelling to the Arctic has again hit record levels with Greenland experiencing its busiest ever season in summer 2022. The same is seen in Svalbard too with information for vessels scheduled to visit the archipelago showing that for the 2023 season there would be 35 conventional cruise vessels and up to 75,000 passengers arriving. This is a large increase from the previous 2022 season number of 57,700[13] to the island. Another notable development is the increasing number of bulk carriers using the North Sea Route. Over the past decade traffic has increased more than 15-fold, with the largest increase coming in 2017 and 2018[14], even with the present situation with Russia there is still considerable traffic using the route owing to the decreasing thickness and less multi-year ice along the route. With this rise in vessels operating in Arctic waters, the likelihood of accidents has also increased. Given the vast distances Arctic waters cover and lack of proximity to larger settlements and infrastructure, search and rescue teams face a considerable challenge to assist stricken vessels and crew if an accident occurs where it could be potentially days before assistance can be given.

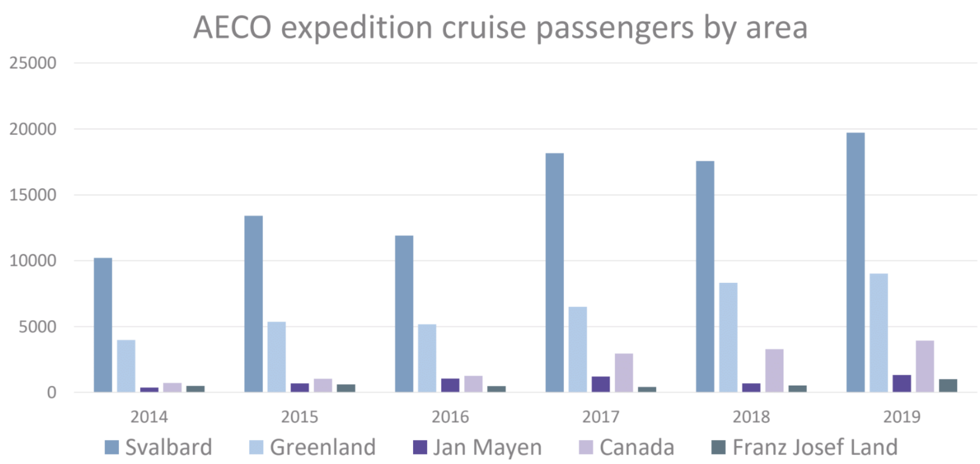


Figure 1: Tourist numbers in the Arctic islands 2014 - 2019[1]

The project collection aims to provide a resource for researchers, students, policymakers, and industry professionals who are interested in education and improving safety in the Arctic. By analysing past accidents and rescue exercises, trends can be identified. Common challenges can also be highlighted along best practices in the context of maritime exercises. Training programs and the field of education in a marine context are also the target users. The project utilises a Geographical Information System (GIS) base to allow data to be visualised in a way that is easily understandable and accessible to a wide range of users. The applications that enable this are the ESRI (Environmental Systems Research Institute) ArcGIS Online, Dashboards, and Storymaps packages which are used to present the data in a variety of formats which range from from interactive maps to multimedia narratives. The intention for this project is to contribute to the goal of making the Arctic a safer and more sustainable region for all who rely and dictate policy on it.

1.1 State Problem

With the unique challenges posed by the extremes of the Arctic in both remote location and scarcity of resources and infrastructure, maritime learning from previous accidents at sea as well as large scale training exercises is an essential need. At present there is no location on the web where all of this information is gathered together. In order to improve preparedness as well as understand previous cases and reasons which led to accidents and response to accident, analysis and collection of these cases is required. That is why the yearly exercises between multiple countries in the arctic is so beneficial. An interactive interface where all this information is displayed and able to be filtered and selected is the aim of the finished project. Quick and easy usability is the priority.

1.2 Objectives

The following are the main objectives set out for the project.

- Gathering of a reasonable collection of cases for both accidents and exercises
- Develop an easy to use interactive tool to showcase data
- Creation of deep dive Storymaps to detail the events of each case
- Provide shapefiles with created data to contribute to existing resources such as BarentsWatch

1.3 Study Area

Defining a distinct study area for the project revolved around relevance to previous research carried out as well as time constraints. The Arctic sea region is a vast expanse of water over several countries and jurisdictions. As well as this the area under the Polar Code regulations for ships was a priority along with some additional areas specifically around the Northern Iceland coast. Reasons for its inclusion even though it is outside the Polar Code area is that it resides insides the Arctic EPPR (Emergency, Prevention, Preparedness and Response) boundary, see Figure 11 for visualisation. With these limitations to not cover the whole Arctic taken into consideration, the areas of Svalbard and the Barents Sea, Greenland and Northern Iceland were chosen as a project scope area.

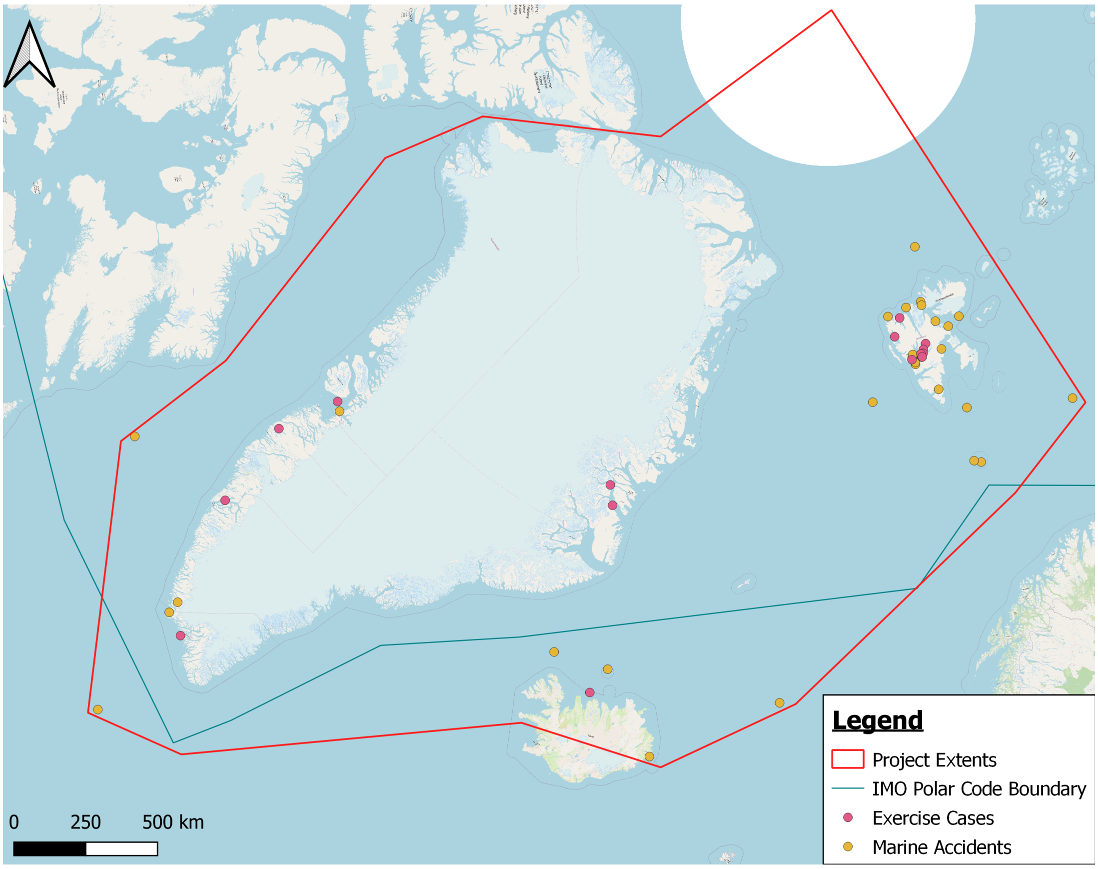


Figure 2: Project Study Area

As this project is a follow on from work done in the MAREC and MARPART projects there is some marine accident information available that can be added to and adjusted to the chosen parameters in this project and they can be included. These cases are primarily in the region of Svalbard and its surrounding waters. The study area is also directly linked with where a lot of the Mass Rescue Exercises (MRO's) and other SAR training have been conducted after the 2011 Arctic Search and Rescue Agreement[15]. The treaty which includes eight countries with Arctic territories, Canada, Denmark, Finland, Iceland, Norway, Sweden, the Russian Federation, and the United States aims to to improve both the coordination as well as cooperation between these Arctic nations with regard to search and rescue operations. Since 2011 there has been one large scale exercise every year. These have been mainly conducted within the Svalbard, Greenland and Northern Iceland areas and thus helped dictate a project boundary area. This was the case for all exercises as well as accidents, to be within this confines. In Figure 2 the exact boundary of the project study area is shown in red with the Polar Code Boundary also highlighted.

2 Background and Literature

2.1 Previous Research Collections and Resources

The basis for this project is following on from work done by Dr Nataly Marchenko on how to show data and learn from previous cases in shipping accidents. In the the paper for the 2021 International Conference on Port and Ocean Engineering under Arctic Conditions a creation of a basic mapping tool that coupled with data could be utilised by users to get brief information on various ice induced incidents in the Arctic[16]. The created map which was hosted on ArcGIS Online included the severity of the incident symbology where the greater the incident the larger the icon as well as categorisation of ship types into four distinct vessels. These were passenger, cargo, fishing and survey. Interactivity on the maps was done by the user clicking on any of the points and a popup with a picture of the vessel as well as a description of the events. More investigation of the incident could be done with hyperlinks included in the description which included accident information and vessel details from sites such as Marinetraffic and Vesseltracker. It stresses as well that once created, the layers for these incidents can then have the possibility of being uploaded to similar databases or sites to combine and unify efforts in maritime preparedness. This current project is a direct follow on from this research and previous to the paper discussed in 2019 which was a GIS online resource for marine emergencies in the arctic[17]. It covered a similar goal, to create a useful and accessible online resource to show accidents and explain what happened in the lead up and their background. The use of Storymaps to convey the information was also discussed and with these two papers taken into consideration, the project aims to take the topic to the next level with a combination of map and Storymaps approach.

As accidents at sea have always occurred, there is a vast array of information available as well as specific collections of data that have been gathered. Work done in creating a database of shipping accidents from Konnekt-able Technologies in 2021 looked at serious accidents that occurred between 2014 - 2019 worldwide at sea with a total of 320 accidents. It utilised unstructured information from accident reports conducted by governmental organisations to create a new, well-structured dataset of maritime accidents and provide intuitions for its usage[2]. The goals of this research is similar to that of the objective of this project in this sense but differs elsewhere as instead of a database approach, this will be a case collection with visual and multimedia to describe and explain accidents. It used existing databases such as The National Transportation Safety Board (NTSB), the Japan Transportation Safety Board (JTSB), and the Marine Accident Investigation Branch (MAIB) databases to obtain accident reports. While this information is easily available from these locations, information from different countries is not always available and in an Arctic context this is even more so. In this research the following headings were chosen to give a brief description of the accident. Following this initial categorisation a more detailed table was created that each incident would fulfill where information was available. This final table is seen in Figure 3. There is a large amount of detail in this description, but for a database it is what is needed. For example there are six different parameters for the weather attributes. Some of the parameters shall be considered to include into this projects consideration. However, for the authors project this amount of detail is not needed as the aim of this summary table in the GIS interface is to firstly be able to filter through different types of ship and accident type as well as injury's.

- Unique ID
- Accident Type
- Vessel Name
- Date of the Accident (Date)

- Vessel Length
- Vessel Type
- Total Number of Persons Onboard (Persons Onboard)

Compiling of information of the accidents in this methodical way and filling in information allows the creator to then be able to generate statistical analysis of the whole dataset quickly. Charts such as ship type breakdown as well as accident type distribution are two such examples. This type of a data collection also highlights where accident reports are lacking in information which is beneficial for organisations to improve on in the future of their reporting. Again, this research is not exactly the same as the aim of this project but does give an indication of approaches to target in collection of data and its subcategories. One that had not been considered thus far in research was the categorising of the sea state using official UK Met Office guides and may considered in the collection creation.

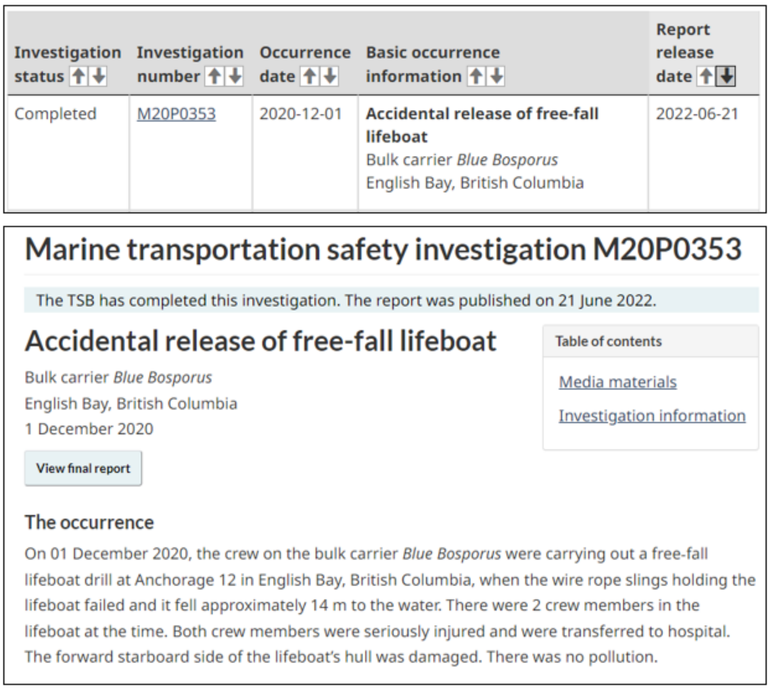
Basic Attributes	Basic Attributes Categories	Attributes Type	Measurement Unit
Unique Id	A Serial Number	Numeric	-
Date	-	MM/DD/YYYY	-
Ship Attributes	Length	Numeric	Meters
	Vessel Type	String	-
	No of Crew Members	Numeric	-
	No of Passengers	Numeric	-
	No of Person Onboard	Numeric	-
	Vessel Name	String	-
Weather Attributes	Rain	Boolean	1 or 0
	Wind Speed	Numeric	m/s
	Wind Direction	String	-
	Water Temperature	Numeric	K
	Air Temperature	Numeric	K
	Visibility	Numeric	Meters
	Sea State	Numeric	Meters
Accident Type	-	String	-
Impact Attributes	No of Deaths	Numeric	-
	No of Injuries	Numeric	-
Accident Description	-	String	-
Effective	-	Boolean	1 or 0
Place	A brief description of the place	String	-
	Location Type	Categorical	0–4
	Place Geo-location	Longitude, Latitude	-
Secondary effects of the initial incident	-	String	-
General Human and organisational factors	-	String	-
Human and organisational factors based on incident type	-	String	-
Environmental Pollution	-	Boolean	1 or 0
Economic Impact	Damage on vessel	Numeric	Dollars
	Damage on facilities	Numeric	Dollars

Figure 3: Attribute categories, sub-categories, type and measurement unit in the second version of the data collection[2]

2.2 Existing Databases and Sites

Looking at the three official databases mentioned in the article published for Konnekt-able Technologies on Shipping Datasets Database[2], the National Transportation Safety Board (NTSB), the Japan Transportation Safety Board (JTSB), and the Marine Accident Investigation Branch (MAIB) databases give an impression of some of how information is presented. The NTSB site[18] filters its accident reports into six categories, the one of interest for this project is the marine subsection. However, within this there is no way to sort or search for specific types of accident. The reports are merely inputted from most recent occurring and do not have a column to show the cause of accident or ship type, only a report title. This lack of user friendliness and inconvenience makes it hard to find what you want or even to discover accidents. For an official government site it is dated in its approach in that the content of these reports is of high quality but how it is stored on the site could be improved and modernised with searchability and GIS tools. The JTSB incident report site[19] is somewhat more usable than the NTSB with parameter headings on the top such as date, name and type of vessel, accident type and location. The downside is that again the database cannot be searched or filtered. The form is a table starting with the most recent and working back from that. This highlights the need for modernisation and more interactive collections such as the aim of this project. The MAIB is the British site for accident reports[20] and is more searchable and useful than the previously discussed two. It has a search bar as well as filter ability through vessel type along with the date of occurrence.

Most official government websites have very few reports on them, however the Safety Board of Canada marine transportation division is the most modern and thorough in the conducting of investigations[3]. The website the accidents are hosted on has some filterability in the form of date of occurrence, status of investigation, report release date and basic occurrence information. The inclusion of a release date is a logical and useful addition as then a user can see if there is an active case on the accident as well as when if the report is completed and its scheduled release date. The occurrence information column is also a welcome addition in comparison to other sites as it gives the ship type along with its name and then a very brief description of what has happened and location of the accident. Clicking into a case shows more detail on the accident itself and a location map using Google maps as a display. Information is available even if no report is yet published. This comes in the form of the investigation process with phase headlines along with the accident investigator on that particular case. In Figure 4, an example accident from the site is shown with the accident shown firstly as it comes in the list and next once it is clicked the additional information is given along with the report file itself. Going forward with the project the brief synopsis of the case details is a very useful addition for anyone wanting to view these accidents.



Investigation status	Investigation number	Occurrence date	Basic occurrence information	Report release date
Completed	M20P0353	2020-12-01	**Accidental release of free-fall lifeboat** Bulk carrier *Blue Bosporus* English Bay, British Columbia	2022-06-21

Marine transportation safety investigation M20P0353

The TSB has completed this investigation. The report was published on 21 June 2022.

Accidental release of free-fall lifeboat

Bulk carrier *Blue Bosporus*
English Bay, British Columbia
1 December 2020

View final report

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Media materials

Investigation information

The occurrence

On 01 December 2020, the crew on the bulk carrier *Blue Bosporus* were carrying out a free-fall lifeboat drill at Anchorage 12 in English Bay, British Columbia, when the wire rope slings holding the lifeboat failed and it fell approximately 14 m to the water. There were 2 crew members in the lifeboat at the time. Both crew members were seriously injured and were transferred to hospital. The forward starboard side of the lifeboat's hull was damaged. There was no pollution.

Figure 4: Top shows the individual case and bottom shows the case details[3]

Existing websites relevant to the project that display marine shipping related information in a geographical form include BarentsWatch, Helcom, Polar View and Arctic Web. Each display and give information on several aspects of shipping. The first, BarentsWatch, gathers and collects information specifically related to Norwegian marine and coastal areas. The primary objective of this service is to provide a platform for information sharing among the public, industry, and government agencies. The web portal shows activity and vessels within the bounds of the Barents sea as well as the Norwegian coast. Using a GIS interface with layers that can be turned on/off as well as downloaded, information such as danger areas, lost fishing gear, maritime boundaries, VHF coverage, ongoing seismic activity and electromagnetic surveys as well as up to date ice concentration, ice edge and locations where vessel icing can occur at present. The creation of BarentsWatch was based on cooperation between 27 Norwegian state agencies and research institutes[21]. Another online spatial data resource similar to BarentsWatch is Polar View. It is a global organisation that uses satellite information and data with a particular focus on the polar regions. Daily illustrations and information in map form for snow, ice and sea ice formations and extents are published with ice-edge and iceberg monitoring included as well. While Polar View's interactivity is limited to turning on and off shapefile layers related to these parameters, it provides visual representations in addition to information for understanding polar conditions.

The most relevant site with regards to displayed marine accident information is Helcom. Helcom is an Finnish based online website hosting a tool that can be used to view marine information with special regard to marine accidents, in this case it is information around the Baltic Sea. The tool is part of the organisation of the Baltic Marine Environment Protection Commission and was established in 1974 to protect the marine environment in the area from pollution of all kinds[4]. The site hosts numerous geospatial datasets and maps which are freely available for download. The tool uses an ArcGIS Online based viewer which enables all users to access the various shapefiles layers. With eight major category headings in the layer list navigation through the data is straightforward. A search tool for these layers facilitates the discovery of specific layers of interest. Concerning this project the category of interest is shipping and contained within this is a shipping accidents layer. In Figure 5 this layer along with the symbology used is shown. It is worth noting that not all the categories available in the tool may be directly applicable to the project at hand, but certain ones such as grounding and fire might be relevant. The choice of symbology is interesting to see as it has all different colours as well as six distinct shapes.This aspect should be taken into consideration when creating the Arctic collection and determining the most effective way to display the data. When clicking on any accident a pop-up appears with various information fields about the accident. However in a lot of cases the information available is very inconsistent and many fields are unpopulated and blank. As well as this ship names are even left out in many accidents. In this sense the site looks dated in how the information is displayed and it is noted before commencing this project.

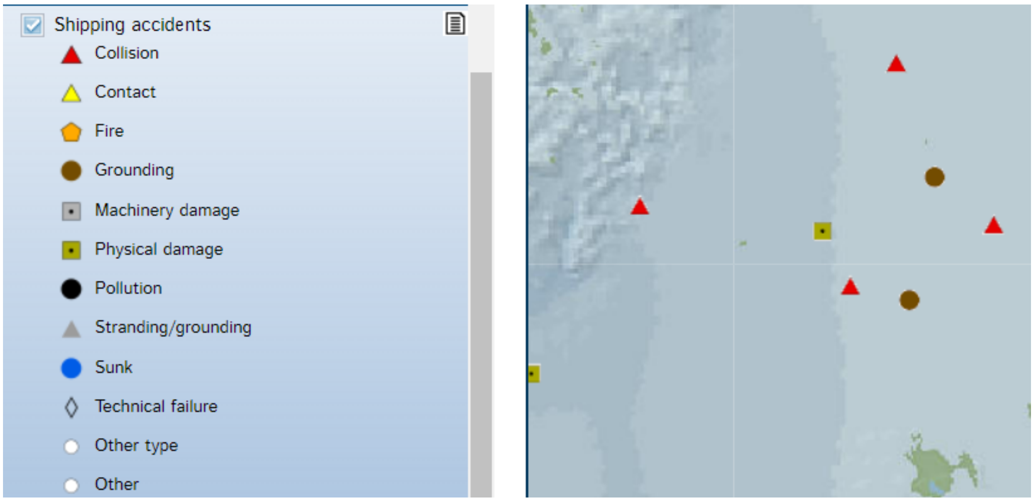


Figure 5: Symbology and Categories of Shipping Accidents on the Helcom map and data service site[4]

2.3 Storymaps

Storymaps are web maps that are a more interactive option to present created maps, text and other multimedia content in a narrative format. The use of the Environmental Systems Research Institute (ESRI) website for creating Storymaps is planned for each collected case. Its capabilities and link with ArcGIS pro make creation streamline. With maps, narrative text, videos and pictures structured into template options, it is relatively easy to create very visually appealing and interactive content. By utilizing templates that incorporate maps, narrative text, videos, and images, Storymaps enable the creation of visually appealing and interactive content. While the stories typically follow a linear structure, users can also explore the contents in a nonlinear fashion by interacting with the embedded maps.[22]. When creating many Storymaps, a practical approach to their creation should be followed, one which can be replicated for many and diverse Storymaps. In the research for this project it was found that the model of creation to be followed would be alike the model shown in the paper about Integrating Digital Datasets into Public Engagement through ArcGIS StoryMaps[23]. This process follows a step by step process where gathered multimedia is displayed to create the Storymap. Starting with the topic of choice, a general storyboard for what happened or about the topic is created. Then some of the text writing can be made where maybe reports or other factual information can be summarised or highlight points can be brought together where they can be inserted where required. After this the use of either obtained shapefiles or datasets can be used to input into an ArcGIS map where import into the Storymaps is easily done. If there are no available datasets at disposal then look into creating within ArcGIS desktop a map that shows the gathered information from the reports. Once this is done then all the elements to create a successful Storymap are at hand and it is merely a process of best utilising the different types of Storymap media displays where some focus more on one particular type of media.

Specific cases effectively displaying a variety of media types include the 'Putting Park Back in Parkway' Storymap which won the 2017 ESRI infrastructure, Planning and Government best Storymap award[24]. It is an excellent example of how Storymaps can effectively communicate urban planning projects and engage the public on a topic that in report form would not appeal to many. The Storymap showcases the Sir John A. Macdonald Riverfront Park Plan, which aimed to transform an underutilised parkway into a busy riverfront park. Through interactive maps, visuals, and storytelling, it highlighted the project's goals, features, and benefits. Through incorporating multimedia elements and community involvement it creates an immersive and engaging experience for readers, making them active participants. Another such example is from the University of Potsdam on Snow Avalanches[25] which is also a featured Storymap on ESRI's website. Features of note in this piece is the use of videos in the background throughout. It also has multiple overlays that can be turned on and off in map insets. The use of the cascade format in a top to bottom way is noted as the flow in this format is more user friendly than the constant clicking through to the next feature seen in the journal format.

2.4 PAME

Previous statistical information as well as accident collections was and continues to be done by the Protection of the Arctic Marine Environment (PAME). It makes up one of six working groups under the Arctic Council and is an intergovernmental forum consisting of the eight Arctic states along with six indigenous organisations. Established in 1991, its primary objective was the promoting cooperation and coordination among Arctic states to protect and sustainably manage the marine environment in the Arctic region. In relation to this master thesis project is PAME's work with Arctic shipping looking at environmental impacts and risks associated with increased shipping activities in the Arctic waters as well as documenting of accidents. Extensive research and reports assist in the overall understanding of Arctic shipping and its future and present as well as a collected database showing all accidents and incidents reported to the various marine authorities within the Arctic. This database is a product of the 2021 produced 'Compendium of Arctic Ship Accidents'(CASA) project[26]. Led by the USA, it aimed to develop a database of Arctic shipping accidents between the years of 2005 to 2017. Six Arctic states submitted data, resulting in 5,004 unique accident records into the CASA data table. However, standardising the data was challenging due to differences in reporting thresholds and requirements. For example there are over 80 different types of vessel within the database, a similar number is seen for the types of accident. As well as this the information provided by countries varies widely and often entries don't even have a ship name. Different thresholds for each state meant some countries like the US entered in accidents of all scales while others only reported the very serious accidents. The data from this project is not displayed visually but it can be downloaded as a CSV file to view. At present the US is spearheading a follow up project aiming to have a standardised template for more clear results that is due to be completed at the end of 2023.

2.5 ArcGIS Dashboards

When conveying data into a public realm, interactive displays such as ArcGIS dashboards provide an easy to use and digestible information on whichever data or research the topic is in. There are many benefits for creators in choosing the dashboards feature of ArcGIS online. This includes familiarity with the navigation on the site and implementing tools and editing as it is similar to the normal ArcGIS online as well as the desktop version. Another advantage highlighted in a paper on spatial analytics dashboards is that it gives researchers and scientists a way to present their data that is closer to a scientific poster than the other option which is an ESRI Storymap[27]. The dashboards simplicity and intuitive set up helps bring many forms of data together with full creator choice on the layout. Some of the elements that can be included are as follows.

- Header
- Map
- Serial Chart
- Pie Chart
- Indicator
- Gauge
- List
- Details
- Rich Text

An aspect important to this project is the software's filtering ability. Using the different shapefiles, filters can be put on any of the attributes where constraints can be imposed on what to display once clicked. Multiple selectors can be made where one choice impacts the second. Particular examples of the Dashboard application being utilised for public and private use include the Wildfire Information Map which is part of the disaster response program set up by ESRI which assists organisations responding to disasters or crises using GIS technology[28]. The dashboard provides real-time information on active wildfires, fire perimeters, evacuation zones, and air quality. Its target users are residents, emergency responders as well as the public and allows them stay informed about the current status and potential threats related to wildfires. This Dashboard is user friendly and intuitive, with many extra layers to be turned on and a display page on the right hand side with illustrated graphics and tables. The Redlands, California Crime Map which is facilitated by the 'neighbourhoodscout' website[29] is a great case of the ArcGIS Dashboard. It is a hosted element on the website itself and displays crime incidents in the city of Redlands, California. It allows users to explore crime patterns, filter incidents by type or date, and visualise crime trends over time. Notable aspects include the filtering. The Dashboard was created by the company Locationinc[30] for the website and they specialise in using many types of geographical and data visualisation of information using Dashboards to best interact with the public in mind as an end user.

2.6 Case Collection versus Database Approach

In approaching this project the case collection versus database approach was an initial consideration. A database approach to data with marine accidents and exercises involves the compiling of data into a table format from all cases for analysis and manipulation. Whereas a case collection not only collects data but also has an extensive look at each case rather than just specific parameters. There are a few distinct differences in the approaches to a collection like the proposed project.

Differences between the approaches included the structure of organisation. Case collections often are stored as individual files or documents. Each case has all relevant information contained within this report which allows for flexibility in the organisation as well as how information and facts are presented. This is seen in the government of the UK MAIB collection for accidents at sea. Contained on the site are 1016 reports of varying lengths describing accidents involving vessels[20]. Filterability is possible through the date it occurred but not by vessel type or losses. Converse to this is the database approach where information on the cases is stored in a structured manner but detail in the case is sacrificed for case specifics. Another difference between the two types for a collection is the scalability and efficiency. A case collection often works better for a smaller collection as when the amount of cases grows, it can become time-consuming and inefficient. Databases such as the PAME[26] one discussed earlier have large amounts of data that contain thousands of entries in them. The aim for this project was to link the best qualities of both approaches to create a more case collection approach but using structure in the collecting of data to make it easy to filter and find cases.

2.7 Shipping in the Arctic

2.7.1 Svalbard

One of the main areas of interest for this project is the Barents sea and the island archipelago of Svalbard. The island is a territory of Norway and located at the latitudes between 74° and 81° N. This makes it the most northerly civilian inhabited island in the world. In comparison to other areas at this high a latitude in the world Svalbard is relatively moderate in its climate. The reason for this is due to the Gulf stream. Warm ocean currents bring warmer water as far as Svalbard and this gives the sea water a higher temperature than similar areas such as Northern Greenland where the sea freezes for large parts of the year. As well as the gulf stream, the island has experienced climate change to an extreme degree with annual temperatures rising over 4°C between the years of 1971 - 2017. This change over the same period is even more stark in wintertime where there is a change of 7.3°C. To put into context in a global view the global increase has been 0.87°C[31]. This has meant drastic changes to the seasons as well as glaciers and sea ice for areas like Svalbard. This phenomenon of increased change in the Arctic is called arctic amplification. It is an issue in every Arctic country as well as seas.

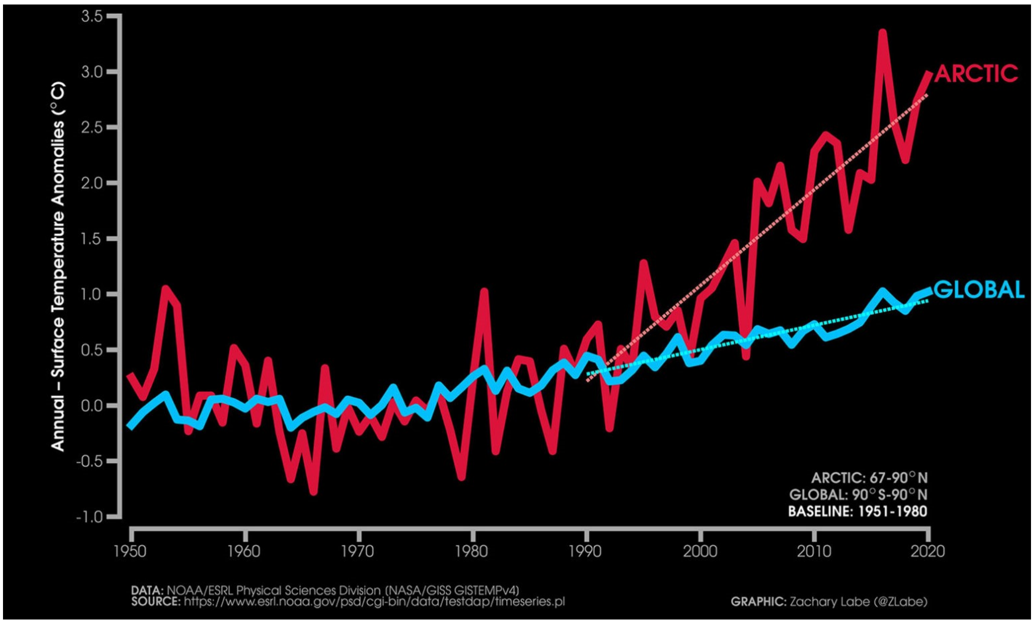


Figure 6: Comparison of global and Arctic temperature change[5]

When looking at the sea traffic around Svalbard it is mainly made up of commercial fishing vessels as well as tourism sector related ships. This trend has long since been the case but with the large increase of popularity in the last 15 - 20 years in tourism has seen summertime have large numbers of passenger vessels sailing around the island. This being said, it is a seasonal peak of business from a tourism perspective whereas fishing continues off its coast year round even in the dark season. The dark season is a two and a half month period where the sun does not rise above the horizon and is pitch dark between the period of mid-November to late January[32]. Any accidents that occur in this period are extremely difficult for search and rescue crews to deal with. Other marine traffic in the area include research and cargo vessels. Before the islands airport was built in 1975, ships were the primary form of transporting goods from the mainland to its inhabitants. Cargo ships in the form of refrigeration ships or 'reefers' regularly frequent areas of Svalbard to offload fish catch by other boats in a fleet. The aforementioned cruise industry is attracting companies with larger and larger ships with capacity of up to 5,000 passengers to the island. This upward trend of visitors is expected to continue increasing into 2025[33]. The main town on Svalbard, Longyearbyen is vitally important as a search and rescue hub for the vessels that operate in the polar waters around its shores. The need to have SAR in Longyearbyen is a step from the Norwegian government who have employed several local measures to help reduce the risk of unwanted events and to avoid loss of life and environmental damage[33]. These measures include strengthening emergency preparedness, developing maritime services around the archipelago (e.g. Marine Automatic Identification System (AIS)-stations), and issuing regulations[33]. Since 2012 local government have regulated the types of vessels as well as the fuel use. In 2015 a ban on heavy fuel oil in the national park waters of Svalbard was enforced. This is particularly relevant in East Svalbard where the environment is very delicate. Mandatory pilotage requirements for captains of larger vessels were also implemented.

2.7.2 Greenland

Similar to Svalbard and the Barents sea area, Greenland has seen a large increase in the number of vessels in Greenland waters, especially in the summer season where cruise ship tourists have drastically increased in the last 20 years. In 2003 tourists visiting on cruises numbers approximately 10,000 people whereas in 2019 the numbers exceeded 46,000[34]. In this increase is the very large cruise ships with thousands of passengers similar to the ones on Svalbard. Cruises sail on both West and East Greenland with most numbers on the more populated West side. These call into numerous towns and glaciers in their travels. The more remote East side of the country still gets tourists but the numbers are much less. The fishing industry is the countries main export in Greenland with it accounting for 90% of exports. The fleet consists of over 950 vessels, these are the larger ocean going vessels[34]. These are scattered off its coasts most of the year, sea ice permitting. Greenland has always received most of its external supplies via cargo ships that nearly all originate out of ports in Denmark. These deliver weekly food and goods to most villages except for more northernly or isolated communities that it depends on ice conditions, for example, the most northerly inhabited town of Qaanaaq receives only two deliveries from the cargo ship each year. All ships within Greenlandic water must adhere to certain safety standards. The country has a positional reporting system for all vessels in the exclusive economic zone. It includes captains having to send a pre-plan of where the vessel is planning to visit when in Greenlandic waters as well as its position at four set times during the day. Failure to report during these initiates a search and rescue operation. It is also akin to Svalbard in its demand for pilotage requirements. These are mainly aimed at larger cruise ships that are more than 250 passengers. Needs for 360 days in polar waters as well as 180 days in Greenlandic waters are required[35]. Implements like this help minimise accidents that occur in polar regions but it cannot stop all from happening.

2.8 Loss of Sea Ice

With the increased temperatures experienced in the Arctic the decline of sea ice has been accelerating greatly in the early 21st century. One of the main variables for sea ice is the volume and this is one of the most sensitive to climate change. In the last 40 years the Arctic Ocean has lost approximately three quarters of its sea ice volume at the end of the summer season[36]. In Svalbard the temperature increase has seen accelerated sea ice melt. Generally, the ice edge north of Svalbard has retreated towards the northeast, along the Atlantic Water pathway[37]. With regard to the extent, the average change in sea ice extents between 1979 and 2021 is seen in Figure 7 where it is 30% lower now than 1979. With current rates of decline projections of the Arctic show that it could be totally ice free by 2050[6].

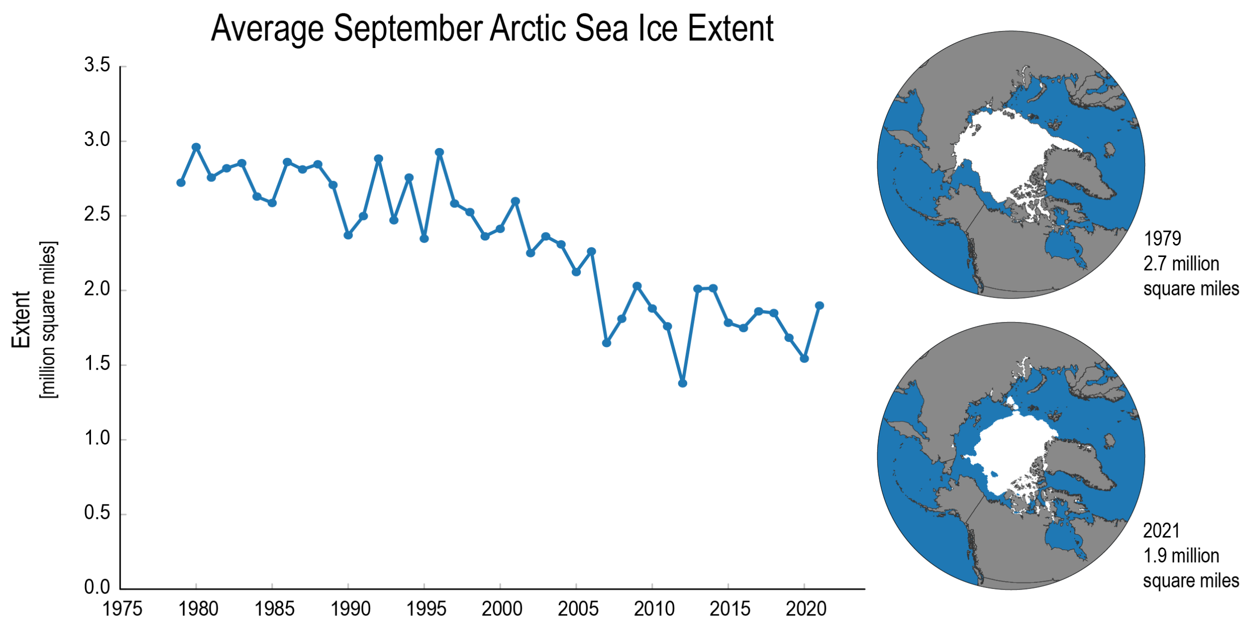


Figure 7: Graph of sea ice extents[6]

The result of melting sea ice is less white surface to reflect back the suns radiation. This is known as the albedo affect. Less white surface means more ocean surface which is darker and therefore absorbing the suns radiation and the melt is continued. Warmer ocean may also melt the ice from below. The area of water between Greenland and Svalbard is the main area of sea ice transport from the Central Arctic ocean.

In the context of this project and ships, the reduction of sea ice has lead to much discussion about the possibility of using new journeys as cargo routes. One of the main ones considered is the northern sea route as an alternative to the Suez Canal. The northern sea route lies along the Russian Arctic coast from the Kara sea, all the way across to the Bering Strait. The Barents sea is not officially included in the route, however ships using it would go through the sea in the area between Bjørnøya and mainland Norway. The main interest is from cargo ships, savings in fuel costs are a priority and companies such as Maersk are looking into the route which can cut journey times by up to two weeks, relative to the Suez Canal. The northern sea route is now feasible to use for three months of the year with lower sea ice increasing this passage even further[38]. Increased presence of ships, not only large cargo ones but also of all other categories as well in the route increases the chance of an accident occurring here.

2.9 Categories of Accident

In assembling cases to add into the collection, each accident has a primary causation for that event linked to it. For a case collection as planned with a filterable element to it, then the accidents must then be categorised according to these causes of the accident itself. Below are the main reasons found for accidents in the study area of Greenland, Northern Iceland and the Barents Sea region. Also included, is search and rescue exercises which is the other element of this case collection and these have been conducted yearly since 2011 in many Arctic areas with large scale multi country coordination.

- Grounding
- Fire
- Icing
- Damage by Ice (Iceberg, Ice-flow, Glacier Calving)
- Oil Spill
- Engine Failure
- SAR Exercises

2.9.1 Grounding

One of the main causes of accidents in the Arctic is ships grounding. Grounding is when a vessel makes contact with the seabed or other rocks and runs aground. In Arctic waters there is sometime a lack of availability of accurate navigational charts especially close to shore where the bathymetry has not been fully mapped yet. The reasoning for this is a mix of the cost to conduct this coupled with the fact that sea ice conditions don't allow it certain areas. Some areas on have spot soundings through which are taken through the ice and are single depth measurements taken at 2,000 metre intervals, and commonly referred to as through-ice bathymetry[7]. A transducer is placed on top of the ice recording its position and depth. The disadvantages of this method is that in between measurements the seafloors contouring is unknown. As well as this is the fact that some areas which were always ice bound are now becoming ice free in summer with warmer temperatures and retreating ice flow. Issues with grounding due to lack hydrographic information in an area has been seen to be an issue for some passenger ships that are exploring very remote and not mapped areas. For example, in 2018 the Akademik Ioffe sustained major damage to its hull and all 163 persons on board the vessel had to be rescued. The cause of the damage was grounding. A last minute change in the voyage plan meant that the new area the ship was going to the captain relied on partial bathymetric data. The depth of water below the vessel's keel reached 100m and a few minutes minutes later it was 14m. Low water alarms from the echo sounders were also ignored and turned off and the vessel ran aground on an uncharted shoal[39]. Damage to the ships hull is shown in Figure 8. Accidents like this are common, although damage is not normally as severe as with the Akademik Ioffe. Human error is often the reason for these groundings and with more cruise ships of all sizes going to more remote areas in the polar regions the likelihood of accidents increases, even with mandatory pilotage requirements.

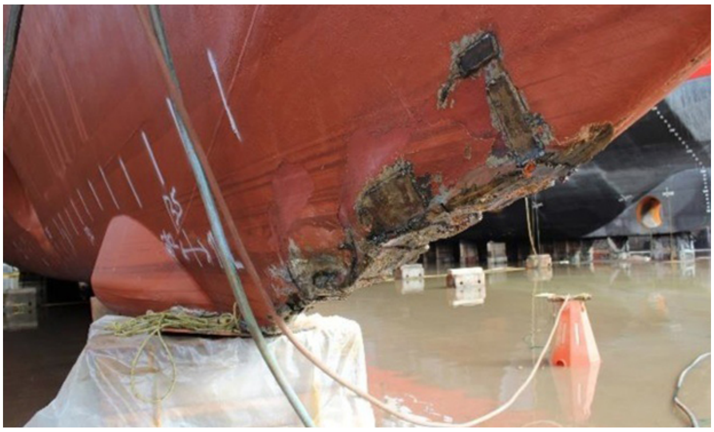


Figure 8: Hull of the Russian cruise ship Akademik Ioffe after grounding in northern Canada in 2017[7]

2.9.2 Fire

One of the most dangerous accidents on board a ship is fire. That coupled with the remoteness of this occurring in polar waters makes it highly hazardous. There are numerous ways in which a fire onboard a ship can start. The large number of electrical wires can short and spark an ignition as well as overheating of the ships engine or fuel leakage. The most common cause of fires on board is related to an equipment malfunction of some kind and the most likely place for a fire to start is within the engine room[40]. If a fire breaks out on board a ship then the only escape if it it not under control is overboard. All ships have plans in place to tackle a fire in different areas of the ship as well as different parts of the ship. Accidents involving crew members when dealing with a fire onboard are also common and indeed the fire may be put out but falls, burns and smoke inhalation injuries are sustained in the tackling of the fire. These injuries would then need assistance and the nearest port is usually a long way away. Distance to the nearest SAR crew results in longer times to get to adequate care for the injured. In Svalbard in 2017 the deck of the M/S Langøysund caught fire during a barbeque event in which 34 people were on board. Quick response from the SAR crew in Longyearbyen deescalated the situation and the fire was put out[41].

2.9.3 Icing

Accumulation of ice on a ship is another form of damage by ice. Icing on ships is a great hazard in extreme cold temperatures below - 10 (DC) while combined with high winds[42]. This makes sea spray freeze on contact with the ship. If the crew does not frequently clear it off it can accumulate fast and cause an upset in the ships balance resulting in a destabilisation and then capsising. It is an issue that is most a risk for smaller ships such as fishing boats because they are more likely to be exposed to sea spray and a smaller amount of ice is required for the destabilisation of the ship. To counter the buildup of ice, some more modern fishing vessels have electronic systems which then use heated surfaces to counter the buildup of ice once the temperature and wind go past a set threshold. However, systems like this are expensive for captains of ships and especially with such tight margins boats face, these systems are not implemented widescale. Although not a common cause of actually capsising ships and causing them to sink, the buildup of ice in cold regions is very common and captains and crew being aware of the issue and consequences if not addressed by crew. The most common way to tackle the ice buildup is with wooden mallets or bats to break off the ice layer[43]. If vessels are close to shore when severe icing conditions occur then they are advised to seek shelter at the nearest harbour. Since this is in the Arctic, then there is rarely a port nearby to seek. In this case then the ships captain is encouraged to steam downwind thus minimising sea spray. These in practice measures to combat ice build up can also be helped by preventative coatings on the vessel. A flurocarbon coating is one that can be applied to the super-structure to repel water and prevent ice accumulation[43].

2.9.4 Damage by Ice

Damage caused by ice in its various forms is a major hazard and has many examples in the Arctic of accidents caused by it. Sea ice, icebergs and calving accidents are some of the types of ice that vessels deal with. There are three main mechanisms in which can damage a ship. The first is an appendage such as the hull, rudder or propeller hitting the ice. Care and diligence must be given by the ships captain in the speed that they are travelling at in certain types of icy waters. The speed in which it hits the boat can be the difference in the hull withstanding the impact or a penetration. The next mechanism is ice hitting the ship itself. This could come in the form of wave-induced impacts or chunks of glacier falling onto the vessel. The last type of mechanism is pressure. This can be where a ship is ice bound and ice is exerting huge amounts of pressure onto the sides of the ship[44]. Some of the large icebreakers designed for navigation through ice fields are designed to negate this issue with egg-shaped hulls but for a normal ship the results are fatal with many incidents especially of early explorers ships being crushed in this way.

Secretariat of the International Ice Charting Working Group who promote the coordination of iceberg information and sea ice services, John Falkingham said that "Arctic shipping will not get safer as the ice diminishes. Since we first recognised the decline of sea ice, the watchword of Arctic mariners and ice experts was that less ice actually brings greater hazards to shipping"[45]. With less bound ice the remaining ice is more mobile and free to drift further South into areas where ships navigate. This drifting sea ice can also then be brought by wind direction as well as swell direction to accumulate at narrow passages or straits as well as port entrances. These are called pressure zones and pose a threat to vessels operating in the Arctic as in small, narrow areas there is little room to maneuver the ship past these sea ice. This freeing of ice into smaller chunks also includes multi year ice. This ice is much denser and harder that regular sea ice and in high seas can cause serious damage to the hull of a ship, especially if its ice class rating is low. It must be said that there is a distinct difference between sea ice and glacier calved icebergs. Glacial ice is very old and extremely hard. It is best avoided by all ships. If an area is declared to be ice free it does not mean that there is no sea ice at all, it means that there is less that 15% ice concentration[45]. This is because the microwave satellite sensors used in the monitoring of the Arctic Ocean ice don't detect the areas where the ice less than 15%. A mistake by a navigator in this regard could have catastrophic consequences. That being said, in areas where there is a known risk of this and at the edge of the ice floe there are special categorised charts produced to avoid and warn captains of the present danger or approximate amount of ice in the area. In Figure 9, an example of an ice chart in the Barents Sea area complete with different categories of drift ice is shown.

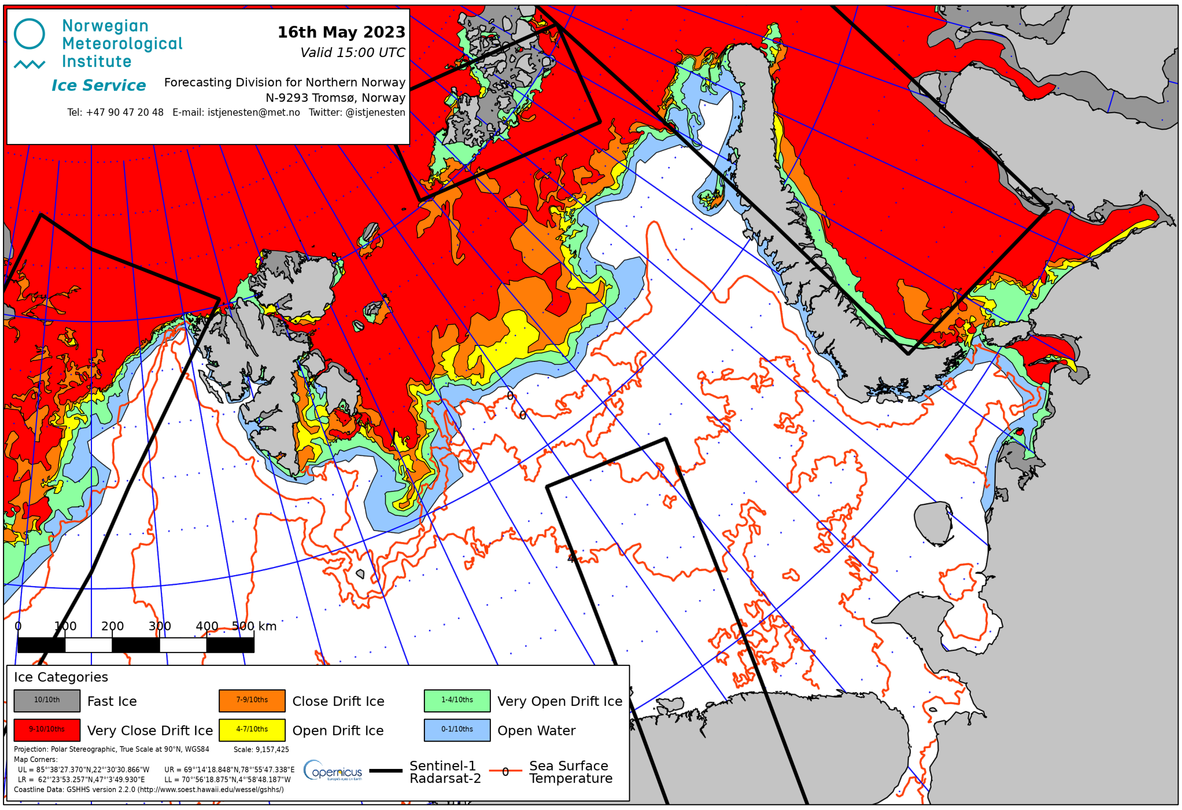


Figure 9: Local ice forecast example from the Barents Sea area[8]

2.9.5 Engine Failure

The possibility of engine failure is a potential to occur in any region. The difference between it occurring in Arctic and other bodies of water is that engine failure, especially in icy water can leave the ship paralysed and vulnerable to collision with ice floes and bergs. Like with many other accidents, the distance of the vessel to the nearest port or from a ship or SAR personnel that can assist and aid them. To minimise the risk of engine trouble regular servicing and maintenance of all components needs to be enforced with the ships engineers. The need for reserve fuel when conducting travel in Arctic waters is a factor ships need to account for due to the unpredictability of the weather conditions. Another common situation is when sediment that would otherwise sit on the bottom of the fuel tank is shaken around in a rough sea and then sucked into the fuel system, blocking the filters[46]. To mitigate against this the engineers in the engine room must keep maintenance to a high standard. The cruise ship Viking Sky suffered a complete engine shut down in a storm off of the Norwegian coast in 2019. A freight ship that also sailed through the same conditions experienced the same engine shutdown. With cruise ships going further into the Arctic in areas such as Franz Josef Land as well as more and more North on the East coast of Greenland issues such as those encountered with the cruise liner Viking Sky must be taken seriously to tackle to causation. In its case it was concluded that the malfunction may have begun in the self-contained propulsion units as the ship sailed through rarely encountered extreme wave conditions. The malfunction subsequently caused engines to shut down[47].

2.9.6 Oil Spill

Oil spills at sea cause huge environmental damage to marine ecosystems as well as the coast surrounding it. In an arctic context this is even more damaging due to the slow degradation of oil at water temperatures at near zero degrees celcius[48]. The Arctic is an especially delicate and fragile environment so accidents with oil spills here have long lasting effects on the wildlife and marine mammals. If an oil spill occurs in ice present water or even at the marginal ice zone where it is produced then the results can be serious. Inaccessibility as well as remoteness limit the ability to clean up such a spill. Research done by the American National Council of Research suggested that due to the low water temperatures that the oil could remain in Arctic waters for periods greater than 50 years[49]. If indeed a large spill was to stay present for such a period of time then it could have an impact on the albedo of that region. Ecosystems effected in an icy environment face long periods of recovery as oil can get confined between ice floes and even within the brine channels[48]. Normal procedure for ships operating anywhere is to discharge certain substances especially when on long trips where proper facilities to transfer them to port facilities are not available. The 1973 International Convention for the Prevention of Pollution from Ships (MARPOL) was introduced after a series of tanker accidents. The convention helped reduce pollution through the regulation of regular discharges[50]. It states that "the amount of legally discharged oil under MARPOL indicates that oil should not pose a significant threat to the local ecosystem as long as the laws are strictly followed". As shipping activity increases within the Arctic oceans, so too does the risk of a major oil spill. Although currently the levels of pollution are on a low level. Between 1993 - 2007 cruise ships within the polar regions had 21 fuel spillage accidents. The majority of these accidents were due to grounding, collision and sinking accidents[48].

2.10 SAR Exercises

There is a need for continuous improvement on the search and rescue techniques and training by the crews operating in the Arctic region. Struggles to overcome the large distances, as well as extreme weather challenge the SAR crews. Coupled with these natural challenges are the limited resources relative to other non Arctic areas which is driven by lack of money. SAR resources mainly include vessels, helicopters, airplanes and radio communication.

The first major maritime legislation was the 1979 SAR Convention. It aimed at developing an international SAR plan along with cooperation when necessary between neighbouring SAR organisations and that there was a national responsibility to establish capacity in the form of coordination centres, for example, the Joint Rescue Coordination Centre (JRCC) in the North of Norway[51]. Following the 1979 SAR Convention the international Maritime Organisation Safety Committee divided the oceans of the earth into 13 SAR areas respectively. This included the Arctic regions that this report investigates. Since this subdivision of Arctic SAR areas there has been little change in the region[52]. The next prominent regulatory framework introduced was the 1982 United Nations Convention on the Law of the Sea (LOS Convention). This convention formed the legal structure for managing activities within the Arctic. Promotion of cooperation between neighbouring countries if necessary as well as the "the establishment, operation and maintenance of an adequate and effective search and rescue service regarding safety on and over the sea"[53]. One of the most relevant agreements relevant to the study area of this project is the 1995 Barents SAR agreement. It is an agreement between Russian and Norwegian SAR services. Previous to this agreement there had been cooperation between Norway and the Soviet Union through an agreement made in 1956. This newer Barents SAR agreement bases its framework on the previously mentioned 1979 international Convention on Maritime Search and Rescue. Containing a total of 12 Articles it sets the conditions for conduction of joint operations, provision of assistance, and clarifies how requests for assistance are to be forwarded[52]. The SAR services of both Russia and Norway should provide mutual assistance to the extent that their capabilities allow. Joint Norwegian–Russian SAR cooperation has evolved over the years subsequent to the agreement through consistent meetings and joint exercises. Bilateral training has proved to be the key factor in both parties progression. In Figure 10 the break down and delineation between states is shown.

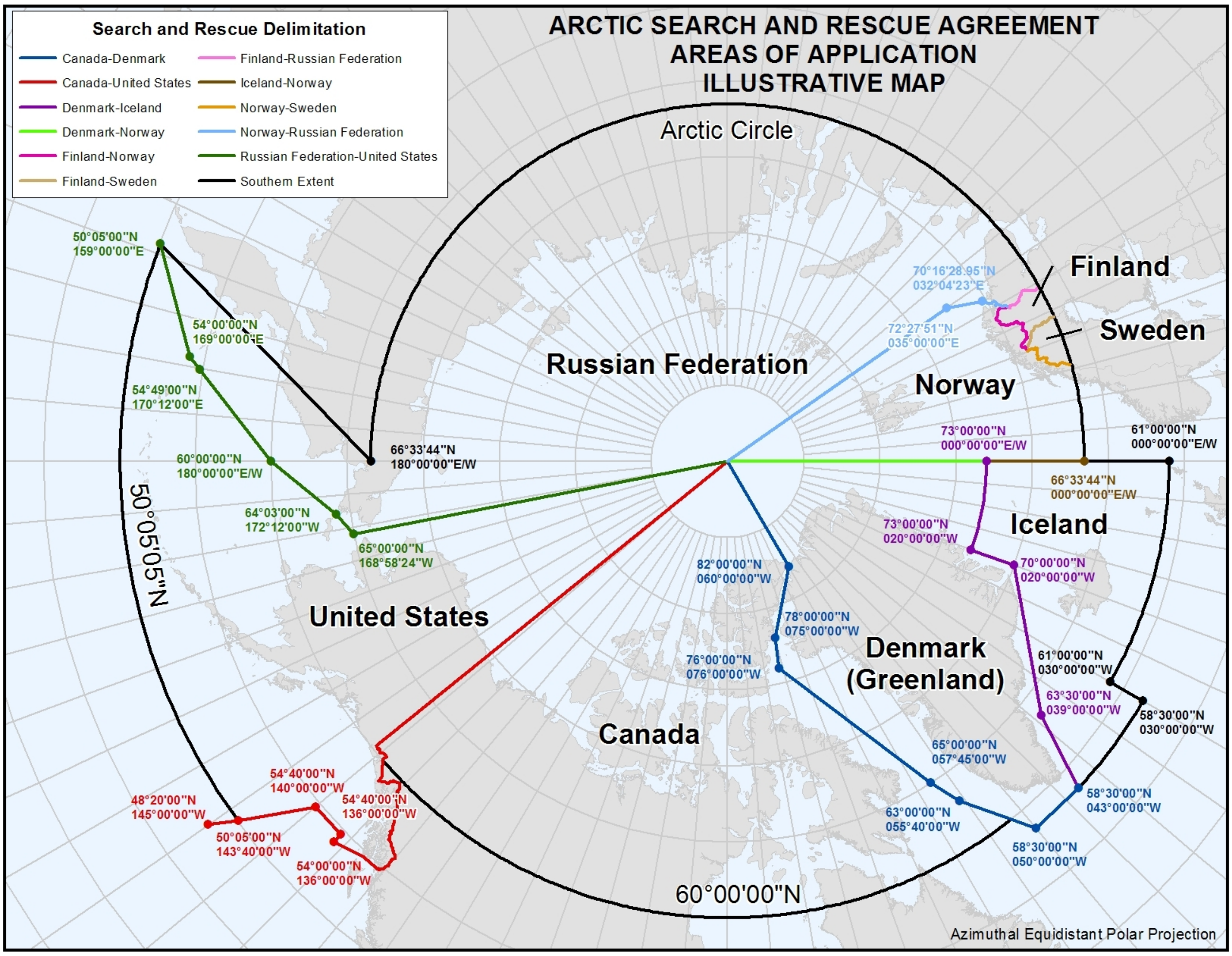


Figure 10: SAR regions relevant to the Arctic SAR Agreement and the Barents SAR Agreement[9]

The most recent agreement and the one that joins into this element of the project is the 2011 Arctic SAR agreement. In adding in larger SAR exercises that have been conducted in the Arctic, this is the agreement that brought together many countries to conduct these large scale exercises on a yearly basis. The agreement was first predated by the 2009 Ministerial Meeting in Tromsø by the Arctic Council where they determined a task force to develop international SAR cooperation in the Arctic. The finalised agreement was signed in 2011 at the Nuuk meeting of the Arctic Council by the 8 Arctic states. It entered into force in January 2013[52]. Although there had been previous multilateral agreements, this built onto pre-existing cooperation and framework[52]. Elements such as streamlining of SAR communication which had been highlighted to the Arctic council as well as sharing of experience, meteorological conditions, joint exercises and training, SAR techniques and service support. The yearly exercises conducted provide all nations with live full-scale exercises as well as evaluation reports on each. The collection aims to include these multi country exercises as the second element accompanying the marine accident cases.

Actual exercises coupled with tabletop simulations between all relevant parties enhances the preparedness as well as coordination. Tabletop exercises involve a simulated scenario discussion conducted in a classroom or conference room setting. These exercises focus on identifying potential challenges.

Virtual exercises like the 2020 Arctic Guardian Table Top Exercise (TTX)[54] which was held by the Arctic Coast Guard Forum with eight Arctic states in attendance. Representatives from each member state gathered in a simulated scenario discussion. The scenario involved a cruise ship experiencing an onboard fire and subsequent evacuation in a remote Arctic location. The tabletop exercise focused on evaluating the coordination and response capabilities of the participating nations. Along with tabletop exercises are the actual physical exercises that this project aims to look at as well. The first major SAR exercise conducted after the signing of the Arctic SAR Agreement was SAREX Greenland in 2012. Comprised of over 1000 personnel from 7 countries, it revolved around a full scale maritime mass rescue operation simulating a cruise ship of 150 passengers is missing in East Greenland. Phases including searching, evacuation from the ship to a triage station onshore and then onto an airstrip where a plane ferried evacuees to Iceland[55].

The Emergency Preparedness, Prevention, and Response (EPPR) Working Group is one of the six working groups operating under the Arctic Council[10]. The EPPR Working Group focuses on enhancing emergency preparedness, prevention, and response capabilities in the Arctic. It collaborates with the IMO and other organisations to address preparedness and response in the polar regions. This includes the implementation and enforcement of the Polar Code. The EPPR geographical extent aligns with the Polar Code's coverage, although it goes further South of the Polar Code line in areas such as Iceland. In keeping with the EPPR and Polar code, this is what will define the project extent.

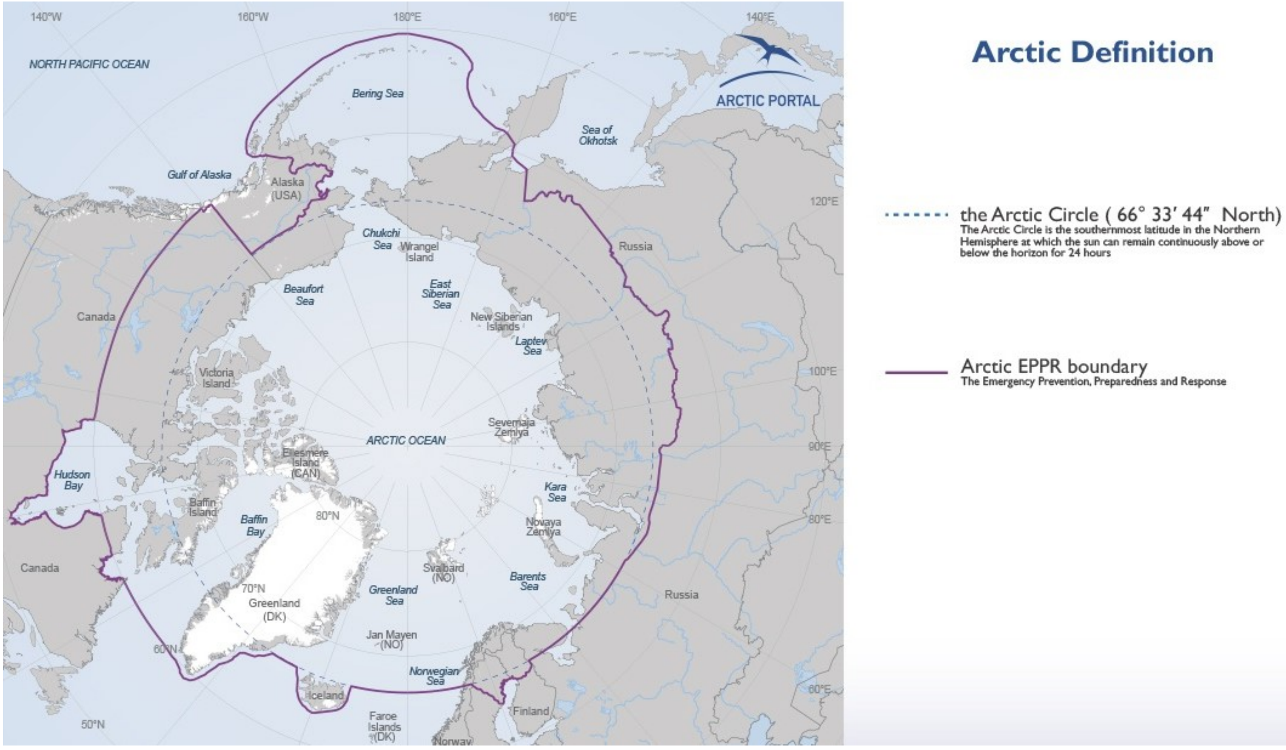
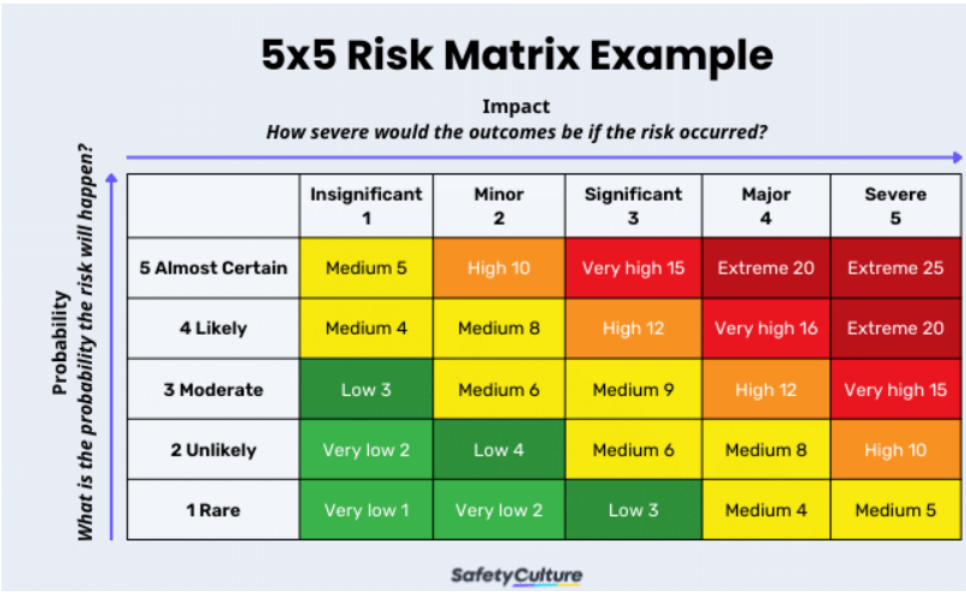


Figure 11: The Arctic area under the Emergency, Prevention, Preparedness and Response[10]

2.11 Risk Classification

In order to get a systematic way to quantify the scale of an accident or exercise a rating based on the severity or other factors can be given. Risk classification matrices helps assess and classify as well as to understanding the severity, likelihood, or other relevant factors associated with different risks. A risk classification matrix has a grid structure where risks are evaluated based on two parameters, such as severity and likelihood. The cells within the grid are populated with ratings or scores, which indicate the level of risk associated with each combination of factors. These ratings are commonly represented using colors, numerical values, or a combination of both. One of the most popular risk matrices used is the construction risk matrix used in the construction industry. Most common size matrices for construction risk matrices are 5x5 and 4x4 in size, sometimes it is even as simple as a 3x3 matrix. They assess the likelihood scale versus impact. The visual representation of the risks allow project teams identify quickly risks that require urgent mitigation and attention. Based on the project size and amount of risks determines the matrix size. Customisation often occurs to suit particular requirements. In Figure 12 an example 5x5 matrix used by many firms to assess risks. Advantages of a 5x5 matrix include a thorough rating to simplify complex issues along with reducing the need to conduct labour consuming quantitative analyses[11]. Other areas such as the financial sector always utilise a risk matrix not too dissimilar to those seen in the construction industry. Here the x,y axis are also given likelihood versus impact ratings but not always in a same size of matrix. For example 3x4 risk matrices are used sometimes where the the likelihood has only three ratings whereas the impact has four.


5x5 Risk Matrix Example

Impact
How severe would the outcomes be if the risk occurred?

Probability
What is the probability the risk will happen?

	Insignificant 1	Minor 2	Significant 3	Major 4	Severe 5
5 Almost Certain	Medium 5	High 10	Very high 15	Extreme 20	Extreme 25
4 Likely	Medium 4	Medium 8	High 12	Very high 16	Extreme 20
3 Moderate	Low 3	Medium 6	Medium 9	High 12	Very high 15
2 Unlikely	Very low 2	Low 4	Medium 6	Medium 8	High 10
1 Rare	Very low 1	Very low 2	Low 3	Medium 4	Medium 5

SafetyCulture

Figure 12: Construction industry 5x5 risk matrix example[11]

3 Data Collection

3.1 Case Selection

The first step taken in the project was to choose the cases for the collection. An initial list was compiled based on the available information from the Arctic region. Determining this initial list came from both previous research in the MARPART project along with some information from the PAME database which was downloaded and inputted into ArcGIS and relevant cases within the project boundary were noted. Some cases that were not included or emitted from the aforementioned locations were found through articles and news briefs. Cases included in this initial list aims were that no significant accident within this project confines would be left out, so research was thorough. Once a list with vessel or exercise names was compiled , more information was sought. This is where, upon further research and analysis, it became apparent that some of the cases had limited to no information available, and they were consequently removed from the list. Separate to this is that a lot of accidents reported to the JRCC in Northern Norway as well as included on the PAME compendium of Arctic ship accidents were medivac operations which would not be included in this project. The final list of cases aimed to provide a representation of different types of accidents, including collisions, groundings. The selection of cases also focused on including recent accidents to reflect the current state of maritime safety in the region.

3.2 Collection of Data

- Identify sources for the data
- Define the parameters
- Collect the data
- Analyse data
- Create relevant shapefiles

The data collection process for this for the project was intensive and used a systematic approach in compiling it together. In conducting the data collection in this way it ensured the accuracy, reliability and consistency of the information retrieved. Collection of data was done through extensive research of each incident following a chosen number of parameters. These included the date and location of the incident, type of vessel involved, cause of the incident, number of persons involved, and the outcome of the incident. The information was gathered from various sources, including official accident reports, news articles, and other publicly available information. A list of the exact parameters gathered for each accident and exercise is shown in Table 1(a) and Table 1(b).

Marine Accidents
Ship Name
Ship Type
Month
Year
Length (m)
Passengers
Accident Type
Loss
SAR
Scale
Injurys
Fatalities
Damage
X (EPSG 3995)
Y (EPSG 3995)
Storymap URL
Image
Storymap Title
Description

(a) Marine Accidents Data Headings

Exercises
Name
Year
Location
Days
Scale
Ship Type
X (EPSG 3995)
Y (EPSG 3995)
Exercise
Image
Storymap
Title
Description

(b) Exercises Data Headings

Table 1: Final parameters for standardised collection for all cases

The data collected was compiled into a data sheet and then checked for its accuracy along with completeness. After this it was then converted into a GIS shapefile for further analysis in ArcGIS. The GIS collection provides an overview of the Arctic marine accidents and search and rescue exercises that occurred over a specific period, offering valuable insights into trends and patterns in the occurrence of these accidents. The GIS shapefile allows for the visualisation of the data on a map. The process of creating the GIS collection involved a significant amount of effort and attention to detail to ensure that the resulting data was both accurate and reliable especially with regards to locations. Some information obtained had incorrect accident coordinates and the locations differed with official data. These had to be further researched and changed accordingly. The created collection from the data processing provides the basis for all work in the creation of an interactive dashboard to view, search and filter through different Arctic marine accidents and exercises.

Ship Name	Ship Ty	Month	Yea	Lengtl	Passeng	Accider	Lo	SA	Sca	Injur	Fatalit	Damag	X (EPSG	Y (EPSG	Storym	Image	Title	Descrip
MS Hans Hedtoft	Cargo	January	1959	82	95	Ice Accide	5	5	5	0	95	Major	-2665918	-2520705	https://stc	https://upl	Hans Hedt	The Danish
MS Syneta	Cargo	December	1986	85	12	Grounding	5	3	5	0	12	Major	-652202	-2692174	https://stc	https://pe	British tanl	The British
MS Sudurland	Cargo	December	1986	88	11	Other	5	3	5	5	6	Major	-176953	-2496219	https://stc	https://wv	6 dead aft	The Icelan
PV Maxim Gorkiy	Passenger	June	1989	192	952	Ice Accide	3	4	4	0	0	Moderate	163066	-1399957	https://stc	https://pb	990 Rescued from icy	
PV Hanseatic	Passenger	July	1997	123	145	Grounding	3	3	3	0	0	Moderate	338068.3	-1033589	https://stc	https://pe	Cruise ship	The cruise
EXP SKA 11	Research	May	2006	12	4	Grounding	3	2	2	0	0	Major	-2374459	-2129327	https://stc	https://wv	Surveying vessel sunk	
EXP Aleksey Maryshev	Passenger	August	2007	65	77	Ice Accide	3	3	3	18	0	Minor	396832.6	-1351223	https://stc	https://pe	Tourists injured from	
FV Frøyanes Senior	Fishing	November	2008	41	16	Fire	2	3	2	0	0	Minor	506765	-1419412	https://stc	https://wv	Machine room fire or	
MS Petrozavodsk	Cargo	May	2009	67	12	Grounding	4	4	4	0	0	Major	559157	-1617923	https://stc	https://pe	Russian ca	The refrige

Figure 13: Example of some of the initial data collection

Regarding the addition of the prefix at the start of each marine accident case, most ships do have prefixes, which are used to identify the country of origin or registration of the vessel. These prefixes are made up of letters and added to the front of the ship's identification number. It must be stated that not all ships have a prefix, particularly smaller vessels such as pleasure boats or fishing boats. The inclusion of ship prefixes for each of the cases in the marine accidents was decided as it gives clarity as well as accuracy when referring and identifying a ship. When communicating with other maritime industry professionals or regulatory agencies, using the correct ship prefix helps to ensure that everyone is on the same page and has accurate information about the ship in question and thus the reason for the inclusion into the collection. In the case of the collected marine accidents, there were four individual prefixes. This excludes the one helicopter case in which it cannot be classified as it is not a ship. Table 2 shows the classification of each prefix to the vessel type. It is pertinent to note that even though some vessels are registered as a certain type of ship, they are now operating as another, this is seen in the collection for the EXP Aleksey Maryshev where it was registered as an expedition ship as it had served as a Russian polar research ship in both the Arctic and Antarctic, however it was operating as a passenger ship at the time of the accident and thus was categorised as a passenger vessel in the collection.

Table 2: Ship Prefix Table

Prefix	Vessel Type
MS	Motor Ship
FV	Fishing Vessel
PV	Passenger Vessel
EXP	Expedition/Research Vessel

3.2.1 Category Selection

The final selection for categories in the accident type, ship type and exercise type focused on having a diverse spread of cases. Care was given to be not too specific so that general trends and patterns could be seen in analysing as well as in the filtering. For example there are many forms of ice accidents such as bounding, ice floe collision, calving accidents but for ease, all of these were grouped under the ice accident category. In classifying accidents into five distinct categories, insights can be gained into the primary causes or contributing factors associated with different types of accidents. A full list of these are shown in Figure 3. The ship classification category was split into four distinct ship types, by not having subcategories of passenger vessels or other types identification of characteristics and patterns in the types of accidents is easier. In the categorisation of marine accidents, an additional category called 'Other' was included to include events that do not fit into the predefined categories. The purpose of this category is to account for accidents that may be unique or uncommon, such as the MI-6 helicopter crash into Isfjorden in 2017.

In the context of exercises related to maritime accidents and preparedness, five categories were been identified. These categories encompass different aspects of exercises and are often interconnected, with some exercises incorporating elements from other categories. This is particularly true for multi-day exercises.For instance, an evacuation exercise may include a simulated oil spill scenario encompassed within it to test the integration of response efforts in a complex emergency situation.

Table 3: Final category selection

Vessel Type	Accident Type	Exercise Type
Fishing	Grounding	Evacuation
Passenger	Ice Accident	Survivial
Cargo	Fire	Oil Spill
Research	Engine Issues	Fire
Other	Collision	Collision
	Other	

4 Methods

4.1 Software Utilised

The project was created using various ESRI products and applications to produce the final interface and collection. For the uploaded shapefiles along with the masterfile containing all marine accidents and exercises respectively, the desktop application of ArcGIS was used. The version used in creating all of the required files was ArcGIS Pro 3.0.0. Along with this, some minor editing of shapefiles and data was performed in the open source application QGIS, version 3.16.15 Hannover. In all cases of created shapefiles the coordinate system WGS 84 Arctic Polar Stereographic system, also referenced as EPSG 3995, was used. This system is commonly used in areas North of 60°N both onshore and offshore, in the Arctic. In addition to ArcGIS Pro and QGIS, the online version of ArcGIS, ArcGIS Online, was used to upload the locally created shapefiles to the cloud. There is limitations in what can be done in ArcGIS Online in comparison to the desktop version so this is why it was used after creating the files locally. ESRI Dashboards was utilised to showcase the data in an interactive way and is a web-based application that allows dynamic dashboards to display various forms of data. The application uses a range of features, including customisable layouts, data visualisations, and filtering options. The other piece of software used was the ESRI Storymaps application which was again a web-based application to use shapefiles and many other multimedia such as text, images, and maps. It allows combination of spatial data with narrative text and multimedia content to create stories.

4.2 Accident and Exercise Scale Classification

In order to better sort through and quickly show the severity of an accident or size of an exercise, classifying the scale of each was deemed an effective tool to both show visually and link the scale of the accident to the size of the icon on the dashboard. A rating scale of 1-5 was used to classify the severity of an accident as well as the size of each exercise. Taking the format from similar classification scales of risk analysis as discussed in the literature review in Section 2.11, a structure to rate the collection was formulated.

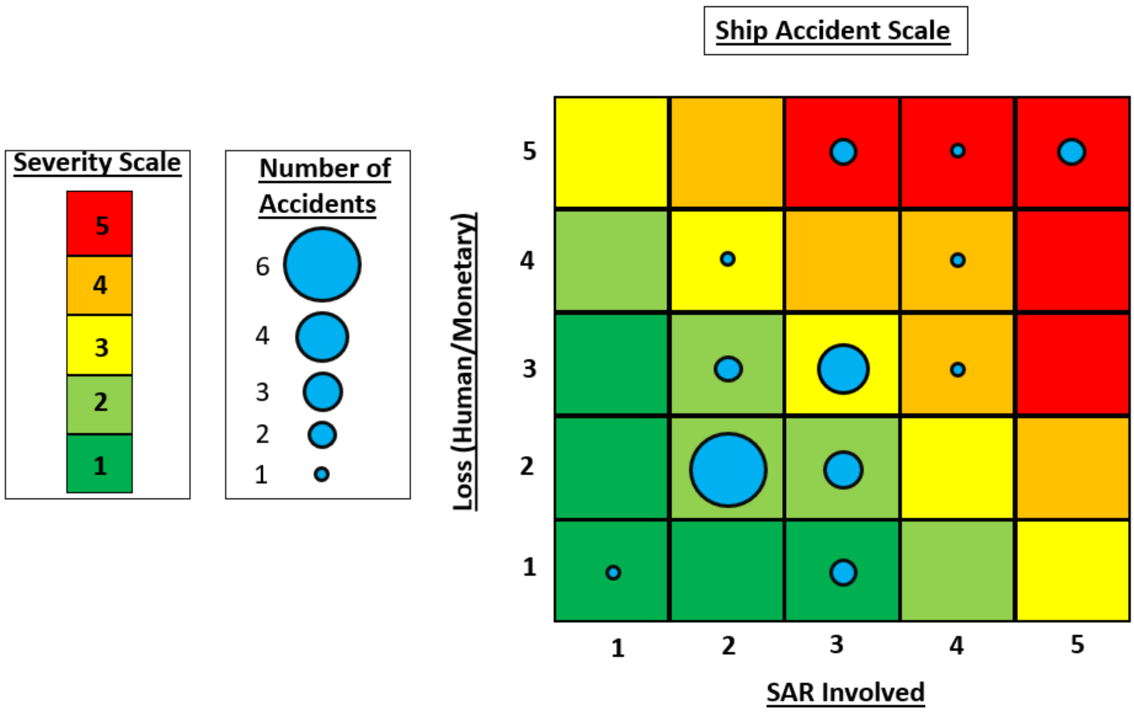


Figure 14: Marine Accident Scale Classification Summary

In the case of the marine accidents, the x-axis in the rating system represents the amount of search and rescue involved in the rescue. For this, exact information was not always available with regards to personnel involved in a search and rescue or recovery or ships/helicopters involved so an approach of putting in bands of personnel numbers was taken with the information that was on hand. When talking about the ratings given, for instance, an accident with a rating of 1 may require minimal search and rescue efforts and could be handled by local emergency services. In contrast, a rating 5 accident might require a massive search and rescue operation, involving multiple agencies and resources, such as helicopters, specialised equipment, and highly trained personnel. The y-axis in this rating system represents the loss, which is a combination of both in human and monetary loss. This is another subjective rating based on the information at hand on the exact details. The severity of the accident is determined by the amount of loss incurred. In this case a rating of 1 accident may result in no loss of life and minimal damage to the vessel, while a rating 5 accident might result in significant loss of life and irreparable vessel damage and/or sinking of the vessel. In Figure 14 the created accident scale matrix is shown along with a summary of the 28 accidents in the collection and where they fall within.

Table 4: Personnel Specifications

Scale	Personnel Involved
5	500+ Persons
4	250-500 Persons
3	100-250 Persons
2	50-100 Persons
1	<50 Persons

A similar process to define the collection of search and rescue exercises was performed. To determine the scale of an exercise, the following two parameters were used, the first which is represented on the x-axis is the amount of personnel involved and the second which is represented on the y-axis is the duration of the exercise in days. For the x-axis with personnel different number bands of persons involved were defined to separate each value. The ranges in the number of personnel were adjusted based on the specific data obtained in the data collection phase. With maximum and minimum values, the exact number ranges are seen in Table 4. The y-axis was outlined in a similar process where the collected days for all exercises was taken into account and then divided into five distinct brackets. With ratings 1-4 they corresponded to 1-4 days, while the fifth was anything five days or more in duration. The created scale matrix is then seen in Figure 15 with a summary of where the collection exercise fall within the table also displayed.

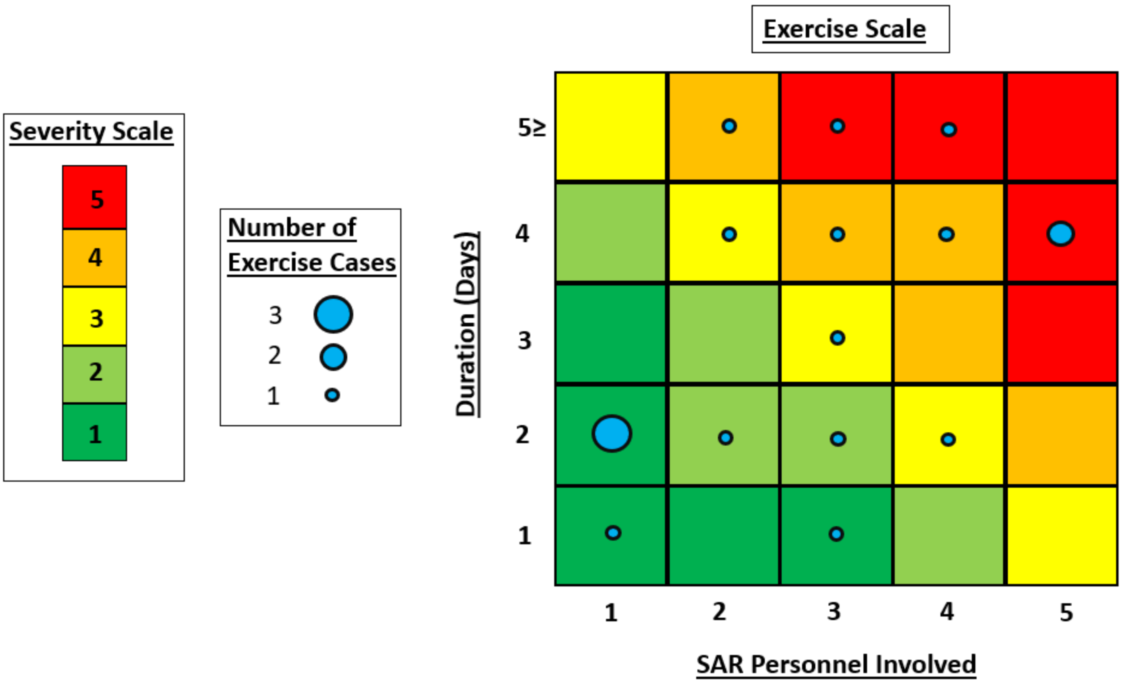


Figure 15: Created Exercise Collection Scale Classification Summary

4.3 Systematisation and Layout

4.3.1 Dashboard Creation

The interactive tool to display all of the created shapefiles is utilising the ArcGIS Dashboards application. Benefits of this application are that it can show many types data files and sources to meet whatever needs the end user requires. When creating a dashboard intended for persons of various skill and familiarity levels, there are several things to consider. Firstly, it is essential to identify the users needs and the information they require. This helps in designing the dashboard into something that is usable. An overall theme was given to the dashboard using the layout functions. Along with the theme, the header itself can be edited and using PNG images and styles. The dashboard was edited to an ocean theme throughout to suit with the content contained within it. Figure 16 shows the UNIS logo along with the ocean themed header that overviews the dashboard. This created a more cohesive look before other content was added.

Uploading of the shapefiles from the desktop to the online cloud that ESRI provides first required the all individual shapefiles to be zipped. Then in the import procedure the zipped shapefiles have an option to create a feature layer alongside the uploaded shapefile. This is important as not creating a feature layer in the upload means that the files cannot be edited. The shapefiles would be able to be uploaded and seen online, however, the lack of a feature layer means editing of various details is not possible. The feature layer, when edited is saved as a shapefile. An important note of all uploaded shapefiles and photos into ArcGIS Online is that once in the cloud they must be edited to share to everyone in the public. Uploaded files automatically are defaulted to be owner access only but there are two other options, one for organisation sharing and then the public sharing. Once the shapefiles were edited and contained within the online version of ArcGIS, they were combined into a webmap which is used as the Dashboard uses webmaps to display shapefiles rather than individual files. The webmap for this project includes the marine accidents and exercises files along with the Polar Code and SAR extents for each Arctic country. Another element allows for bookmarking of specific areas so that when selected the map displays this set location overview at a particular scale. In the case of this project four bookmarks were created. This follows the three main areas in which the collection is based upon along with an overview of the Arctic region. These are West Greenland, East Greenland and Iceland and Svalbard. This is incorporated into the Dashboard with the its when the webmap is added to the feature map widget.

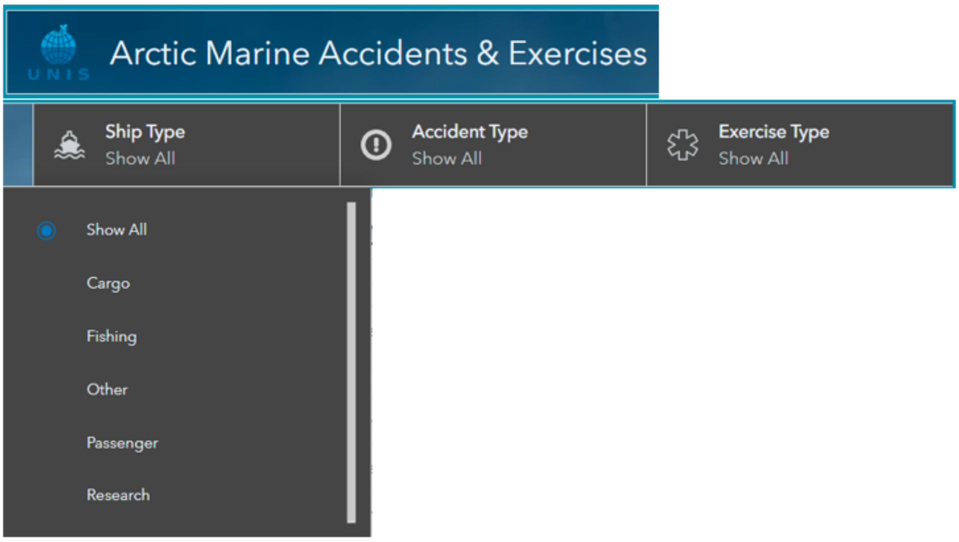


Figure 16: Created Header and Filter Options

Filtering the information from the marine accidents and exercises was deemed the most important after adding the shapefiles. For the marine accidents the ship type filter was made to select through the five distinct categories of ship, while the accident type filter can filter the six accident varieties. The exercise filter then gives the option to toggle the four training exercise varieties. Once the add filter function is selected the shapefile was applied to the filter and category field was selected. Customisation in whether the selection is in the form of a dropdown or a button was adjusted and alongside this the display as well as icon for the filter was able be inputted. In the case for all three filters in this project, the use of edited SVG (Scalable Vector Graphics) text files to be added into the dashboard in order to have the desired symbol displayed beside the dropdown was included. Linking the filter to the map itself allows the selection by the user to change what is shown on the map. Linking between other filters is also required, for example linking so that a user may select all fishing vessel accidents and then choose to only see groundings would yield only fishing boat groundings on the map, the same linking to the filter must be done in the map element component. This ensures that the two elements function as they were intended. The other main feature on the dashboard is the tables element. In the case of each of the filters an additional function defined as 'Show All' resets the choice after a singular selection is picked and it defaults back to displaying all after this is clicked. In Figure 16 all filters along with the aforementioned 'Show All' function is displayed. Attention to what is displayed on the pop-ups and what the tables show is given as repeating information is unnecessary and confusing. Another factor of note is the width of what can be displayed. There can only be a limited number of attributes displayed on the table with five shown on the marine accidents and four attributes shown on the exercises. Akin to the filter element, linking the tables to the map itself gives the full benefit to the user in regards to ease. For both tables the actions of the map when a particular accident/exercise is selected include panning to the location, flashing on the icon and showing the pop-up. In Figure 17 an example of one of the editing tabs in the data field editor for the marine accident table is shown. The map element is also edited to only show the cases within the current view on both table so for example, if it has the island of Svalbard in the view, then only Svalbard cases are displayed.

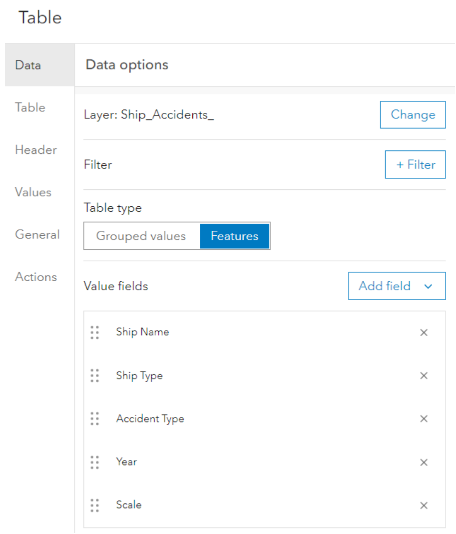


Figure 17: Display fields for marine accidents table

4.3.2 Symbology and Popups

Symbology is essential for effectively communicating information to the public or other stakeholders. It provides a concise way to understand complex sets of data. With regard to GIS maps it plays a crucial role in that it helps users quickly identify patterns and relationships within the data. By looking at the map, a user can easily identify both the scale of an accident or exercise as well as what type of boat was involved in the accident with a glance. The choice to display the type of ship with the icon over the accident type was decided for easier user understanding, with the category of accident being filterable within the dashboard as discussed in previous subsection instead. The displayed ship type is then linked with the calculated scale from the matrix discussed in the previous paragraph with five sizes of icon. The size of the icon can be edited with the ArcGIS online application where linking the scale attribute allows an even size distribution. Care was given that the smallest scale accidents were not too small that the detail in the icon could not be read or distinguished. Vice-versa in the the largest sizes not making the area visually unappealing. After consideration and experimentation a maximum and minimum sizing of 25-15 pixels was chosen for the marine accidents, with a 2 pixel change between each scale number. In the case of the exercises the size of the circles ranged between 17-12 with a 1 pixel increment between each. The visual for this for the marine accidents is shown in Figure 18.

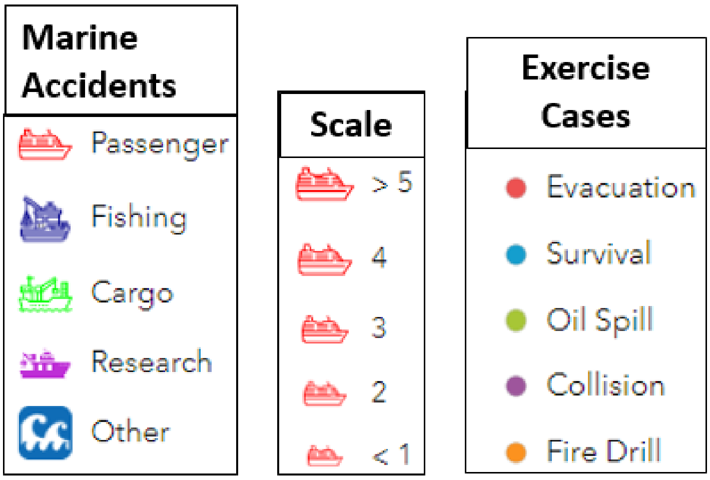


Figure 18: Symbology and Scale sizes for both Marine Accidents and Exercises

All icons to be used as the displays for shapefiles were first using SVG images that were edited before converting into PNG files and uploaded into the cloud. Files were obtained from the web from w3.org [56] and downloaded where they can then be adapted using the notepad application on windows. Features of the SVG's to be edited in the script included the colour, line thickness and shape dimensions. It is important to note that the dimensions of the SVG files must be the same for each ship type, so that the applied scale is consistent across all the icons. This ensures that the icons are displayed in the correct size relative to each other. After editing the SVG files to the desired specifications, they were saved and then converted into PNG's.

When displaying information to a target audience who may not be widely familiar with where to find information on a shapefile, a pop-up tool can be used to show just what is required from within the data attributes rather than every single parameter. Within ArcGIS Online, this pop-up tool allows the display of additional details about a feature, including text, images, and charts. To configure what was required for the project the use of ArcGIS Arcade utilised. Arcade is an expression language used to create custom content within ArcGIS applications. It can perform mathematical calculations, format text, and evaluate logical statements. It also supports multi-statement expressions, variables, and flow control statements[57]. Features edited for this project in the shapefiles included the title and contents displays, expressions to be added and media. Selection of attribute data to display within the pop-ups was done using operators that link the data from the shapefile automatically rather than manually inputting what has to be displayed. A brief summary description along with hyperlinks to each Storymap were included. Coupled with this was the configuration of an image for each was done from the shapefile layer with images attached within each input. In order to have this images viewed they had to be uploaded onto the ESRI online cloud where once publicly shared, the URL was attached to the shapefile layer. In all cases they were made publicly viewable and linked into the pop-up. As discussed, the aim to not repeat information between the pop-up and the Dashboard table was done so that initially the table shows an accident or exercise and then it is clicks and brought up on the map along with a brief synopsis of the accident itself and a picture so the case is understood and then shown with an image as well as the option to get an in-depth run through on the case with the Storymap. An example of a pop-up is shown below in Figure 19.

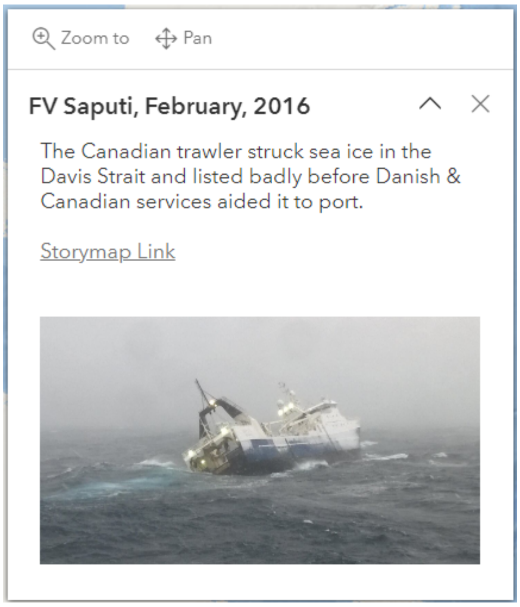


Figure 19: Example pop-up shown for one of the marine accidents

4.3.3 Storymap Creation Process

Creating a uniform process for the design helped streamline the undertaking especially since there was 46 individual cases to create and obtain information for. A process was devised and is shown in the form of a flowchart in Figure 20. Starting with the initial main information on the case written in bullet points in Microsoft word. This clarifies the key information needed to be conveyed by the Storymap. Following on from the main points of a case there is a need to collect and search for data. In this the data can be in the form of published maps with locations or other information relevant to the case. If there are maps available then these are be used to combine and create insert maps with included information within them. If not then the available text information is used the create a map. The combination of various multimedia within a map as well as the Storymap itself is what makes the application such a visually appealing form of information distribution. Where possible, the interactivity is increased so that maps or tours can be explored, clicked and viewed to increase user engagement. By following this structure in all Storymaps in the collection then it became easier to manage multiple cases and display information in both an organised and clear manner.

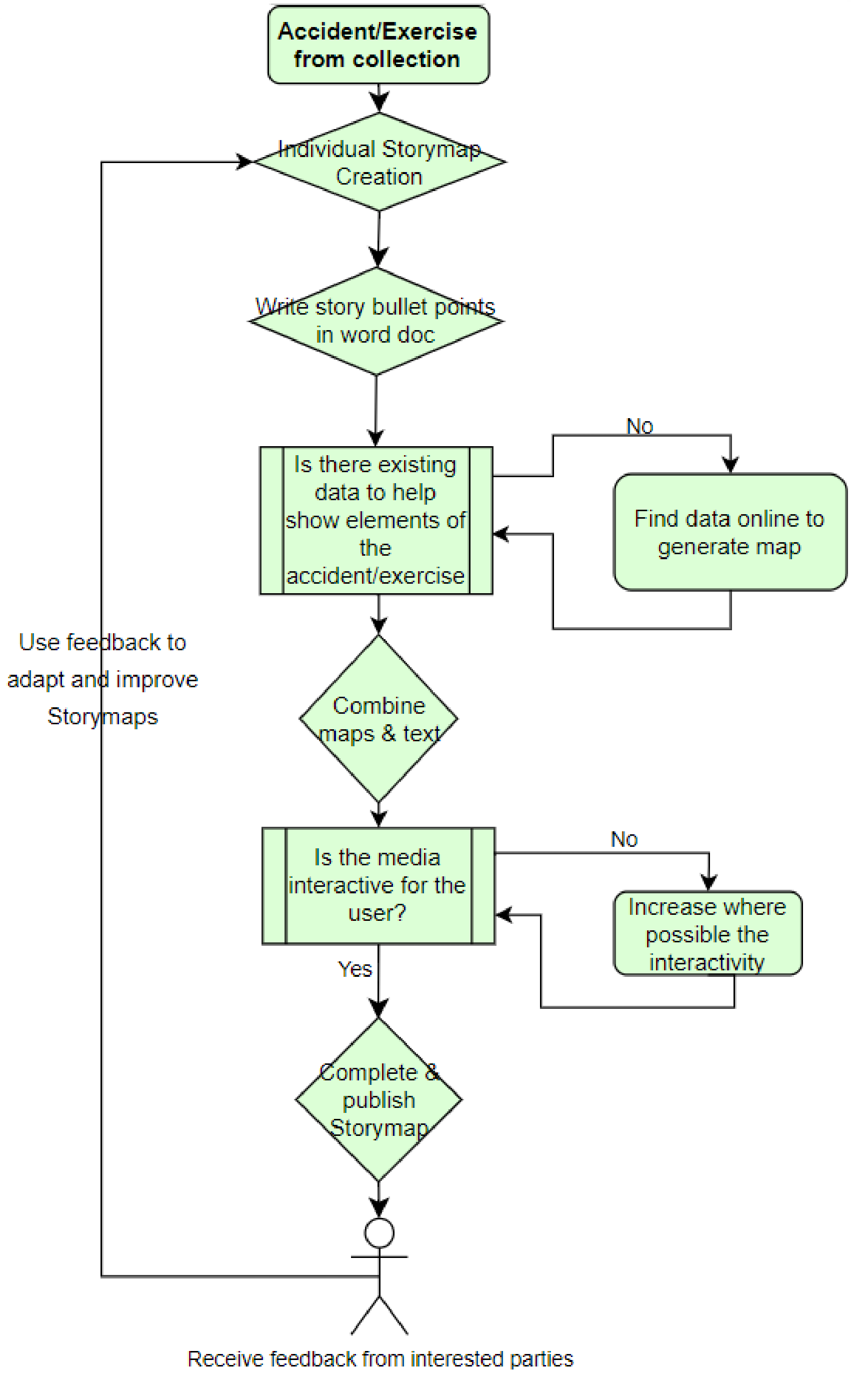


Figure 20: Flowchart of process in creating each individual Storymap

As well as a defined format in creating and researching information for the accidents and exercises, navigation of the story itself is a major area to consider. A standard table of contents like in a report is not an option in the Storymaps application and along with this it would make it more long form. Having a vertical tab is concise and straightforward. In inputting this vertical headline banner the option can be made to have the headings stay visible while scrolling down. It provides users with an easy and convenient way to navigate through the content, particularly in longer Storymaps. This approach allows users to quickly access different sections of the Storymap without having to scroll through the entire page to find the information they require. By clicking on a specific heading in the tab, the user is taken directly to the relevant section. To implement this feature, the built-in table of contents function in the Storymap builder was used. This feature allowed create of a table of contents which was linked to different sections respectively.

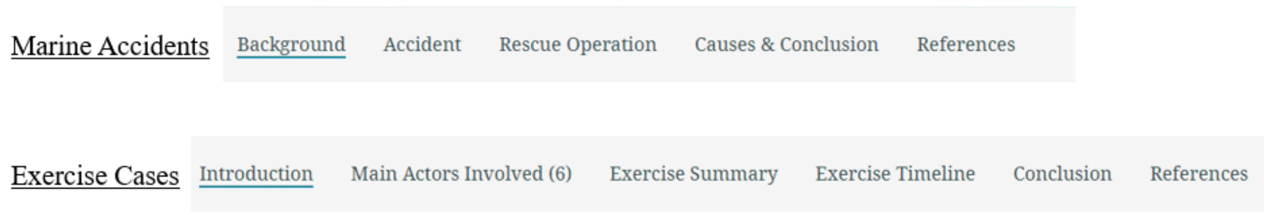


Figure 21: Quick click contents headers for the marine accidents and exercise cases

As there are two distinct categories of cases within the collection, namely marine accidents and exercises, it was essential to consider different standardised headers for the different purposes. For example, in the exercise cases one of the headings, which can be seen in Figure 21 is the actors involved. this details the various rescue services or sometime countries involved in the exercise. In an exercise the players involved is one of large importance and users want to know this information. On the contrary to this, in the marine accidents the accident is one of the main headings and is key to knowing the events leading up before rescue services are involved. In this way the different headings for the two types were created and uses throughout each of the 46 Storymaps.

In creating individual Storymaps for the collection, the obtaining of relevant and high-quality images for each event was aided by Arctic specific news sites such as Svalbardposten[58], TheBarentsObserver[59] and HighNorthNews[60]. These sources were critical in providing details about the accidents, images of the damaged vessels and surrounding areas. Details that are obtained immediately and first-hand from the SAR personnel. By referencing these sources, more visually appealing Storymaps that accurately depict each event were created. All used information and content used is referenced and credited to the relevant person/organisation. In Figure 22 an example from the Canadian trawler FV Saputi accident shows the references used in its creation, broken into two sections, reports (where available) and content/images. Each is hyperlinked to the article itself or in the case of a report it states whether it is a link or PDF download along with the number of pages, and if it is in another language it is highlighted too.

Figure 22: Example Storymap references for FV Saputi

4.3.4 Feedback and Testing

To evaluate the usability of the created interface and Storymap collection, testing was conducted with a range of user groups, focusing on students with varying levels of familiarity with ArcGIS and GIS applications. The approach aimed to gather feedback from both experienced users and those who were relatively new to the technology and how it could be adapted to make it more intuitive. The testing process involved interacting with the dashboard, while users were asked to provide their feedback and impressions. This feedback proved valuable in identifying small issues, areas of confusion, and potential improvements that could enhance the final version.

The iterative nature of testing and gathering user feedback allowed for ongoing adaptations and refinements. In doing this the interface best catered to the needs of a wide range of users, accommodating the requirements of both experienced GIS users and those new to the field.

5 Results and Discussion

The finished GIS collection of marine accidents and exercises in the Arctic region creates a valuable resource for searching and understanding maritime activities in the remote and harsh area. This section presents the results and analysis of the project, which aimed to create a wide spectrum of cases in the collection of Arctic marine accidents and training exercises utilising ArcGIS applications. The main objectives of the project as stated in the introduction were to gather and organise data for a reasonable collection, to create a user-friendly platform for accessing and exploring this data, deep dive Storymaps for all cases within the collection, as well as the results of the analysis of the data. Analysis of these findings could then be used for future safety and preparedness measures in the Arctic region.

5.1 Completed Dashboard and Storymap Collection

One of the primary objectives of the project was to create a broad collection of both types of cases. In Figure 5 below a full list of all 28 marine accidents and 18 exercises that were ultimately included in the collection is shown. Originally, it was intended to include 20 of each, but this number was adjusted after conducting further research during the data collection part of the project. Refer to Appendix A for some complete examples of Storymaps. Along with this a link to the finished Dashboard itself is found below.

Finished Dashboard)

Upon analysing the data, the trend of the marine accidents included in the collection indicates that there were significantly more accidents in the last 15 years, though these accidents were relatively minor in terms of fatalities and scale. The reason for the more recently bias in the data can be attributed to the increased availability of information from online resources in comparison to older accidents where only large-scale incidents were commonly reported and documented. The inclusion of these recent accidents is important though in terms of understanding the current state of marine safety and identifying any potential areas of improvement.

Table 5: Full list of all included marine accidents and exercises within the collection

Marine Accidents		
Year	**Ship Name**	**Accident**
1959	MS Hans Hedtoft	Ice Accident
1986	MS Syneta	Grounding
1986	MS Sudurland	Other
1989	PV Maxim Gorkiy	Ice Accident
1997	PV Hanseatic	Grounding
2006	EXP SKA 11	Grounding
2007	EXP Aleksey Maryshev	Ice Accident
2008	FV Frøyanes Senior	Fire
2009	MS Petrozavodsk	Grounding
2009	FV Remøy	Ice Accident
2012	PV Polaris I	Ice Accident
2012	FV Kamaro	Engine Issues
2014	PV Juvel	Grounding
2015	FV Norma Mary	Fire
2015	FV Soley Sigurjons	Fire
2016	PV Ortelius	Engine Issues
2016	PV Inuk II	Ice Accident
2016	FV Saputi	Ice Accident
2017	Helicopter Mi-8	Other
2018	PV Aurora Explorer	Collision
2018	FV Northguider	Grounding
2018	FV Frosti	Fire
2019	EXP Lance	Ice Accident
2019	PV Malmo	Ice Accident
2019	PV Rembrandt Van Rijn	Grounding
2019	PV Sjøveien	Engine Issues
2022	PV Virgo	Grounding
2022	PV Ocean Atlantic	Grounding

Exercise Cases		
Year	**Name**	**Exercise**
2012	SAREX-Greenland	Evacuation
2013	SAREX-Greenland	Evacuation
2014	Svalbard Exercise	Evacuation
2016	LIVex-Greenland	Oil Spill
2016	SAREX-1	Evacuation
2016	OSR exercise in Tryghamna	Oil Spill
2017	SAREX-2	Survival
2018	ARGUS-18	Evacuation
2018	SAREX-3	Survival
2018	OSR Exercise	Oil Spill
2018	LYR Airport	Fire Drill
2019	ARGUS-19	Evacuation
2019	SAREX-2019	Survival
2020	Arctic SAR TTX	Survival
2020	SAREX-2020	Survival
2021	Arctic Guardian	Collision
2021	AMRO Svalbard 2021	Evacuation
2022	ARCSAR LIVex	Evacuation

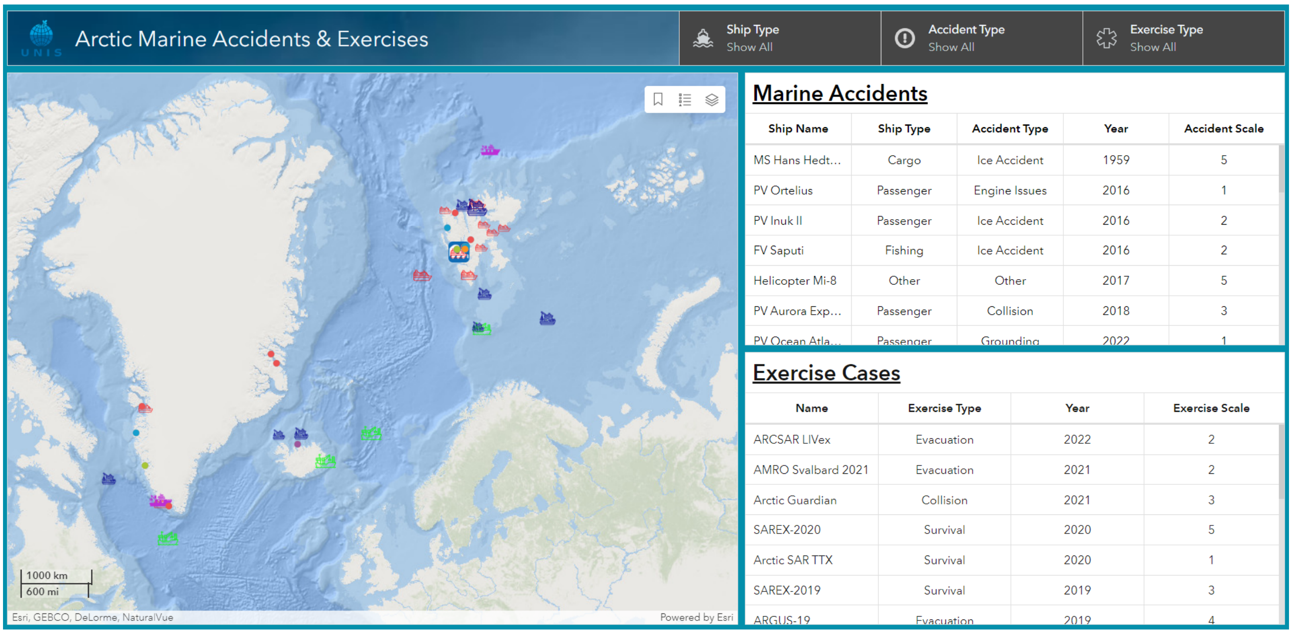


Figure 23: Completed Dashboard Interface

5.1.1 User Manual

The completed dashboard aims to be as user friendly as possible. This short guide through using the collection is targeted to users from the maritime industry and students who may be unfamiliar with GIS platforms. Following it familiarises and showcases the features of the dashboard and how to navigate the data.

- To access the dashboard simply click the link below. Even without an ArcGIS account the collection is viewable.
- Marine Accidents and Exercises Dashboard Link (Click)
- Once clicked the Dashboard should load its basemap and layers.

Legend and Layer Control:

- Figure A(24): The centre icon in the map plugin represents the Legend. Clicking on this icon displays the legend for all the layers on the map.
- Figure B(24): Clicking the right icon in the map plugin allows users to turn on and off other layers. This includes layers such as the local TopoSvalbard map and the Search and Rescue zones with country jurisdiction.

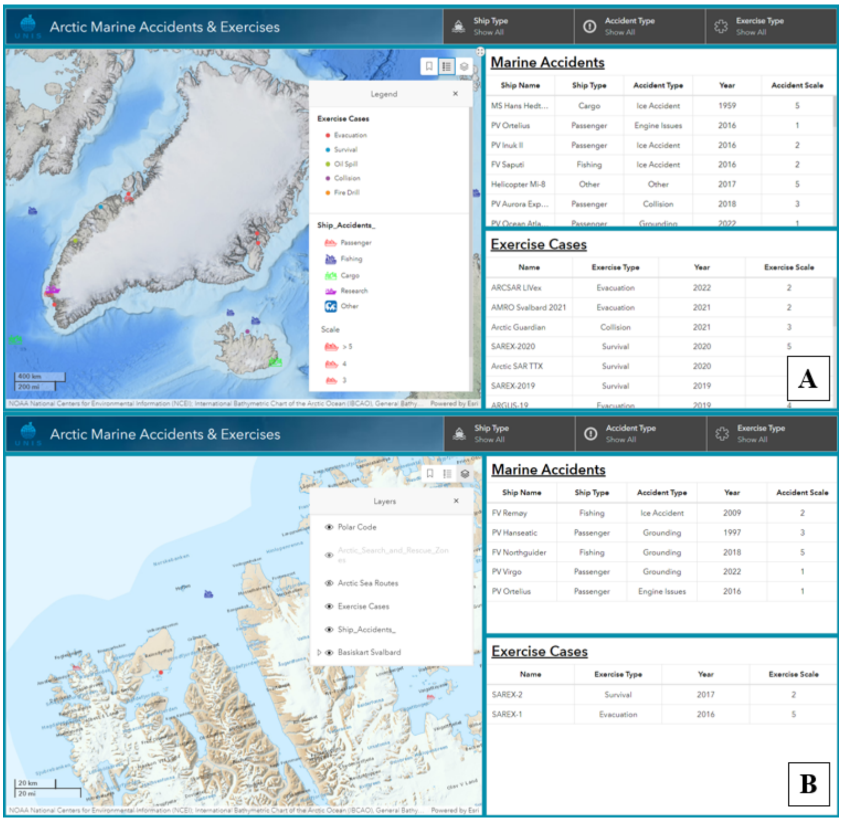


Figure 24: Layer Control

Bookmarked Areas and Filters:

- Figure C(25): The third icon in the map plugin displays bookmarked areas that the project is based on. Clicking on any bookmark will adjust the view to focus on that specific extent, such as Svalbard.
- Figure D(25): A fully opened list of filters is shown. Clicking on any category removes the rest and keeps the selected filters. To reset the selection, simply click on the "Show all" option.

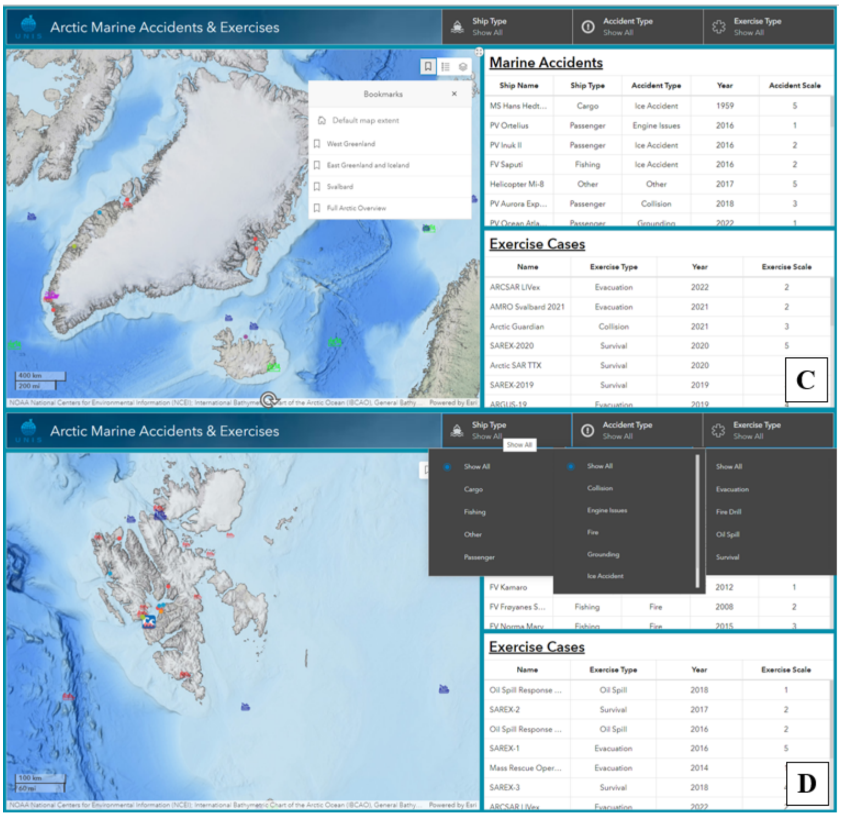


Figure 25: Filtering and project area shortcuts

Downloading Marine Accident and Exercise Data:

- Figure E(26): Users signed in to ArcGIS with an account can access the option to download the full marine accident and exercise data. The download icon appears at the bottom of both tables which is circled. The data is provided in CSV format, which can be then converted into a shapefile.

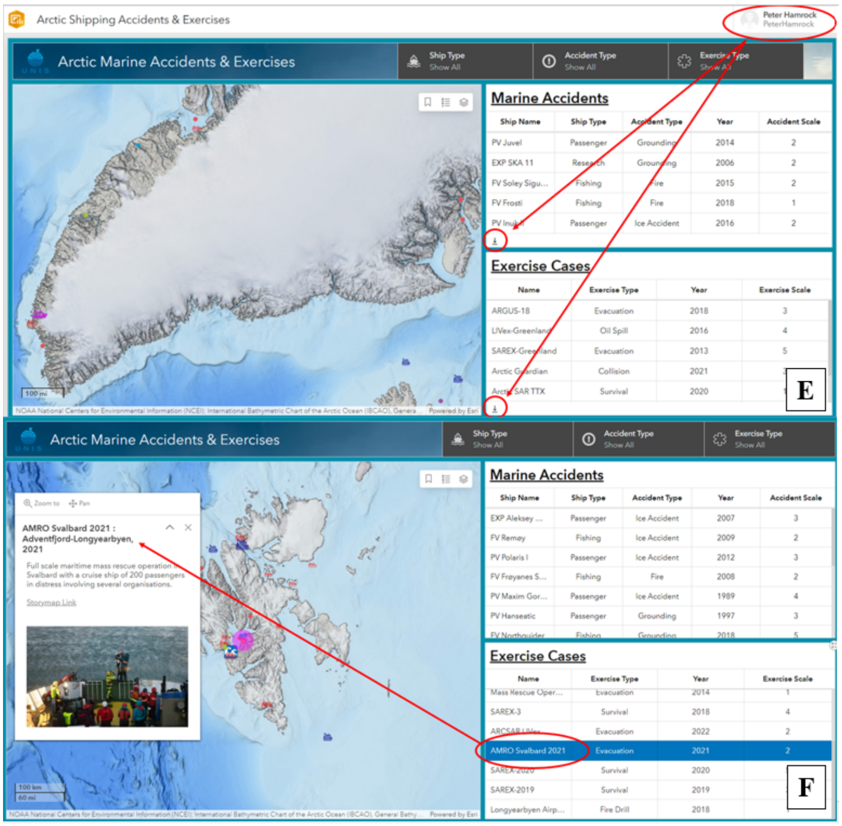


Figure 26: Case selection and data download from dashboard

Selecting and Viewing Specific Cases:

- Figure F(26): Users can select specific cases by clicking on either the map or the table. Clicking on the map displays a pop-up with a description and a link to the Storymap. Selecting a case from the table zooms to the location on the map, flashes, and brings up the pop-up window.
- Figure G(27): To navigate, the user simply scrolls downwards.
- Figure H(27): Once you get to a map feature such as a map tour then the user can see how the locations change as they scroll but there is also flexibility for the user to explore the map itself freely.
- Figure I(28): Slideshow maps require users to manually click the arrow on the right-hand side to scroll through different media and maps.

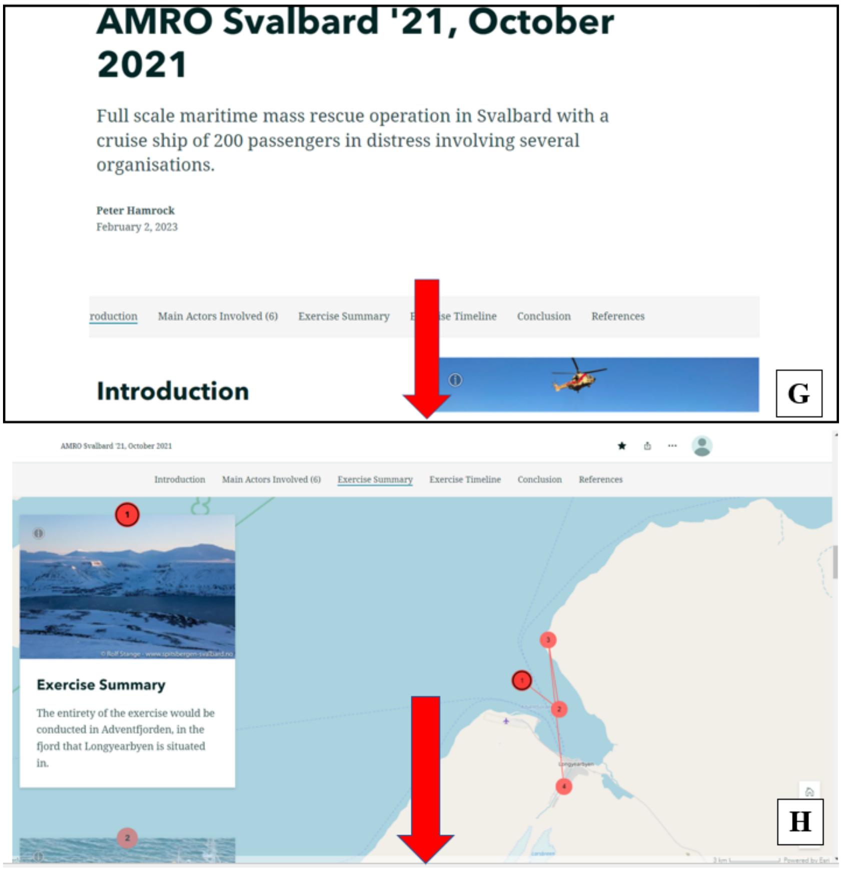


Figure 27: Storymap utilisation

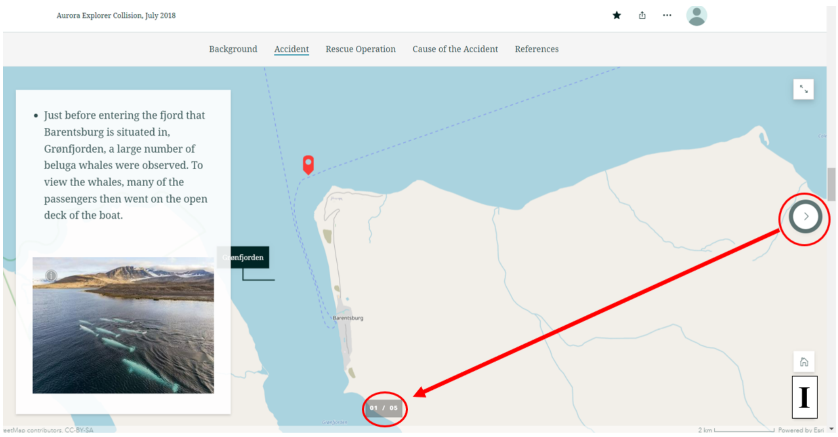


Figure 28: Storymaps tools

5.2 Data Analysis

The data analysis of the created collection looked at the statistics of the gathered data in terms of what vessels were having accidents and common accidents along with the different exercise scenarios practiced information. The analysis generated provides a visual representation of the data within the shapefiles. The graph in Figure 29 displays the breakdown of vessel types involved in the accidents. Figure 30's chart shows the breakdown of accident types for the marine accident, while in the pie chart in Figure 31 gives the spread of exercise types. Section 4.2 which describes the scale classifications for both datasets also shows the spread of cases on the matrix. Notable points include the spread trend of marine accidents which show the mean fall between the low to medium range with accidents rated a 2 on both scales being the most occurring accounting for 23% of all accidents. It could also be said that in general the link between the amount of SAR involved and the loss is somewhat linear. Looking at the exercises chart, the spread of exercises in terms of scale is much more varied with no distinct area trend. Exercises are classified all over the chart, but as an overall bearing towards larger scale exercises which makes sense as the most prevalent types of exercises were larger Mass Rescue operations.

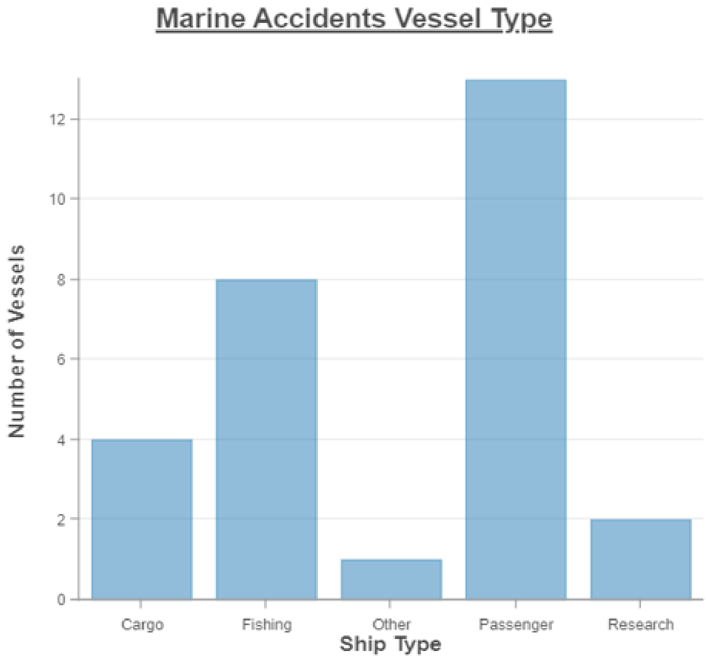


Figure 29: Breakdown the vessel types involved in the case collection

The results from the data analysis showed that passenger vessels were involved in the highest number of accidents, making up over 46% of the accidents in the collection. The next highest amount of accident by category of ship is fishing boats with 29% of the total. The research revealed an interesting trend in this statistic, in that while passenger/cruise vessels are significantly lower in numbers with regards to amount of vessels operating in the Arctic waters[61], the rate of accident is much higher. Fishing boats make up over 40% of all marine traffic above 60°N [62]. Despite this, looking at the amount of accidents in the collection, there are over 1.5 times as many accidents. Another aspect to consider in this trend is that fishing boats also operate much more than passenger/cruise ships, with fishing boats operating in the polar waters year-round whereas passenger vessels are limited to summer/autumn in their operational period. Reasons for the large difference could be that fishing boats are operating in deep open waters off the coast while the passenger and cruise ships that sail in the Arctic take tourists to glaciers, wildlife areas and other features in the near-shore area. In conducting their voyages in this near-shore area they encounter much more shallow areas with rocks and iceberg floes compared to a vessel operating in the high seas.

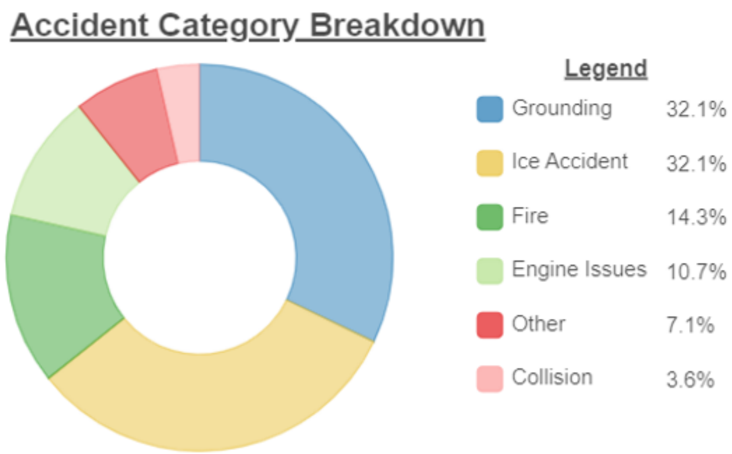


Figure 30: Accident type breakdown

Looking at the most common types of accidents for the two most common vessel types, in the case of passenger and cruises vessels the most common type of accident were grounding and ice accidents with each making up 32% of the total accidents. For fishing vessels the most prevalent category of accident was fire. In all cases, vessels operating in Arctic waters the environment presents unique and harsh challenges. Reasons for the large amount of groundings in passenger ships is again linked to their operational zone being close to shore. One of the reasons for the high incidence of grounding accidents among passenger/cruise ships is linked to the lack of updated and accurate nautical charts. These charts which are used by ship captains to navigate safely and any discrepancies or inaccuracies in the charts can result in ships grounding themselves. In some cases, ship captains or cruise operators may not have updated their charts or may not have access to the most current information. This can be due to a variety of reasons, including the cost of obtaining updated charts. In addition to this, there are areas in the Arctic region that are not even mapped or charted due to the remoteness of the region. This leaves the risk of grounding accidents even higher in these areas, as masters enter an area with no knowledge of how a bay or passage is for rocks or reefs that may jut out. With fishing boats and their operational area being further out to sea it is not surprising that grounding is not as prevalent. Reasons for fire being the most common accident type could relate to the harsh weather conditions, especially in the winter months. Extreme cold along with these conditions can lead to mechanical failures such as electrical faults which can ignite a fire. Area on the boat like the fish processing room and engine room are locations in which fires have started for accidents in the collection.

Examining the scale of the accidents for passenger and fishing vessels, passenger ship accidents in the collection were most commonly a scale of 1 while for fishing boats accidents with a scale of 2 were most frequent. It must be stated that these are including all accident types. For passenger vessels the majority of the scale 1 accidents are groundings and ice floe incidents. Reasoning for these accidents may be because they are often larger and less manoeuvrable than other vessels ships, and therefore more susceptible to getting stuck or running aground on a rock or reef in the Arctic's challenging conditions. In addition to this, passenger vessels may be more likely to take risks in order to stay on schedule or provide their passengers with scenic experiences, which may increase the likelihood of accidents like groundings and collisions with ice floes in comparison to a fishing boat. Fishing vessels are in operation in more open waters and thus there are fewer risks in terms of grounding or pinch points for ice floes than passenger vessels, but when an accident does occur, it may be more serious in nature. The fact that fire is the most common accident type for fishing vessels is also significant, as a fire at sea can be especially dangerous due to the limited resources and options for evacuation in the remote and harsh conditions of the Arctic. A fire on a fishing vessel can quickly escalate and having crew trained in dealing with the fire before it spreads is essential and should be given more consideration in an Arctic context given the remoteness and response time by SAR. An example of good crew training saving an escalation in the fire was in the Soley Sigurjons accident which is contained in the collection where the crew of eight who had been trained recently in a fire course sealed the engine room and activated the fire suppression system immediately which enabled the containment and deescalation of the fire before it became out of hand.

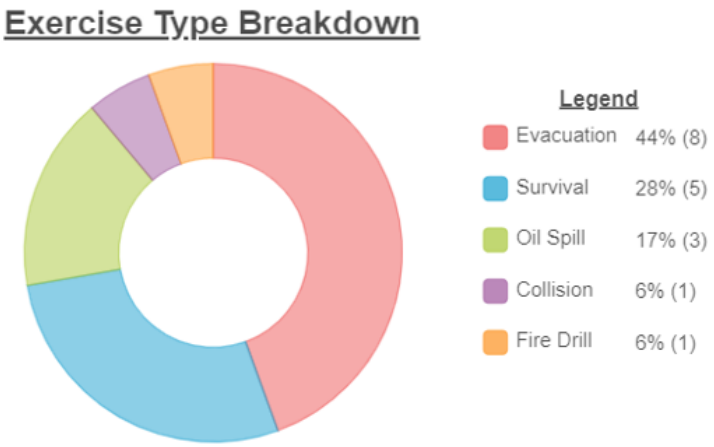


Figure 31: Breakdown of the exercise categories

With regards to the exercise collection cases, the vast majority of these multi country exercise scenarios were either evacuation or survival situations. Evacuation scenarios which were in nearly all cases were in the form of Mass Rescue Operations (MRO's) had the largest amount of exercises. This is largely due to the increase in tourist activity in the Arctic region with the recognised need by many organisations to prepare and practice training in this area along with the parallel for SAR personnel to be prepared for potential mass casualty incidents involving large cruise ships and small passenger expedition vessels. The exercises are designed to test the response capabilities of SAR teams and to identify any areas for improvement in evacuation procedures, equipment, and coordination as well as multi country coordination of a rescue. The second most prevalent rescue exercise is survival which is linked with the Polar Code and testing its fit for purpose. The effectiveness of the equipment and procedures mandated by the Polar Code is tried and adapted afterwards where necessary. In exercises such as the SARex Svalbard 1,2 and 3 this was the case in that the Polar code was tried and practised in various elements and the next year recommendations and changes proposed from the resultant in the previous year were adopted and continuous improvement was practiced.

Analysing the scales of exercise most common for evacuation and survival scenarios, with a scale of 5 most frequent for evacuation and a scale of 3 for survival scenarios. The high frequency of scale 5 exercises for evacuation scenarios can be attributed to the mass rescue evacuation scenarios which can involve over 1000 personnel such as the SAREX Greenland exercises conducted in 2012 and 2013 where full scale evacuation, triage station establishment and ferrying of passengers to the nearest settlement were practiced. The lower rating of 3 for survival scenarios is related to the smaller scale testing of equipment such as liferafts and lower numbers conducting the exercise. Duration's of exercises for both are similar however, the main difference is the number of personnel participating.

To summarise, the data analysis of the case collection of marine accidents and exercises provides valuable insights into the types of accidents and exercises that occur in projects study area. The findings from this analysis could be used to highlight trends that could help to reduce the number of accidents and improve safety for those in the marine industry and relevant academics. It must be stated that the main goal in the project was the actual creation of this collection and the data analysis following it was additional.

5.3 Impact on Industry and Users

When looking at what is available at present by the government and industry in regards to marine accidents and exercises. The created case collection hosted on a GIS platform surpasses the current dated and limited reports available. The collection gives not only a much better visual map, relevant layers and filterability it also has the further detail of the Storymaps which give much more insights than the basic information that other sites have. When looking at the few reports on specific cases there are then this multimedia approach this is a much more appealing and curated way to display the information. Indeed this is a huge limiting factor in the industry. There were only a handful of reports available in both the marine accidents and exercises conducted by official organisations. An example of this is the FV Northguider in December 2018 when the shrimp trawler grounded itself in the Hinlopen Strait in Svalbard with all 14 crew being airlifted back to safety in Longyearbyen. The subsequent oil removal and salvage operation took over two years to complete but there is still no report available on the accident from the MAIB which for such a large and widely known accident is surprising.

Looking at the users, the completed project can be adopted as a learning tool for university students pursuing various fields of study in the maritime or safety industry. Students specialising in marine engineering, maritime safety management, marine law and insurance, as well as search and rescue, can derive substantial benefits from the collection of marine accidents and exercises. Indeed at the University Centre in Svalbard where the this project has been conducted the Arctic Safety Centre has courses which will benefit from this completed collection as well as the shipping in the arctic technology course.

By exploring the collection, academia gain access to an overview of past marine incidents and exercises. This provides them with insights into the underlying causes, consequences, and lessons that can be learned from the event. The collection serves to allow users to delve into the intricacies of maritime safety and comprehend the complexities involved in conducting search and rescue operations specifically within the Arctic region. They can also grasp the significance of adhering to regulations and protocols. Understanding the potential risks and hazards faced by vessels operating in the Arctic's extreme and remote environments helps adapt and bring safer standards into practice.

The collection has a multidisciplinary learning approach bringing together diverse aspects of the maritime industry. It encourages users to consider the inter connectivity. This integrated approach equips users with an understanding of the maritime domain and promotes collaboration among different fields within the industry.

In conclusion, the completed project serves as a resource for various stakeholders but in particular university students, offering them a varied and interactive collection of marine accidents and exercises. By engaging with this collection, students from various disciplines can gain a deeper understanding of maritime safety, the complexities of conducting search and rescue operations in the Arctic region, and the critical lessons to be learned from past incidents. Even if not adopted, the various governmental maritime bodies could adopt a GIS based approach to better show the data that they have and learn from this dashboard.

5.4 Challenges

Developing the Arctic marine accident and exercise case collection using ArcGIS Dashboard and Storymaps posed a number of challenges, these included:

- Difficulty finding usable data
- Lack of specific information on accidents
- Limited information available for Greenland
- Language barriers in researching accidents and creating Storymaps.
- Limited availability of resources and time for the project

One of the challenges in the project was finding usable data in cases for the collection. This refers to finding relevant or reliable data on the specific accidents or exercises. Information may be missing in terms of being able to create a Storymap for the case as it may just be noted that an accident occurred at a location and there was no large investigation or other reports, official or news articles made on the matter. This was compounded by the fact that many existing databases were restricted to just statistics and lacked the level of detail required for the addition to the collection as parameters could not be filled in. While projects like the Protection of the Arctic Marine Environment (PAME) have compiled statistics on shipping accidents in the Arctic region, access to detailed information is often restricted due to confidentiality reasons or behind a paywall and in many cases just not there. This lack of public access limited the quantity of cases in the project and made it more difficult to create. This links in with the next point on the bullet list of lacking specific information, things such as no exact co-ordinates given or in the case or multiple exercises, the exactities of the scenario or total numbers involved is not available to look at as many of these are conducted by the various Arctic nation navies and thus the detailed information is not released for public consumption. In many of these exercises, details are based on eyewitness accounts or media reports to piece together definite information on an exercise.

The lack of available information on marine accidents in Greenland also proved difficult. Despite its significance as a region with high Arctic shipping traffic, Greenland has limited reporting on marine accidents and incidents. This makes it difficult to have a comprehensive understanding of the region and the risks associated with maritime activities offshore of the island of Greenland. Reasons for this lack of data include the lack of resources by the Greenlandic government and the complex political structure that makes up the authorities where there is Danish and Greenlandic miscommunication or poor cooperation. This can lead to discrepancies and difficulties to access information.

Language barriers were a significant challenge in the project creation. As the Arctic region encompasses several countries and territories, each have their own official language or languages. Searching for information on marine accidents and training exercises required searching in languages such as Norwegian, Danish, Icelandic, and English. It was not always easy to find information especially when dealing with historical data. When information was available in these languages, differences in terminology and phrasing could make it challenging to find exact relevant data. To overcome this challenge, utilisation of translator terms and searching keywords that are ubiquitous to all languages such as the ship or exercise name were employed. A significant amount of time was spent translating and analysing data to ensure that it was accurately incorporated into both the project itself as well as each individual case and created Storymap.

The limited time in which to complete the collection was demanding in the project. Prioritisation of having a working interface which satisfies ease and functionality and creation of each individual accident/exercise was balanced with the given time-frame. Defining a total number to include in the collection was key, commencing the project the aim was for 20 marine accidents and 20 exercises. This changed slightly when difficulties in getting this set number of exercises were encountered with lack of information issued by the various countries after each exercise. In addition to this it must be noted that all of these exercises stemmed from the 2011 Arctic SAR Agreement so it is a limited time since this agreement to fulfill the 20 individual cases. The challenge in the length of time was seen in the creation of Storymaps where information gathering would vary hugely in each case. Despite the challenges, the completion of the project was done by working efficiently and streamlining the data collection and organisation process where possible in prioritising the most important aspects. In a time perspective the Storymaps were by far the most consuming in gathering the details so that a case could be created.

5.5 Future Research/Expansion

Going forward, the project has potential to be expanded and developed more. With the explained time constraints limiting the size of the collection in number and location there is a potential to enlarge it in the future. The limits of the project case collection in a geographical sense that are shown in Figure 2 could be expanded to include the whole Arctic area. This would include Canada, America and Russia with a much larger amount of accidents available to include. As well as the Arctic a similar approach for the Antarctic region could be done as the seas surrounding it fall under the Polar Code for ships operating here. This expansion of the zones could again be compiled in the same way as in this project and further bookmarks could then be included into the Dashboard interface where clicking brings to the location and shows the relevant accidents or exercises. With accidents from Canada there would be use of the Transportation Safety Board of Canada's website and comprehensive database of reports to include. Information in an exercise context could be added as well as there has also been US and Canada SAR large operations such as the joint country exercise conducted in Nunavut in September 2021 near Resolute Bay. Both components of cases offer many new additions with an expanded area to include in the collection.

The incorporation of including the project itself into some of the syllabus at the University Centre in Svalbard (UNIS) courses to teach students both ArcGIS Storymaps as well as understanding marine accidents or safety from an MRO exercise perspective. It could be leveraged as a valuable and relevant learning tool. This could also be facilitated through the transfer of ownership of the Dashboard to another individual or individual's within the organisation, in this case UNIS. This avoids issues with being unable to edit or update the Dashboard and with regards to Storymaps they need only to be created by any user and linked within the shapefile through the unique URL each creates.

Another possibility for the project going forward is the inclusion into an existing database as touched on in Section 5.3. A collaboration between a site such as Barentswatch which is expanding in its available information available on its website. To host the dashboard on a site such as this has several advantages. This includes the immediate existing user base that the website has and the subsequent reach it would give to the project ensuring that the research reaches relevant stakeholders, decision-makers, and practitioners in the field. Another advantage here would be the possibility to work with staff from the Norwegian Coastal Administration who manage the website with information that they have that may not be easily available to expand further the collection in a synergy process.

6 Conclusion

The Arctic's unique challenges demand access to comprehensive maritime accident data and training exercises to enhance preparedness where at present there is no centralised platform to view this information. The thesis project aimed to create a diverse ranging collection of marine accidents and exercises, with the resulting output of 26 accidents and 18 exercises cases. With over 57% of the marine accidents collected occurring in the last 10 years, the recently bias in cases reflects the improved information availability. The case collection provides a portal into marine safety and its past in the Arctic region using modern GIS-based tools including ArcGIS Online, Dashboards, and Storymaps to present data in easily accessible formats that are both user friendly and interactive. The collection, both Dashboard and all case Storymaps are available to view online to any persons without the need for an ESRI account.

The completed project can be used as an educational tool for university students in maritime and safety-related fields. The collection improves understanding of SAR operations and the importance of regulations such as the Polar Code in the Arctic. Greater knowledge enables any users to grasp the risks in extreme Arctic environment which in turn contributes to a safer and more informed maritime industry.

The thesis work has considerable potential for future expansion and impact. By enlarging the geographical extents to include the whole Arctic region along with possible collaboration with platforms to host the dashboard map such as Barentswatch, the project can reach a wider audience and connect with relevant stakeholders in the Arctic safety zone of influence. A possible incorporation into UNIS courses and transferred ownership of the dashboard would ensure that its continued development and use an an educational tool. In addition to this, synergistic partnerships such as with sites like Barentswatch who are run by the Norwegian Coastal Administration could provide further access to valuable information and bring the collection on further. Overall, the project has succeeded in its creation and its future lies in expansion of the scope, collaboration and leveraging on existing platforms in the promotion of safety and education in the Arctic.

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A Appendix: Example Case Storymaps

This appendix contains some example Storymaps from both the marine accidents and exercises.

AMRO Svalbard '21, October 2021

Full scale maritime mass rescue operation in Svalbard with a cruise ship of 200 passengers in distress involving several organisations.

Peter Hamrock
February 2, 2023

Introduction

One of the Super Puma Helicopters during the exercise

The exercise is an Arctic Mass Rescue Operation (AMRO) and involves the evacuation of a large number of persons from the wrecked ship via helicopter. The backdrop for this type of exercise came from the 2019 incident of the cruise ship Viking Sky which got into engine difficulties off the northwestern coast of Norway and required 470 passengers to be airlifted off the ship. Deputy Svalbard Governor Espen Olsen said that this type of accident could happen in Svalbard too and with SAR resources more scarce and locations more isolated, that training for such an accident would be hugely beneficial for all parties.

Main Actors Involved (6)

Main actors involved in the AMRO Exercise

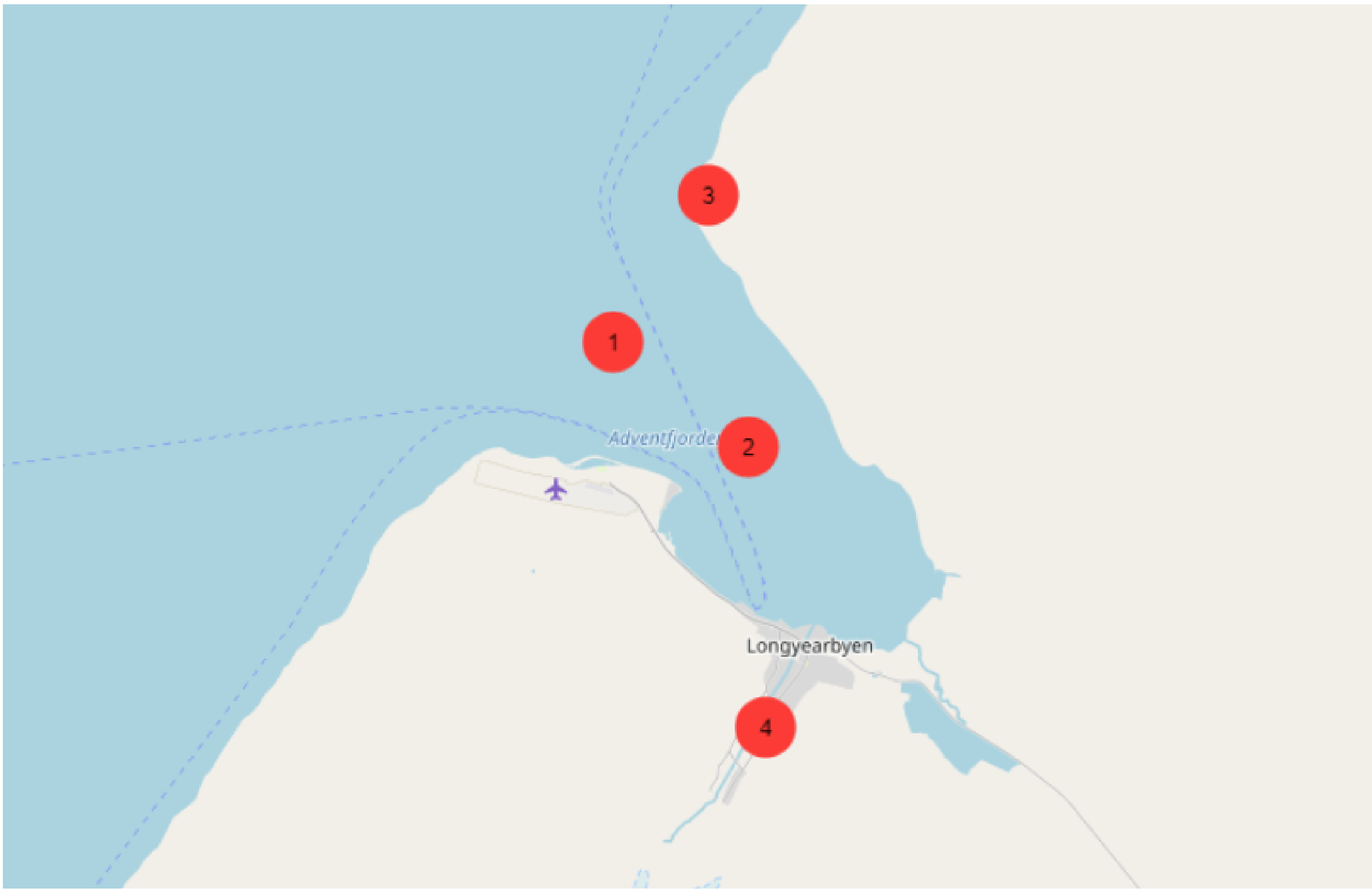
- Polarsyssel
- Joint Rescue Coordination Center North Bodø
- Sysselmesteren
- Norwegian Coastguard, KV Bison
- Longyearbyen Røde Kors
- The University Centre in Svalbard students

Vessel in Distress

The OV Bøkfjord before the exercise began in Adventfjorden

The vessel used as the cruise ship in distress for the exercise was the OV Bøkfjord. It is a pollution control vessel owned by the Norwegian coastguard. Its length is 44 metres with a large open space on deck and at the bow where passengers could gather in the open air to await the airlift.

Exercise Summary



 3 km

1 Exercise Summary

The entirety of the exercise would be conducted in Adventfjorden, in the fjord that Longyearbyen is situated in.

2 Initial Commencement

The exercise would start with a mayday from the ship and then response from rescue services to the situation.

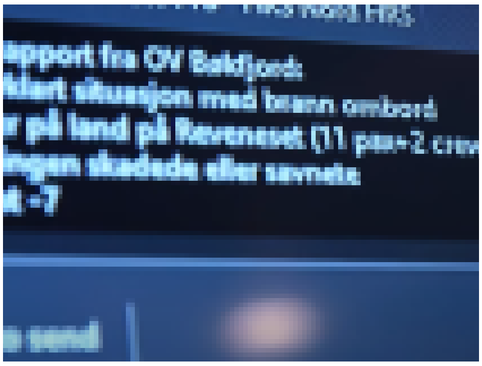
3 Evacuation

Evacuation of the passengers from the deck of the ship in distress to an emergency camp set up at Revneset at the North of the fjord.

4 Transport to Longyearbyen

The last phase of the exercise has passengers transferred back to Longyearbyen hospital and Svalbardhallen for treatment

Exercise Timeline



08:08

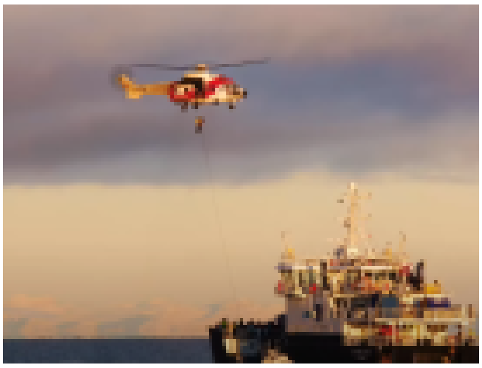
Mayday sent from OV Bøkfjord. Fire onboard. 60 Nautical Miles off the northwest of Svalbard, 170 persons, 0 injured, 13 onshore at Revneset.

09:31

Co-ordination between Sysselmesteren in Longyearbyen and the JRCC in Bodø. 09:31 first helicopter is in the air and approaching the vessel with Røde Kors members onboard.

09:40

The Norwegian coastguard vessel KV Bison is appointed Aircraft Co-ordinator (ACO) and is on scene to direct the rescue operation in co-ordination with the JRCC and Sysselmesteren.



09:48

Hoisting of first passengers from the vessel starts. Passengers brought to Revneset where an emergency camp has been set up by the people initially there.

10:30

Police and local services request additional assistance for the situation due to the scale

12:24

Hoisting of passengers to the camp continues. Additional assistance in the form of 330 squadron (Norway's military search and rescue service) arrives from Bjørnøya in a Sea King Helicopter making it three helicopters involved in the evacuation.

12:41

Evacuation from emergency camp at Revneset to Longyearbyen. At the emergency camp evacuated passengers are assessed for injuries and depending on the severity are prioritised for transport back to Longyearbyen hospital and Svalbardhallen.

14:17

Coastguard members from KV Bison assists the vessel with firefighting and extinguish the fire onboard.

15:39

KV Bison establishes a tow rope with the stricken vessel and tows it to the harbour.

16:52

Exercise ends.

Link below for video shot by UAS Norway of the exercise.

AMRO2021: Unik masse-evakueringsøv...

regi av Sysselmesteren på Svalbard og Kystverket. I tett samarbeid med Kystvakt,...

https://www.youtube.com/watch?v=17mQwHDJBE8

Conclusion

In an interview with media Deputy Svalbard Governor Espen Olsen said that he was very satisfied with the overall exercise with the only minor issue being that it took longer to mobilise than anticipated.

Weather conditions were near perfect on the day and he admitted that evacuation wouldn't have been as quick in other conditions. 151 people were evacuated by helicopter with an average time of 1.5 minutes per passenger.

The need for these type of exercises involving a lot of parties help all get used to co-ordinating in a large scale rescue and learn from any issues to improve rescue.

References

The following resources were used to create this storymap.

Images & Content	Sysselmesteren, UNIS, HighNorthNews, Svalbardposten, UAS Norway, Kystverket

Oil Spill Response Trygghamna, September 2016

Cleanup exercise in Isfjorden on Svalbard by coastguard and Governor to respond to a large oil spill in a fjord from a cruise ship.

Peter Hamrock
April 11, 2023

Volunteers onshore during the conducted exercise.

Introduction

The exercise was an Oil Spill Response (OSR) and involved the quick response of all available resources from the rescue and coastguard services to a major oil spill within the Isfjorden area.

The occurrence of oil spills poses a significant threat in the Arctic region. Along with the substantial environmental and social consequences affecting not only human communities but also wildlife, the challenging conditions in this area present imposing obstacles to effective oil spill response efforts. The unique environment Arctic ecosystems have mean they have a low reproduction rate and thus a contamination or spill would be severe and lasting in its consequences.

This type of accident could happen in Svalbard with an increasing number of tour vessels visiting and with resources to deal with oil spills scarce and locations more isolated, training for such an accident is hugely beneficial for all parties to prepare for such an event. The 2018 grounding of the Northguider in North Spitzbergen with over 323,000 litres of diesel brought these fears more into the administrations priorities. This exercise in Tryggamna was the first large scale oils spill response and cleanup simulation on the island.

Main Actors Involved (4)

Main actors involved in the OSR Exercise

- Norwegian Coastguard, KV Barentshav
- Polarsyssel
- OV Bøkfjord

Exercise Situation

While there was no actual ship in distress, the 2 day exercise simulated a scenario involving a large container ship running aground and leaking heavy oil (simulated with foam for

Banner in agreement with the heavy fuel ban for the Arctic.

portions of the exercise) into the sea. These ships contain huge amounts of fuel, much of this heavy fuel. This is fuel that is so hazardous that it is considered to be hazardous waste. In 2020 Norway proposed a complete ban on the use of heavy fuels in the waters around the Svalbard archipelago. The exercise was also the first deployment of the 44-metre OV Bøkfjord.

Exercise Summary

1 Exercise Summary

The entirety of the exercise would be conducted in Tryggamna within Isfjorden on the West of Sptizbergen.

2 Response boats

The response boats to the spill would be either in Longyearbyen in Adventfjorden or in the Isfjord area.

3

Exercise

Once all boats responded to the exercise they would go to Trygghamna immediately and deal with the task at hand and deploy beach cleaning equipment as well as floating bunds to contain oil.

Exercise

The exercise scenario was initiated with the first day of the live containment exercise focusing on containment at sea using the only the resources the governor has at hand. This was in the form of Polarsyssel and auxiliary vessels deploying booms to contain a supposed 60 cubic meters of oil along a stretch of a few kilometres. Using only the equipment onhand in the initial phase of a spill gives responders an understanding of the difficulties and the need to prioritise certain elements,

Helium balloon fitted with a specialized video camera.

such as containment as best as possible until further reinforcements come. A plane conducted an ariel survey shortly after the ships reached the “spill” site, but much of the overhead observation was done using a large helium balloon fitted with a specialised camera. The Norwegian Coastal Administration who co-led the simulated cleanup at sea aboard the NCA’s Barentshav during the main part of the exercise. The OV Bøkfjord has the ability to recover over cubic litres of oil and its use was a significant area of interest to all parties involved.

Norwegian Coastal Administration officers monitor the area of a simulated sea oil spill Wednesday aboard the Barentshav.

On the second day of the exercise the NCA took lead command of the exercise. During this, the focus was on removing a smaller, but often much harder to access amount of oil, from both the sea and shore. The governor’s Polarsyssel vessel was used as the command centre for the shore cleanup on the second day, which involved the transport of workers using smaller boats from several agencies. There was also the real-life need to watch for polar bears which another factor that might have been a seriously limiting factor in unfavourable weather in hampering the speed and safe zone for conducting a cleanup. In this case weather throughout the 2 day exercise was very favourable with good visibility and temperatures.

Former leader of The Governor of Svalbard's environmental department who coordinated efforts with local officials during the exercise, said in a statement about the second day, "today we know where the oil has hit the shore," he said. "We also know that the ship that grounded yesterday is empty so there will be no more oil from there. Now it's about saving the beaches." On shore, a couple of workers poured specially treated foam into a blower, with another person spraying it until the rocks on shore were covered. A large rotating brush was then used to scrub the bark into the rocks, which in real life would soak the oil from them.


Photos from the second day of the exercise.

The first picture above shows workers bringing an ATV ashore using one of the Norwegian Coastal Administration's auxiliary boats. The second shows crew using a skimmer to suck foam representing spilled oil from the water near shore area. The third shows a crew member spraying specially treated bark chips designed to soak up oil over a shoreline as equipment is unloaded from the Bøkfjord.

Conclusion

In an interview with media after the exercise Johan Marius Ly NCA's emergency preparedness director, said in a prepared statement afterward the initial indicators are positive.

"We conclude that we reached the goals we had set for ourselves for the exercise, and now we will go through the learning points and what we should practice more," he said. "This will make our emergency preparedness stronger before any major events affect the particularly vulnerable natural areas on Svalbard." Following the exercise in the years after oil spill capabilities on the governors vessel Polarsyssel have been upgraded as well as training to more personnel in Longyearbyen to deal with such an accident.

References

The following resources were used to create this storymap.

Images & Content Svalbardposten, Icepeople, batomtaler.skipsrevyen.no

SAREX Greenland Sea, 2012

Full scale maritime mass rescue operation simulating a cruise ship of 150 passengers is missing in East Greenland.

Peter Hamrock
February 15, 2023

Introduction

Some of the vessels in the waters around Ella Island

The exercise is an Arctic Mass Rescue Operation (AMRO) and involves the searching for a missing vessel in the remote waters around East Greenland as well as when finding the vessel that it is aground and on fire. The backdrop for this full scale SAR exercise is the year on year increasing traffic in the seas around Greenland by cruise ships as well as research and exploration vessels and new fishing grounds. Preparation for a potential accident among multiple SAR services across many countries helps familiarise the situation for personnel and deal with the response better. The exercise would have over 1000 participants.

Main Actors Involved (7)

Some of the vessels & aircraft used during the exercise.

- Norway - P3 Orion plane
- Greenland - Police, Air Greenland Bell 212
- Denmark/Faroe Islands - Hercules, Challenger plane, 2 Offshore Patrol Vessel (OPV) Inspection Class, Arctic OPV, Danish Emergency Management Agency
- Iceland - Air Base, ICE-SAR, MPA Dash 8 plane, Multi purpose OPV
- Canada - Hercules plane, Para techs

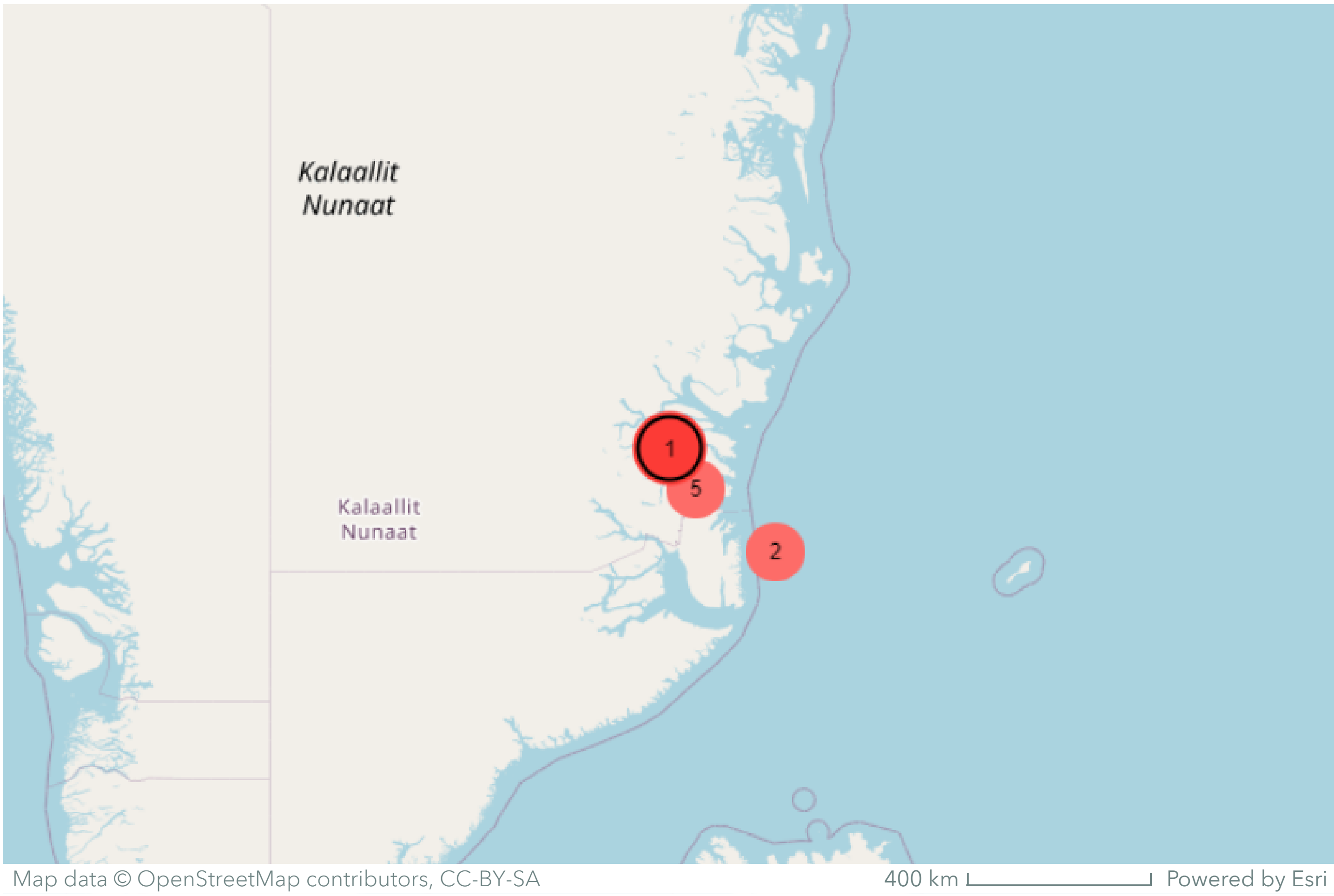
- USA - Hercules plane, USAF Airlift wing

Vessel in Distress

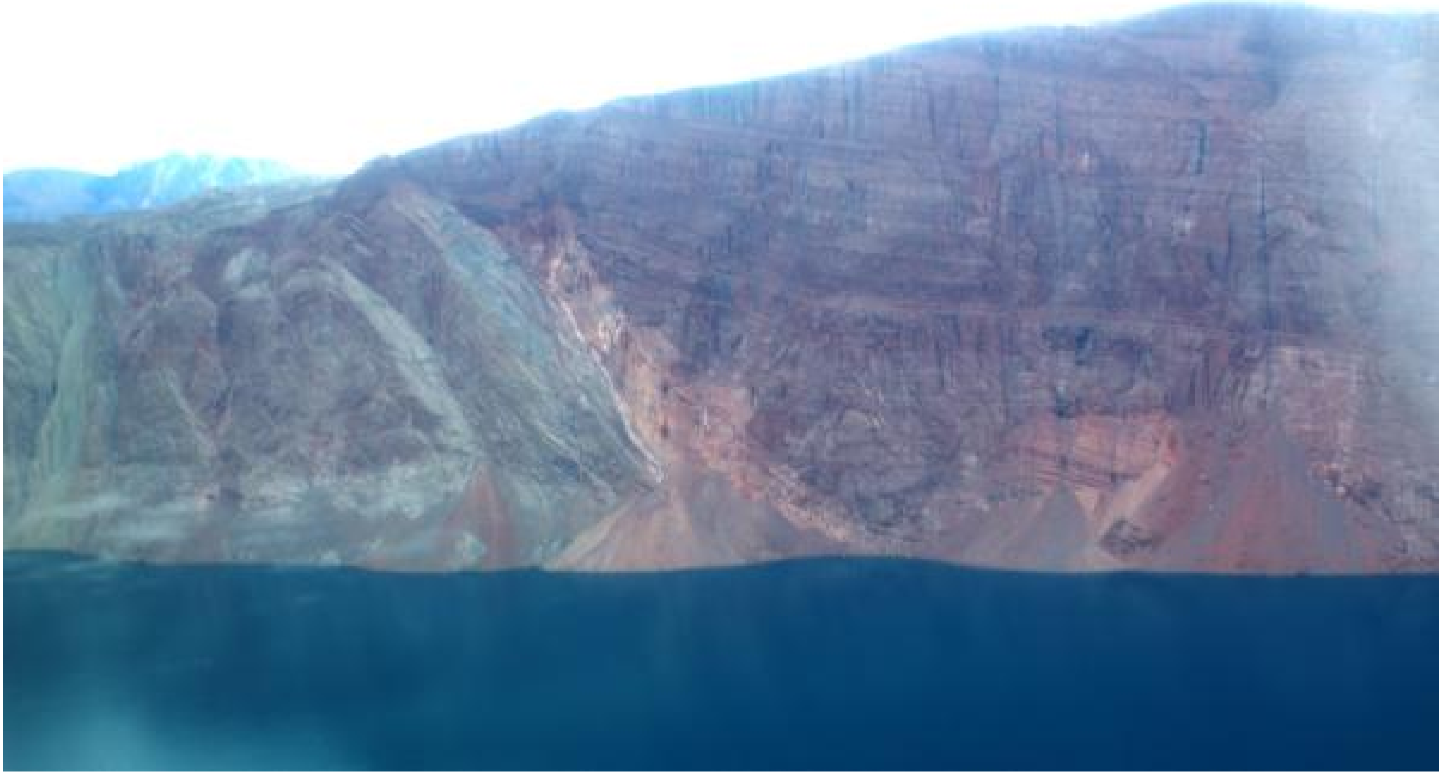
The HDMS Triton on patrol in Greenland.

The vessel that was used as the cruise ship in distress for the entirety of the exercise was the HDMS Triton. For the full exercise she was called the Arctic Victory. She is a Danish Navy ocean patrol vessel that operates in the waters around the Faroe Islands and Greenland. The ship is 113 metres with a large stern deck that has a helicopter landing spot on it as well as room for cruise ship passengers.

Exercise Summary



1 Exercise Summary



The entirety of the exercise would be conducted in the area around Ella island at the mouth of Kempe Fjord in Northeast Greenland. The Sirius patrol has a cabin on the island.

2 Search Phase

The exercise would start with no contact from the vessel in distress, followed by a mounting of a full scale search around the area it was last in contact.

3 Rescue Phase

In this part of the exercise the exercise ship 'Arctic Victory' had caught run aground and caught fire just off the North side of Ella island.

4 Evacuation off ship

The fire escalated and a full evacuation was needed. Using an evacuation chain, of small boats and then helicopters to ferry the passengers from the ship onto Ella island.

5 **Airstrip Casualty Treatment**

Using small planes and helicopter passengers were brought to Mestersvig. It is a military outpost with a runway where the Hercules planes could land and transfer injured to the nearest hospital in Iceland.

Exercise (3)

Searching Phase

Once the rescue was initiated and the searching phase began the SAR Mission Coordinator utilised the vessels and aircraft on hand to coordinate the search for the missing cruise ship and its passengers.

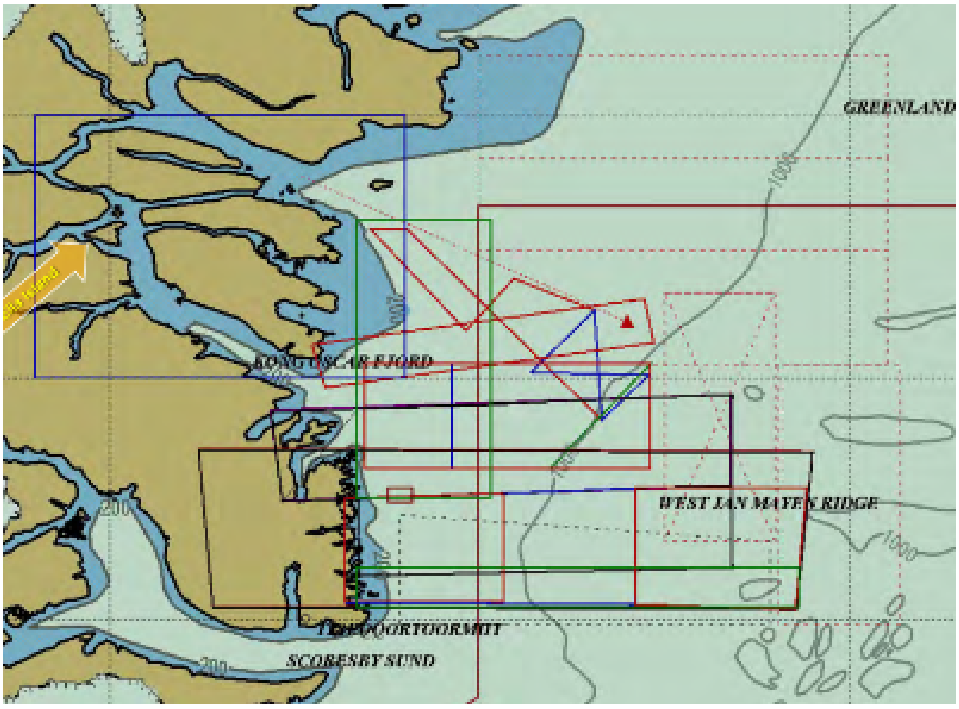


Image from the Mission coordinator with the search patterns used.

This part of the exercise was performed by three ships and a number of the reconnaissance aircraft. The use of both aircraft and ships together to best utilise time in finding a potential ship was practised. Different SAR search techniques were also used.

Rescue Phase

The second part of the exercise was the simulated cruise ship catching fire and running aground in the area just North of Ella island at Kap Oswald. The icons in the image show approximately how rescue craft were located for the exercise.

Illustration of where different SAR services were situated.

Helicopters from onboard some of the navy ships as well as from the different country SAR services started a chain of evacuating the passengers from the vessel. A team of firefighters and specialist team were parachuted beside the vessel to help battle the situation while passengers were hoisted off. There was a simulated 5 dead and 20 - 40 injured with varying degrees of severity.

Firefighters & other personnel onboard dealing with the fire meanwhile helicopters evacuated passengers.

Evacuation from Ship

Once evacuated from the ship, people were brought to Ella island where they were assessed for injuries and lined up for evacuation to Mestersvig where more equipment and tents were set up to deal with casualties.

ICE-SAR were based on Ella island where they had 16 persons and seven tonnes of equipment for both communications with the other SAR crews and mission coordinator as well as first aid.

Evacuation centre on Ella island.

Evacuation to Mestersvig & Iceland

A chain of evacuation from Ella island to Mestersvig was formed once passengers were assessed on land and the most serious were ferried to the Mestersvig runway where a more extensive aid station and triage had been set up. The most injured would be sent to the nearest hospital which is in Iceland via one of the Hercules aircraft.

The setup at Mestersvig to deal with casualties.

Conclusion

The exercise, conducted over four days was the first major mass rescue operation carried out by Arctic nations together since the Arctic SAR agreement was signed in 2011 and with the involvement of over 1000 personnel from over 8 countries, it was deemed a very good training exercise which could be improved on in some areas such as overall communication and coordination but this was expected as it is a huge undertaking that hadn't been done in an area such as Greenland before.

The distance to reach and rescue a ship in the exercise situation is huge and its remoteness was fully realised. Arctic nations have to be ready for this type of event if it did occur and understand that the approach to it is different that in other regions.

Distances and times to reach the area.

References

The following resources were used to create this storymap.

Images & Content	Icelandic Coastguard, Semitsiaq
Report	Joint Arctic Command Exercise Report 32 Pages (Download)

Mi-8 helicopter Crash, October 2017

The Russian company helicopter crashed into the sea in Isfjorden in Svalbard with the loss of all 8 persons onboard.

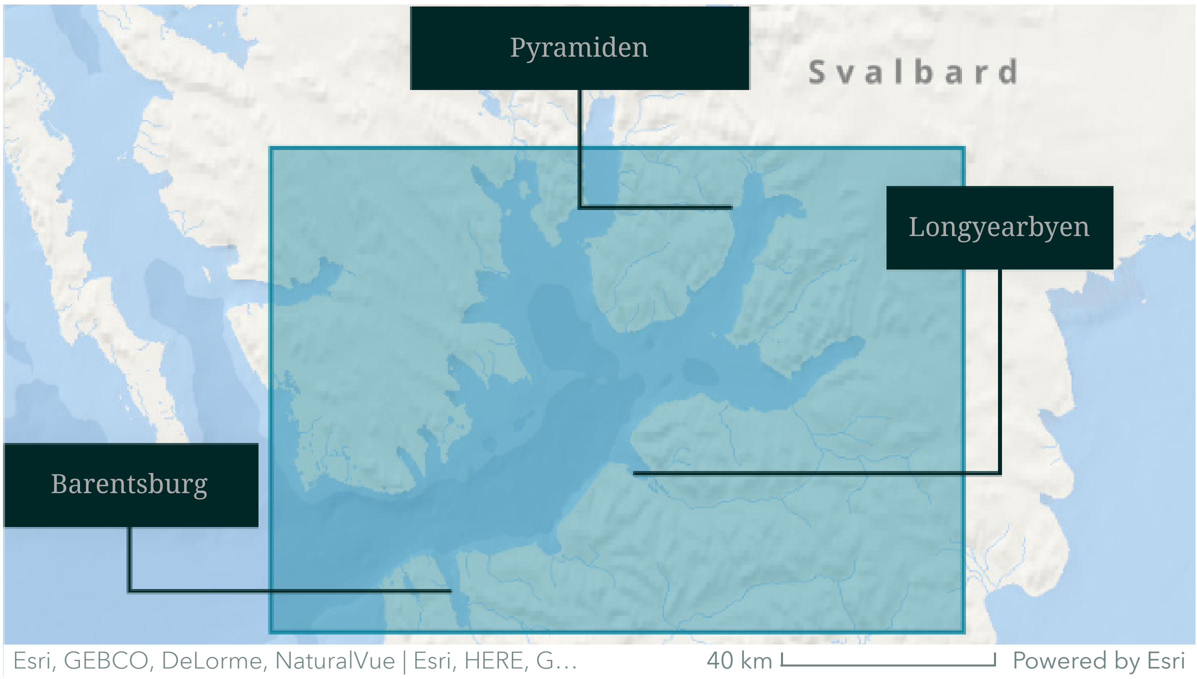
Peter Hamrock
April 3, 2023

The Mi-8 helicopter that crashed seen at Barentsburg the previous year.

Background

The accident occurred in the Isfjorden area of Svalbard. It is located on the West side of Spitsbergen, which contains the main town on Svalbard, Longyearbyen as well as the Russian settlements of Barentsburg and Pyramiden where the accident occurred. Since the winter of 1998/99, Pyramiden has been depopulated owing to the fact that the coal mine closed down. However, during the summer there is a personnel presence of at the settlement maintained. Barentsburg is an active coal mining town and has a population of just over 350. Both settlements are Russian owned and run by the company

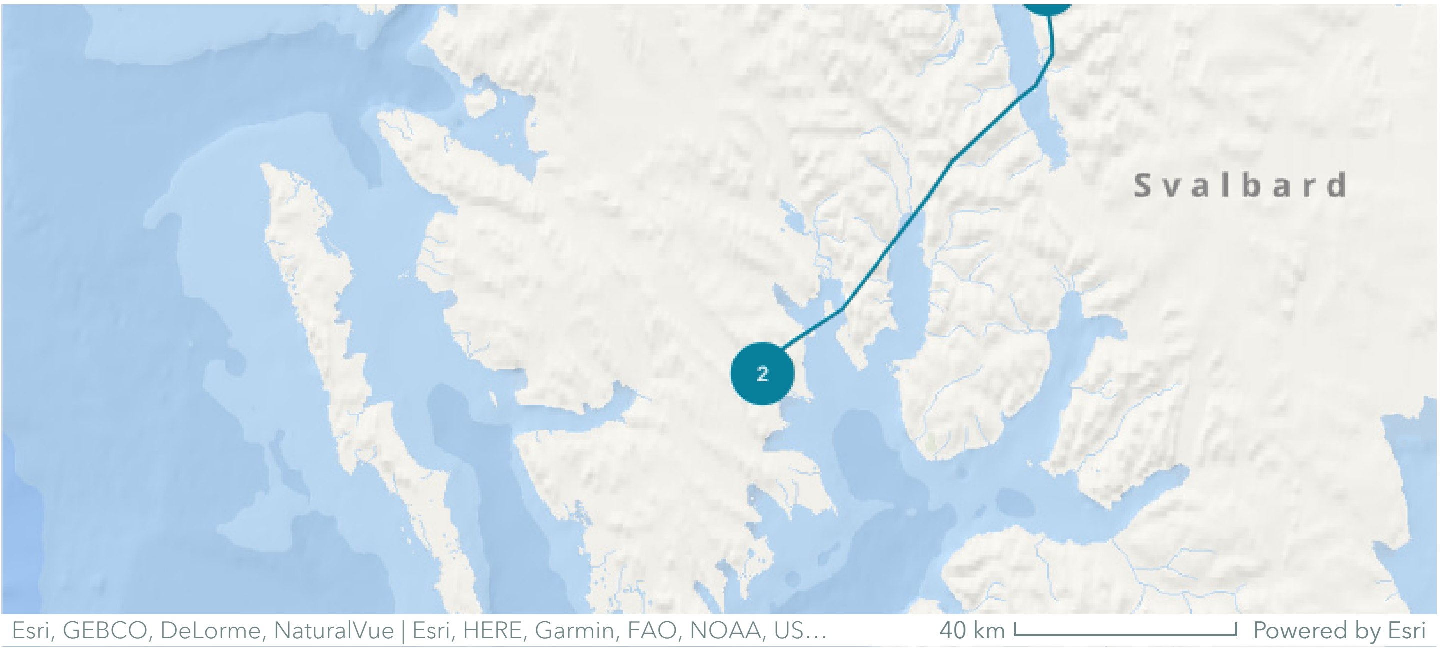
Arktikugol. The helicopter itself was company owned and used to shuttle workers at Pyramiden from Barentsburg, especially in the winter months when sea ice blocked the way for ships.



Accident location on Svalbard

Accident

The scheduled trip on the day of the accident on October 26 was to fly the management group of Trust Arktikugol from the helicopter landing site at Heerodden beside Barentsburg to Pyramiden. While there the management group were to hold a meeting with personnel at Pyramiden. The helicopter returned to Barentsburg after dropping them off and was to return before the meeting was over. For logistical and practical reasons, three scientists were picked up as passengers for the return flight to Heerodden.



The helicopter took off to return to Heerodden from Pyramiden at 14:43. There were a total of eight persons onboard, with a helicopter crew of three, and five passengers. Two of the passengers were technicians who were tasked with performing technical maintenance on the helicopter when it was away from the base.

At 14:45 the helicopter contacted AFIS at Svalbard Airport Longyearbyen. The Commander reported that they were at

Pyramiden, and that they were continuing on to Barentsburg at a height 600 ft with 8 persons on board, and that they would call back when passing "reporting point Bravo inbound". See picture below for points Bravo and Alpha.

At 14:57 the Mi-8 started the approach to Heerodden and initiated descent from an altitude of approximately 235 metres. at 15:01, the First Officer alerted the Commander that they were about to pass "reporting point Alpha". The Commander then contacted Longyearbyen tower. He reported that they were "abeam Alpha"

At 15:05 they called up Svalbard Airport and reported that they were going to establish radio contact with Heerodden. The Commander also reported that they were now 5 NM “inbound” Heerodden. The Commander then called out that the altitude was now 200 metres, that they were climbing, and at the same time requested descent to 80 metres’ altitude.

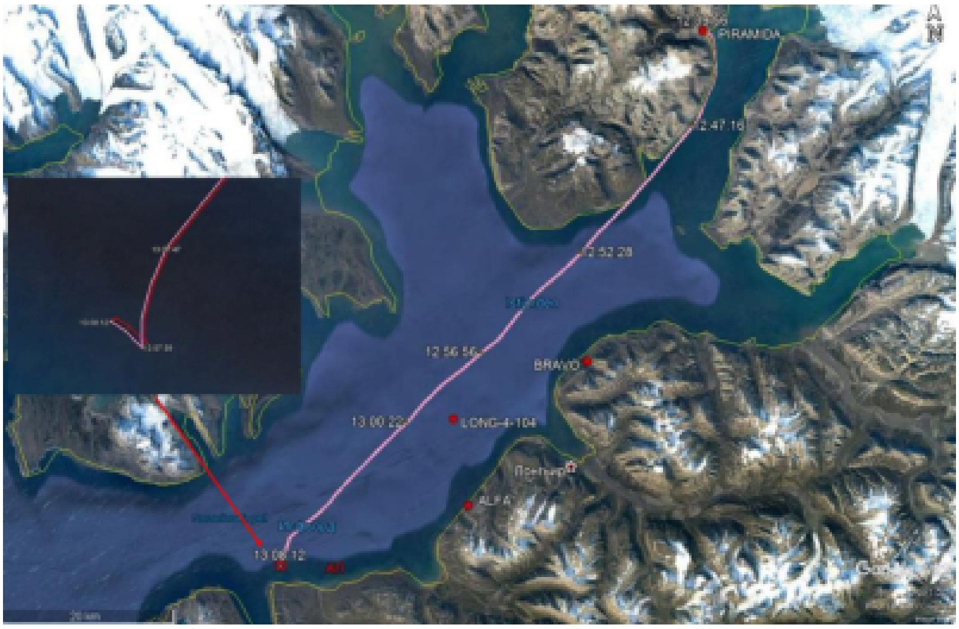
At 15:07:48 the radio altimeter “altitude alert signal” sounded, and the helicopter was losing altitude. The distance to Heerodden was approximately 2 km. At this point in time the helicopter’s altitude was 40 meters.

The officer on duty in the tower at Heerodden has explained to the AIBN that based on the distance to nearby light sources he could with good certainty say that the horizontal view was approximately 1 000 m. He further stated that when the helicopter was less than 5 NM (9.2 km) from the helicopter base, he could hear the noise from the helicopter for approximately 30 to 40 seconds. He believed that the sound from the helicopter was normal before it suddenly disappeared. He perceived the situation as serious and immediately called up the helicopter receiving no answer.

The tower officer then called the coal mine rescue group in Barentsburg. Then he contacted the Trust Arktikugol, which came 10 to 15 minutes later with a fire truck and doctors. He received help from an english speaking scientist who was at the premises to explain to Svalbard Airport what had happened. They confirmed the message received and that help would be organized from there.

Rescue Operation

Less than one hour after the time of the accident, boats were on their way to the accident area in Isfjorden to participate in the rescue operation. In addition, both helicopters from the Governor of Svalbard were scrambled. The first helicopter was over the area approximately 16:15, and the other helicopter was there approximately 16:30. No objects were observed on the sea surface.



Plotted track and accident location.

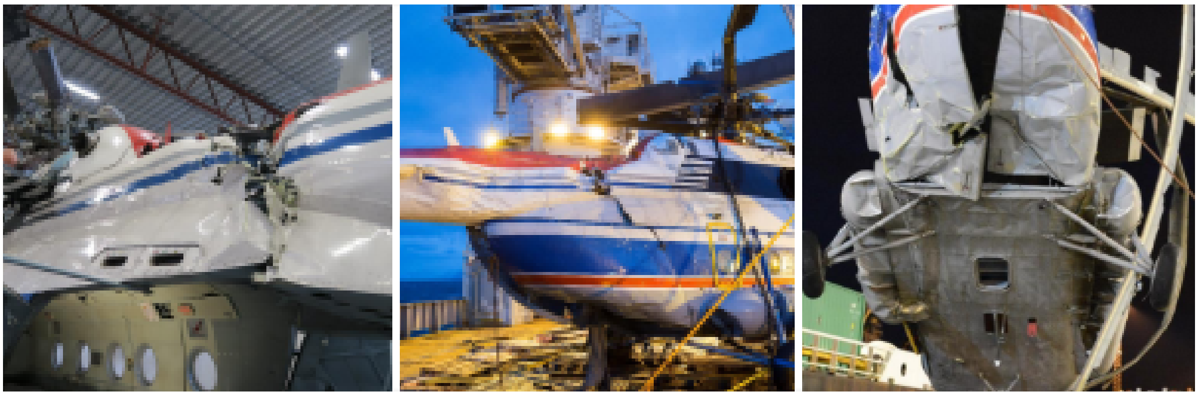
A local crisis response team was established in the hangar at Heerodden, and local area searches were organized. Two search groups, each of four persons, went east respectively towards Kapp Laila and inward along the Grønfjorden towards Barentsburg. They searched approximately 3 km in each direction without any observations. The Governor was notified of the accident at 15:33, whereupon the Longyearbyen crisis management team was assembled. The Joint Rescue Coordination Centre in Bodø took over the control of the search and rescue phase at 15:42. Subsequently, the amount of resources used to search for survivors escalated. The helicopters have “Forward Looking InfraRed” (FLIR) search cameras for detection of objects with a temperature different than that of the surroundings. The Governor’s ship, Polarsyssel, was activated at 16:00.

Overview of shorelines searched in red with crash area searching shaded.

Several local boats came to the accident area the same evening to take part in the search. The smell of jet fuel was detected in the accident area. A Norwegian Air Force P-3 Orion and the Coast Guard vessels KV Barentshav and KV Senja arrived early the next morning to the area to take part in the search. The G.O. Sars, started searching in the area using an ROTV24 in the afternoon of October 28. At 06:20 on October 29 G.O. Sars reported a possible find. This was later confirmed by KV Barentshav. The deceased was later found and taken on board G.O. Sars at 09:13 on 31 October.


Maersk Forza hauling the wreckage onboard.

At 01:30 on October 29 a team from the Russian emergency ministry, EMERCOM, arrived. They had brought a ROV, scuba diving equipment and dinghies. These resources were among other things used to search along the shoreline, and the ROV was used for some search operations on the sea bottom. The main part of the helicopter wreck was salvaged in the morning on November 4 and was hoisted aboard the Maersk Forza.



Pictures of the Mi-8 wreckage.

The search and rescue stage was concluded on October 29. A phase of search for missing persons presumed dead was started. Extensive searches along the shores on both sides of Isfjorden were carried out. Several hundred kilometres of shoreline was examined by foot patrols, boats and scuba divers. No observations were made that could be connected to the accident. Despite the great efforts and extensive use of resources this search resulted in no findings. The search was stepped down on November 8 and terminated November 10.

Of the eight persons on board, only one was found. The deceased was found at a depth of 200 meters approximately 150 meters to the southwest of the helicopter. Despite extensive searches with considerable resources, the remaining seven were not found. One can assume that they were taken away by the currents in Isfjorden.

Causes & Conclusions

The Accident Investigation Board Norway (AIBN's) investigations and interviews with persons involved did not give any indication of technical failure of the helicopter or any of its systems prior to the accident. On the other hand, there were circumstantial factors indicating that safety problems related to operational conditions in a challenging weather situation contributing to the accident. Based on available information, the AIBN concluded that the helicopter hit the water surface with the tail portion of the fuselage first at low or no speed forward. This indicated a loss of visual references in poor visibility with subsequent loss of control over the helicopter. Therefore, in the analysis, focus was on general operational conditions, weather conditions and the change in visibility conditions during the approach, which probably led to the loss of visual references.

This investigation showed that they had begun the approach even though the visibility was significantly less than that set as minima. AIBN concluded that the accident occurred after loss of visual references. The impact with the sea surface was with little energy, and everyone on board was able to evacuate the helicopter. None of the occupants had adequate survival equipment to survive in the cold water.

Following this the AIBN made the following safety recommendations.

- The AIBN's investigation found that the Barentsburg landing site at Heerodden had developed deviations in relation to the procedures and standards, despite the fact that the base is subject to quarterly internal audits. It recommended a systematic audit of the company's organization at Heerodden and implements measures to achieve an expected good safety standard.
- No one on board used survival suits nor were they wearing life vests. The helicopter was not equipped with liferaft nor emergency floats. National regulations do not set requirements for such emergency equipment for multi-engine helicopters when flying more than 10 minutes from the coastline. The Accident Investigation Board Norway recommends that the Civil Aviation Authority Norway extend the national regulations so that requirements are set for the use of adequate emergency equipment for all types of helicopters in mountains and desolate areas and on Svalbard. In addition, emergency floats should be used

on helicopters when flying over sea irrespective of distance to the coastline on Svalbard.

- The accident occurred during weather conditions that were reported to be significantly lower than the published weather minima for Heerodden. Convers Avia Airlines JSC allowed only VFR flights on Svalbard. In the demanding weather and at dusk, the pilots lost their visual references and subsequently lost control of the helicopter. The AIBN saw the need for all helicopter operations that take place during the polar night on Svalbard to be made with helicopters and crews capable of flying according to instrument flight rules

References

The following resources were used to create this storymap.

AIBN Report	Statens havarikommisjon Report 55 Pages (Download)
Images & Information	Aerosurance

FV Saputi ice collision, February 2016

The Canadian trawler struck sea ice in the Davis Strait and listed badly before Danish & Canadian services aided it to port.

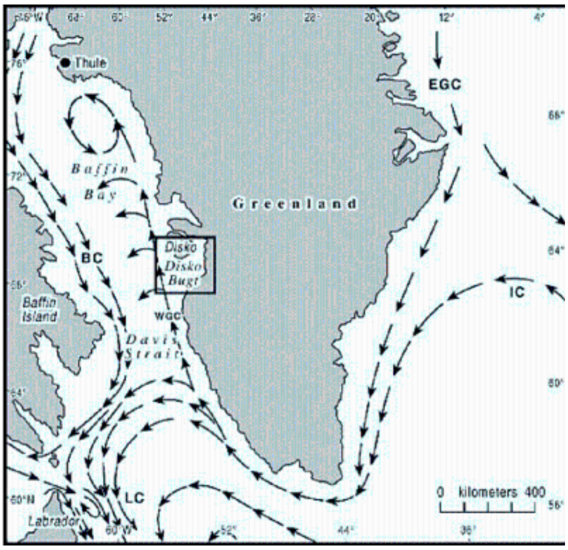
Peter Hamrock
February 14, 2023

The trawler pictured listed heavily after striking sea ice in the Davis Strait.

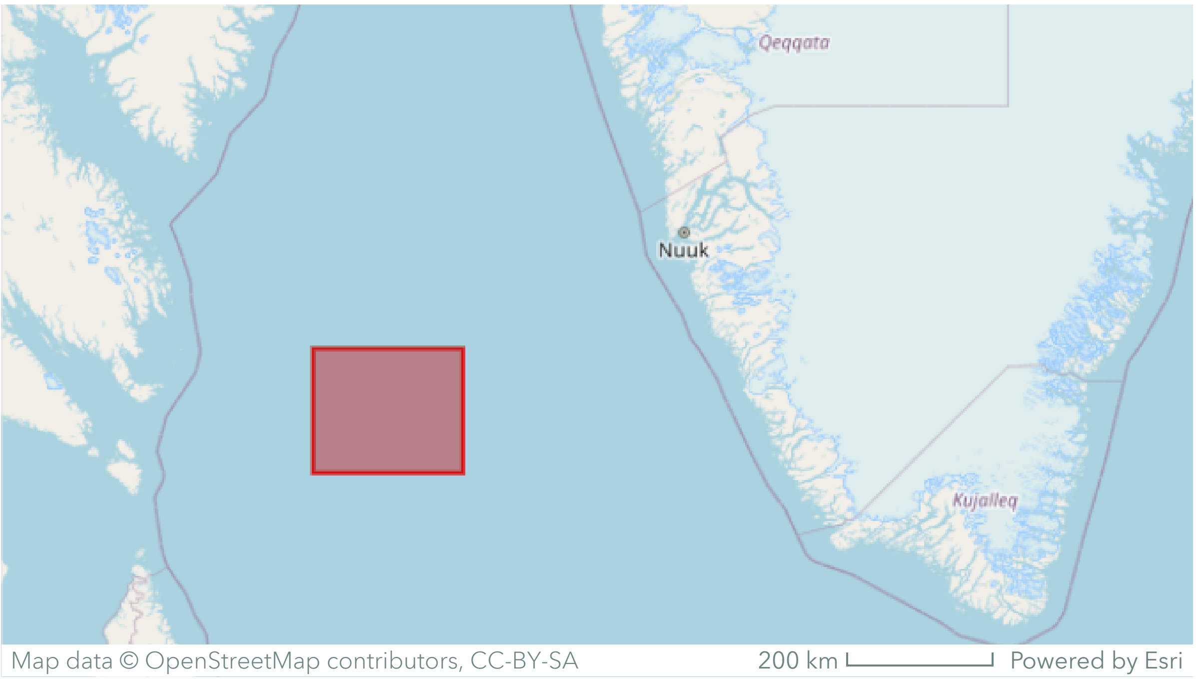
Background

The accident occurred in February in the middle of the Davis Strait which separates Greenland and Canada. The ship has an ice class 1A1 and had operated in iceberg and smaller ice fragment waters many times before. Its primary catch is shrimp and turbot. There was 30 men onboard.

The area the ship was operating in is well known for sea ice and icebergs. As seen in the figure, the Baffin Current brings cold Arctic water Southward along Eastern Canada at the Davis Strait. The area the Saputi was casting its nets in was near the frozen ice edge itself.



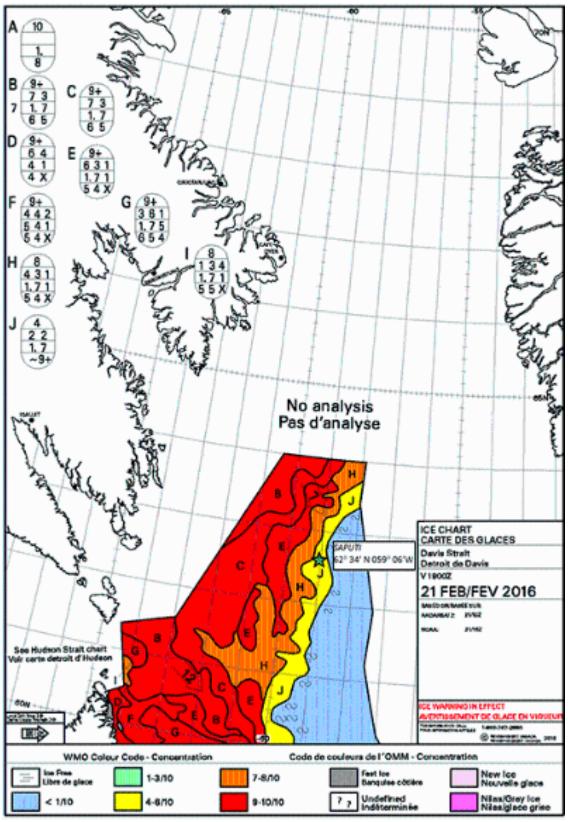
Surface sea currents in Baffin Bay and the Davis Strait



Location map of the accident

Accident

The ship left Bay Roberts in Newfoundland on the 29th of January before going Northeast to fish for shrimp. On the 5th of February it headed North to fish turbot towards the Davis Strait East of Baffin island along the ice edge. The vessel continued fishing turbot along the ice edge until the 21st of February.



The ice conditions at the time and Saputis location

18:30

The master was alone on the bridge beginning to shoot the trawls. Visibility was good. Speed was 5 knots.

18:40

The master observed a single piece of ice 3 nm on the port side and confirmed it visually.

18:55

He began the tow of the net and reduced speed to 3 knots.

19:30

The vessel approached the piece of ice. The master altered course to avoid the ice.

19:35

As the vessel turned the ice was at 5m distance when the vessel fell off the swell and it made contact with the ice where it made a loud bang. The vessel continued on. The piece of ice was estimated to be 5 m in length, 4 m wide at its widest and 0.5 m in height above the surface, and it appeared to be composed of smaller pieces of ice pushed together and frozen into one larger piece.

20:30

The engineer on watch was alerted by a bilge alarm in the cargo hold. Once found not to be a false alarm other crew were instructed to move the cargo.

21:10

The engineer on watch transferred the fuel to port to try cause the vessel to list to the port and keep the damaged area above the waterline. They recovered the trawls and called Northern Canada Vessel Traffic Services (NORDREG).

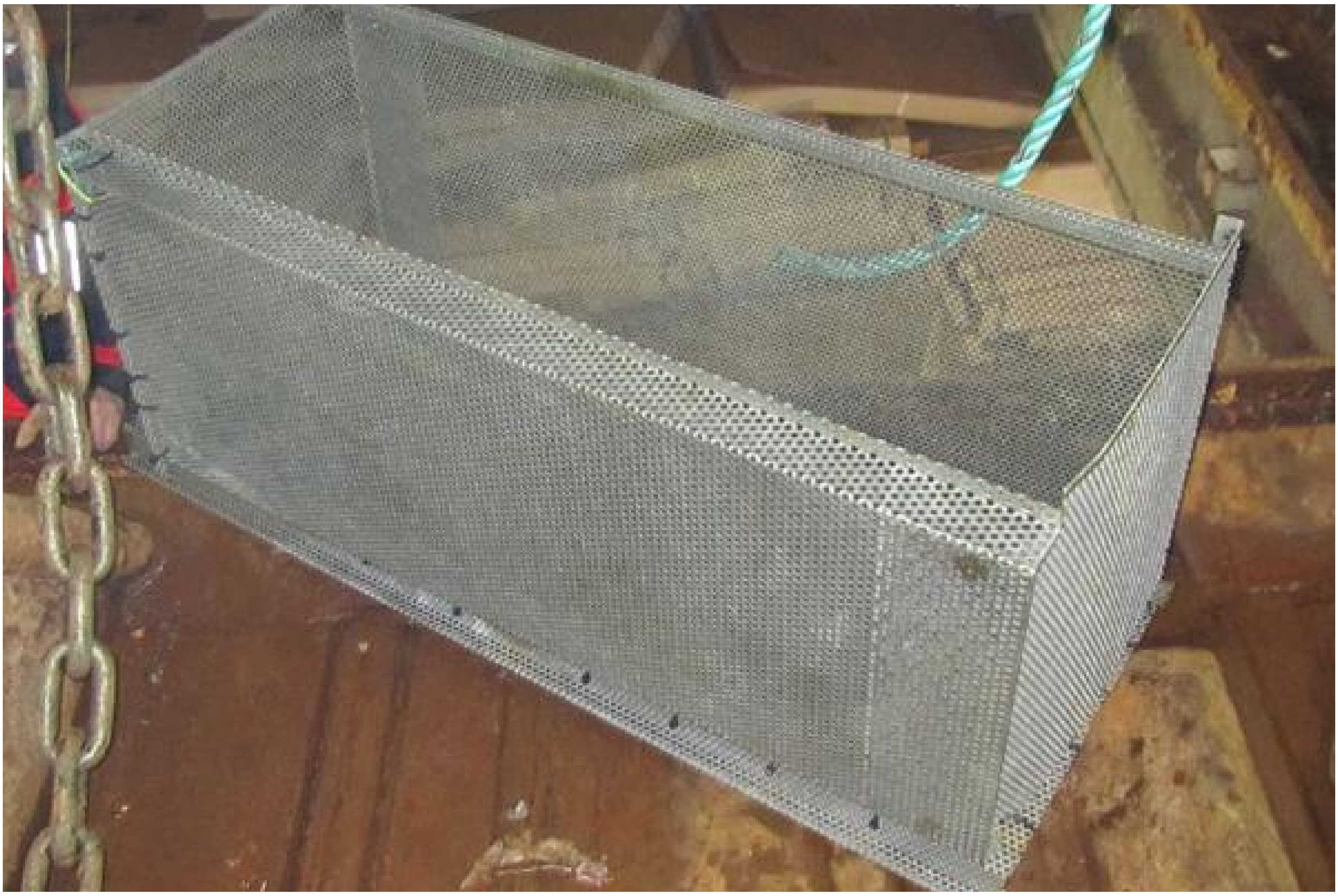
Rescue Operation

NORDREG communicated the vessels situation to the Joint Coordination Centre (JRCC) Halifax and also JRCC Greenland. At this point a significant amount of water was entering the vessel through the crack.

The Danish naval vessel Knud Rasmussen left Greenland to provide assistance but it would take 18 hours to reach the Saputi. At 02:51 the master advised the JRCC that it couldn't keep up with ingress with the pumps and required more.

The JRCC sent a Hercules plane with additional pumps. At this stage the captain was preparing the possibility of abandoning the ship.

At 08:30 the aircraft dropped 4 gasoline powered SAR pumps to the ship. This came at a crucial time and crew had them pumping water from the hold in quick time. The ship was heeling 25°.



At 14:00 the Knud Rasmussen arrived at the Saputi and transferred by zodiac 3 crew to assess the situation. They then used rags and expansion spray foam to plug any opening to slow water inflow.

Two more pumps were transferred onboard and the Danish crew made strainers to filter debris from clogging the pumps. With 4-5 m seas the vessel continued towards Nuuk at 6 - 10 knots.

One of the submersible pumps failed leaving only one which was not able to keep up with inflow. Weather further deteriorated and the water in the cargo hold increased. The vessel then listed as much as 40°.

Pumping operations were not enough to reduce flow and pumping was stopped. Efforts to make the cargo hold secure using jack posts so that the increasing water pressure wouldn't pop the hatches.

Crew were tried to be evacuated but efforts were abandoned after the Knud Rasmussen's zodiac sustained damage. Listing reached 40-45° and a SAR helicopter from Greenland sent to evacuate crew again turned around due to icing.

The vessel struggled through large swells until it got into Nuuk. It arrived in the town on the 24th of February at 00:23, nearly three days since being holed by ice.

Causes & Conclusion

The ships shell plating was sampled to test its specifications and several results showed impact energy needed to fracture the steel was lower than others at the same temperature, but these are not indicative of a fault or defect. The master had significant experience in ice and the vessel made its required specifications.

Under difficult conditions the coordination between the JRCC in Canada and Greenland worked well to provide different assets to rescue the vessel. Ultimately the mission was a success as both crew and vessel were saved.

References

The following resources were used to create this storymap.

Report	Transportation Safety Board of Canada 48 Pages (Download)
Content & Images	Maritime Executive, CBC, Marine Insight

Polaris I Accident, August 2012

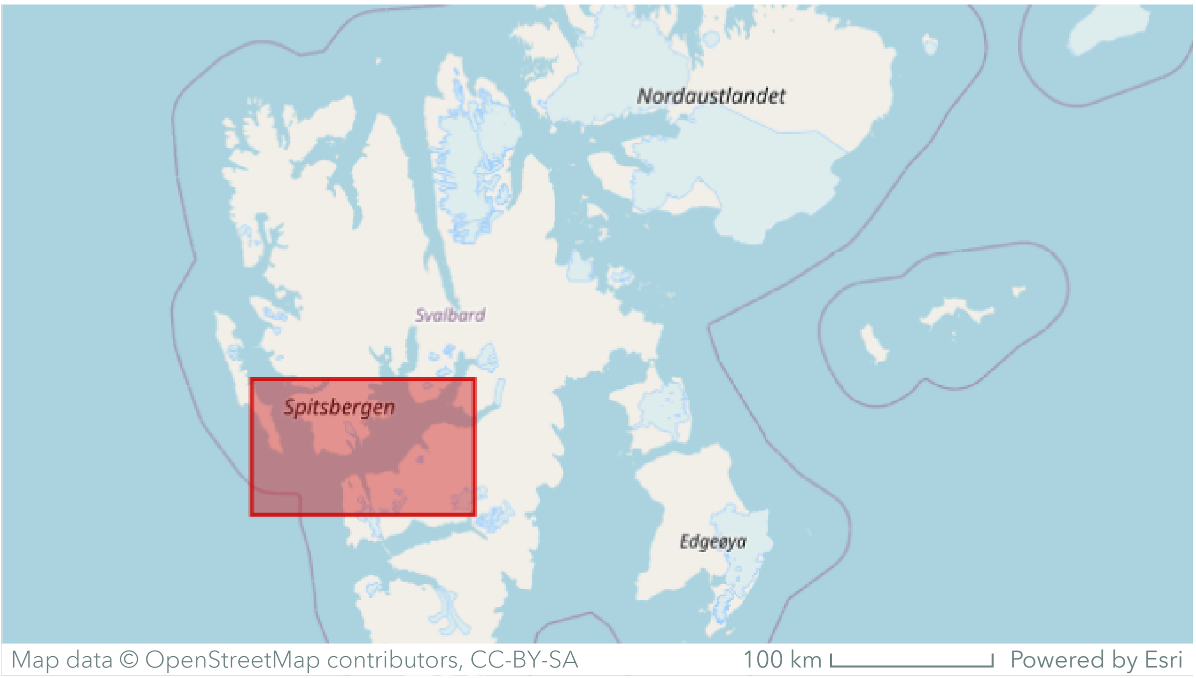
Tourist boat involved in glacier calving incident with dinghy causing injuries and one fatality in Svalbard.

Peter Hamrock
November 3, 2022

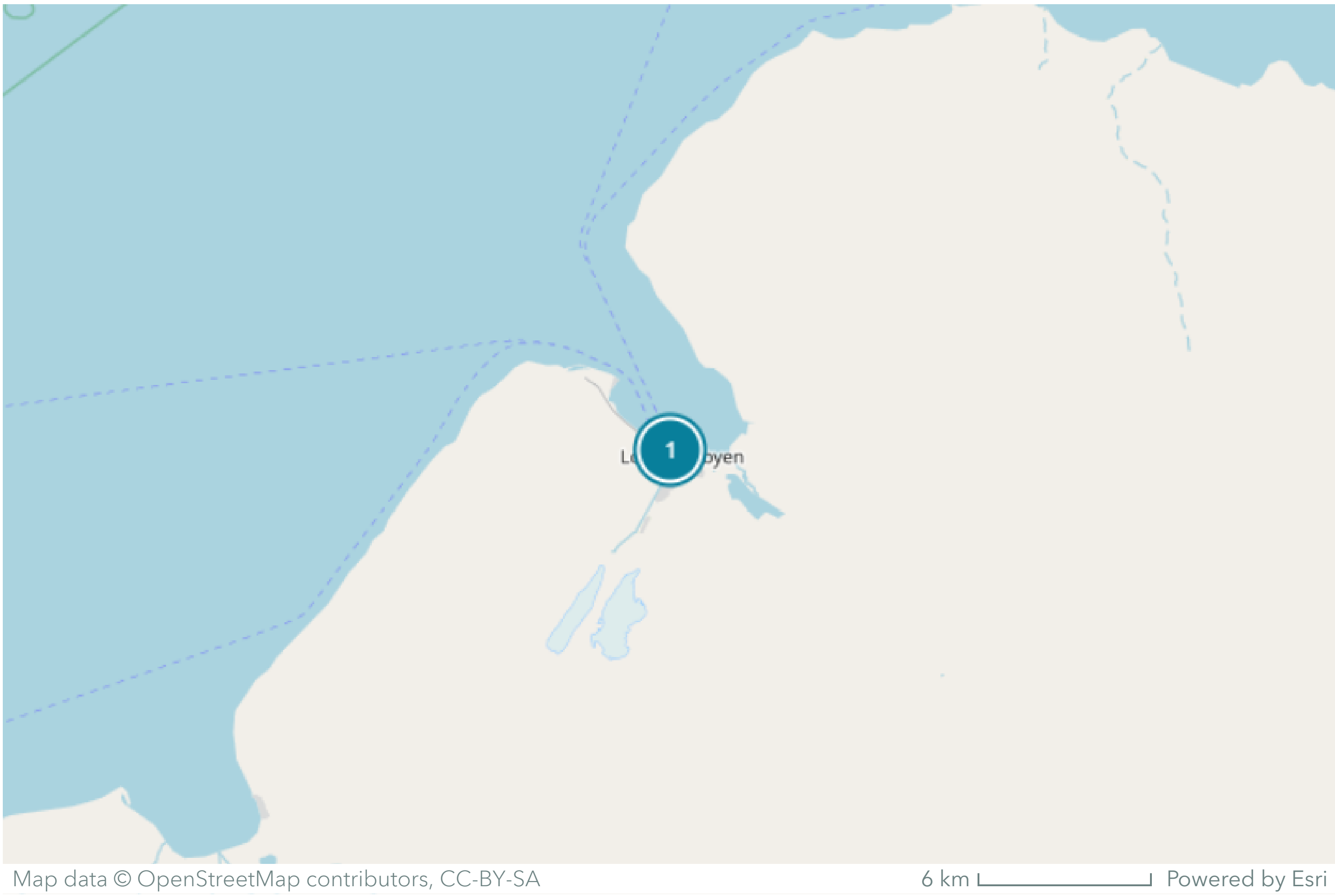
The passenger ship Polaris I pictured in Svalbard where it operates as a luxury cruise vessel

Background

The accident occurred in the Isfjorden area of Svalbard. It is located on the West side of Spitsbergen, which contains the main town on Svalbard, Longyearbyen as well as the Russian mining settlement of Barentsburg. Tourism in the region has increased exponentially in the last 15 years with over 150,000 people visiting the island in 2019. To put these numbers into perspective, the total population of the island is approximately 2,900 people. Many of these visiting tourists take tours to the numerous glaciers using cruise vessels like the Polaris I.



Location map of the accident



1

Longyearbyen

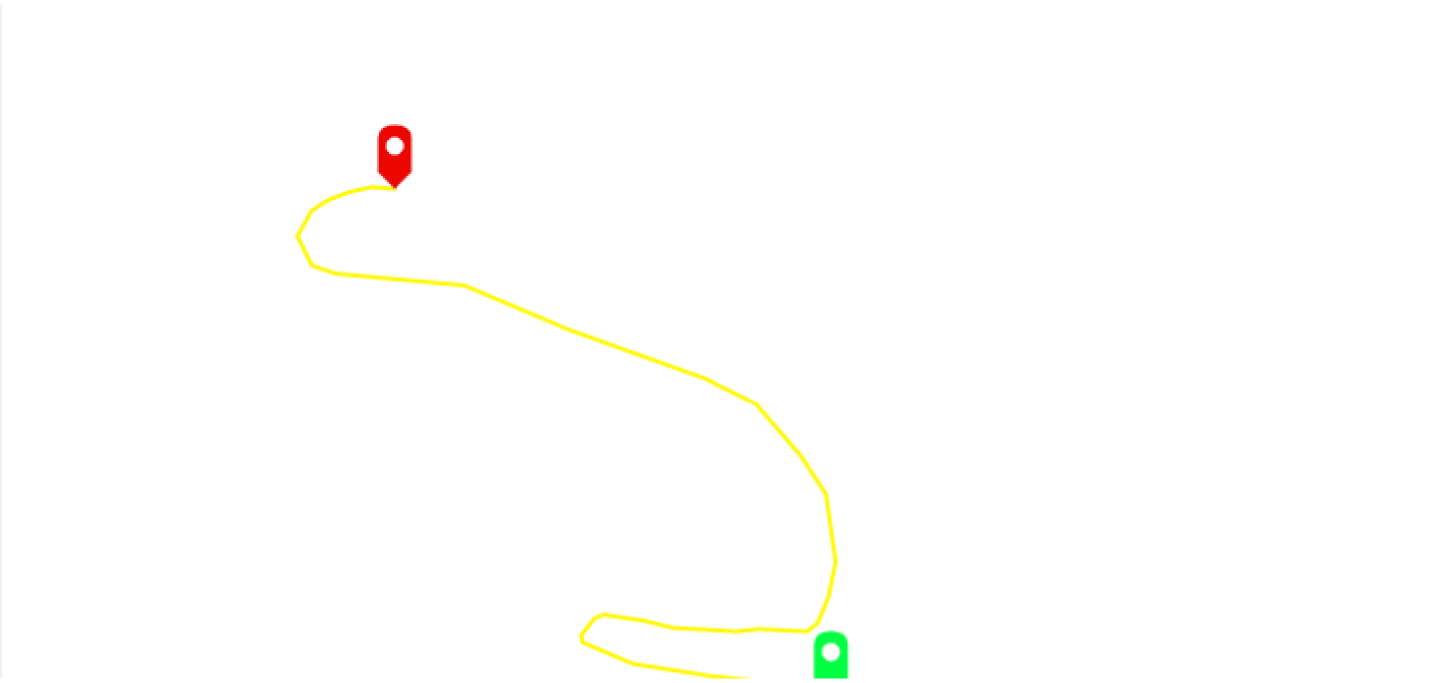
Lying on the South side of Isfjorden. Longyearbyen is the embarkment location for all cruise ships on the island.

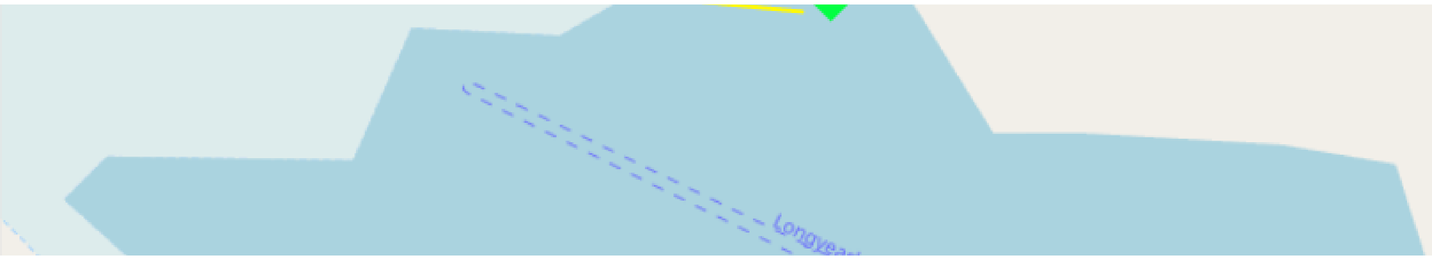
2

Esmarkbreen Glacier

The accident occurred in front of the Esmarkbreen glacier in a bay on the North side of Isfjorden. It took place as the tour guides gave passengers a closer look at the glacier in dinghies.

Accident





Map data © OpenStreetMap contributors, CC-BY-SA 0.4 km Powered by Esri

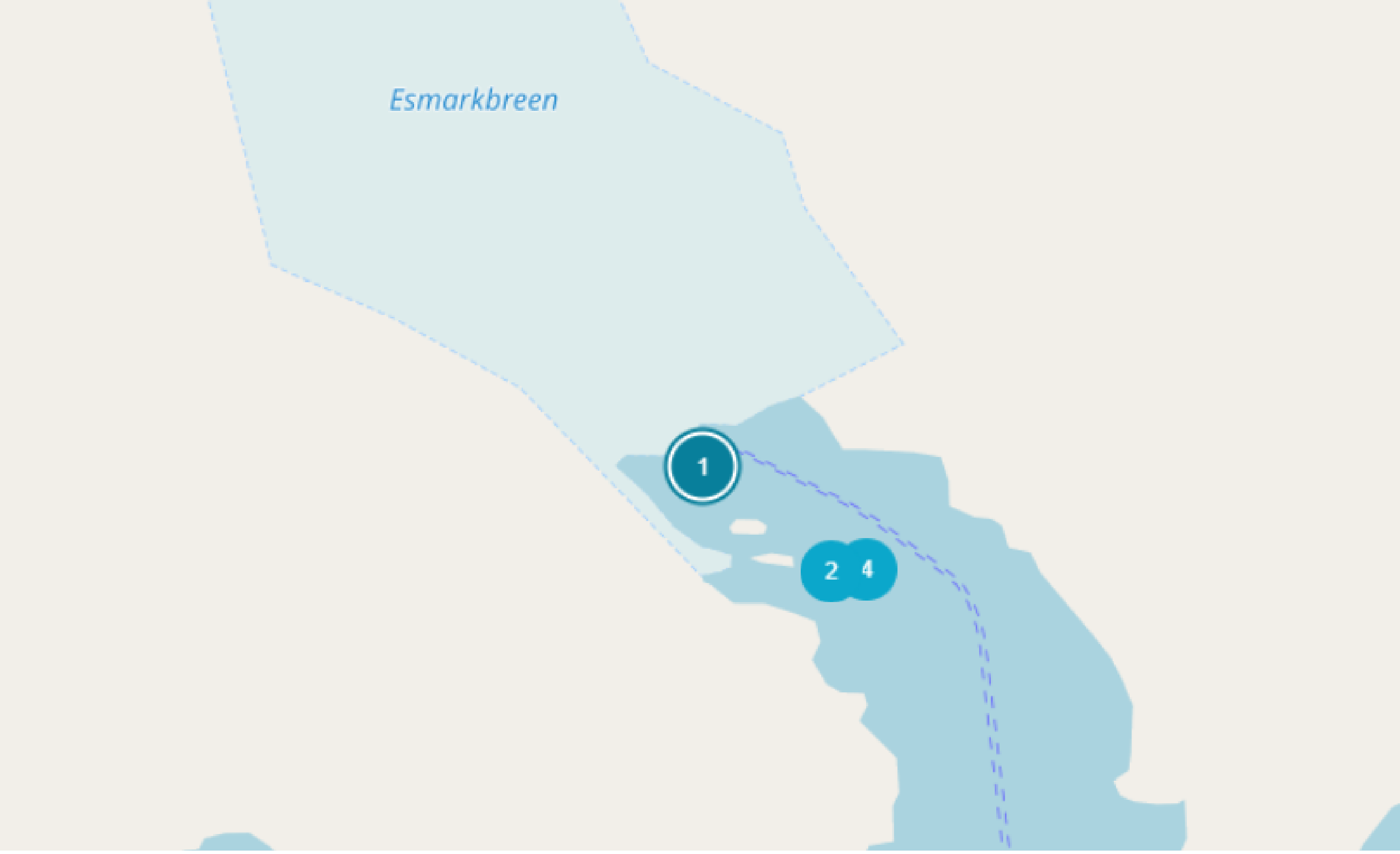
This map shows the location in green of the ship itself with regards to the glacier area and the accident itself. Passengers got into two rubber dinghies of 7 persons each and proceeded to be guided nearer the glacier itself. The yellow line indicates the route taken by the group before coming to the main glacier front itself where the accident occurred.

The night before the crew had observed no significant calving during the night. Some calving was observed as the two dinghies moved. The ice hit dry land and lumps of ice were thrown horizontally from the shore. The boats continued parallel to the glacier while following a seal as well as observing a minor calving.

The location on the glacier where the accident occurred

Passengers as well as guides on the dinghies estimated the distance at this stage from the glacier to be greater than the minimum distance of 200 metres. It was then that the large glacier calving occurred. A large bang was heard followed by the glacier front coming loose and falling forward. The image shows the location of where the calving came from. Ice blocks fell from approximately 33 metres onto dry land causing them to shatter and be projected into the fjord. Pieces of the ice hit the first dinghy at high velocities. It was then the injury and fatality occurred when a piece of ice hit one of the passengers in the head causing near instant death. Another passenger received minor injuries.

Rescue Operation



Map data © OpenStreetMap contributors, CC-BY-SA 2 km Powered by Esri

1 10:06 Accident Occurred

The guide of the dinghy alerted the other dinghy via radio immediately and the woman was found to be unconscious and CPR was started. The captain of the Polaris I was notified at 10:15.

2 10:20 Dinghy arrives at Polaris I

CPR continued en route back to the boat and once on board too with both crew and passengers performing the CPR. She was then attached to a defibrillator with no signs of heart rhythm.

3

10:20 Governor Notified

The governor was called by the captain of the Polaris I and he notified the helicopter crew to scramble. On board of the helicopter is a trained doctor.

4

11:00 Helicopter arrives

With efforts on board the Polaris ongoing the helicopter arrives at the vessel 40 minutes after the call was made. Helicopter crew then were roped onto the boat where they took over first aid. The injured person was pronounced dead 15 minutes afterwards by the doctor.

Causes & Conclusion

The Accident Investigation Board Norway (AIBN) concluded the following after investigating the accident.

- Before the accident, both the guides and the passengers had been made aware that the glacier front might calve and that the ice could land on dry land, but they did probably not anticipate such violent calving.
- There is a lot of uncertainty in the distance the dinghies were to the glacier at the time of the accident. The AIBN estimated that the distance was between 100 - 130 metres but this is not certain. Regardless, they were close enough that a piece of calving ice caused a fatality.
- The minimum distance of 200 metres away from glaciers is hard to perceive as there are no objects of reference. The

guidelines don't describe a greater distance to give between the persons and glacier if there is subaerial calving over dry land.

- The Accident Investigation Board Norway recommended that the Governor of Svalbard coordinate the work on preparing guidelines that set out practical methods whereby guides and ships' crews can obtain information about the actual distance to a glacier front.

References

The following resources were used to create this storymap.

AIBN Report National Accident Investigation Board Norway Report 29 Pages (Download)

Images AIBN, Barents Observer, Blue Planet Expeditions, MarineTraffic

NTNU
Norwegian University of
Science and Technology

UNIS
The University Centre in Svalbard

DTU Danmarks Tekniske Universitet