YRKESHÖGSKOLAN
NOVIA

Autonomous and remotely controlled ships and ice navigation

Master's thesis

Maja Sabolic

Master of Engineering in Autonomous Maritime Operations

Novia University of Applied Sciences

AboMare Turku, 2022

Finland

DEGREE THESIS

Author: Maja Sabolic
Degree Program: Master of Engineering in Autonomous Maritime Operations
Campus: Aboa Mare, Turku,
Specialization: Autonomous ships
Supervisor: Johanna Salokannel

Title: Autonomous and remotely controlled ships and ice navigation

Date: November 2022 Number of pages 69 Appendices 2

Abstract

This paper contains thoughts and research results on the possibility of autonomous and remotely controlled ships in the polar region. Two, not so-widely known subjects were taken into consideration and the idea of this research was to see if both can coexist in a very harsh and hard environment like the Arctic and Antarctica. A SWOT and PESTLE analysis was performed on the subject. The idea was to understand the rules of ice navigation and try to explain to the reader how this knowledge is comprehended by the human operator. Today we have newly developed technologies. These technologies explained in the text below will speed up the process of remotely operated vessels.

The research was done by reading literature and articles on the subjects. Another side of the research was my personal experience of 7 years sailing on the ice. Different countries and organizations already tried to research the problem, but none looked at it from an ice navigator's standpoint.

After the research was completed, the conclusion was that the concept of remotely operated vessels in the Arctic might be feasible, even though we would have to work through the labyrinth of maritime rules and regulations along with developing trustworthy technology. Perhaps, an even more demanding part will be convincing people and building public trust for this new technology that still needs to be developed in many ways. A timeline for something like this, a new concept in a very unfamiliar area, is hard to set because factors such as economic growth, geopolitics, and technological advancement will be major factors in the development of autonomous and remotely controlled operations in the polar region.

Language: English Keywords: Autonomous ships, ice navigation, Arctic,

Table of contents

List of appendices

APPENDIX I Types of ice

APPENDIX II Ice concentration and how it is displayed on the ice chart

List of abbreviations

AI – Artificial intelligent
AIRSS – The Arctic Ice Regime Shipping System
AIS – Automatic identification system
AR – Augmented reality
CCTV – Close circuit TV
CNN – Convolutional neural network
COLREG – International Regulations for Preventing Collisions at Sea
CPA – Closest point of approach
CPU –Central processing unit
DGPS –Differential Global Positioning System
DNV –Det Norske Veritas
DP – Dynamic Positioning
DPC-3 – Dynamic Positioning Controller
DSV – Dive Support Vessel
ECDIS – Electronic Chart Display and Information System
ENC DATA – Electronic navigational chart data
ETA – Estimated time of arrival
GNSS – Global Navigation Satellite System
HFO – Heavy fuel oil
I/O – Input / Output
IACS – International Association of Classification Societies
IMO – International Maritime Organization
ISO – International Organization for Standardization
LEO – Low Earth Orbit satellite
LIDAR – Light Detection and Ranging cameras
LNG – Liquefied Natural Gas
LPG – Liquefied Petroleum Gas
LT – Local Time
MDO – Marine Diesel Oil
MLC – Maritime Labour Convention
NEP – North East Passage
NWP – North West Passage
OOW – Officer of the Watch
PESTLE – Political, Economic, Social, Technological, Legal, and Environmental Analysis
POLARIS – Polar Operational Limit Assessment Risk index system
PWOM – Polar water operational manual
RBUS – high-speed serial I/O bus
RCU – Triple controller for application data
SCC – Shore Control Center
SOLAS – Safety of Life at Sea
SONAR – Sound navigation and ranging
STCW – Standards of Training, Certification, and Watchkeeping
SWOT – Strengths, Weaknesses, Opportunities, and Threats analysis
TCPA – Time of the Closest point of approach
TRAFICOM – The Finnish Transport and Communications Agency
VTS – Vessel Traffic Service

1. Introduction

At the end of September 2021, I was flying home from my ship assignment and I found an interesting TED Talk on the inflight entertainment system. Even though the video is from September 2019, it caught my attention due to the title *The human skill that we need in an unpredictable world*. It is in human nature to be curious about the future and we all want to be relevant in it. Very often when talking about the future we are talking about efficiency. Every manager, regardless of where they are in the company or systems hierarchy, wants the highest efficiency possible with minimum cost, which is not a new concept but there might be some new ideas on how to achieve that.

In the last few months, we have seen how fragile the shipping industry is and how important it is in global trade and the economy. Not so long ago, one of the largest ships in the world got stuck in the Suez Canal for six days. According to the Bloomberg article (Chellel et al., 2021), the ship obstructed worldwide shipping and froze nearly $10 billion in trade per day. Immediately, shipping companies were looking for alternative routes to deliver the goods more efficiently and cheaply. As one of the solutions, Northern Passages were considered. The Northeast (NEP) and Northwest passages (NWP) are covered with ice most of the year and for now, there is part of the year when passing through is a highly intensive endeavor from a financial and technical standpoint. Sailing through the ice with a ship is a different type of sailing and requires a different set of knowledge and a set of skills that only a small percentage of seafarers have.

One of the solutions to increase efficiency and deliver goods is to include more and more technology in the process. So far, artificial intelligence and machine learning work well with predictable situations, but when unpredictable and unexpected situations arise, can technology help us increase efficiency or keep the same efficiency as a human operator? The unexpected situation in ice-covered areas is the norm but can they be predicted, or calculated? How will that affect human operators? Will remotely controlled ships benefit humans or will humans lose their knowledge, experience, and efficiency?

I have been working on board the ships that sail in the ice-covered area for 7 years now and I got in contact with a lot of new officers who have never sailed in the ice. I was wondering what is the easiest way to explain them how we navigate in the ice. Can technology and too much automation cause people to not understand the process? Can we lose knowledge and experience, and what does that mean for the future?

1.1. Problem formulation: What are the key concepts when navigating remotely with the ship in the ice?

First, basic terminology regarding ice navigation and autonomous ships will be defined. An analysis regarding the pros and cons of remotely controlled ships in the ice will be carried out. This analysis will entail exploring the benefits, concerns, possibilities, challenges, and safety aspects of the entire idea.
While researching the topic, I have found interesting studies related to the subject but at the same time, I have not found anyone researching the subject from an ice navigator's standpoint.

During the research, I have found that interesting new technology is being developed. This new technology might be useful for the concept of the remotely controlled ship in ice-covered areas and eventually can lead to autonomous ships.

Potentially partial autonomy is a solution with people monitoring and controlling the process and activities on the spot, and stepping in when necessary to maximize situational awareness and efficiency.

I have several questions on the subject: How much traffic there is in ice-covered areas, aside from cruise ships? How come ice navigation is so different and only a few seafarers are competent to sail in those areas? Why is so hard to teach Artificial Intelligence about ice navigation? How can we develop a system where both human element and technological elements have full situational awareness and work together towards the common goal? What is situational awareness? Why is situational awareness so important when completing a task? How will this new environment affect humans as a redundancy system?

How will geopolitics have an essential role and can stop the entire concept? This area is under a lot of jurisdictions, and borders are questioned continuously.

1.2. Aim of the research

This research will aim to answer on some of the questions above. The goal is to research how ice navigation is perceived by human operators and whether can algorithms be taught to do the same work on the same, if not better level than humans. Would this be beneficial for humans, the environment, and ship development?

1.3. Research problems

To achieve this aim, we need to understand the following:

- definitions in subjects like ice navigation, autonomous and remotely operated ships;
- important concepts on how to sail in the ice;
- automation and situation awareness in ice navigation; and
- analysis of pros and cons (SWOT).

2. The Arctic traffic

Throughout the history of the maritime industry, the most challenging areas for sailing were those covered with ice. Those areas have not been fully discovered even to this day. Ships sailing in these areas usually had only one goal: exploration. However, during the 19th and 20th-century motivation changed.

Climate change and melting ice in the Arctic and Antarctic have been widely discussed in the scientific literature as well as in the media, such as the Climate Feedback article *How sea ice in the Arctic and the Antarctic is influenced by climate change* (Valentine, 2022), *Antarctica is colder than the Arctic, but it's still losing ice* (Scott, 2019) and *The Arctic Shipping Route No One's Talking About (*Bennett, *2019)* just to name a few. Climate change triggered debates and conversations about the potential further development of commercial shipping in the Arctic. Different types of areas are being discussed with different meanings. When sailing in the Arctic is mentioned, people first thought is about the Northwest and Northeast passages, which are the routes that will cut distances and CO_2 emissions when compared with classic itineraries through the Panama Canal or Suez Canal and the Malacca Strait. (Autonomous ships for container shipping in the Arctic routes, Munim et al., 2021).

Since I started sailing in the Arctic and Antarctica, the first question that people usually have is, ”Is it true, are the Arctic and Antarctica melting?” The fact is, there is no easy answer because it is not a straight forward process. Ice conditions differ from year to year and the prediction of the ice situation even for next year is not an easy task, if even possible. Ice is declining on the macro scale, but micro situations in short periods are really hard to predict. We have evidence of these unpredictable patterns in historical data that can be found on the internet or in numerous articles *A critical situation might be in the making on the Northern sea route, One year after the crisis, there is again early ice on the Northern Sea Route,* (Staalesen, 2021; Staalesen, 2022).

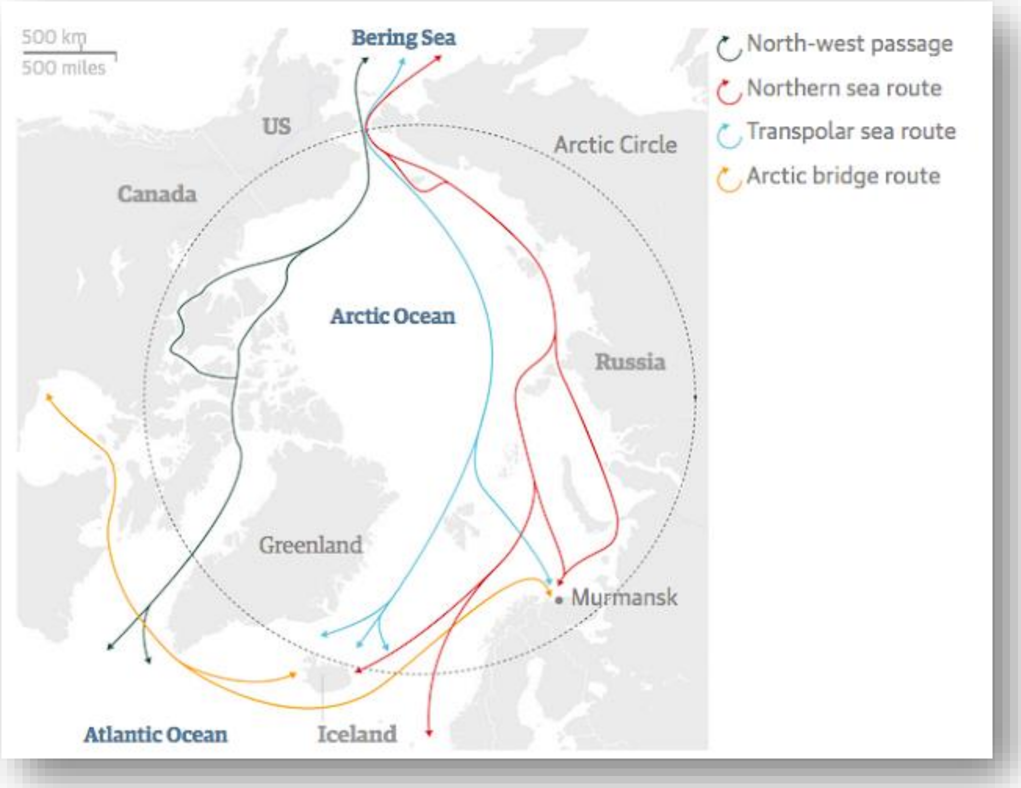


Figure 1. Main Arctic shipping routes

Source: https://blog.geogarage.com/2016/02/arctic-shipping-passage-still-decades.html

In the last decade, numerous papers were published on topics about commercial shipping, and vessel traffic in the Arctic, and the number of successful voyages indeed increased. Rosen (2021) stated in the online article *More ships are traveling longer distances in Canada’s Northwest Passage,* (according to the Protection of the Arctic Marine

Environment working group report, 2019) that the number of ships sailing to the Canadian Arctic increased by 44% from 2013 to 2019. A dramatic increase was seen in the mileage sailed which jumped from 2980 nautical miles in 2013 to 6170 nautical miles in 2019. However, ship transit from the Far East to Europe and from the West Coast of America to Europe is a highly dependable on-ice situation that cannot be precisely forecasted for the sailing season. Nevertheless, big shipping players in different markets such as container, bulk, and LNG are more interested and invested in developing new technologies and designing new ships that will sail in the high Arctic. (*Maersk sends the first container ship through the Arctic route*, Stine Jacobsen, 2018). In the picture below only a few of the ships were listed but ideas and used routes are the same.

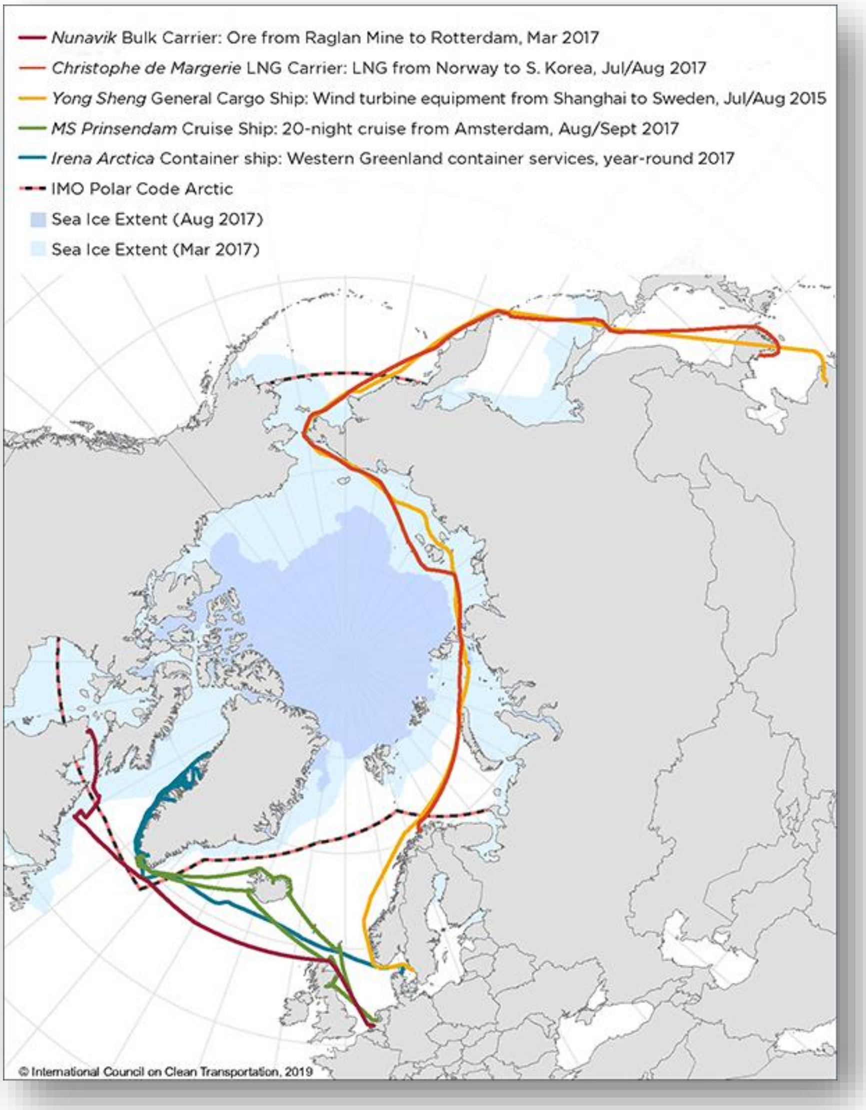


Figure 2. Successful passages in the Arctic

Source: https://theicct.org/event/marine-black-carbon-emissions-identifying-research-gaps/

2.1. Types of commercial traffic in the Arctic

We have different types of shipping activities happening today in the Arctic region. In the last few years, more cruise ships are being built for sailing in polar regions. Due to the considerable differences in operation and because human interaction cannot be ignored, in this paper, I will focus on the cargo fleet. (Guy et al., 2021)

Everywhere in the world, requirements for specific goods are in direct correlation with requirements for transportation. In light of the recent developments in the shipping industry, ships being built today are getting bigger and the number of new builds is not reducing. Unlike ships built in past, today's ships are highly specialized for specific cargo and specific routes, and specific environmental requirements. (*Container-ship building spree not over yet; new orders still rising*, Greg Miller 2022).

According to Guy and Lasserre (2016), we can divide the Arctic traffic into the following categories: transit traffic, destination (with loading port in the Arctic) traffic, and supply traffic.

2.1.1. Transit traffic

In this type of traffic, ships are navigating through the Arctic region to connect southern ports. Within this type of traffic, the Arctic region is presented as a shortcut in distance, especially when we are talking about connecting Baltic and North Atlantic ports with East Asian ports. According to Guy and Lasserre (2016, s. 2), sailing distance is shortened by 25 or 30 % along certain routes. Routes shown in Figure 1 are most popular in this type of traffic, but consideration cannot be given only to the shorter distance but also to an increase in operational costs implied by the Arctic routes. Under transit traffic, we also have two types of shipping. One type of transit traffic is tramp shipping, whose characteristics are connected with unscheduled sailing. The cargo of trump shipping is mostly ores, grains, and other cargoes in bulk form, and shipments are made, only on demand. The other type of shipping is so-called liner shipping. The ship follows a strict preplanned route and the schedule and delivery on time are of utmost importance. This is usually a year-round service and ship operator is planning ports and schedules a few years in advance. Unlike tramp shipping, liners would not benefit from this seasonal possibility in the Arctic, and the risk of being stuck in the ice or not being able to execute the plan, which was assembled years in advance would cost ship operators more than existing routes through Panama and Suez Canal.

2.1.2. Destination traffic

This type of traffic is also called Resources-based traffic according to Guy and Lasserre (2016, p. 4). Ships that are considered within this type of traffic are loading cargo in the region. This type of traffic can be found in the Gulf of Finland, the Gulf of Bothnia, the Norwegian Sea, the Labrador Sea, Baffin Bay, the Greenland Sea, the Barents, and the Kara Sea. This is mostly bulk cargo when we are talking about the eastern Canadian Arctic and LNG and oil exploitation when we are talking about the Russian Arctic or Barents and Kara Seas. Here we do not have an alternative route because we are sourcing goods from countries that are geographically placed in the Arctic. Every ship-owner who is operating in this region knows the environment and the entire fleet is adjusted to operate in that area, so the cost of operation is partially predictable. This cost and profitability are already included in the business plan and the duration of the shipping season will only reduce or increase profits. Plants for the exploitation of goods are built in a way that if they need, they can store additional goods and wait until the sea route is open again.

Melting ice in the Arctic is also creating opportunities for investors and mining companies who are searching for minerals capable of moving humanity to greener energy. (Marsh, 2022). This potentially means that we could expect more destination traffic in the Arctic.

2.1.3. Supply traffic

Supply traffic or Re-supply traffic according to Guy and Lasserre (2016, p. 4) is connected with local communities and their needs. Nowadays we have living communities in high latitudes and like everyone else, they have all the available means to live and work in those areas. The port facilities are getting bigger and during my sailing in the area for the last 7 years, changes and investments are visible in places like Nuuk in Greenland. The main goal is to increase the berth numbers and cargo capacity to be able to receive everything from engine parts to European food. Canadian Arctic, Cambridge Bay, and other year-round communities are supplied by ships. In the case of year-round communities, scientific research and socio-economic evolution in the area are shaping demand for shipping more than climate and ice conditions. (Arctic Council, 2021). A good example of the supply traffic in the Russian Arctic is Murmansk, the largest city in the world north of the Arctic Circle, according to Britannica.

2.2. Present traffic in the Arctic

Examples of successful transits are increasing every year as shown in the previous chapter. In conversation with Arctic ice pilots, more than fifty bulk carriers are sailing on the same route between the Canadian Arctic and Europe daily, transporting different types of ores and diamonds. Traffic in Greenland (Royal Arctic, 2021) and Svalbard (Olsen et al., 2020) have stable development and increasing numbers in traffic are visible. Traffic in the Gulf of Finland and Gulf of Bothnia in every testing model that was run by studies showed growth between 30% and 60%. (Pekkarinen & Repka, 2014; Slavina, 2013). In January 2021, three Arc7 ice-class vessels (PC4 ice-class vessels) safely sailed along the Northern Sea Route, along the north coast of Russia, without icebreaker assistance transporting LNG (liquified natural gas). (Chen et al., 2022).

In a new 2022 study, historical changes in navigability along trans-Arctic routes during the past four decades were reassessed, and it was found that the NEP and NWP became increasingly navigable at rates that were much faster than those previously projected by Global Circulation Mode. The open water vessels could freely transit the Arctic NEP for 92 ± 15 d in the 2010s, a length of time that was projected to be unachievable until the mid-21st century by previous studies (Smith & Stephenson, 2013). The navigable duration of the NEP increased at a rate of 2.72 ± 0.58 d/y during 1979–2019. The 90-day safety shipping area for open water vessels expanded by 35% to 8.28 million km^2 in 2018, at an increasing rate of 0.08 ± 0.01 million km^2 per year. The shortest trans-Arctic routes shifted further north than projected by existing modeling works. Regular ships have been able to safely transit north along the islands in the NEP and through the M’Clure Strait along the Canadian Arctic Archipelago in the 2010s, while previous studies projected that this would not be feasible until the mid-21st century. (Cao, et al., 2022).

All these positive examples and projections from the new studies show us that there are possibilities in the Arctic but we have to develop a system to use this possibility for our gains and at the same time preserve the pristine environment of the Arctic. Perhaps remotely operated ships and eventually, autonomous ships are the answer.

3. Ice navigation

Ice floes and icebergs present obstruction for the shipping lanes, delaying transit and creating a hazardous environment for ships and those on board. Ice caused one of the most famous maritime disasters: the sinking of the Titanic off the coast of Newfoundland in April 1912. Even before that disaster, polar explorers and history have shown us how demanding and dangerous ice navigation is. Since ice navigation has been more popular in the last few decades, more ships are sailing in these areas than ever before. There are a lot of good books written about ice navigation and ship winterization. Each book is a few hundred pages long and it would be too much to put all of the information in this research paper. Therefore, in this paper, I will concentrate mostly on the navigational aspect of ships sailing in the polar region.

Ice navigation can take place in different forms. By attending various seminars and lectures about the ice navigation subject, I concluded that one of the ways we can divide ice navigation is based on the presence of the icebreaker.

If an icebreaker is present, it can be in the following forms:

- one icebreaker and one ship (cargo or passenger) or
- one icebreaker and convoy of ships behind it.

The other form is without an icebreaker assistance, which means that the ship will have to have some grade of ice class.

3.1. Ships for ice navigation

Successful ice navigation and safety is the responsibility of the captain, who will with a specific set of skills and information make navigational decisions. Ships that are sailing in the ice-covered area are exposed to a different type of stress and they need to endure much more outside pressure; therefore, they are arranged in ice classes. Building a ship to a specific ice class means that the hull must be thicker, frames on the ship must be placed closer to each other, sea chests need to be arranged differently, more watertight bulkheads are placed around the ship, and heating elements on fuel tanks, ballast tank, fuel pipelines, and fire fighting systems are added. In the higher ice class, there is also additional protection for the rudder, and propeller tips are often strengthened. Because the Arctic and ice-covered areas are vast and stretched throughout numerous countries we have different ice classes assigned by a classification society or national authority. In this paper, I will list only two that are mostly used amongst cargo fleets: Finnish Swedish ice class rules and Polar Classes set out by the International Association of Classification Societies IACS.

Finnish-Swedish ice class rules are implemented on every ship that has calling ports in the Northern Baltic, to ensure that ships have sufficient capacity to maintain safe and efficient navigation year-round to Finnish and Swedish ports. Aside from the capabilities of the ship, ice class is important to be eligible for the icebreaker's assistance which is based on ice class and deadweight. More information about the subject can be found in guidelines issued by the Finnish Transport and Communication Agency so called Traficom.

Table 1. Finnish-Swedish ice classification

Ice class	***Meaning***
1A Super	*Ships are intended for year-round operation in the Baltic Sea area and the Administrations do not set traffic restrictions for this ice class.*
1A	*Ships are intended for year-round operation in the Baltic Sea area and are escorted if necessary.*
1B	*Ships have limited access to Finnish and Swedish ports for part of the year, depending on the ice conditions.*
1C	*Ships have limited access to Finnish and Swedish ports for part of the year, depending on the ice conditions.*

II	*These ships do not meet the requirements of the ice-class regulations. These ships are meant for easier ice conditions than those encountered in Northern Baltic and they might be eligible for icebreaker assistance if they have a sufficient deadweight.*
III	*These ships do not meet the requirements of the ice-class regulations regardless of ice conditions and they are never eligible for icebreaker assistance.*

Source: Guidelines for the Application of the 2017 Finnish-Swedish ice class rules, Traficom, Swedish Transport Agency, January 2019

However, unlike the Finnish-Swedish ice classes which are intended for operation in first-year sea ice, Polar Classes set out by IACS include old ice inclusion and glacier ice. Differences and why this distinction is important will be seen in the text further below. The lowest polar classes, PC 6 and PC 7 in Polar Classes set out by IACS, are equivalent to the highest, 1A Super and 1A respectively in Finnish-Swedish ice class.

Table 2. Polar Classes set out by IACS

Ice class	***Meaning***
PC 1	*Year-round operation in all Polar waters*
PC 2	*Year-round operation in moderate multi-year ice conditions*
PC 3	*Year-round operation in second-year ice which may include multi-year ice inclusions*
PC 4	*Year-round operation in second-year ice which may include multi-year ice inclusions*
PC 5	*Year-round operation in second-year ice which may include multi-year ice inclusions*
PC 6	*Year-round operation in second-year ice which may include multi-year ice inclusions*
PC 7	*Year-round operation in second-year ice which may include multi-year ice inclusions*

Source: *Ice navigation in Canadian waters, Fisheries and Oceans Canada, August 2012*

3.2. Rules of ice navigation

Ice navigation is probably the most challenging mode of navigation. Ice is an obstacle to any ship regardless of the ice class or icebreaking capability. Ice navigators need to develop a healthy respect for the power and strength of ice in all its forms. However, it is quite possible and continues to be proven so, for well-built ships in capable hands to navigate successfully through ice-covered waters. The first principle of successful ice navigation is to maintain the freedom of maneuver because if the ship becomes trapped in the ice, the ship will go where the ice floe goes. Ice navigation requires great patience and can be a tiring job with or without an icebreaker. Sometimes the quickest way through the ice is to sail around it. Experience has proven that in ice of higher concentrations, four basic ship handling rules apply:

- keep moving-even very slowly, but keep moving;
- try to work with the ice movement, with current and wind, not against them;
- if you sail with excessive speed, the result is always hull damage; and
- know your ship's maneuvering characteristics and capabilities (Ice navigation in Canadian waters, 2012).

3.2.1. Signs of Ice in the vicinity

Taught by previous experience, I learned that one of the most important activities in ice navigation is a good and timely lookout. According to almost every ice navigation publication published, including Ice navigation in Canadian waters, when sailing through the open waters we have a few good signs that navigators can use as an indication of ice in the vicinity:

- An iceblink is a reliable and easy-to-recognize indication. This is one of the first signs that a navigator can spot in ample time sometimes even 10 nm ahead of the ice field. This is a luminous reflection on the lower part of the clouds just above the ice. During clear days this indication might be hard to see but it may appear as a light or yellowish haze. Even during clear nights with moonlight iceblink can be seen.

- When small fragments of the glacier ice are found, usually in the vicinity we can find a huge iceberg that is falling apart.
- Sudden calmness of the sea state and swell occur when we are on the leeward side of the ice field.
- The appearance of fog often indicates the presence of ice.
- On a sunny day, there may be abnormal refraction of light distorting the appearance of features. Although the ice field will be seen at a greater distance than would normally be possible without refraction, its characteristics may be magnified out of all proportion – it may even appear as giant cliffs of ice in the far distance, with breaks between them where the open water lies.

3.2.2. Entering the ice

To decide the route of sailing through the ice, the latest available ice chart and weather conditions are consulted. In today's world, all of this information is easily available and sometimes even updated a few times a day. But still, navigators have to bear in mind that as soon as they receive the ice information or weather information that is already a past state. Based on the latest ice charts, experience, and predictions of where ice might end up under the influence of predominant wind and current, ice navigators will choose the optimal route for sailing. The following notes on ship handling in ice have proven helpful (Ice navigation in Canadian waters, 2012):

- If an alternative route exists, although longer, avoid the ice.
- It is easy to underestimate and make a wrong assessment about ice type and that can damage and sink the ship.
- For a constant mass, force equals mass times acceleration, which means that the faster we enter the ice field and start ”touching” the ice a bigger force will be developed which can cause hull damage. Special attention needs to be given to speed and a balance between the ship’s maneuverability and safety needs to be established.
- If designed to do so, some ships can also move stern first in the ice. This activity should be carefully executed because of potential damage to the rudder and propellers.

- Glacier ice like icebergs, bergy bits, and growlers are current driven whereas pack ice is wind-driven. Huge pieces of old ice may be moving in the direction upwind or across wind according to the direction of the current.
- Pressure ridges should be avoided and passage through pack ice under pressure should be avoided as well.
- If stuck in the beset, the ship might be able to free itself by pumping and transferring ballast from side to side.
- Additional equipment like searchlights during the night and additional means of lookout should be utilized.
- Engine room should be notified and engines should be in maneuver mode.
- Ice draft should be utilized.

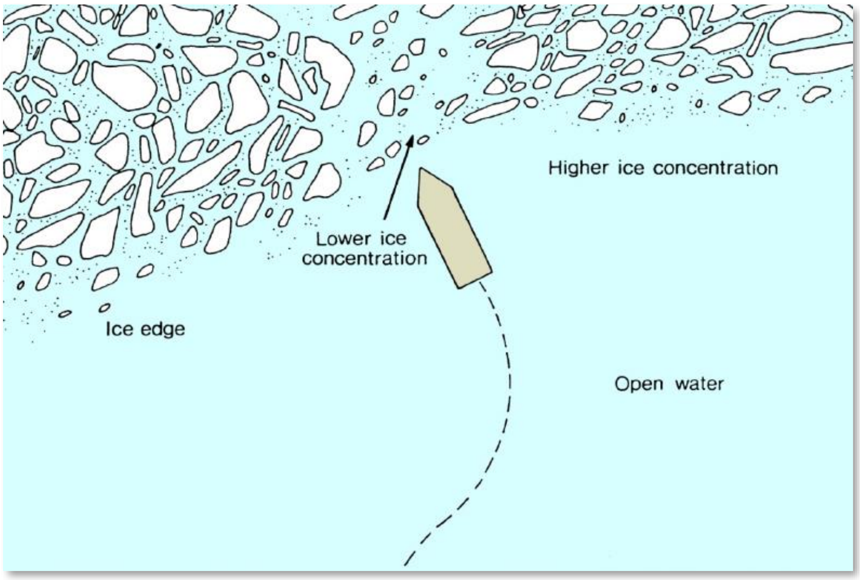


Figure 3. Entering the ice field at a right angle to the edge of the pack in the area of lower ice concentration

Source: Ice navigation in Canadian waters, Fisheries and Oceans Canada, August 2012

3.2.1. Navigating in the ice field

Once when the ship is on the ice, the speed of the vessel should be adjusted according to the prevailing ice conditions, weather conditions, visibility, and ship maneuverability. A few general rules are applicable (Ice navigation in Canadian waters, 2012):

- Use ice distribution to your advantage, and use open water and lighter ice-covered area for sailing if that does not mean you have to deviate from your original course too much.
- Always monitor the depth under the ice and monitor charts to determine if ice is grounded or movable
- In fog, bear in mind that a clear area can be a trail of an iceberg.
- If possible turn the ship's course in the area with light ice concentration.
- When turning around the iceberg be aware of the ”Foot” of the iceberg.

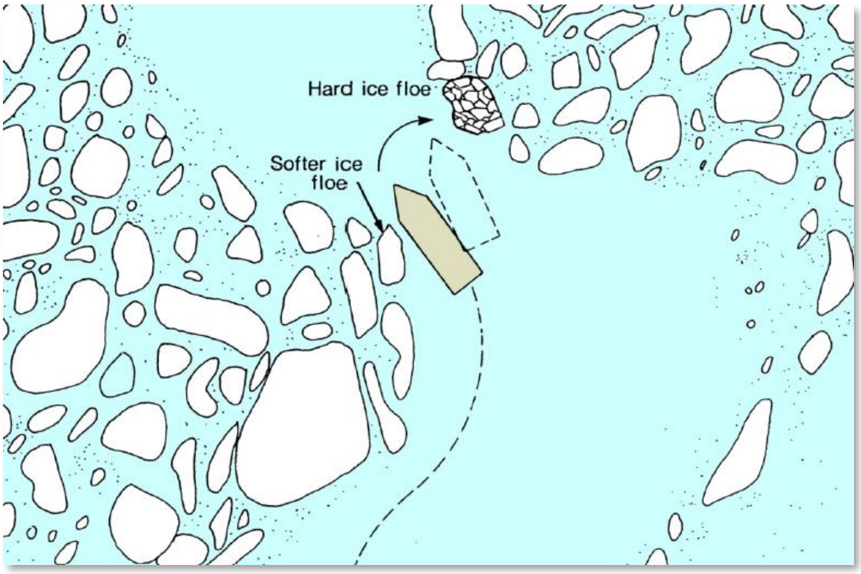


Figure 4. Turning in the ice

Source: Ice navigation in Canadian waters, Fisheries and Oceans Canada, August 2012

- Backing in the ice should be avoided by any means, but if necessary, it should be done at a slow speed, with the rudder in midship, and only with ships that are designed and built to do that. These ships are called double-acting ships.

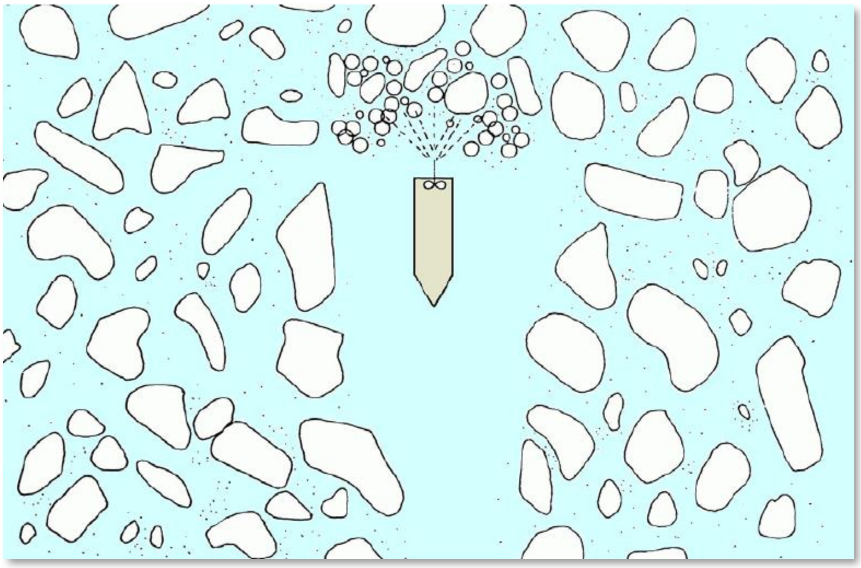


Figure 5. Backing in the ice

Source: Ice navigation in Canadian waters, Fisheries and Oceans Canada, August 2012

- When a ship is sailing through the ice there is an open path behind the ship. Usually, there will be a slight closing from the release of pressure as the ship passes through the ice but if the ice begins to close completely that means that pressure in the ice field is increasing.

3.3. Ice-types and what that means for navigation

According to the Ice navigation in Canadian waters, we divide the ice into two types by their place of origin and stage of development:

- lake and river ice, formed from the freezing of freshwater;
- sea ice, created from the freezing of seawater; and
- glacier ice is created on land or as an ice shelf from the accumulation and recrystallization of snow (Canadian Coast Guard, 2012).

Due to different certifications, rules, and regulations, I will concentrate on sea navigation, therefore, lake and river ice will not be considered in the text below. Pictures of the different types of ice can be found in Appendix I.

3.3.1. Sea ice

There are various types of sea ice, usually divided according to their stage of development (House et al., 2010). Within each of the stages, there are also sub-types, depending on the internal structure of the ice. Sea ice forms slower than glacier ice and the freezing point depends on salinity. We can classify ice by age:

- New ice is a general term for ice that is recently formed; it can be recognized for its soupy texture and matt appearance. The various categories of new ice are frazil ice, slush, shuga, grease ice and nilas.
- Young ice is the transition stage of sea ice between nilas and first-year ice. As young ice thickens it grows progressively lighter in color as well from grey to grey-white.
- First-year ice when it is formed is relatively soft but it grows in thickness and gets hardened as the season continues. This is one of the most dangerous stages of sea ice because sometimes it is hard to distinguish how thick the ice is and this crucial activity is mostly done by the experience of the navigator. It is divided by thickness:
    - Thin first-year ice (white ice)
        - The first stage is 30-50 cm thick
        - The second stage is 50-70 cm thick
    - Medium first-year ice 70-120 cm thick
    - Thick first-year ice >120 cm tick
- Old ice has survived at least one melting season. It is at least 3 meters thick. This ice is extremely dangerous even for icebreakers and special attention needs to be given when sailing in the ice field with this ice. At this stage, this ice can be hard as steel. It is divided as follows:
    - Second-year ice stands higher out of the water. Because of the summer melting and then freezing again, it is usually greenish-blue color.
    - Multi-year ice has survived at least two melting summers. Ice is usually blue and the abbreviations pattern consists of large interconnecting, irregular puddles with a drainage system.

All sea ice in the Baltic sea is of one-year variety, while in the oceans we have one-year and multi-year ice, with a variety of thicknesses.

3.3.2. Glacier ice

Glacier ice is the ice of land origin. This ice is usually characterized by different colors. Colors used to describe ice types are dependable on the light that falls on the ice and the contamination of the ice structure (like protein-nitrogen contamination and ground dirt). Glacier ice is divided into three categories (House et al., 2010):

- Icebergs are very common in the Arctic waters. They differ from the sea ice and they are completely formed from freshwater. They are formed when a piece of the glacier breaks off or calves into the sea. In the Arctic, we can find Ice islands (tabular icebergs).
- Bergy bits are pieces of ice that have broken off from the main icebergs. They can be found adrift in the vicinity of larger bergs. Radars can detect bergy bits 3 meters above the surface at approximately 3 nm during calm seas. Rough seas will reduce that range and accuracy which represents a big threat to shipping.
- Growlers are smaller bergy bits that have melted down so that their surface above sea level is less than a meter and with an area of 20m^2. Due to their shape and the fact that they are sometimes really small, ships have a hard time detecting them on the radar, especially on high seas.

3.3.3. Fast and pack ice

Aside from origin, we can distinguish ice by its mobility (House et al., 2010). The ice that forms and remains fast along the coast, and is attached to the shore to an ice wall, to an ice front, between shoals or grounded icebergs. It may move slightly in response to tides (vertical movement) but, throughout the winter, shows little lateral motion. This ice can be found in the Canadian Archipelago, north of Alaska, the entire Siberian coast, the White Sea, and North of Greenland. Fast ice can be more than one-year old in which case it may be prefixed with the appropriate age category (e.g. old, second-year, or multi-year). If thicker than 2 meters above sea level, it is called an ice shelf. In tidal areas, a tide crack will occur along the shore which may contain pressure ridges and areas of open water. (Canadian Coast Guard, 2012)

On the other hand, we have pack ice or drift ice (a mass of individual ice pieces known as floes). Pack ice is mobile and it drifts in response to winds and currents. The dynamics of pack ice may result in the ice being put under pressure, frequently leading to the deformation of the ice cover in the form of compact ridges and hummocking. Both the pressure itself and the deformed ice can affect ship navigation and it can even prevent icebreakers from navigating in this area.

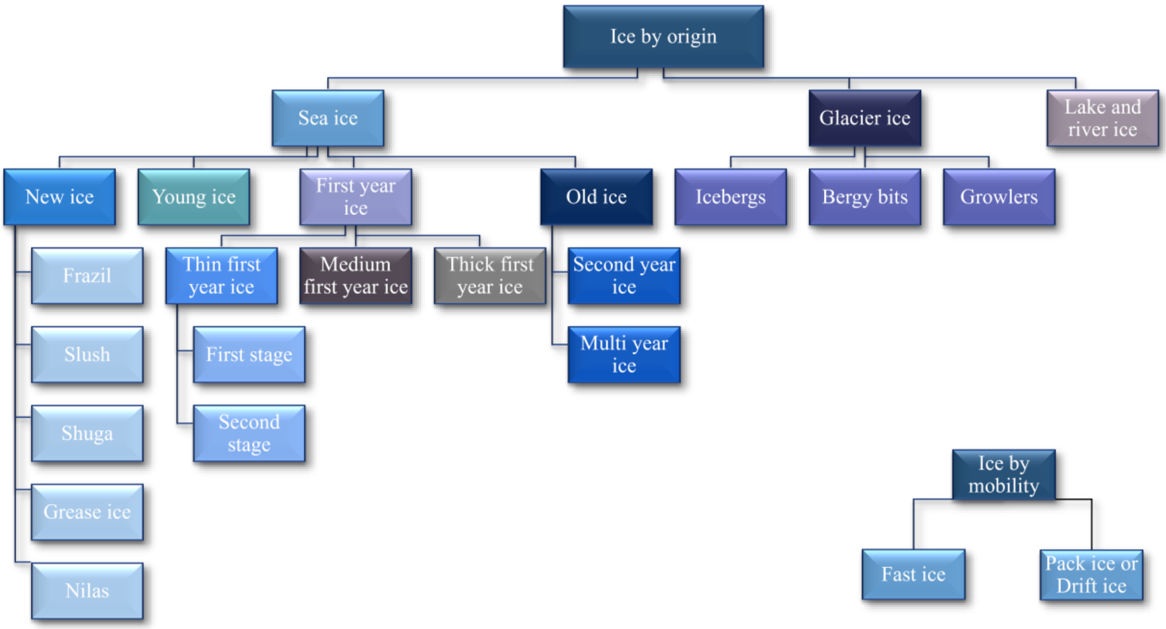


Figure 6. Ice types

Source: Ice navigation in Canadian waters, Fisheries and Oceans Canada, August 2012

3.3.4. Ice concentration

The other important factor in ice navigation aside from the ice type is also ice concentration of ice. This is information that we get from the ice charts: *”Concentration is a unitless term that describes the relative amount of area covered by ice, compared to some reference areas”*. Ice concentration can be reported as a percentage (0 to 100 percent ice), a fraction from 0 to 1, in tenths (0/10 to 10/10), or simply by color. Examples can be seen in Appendix II. (National Snow and Ice Data Center).

3.3.5. What does all this mean for navigation?

For ships operating in the ice, knowledge about the ice and rules about navigating in the ice are crucial, and these can prevent accidents and incidents during sailing. Ice navigation begins long before we see ice. As mentioned before, today's ice charts and ice information, in the form of a written report of satellite pictures are easily available for whoever needs them. Local hydrographic organization and Coast Guards in Arctic countries are providing their satellite pictures, and they are encouraging navigators to use all available information. Governments have different systems of how they symbolize ice on the chart. An explanation of the symbols is usually described in the legend at the bottom of the chart. Every operator either on the ship or in remote locations or AI in the future will be required to be familiar with the ice chart and its meaning. But regardless of the system, the information given is the same; it is about the type and concentration of the ice in the specific area. Based on the ship's capability, ice type, and ice concentration, the navigator or algorithm will decide on where the ship will sail, and route planning and risk assessment will be performed.

3.4. Route planning and risk assessment

Due to the danger that ice navigation represents, route planning is one of the crucial activities while sailing in ice-covered water. According to Ice navigation in Canadian waters (2012, p.107), we divide passage planning into two steps or two phases. The first phase is called **Strategic planning** (when in port or open water), and the second phase is **Tactical planning** (when near or in ice-covered waters). Both of these phases involve four stages: Appraisal, Planning, Execution, and Monitoring.

3.4.1. Strategic phase

In the appraisal stage, we use all information sources that we would normally use in open water passage (e.g. weather information, current information, Notices to mariners, local regulations and requirements, Sailing directions, etc.) plus any other information that can be obtained to give a complete picture of the ice conditions (like ice charts, satellite pictures, navigational warnings in relation with the ice situation, etc.). (Ice navigation in Canadian waters (2012, p.108). In addition, all historical data about wind, current, and ice is also used.

In the planning stage, we look to assess the ice conditions that the vessel is likely to encounter during the voyage. This stage relies on weather forecasts and ice charts. Here we will make a route based on information obtained in the appraisal stage. In this stage, we can also carry out a risk assessment with limitations such as availability of ice information (the ice chart is already history), reduced visual detection of ice hazards in the late season or winter voyages (hours of darkness), reduced visibility due to fog (widespread in summer months), poor or old charts with a limited amount of soundings, and so forth. The ship's capabilities and limitations are also considered along with the Polar water operational manual (PWOM), Polar Operational Limit Assessment Risk index system (POLARIS) and The Arctic Ice Regime Shipping System (AIRSS).

In the execution stage, we develop tactics on how to execute a plan that we assembled in the previous stage. ETA is determined based on expected ice conditions along the route, speed reduction, and significant deviations in the course (due to ice or bad visibility, or both). Remote control center manning can be determined in this stage as well.

The monitoring stage is continued until the ice-covered area is reached. As the ship approaches the ice-covered area, the quality and quantity of ice information improve, which gives us a better understanding of the situation and can lead to changes in the previously set up time of arrival and route that the ship will sail.

3.4.2. Tactical phase

If we did not have any ice information in advance or if the information received was outdated, the ship would be limited to the tactical planned route.

The appraisal stage in the tactical phase is based on tactical information in the form of ice charts and satellite pictures, marine ice radar, visual observations, helicopter/drone reconnaissance, and so forth.

The planning stage here means finding open water leads, finding first-year ice leads in close ice or old ice fields, avoiding areas of ridging, and avoiding areas of pressure or potential pressure. Ice movement either due to wind, current, or tide needs to be considered along with depth (ice can get grounded in shallower waters, and hitting grounded ice would be like hitting an island).

In the execution stage, we perform the planned route and continually monitor weather conditions, particularly visibility or wind direction and speed, and ice behavior.

The monitoring stage refers primarily to the position of the ship about the planned route, soundings, and landmasses. The buoy or other navigational aids that are not fixed on land should not be used because ice can push the buoy from its original position. (Ice navigation in Canadian waters, 2012, p.109)

4. Practical examples of ice navigation

A few months ago, I was sailing in an ice-covered area with officers who have never been in the ice before. Some of the officers trained in the ice simulator and they had some basic knowledge mostly related to the recognition of the ice origin. I wanted to explore that fact because as mentioned before teaching inexperienced human operators and machines has a lot of similarities.

4.1. Strategic phase preparation for sailing in Hannuse bay

In this example, we were sailing in Hanusse bay and since it was the month of March, civilian twilight was at 2050 LT. Historical data of the weather patterns, current patterns, and historical ice conditions data were taken into account. Environmental requirements like speed restrictions in the area are also taken into account. Available depth data was limited and the ship relied on historic OLEX data along with sonar. The ship's data about the area was limited but both the Captain and Staff Captain have been sailing in the area multiple times so their experience played a major role in the decision-making process. The available ice chart and satellite pictures for the area were 4 days old, and in my experience, we considered those ice charts to be a limited source of information. To get a better picture of the ice, we needed to include the prevailing wind and current in the area in the last few days. The strategic phase of the voyage planning was concentrated on the weather conditions.

4.2. Tactical phase- appraisal stage for sailing in Hannuse bay

The weather forecast for the sailing area was good, with no wind, good visibility, and a clear sky and it was forecasted to stay like that for 48 hours. Because there were no new ice charts and satellite pictures, the ship's helicopter was utilized and a reconnaissance flight was sent to check the ice condition while the ship was slowly approaching the south end of Gullet. After the flight was completed, the intended route was planned as shown below. In these areas depth information is limited to only a few sounds in the bay. The decision about the route, made by senior officers on board, was mainly based on the previous OLEX tracks and the ice situation observed during the reconnaissance flight. Deviation from the planned route was allowed, but the ship had to stay within the OLEX track limits.

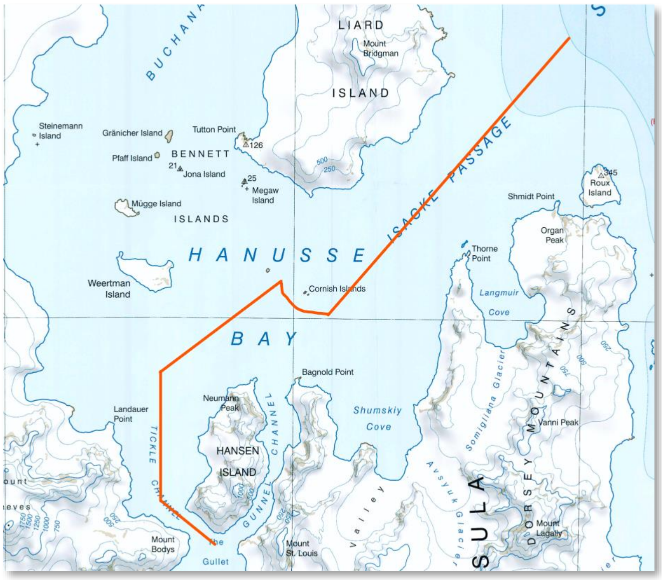


Figure 7. Area of interest

Source: Adelaide Island & Arrowsmith Peninsula 2, British Antarctic Survey chart

The plan was based on the following pictures: (all of these pictures were taken from the helicopter around 0730LT).

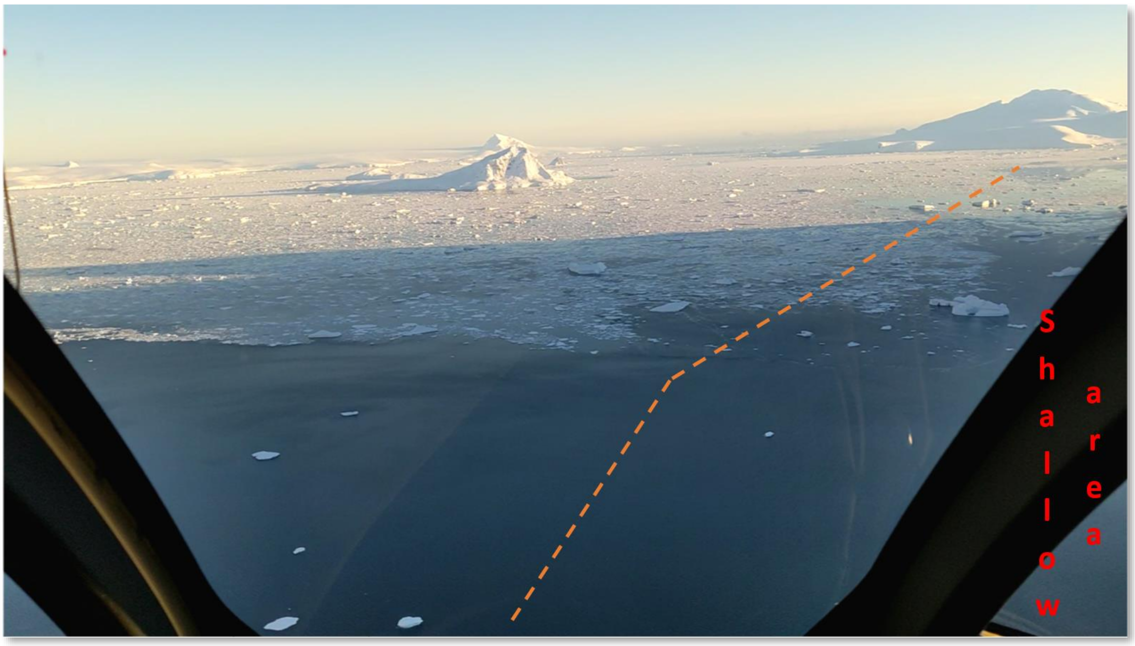


Figure 8. The south end of Hannuse bay
Source: private collection

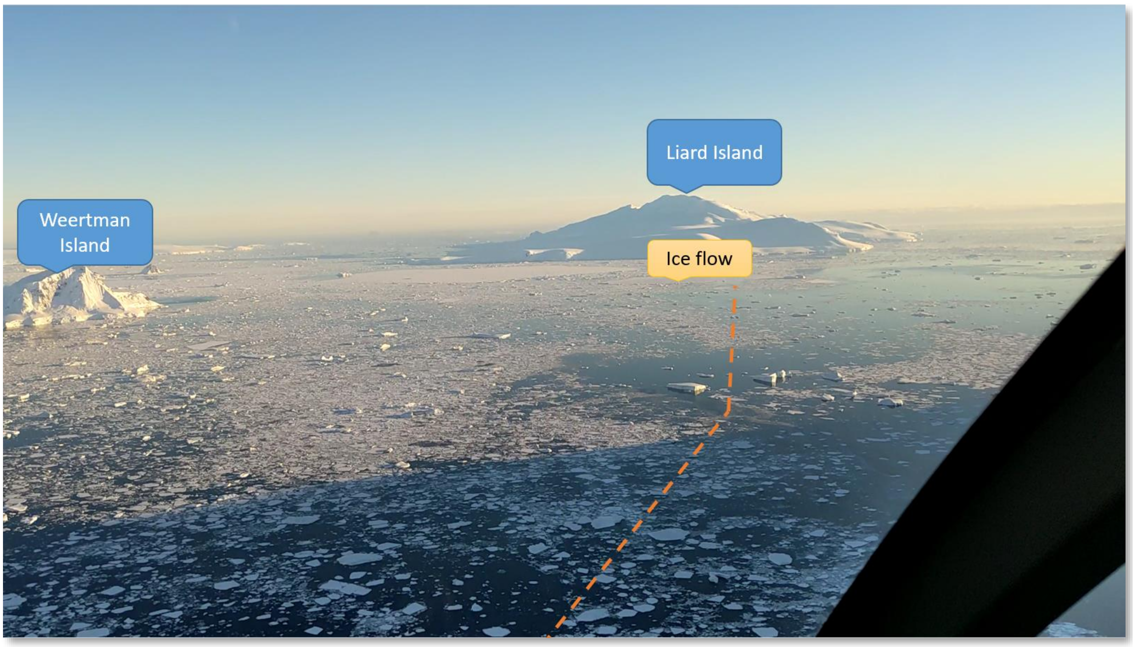


Figure 9. Approach to the ice floe
Source: private collection

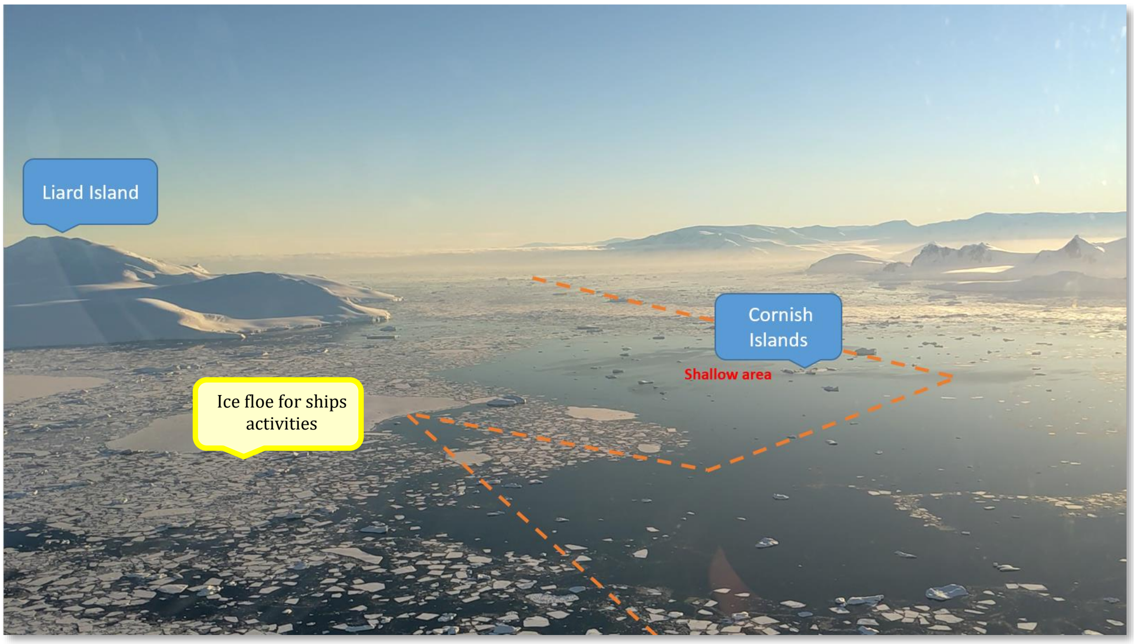


Figure 10. Ice floe and Cornish Islands
Source: private collection

Figure 11. View from the East
Source: private collection

Appraisal of current and wind conditions indicated the floe would most likely move eastward. The ice floe eventually moved 0.5 kt per hour and in approximately 4 hours. The big ice floe that the ship was sailing toward to perform the ship’s activities, ended up next to the Cornish islands.

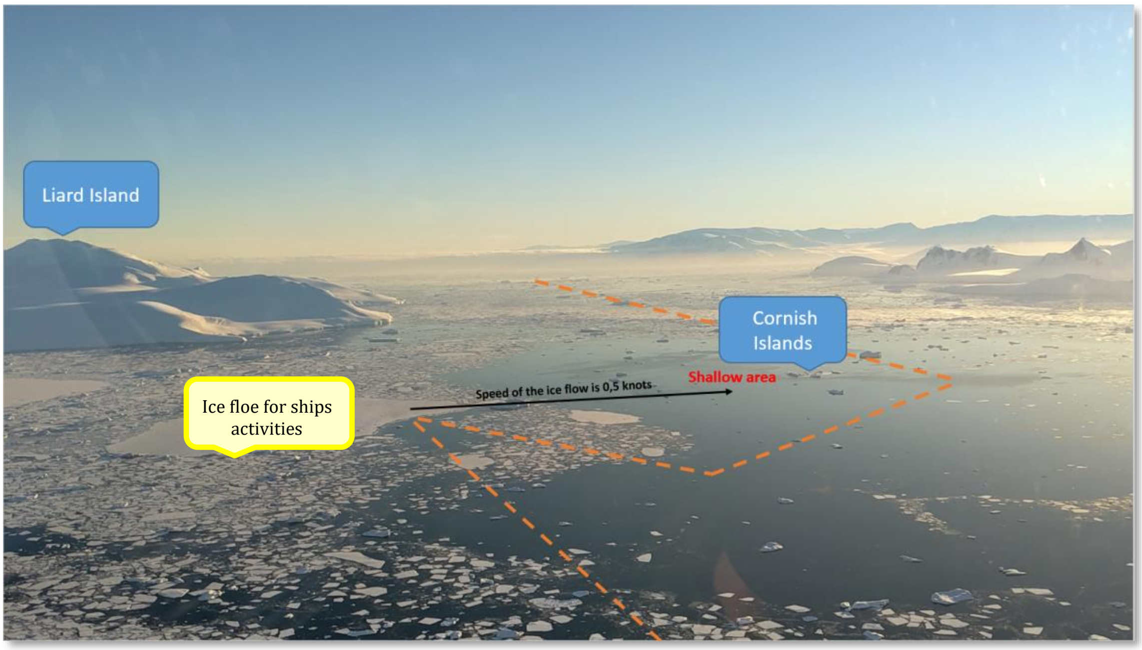


Figure 12. Ice movement
Source: private collection

4.3. Tactical phase- planning, execution, and monitoring stage during sailing in Hannuse bay

The planning, execution, and monitoring stage are all happening simultaneously so these stages will be observed together.

At this stage of the voyage, all personnel on the bridge needed to work together. The main task was to find a way through the different types of ice with different stages of development. Depth, topography, and weather conditions needed to be constantly observed as well. The ship's capabilities, company procedures, and Polar water operational manual (PWOM) are considered to be the base for operation in the ice. The Bridge team consists of a Captain, a Staff Captain, an Officer of the watch, and a lookout. Both, Captain and Staff Captain had many years of experience in the polar region and ice navigation. The officer of the watch, on the other hand, had only a few months of ice experience and mostly in light ice conditions, and he had never sailed in this particular area before. In the next few pictures, I will try to explain how the ship sailed through the ice field. In the pictures below

- yellow arrows represent multiyear sea ice,
- black arrows represent icebergs,

- purple arrows represent growlers,
- the green arrow represents the ridge and
- red arrows represent the intended sailing route.

Ice navigators look at the ice field through two different ”lenses”. The first one is a ”long lens”, to set a general direction of where the ship will be sailing. That is usually determined by observing the number of big icebergs and their mutual arrangement with each other. If there is clear water ahead, an experienced navigator will aim for that area, because through that space it is easier to sail and the ship can speed up for a few miles if needed. A clear area represents a potential space where ice that is on the way can be displaced and it is a good indication of the pressure on the ice field. The second lens is the so-called ”short lens”. Here we will determine how to get to the position that was determined by observing the ice field with a ”long lens”. We will consider a general direction that we need to obtain to get to our destination. The existence of the OLEX track in that direction, sounding information on the chart, ice that is on the way, and sun position will also be taken into consideration. Sailing directly into the sun should be avoided if possible due to reflection in the water.

Due to the amount of ice in the area, situation awareness amongst young OOWs was reduced, and often they would completely forget to monitor the stern camera and the situation behind the ship. They did not pay attention to the sun and very often proposed a route directly into the sun. Furthermore, OLEX tracks and depth data were often forgotten.

The ship in question was not an icebreaker and the principle of sailing through the ice fields with a PC6 (1A Super) classified ship is to push ice at a safe speed. Decisions of which ice piece to push and which ice piece needs to be avoided are based on the concentration of the ice, the type of ice, shape, floe size, and position where contact will be made between the ship and floe. First-year sea ice can easily be broken. Multi-year sea ice can be used to push bigger pieces of glacier ice that have a bergy shape. Glacier ice and bergy bits need to be avoided because they can be very unstable. Most of their ice volume is under the water level and if they are touched or pushed, icebergs, bergy bits, and bigger growlers can easily flip and damage the ship's hull.

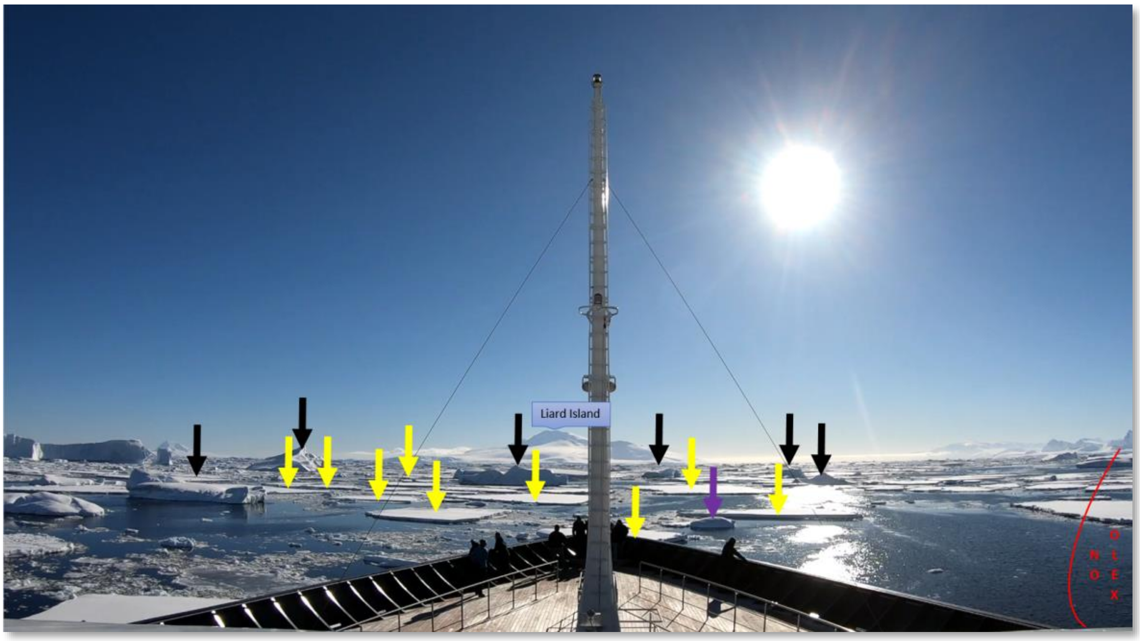


Figure 13. Entering ice field
Source: private collection

As seen in the picture above, on the starboard side there are no OLEX tracks and the eastern side of the bay is lacking soundings. OLEX track exists in the northerly direction. Our destination is just south of Liard Island and the picture above is just ahead of us. It was decided that the ship will turn a few degrees to port into the area with a grouping of yellow arrows (multiyear sea ice). The ship will aim at the edge of big ice pieces as shown in the picture below. It will stay clear of big icebergs and potential ”foot”, and it will maintain an almost straight course. The ship will not sail in the sun's direction and the ship will stay on the OLEX tracks. It was observed that tidal current is not significant. The ice situation ahead based on reconnaissance pictures was considered to be doable. The expected sailing through the ice was 12 hours. (including 2 hours of ship activities). In that period weather conditions were expected to stay the same.

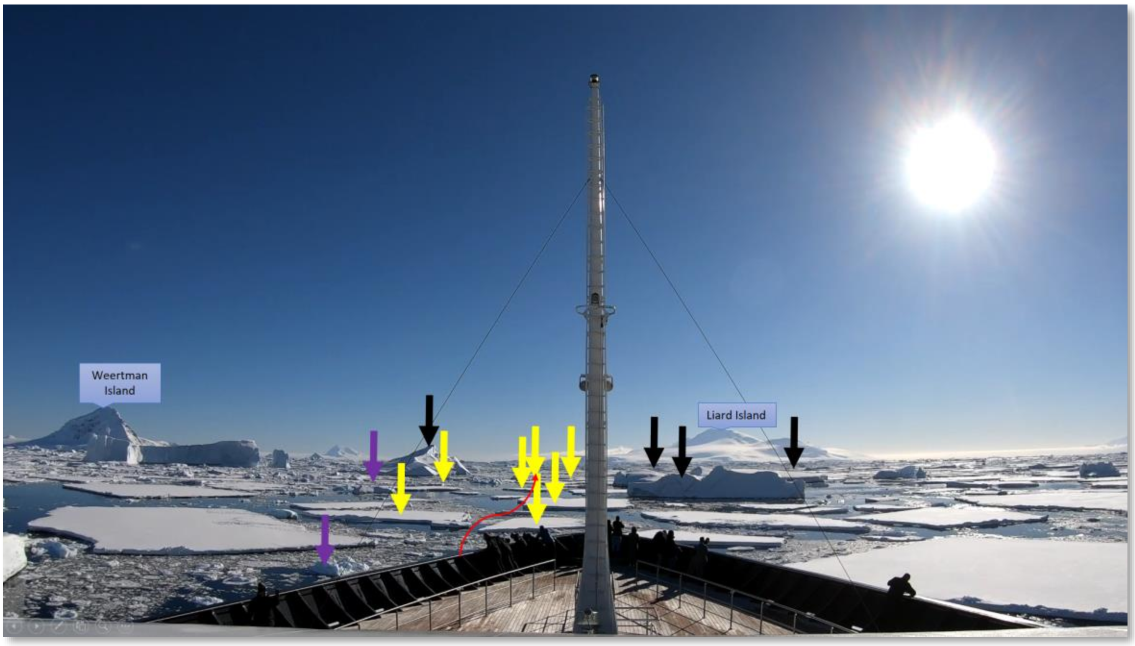


Figure 14. Sailing in Hannuse bay
Source: private collection

It is visible in the pictures that there is enough space to push the ice and that the pressure of the ice field is not relevant for now. This is something that due to the current can easily be changed so the pressure of the ice field is constantly monitored and observed. The red line in the picture above indicated the intended route.

In the picture below, purple arrows indicate growlers and bergy bits. Even though they are smaller than icebergs they have the same origin, glaciers. They are avoided but if there is a need to sail through, the ship's speed needs to be additionally reduced.

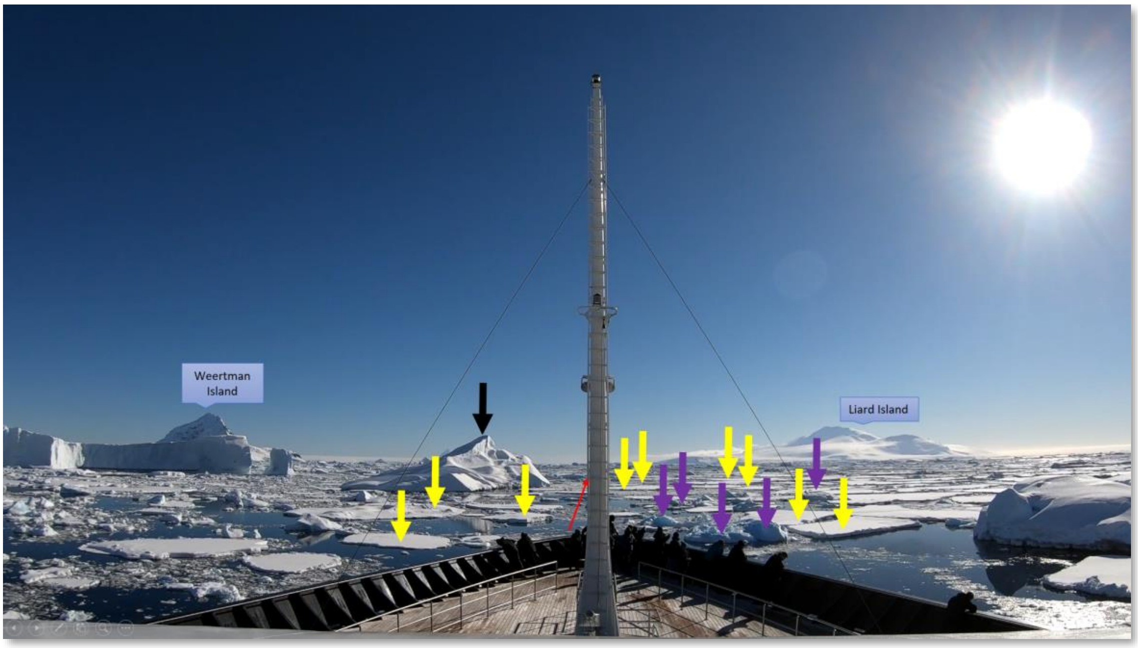


Figure 15. Ice field Hannuse bay
Source: private collection

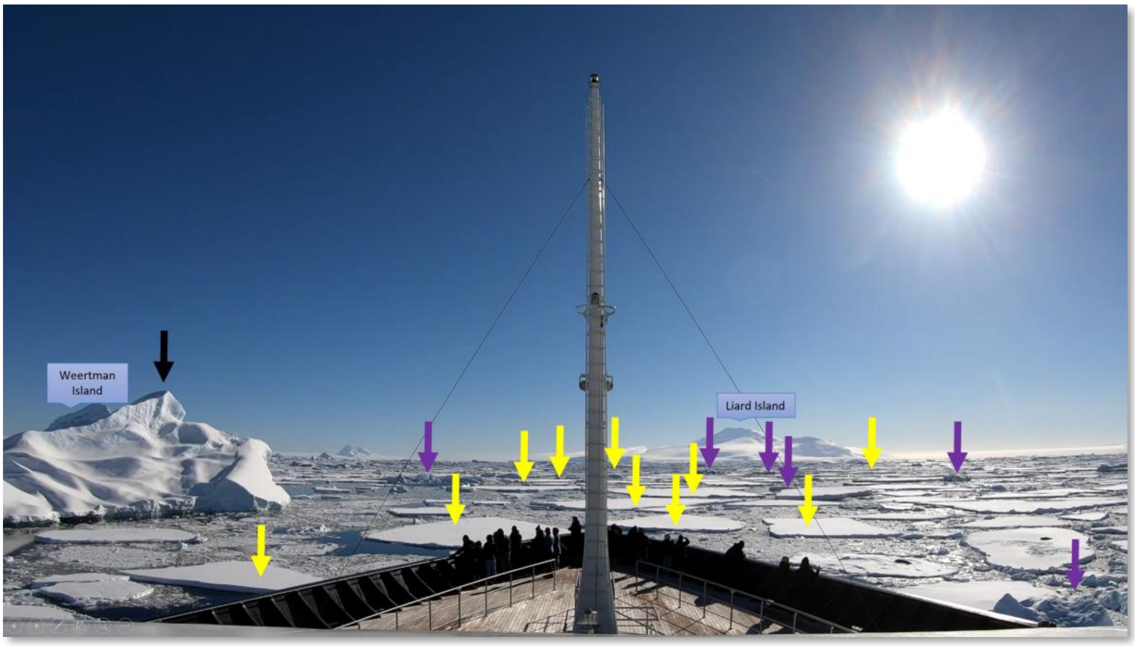


Figure 16. Ice floes Hannuse bay
Source: private collection

In the picture below, the ice ridge arose between two ice pieces. That happened because the ship pushed a piece that is close to the ship toward the second piece. This is something that needs to be taken into consideration because with the slow speed of 2-3 knots, ships cannot push numerous numbers of ice pieces together. The build-up of the ice pieces that the ship is attempting to push can stop the ship. That is dangerous because by losing speed, the ship is losing her maneuverability and can be pushed into icebergs, bergy bits, and growlers.

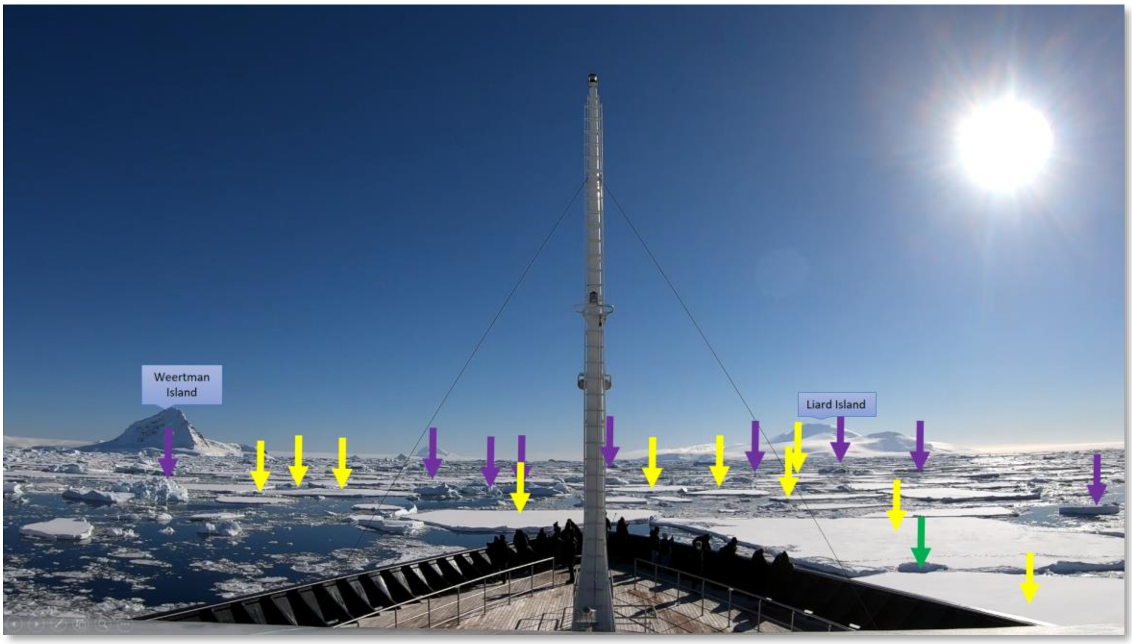


Figure 17. Ice ridge
Source: private collection

5. Autonomy in ice navigation

In recent years, technology has been developing at an exponential rate, pushing and changing the boundaries of what we consider to be possible. Autonomous technologies are mainly mentioned in the car and truck industry, and the rate of advancement is happening rapidly in those industries mainly due to public interest and a wide range of use (Report Linker 2021), but more and more autonomy is being considered for ships and the maritime industry as well (Bosch, 2022).

International Maritime Organization (IMO) a few years ago identified four degrees of ships autonomy:

- **Degree one**: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
- **Degree two**: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and operate the shipboard systems and functions.
- **Degree three**: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- **Degree four**: Fully autonomous ship: The operating system of the ship can make decisions and determine actions by itself.

Regardless of the degree of autonomy on the ship, and regardless of who is at the helm, AI, a human operator on board, or a human operator in the remote control center, there is one thing that all of them have in common, the need for situational awareness.

To understand situational awareness and its complexity, first, we need to understand the environment or system where situational awareness needs to be obtained.

5.1. Sociotechnical system

In the work environment where humans and technology meet and work toward a common goal, it is of utmost importance that communication between all elements is clear and immediate. These kinds of systems are called sociotechnical systems and they are based on sociotechnical system theory. The theory focuses on the interaction between social and technical elements to improve communication. In a simple system, interaction is linear and can be predicted, but in a complex system like a ship, environment interaction becomes more multileveled, interlinked, and unpredictable. (Hynnekleiv et al., 2019)

Relationships between elements such as seafarers, AI software agents, or operators in shore centers along with their hierarchy in the system must be defined. Hynnekleiv et al. (2019) stated that their relationship can be displayed in the following design approaches:

Table 3. Design approaches for human/system interaction,

Design Approach	Description
Augmentation	The system improves human performance
Replacement	The system replaces human functions and/or entire human jobs
Remoting	Allows the user to act on the physical environment at a distance
Teaming	The human and machine work together for a common goal
Symbiosis	The human and the system are closely linked working together for mutual benefits
Parasitic	The human is a source of data collected by the system, but with little or no benefit to the human
Influence	Intelligent systems influencing human behavior
Unknown	As yet undefined paradigms relating to organizational social/cultural, and societal relationship
Benevolent Governance	Human/humanity passing governance to AI

Source: Siri, sail the ship!, A.Hynnekleiv, M.Lutzhoft, J.V. Earthy

5.1.1. Augmentation

Augmentation in this case is viewed as human augmentation. It refers to technologies that enhance human productivity or capability (ISO). One of the first ideas about augmentation on board the ship is to help with the lookout. According to International Regulations for Preventing Collisions at Sea (COLREG) in Rule 5, lookout is recognized as:

> Every ship shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions to make a full appraisal of the situation and the risk of collision.

It is obvious from the definition above that, for now, we still can not remove humans from the loop, because sight and hearing requirements in this case are considered to be human abilities, but there is a possibility to add means for better situational awareness. There is no doubt that there is room for improvement, human lookout gets fatigued, concentration goes down and the quality of the lookout is diminished. Recognition of ”what you see” is hard to develop and at the moment still needs to be done by a human operator. The concept of teaming would be the most likely outcome. An environment where automated lookout and human operators (either on board or in the remote center) can ”discuss” what they see and develop collective situational awareness would improve lookout on board the ships. (Hynnekleiv et al., 2019).

5.1.2. Replacement

International Organization for Standardization (ISO) defines replacement as follows: ”The system replaces human functions and/or entire human jobs”. There is a common perception amongst seafarers that they will lose all of their jobs as soon as companies start introducing automation and AI. That might be partially true but looking at the bigger picture, time is a big factor that needs to be included in the equation. Humans today are performing a lot of interpretation in the complex, always changing environment. They based their interpretation of the situation on their knowledge, and experience, and by recognizing patterns. For now, we still can not rely on technological elements or systems to perform this cognitive process on the same level as humans do. On the other hand, some tasks like crossing over the Pacific

Ocean might be one of the first tasks that technological elements or AI systems will be able to perform.

The other common catchphrase is that human errors need to be removed which leads to the assumption that technology (machines) will not make any mistakes or errors. Even today with newly installed autopilot on board, operators are encouraged to ”teach” the system and to adjust the rate of turn and perform a turn on heading or course mode so track pilot mode can ”learn” how the operator performs turn. New technologies and systems will need time to learn to perform simple tasks on a human level and there will not be better teachers than humans. Humans require rest, stimulating, rewarding and meaningful jobs, and have a limited supply of alertness and attention so teaming and augmentation with the technology will benefit both instead of replacing one system with the fault with another system with the faults. (Hynnekleiv et al., 2019)

5.1.3. Remoting

As per the ISO definition user will remotely control physical objects at distance. There are a few points that will need to be addressed. First, there are more ways to set up remote operations. One way is for a ship to be remotely operated from the remote control station that is placed in the major cargo port or the ship can be remotely controlled by another ship for example in a convoy through the ice, the leading ship can control the remaining part of the convoy. Secondly, even today in the simulators, operators lose the authentic experience and contextualized feeling. Received pieces of information are perceived differently than those that are experienced in real life when the person is on board (Hynnekleiv et al., (2019). In addition, new operators who do not have previous experience with the ship will be deprived of the experience and skills of ship handling, equipment, and system management on board. A new type of operator will have to be trained in the future and training would have to be more like today's drone operators’ training and less like a seafarer who started on board as a cadet painting and derusting ship's deck.

5.1.4. Teaming

Teaming of the technological and human elements, according to Hynnekleiv et al. (2019) can be developed in two ways. Either to remove some of the jobs from humans or to improve safety and implement an additional layer of redundancy. The automation will require knowledge and experience and being in the same team can take some of the workload. To do that automation or technological system will have to have some situational awareness like human operators and it needs to have means and possibilities to communicate that with the human operator. Design goals will have to fulfill requirements for collaborative work and social exchange. As AI elements learn new skills and gain experience from humans or events, it will be perpetually changed and the new state needs to be understandable and transparent to a human operator. In the case that humans have to take over the control abruptly, the human operator has to increase situational awareness almost immediately. This issue will have to be addressed while designing the system.

5.2. Symbiosis

Symbiosis can be seen as the best version of teaming where both humans and AI elements have mutual benefits (ISO). The basis for symbiosis is good communication between a human operator and AI element where both can ”jump in” into the problem and solved it together. This scenario, due to the complexity of the work environment, to be truly symbiotic, requires both humans and AI elements to be highly skilled and to trust each other (Hynnekleiv et al., (2019).

5.2.1. Parasitic

The line between symbiotic and parasitic environments is blurry and it can easily be crossed from one side to another. It is really easy to move from a symbiotic environment to a parasitic environment on board the ship when a human operator is used as a trainer of the AI element. At the beginning of the interaction, the relationship can be beneficial for both but down the line, humans can be replaced or be used as a data source without specific benefit for themselves. (Hynnekleiv et al., 2019)

5.2.2. Influence

There is no doubt that even in today’s environment, human operators are influenced by the even low level of automation. We can see this kind of situation with unattended engine rooms. There is a lack of willingness to leave the control room to check what the sensors are telling us, combined with the trust that everything is working as it should with the monitoring system. (Hynnekleiv et al., 2019)

5.2.3. Benevolent governance

In this environment governance of the ship is completely handed over to the AI element (ISO). Usually, when talking with seafarers this is the first idea that comes to mind. In reality, this is hard to design and it will not be applicable in the near future. There is also a question should humans be completely isolated in the first place because humans still contribute to the environment even with the different roles that they have at the moment. (Hynnekleiv et al., 2019).

5.2.4. Potential issues within sociotechnical systems

Connecting humans with any type of technology will raise a range of issues. Hynnekleiv et al. (2019), (according to Ergonomics of human/system interaction – Part 810: Human/system issues of robotic, intelligent and autonomous systems, by ISO), identify and arranges issues in six groups:

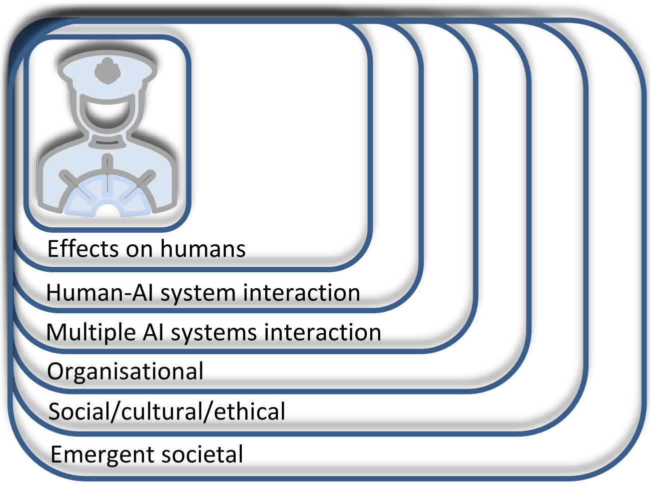


Figure 18. Categories of sociotechnical issues

Source: Siri, sail the ship!, A.Hynnekleiv, M.Lutzhoft, J.V. Earthy

As shown in the picture above the effect of the issues is concentrated around humans and it starts with the individual who is in direct contact with the AI system. But issues and effects of the issues are not limited to the individual. They are spreading to teams, organizations, and even cultures and societies.

To overcome these issues, AI elements within the systems will have to be designed around humans to maximize the proficiency and capabilities of both humans and AI elements.

5.3. Situational awareness

In the world of automation, humans have remained a critical part of an automated system. They have been tasked to monitor for failures and to be present and perform the task when the system encounters a situation that was not designed to handle. When we task humans to perform a monitoring role in a complex automation system, humans are very often slow to detect that problem occurred necessitating their intervention. Once when humans detect that automation needs their assistance, additional time is required to determine the state of the system to sufficiently understand what happened to be able to act appropriately. The aviation industry and car industry have much more collected data on the mentioned issues. In the aviation industry in the 80-ties we had numerous incidents connected with insufficient situational awareness that caused loss of life and equipment. According to Endsley (1994), in recent reviews of commercial aviation accidents, 88% of those with human error involved a problem with situation awareness. Not so long ago in the car industry autonomous cars, who are graded at a higher level of automation, also had incidents connected with a lack of situation awareness of the driver. (Endsley (1994).

Although the maritime industry is catching up with automation (Pazouki et al., 2018), there is hope that it can learn from the aviation and car industry and avoid making the same mistake. Unfortunately, there are already examples of accidents in the maritime industry caused by a lack of situational awareness.

In 2013, the dive support vessel (DSV) Bibby Topaz was performing diving operations at a 91-meter depth when the ship suffered a DP control System Failure and consequently lose control of the vessel movement. Weather in the North sea, where diving operations were performed, at times, can be challenging and the situation was no different in this instance. The wind was NW'ly gusting up to 30-45 kts with a wave height of 4 m. Ship is equipped with 4 generators two main propulsion systems, two retractable azimuth, and two tunnel thrusters. During operations 3 generators were engaged and 5 out of 6 thrusters were running on DP. Two divers, shortly after 2000 hrs LT descended to the drilling template to carry out valve operations for barrier testing. At 2209 hrs LT, the DP system sounded an alarm related to K-Pos RBUS communication, which is a Redundant Communication BUS. The amber alarm was activated by the DPO and the instruction was immediately given to the Dive Supervisor for divers to make their way back to the diving bell. The initial DP alarms were followed by the loss of all analog and digital RBUS Input/Output signals, which means that the DP system lost the I/O signals of position references (DGPS) and all environmental signals (wind data etc). At 2211 hrs LT, DP red alert was activated and the ship was easily drifting easterly, all references and thrusters were unavailable to DP, 4th generator started but both divers were still on top of the template. Diver 1 managed to get off the template but diver 2 umbilical snagged on the transponder and was stuck on the template. Between 2213 and 2215 hrs LT, Diver 2 umbilical severed, and he was left on the template while Diver 1 managed to get to the bell stage. By the 2217 hrs LT, the vessel drifted 240m NE of the Drilling Template. The Chief Engineer, 1st and 2nd engineers along with ETO verified the status of DP controls and thrusters in the instrument room and main propulsion, confirming that the problem was in the DP control system rather than in the thrusters. At 2217 hrs LT, Captain and Chief Officer gained manual control of the thrusters and headed the vessel back to the drill template. By 2240 hrs LT, the power of DP was recycled and the vessel was able to return to full DP auto mode on top of the drilling template. At 2248 hrs LT Diver 2 was recovered unconscious but alive. He regained consciousness shortly after.

According to the Incident investigation report made by the contractor, DP manufacturer/supplier, the Classification Society, and the regulatory authority, it was determined that the RBUS jammed involving faults in one or more RBUS I/O modules in the DPC-3 cabinet (one of 3 cabinets/central processing units containing DP control system hardware). No definitive cause of the jamming was identified. However, several hardware faults were found, and the control system did not detect the jamming of the RBUS and take appropriate action. Faults that were found are: loose/intermittent connections of fuse in DPC-3 cabinet, grounding; the current was measured in the bond from the RCU units to ground, Inner shield on field cables was not connected to instrument earth and DPC 3 cabinet was not earthed to ship hull structure.

I believe this is a good example of how complex these systems are (in this example, the task of this system was ”only” to hold the ships’ position against the wind and current) and how one group of people can not know everything about the system itself. One can argue that Captain and Chief Officer on board needed a long time to regain control of the vessel. That might be caused by the lack of situation awareness and at the same time, a team of Engineers needed some time to check and understand what is the problem, and where the problem is generated. This can be caused by a lack of situation or system awareness but at the same time, it can be a fault in the system in the shipbuilding process. In most situations, the team on board needs time to understand where the problem is and this is mostly done by a principle of elimination or by experience.

At the time of the incident, DP systems have been used for a long time in the maritime industry and still, this kind of complex incident happened. One of the results that came out of this incident is a few modifications to the system itself. A permanent solution has been made available as an RBUS I/O Modules Firmware Update kit consisting of installation and verification procedures, the watchdog functionality self-test function was installed that will allow the unit to recognize jamming faults and provide diagnostic coverage for other CPU faults and isolation modules were provided should any of the faults occurs, the system will be able to remove the faulty unit from the network ensuring that the inbuilt network redundancy can be utilized. It is visible by the results and measures that were consequences of the incident, that knowing how the system works and what is the operator’s role in the system, even in the automation system, and especially in a remotely controlled system, is crucial for situational awareness.

Regardless of who is responsible for operation or functions on board a vessel, either a human operator in a remote control center or AI, both will need sufficient situational awareness to provide a firm basis for analyzing the situation, planning actions, and executing remote control of the function.

Ice navigation requires a high level of real-time situational awareness. The pre-planned route can be changed various times before the ship even arrives in the icy waters. Ones when the ship is in ice, monitoring of the ice situation needs to be maintained at all times.

Situation awareness is defined by Endsley (1988a) as ”the operator's perceptions of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.″

In this definition by Endsley we have three different levels of situation awareness:

- **Level 1** - the perception of the elements in the environment;
- **Level 2** - comprehension of the current situation and
- **Level 3** - the projection of future states.

To fulfill all three mentioned levels above, we can divide ships systems as follows:

1. Ships position monitoring system,
2. Object detection system,
3. Recognition system,
4. Prediction system and
5. Action system.

5.3.1. Ships position monitoring system

Even today, we already depend massively on sensor technology. I am working on board the ship that was built in 2019. Almost every single system on board has some kind of sensor, pressure sensor, level sensor, pitch sensor, angle sensor, temperature sensor, roll sensor, etc. Today's systems are being built in a way that they are more robust in case something happens. It is common to see, especially on newly built ships, multiple independent DGPS and GPS systems onboard. In the future with remotely operated ships and autonomous ships, the importance will be even higher. (Gardner, 2021). Problems come when, even with redundancy systems, we lose the signal and input into a monitoring system, as seen in the case of the Dive Support Vessel. Since harsh weather conditions and long fjords in the Arctic are very common, a good system will always have multiple inputs. For position monitoring purposes, we could have different independent inputs. For example, automatic position plotting with radars pictures and cameras (to cross-check the DGPS information) could be developed and the system could do the same thing that today, we call terrestrial navigation, information received from cameras and radars could be cross-checked with ECDIS information, OLEX information, SONAR or Eco Sounder information.

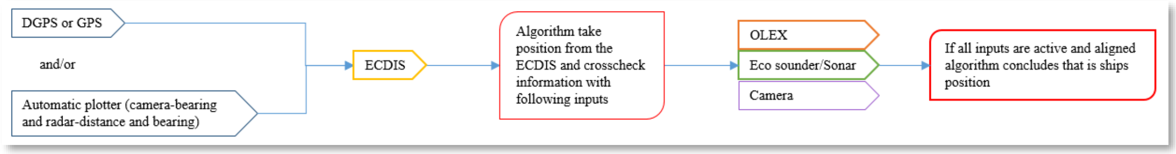


Figure 19. Ships position monitoring system

Alternative systems and concepts like doppler-based solution *The Next Constellation* (of LEO Satellites) made by Iridium and automated celestial navigation such as Daytime Stellar Imager made by Northrop Grumman and Trex Enterprises could be integrated into the systems as redundancy as well. (Gardner, 2021).

With these two independent systems, we have redundancy even in the case of a cyber security breach of the GPS network. The important part of this process is held within ECDIS, as seen in the example above, and therefore the quality of the electronic chart will be crucial for operation. In the Arctic, surveying is hard, half of the year area is covered with fast ice and darkness. Even during the summer months, some parts of the bays and fjords are completely covered with pack ice, and therefore surveying in the way that is being done today is not possible. New technology and maybe even underwater vehicle will have to be used to maximize and speed up the process of surveying, in this, very often to this day, unexplored and surveyed area.

5.3.2. Object detection system

Rule 5 of COLREG says

> Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate to the prevailing circumstances and conditions to make a full appraisal of the situation and the risk of collision.

To have safe navigation, any element or object that can affect the navigation must be detected on time. We can divide these elements into geographic elements, bathymetric elements, fixed objects, floating objects, weather conditions, ice conditions, and conditions that can affect a ship's maneuverability. Today for detection, as seen in the rule above, we are mainly relying on the human that is supported by sensors, like radar. To replace this requirement for the human operator, we need to add sensors that can do what the human operator does now, so we need something that can collect visual and sound data. Sensors that could be used are daylight cameras of different types (stereo, multispectral, etc.), infrared cameras, Light Detection and Ranging cameras (LIDAR), as well as sound detectors. All these sensors would need to be weatherproof so they would be operational and useful in heavy weather conditions, heavy rainfall, snowfall, fog, and darkness, especially in the Arctic where we can navigate in the fog and darkness for months.

One of the intelligent alarm systems that are already available on the market is SEA.AI Sentry. (sea.ai). The system had been used to enhance the safety of crew members but with further development, it might be used as a good start with remotely operated ships and eventually autonomous ships. It combines optical and thermal camera setup and artificial intelligence to detect floating objects during the day and night. It assesses the risk of both, collision and approaching objects when at anchor, in real-time, and warns the operator of any danger. SEA.AI Sentry contains two main parts, a mast module that is placed on top of the mast of the ship and a processing module that is placed on the bridge. The mast module is made of two thermal cameras and one daylight camera along with one gyro sensor. Cameras are taking the image, stabilize the image and then the image is sent to the processing unit. The processing unit analyzes the image, and objects that are on the water, the position is calculated and if there is a collision or risk alarm is triggered. This alarm in the future could be connected to an autopilot unit that if needed could change the course. On top of the image, the system ads layer for augmented reality with object information.

SEA.AI Sentry uses machine-learning algorithms based on statistical methods and it mimics what humans can do. AI needs a big database to be trained. Potentially in the future, this system could be used to detect even small growlers in the rough seas, during fog or darkness, something that radar, and especially human operators have problems with.

Another system already available for cargo fleets is a system called ORCA AI. In May 2022, cargo ship Suzaku, a 749 gross ton vessel sailed through the congested waters of Japan for 40 hrs. on full autonomy for 99% of the journey's time. During the trial (about 9 months), the vessel performed 107 collision avoidance maneuvers avoiding 400-500 ships. (Chaudhary, 2022). The system was delivering real-time detection, tracking, classification, and range calculation on eighteen onboard cameras integrated with ECDIS, GPS, radar, and AIS. Cameras are detecting hidden objects increasing the awareness of hazards in ports, and congested waters during hrs. of darkness and fog. The system is powered by maritime purpose-built machine learning and computer vision algorithms. (orca-ai.io) With proper datasets, this system might be able to detect the ice.

a) Line of sight b) Thermal camera

Figure 20. ORCA AI Reduced visibility (fog)
Source: https://www.youtube.com/watch?v=dCNkTikRwk8&t=2s

a) Line of sight b) Thermal camera

Figure 21. ORCA AI Exiting a port during the night
Source: https://www.youtube.com/watch?v=dCNkTikRwk8&t=2s

5.3.3. Recognition system

When we have both, information about our position and information about objects surrounding us, all this information has to be collected and used to analyze the condition of the ship at any given time. To have a satisfying level of situational awareness all detected objects need to be recognized (Endsley, 1988). If we remove the crew on board, this task will be done by an algorithm or remote operators. To simplify things and speed up the process, all objects will need to be classified based on the type of object and sensor that information is coming from. Geographical information and a fixed object, like those we can find on the chart, could be classified as ENC data, and transmitted information from another ship could be classified as AIS data (Automatic Identification System). For those ships that are not transmitting AIS signals, like small objects, sailing boats, fishing boats, etc, radars and cameras could be used to identify an object, so that will be Radar data. Acoustic sensors could be utilized for traffic purposes in the case of bad visibility. As mentioned before in the case of SEA.AI Sentry, machine learning algorithms are working with huge databases and without them, they will not be very useful. A system called “Ask Knut” is being developed to find and identify ice (Aakervik, 2021). The main idea of the system is to help, navigators on board the ships to discover and identify different types of floating ice to prevent accidents and injuries. The system is using Convolutional neural network (CNN). CNN was introduced by LeCun in1990s (Kim, et al., 2019) and has demonstrated good performance in tasks such as image analysis and object detection. In recent years the network has been used in even more challenging tasks like colorization of black and white images, remote sensing, and medical diagnostics but despite the successful application across different fields, the classification and recognition of ice objects from close-range imagery remains a challenge according to Pedersen, and Kim (2020). More and more close-range imagery data are becoming available, but the labeling of such data is costly. Because of the specific knowledge required to label the data, labeling cannot be crowdsourced. In addition, labeling has a degree of subjectivity as the viewer's interpretation of the image affects the label of the image. The other problem is that visual conditions can vary in the Arctic in a big range. For training of the network, testing data must be independent and identically distributed which means that enough samples need to be collected for all variations of ice conditions, weather conditions, and visibility conditions. It is been shown that neural network does not handle distorted images well and it is uncertain how well CNN will perform with this kind of image since its training is done in good, "normal" condition. Mariners who are sailing in the area can testify of an increased number of snow and fog days in both Artic and Antarctica. Snow and fog represent an additional challenge because snow and ice are highly reflective, meaning some features can be reflected in each other. Because ice types are not equally represented there is also the problem of the imbalanced dataset, which means that network will typically predict the majority classes too often and less represented classes will be seldomly predicted.

The study that was done on how well neural networks perform with ice recognition got some interesting results. In the paper that reflects the study written by Pedersen, and Kim (2020) it was shown that the network worked very well with some classes of ice, such as icebergs, floebergs, and level ice while failing on others such as ice floes, floe bits, and pancake ice. To understand this, it was investigated which areas of the image network pay more attention. It was clear that the network looks at the icebergs for classifying them, but it was seen that the network also confuses icebergs with mountains (due to the reduced number of mountains in dataset imagery). Regarding ice floe images, the network instead of looking at the ice floes, only focus around the edges of the floe, or, when there are no edges or only a few of them, the network focuses on random locations. There is the assumption that the network has a problem with the ice floes because ice features are not located around a small area of the image and because ice floes have few defining characteristics on a local scale. The other reason might be that the training set never taught the network about open waters which surrounds ice floes which leads to models not understanding that a floe is a floe and not drift ice. These results are a base for future work in the area of automatic ice object recognition from close-range imagery. For future studies, it would be relevant to improve the results on the distorted imagery, improve the model for identifying specific classes of ice and find a more efficient method for large-scale data collection. It would be also interesting to include imagery taken during hours of darkness and winter months when there is much more sea ice with pressure ridges along with a variety of multiyear sea ice and one-year sea ice.

In the future this system could be installed on the ship's bridge and continually scan and film the surface, classifying all the ice. In the case of remote operation, feed with data about ice type could be sent to the Shore control center (SCC) and the human operator will decide what to do, or eventually, in the case of an autonomous ship, it can send data to an algorithm that will decide. The goal of this system is to be able to identify different types of ice even in fog or snowfall. For now, this system is still under development, and it is building its database of ice pictures so the algorithm can learn to recognize types of ice.

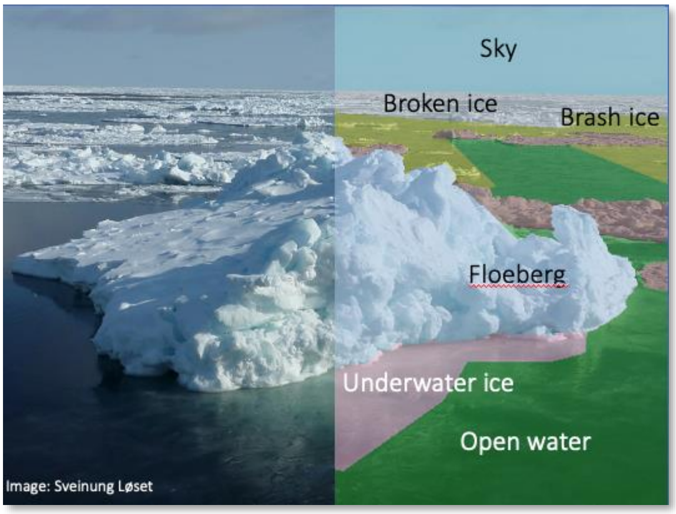


Figure 22. What eye can see and what “Knut” can see (1)

Source: https://partner.sciencenorway.no/apps-artificial-intelligence-glaciology/what-kind-of-sea-ice-is-that-ask-knut/1887838

Figure 23. What eye can see and what "Knut" can see (2)
Source: https://partner.sciencenorway.no/apps-artificial-intelligence-glaciology/what-kind-of-sea-ice-is-that-ask-knut/1887838

In this step, the database with all ice types mentioned in the previous chapter needs to be covered because all of them might represent different obstacles or opportunities.

5.3.4. Prediction system

After the algorithm receives all these data packages, which are classified by the sensor and all objects are identified, the condition analysis algorithm needs to predict the possible future states of these objects. (Endsley, 1988a). Some objects will be relatively easy to predict. Data from ENC, like a buoy, navigational marker, etc are not mobile so they will stay relative to our position. Ships might be required to electronically exchange their intended route and data like speed and distance, to easily calculate CPA (Closest point of approach) and TCPA (Time of close point of approach). In the case of ice avoidance, with a long-term motion monitoring system we could follow the object, and calculate what is the speed and direction of the ice (either due to wind or current). That information could be cross-checked with depth data from ENC, and a prediction of the possible future state of the ice could be made.

When the algorithm understand where all the object will be relative to our position every second until we pass the object, it could send the signal to the action algorithm.

5.3.5. Action system

Once when our surrounding is analyzed and predictions of future state are made, a course o action can be set according to Endsley (1988a). The first part is action planning. Action planning is based on a predefined ship's mission and a set of rules. Regardless of who is operating, the human operator in SCC or AI and algorithm, the decision about course alteration will be made based on the rules of COLREG and possibilities that will allow the system to perform the mission (depth data on the potential route, ice condition on the potential route, the future state of ice condition that was calculated by prediction algorithm must be checked). Rules about ice navigation mentioned in the previous chapter will have to be programmed and an algorithm will follow those set of rules to successfully navigate through the ice. When it is decided how we will avoid obstacles, the decision must be actuated. Navigational decisions are actuated by the propulsion system onboard. The Control system which is part of the action system, also ensures that the resulting manoeuvers are by the input. For an autonomous system, the control commands will be generated and sent from the action plan software to the control software. The reliability of the action control will depend on the reliability of the control system and actuators.

5.4. Impact of automation on situation awareness

According to Endsley, (1994) automation in every environment can have a direct impact on situation awareness through three major mechanisms:

1. Changes in vigilance and complacency associated with monitoring:
    a. There are numerous cases in which operators are unaware of automation failure and do not detect critical system state changes when they have only a monitoring role. Its been noted that human failure in monitoring automation increases when devices behave reasonably but incorrectly and when operators are simply not alert to the state of automation.
    b. Complacency and over-reliance are huge factors especially when automation systems are used for a long period and they already have proven to be reliable (like DP in the example above). Along with the trust toward automation, the

operator can neglect the automated system and parameters overseen by the automated system in favor of multitasking and shifting attention to some other jobs.

   c. Monitoring problems were found in the systems that have a high incidence of false alarms. This leads to alarms being ignored or disabled by the ship's crew.

2. Assumption of a passive role instead of an active role
   a. Studies have shown that situation awareness was lower under fully automated and semi-automated conditions than under manual performance. The perception of the elements in the environment was not affected but the comprehension of the current situation and the projection of future states was. The subject was aware of low-level data (they were aware of the existence of the object) but they have less comprehension of what that data (object) means for operational goals. Turning the human operator from a performer and active role, into an observer and passive role can negatively affect situation awareness, even if the operator can perform a monitoring role. This can lead to significant problems in taking over during automation failure.

3. Changes in the quality or form of feedback provided to the human operator and not understanding automated processes.
   a. Either intentionally or unintentionally, the design of many systems poses a challenge to situation awareness through the elimination of or change in the type of feedback provided to operators regarding the system's status. Unless big attention is given to the format and contact of the information displayed, the issue can easily diminish situation awareness when the operator is working and heavily relying on the automated system.
   b. One of the problems with the successful implementation of automation is not understanding the automated system. This could be a consequence of poor interface design, inadequate training of everyone involved in the automated process, not just the operator but also the person installing the system and person maintaining the system, and even the fact that multiple persons are involved in the process who often do not have any point of contact while the automated system was installed and tested.

5.4.1. Design and a new approach to automation systems

It has been established that the design of the automated system and the out-of-the-loop performance problems, create critical issues in the effectiveness of human-machine performance. At a minimum, according to Endsley (1994), the design process should include steps to insure that needed information is always presented to the operator, regardless of the state of the automation and the state of the parameters being monitored in a clear, always the same format. Aside from the design problems, many issues related to low situation awareness involving automation are being attributed to how automation was implemented in the system. In most cases, the task has been given to the automation system and the human element is there just to monitor the operations. New approaches, are currently being explored that challenge this division and challenge the gap between two elements in the system. The new approaches seek to optimize who is a controlling system between human and automated systems by keeping both elements in the operations and sharing control between two elements over time. Adaptive automation optimizes the allocation dynamic of tasks by creating a mechanism for determining in real-time when tasks can be automated and when a task needs manual control. In navigation for example, when the system recognizes that waters a hundred miles ahead are cleared, and the probability of hazardous events is low automation can take over the controls, notifying the human operator that for the next few hours the controls will be automated. One way of establishing this kind of system is to combine all degrees of autonomy in one system. By doing so, it was proven that the human operator who is actively participating in the decision-making loop (accepting the suggestion of an automation system that for a few hrs system can take over the control of the ship) has situation awareness on a higher level and its ability to assume manual control if and when needed.

5.5. Example of situational awareness in the ice

We can analyze the picture below as per three different levels of situation awareness defined by Endsley (1988):

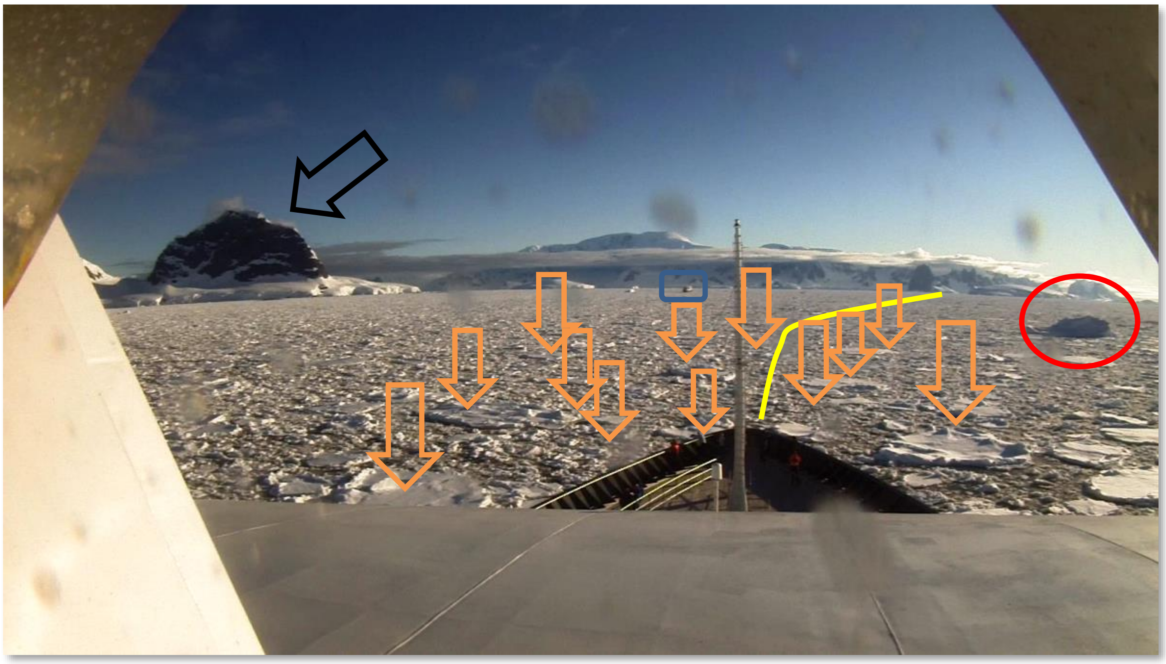


Figure 24. North entrance of the Bismarck strait (image is taken from ship forward-facing CCTV camera)
Source: private collection

Level 1 analysis <u>- The perception of the elements in the environment.</u>

The ship is sailing at 6 knots with 1A-super ice-class strengthen hull and propellers, with two azipods that give ships excellent maneuverability in waters where both glacier ice and sea ice are present. Due to the month and time of sailing, based on the operator's experience, it was known that most of the ice was sea ice and that there is multiyear sea ice and first-year sea ice. The presence of glacier ice can be expected because there are a lot of active glaciers in the area. This area is deep enough and wide enough for sailing with a 5.7 meters draft. The position is cross-checked with multiple independent sources. The ship visible on our port bow (in a blue square) is heading north, his route is known but it is expected that he will have ice on the route as well, so he will not maintain the same course all the time. The ship is sailing at a relatively slow speed around 2 knots. Ice in the red circle is glacier ice, and it needs to be avoided. A minimum safe distance of 50 meters needs to be maintained due to the possibility of rolling. Orange arrows mark multiyear sea ice, which can be hard on impact with six knots speed. The ship's speed will be reduced if needed before coming into contact with multi-year ice. The yellow line represents the potentially best route to sail in present conditions. The black arrow marks land, information that is crosschecked on the ENC.

Level 2 - comprehension of the current situation

Ship in this position is in a good situation. We have two smaller pieces of multiyear sea ice in the vicinity just in front of the vessel but with speed reductions that do not represent the danger. (Algorithm or remote operator needs to be familiar with the rules and ice classification and based on the identification of the ice, the algorithm or human operator in SCC will reduce the speed)

The weather is good, with no wind, its excellent visibility, due to the time of sailing sun already moved towards the west, and it will not bother the camera view while sailing south. At the moment, the tidal current has not been observed but it will be constantly monitored.

Level 3 - the projection of future states.

Due to the known weather forecast and tide forecast, it is safe to assume that the condition of sailing will not change, and that ice will not move significantly. Collision avoidance with approaching ships will be done according to COLREG rules (port to port). The chosen route can be executed, and the result will be positive.

It is visible in this analysis that situation awareness is essential. To do proper analysis and make the right decision, remote operators, or AI, have to have appropriate, good quality, real-time data with minimum latency.

6. SWOT analysis and PESTLE analysis of autonomous operation in the Arctic

SWOT (**S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats) analysis is a framework used to evaluate the competitive position in real-time of a subject of analysis and to develop strategic planning. SWOT analysis assesses internal and external factors, as well as current and future potential. (Kenton, 2022)

Strengths and weaknesses are considered internal factors and opportunities and threats as external factors.

6.1. Strength

As for strengths, we will consider positive factors that will come out of using remotely controlled ships and autonomous ships in the high Arctic.

STRENGTHS:

- **Reduction of human interaction**: approximately 80% to 85% of marine accidents has been caused by human error (Hasanspahic et al., 2021). Computers and computerization are being utilized on board to reduce human error, but in many examples, as seen before that is not the case. Humans still have a central role in the decision-making process. So reduction and eventual elimination of that role will be beneficial for operations in general. People get tired, complacent, and sometimes even lazy to doing necessary steps to avoid an accident, especially on the long passages where boredom kicks in.

- **More cargo space**: by reducing or eliminating human occupants and by removing the accommodation part of the ship, we will have more cargo space and cargo load, which is in direct correlation with profit.

- **Additional utilities in remote areas will not be needed**: when considering transit voyages in the high Arctic, where there is not much infrastructure or hospitals, having unmanned vessels can prevent loss of life in the case of any type of emergency related to humans. When we are talking about destination voyages, we mean the local native people in those areas, and even though they get supplied by the ship, they do not need additional crew members from ships consuming their food, medical supply, or any other provision.

- **Reduced labor cost**: It is been stated that crew costs that include air-conditioning units, crew accommodation, flights, insurance, salaries along with other amenities can reach up to 44% of a ship owner's operating expenditure (Krist, 2017). Arctic communities, being so isolated, flight options are limited so the cost of crew accommodation and flight to get the crew on board is even more expensive than in the other parts of the world.

- **Situation awareness system:** integrated situation awareness system with all navigational and communication equipment can collect and process more data than any human.

- **Rested operators:** if we are talking about remotely operated vessels one of the advantages will be motivated and rested operators that can come to work close to their homes, family, and friends and operate vessels during normal working hours without fatigue and for a shorter period, few weeks instead of 4-9 months.

- **Safer, efficient, reliable, sustainable, and easily "upgradable" ship:** shipbuilding will have to be changed. Cargo could be placed in the forward part of the ship, dimensions of the ship could be optimized in a better way to sail through the ice-covered area, hull design could be significantly improved, and crew accommodation and livelihood systems could be removed from the ship. All of that will reduce energy consumption and extend operational capacity. Technology onboard could be designed and constructed in the way that basic maintenance could be done underway by drones and ROV or simply updating or upgrading the software or system. Discharge from the ship that is being practiced today (outside of 4 and 12 nm respectively) would not be necessary.

- **Reduction of port costs:** with completely automated cargo operations at the port and at sea (for example: reading the temperature information for reefer containers) cost of port stay could be reduced. It is known that a ship makes money when it is sailing not when it is staying in port, so faster port operation will be beneficial. Container ship spends 25% of their time at berth, by reducing this time allows ships to sail slower and save fuel. This fact is beneficial for transit voyages in the high Arctic because the ship can have some spare time in their "pockets" in the case of ice problems. Mooring operations even today in some ports are already done without crew members. (Senol, et al., 2017)

- **SAR operation:** in areas like the Canadian Arctic, Russian Arctic, and Svalbard, Search and Rescue operations are organized by government authorities. Because of climate change, it is expected that traffic will increase. If there are no people on board, facilities, and equipment already existing in those areas (for local fishermen and local population) would be sufficient, and large additional investment from the government side for the whole infrastructure would not be necessary. (Dimitrios, 2019)

- **Aging workforce:** The attractiveness of seafaring is declining and with plans for further speed reduction (to lower the carbon footprint), recruiting new workers for the longer voyages is becoming more challenging. By reducing ships' speed we are opening requirements for more ships which further deepens the problem. A lot of seafarers quit their job and decided not to go back to the sea after the pandemic. It has been predicted that by 2025 an additional 147500 officers will be needed. (Vos et al., 2021). For a lot of young seafarers, Arctic sailing is not attractive due to the lack of social interaction and possibilities that other parts of the world are offering. The existing ice navigators will have to retire and there is a possibility that knowledge will be reduced or even lost.

- **Intelligent data:** providing and planning the routes based on big data, "you do not have to use what everyone else is using." This is something that might be developed down the line after many years of creating, utilizing, and updating voyage databases.

- **Convoy concept for transit traffic:** this strength will be easily recognizable in the transit traffic over the Arctic because we can have only the first ship manned (maybe even appointed icebreaker) and the rest of the following ships can be either remotely controlled from the first ship or remotely controlled from Shore Control Centre (SCC) or simply autonomous and given the task to follow ship ahead. The second option is that even the first ship, along with all the others in the convoy will be remotely controlled by the SCC. (Nilsen 2018).

6.2. Weaknesses

As for weaknesses, we will consider negative factors inside the maritime industry that will come out of using remotely controlled ships and autonomous ships in the high Arctic. This factor is important to be identified so it can be dealt with.

WEAKNESSES:

- **Maintenance schedule**: onboard a ship where the crew is present, maintenance work is being done regularly. On an unmanned ship that will not be the case so maintenance will have to be done in the port. Port stay will be shorter, and the maintenance crew might be on the way for cargo operation, or simply will not have enough time to finish the work. Some of the maintenance can not be done in harsh Arctic weather so this will even further limit the possibilities of the maintenance and ports.

- **Sensor and telecommunication technologies**: in both remotely controlled ships and autonomous ships this will be something crucially important because humans will not be able to physically check the situation onboard. Numerous times on today's ships we have situations when we have sensor problems from something simple like air temperature in the room, or CCTV camera, or void or ballast water sensor. Today's ships are built with redundancies but simply doubling systems and wires will not be enough. How we would design ships and how we would protect sensors and connectivity between sensors and systems, will enable higher degrees of autonomy than what we have today. A sensor that will be placed outside will have to be weatherproof and will have to sustain hard weather conditions.

- **Emergency response:** probably one of the biggest problems regarding emergencies on board unmanned ships (like fire) is situational awareness or lack of situational awareness (Nylander, 2021)

- **High capital investment**: because these ships will redefine shipping they will have to be built with lots of new technology so only big players on the market will be able to get started which can lead to a monopoly. For the ability to navigate in the Arctic better part of the year, ships will have to be built with high ice class. (Chen, 2022). That brings costs substantially higher than conventional ships plus according to Munim (2019) and *Autonomous ship: a review of innovative applications and future maritime business models*, the price for a newbuild autonomous ship is likely to be three times higher than for conventional ships.

- **Need for more than one redundancy system**: when humans are on board, we can consider them as "redundancy systems" in a way. However, if there are no humans on board redundancy system will have to be in the same or similar way as the primary system, and it can be in danger of failing due to the same reason. (fire on board, flooding, vibration, etc.). Any redundancy system on board ships sailing in the Arctic will have to be self-sustainable because of the possibility of losing connections due to topography.

- **Delayed repair support**: repair would be possible only in port. Today on board the ship, the crew usually steps in and prevents additional problems by securing or repairing damaged items. Spare parts and a reliable workforce are hard to find in those remote areas of the Arctic and shipping spare parts and people to repair something is hard and expensive.

- **Need for qualified personnel**: the need for seafarers would be declining, but the need for new personnel would arise. Training for the new workforce will be demanding and expensive. (Emad 2020)

- **Lack of on-spot training facilities**: nowadays new seafarers usually board the ship for the first time as a cadet (deck or engine). During this period, usually a year, the cadet is taught and shown how the system and operations work. Some jobs are still better to learn onboard and by removing this opportunity there will be a decline in knowledge and experience. If we are talking about humans as a redundancy in the SCC, the efficiency of redundancy will decline.

- **Lost knowledge and ability to be ”effective”**: same as pilots in airplanes, the crew on board the ship learn how to sail the ship on board. There is a limit on how much human operators can learn in the classroom and within the simulator. I had the opportunity to experience that in recent years. Ship ”A” had an azipod propulsion system and she was sailing in the polar region. Ships operations required that ships is staying for a certain number of hours on one spot. On this ship, OOW was moving the azipods and holding the ship's position. Certain rules need to be followed to prevent accidents. Ship ” B” had the same propulsion system and the same operations, but because the ship was newer, the company decided to invest more money and get DP (dynamic positioning) system on board. The system on board was graded as 0 (zero) because the main system did not have any redundancy so it was only one DP computer. If something happens with this DP computer, a human operator needed to jump in and correct the actions. On ship ”A” all officers were familiar with the operation, they actively participated in the decision in what direction azipods will be turned, while on ship ”B” officers were only observing what the DP computer is doing and how the azipods are turned. On ship ”A” operators had confidence that they will be able to do with the ship whatever is necessary for whatever weather and ice conditions they might encounter, but on ship ”B” operators did not have the same level of confidence in the case if something goes wrong. The only difference between the two ships is knowledge about the ship, based on experience.

- **Digital piracy and cybersecurity**: possible attackers could be terrorists, hackers, activists, and organized crime, and the reasons for the attack could be a terrorist activity like causing pollution, stealing information, or demanding ransom for cargo and ship. (Tam 2018)

- **Communication in the emergency**: usually in the case of the emergency crew on board assess the situation and report findings to the VTS or Coast guard, so they can act upon it. With unmanned ships, it will be hard to report the emergency especially if sensors or cameras, or other data collectors are endangered by an emergency or simply do not exist. Accompanying infrastructure will have to be built. A good example of this problem is the case if a ship gets stuck in the ice. Detailed information about the ice surrounding the ship will be crucial for emergency response.

- **Damage control and assessment**: relates to the previous one, a system for surveillance can be physically limited.

- **Massively dependable on a good connection:** which can be challenging in the fjord and the high Arctic which requires more dense infrastructure for good coverage. Not the mention that all data needs to be protected.

- **Communication in high latitudes:** this factor is in direct correlation with the previous one. Both autonomous ships and remotely controlled ships are heavily dependent on good communication. To use network-connected resources like GPS, ECDIS, chart corrections services, etc connectivity needs to be easily available. Geostationary satellites have reduced reliability passing 72^0N and after 75^0N they are considered unreliable, especially when navigating in long fjords.

6.3. Opportunities

Opportunities are a combination of different external circumstances at a given time that offers a positive outcome if taken advantage of. Within this part of the analysis, the PESTLE analysis will be added as well, in the form of letters *(P-political, Eco-economical, S-Social dynamics, T-technology, Env-environment, L-legal).*

OPPORTUNITIES:

- **Eliminate "middle man":** with autonomous shipping the crewing agencies and selling cargo transportation slots (containers or cargo holds) could be handled directly by the shipowner. That might lead to an advantageous intervention in case of any need. ***(Eco, S)***

- **Standardization of equipment:** as a center of autonomous shipping, equipment would have to be regulated by rules and regulations (like humans now) so even though we would have different manufacturers they would all have to follow the same rules and features for safety reasons and easier communication with SAR services and VTS. ***(T, L)***

- **Designing human-centered equipment:** when we are talking about remotely operated vessels, SCC will have to be designed around humans to maximize situational awareness, keep the operator in the loop, provide automation transparency, and minimize automation complexity (Endsley. 2018)

- **Eco-friendly ships:** new engine technologies and using LNG or LPG or nuclear power as the main alternative for HFO. Even today in the Arctic there is a set of regulations that a higher grade of fuel needs to be used, so today we are using MDO. These ships will be "greener ships". (DNV,2019) ***(Eco, P, Env)***

- **Reduction of maritime accidents:** If autonomous ship technology can reach the desired level, based on the reduced human factor, reliable software, algorithm, instantaneous intervention to changes, etc., it will reduce marine accidents on a large scale. (Senol, 2017) ***(T, S, Env).***

- **Equal distribution of the workforce:** shore operators will be qualified local personnel. That will contribute to equal opportunity for the local workforce and increase employment in the Arctic counties. ***(S, Eco,)***

- **Environmental protection:** it is essential to ensure environmental protection. Lower speed (that we can plan and effort due to shorter distance) is leading to lower fuel consumption and that will reduce exhaust emission during Arctic voyages. Governments that are governing the Arctic region said that they will only allow exploration and exploitation if it is done in a friendly way. The technological advancement that is already on the horizon with Kongsberg electrical autonomous ship can reduce energy consumption by 74 % in combination with the regular ship on heavy fuel oil as a combination of the different energy sources and no crew (no accommodation) on board. (Munim, 2021) ***(Env, P)***

- **Surveying:** due to climate change and the need for better soundings new hydrographic data will have to be collected, and better charts will have to be made if we want safer shipping in the Arctic. This is a time-consuming task, but it can be done by ROV and unmanned surveying vessels that will collect depth data, current data, and weather data. ***(Env., T)***

- **Expanded exploitation of natural resources:** is known that there is a lot of natural resources in the Arctic (Arctic Resources race), geopolitics, and country with direct access to the Arctic will have to find an agreement to properly use it, not to endanger the environment and local population (Duxbury 2020). ***(P, Eco, Env, S, L)***

- **Satellite constellations:** due to the lack of satellites that are available in those high latitudes new satellite constellations will have to be established. Low earth orbit and Highly Elliptical Orbit satellites could be particularly interesting for the Arctic region. (Höyhtyä, 2017) ***(T, P, Eco.)***

- **Installation of navigational marks and navigational aids:** in the past, before satellites, navigators were using navigational marks that were positioned along the navigational routes. Sighting bearing and distance from multiple marks and with a little bit of math, algorithms can calculate ships' position. Even today in Svalbard, Greenland, and Canada marks are still being used when a ship is turning in a narrow area. These marks can be logged on navigational charts and a remote operator, or AI with the LIDAR, radar, or camera could sight the markers and by triangulation find the ship’s position. Infrastructure for this is not developed but this can be a good redundancy system in the Arctic in the case that satellites and GNSS systems are not working. ***(T).***

6.4. Threats

Threats are external negative factors that are representing threats to the industry, but we cannot control them or influence them in any way. Within this part of the analysis, the PESTLE analysis will be added as well, in the form of letters *(P-political, Eco-economical, S-Social dynamics, T-technology, Env-environment, L-legal).*

THREATS:

- **Legal issues**: rules and regulations regarding humans on board and their role on board will have to be changed. Minimum manning, training, and certification, all will have to be changed. ***(L, S)***
    - Polar code,
    - STCW,
    - SOLAS,
    - MLC, etc.

- **Traffic in the high Arctic**: The threat represented by developing shipping in the Arctic can be described as follows. Traffic is unlikely to be heavy: the Arctic will not be another Panama Canal or Suez Canal. Traffic will, however, be boosted by either bulk transit or, more probably, by mineral and oil exploitation—potentially very polluting cargo. Control and regulation of shipping in the Arctic, therefore, remain necessary to reduce pollution risk. (Guy et al., 2010) ***(Eco, T)***

- **Political influence**: complex policies and stands on different really important topics like environmental preservation and human safety can differ between Arctic countries. ***(P)***

- **Difference between NE and NW passage**: clogging of NWP with ice is highly possible, due to topography, currents, and wind, ice situation could vary from year to year and even in the same year between NEP and NWP. ***(Env)***

- **Bureaucracy and "right of passage":** government controlling the passage can complicate transit, or they can also charge it as they do in the Panama Canal or Suez canal. (Humpert, 2012) ***(P, Eco, L)***

- **Insurance:** sailing in the high Arctic could be identified as higher risk sailing than in waters without the possibility of ice ***(Eco, L)***

- **Aid to navigation does not exist:** even fully autonomous ships will have to have some references and navigational aids as referent points**,** the problem with a navigational mark in the high Arctic is ice and constant shifting of ice, although this could potentially be solved with AR. ***(T)***

- **Environmental and climate uncertainties unable to predict ice conditions:** weather and ice condition varies from year to year and its hardly predictable ***(E)***

- **Acceptance by the general public**: like every new technology the general public can be skeptical of it ***(S, T)***

- **Liabilities:** from the legal standpoint who will be responsible in the case of an accident with other autonomous ships or manned ships? ***(L)***

7. Conclusion

Based on the literature and studies that I have read, I believe that there is a potential for remotely operated ships in the Arctic, but the process of development and implementation will not be easy. IMO automation Levels 3 and 4 will be hard to develop, but they are not impossible. There is one readily available thing we can learn from: history. At the beginning of the maritime industry, the one that we have today, there were a lot of risks involved, and a lot of unknowns. In the beginning, ships were sailing along the coast but human curiosity and courage pushed people to sail away from the coast into the unknown. Challenges along the way were pushed through and overcome, and ships were sailing behind the horizon on to new endeavors. It is in human nature to look at what is behind the horizon. That is the reason why we have all these technological marvels.

The most profitable traffic type in the Arctic will have to be decided. And then I believe, we will see the major players in the shipping industry moving in the direction of automation, remote operations, and eventually autonomy in the Arctic. The fact that the route through the Arctic is the shortest will not be enough to make a major step toward the Arctic, so destination and supply traffic will start with the data collection and potentially could be used as a proof of concept. Due to the difficulties and unpredictability of the ice situation and the fragility of the area in question, I believe that it is in everyone’s best interest to develop new concepts in the Arctic carefully and with concepts that will protect humans and the environment of the Arctic.

The ship mentioned in the thesis needed only 9 months of ”learning and training” to be able to perform 107 avoiding maneuvers. (Doll, September 2021, May 2022). This ”proof of concept” could be a good starting point in developing future concepts of remotely operated vessels and eventually autonomous ships.

I believe that the SCC controlled semi-autonomous ships will be possible in the future. With new technology and with a desire to move in this direction, this concept is not hard to imagine. A lot of technology still needs to be developed and even some of the existing technology needs to be implemented onboard the ship. Major capital investments will have to be made both from the government side and the ship owner's side. Governments will have to work together toward the geopolitical solution and help each other to speed up the process.

People will still be a central part of the systems, from a technological point of view to a seafarer's point of view. Even today on the new build, we were instructed to ”teach” an autopilot how to turn the ship. With time, an algorithm becomes better and autopilot can perfectly perform the turn. I believe that it will take time to build up the database and teach the algorithm how to navigate through the ice. We have seen that even recognizing the ice is not an easy task, but with help of a human, the algorithm will learn and eventually even get better and more efficient even in unexpected situations. Humans are good in unexpected situations only because of experience. The transition should be made gradually so that when we eventually remove humans from the loop, the algorithm can perform tasks independently and safely and humans as a redundancy system will not be necessary. Because the truth is, human operators will start losing knowledge by losing the experience of doing things on board. Proof of that can be seen even today when some of the captains use DP systems to berth the ships and they gradually lose knowledge of how to bring the ship alongside without the DP.

It was visible from this paper that the first advancements in on board technology should be concentrated on automation. Automation will need some time to learn and humans will need some time to learn to trust automation.

Most likely counties like Finland, Norway, Canada, Japan, and China will lead the way in the process of automation on the ice. The Bay of Finland and the Norwegian fjords are the perfect testing and training grounds for autonomy, due to their geographical advantages and satellite coverage.

One might ask ”What is the point of ice navigation in the Arctic when the entire concept is based on the idea of melting ice”? Studies have confirmed that the concept of Arctic sailing will only make sense if it happens throughout the entire year, even during the winter months when ice is forming.

With the increasing need for goods around the world and with a decline of interest in the seafarer's profession, remotely controlled ships and automation might be the answer that we are waiting for.

7.1. Acknowledgments

The journey of writing this thesis was interesting and during my research and the writing process, I changed my opinion about a lot of concepts that were sometimes misunderstood and misinterpreted by the general media.

I am grateful that I got the opportunity to study this new concept in the maritime industry and to deepen my knowledge and understanding of it. During my research for writing this thesis, I decided to continue reading about the subject and to stay in the loop of real studies and maybe down the line even be part of one.

It was a pleasure and honor to meet extremely professional people all connected with the maritime industry in one way or another. To all of my colleagues, thank you for being part of this journey and being one of the best groups of people that I have ever worked with.

I would like to use this opportunity to thank my mentor for helping and guiding me through the process of writing this thesis.

Special thanks need to be given to the colleagues and ice pilots who were crosschecking my ice analysis:

- Captain Victor Gronmyr (Ice navigator) and
- Captain David (Duke) Snider (Ice navigator).

Reference list

Bibby Offshore, (w.y.), *DSV Bibby Topaz – Case Study & Discussion of Lessons Learned*, (w.p.), Bibby Offshore

Canadian Coast Guard, 2012, *Ice navigation in Canadian waters*, Canada, Fisheries and Oceans Canada, Canadian Coast Guard, Fs154-31/2012E-PDF

Cao, Y., Liang, S., Sun, L., Liu, J., Cheng, X., Wang, D., Chen, Y., Yu, M., Feng, K. (February 2022). Trans-Arctic shipping routes expanding faster than the model projections, *Science Direct, Global Environmental Change 73* (2022) 102488

Chen, S., Kern, S., Li, XQ., Hui, F., Ye, Y., Cheng, X. (September 2022). Navigability of the Northern Sea Route for Arc7 ice-class vessels during winter and spring sea-ice conditions, *Science Direct*, *Advances in Climate Change Research 13,* (2022) 676-687

Dimitrios, D. (2019). Arctic SAR: Current Infrastructure and Opportunities for Maritime Autonomous Surface Ships (MASS), *Research Gate*, (2019) 333117945

DNV (2018). Remote-controlled and autonomous ships in the maritime industry, Group Technology & Research, Position Paper

Emad, G.R., Khabi, M., Shahbakhsh, M. (2020). Shipping 4.0 and Training Seafarers for the Future Autonomous and Unmanned Ships, *Research Gate*, (2020) 3383995285

Endsley, M.R. 1996. Automation and Situation Awareness, *Department of Industrial Engineering, Texas Tech University,*

Endsley, M.R. 2018. Situation Awareness in Future Autonomous Vehicles: Beware of the Unexpected, *Research Gate* (2018) 325298406

Goerlandt, F., Montewka, J., Zhang, W., Kujala, P. (2017). An analysis of ship escort and convoy operations in ice conditions, *Science Direct*, Safety Science 95 (2017) 198-209

Guy, E., & Lasserre F. (2016). Commercial shipping in the Arctic: new perspectives, challenges, and regulations, *Polar Record*, online version 10.1017/S0032247415001011

Hasanspahic,N., Vujicic,S., Francic,V., Campara, L. (2021). The role of the Human Factor in Maritime Accidents, Journal of Marine Science and Engineering, 2021, 9, 261

House, D., Lloyd, M., Toomey, P., and Dicking, D. (2010). *The Ice navigation manual,* UK, Witherby Seamanship International Ltd.

Humpert, M., Raspotnik, A. (2012) The Future of Arctic Shipping Along the Transpolar Sea Route, *Research Gate*, 2012, 309282763

Hynnekleiv, A., Lutzhoft, M., Earthy, J.V. (2019). Siri, sail the ship! Exploring human-RIA relationships in the maritime domain, *Department of Maritime Studies, Western Norway University of Applied Sciences, Lloyds Register*

Höyhtyä, M., Huusko, J., Kivirant, M. (2017). Connectivity for Autonomous Ships: Architecture, Use Cases, and Research Challenges**,** *Research Gate***,** 10.1109/ICTC.2017.8191000

Johansen, K (May 2013). *Optimization of Maritime operations in the Arctic,* Master`s thesis in Technology and Safety in the High North, University of Tromso, Faculty of Science and Technology, Tromso Norway

Khramushin, V. (2014). *Features the architecture of mean ship to navigation in heavy, stormy, and ice conditions on the northern seas,* The 14th International Ship Stability Workshop, Kuala Lumpur, Malaysia

Kim, E., Dahiya, G.S., Løset, S., Skjetne, R. (2019). Can a computer see what an ice expert sees? Multilabel ice objects classification with convolutional neural networks, *Science Direct, Results in Engineering 4* (2019)100036

Kitchen, N. (2005). *Navigation in ice,* UK, Videotel

Mehta, R., Winter, S.R., Rice, S., Edwards, M. (2021). Are passengers willing to ride on autonomous cruise ships*? Maritime Trasport research, 2* (2021) 100014

Munim, Z.H., Saha, R., Schøyen, H., Ng, A., Notteboom, T.E. (July 2021). Autonomous ships for container shipping in the Arctic routes, *Journal of Marine Science and Technology,* (2022) 27:320–334,

Nylander, J. (2021) *Fire hazards onboard unmanned vessels,* Master of Engineering in Autonomous Maritime Operations, NOVIA, University of Applied Sciences, Helsinki, Finland, Olsen, J., Hovelsrud, G., Kaltenborn, B. (2020). Increase Shipping in the Arctic and Local Communities Engagement: A case from Longyearbyen on Svalbard, *Research gate*, 339764659

Ottesen, A.E. (w.y.). Situation Awareness in Remote Operation of Autonomous Ships, Shore Control Center Guidelines, *Department of Product Design, Norwegian University of Science and Technology*

Pazouki, K., Forbes, N., Norman, R.A., Woodward, M.D. (2018). Investigation on the impact of human-automation interaction in maritime operations, Research Gate, Ocean Engineering, 323734349

Pedersen, O., Kim, E. (2020). Arctic Vision: Using Neural Network for ice Object Classification, and Controlling How they Fail, *Journal of Marine Science and Engineering,* 2020, *8,* 770; doi:10.3390/jmse8100770

Reid, T., Walter, T., Enge, P. (2014). *Crowdsourcing Arctic Navigation Using Multispectral Ice Classification & GNSS*, Stanford University, USA

Royal Arctic Line. (2021). *Interim Report 2021,* (w.p.)

Senol, Y. E., Gokcek, V., Seyhan, A. (2017). SWOT-AHP Analysis of autonomous shipping, Research gate, 327690541

Smith, L. C., & Stephenson, S. R. (2013). New trans-Arctic shipping routes were navigable by the midcentury. *Proceedings of the National Academy of Sciences, 110*(13), 1191–1195.

Tam, K., Jones, K. (2018). Cyber-Risk Assessment for Autonomous Ships, *Research Gate*, (2018) 325195302

Traficom. (2017). Guidelines for the Application of the 2017 Finnish-Swedish ice class rules, Finnish Trasport Safety Agency, TRAFI/383804/03.04.01.00/2016

Traficom, Swedish Transport Agency (January 2019). Guidelines for the Application of the 2017 Finnish-Swedish ice class rules, TRAFI/708629/03.04.01.01/2018

Vos, J., Hekkenberg, R.G., Valdez Banda, O.A. (2021). The Impact of Autonomous Ships on Safety at Sea – A Statistical Analysis, *Science Direct*, Reliability Engineering & System Safety 210 (2021) 107558

Internet pages used for writing the thesis:

Aakervik, A., 2021, Ask Knut – A system for finding and identifying ice [Online] https://ntnudiscovery.no/en/ask-knut-et-system-for-a-oppdage-og-identifisere-is-2/ (Retrieved: 24.11.2022)

Acharya-Patel, N., 2019 Building connections in the Canadian High Arctic [Online] https://canadiangeographic.ca/articles/building-connections-in-the-canadian-high-arctic/ (Retrieved: 24.11.2022)

Aoki, R., 2016, Maersk Shipping: Melting ice caps to open faster and cheaper Arctic shipping routes? [Online] https://d3.harvard.edu/platform-rctom/submission/maersk-shipping-melting-ice-caps-to-open-faster-and-cheaper-arctic-shipping-routes/# (Retrieved: 24.11.2022)

Azzara, A., Rutherford D. 2014 Marine black carbon emissions: Identifying research gaps [Online] https://theicct.org/event/marine-black-carbon-emissions-identifying-research-gaps/ (Retrieved: 24.11.2022)

Bazilchuk, N., 2021, What kind of sea ice is that? Ask Knut! [Online] https://norwegianscitechnews.com/2021/07/what-kind-of-sea-ice-is-that-ask-knut/ (Retrieved: 24.11.2022)

Bennett, M., 2019, The Arctic Shipping Route No One's Talking about [Online] https://www.maritime-executive.com/editorials/the-arctic-shipping-route-no-one-s-talking-about (Retrieved: 24.11.2022)

Benzerrouk, H., 2019, Iridium Next LEO Satellites as an Alternative PNT in GNSS Denied Environments – Part 1, [Oline] https://insidegnss.com/iridium-next-leo-satellites-as-an-alternative-pnt-in-gnss-denied-environments-part-1/ (Retrieved: 24.11.2022)

Bosch, H., 2022, Column I Semi-autonomous navigation: Yara Birkeland, Suzuki, Njord Forseti and Orca AI (Offshore accounts) [Online], https://www.bairdmaritime.com/work-boat-world/offshore-world/column-semi-autonomous-navigation-yara-birkeland-suzaku-njord-forseti-and-orca-ai-offshore-accounts/ (Retrieved: 24.11.2022)

Canadian Coast Guard, 2018, Arctic Ice Regime Shipping System-Pictorial Guide https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration (Retrieved: 24.11.2022)

Chaudhary, A., 2022, AI-Powered Autonomous Cargo Ship Completes 500 nm in 40 hrs. [Online] https://themaritimepost.com/2022/05/ai-powered-autonomous-cargo-ship-completes-500-nm-voyage-in-40-hours/ (Retrieved: 24.11.2022)

Chellel, K., Campbell, M., Ha, K.O., 2021 Six Days in Suez: The Inside Story of the Ship That Broke Global Trade, [Online] https://www.bloomberg.com/news/features/2021-06-24/how-the-billion-dollar-ever-given-cargo-ship-got-stuck-in-the-suez-canal (Retrieved: 24.11.2022)

Doll, S., 2022, Autonomous cargo ship completed 500 miles voyage, avoiding hundreds of collisions [Online] https://electrek.co/2022/05/13/autonomous-cargo-ship-completes-500-mile-voyage-avoiding-hundreds-of-collisions/ (Retrieved: 24.11.2022)

Doll, S., 2021, ORCA AI begins research trial of safety system for autonomous ships [Online] https://electrek.co/2021/09/09/orca-ai-begins-research-trial-of-safety-system-for-autonomous-ships/ (Retrieved: 24.11.2022)

Duxbury, C., 2020, The 5 most important races for the Arctic [Online] https://www.politico.eu/article/5-races-for-the-arctic-trade-resources-supremacy-tourism-salvation/ (Retrieved: 24.11.2022)

Gardner, N., 2021, Understanding GPS redundancy options for autonomous ships [Online], https://thetius.com/gps-redundancy-for-autonomous-ships/ (Retrieved: 24.11.2022)

Gross, Y. 2019, Orca AI – demo [Online-video] https://www.youtube.com/watch?v=dCNkTikRwk8&t=2s (Retrieved: 24.11.2022)

IMPA, 2013, Serious DP diving incident, [Online] https://www.imca-int.com/safety-events/serious-dp-diving-incident/ (Retrieved: 24.11.2022)

Jacobsen, S., 2018, Maersk sends first container ship through Arctic route [Online] https://www.reuters.com/article/us-arctic-shipping-maersk-idUSKCN1L91BR (Retrieved: 24.11.2022)

Kenton, W., 2022, SWOT analysis: How to with table and example [Online] https://www.investopedia.com/terms/s/swot.asp (Retrieved: 24.11.2022)

Krist, S., 2017, How will autonomous shipping affect the maritime industry? [Online] https://www.houstoninjurylawyer.com/will-autonomous-shipping-affect-maritime-industry/ (Retrieved: 24.11.2022)

Malewar, A., 2021, Orca AI begins trails of new safety support systems for autonomous ships [Online] https://www.inceptivemind.com/orca-ai-nyk-trials-new-safety-support-systems-autonomous-ships/21130/ (Retrieved: 24.11.2022)

Marsh, R., 2022, Billionaires are funding a massive treasure hunt in Greenland as ice vanishes [Online] https://edition.cnn.com/2022/08/08/world/greenland-melting-mineral-mining-climate/index.html (Retrieved: 24.11.2022)

Miller, G., 2022, Container – shipbuilding spree not over yet: new orders still rising [Online] https://www.freightwaves.com/news/container-ship-building-spree-is-not-over-yet-new-orders-still-rising (Retrieved: 24.11.2022)

Mordor Intelligence LLP, 2021, Autonomous/Driverless Car Market – Growth, Trends, COVID-19 Impact, and forecast (2021-2026) [Online] https://www.reportlinker.com/p06101202/Autonomous-Driverless-Car-Market-Growth-Trends-COVID-19-Impact-and-Forecast.html?utm_source=GNW (Retrieved: 24.11.2022)

Nilsen, T., 2018, Russia to develop unmanned ship for the Arctic [Online] https://thebarentsobserver.com/en/arctic/2018/04/russia-develop-unmanned-ships-arctic (Retrieved: 24.11.2022)

NSIDC, (w.y.) Sea ice https://nsidc.org/learn/parts-cryosphere/sea-ice/science-sea-ice (Retrieved: 24.11.2022)

Offshore energy, 2018, IMO MSC Identifies 4 Degrees of Ship Automation, [Online] https://www.offshore-energy.biz/imo-msc-identifies-4-degrees-of-ship-automation/ (Retrieved: 24.11.2022)

ORCA.AI, (w.y.) [Online] https://www.orca-ai.io/ (Retrieved: 24.11.2022)

Pekkarinen, A., Repka, S., 2014 Maritime Transport in the Gulf of Bothnia 2030 [Online] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4165837/ (Retrieved: 24.11.2022)

Rosen, Y., 2021, More ships are traveling longer distances in Canada’s Northwest Passage [Online] https://www.arctictoday.com/more-vessels-are-traveling-longer-distances-in-canadas-northwest-passage/ (Retrieved: 24.11.2022)

Scott, M., 2019, Antarctica is colder than the Arctic, but it’s still losing ice [Online] https://www.climate.gov/news-features/features/antarctica-colder-arctic-it%E2%80%99s-still-losing-ice (Retrieved: 24.11.2022)

SEA.AI, (w.y.) Sentry [Online] https://sea.ai/product/sentry-collision-avoidance-for-motor-vessels/ (Retrieved: 24.11.2022)

Shane, D., 2018, Maersk to send first container ship through Arctic [Online] https://money.cnn.com/2018/08/21/news/companies/maersk-line-arctic-container/index.html (Retrieved: 24.11.2022)

Slavina, S., 2013, First-ever bulk carrier passed through the Northwest Passage [Online] https://www.fleetmon.com/maritime-news/2013/2345/first-ever-bulk-carrier-passed-through-northwest-p/ (Retrieved: 24.11.2022)

Staalesen, A., 2021, A critical situation might be in the making on the Northern Sea Route, [Online] https://thebarentsobserver.com/en/arctic/2021/11/critical-situation-might-be-making-northern-sea-route (Retrieved: 24.11.2022)

Staalesen, A., 2022, One year after the crisis, there is again early ice on the Northern Sea Route, [Online] https://thebarentsobserver.com/en/2022/11/one-year-after-crisis-there-again-early-ice-northern-sea-route (Retrieved: 24.11.2022)

The Arctic Council, 2021, Celebrating 25 years of Arctic cooperation [Online] https://www.arctic-council.org/news/arctic-council-celebrates-25-years-of-arctic-cooperation/ (Retrieved: 24.11.2022)

The editors of Encyclopaedia Britannica, 2022 [Online] https://www.britannica.com/place/Murmansk-Russia (Retrieved: 24.11.2022)

Trex Enterprises corporation, (w.y), Optical GPS, [Online] http://www.trexenterprises.com/Pages/Products%20and%20Services/Sensors/opticalgps.html (Retrieved: 24.11.2022)

Valentine, K., 2022, How sea ice in the Arctic and Antarctica is influenced by climate change, [Online], https://climatefeedback.org/how-sea-ice-in-the-arctic-and-the-antarctic-is-influenced-by-climate-change/ (Retrieved: 24.11.2022)

Vartdal, B., 2019 The future-proof ship [Online] https://www.dnv.com/expert-story/maritime-impact/the-future-proof-ship.html (Retrieved: 24.11.2022)

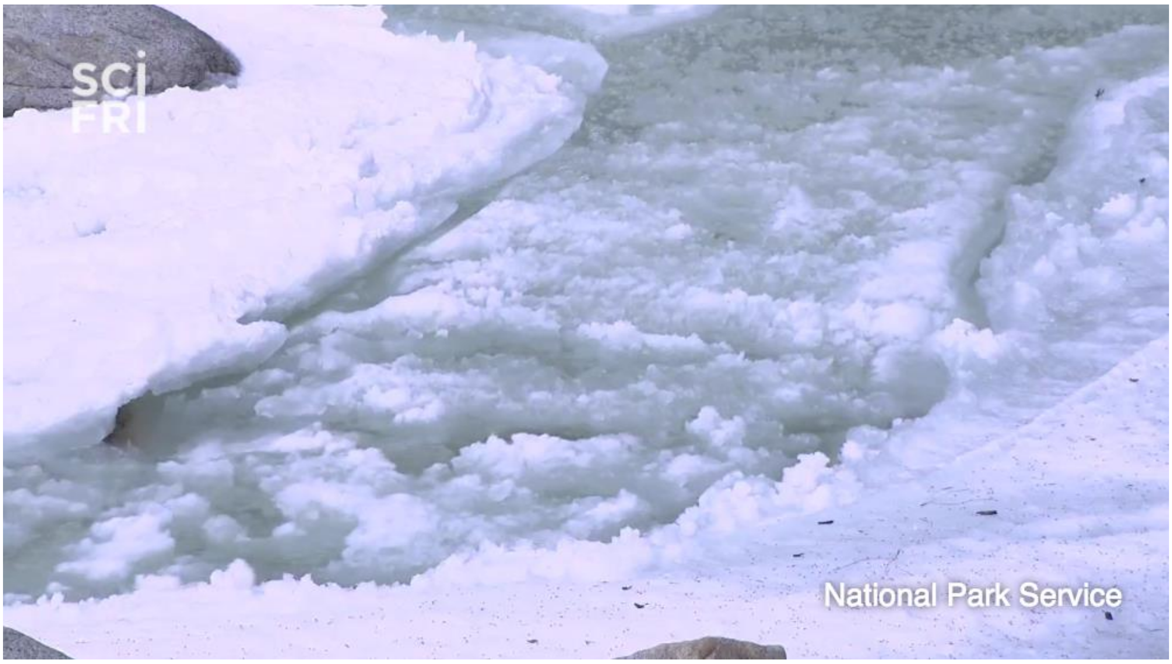
Vidal, J. 2016 Arctic shipping passage ”still decades away” [Online] https://blog.geogarage.com/2016/02/arctic-shipping-passage-still-decades.html (Retrieved: 24.11.2022)

List of Tables

List of Figures

APPENDIX I

Types of ice



Frazil ice

Source: https://medium.com/science-friday-spoonfuls/what-are-pancake-and-frazil-ice-7152b6b5d7d5

Slush ice

Source: https://www.wired.com/story/geoengineering-tiny-glass-beads-prevent-arctic-ice-from-melting/

Shuga with growlers, Bergy bits, and icebergs

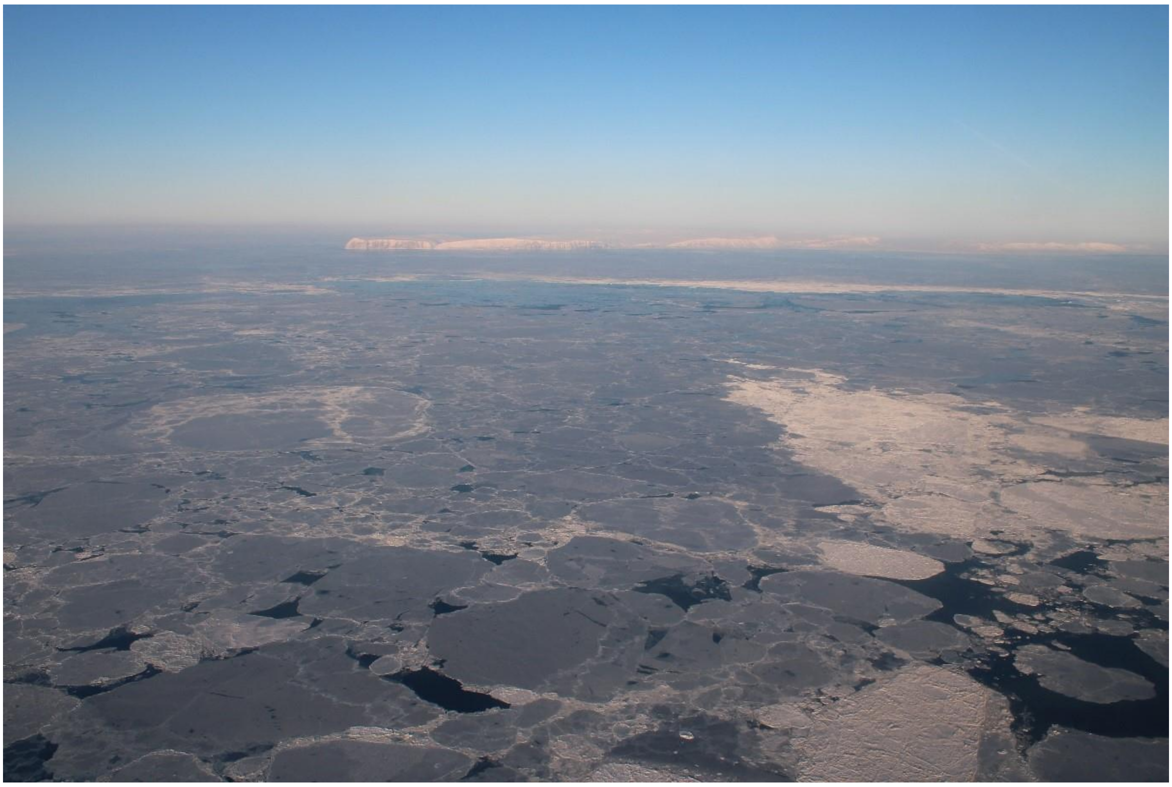
Source: The Mariners handbook

Grease ice

Source: The Mariners handbook

Nilas

Source: Ice navigation in Canadian waters



Young ice

Source: https://www.flickr.com/photos/esa_events/32408104477/in/photostream/

First-year sea ice

Source: https://ice-glaces.ec.gc.ca/content_contenu/ice_codes/pop_ups_fist_yr_ice_eng.html

Multy year hummock

Source: https://jukebox.uaf.edu/site7/media-gallery/detail/2821/15240

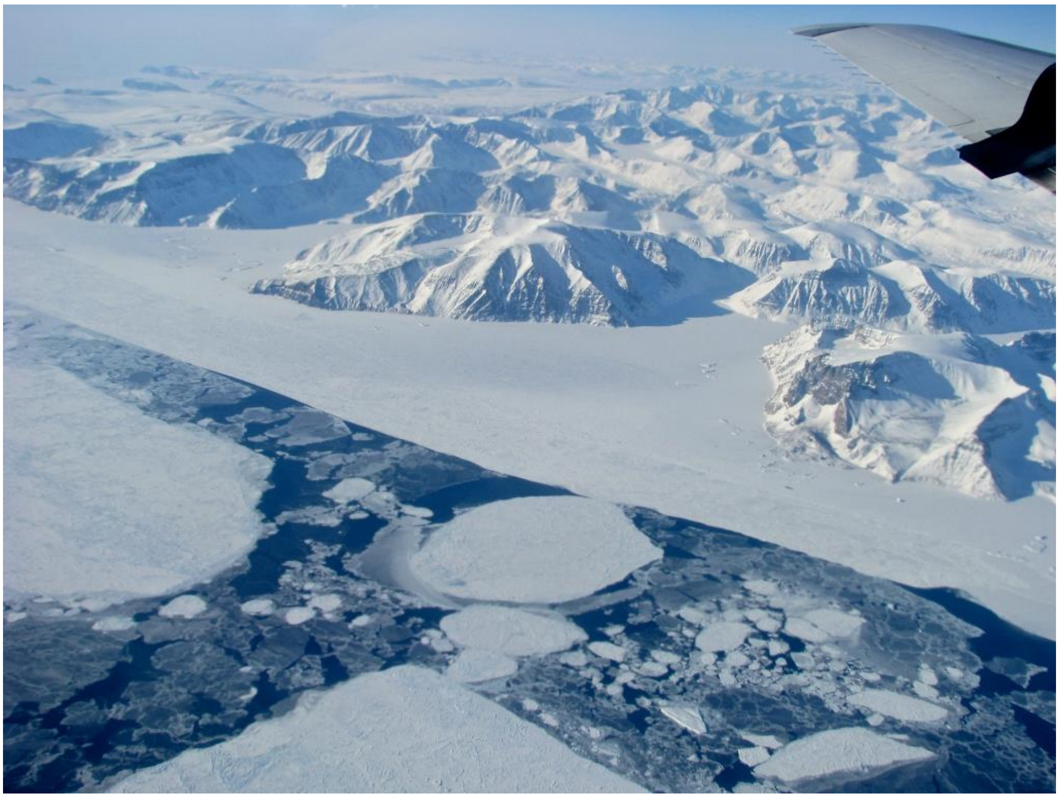
Disco bay, Greenland, iceberg

Source: private collection

Wichebukta, Svalbard; Iceberg surrounded by bergy bits and growlers

Source: private collection

Pack ice
Source: https://www.britannica.com/science/pack-ice

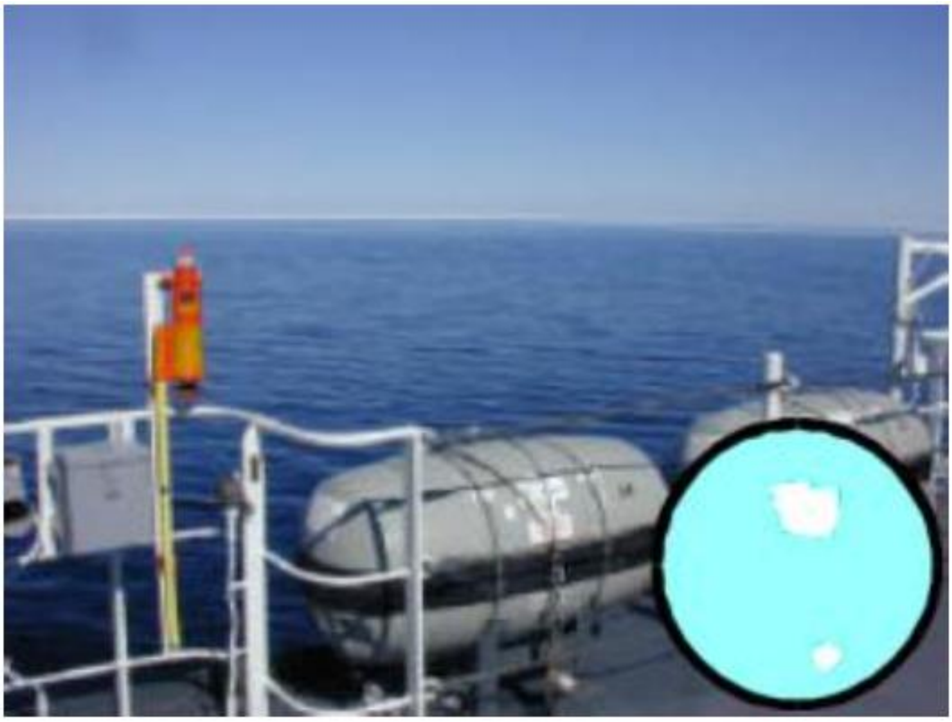


Fast ice in the Davis Strait, Baffin Island, Canada.

Source: https://media.arcus.org/album/polartrec-2014-russell-hood/23286

APPENDIX II

Ice concentration and how it is displayed on the ice chart

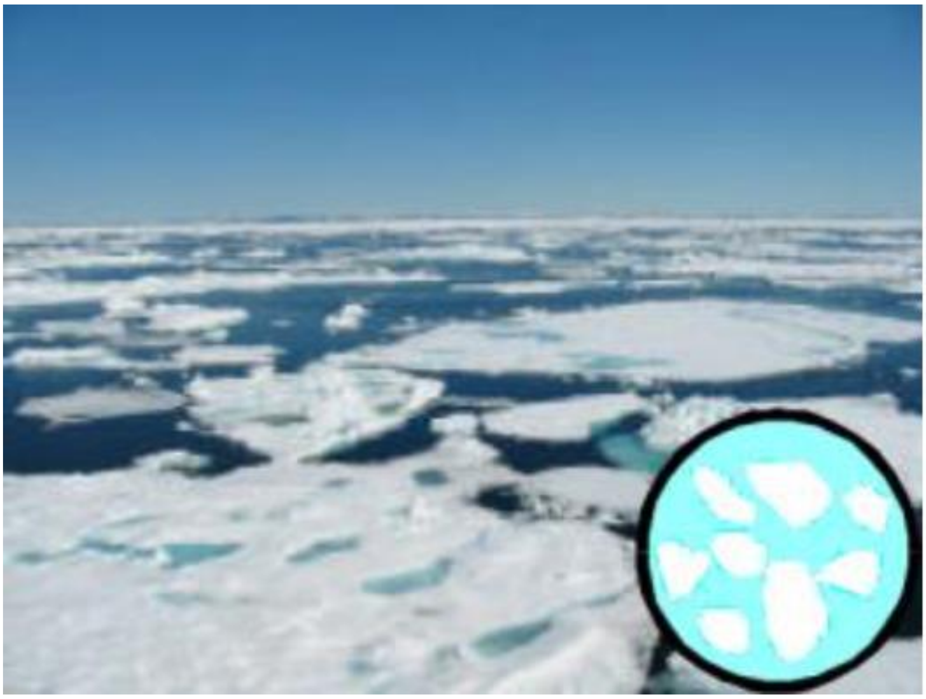


Less than 1/10, Open waters

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration

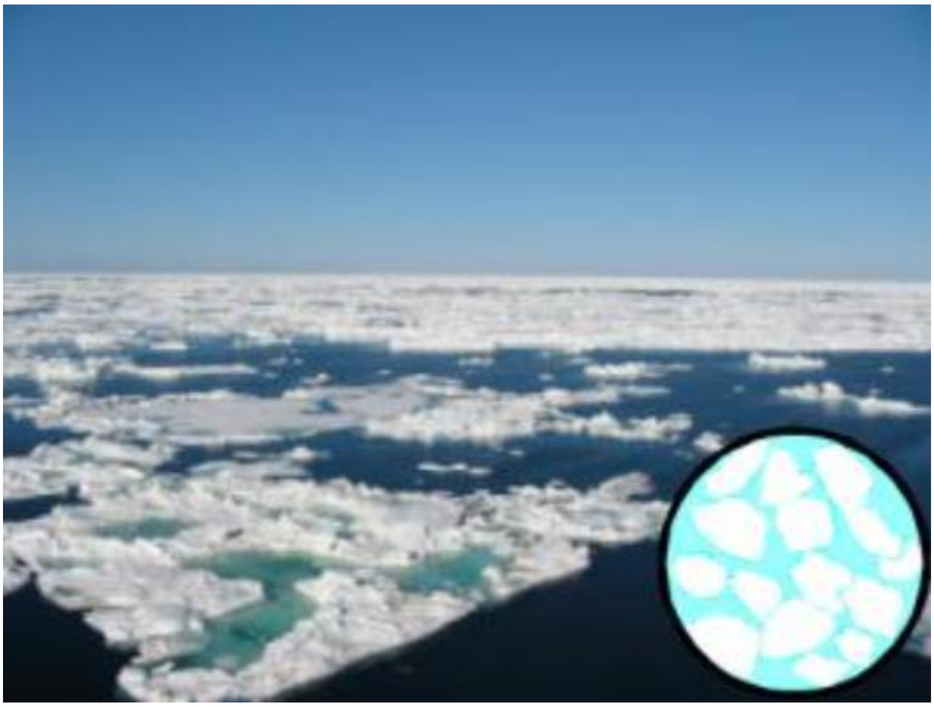
1/10 to 3/10, Very open drift waters

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration



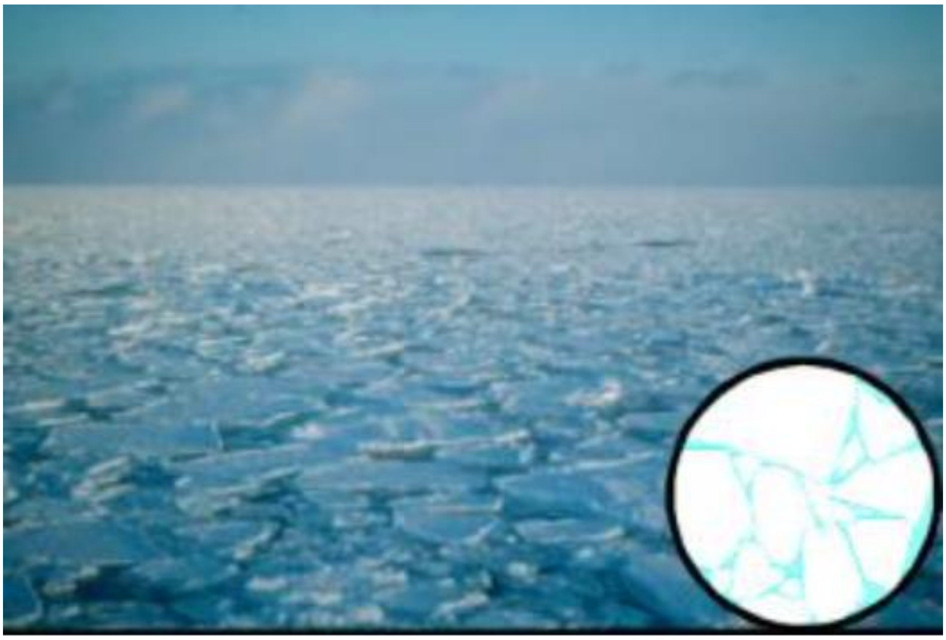
4/10 to 6/10, Open drift waters

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration



7/10 to 8/10, Open drift waters

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration

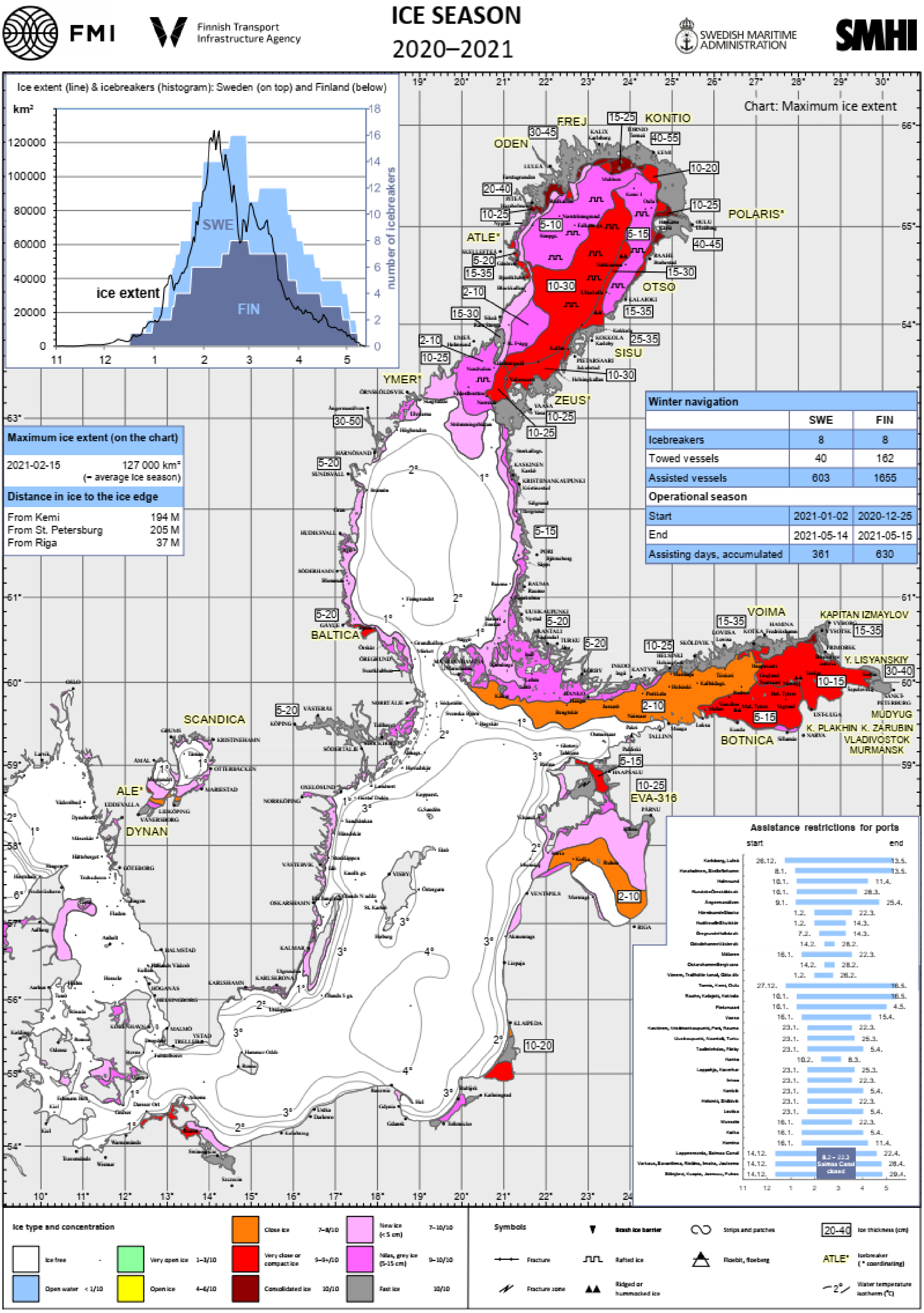


9/10, Very close waters

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration

10/10, Compact/Consolidated ice

Source: https://tc.canada.ca/en/marine-transportation/marine-safety/arctic-ice-regime-shipping-system-pictorial-guide#ice-concentration



Maximum ice extent (on the chart)

2021-02-15 127 000 km²
(= average ice season)

Distance in ice to the ice edge

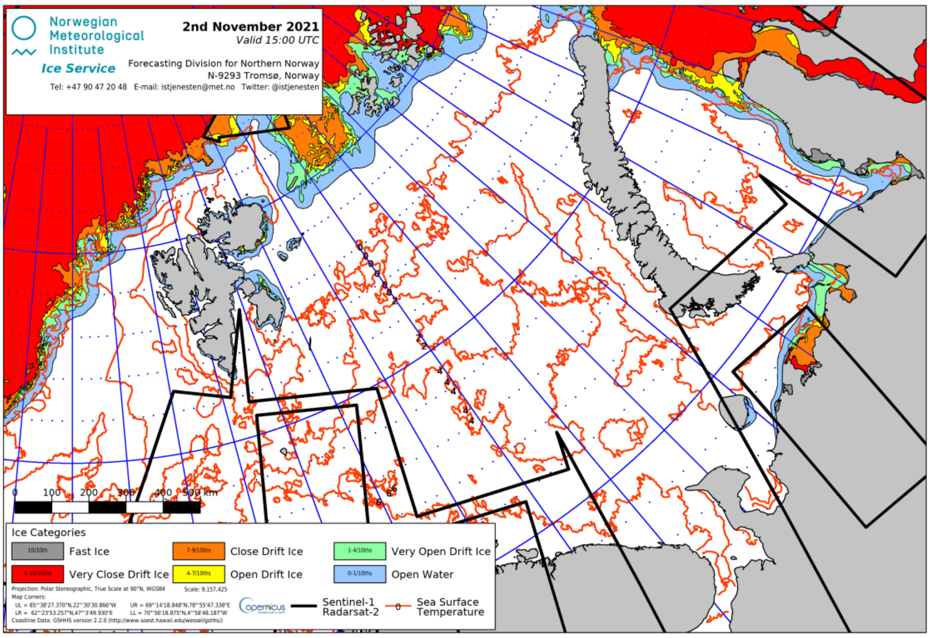
From Kemi	194 M
From St. Petersburg	205 M
From Riga	37 M

Winter navigation

	SWE	FIN
Icebreakers	8	8
Towed vessels	40	162
Assisted vessels	603	1655
Operational season		
Start	2021-01-02	2020-12-25
End	2021-05-14	2021-05-15
Assisting days, accumulated	361	630

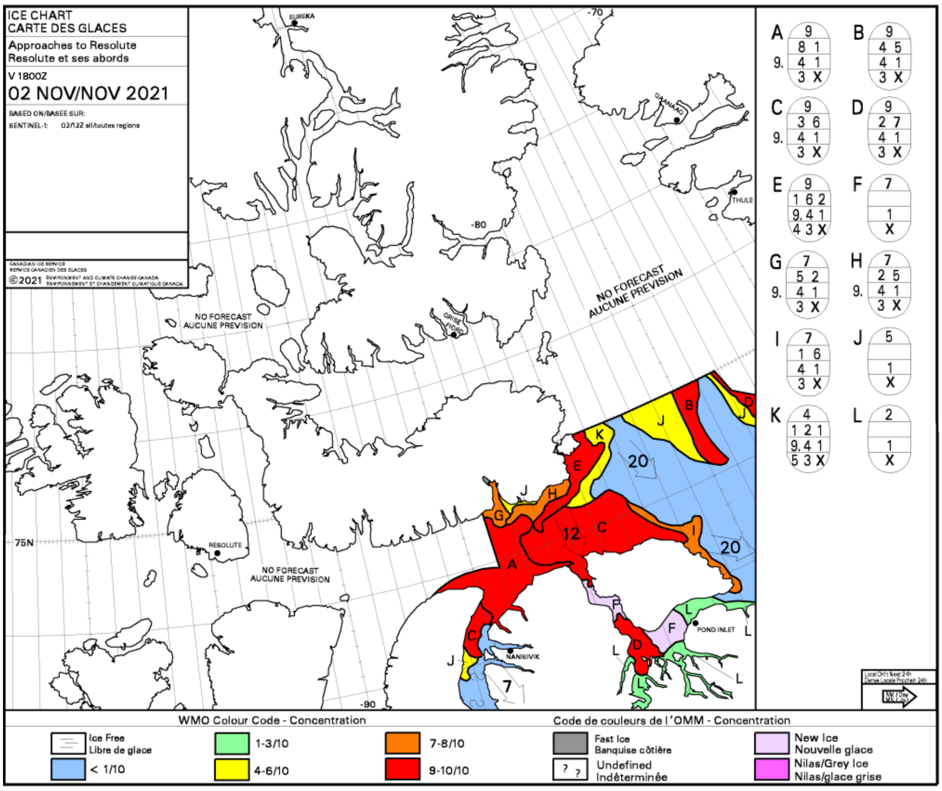
Finnish ice chart

Source: file:///C:/Users/Maja/Downloads/MaxIceChart2021.pdf



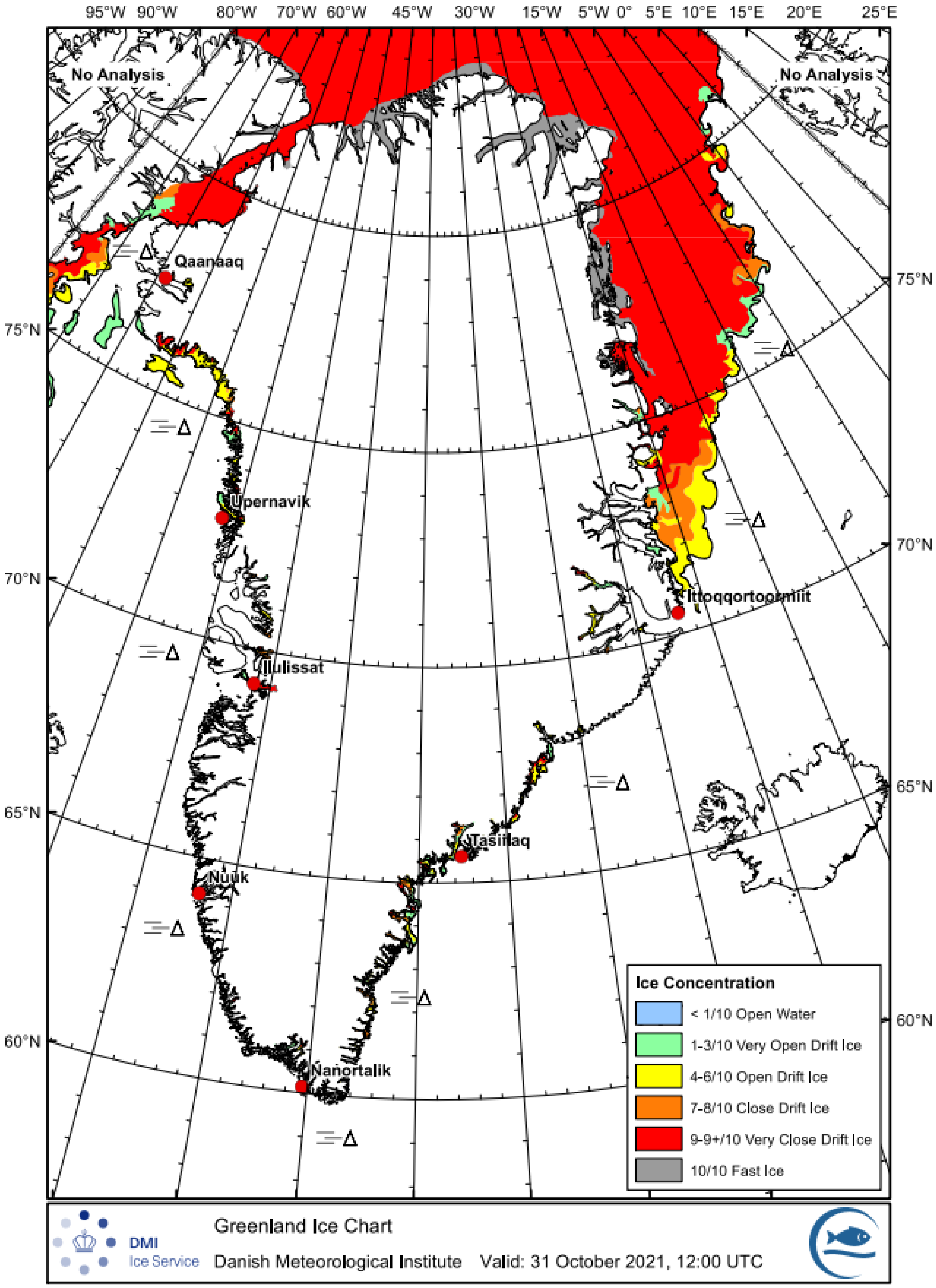
Norwegian ice chart

Source: https://cryo.met.no/sites/cryo.met.no/files/latest/general_latest.png



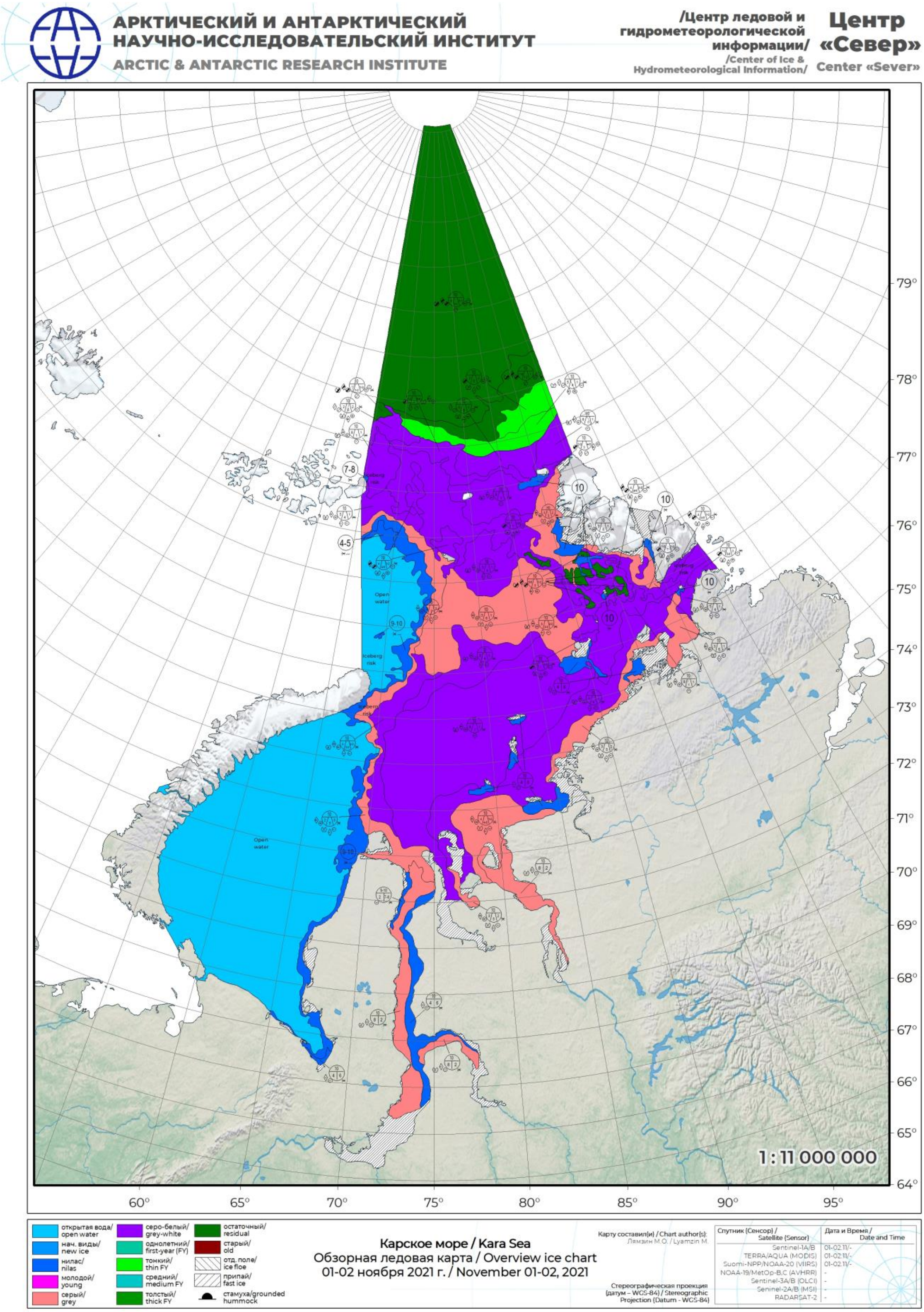
Canadian ice chart and EGG code

Source: https://ice-glaces.ec.gc.ca/prods/WIS35CT/20211102180000_WIS35CT_0011827264.pdf



Danish ice chart for Greenland

Source: http://ocean.dmi.dk/arctic/images/MODIS/Greenland_WA/202110311200.ISKO.pdf



Russia ice chart

Source: http://www.nsra.ru/en/navigatsionnaya_i_gidrometinformatsiya/chart_ice_kara_sea.html