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EXECUTIVE SUMMARY
Climate warming in the Arctic Region opens up for new or changes and expansion of existing maritime business activities. The future business development perspectives for three important components of the Arctic Blue Economy – maritime transport via the Arctic Ocean, cruise industry in the Svalbard area and fishery in the Barents Sea has been analysed. The maritime transport and cruise industry will potentially increase substantially over the coming years due to retreat of Arctic sea ice. In 2020 and 2021 the Covid-19 pandemic had severe negative impact on the cruise industry, whereas in 2022 the cruise traffic in the Arctic has recovered and was at the same level as the peak year in 2019. Barents Sea fishery is among the most important in Europe and represent a significant economic value for the industry. However, climate change with associated ecosystem changes will have impact on the stock composition and distribution, and consequently on the commercial fisheries. Entering into operations in the harsh Arctic environment requires good knowledge and understanding of the physical environmental conditions to ensure a sound decision process on economy, efficiency, safety of ship, crew and cargo and protection of the vulnerable Arctic environment. Therefore, examples of basic statistical analysis of relevant parameters like sea ice, wind, waves, temperature and salinity has been performed to outline the trends in change of environmental condition of importance for maritime operations in the Arctic. Additionally, operational meteorological and oceanographic near real time products and services are important when actually operating in the area. Satellite observations and outputs from numerical models are essential data sources for generation of operational products and services; but the trustworthiness of the information's from these two data sources depends critically on the availability of in situ observations of key variables for assimilation in the models and especially for validation of quality of the generated data products. Unfortunately, the availability of enough relevant and high-quality in situ observations of oceanographic and meteorological variables from the Arctic Region is far from satisfactory for this purpose. **It is therefore crucial to design and implement a fit-for-purpose Arctic Observing System to ensure the availability of high-quality in situ data needed for assimilation into forecasting models. The in situ data are also needed for validation of modelling and remote sensing products used both for operational monitoring and in statistical trend analysis.** In the perspective of increased maritime activity in the environmentally vulnerable Arctic Region it would be advisable to perform monitoring and analysis of environmental pressures similar to the one performed by European Maritime Safety Agency (EMSA) and European Environmental Agency (EEA) for the European Seas (EMSA & EEA,2021).

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Introduction

Substantial effects of climate change in the Arctic Region have been documented in scientific publications and reports over the past decades and summarized in the most recent IPCC report on the Ocean and Cryosphere in a Changing Climate (Meredith et al, 2019). The most visible signs of the dramatic changes are the warming of the Arctic Region at a rate of nearly double of the global average resulting in transformation of physical and biological processes across the entire region. For the Arctic Ocean the IPCC report identified the most important changes to be:

- The Arctic Ocean upper mixed layer temperature in the ice-free areas increased at a rate of about 0.5ºC per decade from 1982 to 2017. For the other areas there is very little data and difficult to assess any trends.
- Arctic sea ice extent continues to decline in all months of the year, the strongest reductions in September (very likely –12.8 ± 2.3% per decade; 1979–2018).
- Arctic sea ice has thinned, concurrent with a shift to younger ice: since 1979, the areal proportion of thick ice at least 5 years old has declined by approximately 90%.
- Climate-induced changes in seasonal sea ice extent and thickness and ocean stratification are altering marine primary production, with impacts on ecosystems. Changes in the timing, duration and intensity of primary production have occurred with marked regional or local variability.
- In the Arctic, changes in primary production have affected regional species composition, spatial distribution, and abundance of many marine species, impacting ecosystem structure.
- Climate-induced changes in ocean and sea ice, together with human introduction of non-native species, have expanded the range of temperate species and contracted the range of polar fish and ice-associated species. Commercially and ecologically important fish stocks like Atlantic cod, haddock and mackerel have expanded their spatial distributions northwards many hundreds of kilometres, and increased their abundance.
- Future climate-induced changes in the Arctic Ocean, sea ice, snow and permafrost will drive habitat and biome shifts, with associated changes in the ranges and abundance of ecologically important species. Projected shifts will include further habitat contraction and changes in abundance for polar species, including marine mammals, birds, and fish. Projected range expansion of subarctic marine species will increase pressure for high-Arctic species with regionally variable impacts. Continued loss of Arctic multi-year sea ice will affect ice-related and pelagic primary production, with impacts for whole ice-associated, seafloor and open ocean ecosystems.

The substantial changes in the Arctic climate opens for new developments and associated increase in Arctic Blue Economy activities, including shipping routes, cruise tourism, fishery in new areas and on new species, mineral and oil extraction, etc. An accurate knowledge of the environmental fields affecting these marine operations in the Arctic Ocean is a critical information for all these industries for long- and short-term investment planning, risk assessment and operational purposes.

The present study will focus on three selected business areas – shipping along the Arctic Ocean, cruise industry in the Svalbard area and fishery in the Barents Sea. Their present and

future business potential will be presented shortly. In their business development planning, which among other things also includes economy, efficiency, safety of ship, crew and cargo and protection of the vulnerable Arctic environment, it is important to have reliable statistical information's on key physical environmental parameters such as sea ice cover, wind and waves conditions, temperature and salinity of the water masses. The report presents examples on such statistics based on available data from OSI-SAF (satellite based observations of sea ice) and Copernicus Marine Environmental Monitoring System – CMEMS (numerical model outputs), but the provision of valid and trustworthy statistics and operational information of environmental parameters is entirely dependent on a fit-for-purpose sustained observation system (in situ and satellite-based) together with state-of-the-art meteorological and oceanographic reanalysis and forecast models.

Finally, the report presents some of the most important environmental threats to marine environment due to an increased maritime business activity.

1. Use case 1: Maritime transport via the Northeast Passage

The reduction in Arctic Sea Ice due to climate change opens up for increased commercial activities in the Arctic Ocean of which opening of new shipping routes linking the Atlantic and Pacific Oceans has a great potential.

1.1 Arctic shipping routes potential

To illustrate the potential for Arctic shipping, a comparison of a voyage between Europe (Hamburg port) and Japan (Yokohama port) taking four alternative routes of which three is via the Arctic Ocean (Fig.1.1) is performed:

1. The traditional route via the Suez Canal;
2. The Northeast Passage along the Russian Coast;
3. The Northwest Passage;
4. The Transpolar Sea Route

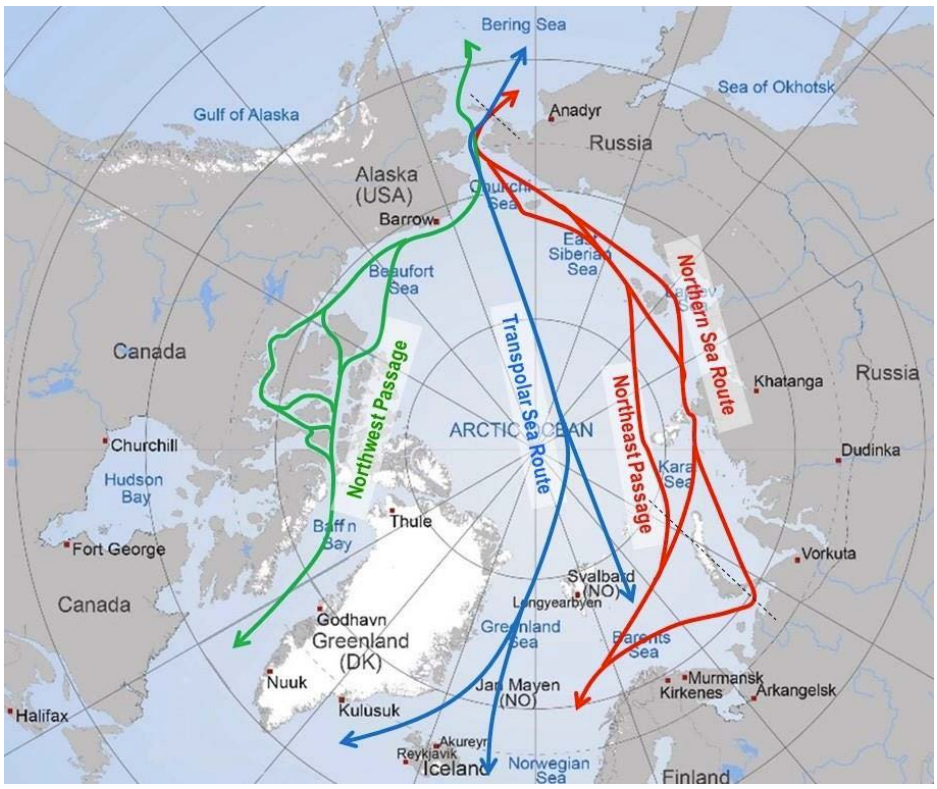


Figure 1.1 Arctic Sea Routes (Dyrcz, 2017)

The comparison is based on the assumption that the Arctic transit is performed without icebreaker support (i.e., under ice-free conditions). This implies that transit along the Northeast- and Northwest Passage in the present climate conditions only can take place part of the year, but the "opening window" is expected to increase in the years ahead. The Transpolar Sea Route constitute, for the same reason, a future possibility. That the Arctic transit can be done without help of icebreaker do not imply ice free conditions, presence of sea ice and related phenomenon's such as fog or reduced visibility must be also taken into account causing reduction in speed.

Table1.1. Distance, transit time, fuel consumption and other expenses related to a voyage for a cargo vessel between Hamburg and Yokohama using different routes

Hamburg-Yokohama Via				
	Suez Canal	**Northeast Passage**	**Northwest Passage**	**Transpolar Sea Route**
Distance				
• Hamburg-Novaja Semlja		2000		
• Hamburg-Svalbard				1600
• Hamburg-Davis Strait			2300	
• Novaja Semlja-Bering Strait		2500		
• Svalbard-Bering Strait				2300
• Davis Strait-Bering Strait			3000	
• Bering Strait-Yokohama		2700	2700	2700
Total Distance	**11430**	**7200**	**8000**	**6600**
Transit time (speed 14kn outside and 12kn inside Arctic Ocean):				
• Hamburg-Novaja Semlja		6,0		
• Hamburg-Svalbard				4,8
• Hamburg-Davis Strait			6,8	
• Novaja Semlja-Bering Strait		8,7		
• Svalbard-Bering Strait				
• Davis Strait-Bering Strait				8,0
• Bering Strait-Yokohama			10,4	
		8,0	8,0	8,0
Total transit time (days)	**34,0**	**22,7**	**25,2**	**20,8**
Fuel consumption (tonnes):				
• Hamburg-Novaja Semlja		147,6		
• Hamburg-Svalbard				118,1
• Hamburg-Davis Strait			167,3	
• Novaja Semlja-Bering Strait		134,9		
• Svalbard-Bering Strait				
• Davis Strait-Bering Strait				124,0
• Bering Strait-Yokohama			161,2	
		186,8	186,8	186,8
Total fuel consumption	**836,4**	**469,3**	**515,3**	**428,9**
Other expenses ($):				
• Suez Canal toll	61.168			
• Increased insurance for sailing in ice infested waters		10.600	10.600	10.600

In the analysis, a cargo ship with a service speed of 14 knots consuming 24,6 tons of fuel per day (Wergeland, 2010) is taken into consideration. In the Arctic Ocean it is expected that the average speed is reduced to 12 knots, this will on the other hand reduce to fuel consumption to 15.5 tons per day.

In Table 1.1 some simple calculations have been performed to illustrate the potential for using three different Arctic passages instead of the traditional route via the Suez Canal. The order of magnitude of savings (time and expenses) are summarised in table 1.2.

Table 1.2 Savings in time and expenses for a cargo vessel travelling Hamburg -Yokohama via the Arctic Ocean without icebreaker assistance

	Northeast Passage	Northwest Passage	Transpolar Sea Route
Days saved	**11,3**	**8,8**	**13,2**
Fuel cost savings (fuel price: 400$ pr. ton)[1]	146.840	128.440	162.000
Suez Canal toll[2]	61.168	61.168	61.168
Insurance	-10.600	-10.600	-10.600
Total savings ($)	**197.408**	**179.008**	**212.568**

[1] *Fuel prices vary constantly – the 400$ used in this example represents prices early 2020.*
[2] *The Suez toll represents the April 2020 price.*

The above simple analysis illustrates that there are potential savings in time and fuel consumption associated to using alternative Arctic sea routes instead of the traditional route via the Suez Canal.

Some specific comments to the above analysis:

- The Transpolar Sea Route is the most advantageous but is not realistic in a foreseeable future due to year-round ice cover in the central Arctic;
- For ship traffic between Europe and Asia the Northeast Passage route gives best savings in time and expenses. The numbers given in Table 1.1 and Table 1.2 give a representative picture but may vary since the path through the Arctic Ocean can change due to the sea ice distribution – see Fig.1.1 and Chapter 1.2.
- Reduction in travel time of around 33% will:
    - Liberate maritime transport capacity leading to either increased ship-based transportation or reduction in ship capacity;
    - Possible reduction in freight rates;
- There is an environmental impact to be considered:
    - The reduction in travel time and fuel consumption of the individual voyage will reduce the impact on the environment, but if the freed transport capacity is fully utilised, the environmental impact will be the same,
    - The environmental impact will however be moved geographically from low to high latitudes,
    - Restructuring part of maritime transport to the Arctic will increase the risks for accidents and oil spills in general due to the presence of sea ice and related visibility problems and to the Arctic Ocean in particular due to increased ship

traffic in the area. This is of particular concern due the vulnerability of the Arctic environment and the lack of oil spill combatting preparedness in the area.

- There are also safety issues to be considered:
  - The harsh Arctic environment raise special demands to secure a safe journey for the ship and its crew e.g.:
    - Construction of the ship
    - Education of the crew
    - Operating procedures on the ship
    - High quality operational meteorological and oceanographic forecast products and services
  - Search and rescue facilities are minimal

It is therefore of outmost importance to collect a variety of information before entering into maritime transport business via the Arctic Sea Routes. In addition to the ship technical and navigational issues, which are outside the scope of this report, it will also be beneficial to collect basic statistics on environmental meteorological and oceanographic parameters such as sea ice (distribution, concentration, thickness, drift velocity), wind, visibility, waves and currents - examples of such information will be provided in Chapter 4.

During the actual voyage it is important from a voyage optimisation and security perspective to receive operational information on the same environmental parameters on a regular and real-time basis.

1.2 Actual ship traffic in the Arctic

One way of measuring the actual maritime transport and ship traffic in the Arctic is through the ship reporting data of the Automatic Identification System (AIS), collected by coastal stations and satellites. AIS is an automatic ship transponder system used onboard commercial vessels. The system was conceived to assist vessels' watch standing officers and allow maritime authorities to track and monitor vessel movements for purposes such as collision avoidance, maritime security, aid to navigation, search and rescue, etc.

AIS data, being a commercial product, is not freely available, however, some public institutions provide maps of shipping density based on AIS data, which are freely available. In the following only publicly, available information is presented.

1.2.1 EMODnet human activity portal

The EMODnet human activities portal (https://www.emodnet-humanactivities.eu/view-data.php) released in March 2019 a product with vessel density maps in EU waters. EMODnet mandate is to cover EU waters, so their maps only cover European Arctic.

This product is based on AIS data derived from a commercial provider – *Collecte Localisation Satellite* (CLS) and ORBCOM. Density is expressed as total number of hours spent by ships in a grid cell in a month. This unit of measure can immediately be converted into average number of ships in a grid cell in a month. At the moment of writing this report only year 2017 and 2018were available. Figure 1.2 shows the vessel density map for 2018.

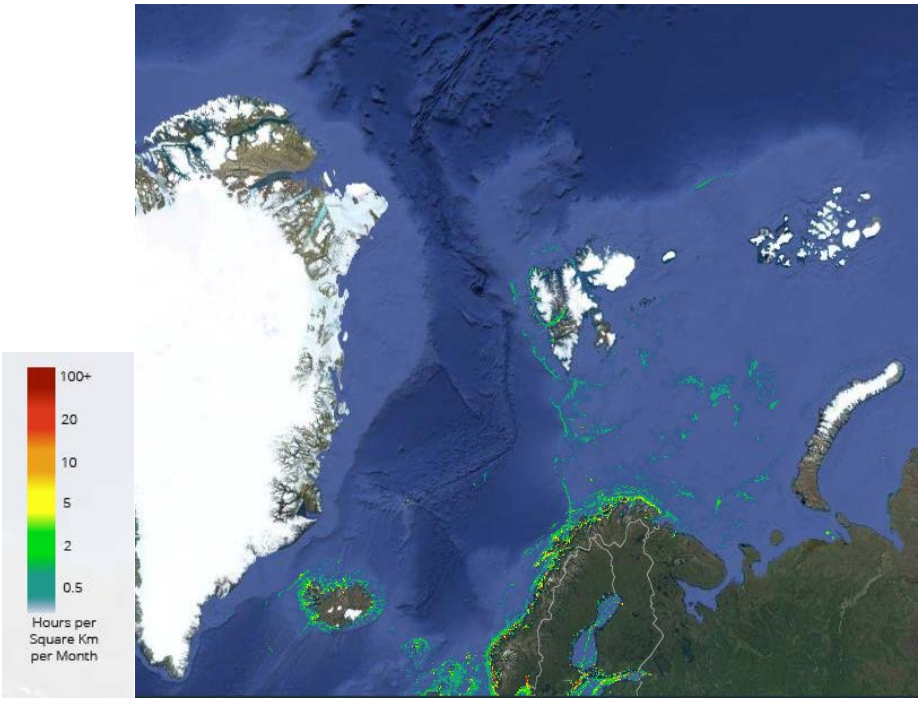


*Figure 1.2. Average vessel density map in 2018 from EMODnet human activity portal. The map show shipping density in 1km*1km cells*

EMODnet also makes available the shipping route density, computed by the European Marine Safety Agency (EMSA). In this route density maps, density is expressed as number of ship routes in a grid cell in a month. The route density map displays the total number of "ship crossings" in a given cell (See Fig. 1.3 for year 2019). EMSA computes these maps though use of data received by the Member State operated land stations and purchased satellite data from Luxspace. Fig1.3 displays a high shipping activity between Northern Norway and Svalbard.

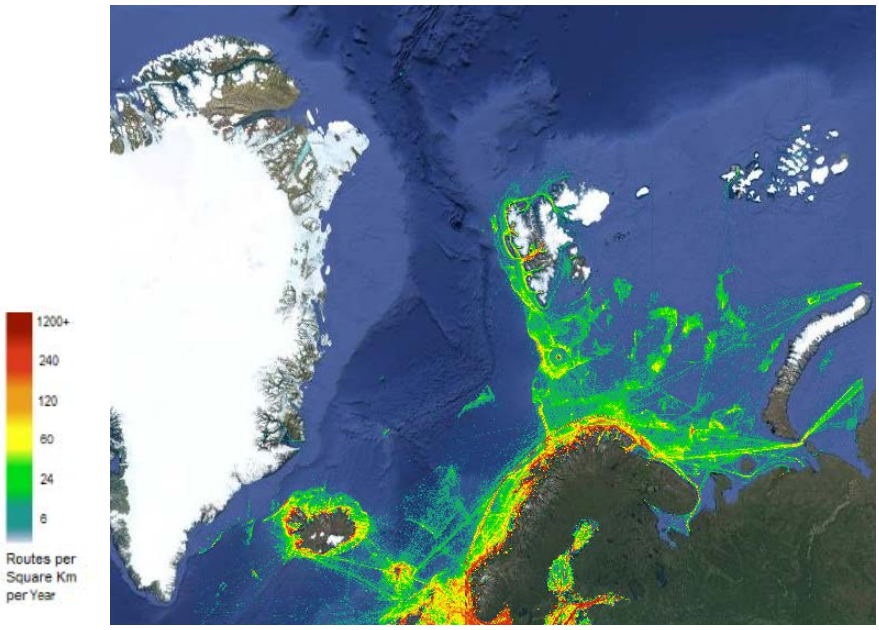


Figure 1.3. Total routes per square Km density in 2019 from EMODnet human activity portal and computed by EMSA.

1.2.2 Joint Research Center - JRC

The JRC has produced a report on Human Activities at Sea in the Arctic using Remote Sensing and Vessel Tracking Systems, where historical AIS data have been used to make maps of maritime traffic and related human activities in the Arctic Sea (Vespe et al., 2018). The following maps in Figures 1.4 and 1.5, obtained from this report, show the arctic-wide seasonal changes in human activities depending on the ice extent for two periods (maximum and minimum extent of Arctic Sea Ice). Shipping, exploration, icebreaking and fishing activities is obtained from ship type information in the AIS messages. The raw AIS data for this study has been obtained from the Norwegian Defence Research Establishment (FFI), the Norwegian Coastal Administration and the MSSIS (US Department of Transportation and the US Navy).

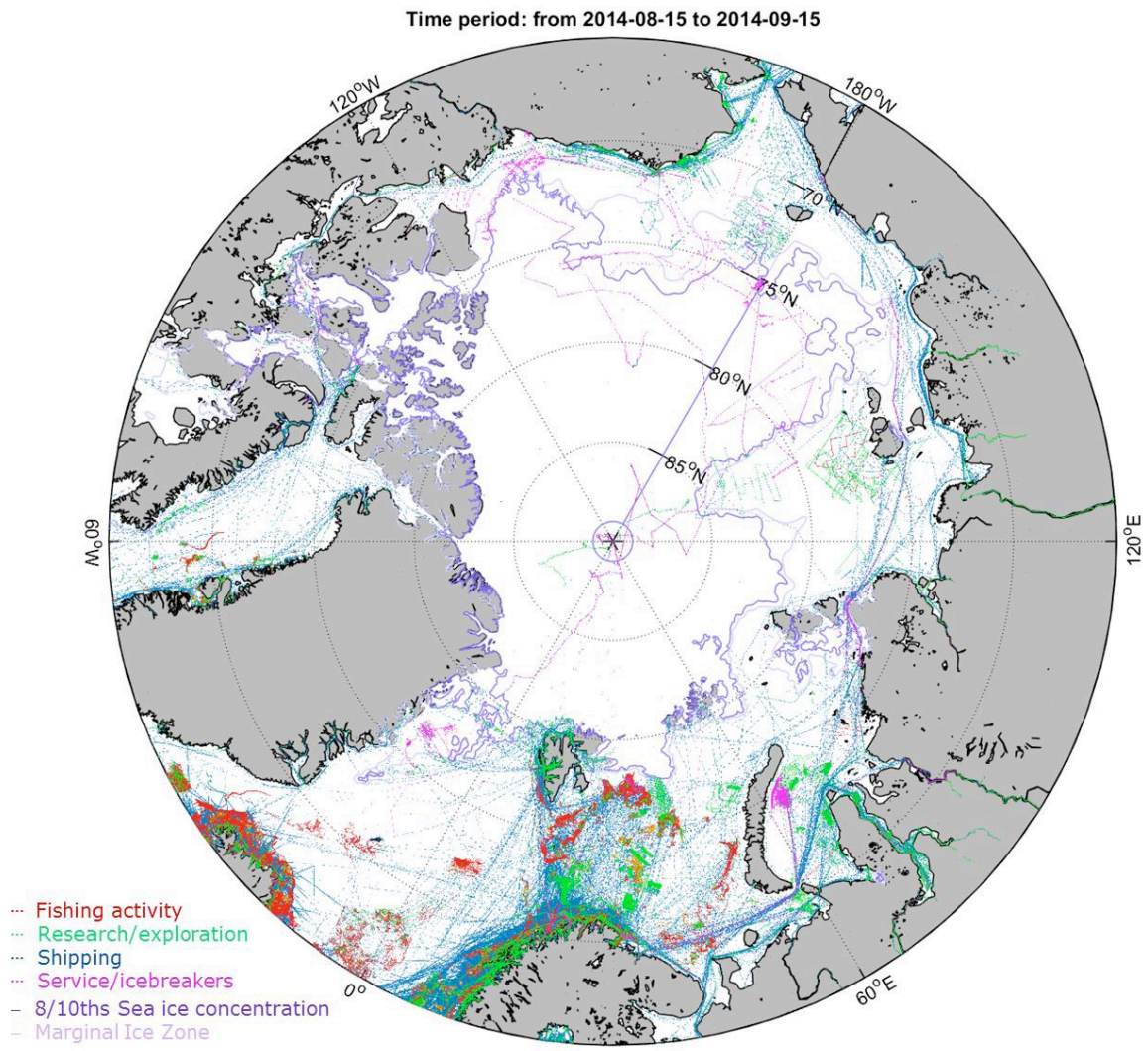


Figure 1.4 Maritime traffic in the Arctic and ice extent for the period mid-August to mid-September 2014, period of minimum extent of Arctic sea ice (From Vespe et al. 2018)

As a result of their study, JRC claims that the satellite AIS system is a very powerful tool to monitor shipping activities in the Arctic, but there is however, a significant amount of Arctic information from vessel tracking systems which is still not available and could help to increase the understanding of the Arctic human activity dynamics. More collaboration and information

sharing among research community and operational authorities is needed to bring together all available data.

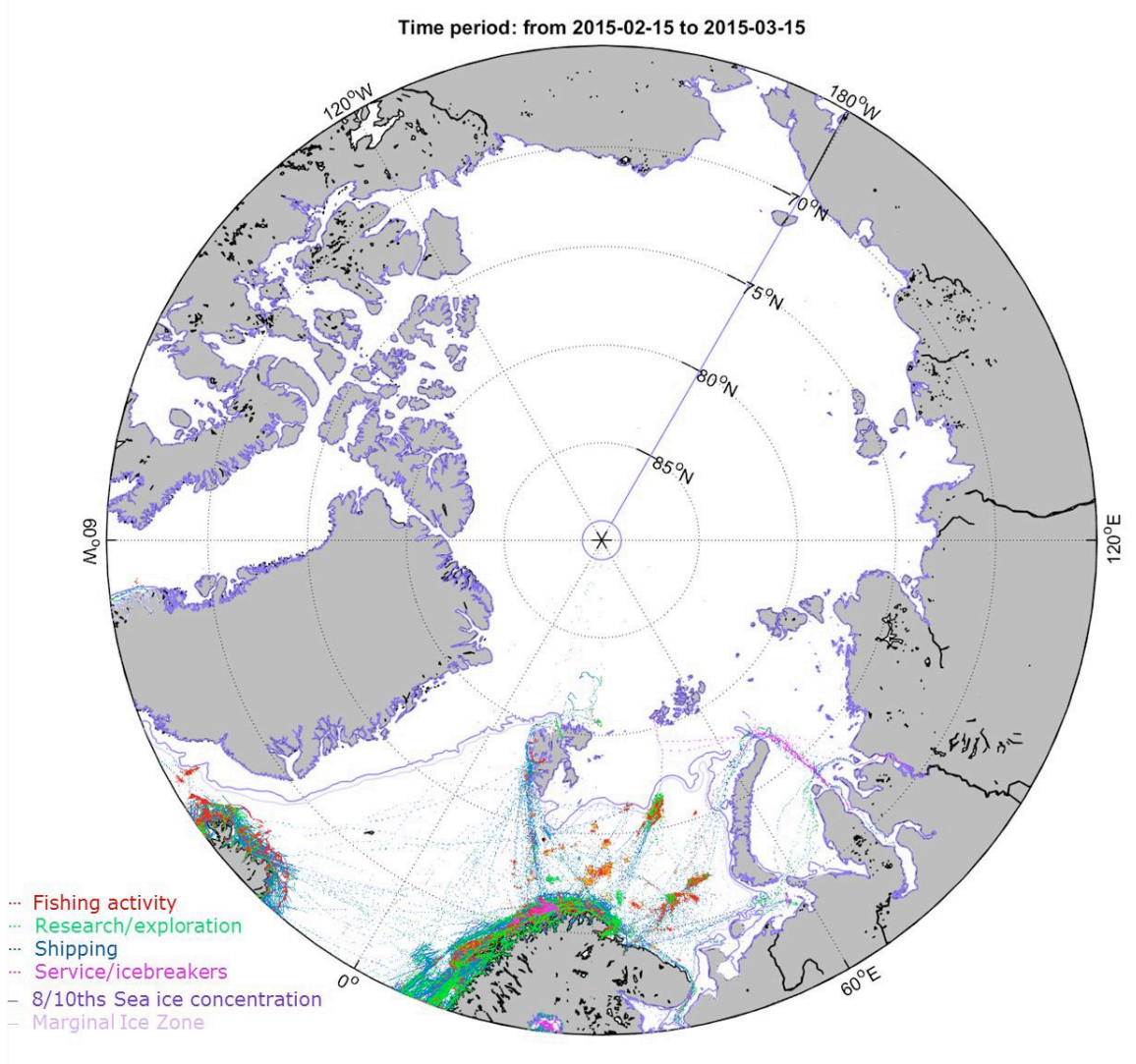


Figure 1.5 Maritime traffic in the Arctic and ice extent for the period mid-February to mid-March 2014, period of maximum extent of Arctic sea ice (from Vespe et al. 2018)

1.2.3 DNV-GL

The company DNV-GL has produced an Arctic Risk map (https://maps.dnvgl.com/arcticriskmap/) showing information on Arctic Shipping activity in year 2012 obtained from AIS data provided by Norwegian Coastal Authority. This information has been processed and prepared for visualization by DNV GL. The product facilitates selecting the routes by month and type of ship/vessel, but the data cannot be downloaded.

Figure 1.6 and 1.7 display examples of shipping routes for year 2012: September (the month with minimum ice extent) and February (the month with maximum ice extent). In September some icebreakers crossing towards the North pole and some routes in the Northeast Passage (northern Russia) can be seen.

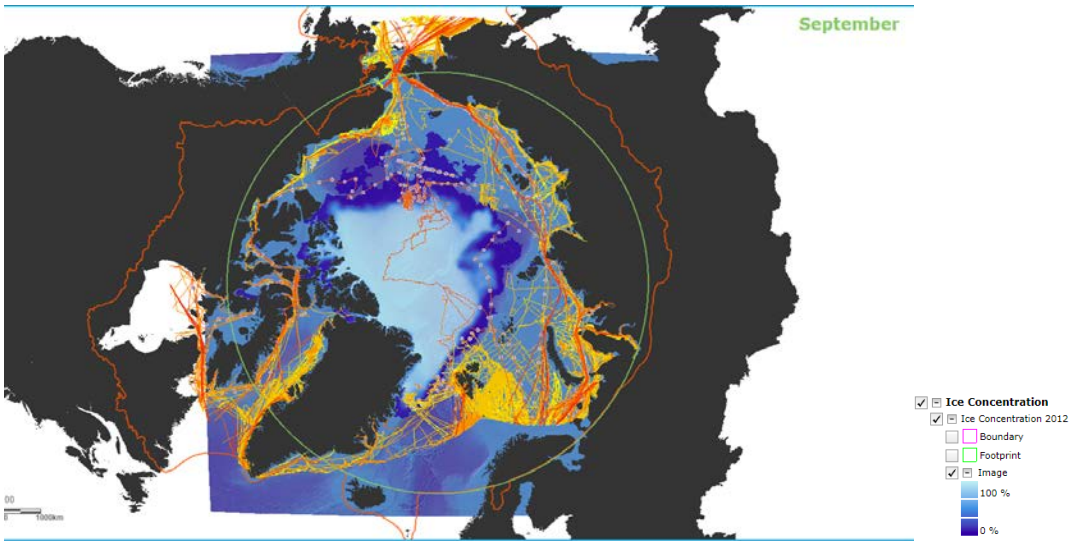


Figure 1.6 Shipping activity in September 2012 (From the DNV Arctic Risk Map), the blue-white colour represents the Ice concentration.

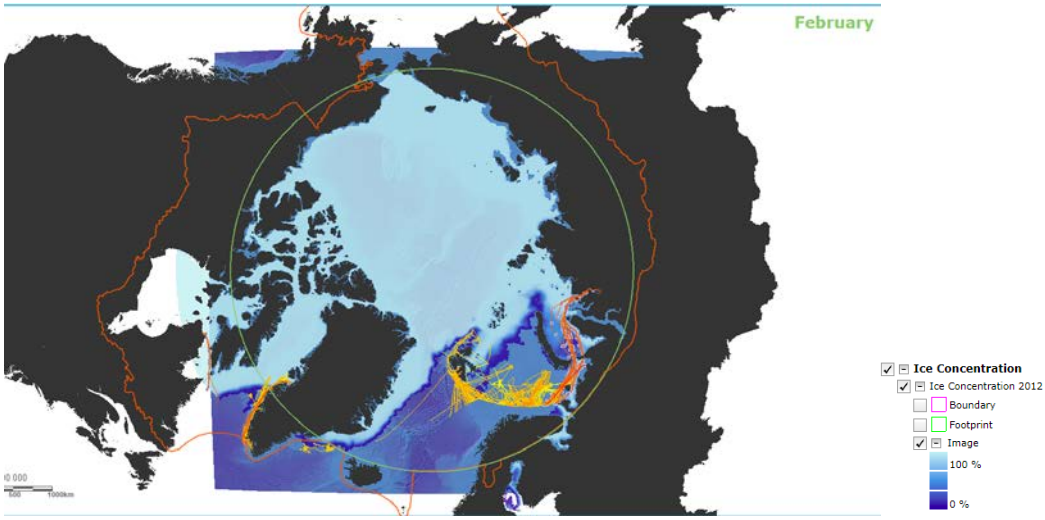


Figure 1.7 Shipping activity in February 2012 (From the DNV Arctic Risk Map), the blue-white colour represents the Ice concentration.

1.2.4 PAME Arctic Ship Traffic Data

Protection of the Marine Environment (PAME) is one of six Arctic Council Working Groups. PAME's has developed an Arctic Ship Traffic Data (ASTD)[1] project in response to a growing need to collect and distribute accurate, reliable, and up-to-date information on activities in the Arctic.

The ASTD System collects a wide range of historical information, including ship tracks by ship type, information on number of ships in over 60 ports/communities across the Arctic, detailed measurements on emissions by ships, shipping activity in specific areas (e.g. the EEZ's, Arctic LME's and the Polar Code area), and fuel consumption by ships.

[1] http://www.astd.is/

PAME operates with four types Arctic Shipping:

- Destinational transport, where a ship sails to the Arctic, performs some activity in the Arctic, and sails south.
- Intra-Arctic transport, a voyage or marine activity that stays within the general Arctic region and links two or more Arctic States.
- Trans-Arctic transport or navigation, voyages which are taken across the Arctic Ocean from Pacific to Atlantic Oceans or vice versa.
- Cabotage, to conduct trade or engage in marine transport in coastal waters between ports within an Arctic State.

The ASTD system has documented an increase of Arctic Shipping since 2013 – In 2013 1298 ships entered the Arctic, in 2019 the number was 1628 i.e an increase of 25% over 6 years; Fig. 1.8 show the distance sailed in the individual years and Fig. 1.9 shows the ship types entering the Arctic in 2019.

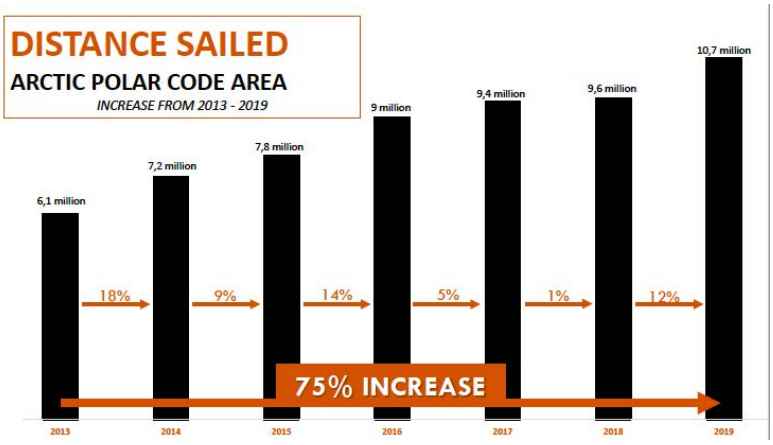


Figure 1.8 Development in distance sailed by ships entering the Arctic Area in the years 2013-2019 (Source: PAME, 2020)

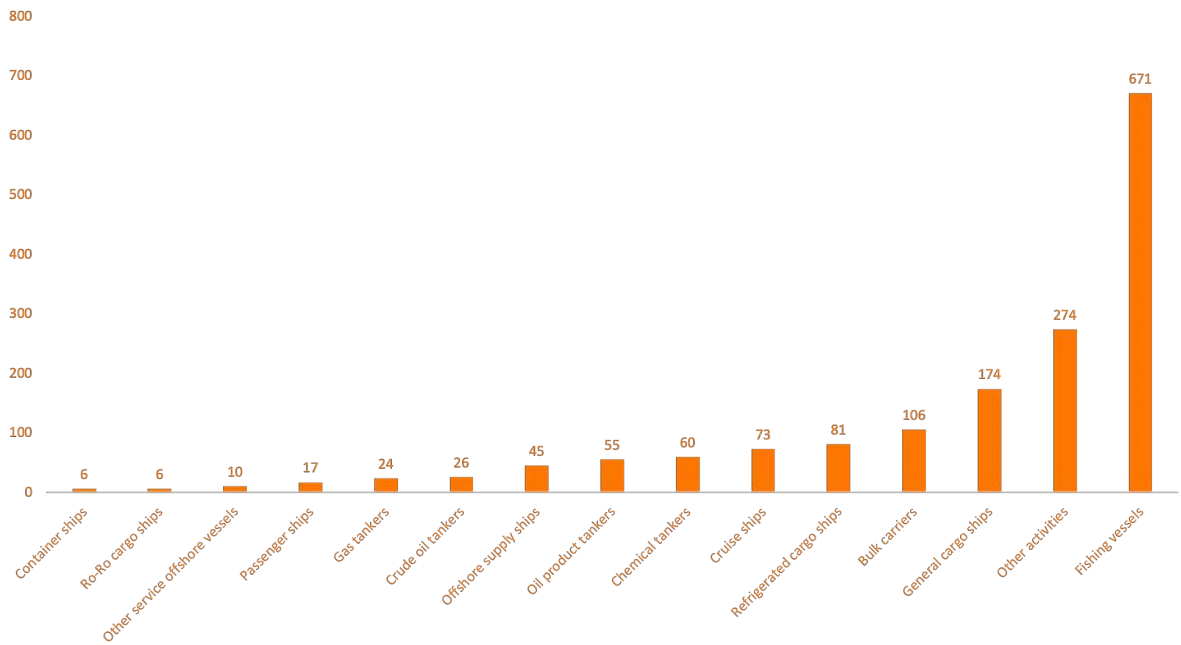


Figure 1.9 Ship types entering the Arctic in 2019 – fishing vessels dominant (Source: PAME 2020)

2. Use case 2: Cruise tourism around Svalbard and East Greenland

2.1 Arctic cruising development

The Arctic Cruising Industry has developed since the 1960's. In the early stages of development these types of cruising were described as expeditionary cruising or just expeditions typically organised by companies specializing in adventure travels. Later they were joined by companies that emphasized scientific education and nature studies. The ships used were often old icebreakers mainly of Russian origin and travel conditions ranged from comfortable to spartan.

During the past couple of decades luxury cruise lines have begun to venture into the high Arctic waters, since a warming Arctic with increasing retreat of sea ice has opened areas to cruising that previously were restricted to icebreakers.

Arctic cruising focus areas are primarily (see Fig 2.1):

- Eastern Atlantic where Svalbard plays a central role but also includes trips/expedition into the central Arctic towards the North Pole
- Western Atlantic including the Baffin Bay
- The northwest Passage
- Alaskan waters

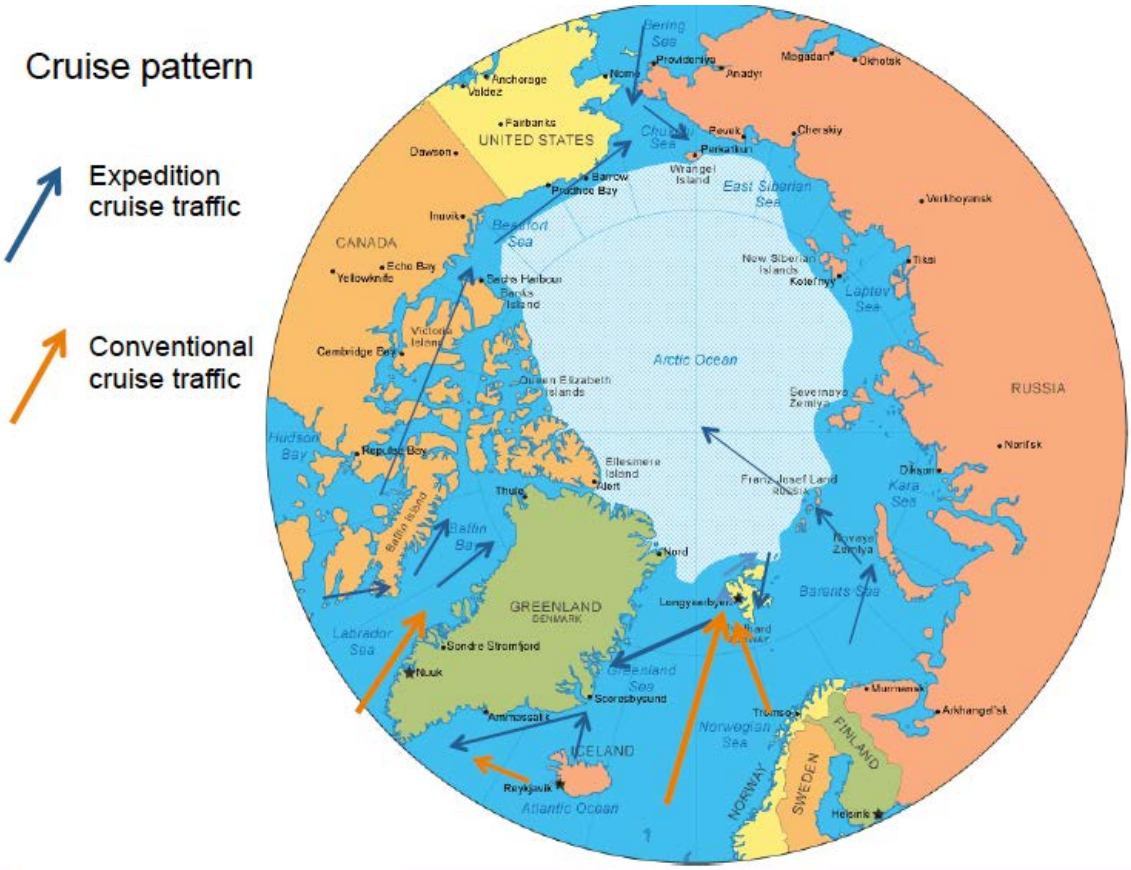


Figure 2.1 Arctic cruise pattern and type of cruises (Source: AECO – Association of Arctic Expedition Cruise Operators)

The increase in the number of cruise passengers in the Arctic region has been substantial over the past 1-2 decades. In Fig 2.2 is shown the number of cruise passengers to five different location for the period 2005- 2017 based on information kindly provided by the Association of Arctic Expedition Cruise Operators (AECO, pers. communication). It is clearly seen that Svalbard and Greenland areas are the most popular destinations.

Figure 2.2. Number of cruise passengers to Svalbard, Greenland, Frans Joseph Land, Nunavut and Northwest Passage - 2005-2017 (Source: AECO – Association of Arctic Expedition Cruise Operators)

Business prognoses foresee this increase to continue also in years to come; and the latest trend is to deviate from the normal cruising season during the few summer months (June to September) and also organise cruises during late-winter/early spring period.

However, the Covid-19 pandemic outbreak in early 2020 has indeed changed this development pattern. There are no exact numbers on the reduction in the Arctic cruise traffic in 2020 and 2021 at the time of preparation of this report but indications says more than half of planned cruise activities has been cancelled and it is expected that it will take several years before the Arctic Cruise Industry is back to pre-COVID conditions.

Operating in the Arctic Region put special demands on the ships and the skills of the crew to ensure a save journey for the ship, crew and passengers, but also to protect the vulnerable Arctic environment. The ships being used for Arctic Cruises are divided in five categories:

- Icebreakers - used to access the extreme north
- Research vessels – often refurbished to obtain close to cruise quality
- Other ice class vessels - a few purpose-built cruise vessels with high ice class
- Ice strengthened vessels
- Vessels with no ice capability

Vessels belonging to the last category are few but do unfortunately exist.

Figure 2.3 Costa Delizios (no ice capability) in Disko Bay, Greenland 2011 (Source: DMI)

Another safety aspect that put demands on ship, crew and planning of the voyages is the limited availability of Search and Rescue (SAR) facilities in the Arctic Region, a topic of great concern to the national SAR authorities in the Arctic nations. The new Polar Code for Arctic ship operators requires ships to have lifesaving equipment that ensures a minimum of 5 days survival time while waiting for external rescue. This is however regarded as a theoretical statement by SAR officers, since there do not exist such equipment that can keep elderly people alive for 5 days in Arctic environment.

It is therefore extremely important that cruise ship officers have easy access to the most recent environmental information's – observations and forecasts – of meteorological, oceanographic and sea ice conditions in order to take these into account in their operational planning.

Figure. 2.4 Example of an Arctic cruise line – Magnetic North Travel.

3. Use case 3: Fishing in the Barents Sea

3.1 Barents Sea Ecosystem

The Barents Sea ecoregion covers the shelf sea to the north of Norway and Russia (Fig 3.1). Its western boundary follows approximately the shelf break towards the deep Norwegian Sea, and its northern boundary follows the shelf break towards the deep Arctic Ocean. To the east, the ecoregion borders Novaya Zemlya and the Kara Sea. The two Arctic archipelagos of Svalbard and Franz Josef Land are situated within the ecoregion. There are relatively deep areas to the west, while the eastern parts of the ecoregion are dominated by bank areas.

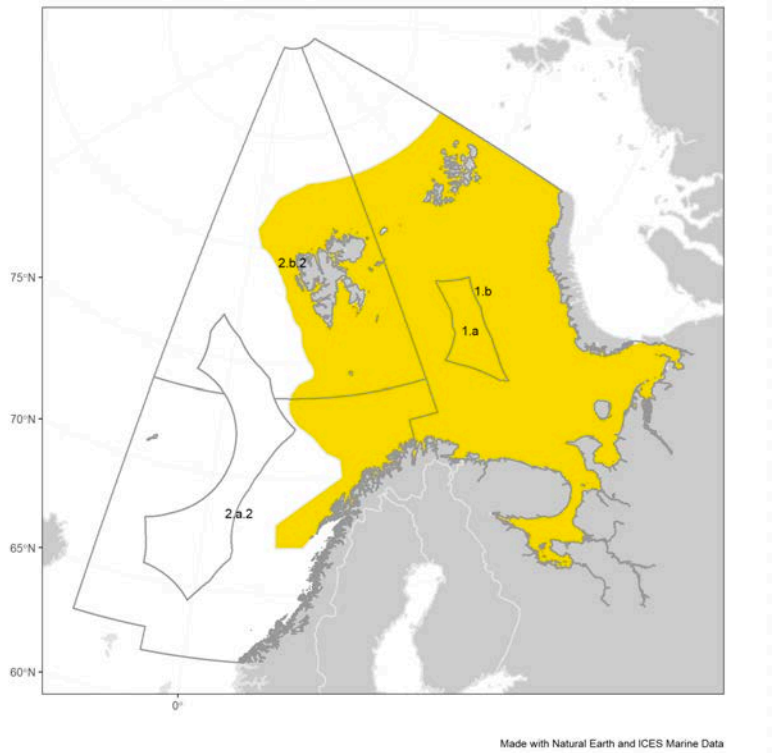


Figure 3.1 The Barents Sea ecoregion (highlighted in yellow). (source: ICES, 2019)

3.1.1 Oceanography

The physical conditions in the Barents Sea have been summarized by Eriksen et al, 2017 as follows:

> *The mean depth is 220 m (Gorshkov, 1980), and the maximum depth in the western Barents Sea is approximately 500 m. The bottom topography, with its banks and basins, steers the currents and governs the distribution of water masses (Loeng, 1991). The ocean currents in the Barents Sea are dominated by Atlantic Water flowing into and across the Barents Sea. The flow of Atlantic Water across the western boundary is influenced by the atmospheric pressure and winds. South-westerly winds tend to strengthen the inflow, while north-easterly winds tend to slow the inflow and may even reverse it and cause outflow events, particularly in the northern portion of the western entrance to the Barents Sea (Ingvaldsen et al., 2003). There is also an inflow of Atlantic Water from the West Spitsbergen Current to the northern Barents Sea through the deeper parts of the northern shelf (Lind and Ingvaldsen, 2012).*

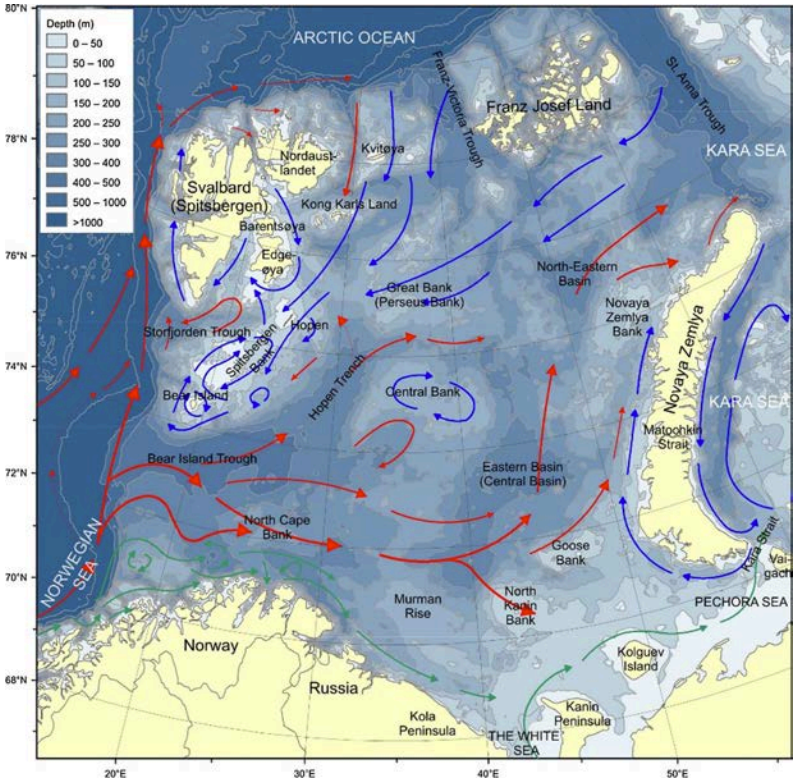


Figure 3.2. The Barents Sea. Red arrows show Atlantic water currents, blue arrows Arctic currents and green arrows currents of coastal waters. (Source: Eriksen et al, 2017)

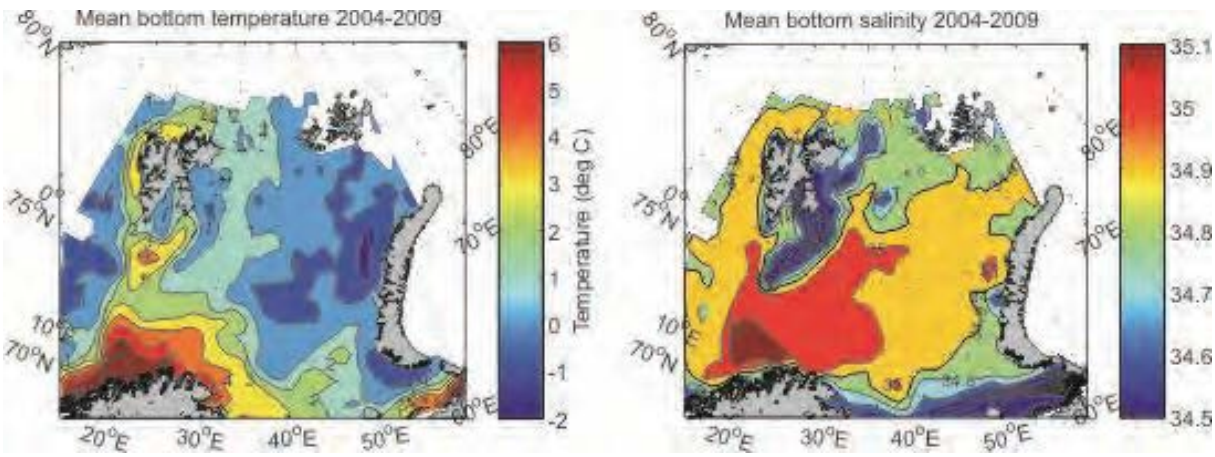


Figure 3.3. Mean bottom temperature (left) and bottom salinity (right) in August-September 2004-2007. (source: Wienerroither et al., 2011)

Cold Arctic Water is found overlying the Atlantic Water in the northern Barents Sea. Some of the Arctic Water of the northern Barents Sea possibly circulates around the archipelagos, both Svalbard and Franz Josef Land. There is probably also exchange of the Arctic Water between the northern Barents Sea and the adjacent Nansen Basin of the Arctic Ocean. The inflowing Atlantic Water is relatively warm and gives boreal conditions in the western and southern part of the Barents Sea, while the Arctic Water is cold and gives sub-arctic and arctic conditions in the northern part (Ozhigin et al., 2011; Smedsrud et al., 2010, 2013). The boreal and Arctic regimes are separated by a sharp oceanographic polar front in the western part of the Barents Sea (Ozhigin et al., 2011).

Most of the sea ice in the Barents Sea is moving first-year pack ice that forms seasonally, but multi-year ice is found in the northern Barents Sea where it is partly advected in from the Arctic Ocean (Vinje, 2001). Ice cover varies seasonally and interannually. Ice coverage is at a minimum in September, when an average of 5% of the Sea is covered with ice. The extent of the ice varies widely depending on the weather conditions; in extremely warm years, there is no ice in August– September, while in cold years, drifting ice covers approximately 30% of the area. Maximum ice cover is in April and ranges between 35 and 85%, with an average of approximately 60%. The long-term yearly mean ice overage is close to 40% (Ozhigin et al., 2011). Climate and the extent of ice cover have varied during the total observation period, and in recent years, there has been a warming trend (Drinkwater et al., 2011).

3.1.2 Barents Sea fishes and species abundance

According to data collected over the past decades, more than 200 fish species from 66 families are found in the Barents Sea (*Wienerroither et al, 2011)*. The predominant families are: eelpouts (Zoarcidae), snailfishes (Liparidae), codfishes (Gadidae), sculpins (Cottidae), flatfishes (Pleuronectidae), and rockling, ling, and tusk (Lotidae). These families account for nearly 80 % of the species that occur regularly in the Barents Sea, and more than 40 % of the species recorded in this region.

Around 100 fish species turn up regularly in trawl catches during scientific surveys in the Barents Sea. The total biomass and number are dominated by a few species; the ten most abundant fish species usually account for more than 90 % of the total number of all specimens that are caught in surveys using demersal trawls. Some species occur in the Barents Sea throughout their life cycle and spawn there (e.g., capelin, Greenland halibut, long rough dab). Others have their main feeding area in the Barents Sea but spawn elsewhere (e.g., juvenile herring, Norway pout). Yet other species, whose main feeding areas are elsewhere, regularly visit the Barents Sea during the feeding migration in summer (e.g., blue whiting), and some species occasionally occur in the Barents Sea due to inflow of warm currents (e.g., spotted barracudina Arctozenus risso). Many species from this latter group are rarely recorded, and at least 40-50 of the species do not occur in the Barents Sea every year (e.g., king of herrings Regalescus glesne, sea breams Brama brama, Pterycombus brama, Taractes asper, etc.). However, for many of the species found in the Barents Sea, their life cycle, migration pattern and spawning areas are still poorly known, Wienerroither et al, 2011.

Both Arctic cold-water species characteristic of Arctic water masses and boreal temperate water species characteristic of Atlantic (also called boreal) water masses, are found in the Barents Sea. Further, the fishes can be classified based on their vertical distribution: demersal fish are linked to the bottom, but can also migrate vertically e.g. when feeding, whereas pelagic fish is found in the free water masses.

Most of the fishes found in the Barents Sea are demersal. The distribution of both pelagic and demersal fish is determined by water mass distribution, water temperatures and salinity, in addition to the distribution of their prey. For demersal fish, the bottom depth and sediment type are also important for their distribution. The fishes can also be classified according to

their diet. Most pelagic fish feed on zooplankton, whereas most demersal fish feed on fish or benthic organisms. However, the diet changes with fish size and most demersal fish have larvae and juveniles that lives pelagically and feeds on plankton, and e.g. cod can include a large proportion of large zooplankton in their diet even at a large size.

3.1.3 Fisheries

ICES provide advice for the 15 most important fish stocks in the Barents Sea and the following reflects their overview published in 2019 (ICES, 2019).

Landings of pelagic species (mainly capelin) within the Barents Sea showed a sharp increase in the late 1960s, then remained high until the mid-1980s. The capelin landings have fluctuated since then, reflecting alternating periods with either total fishing ban, or with TACs in the order of 0.3–1.0 million tonnes (Fig. 3.4). Landings of demersal fish were highest both at the beginning and near the end of the time-series. Landings of crustaceans and "undefined" species (not assigned a specific guild) have been low, compared to landings of pelagic and demersal fish during the whole period (Fig. 3.4). Crustacean fisheries have remained relatively stable in the last few decades; deep-water shrimp accounts for the highest landings. Other important crustacean species include red king crab and, in recent years, snow crab. Cod, haddock, and saithe account for the highest landings of demersal species (Fig. 3.5).

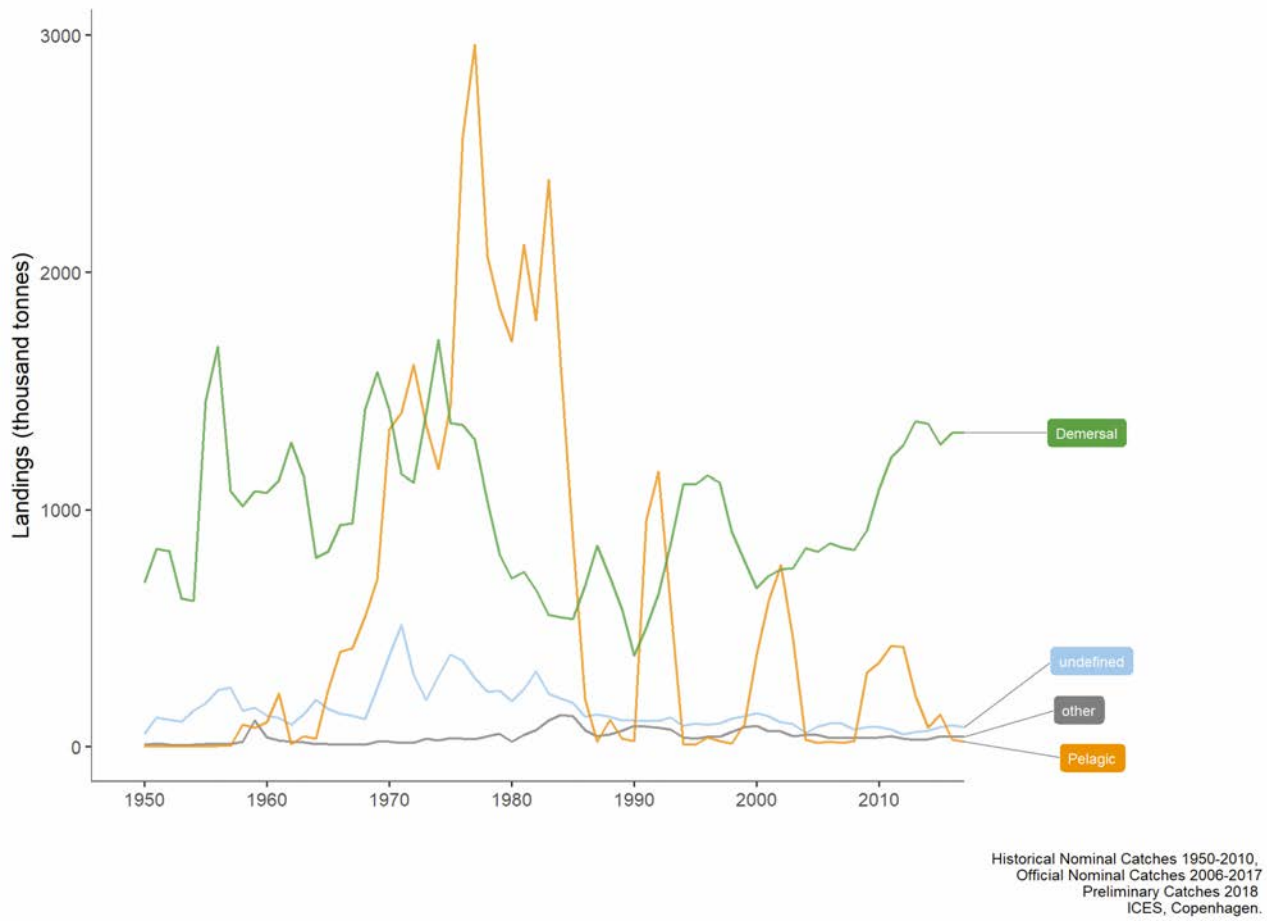


Figure 3.4 Landings (thousand tonnes) from Barents Sea in 1950–2018, by fish category. (Source: ICES, 2019)

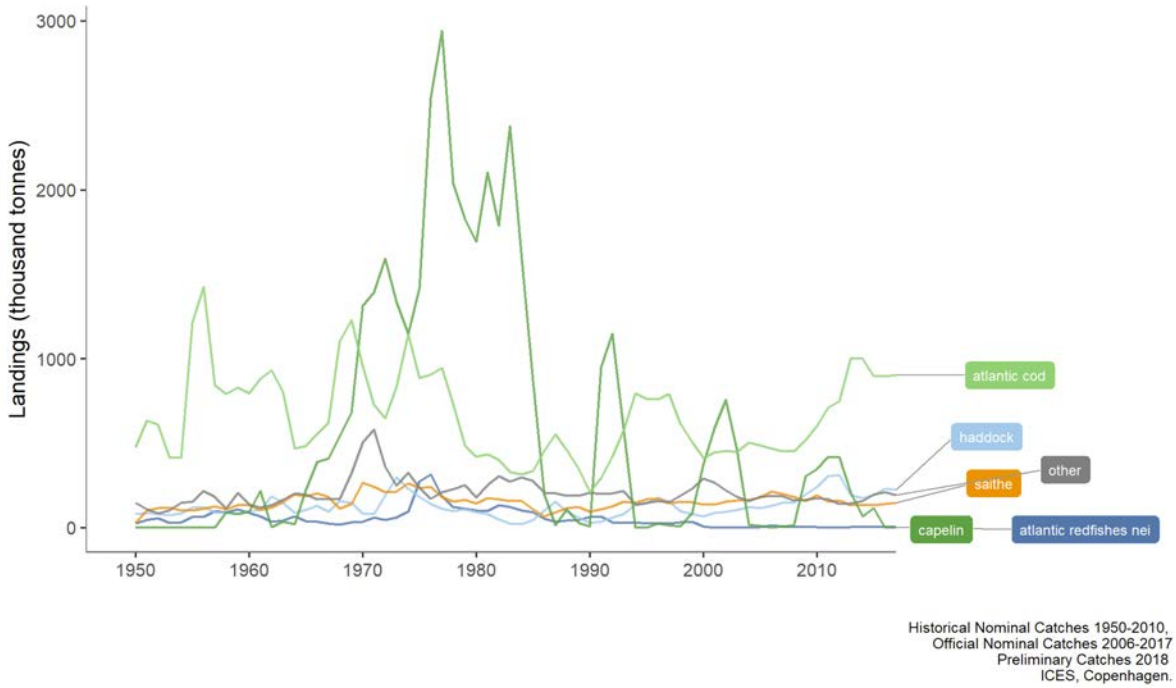


Figure 3.5 Landings (thousand tonnes) from Barents Sea in 1950–2018, by species. The five species having the highest cumulative landings over the entire time-series are displayed separately; the remaining species are aggregated and labelled as "other". (Source: ICES, 2019)

There are currently 12 nations with fisheries targeting the stocks in Barents ecoregion. The country with the highest landings is Norway, followed by Russia. Lower landings are made by Denmark, Estonia, Faroe Islands, France, Germany, Iceland, Poland, Portugal, Spain, Belarus, and the UK (Fig. 3.6).

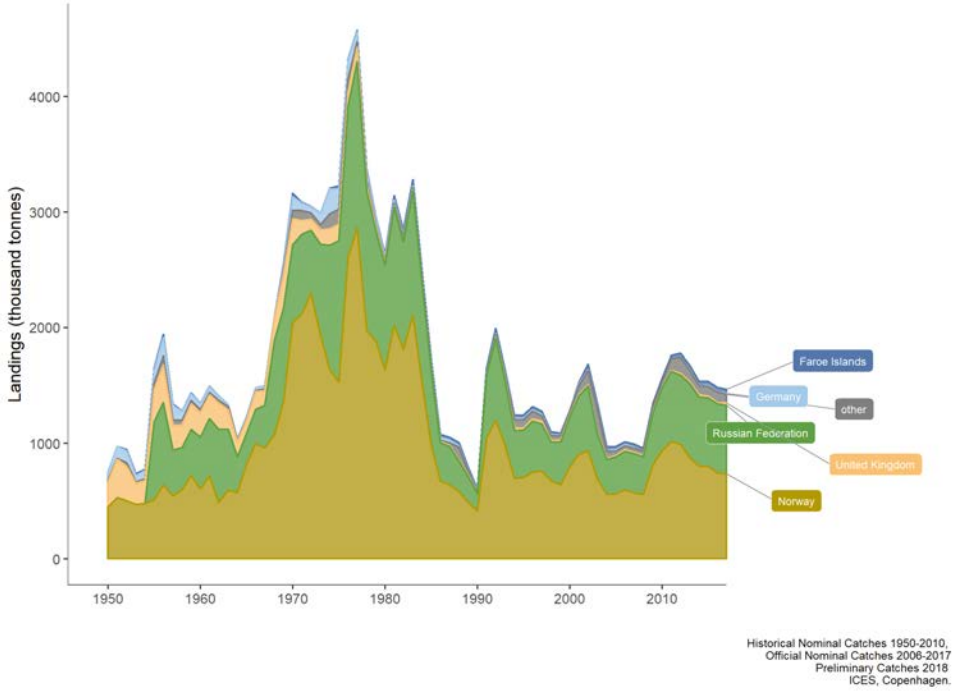


Figure 3.6 Landings (thousand tonnes) from Barents Sea in 1950–2018. The nine countries having the highest cumulative landings over the entire time-series are shown individually, and the remaining countries are aggregated and displayed as "other". (Source: ICES, 2019)

Prior to the establishment of exclusive economic zones in the ecoregion in the late 1970s, several nations were fishing in the area. The major fishing fleets were from Norway and Russia. Historically, landings by all nations were dominated by demersal species such as cod and haddock; redfish (beaked and golden) and Greenland halibut were, however, also important up to about 1990.

Landings of capelin, the only major pelagic fish species in the area, peaked at three million tonnes in 1977. The capelin stock "collapsed" to very low levels in the mid-1980s. Before the establishment of a minimum landing size for Norwegian spring-spawning herring, for which the Barents Sea serves as a nursery area, large catches of immature herring were also taken in the ecoregion; this was mainly by Norwegian and Russian fishers. In recent years, Norway has fished some legal-sized herring in a restricted coastal purse-seine fishery inside four nautical miles off the Finnmark coast. In the southwestern part of the ecoregion, an international herring fishery has operated in some seasons.

Norway dominates the Northern shrimp fishery. Catches increased with much of that increase coming from fleets fishing in the international waters between the Norwegian Exclusive Economic Zone (EEZ), the Fisheries Protection Zone around Svalbard, and the Russian EEZ. Red king crab are fished by Russia in near-coastal Russian waters, and by Norway in the coastal waters of the northernmost counties of Norway, Troms and Finnmark. A fishery has developed for the snow crab in recent years; this is a species first encountered in the ecoregion in 1996. This fishery is mainly carried out by a Russian fleet, in the Russian part of the Barents Sea shelf.

The recent IPCC Report (Meredith et al, 2019) points to climate-induced changes in seasonal sea ice extent and thickness and ocean stratification are altering marine primary production, with impacts on ecosystems. Changes in the timing, duration and intensity of primary production have occurred with marked regional or local variability. In the Arctic, changes in primary production have affected regional species composition, spatial distribution, and abundance of many marine species, impacting ecosystem structure. These changes together with human introduction of non-native species, have expanded the range of temperate species and contracted the range of polar fish and ice-associated species. Commercially and ecologically important fish stocks like Atlantic cod, haddock and mackerel have expanded their spatial distributions northwards and increased their abundance. In some Arctic areas, such expansions have affected the whole fish community, leading to higher competition and predation on smaller sized fish species, while some commercial fisheries have benefited.

These environmental changes are altering biodiversity in the Arctic marine ecosystem and are expected to continue in the coming decades.

4. Environmental data statistics

Access to environmental data and statistics on meteorological and oceanographic conditions is critical for any maritime activity in the Arctic, as well as for other economic activities in the region. For instance, statistics and trends on the following parameters are of great relevance for the Arctic ship traffic, cruise activities and fishing activities in the Barents Sea:

- Trend in "open water/ice-free" temporal window in the Northeast Passage and around Svalbard Islands;
- Monthly maps of wind, wave, currents or visibility climate in the main shipping routes in the Arctic.
- Trends in temperature and salinity in the Barents Sea;

This chapter will present some basic analysis, statistics and trends on relevant environmental variables of interest to the above economic activities in the region based on publicly available European data sources.

4.1 Sources of environmental data in the Arctic Ocean

To perform robust statistics and derive trends on environmental meteorological and oceanographic conditions in the Arctic region, it is necessary to use reliable long-term time series of data which for the Arctic region mainly can be achieved via reanalysis products. A major open and free source of datasets is the Copernicus Marine Environmental Service (CMEMS) (https://marine.copernicus.eu/), that in its products catalogue have relevant historical long-term environmental information in the Arctic combining satellite observations, numerical model outputs and *in situ* data (when available). An overview of historical datasets suitable for the present analysis is given below.

4.1.1 CMEMS Arctic Ocean Physics Reanalysis

Source: Numerical model (including data assimilation) – TOPAZ System model.
Temporal coverage: From 1991-01-01 to 2019-12-31 (28 years)
Spatial coverage: -180 to 180 62N to 90 N / **Spatial resolution**: 12.5 Km x 12.5 Km
Temporal resolution: daily and monthly means.
Variables provided:

- Temperature, Salinity, Sea surface Height (SSH)
- Currents
- Sea Ice area fraction
- Sea Ice Thickness
- Surface Snow Thickness

Link:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=ARCTIC_REANALYSIS_PHYS_002_003

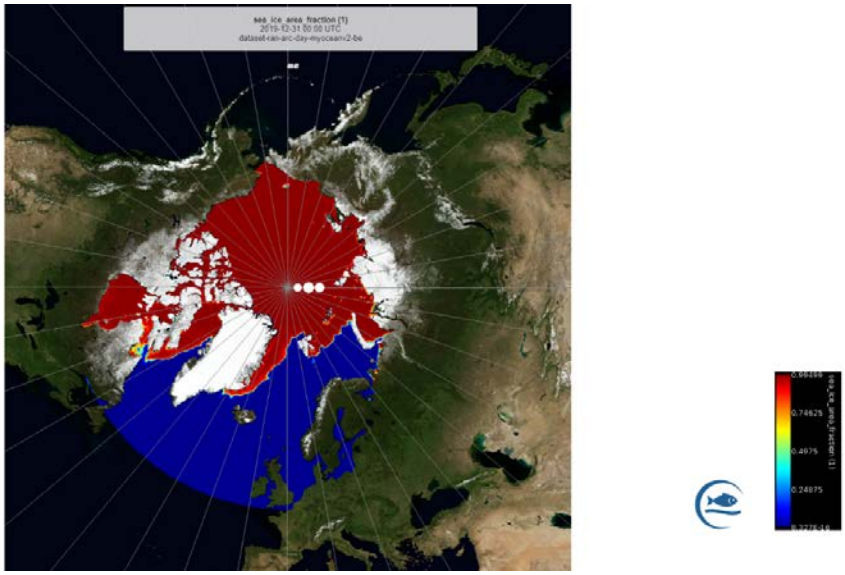


Figure 4.1 Example of Sea ice area fraction information (Dec 2019) from CMEMS Arctic Ocean Physics Reanalysis product.

4.1.2 OSI-SAF Global Ocean Sea Ice Concentration Time Series Reprocessed

Source: Satellite Observations (EUMETSAT OSI SAF (OSI-450 and OSI-430-b) http://www.osi-saf.org/)
Temporal coverage: From 1979-01-01T00:00:00Z to Present.
Spatial coverage: global / **Spatial resolution**: 25Km x 25 Km
Temporal resolution: daily means
Variables:

- Sea ice area fraction

Link:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=SEAICE_GLO_SEAICE_L4_REP_OBSERVATIONS_011_009

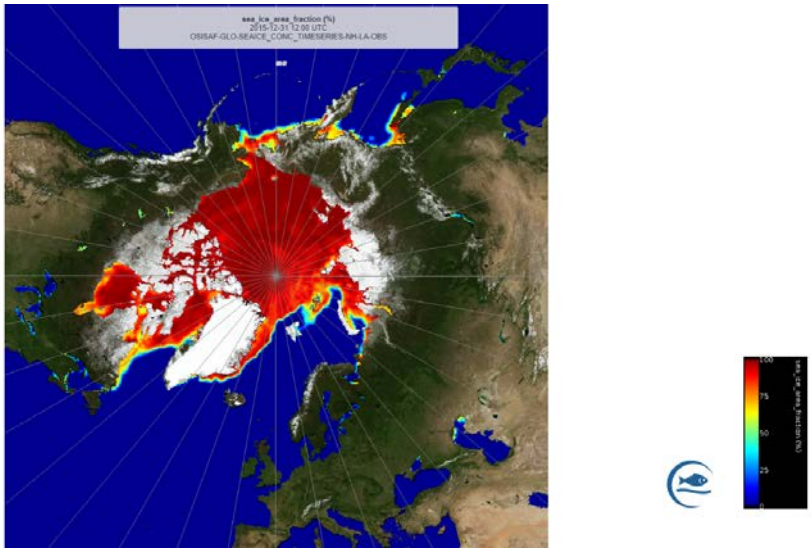


Figure 4.2 Example of Sea ice area fraction information (December 2019) from Global Ocean Sea Ice Concentration Time Series Reprocessed (EUMETSAT OSI-SAF).

4.1.3 CMEMS Arctic Ocean Wave Hindcast

Source: Arctic Ocean Wave Hindcast system uses the WAM model at 3 km resolution forced with surface winds and boundary wave spectra from the ECMWF (European Centre for Medium-Range Weather Forecasts) ERA5 reanalysis together with ice from the ARC MFC reanalysis (Sea Ice concentration and thickness).
Temporal coverage: from 2002-01-01T00:00:00Z to 2019-12-31T00:00:00Z
Spatial coverage: Arctic (69 to 89.5 N) /**Spatial resolution**: 3Kmx3Km
Temporal resolution: hourly
Variables provided:

- sea_ice_area_fraction (SIC)
- sea_ice_thickness (SIT)
- sea_surface_wave_significant_height (SWH)
- sea_surface_wave_mean_period_from_variance_spectral_density_inverse_frequency_moment (MWP)
- sea_surface_wave_mean_period_from_variance_spectral_density_second_frequency_moment (MWP)
- sea_surface_wave_period_at_variance_spectral_density_maximum (MWP)
- sea_surface_wave_from_direction (VMDR)
- sea_surface_wave_from_direction_at_variance_spectral_density_maximum (VMDR)
- sea_surface_wave_stokes_drift_x_velocity (VSDXY)
- sea_surface_wave_stokes_drift_y_velocity (VSDXY)
- sea_surface_wave_significant_height (WW)
- sea_surface_wind_wave_mean_period (WW)
- sea_surface_wind_wave_from_direction (WW)
- sea_surface_primary_swell_wave_significant_height (SW1)
- sea_surface_primary_swell_wave_mean_period (SW1)
- sea_surface_primary_swell_wave_from_direction (SW1)
- sea_surface_secondary_swell_wave_significant_height (SW2)
- sea_surface_secondary_swell_wave_mean_period (SW2)
- sea_surface_secondary_swell_wave_from_direction (SW2)
- sea_floor_depth_below_sea_level

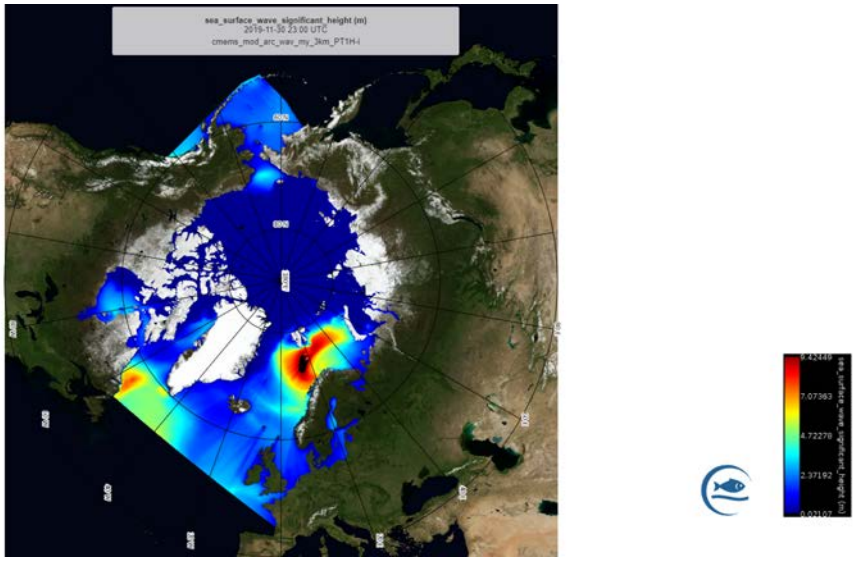


Figure 4.3 Example of Sea Surface wave height (November 2019) from CMEMS Arctic Ocean wave hindcast product.

Link:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=ARCTIC_MULTIYEAR_WAV_002_013

4.1.4 CMEMS Global Ocean Wind

Source: The IFREMER CERSAT Global Blended Mean Wind Fields estimation of the 6-hourly blended wind products make use of all the remotely sensed surface winds derived from scatterometers and radiometers available at this time and used as observation inputs for the objective method dealing with the calculation of 6-hourly wind fields over the global oceans. L4 winds are calculated from L2b products in combination with ERA interim wind analyses from January 1992 onwards. The analysis is performed for each synoptic time (00h:00; 06h:00; 12h:00; 18h:00 UTC).
Temporal coverage: from 1992-01-01T00:00:00Z to 2019-12-31T00:00:00Z
Spatial coverage: Global, from 80S to 80N /**Spatial resolution**: 0.25°x0.25°
Temporal resolution: 6-hourly
Variables: Wind components (meridional and zonal), wind module, wind stress, and wind/stress curl and divergence. The associated error estimates are also provided.

Link:
https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_006

Besides the above-described historical datasets, real time operational short-term forecasts of Arctic sea ice, waves, currents, temperature and salinity are also freely available from CMEMS catalogue (or other sources of information at national levels) and can be used to support shipping operations in the Arctic.

The quality of satellite -and model-based product needs regular validation against high-quality in situ measurements. However, the availability of in situ observations from the Arctic region is limited (Buch et al, 2019) or even at questionable quality which compromises the quality of available satellite and model products.

4.2 Sea ice cover and open water days statistics and trends

An extensive scientific literature exists already on the study of the climate warming conditions and retreat of sea ice in the Arctic based on long term observations and climatic models (e.g. https://www.arctic.noaa.gov/report-card; http://ocean.dmi.dk/arctic/index.uk.php). The aim of the present analysis is visualizing how the maritime industry can be supported in their business development analysis and decision making on entering into activities in the Arctic Region by presenting some simple trend analyses obtained from the above-mentioned sources of environmental open datasets.

To achieve this objective, some strategic geographical points were selected based on the main shipping routes through the Arctic defined by the AIS maps (section 1.2). These points (Fig 4.4) are located on the Northeast Passage and the areas around Svalbard and in Barents Sea to address the three selected use cases.

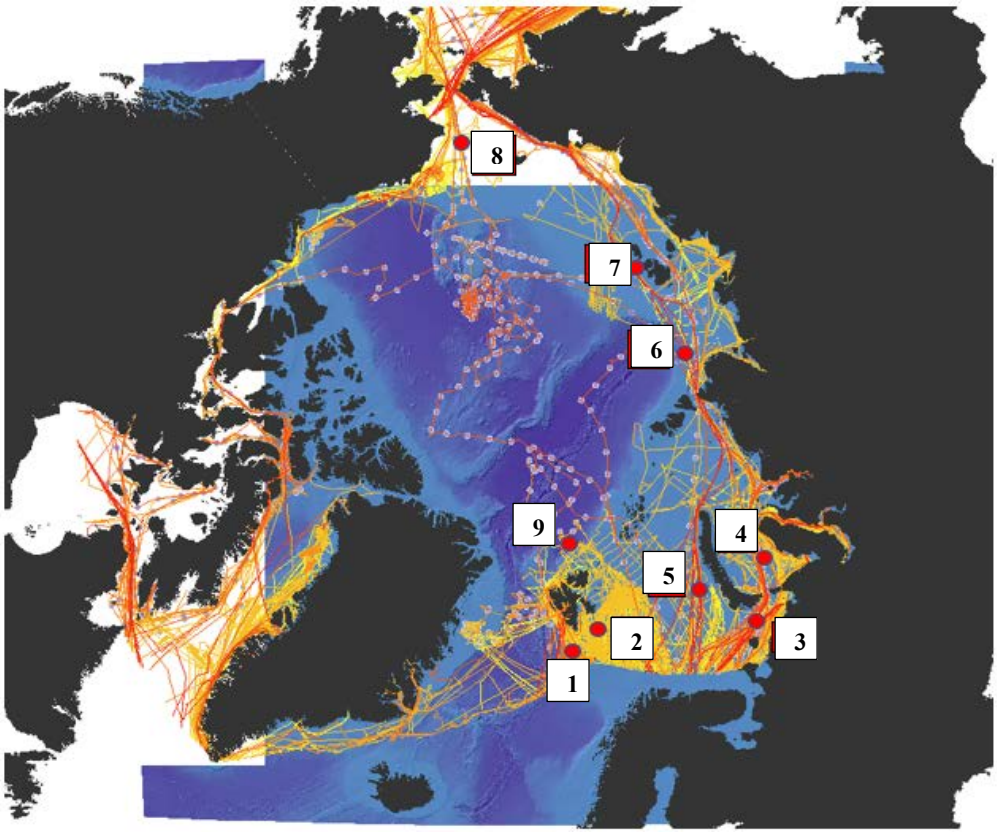


Figure 4.4 Points selected for performing statistics of environmental parameters around Svalbard, Barents Sea and along the Northeast passage.

Table 4.1. Position of points selected for performing statistics of sea ice cover around Svalbard, Barents Sea and along the Northeast passage

Around Svalbard

Point #	LAT	LON
1	75.23	13.37
2	76.21	22.9
9	82.33	24.04

Barents & Kara Sea

Point #	LAT	LON
3	69.99	52.06
4	72.06	63.78
5	74.21	50.1
Northern Passage (Laptev, eastern Siberian and Chuckchi Seas)		
6	77.4	117.64
7	76.23	146.42
8	69.79	-168.78

As an indication on how the temporal evolution of the sea ice area fraction (in %) has a trend towards a less ice coverage a time-series evolution from 1979 to 2016 of the ice coverage

fractions for a point around Svalbard (point #2) is produced from the Global Ocean Sea Ice Concentration Time Series Reprocessed (OSI-SAF) data, Fig. 4.5. The red colour represents 100% ice coverage while the blue colours represent 0% ice coverage (ice-free area). The seasonal cycle (red colour in winter and blue colour in the summer) is clearly displayed, but interestingly there is a clear trend towards larger blue colours stripes – less sea ice - in the recent years.

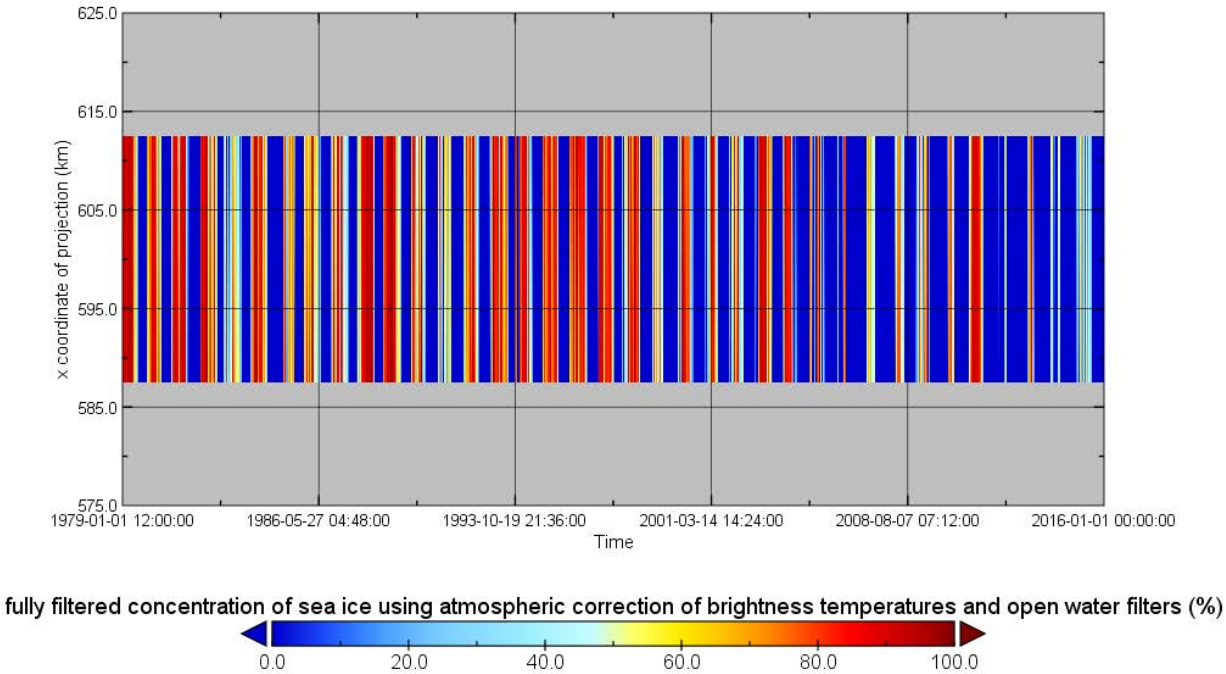
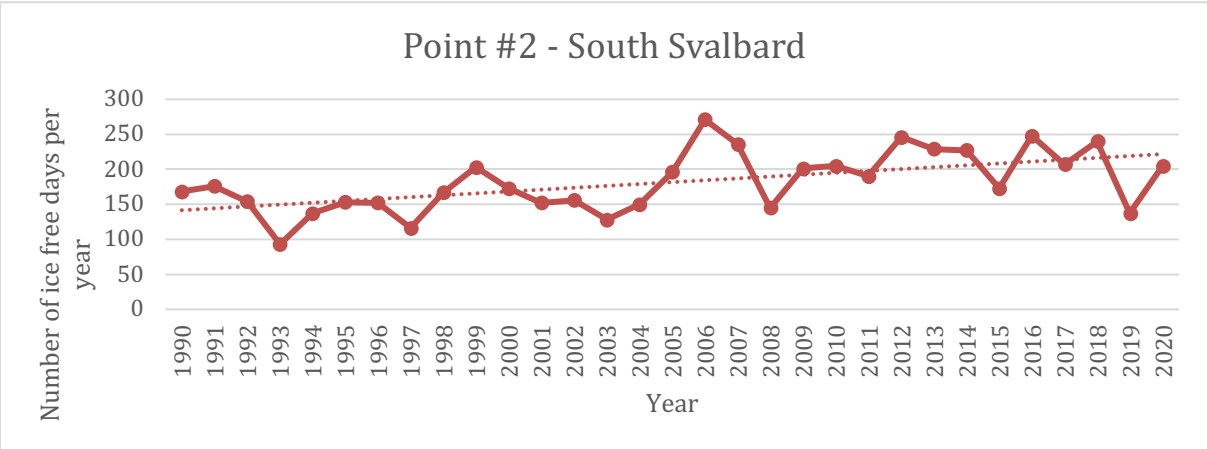
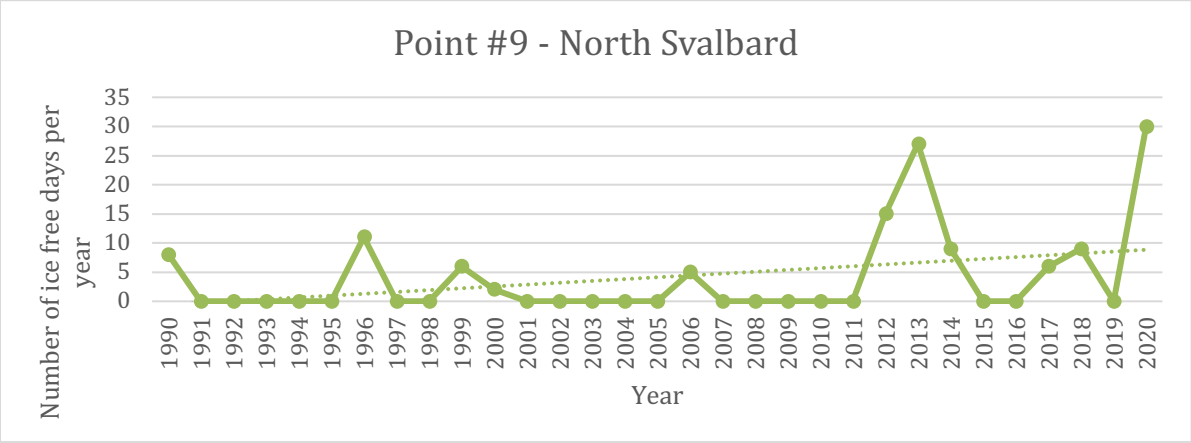


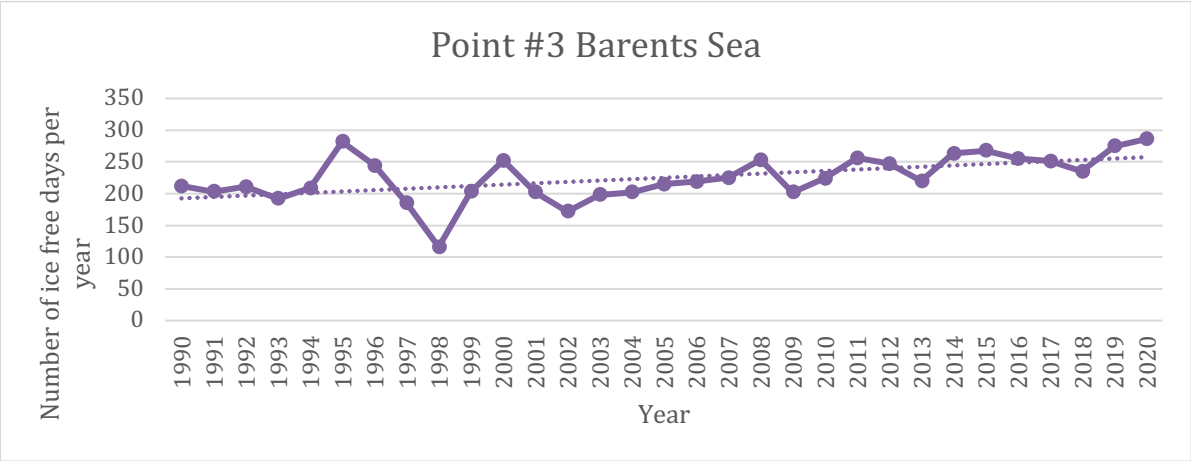
Figure 4.5 Graphical representation of the temporal evolution of the sea ice area fraction (in %) at Point #2 (near Svalbard) obtained from OSISAF data.

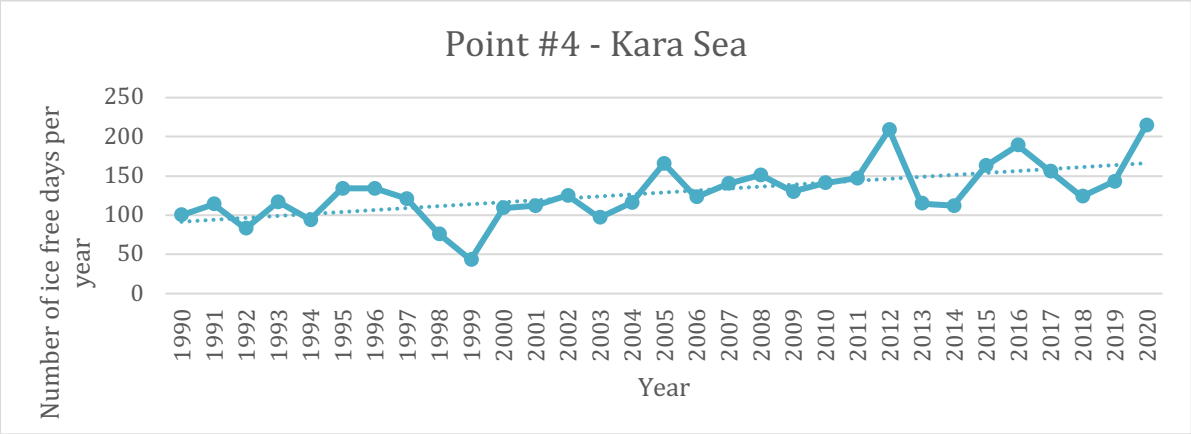
In order to get a more robust trends analysis of interest for the maritime activities, statistics on the number of consecutive open water/ice free days for each of the selected nine points has been calculated using the OSI-SAF dataset (Fig 4.6 for each of the points). By an open water/ice free day is understood a day with a sea area fraction less than 15%.

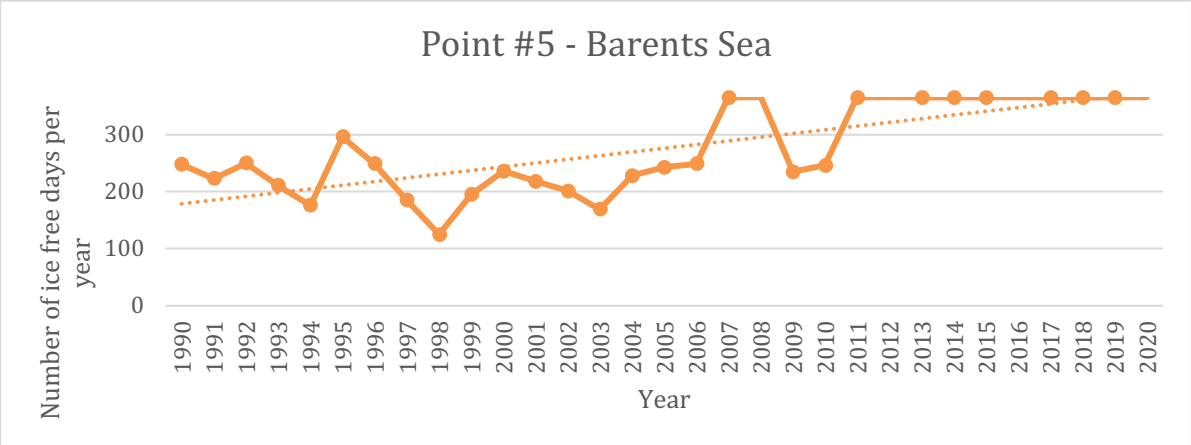
Point #1: all year long free ice.




Point #9 - North Svalbard
Number of ice free days per year
35
30
25
20
15
10
5
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year


Point #3 Barents Sea
Number of ice free days per year
350
300
250
200
150
100
50
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year


Point #4 - Kara Sea
Number of ice free days per year
250
200
150
100
50
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year


Point #5 - Barents Sea
Number of ice free days per year
300
200
100
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year

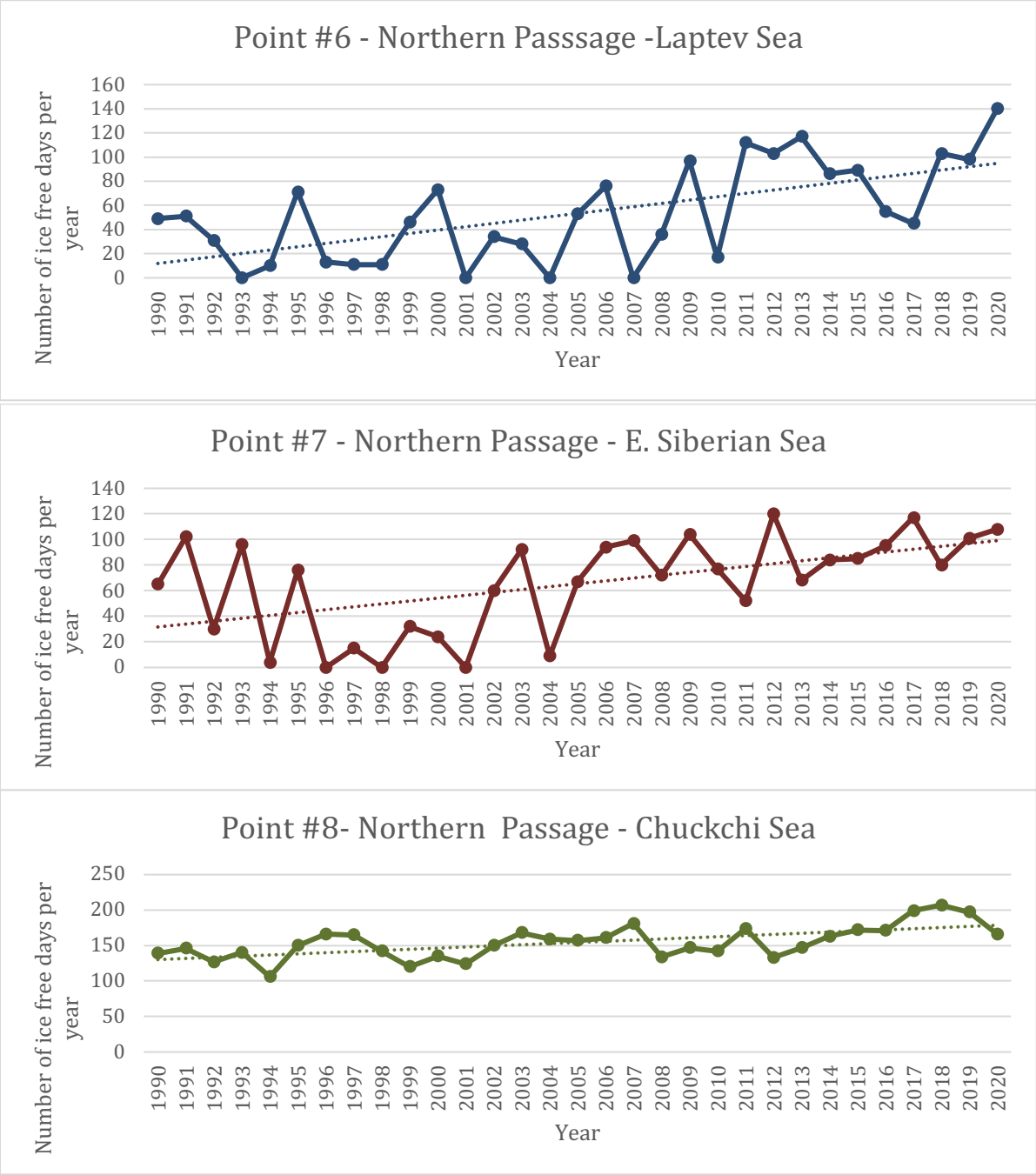


Figure 4.6 Open water days at the 9 selected point for the period 1990 -2020

It is seen that all the selected points show a clear positive trend in the number of open water days for the period 1990 to 2020, which also is consistent with the trend of ice retreat in the region reported in the literature. This is valuable information to the maritime industry because it means an increase in the period window per year where operations in area, for instance transports via the Northeast passage, is possible. Additionally, there are no signs in the displayed trends, nor in climate projections, that indicate the positive trend in open water days will decrease or stop in the near future.

4.3 Surface wind statistics

The sea surface winds is another crucial environmental variable to consider carefully when performing maritime operations. A simple wind statistic for the Arctic area can be obtained using the open sources of environmental datasets described in section 4.1.5; only the total surface velocity (not the wind direction) is considered in the present analysis. The wind velocity is extracted for the same points as used for the ice cover statistics (See map in Fig. 4.5), the wind dataset reaches, however only to 80°N, so the point #9 (north of Svalbard at latitude 82.33°N) is not included in this analysis. As the resolution of the wind field is 0.25°, the exact geographical coordinates of the selected points are the ones shown in Table 4.2.

Table 4.2. Position of points selected for performing statistics of wind data around Svalbard, Barents Sea and along the Northeast passage

Points around Svalbard		
Point #	**LAT**	**LON**
#1	75.25	13.25
#2	76.25	23.00
Points in Barents & Kara Sea		
	LAT	**LON**
#3	70.00	52.00
#4	72.00	63.75
#5	74.25	50.00
Northern Passage (Laptev, eastern Siberian and Chuckchi Seas)		
#6	77.50	117.75
#7	76.25	146.50
#8	69.75	-168.75

As the wind datasets include 6-hourly mean wind speed the monthly averages for each of the selected points can be computed as well as simple statistics of the percentage of the time the wind speed is above a certain value.

Figure 4.7 shows the time series of monthly mean wind speed for each of the selected points. The strongest average monthly winds (above 11m/s in January and February) are in point #1, located to the west of Svalbard, probably more exposed to the North Atlantic wind regime. There is a clear seasonal cycle with weaker average winds in the months of June, July and August. This seasonality is less evident in points #6 and #7 located in the Laptev and Chuckchi Seas (more enclosed sub-basins), where also the monthly wind intensities are generally lower (less than 7m/s)

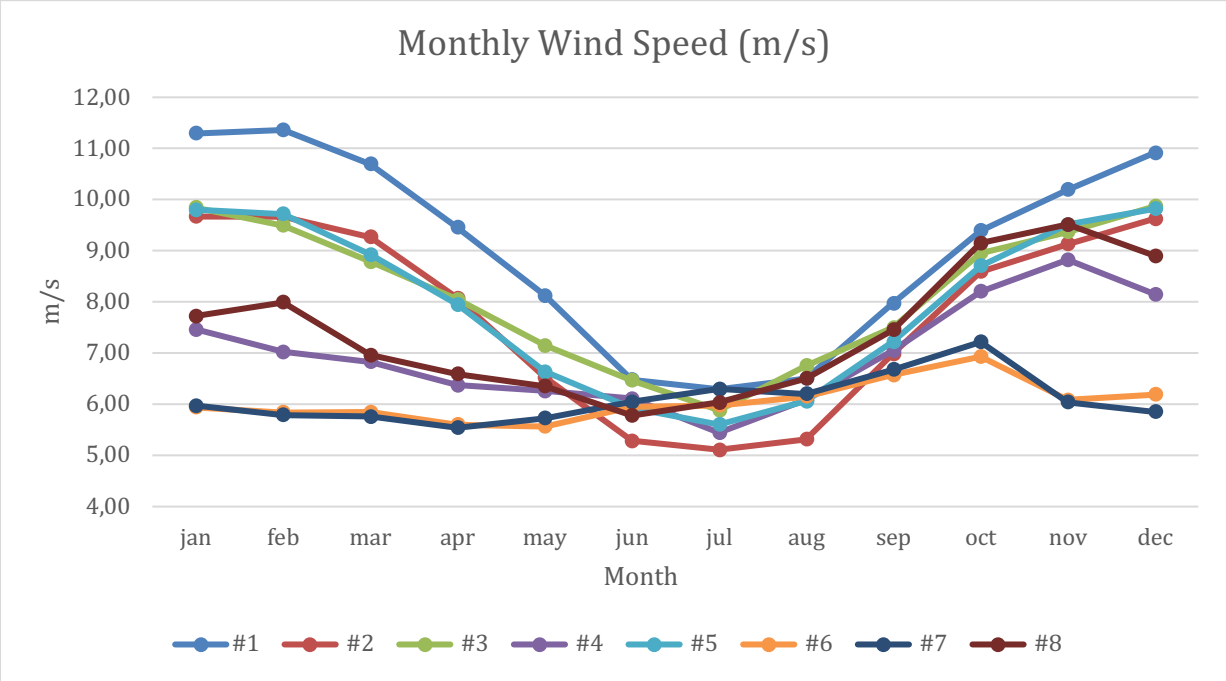


Figure 4.7 Monthly mean wind speeds for the different points in the Arctic. The monthly averages are computed from a 28-years' time series of 6-hourly wind speed dataset.

As there is a lot of temporal variability in the 6-hourly wind fields, it is relevant for the statistics to calculate the percentage of the time with winds stronger than a certain threshold of interest. In table 4.3 displays the time percentage for each month with winds is stronger than 17 m/s e.g., high wind/fresh gale according to Beaufort Scale.

High winds are only relatively frequent (8-10% of the time) in the region around Svalbard in the months from December to March. For the points in other regions, the percentage of the time that the wind reaches this magnitude is very small, and almost negligible in Laptev-, eastern Siberian - and Chuckchi Seas.

Table 4.3 Percentage of time for each with winds is stronger than 17m/s.

	Point #1	Point #2	Point #3	Point #4	Point #5	Point #6	Point #7	Point #8
Jan	9.7	3.7	3.4	0.8	5.4	0.2	0.2	1.0
Feb	9.5	2.8	1.8	0.5	3.4	0.1	0.0	0.9
Mar	6.9	1.8	1.5	0.6	2.4	0.4	0.1	0.2
Apr	3.0	1.0	0.5	0.2	0.5	0.0	0.0	0.1
May	0.7	0.1	0.4	0.1	0.2	0.0	0.0	0.1
Jun	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Jul	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Aug	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Sep	0.7	0.1	0.6	0.1	0.3	0.1	0.1	0.1
Oct	3.0	1.9	1.9	1.0	1.0	0.3	0.3	1.4
Nov	5.1	2.4	1.8	1.1	3.3	0.1	0.0	3.3
Dec	8.0	2.8	2.3	0.9	3.9	0.3	0.2	1.9

Very strong winds of up to 25 m/s ('storm') or higher are regularly identified in point #1 west of Svalbard (Fig 4.8). Such extreme winds are seldomly detected in the other points (less than 5 times in 28 years).

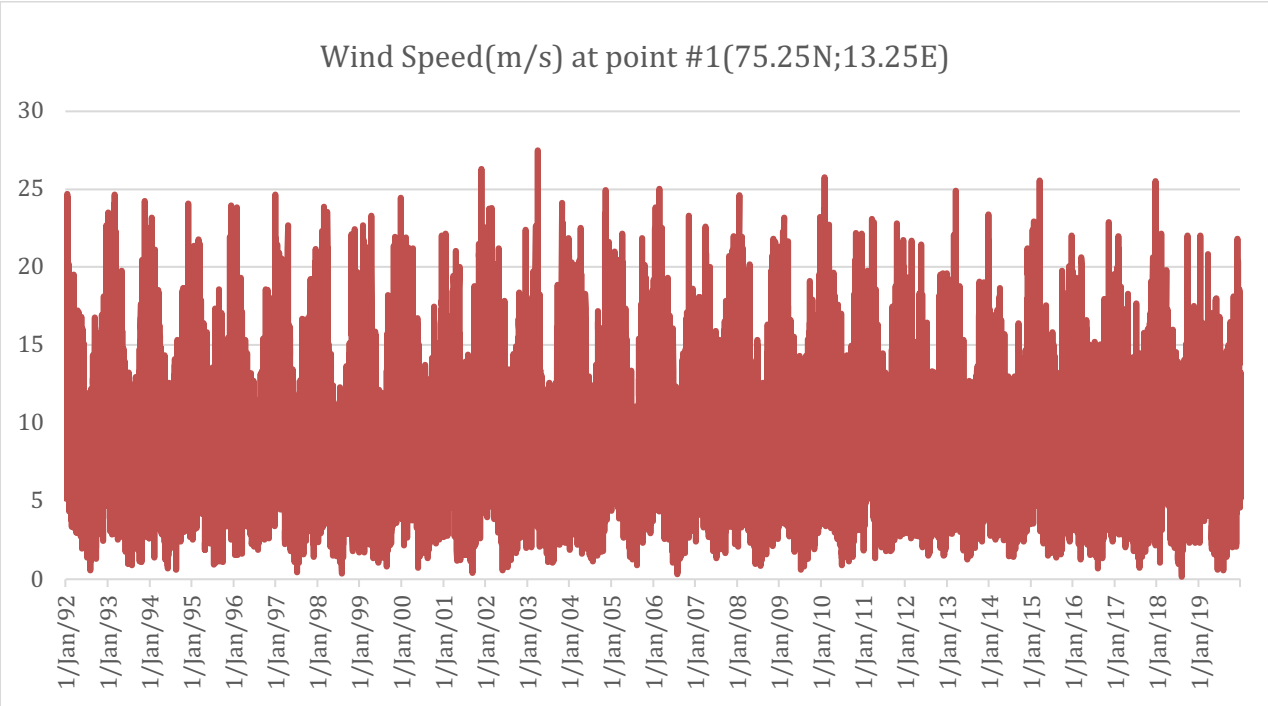


Figure 4.8. Time series of 6-hourly wind speed at point 1 (west of Svalbard).

4.4 Surface wave climate, statistics and trends

Surface wave height data is another relevant oceanographic information for maritime operations, both real time forecasts and climatological analysis of wave height in the different areas of the Arctic Ocean are of value.

There exist an extensive scientific literature showing wave climate and trends studies in the Arctic using altimetry data together with wave hindcast models (e.g. Waseda et al., 2018; Stopa et al., 2016; Liu et al., 2016; Khon et al., 2014). All satellite altimetry and wave modelling studies should preferably be supported by in-situ wave-buoy measurements for validation and assimilation purposes in order to improve quality of the climatology and real-time forecasts; but unfortunately, there are almost no in situ wave measurements available from the Arctic Ocean. It will be important to address this problem in the design of a future Arctic Observing System in support of a better understanding of the wave-ice-wind process and validation of the models and altimeter observations.

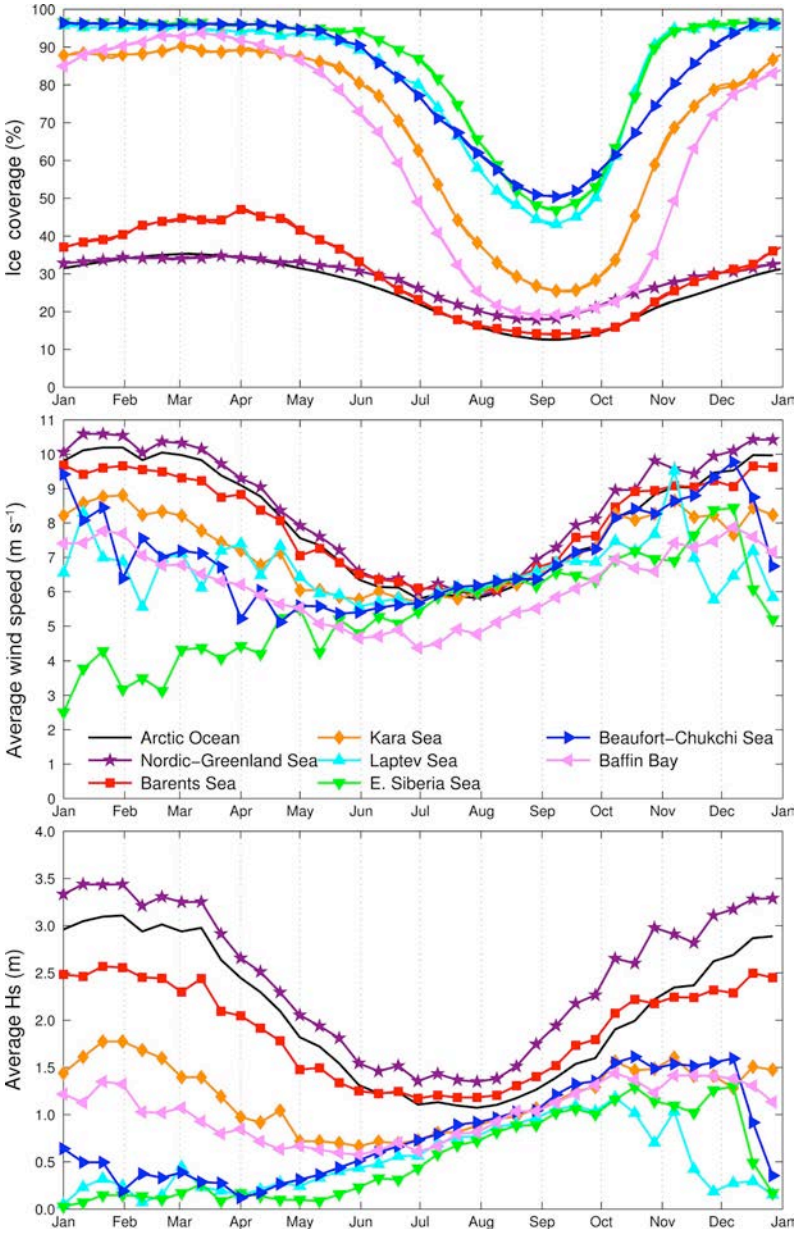


Figure 4.9 Ice coverage (top), wind speed (middle), and Significant Wave Height (Hs) daily averages computed from a spatial average for each Arctic region derived from a 1992-2014 hindcast) (Source: Stopa et al. 2016)

The wave field in the Arctic Ocean, which is highly dependent on an ice-fee ocean and wind conditions (ice and wave interaction is a coupled two-way system), is impacted by the diminishing Arctic sea ice. Model simulations and altimeter observations show that the reduction of sea ice is resulting in increased wave heights in the Arctic Ocean because larger ice-free areas mean increased wind fetch areas.

The wave conditions in the Arctic, and its seasonality, is therefore very dependent on the position and ice conditions of the basin, as shown in Fig. 4.10. The Norwegian-Greenland Sea (mostly ice-free and have a large wind fetch) has the highest waves in the Arctic reaching 3.5 metres on average, while semi-enclosed seas (like Kara, Laptev, East Siberia, Beaufort-Chuckchi Sea and Baffin Bay) have smaller waves.

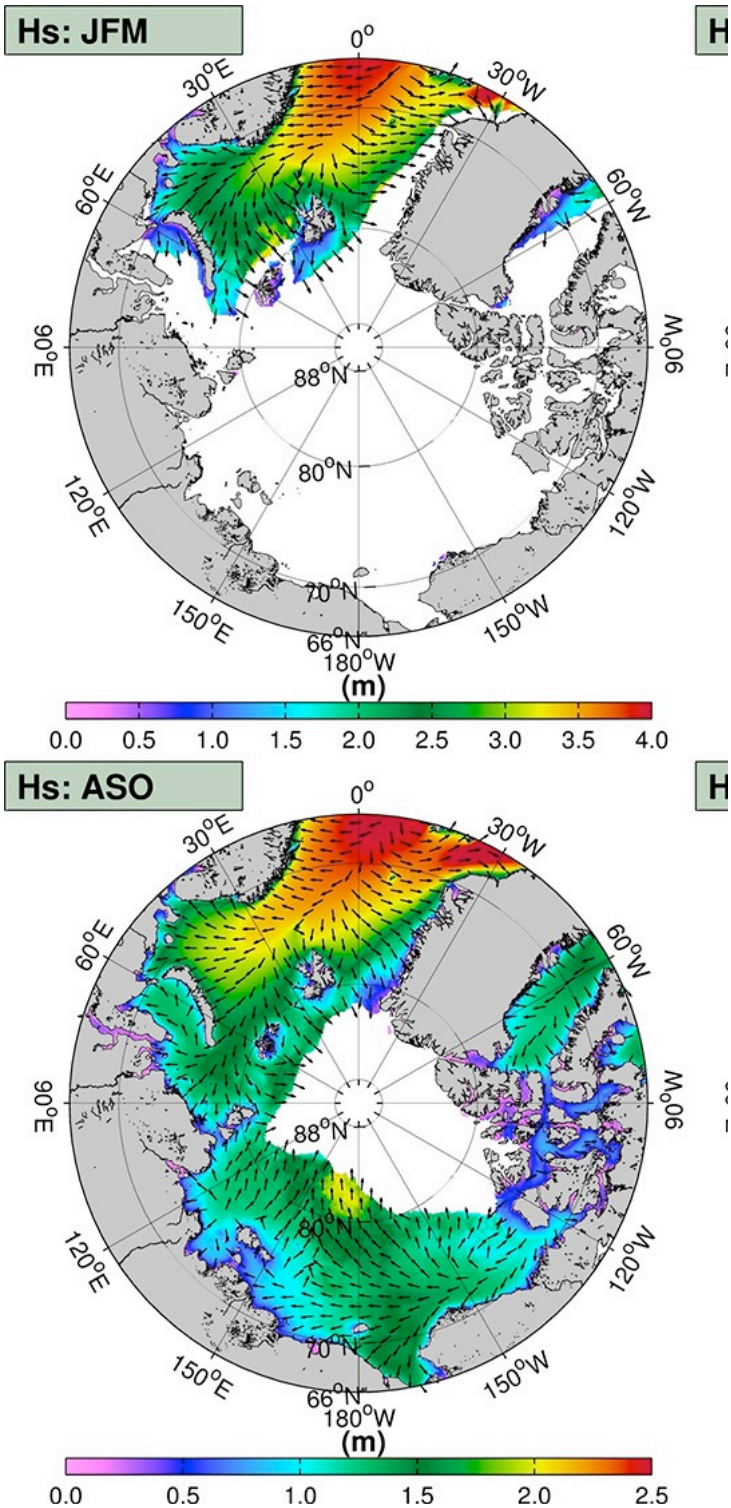


Figure 4.10 January–February–March (JFM) and August–September–October (ASO) seasonal averages of significant wave Height (Hs). From a wave hindcast 1992-2014 (Source: Stopa et al., 2016)

In a study of climatology and trends of oceanic winds and waves over a twenty-year period (1996-2016); Liu et al., 2016 showed that waves in the Chukchi Sea, Beaufort Sea (near the northern Alaska), and Laptev Sea have increased at a rate of 0.1–0.3 m per decade with a

statistically significance level at 90%. The trend of change in the wave height within the Norwegian-, Greenland- and Barents Seas, is, on the contrary, rather weak and not statistically significant.

Liu et al. 2016 additionally predicts that the significant wave height and its extremes will increase within the inner Arctic Ocean areas due to reduction of sea ice cover and regional wind intensification in the 21st century. The opposite tendency, with a slight reduction in wave height appears for the Atlantic sector and the Barents Sea.
In addition to the presented trends in significant wave height over time, it is of importance as a decision support tool, to have information on the percentage of time the significant wave height is higher than different threshold values. Such statistics has been subtracted from the CMEMS Arctic Ocean Wave Hindcast (see 4.1.3) for selected points – a subset of the sea ice statistical points plus one in the eastern Greenland Sea (Fig. 4.11).

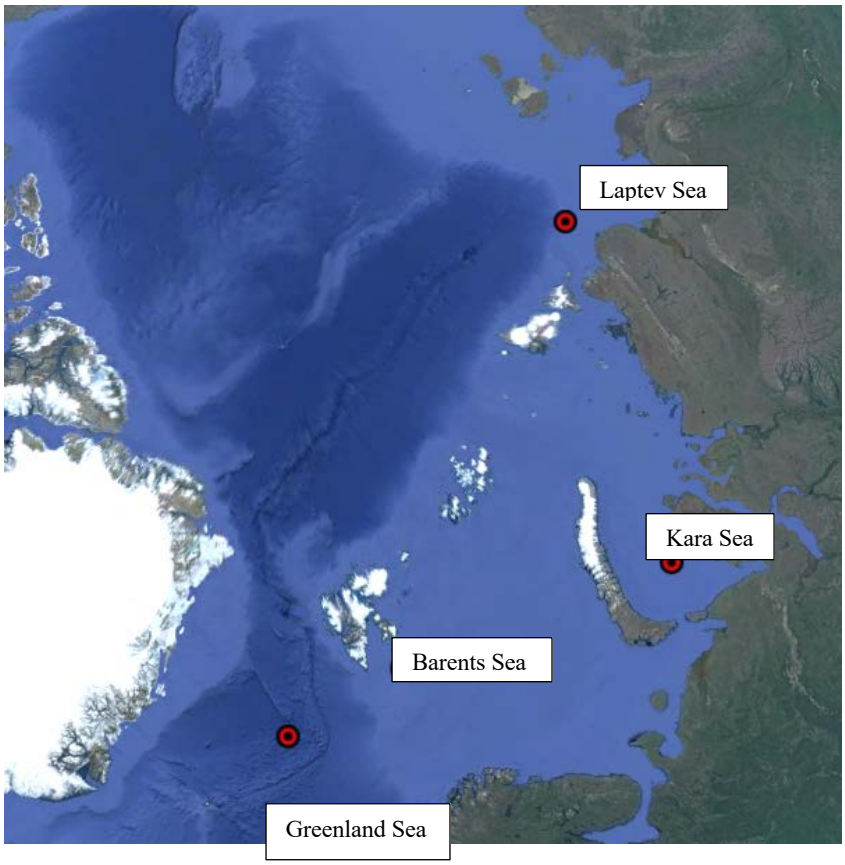


Figure 4.11 Points where significant wave height data was extracted.

It is additionally of interest to investigate trends in the percentages of time for the individual wave height intervals. Therefore two 5-years periods (2002-2006 and 2014-2018) was selected for analysis and statistic was prepared for significant wave heights above 1, 2, 3 and 4 m for the full year and for two seasons: summer -ice free- (July, August, September) and winter -ice covered- (January, February, March).

The time series of significant wave heights and the corresponding statistics are presented in Fig. 4.12 – 4.15 and tables 4.4-4.5 for the selected points.

Svalbard and Barents Sea

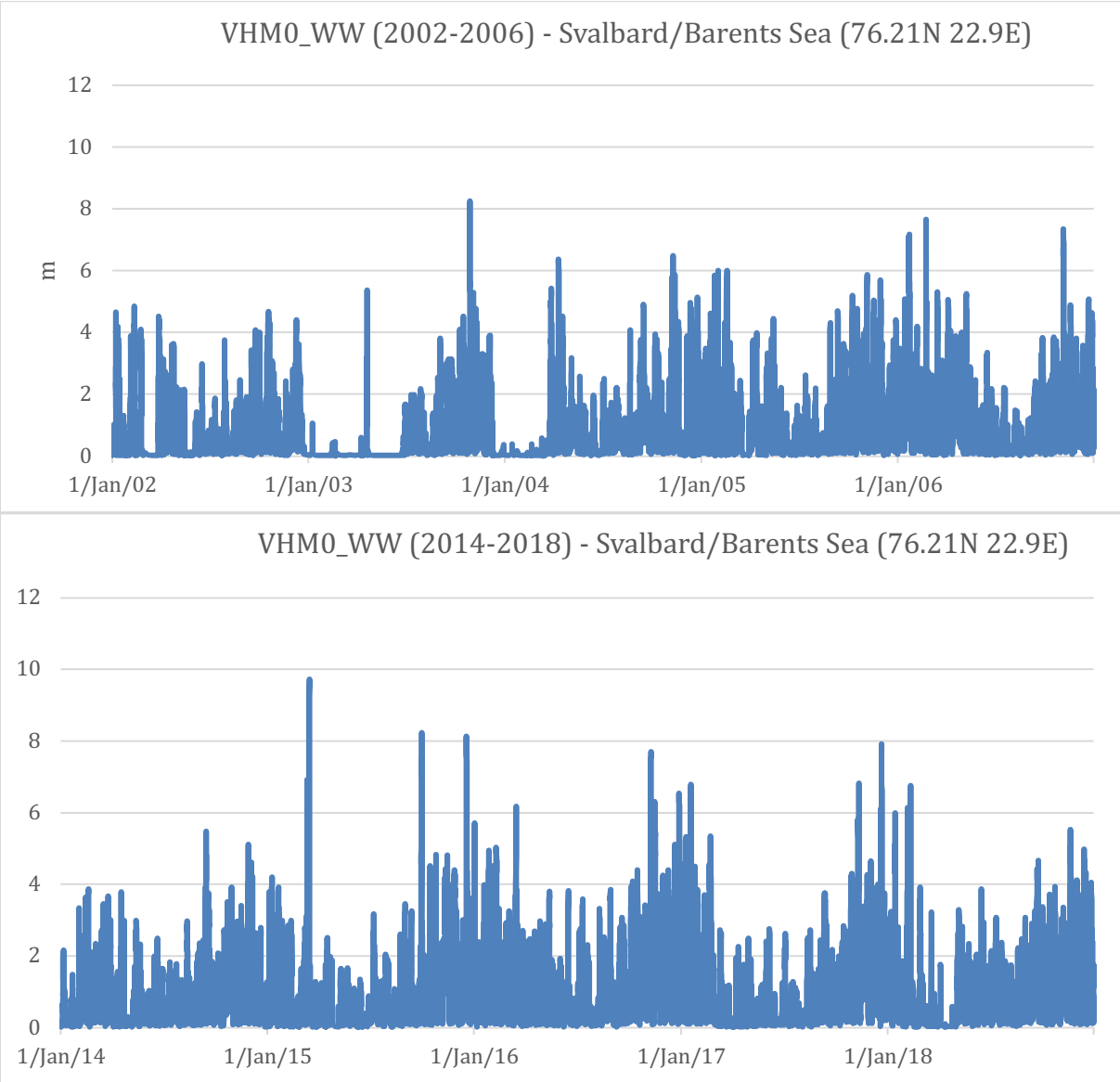


Figure 4.12 Significant wave height (m) for two 5-year periods in the Svalbard-Barents Sea

Table 4.4. Percentage of time during the periods 2002-2006 and 2014-2018 where the surface wave height in the Barents Sea is above a certain value.

2002-2006			
Significant Wave height (m)	**% in time (hourly data) SUMMER (JAS)**	**% in time (hourly data) WINTER (JFM)**	**% in time (hourly data) Full year**
>1	22.5%	22.2%	27%
>2	6.3%	12.7%	12.2%
>3	1.7%	**5.7%**	5.3%

>4	0.5%	**2.6%**	1.9%
2014-2018			
Significant Wave height (m)	**% in time (hourly data) SUMMER (JAS)**	**% in time (hourly data) WINTER (JFM)**	**% in time (hourly data) Full year**
>1	25.1%	33.3%	30.9%
>2	8.3%	14.3%	12.9%
>3	2.7%	5.9	5.1%
>4	0.6%	2.2%	1.7%

(JAS: July August September JFM: January February March)

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There is no clear statistical trend on change over time in percentage of time within and between the individual height intervals.

Greenland Sea

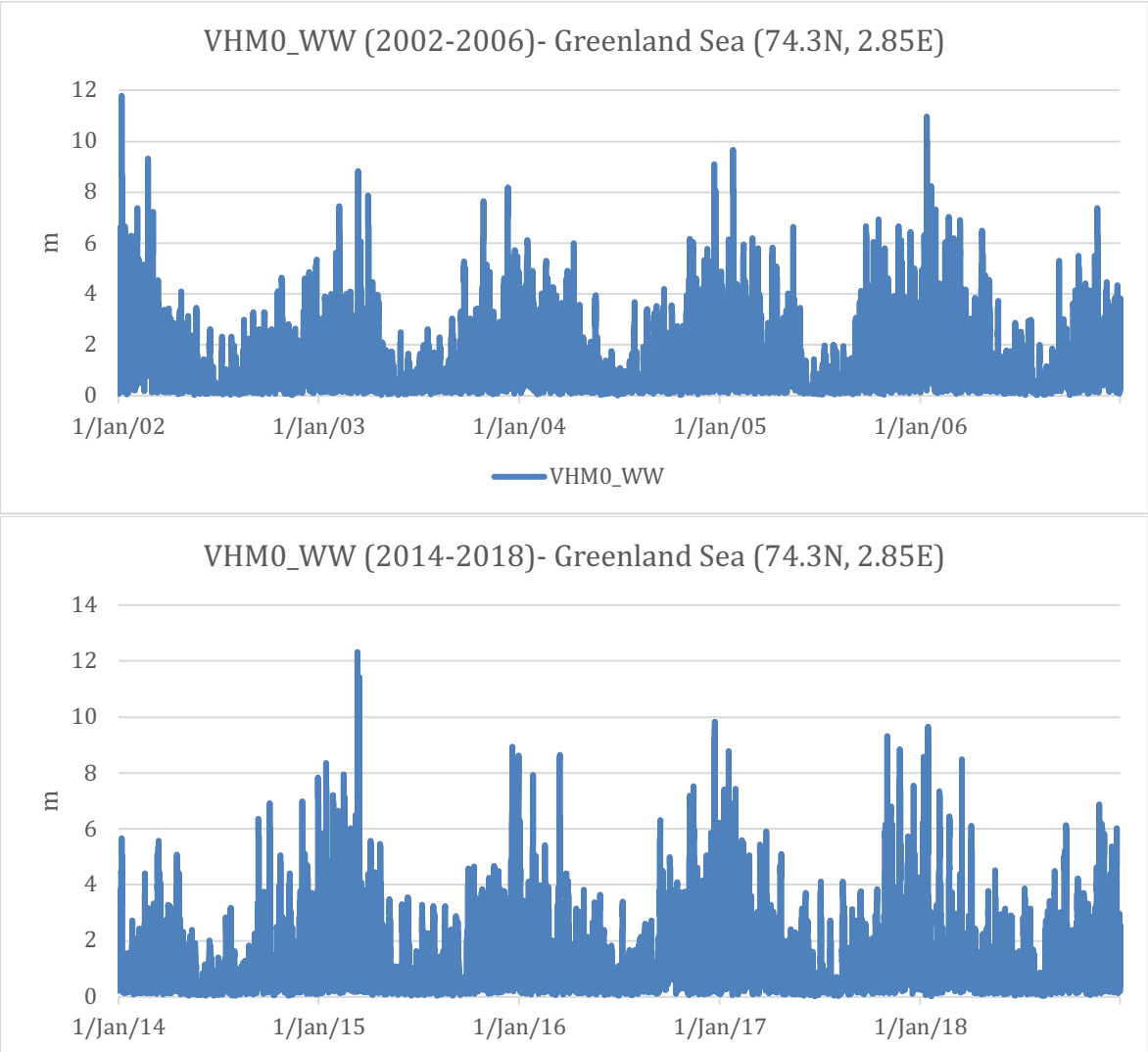


Figure 4.13 Significant wave height (m) for two 5-year periods in the Greenland Sea

Table4.5. Percentage of time during the periods 2002-2006 and 2014-2018 where the surface wave height in the Greenland Sea is above a certain value.

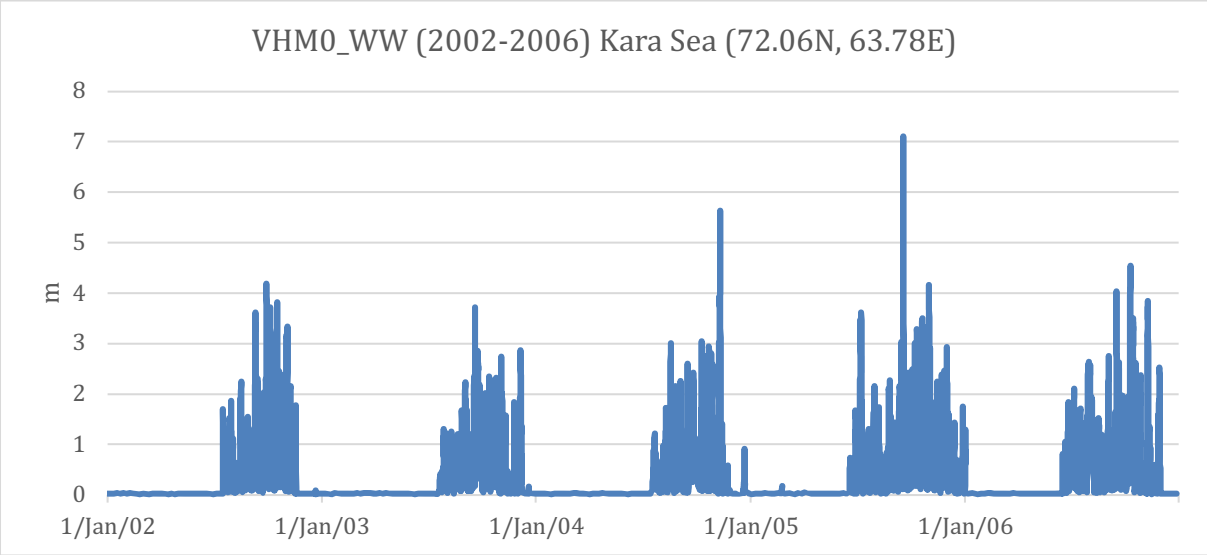
2002-2006			
Significant Wave height (m)	**% in time (hourly data) SUMMER (JAS)**	**% in time (hourly data) WINTER (JFM)**	**% in time (hourly data) Full year**
>1	23.6%	60.6%	42%
>2	8.7%	38%	21.8%
>4	1.2%	9.6%	4.7%
2014-2018			
Significant Wave height (m)	**% in time (hourly data) SUMMER (JAS)**	**% in time (hourly data) WINTER (JFM)**	**% in time (hourly data) Full year**
>1	29.3%	55.5%	44.2%
>2	9.9%	32.4%	21.6%
>4	1.2%	9.7%	4.9%

JAS: July August September, JFM: January February March

Kara and Laptev Seas

The Kara and Laptev Sea are semi-enclosed basins with an ice cover during long periods of the year, and this affects the significant wave heigh statistics. As can be seen in the figures below the significant wave height rarely exceeds 4 m height and is larger than 1 m only for some specific time windows (normally between July and November).

Significant wave heights in the Kara Sea (Fig. 4.14) displays are higher than 1 m for the 19% of the time during the months July to September in the period 2002-2006, while this percentage increased to 25% in during July to September in the 2014-2018 period (only free ice periods are being considered).



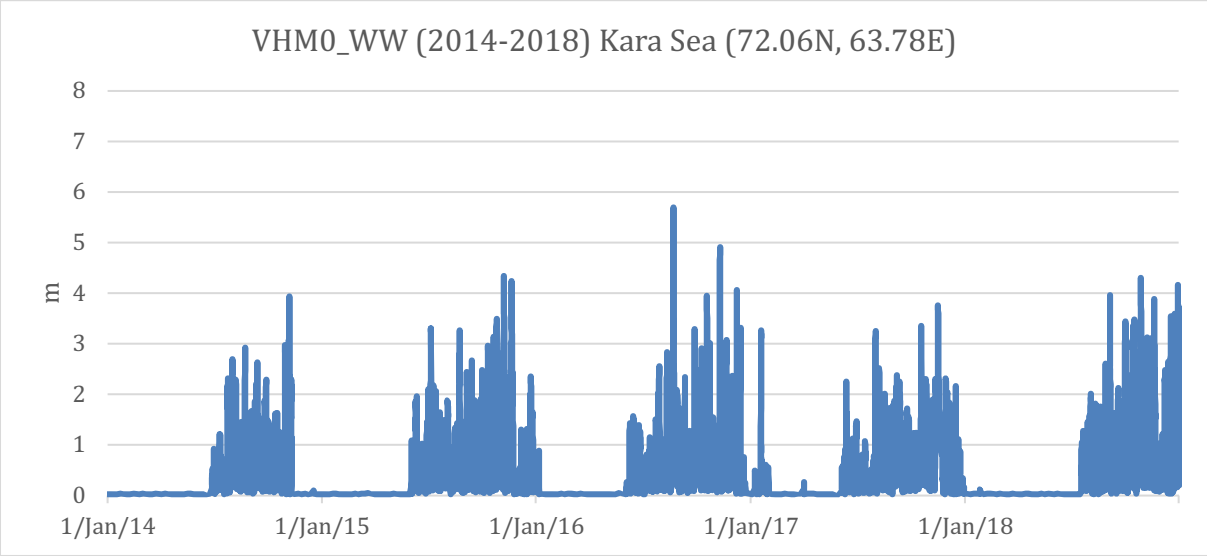


Figure 4.14 Significant wave height (m) for two 5-year periods in the Kara Sea

In the Laptev Sea (Fig 4.15), the waves are present only in the summer window (from July to October) 13% of the time in the months from July to September the waves are higher than 1m during the period 2002-2006 and this percentage has increased to 19% in the period 2014-2018.

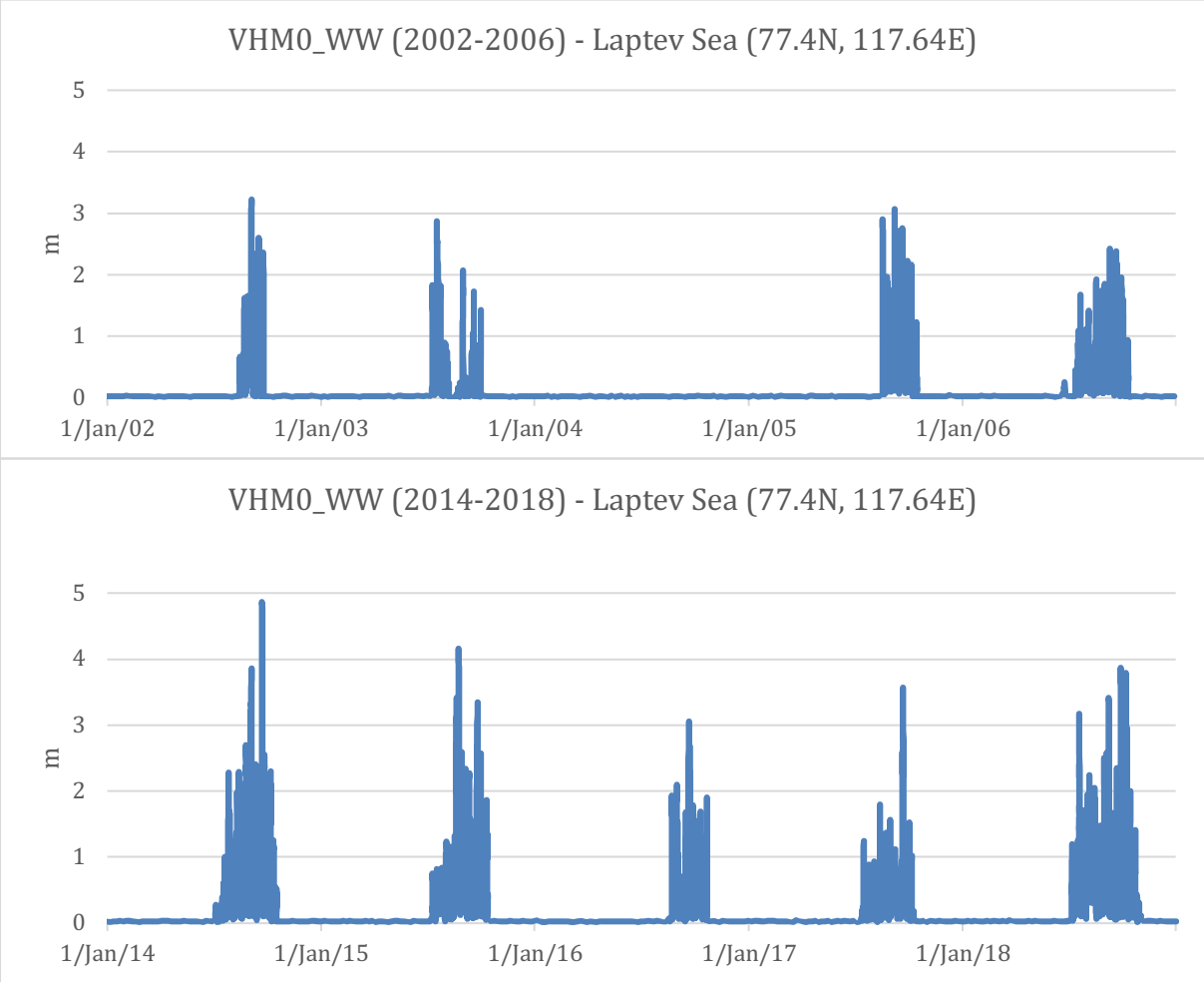


Figure 4.15 Significant wave height (m) for two 5-year periods in the Laptev Sea

Generally, the wave climate is fairly stable in regions with little or no sea ice e.g. Norwegian-, Greenland and Barents Sea where also the highest waves are found. Ocean areas with sea ice parts of the year experience an increase in wave heights over time due to the retreating sea ice. Statistics show that time with waves height above 3 and 4 metres are limited, only the Greenland Sea display wave heights above 4 metres close to 10% of the time during winter.

4.5 Temperature and Salinity statistics

The fishing activities, linked to the fishing abundance for several fish species has a strong dependence on the water masses characterised by temperature and salinity. It is therefore important to monitor temperature and salinity conditions in an ocean area and their variability as a function of time and space in order to understand and manage the Barents Sea fish stocks. To illustrate the variability of temperature and salinity in the Barents Sea data has been subtracted from CMEMS Arctic Ocean Physics Reanalysis (1991-2019)[2] for several depths at two points in the Barents Sea, one in the northern part and one in the southern of the basin, Fig 4.16. The model outputs are monthly averages.

Figure 4.16. Two different points where the analysis of the Temperature and Salinity is done: Barents 'North': 78.6N; 40.5E (283 m depth) and Barents 'South': 73N; 25E (414 m depth).

<u>Barents Southern point (73N; 25E)</u>

Fig 4.17 shows the temporal evolution of the monthly averages of the temperature at three different depths: surface (5 m), intermediate depth (100 m) and at the sea floor (~414 m. A seasonal cycle and interannual variability are clear, especially in the surface layer (5 m).

2 https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=ARCTIC_REANALYSIS_PHYS_002_003

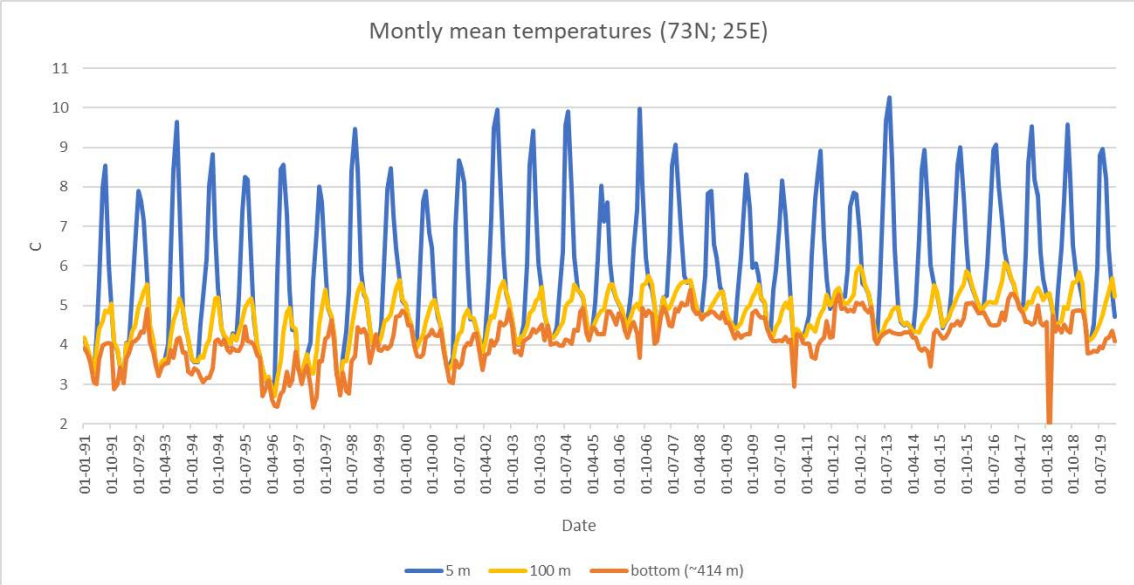


Figure 4.17 Monthly mean temperature at different depths in the Barents Southern point.

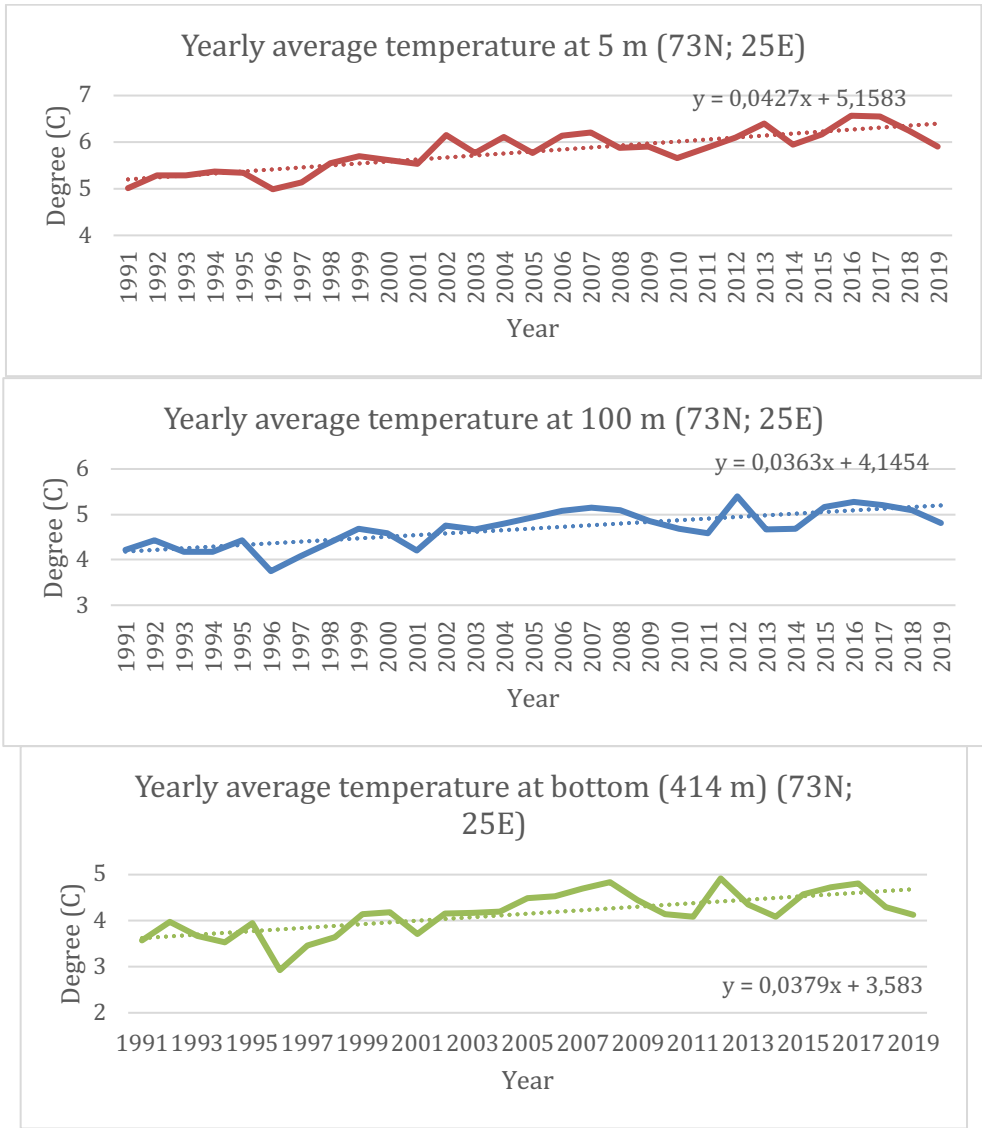


Figure 4.18. Yearly average temperature at the Barents Southern point at three depths. The tendency lines shown for each depth.

In order to display long-term trends, the yearly averaged temperature is calculated, Fig. 4.18. A clear warming trend is marked at all depths.

A similar analysis is done for salinity, Fig 4.19 and 4.20. In the surface layer there is a clear negative trend in the salinity reflecting an increased presence of fresh water due to melting sea ice and melting land ice/glaciers. Both the 100 m and bottom layer shows a positive trend in salinity - most markedly in the bottom layer – reflecting changes in salinity of the inflowing North Atlantic Water.

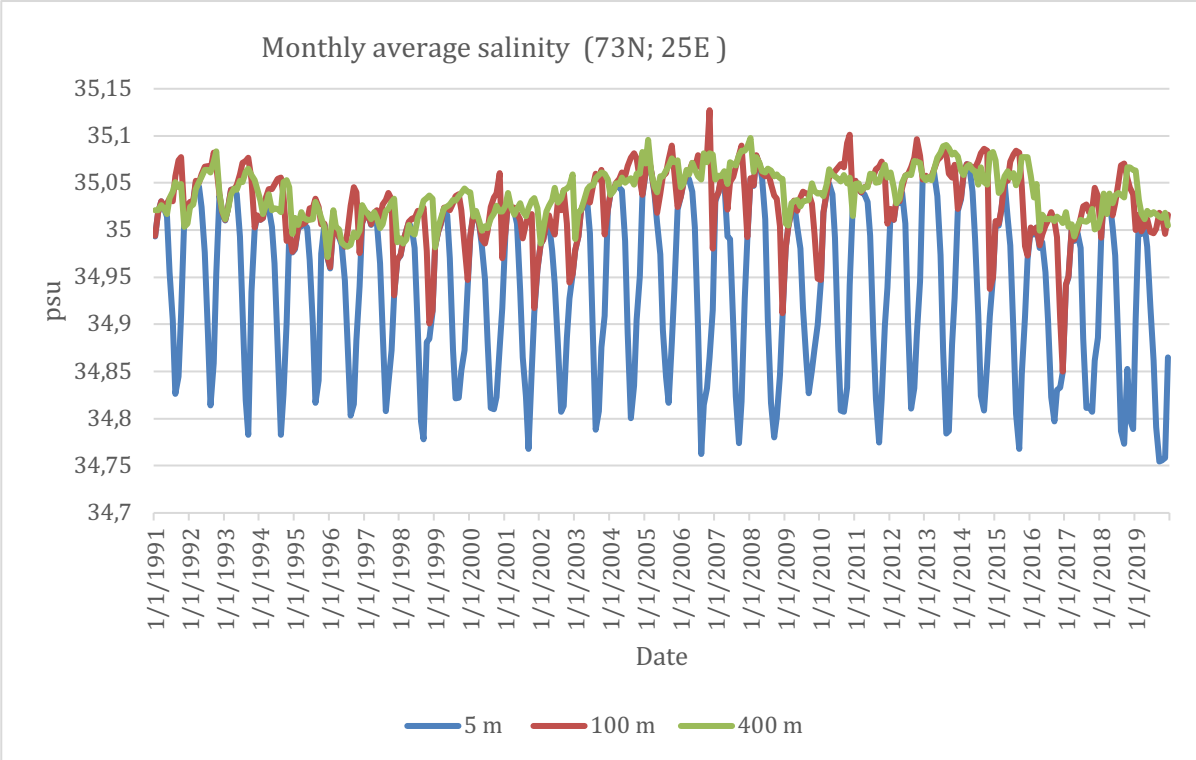
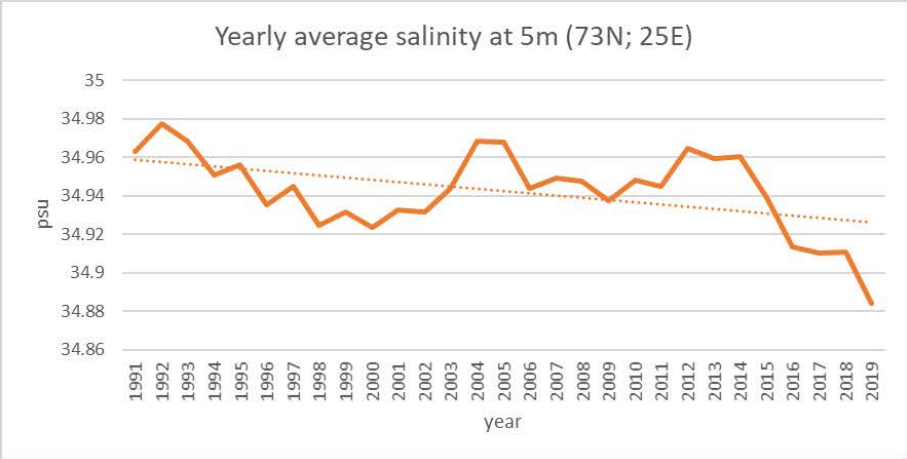
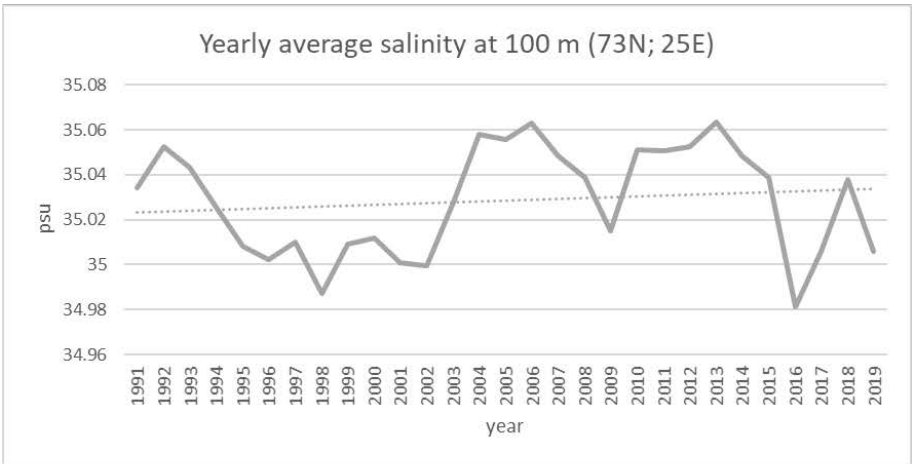


Figure 4.19. Monthly mean salinity at different depths in the Barents Southern point.





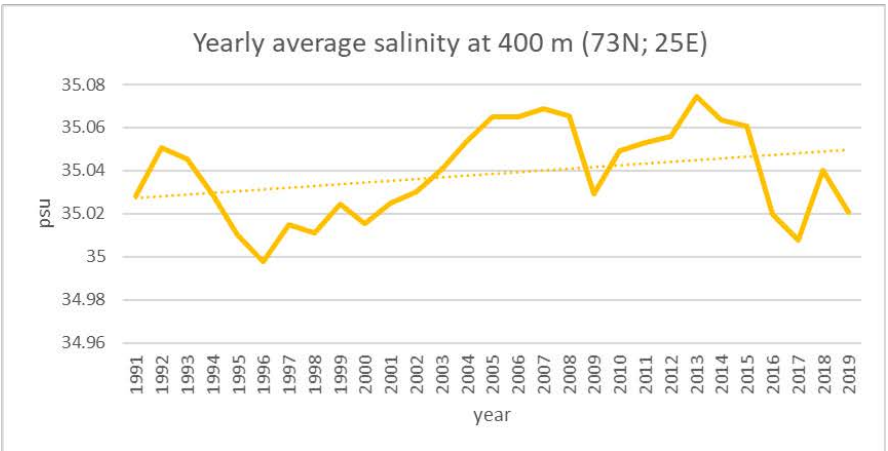


Figure 4.20 Yearly average salinity at the Barents Southern point at different depths.

<u>Barents Northern point (78.6N; 40.5E)</u>

Fig 4.21 shows the temporal evolution of the monthly averages of the temperature at three different depths: surface (5 m), intermediate depth (100 m) and at the sea floor (~283 m) – the seasonal cycle and its interannual variability is clear especially in the surface layer (5 m).

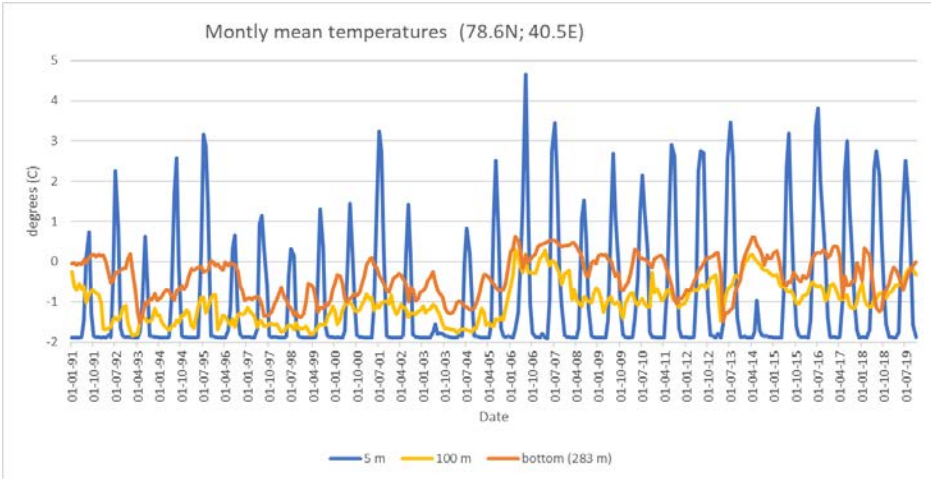


Figure 4.21 Monthly mean temperature at three depths in the Barents Northern point.

In order display long-term trends, the yearly averaged temperature is calculated, Fig. 4.22. Also, at the northern point a clear warming trend is observed at all depths.

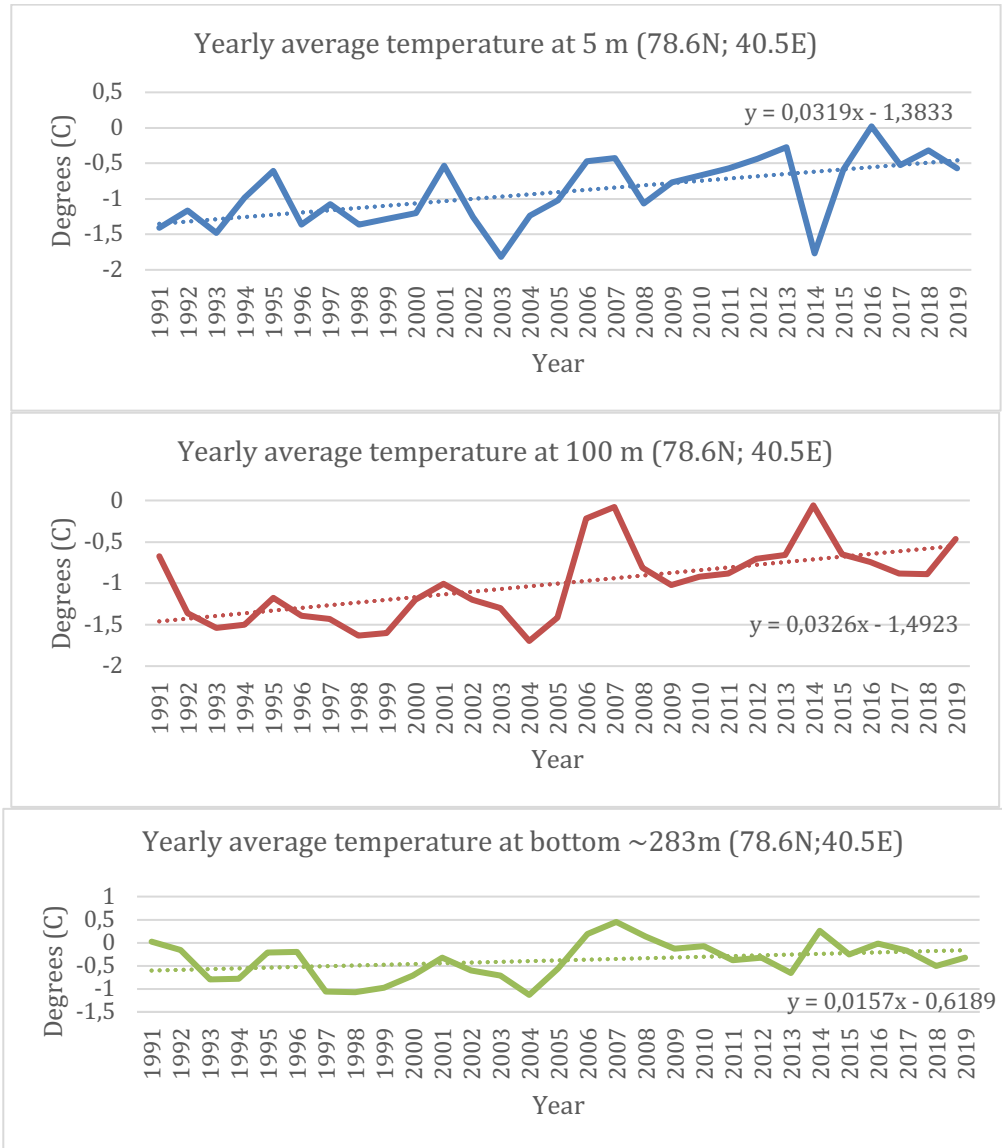


Figure 4.22. Yearly average temperature at the Barents North point at different depths

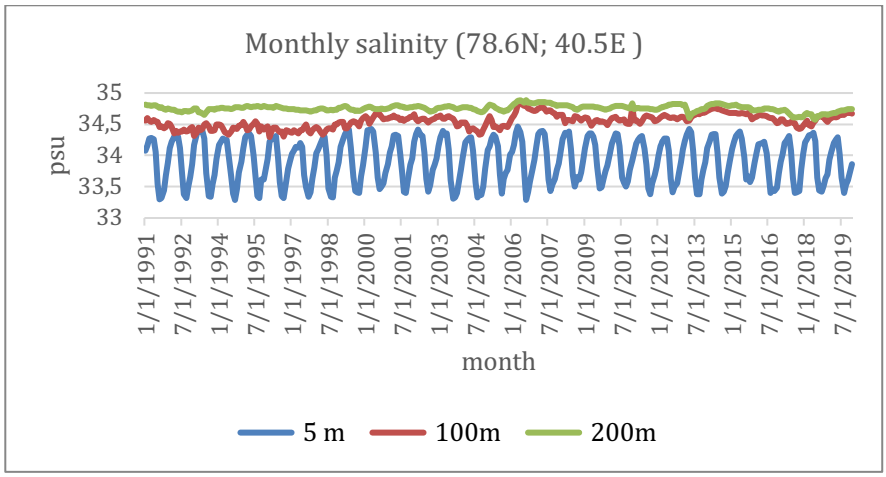


Figure 4.23. Monthly mean salinity at different depths in the Barents northern point.

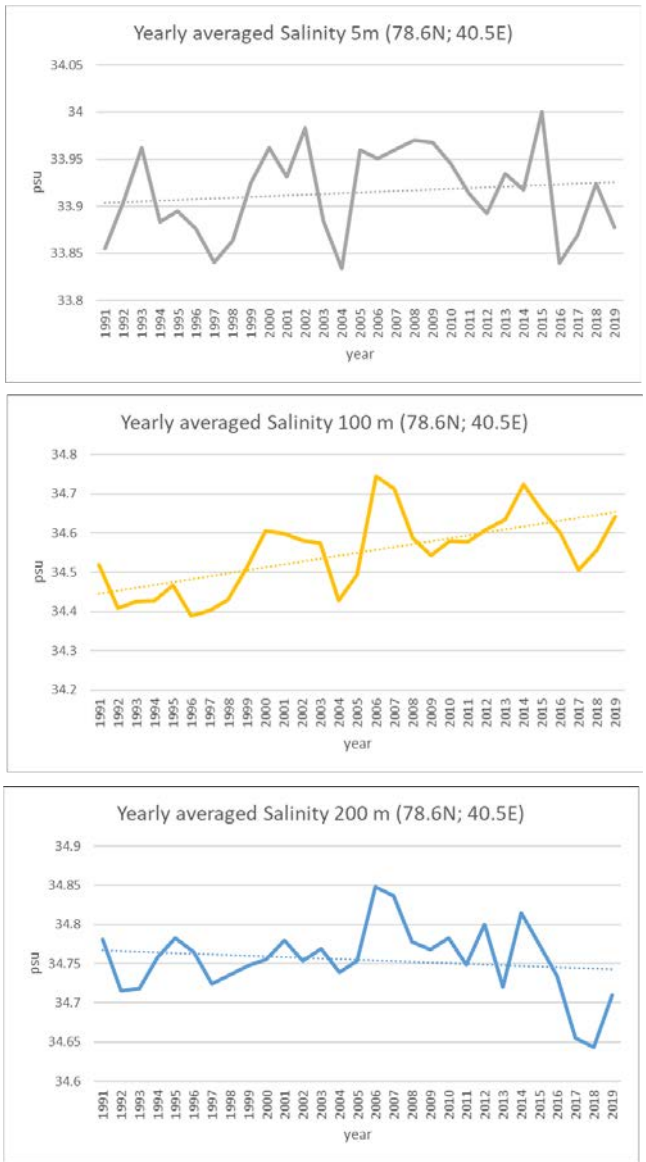


Figure 4.24 Yearly average salinity at the Barents northern point at different depths.

The timeseries and statistics for salinity are displayed in Fig 4.23 and 4.24. The Northern point is more influenced by Arctic water masses, the trends is are slightly positive for the surface and 100 m layer while negative for the bottom layer which however is highly due to low-salinity conditions in recent years.

Data from the two selected points demonstrates a clear warming trend for the Barents Sea water masses which is believed to generate a migration of existing fish and marine mammals as well as an invasion of fish stocks from lower latitudes in search of their preferred habitats and food sources. Some species are gaining habitat, while others are being squeezed out by new arrivals and habitat loss. These changes are likely to have major impacts on both commercial fishing and food security of native peoples.

5. Maritime transport effects on the environment

The maritime transport sector is an essential element for global trade and economy, and has therefore a strong international dimension. In the EU alone, it handles 77% of its external trade and 35% of all intra EU trade. While the maritime transport sector brings substantial economic and social benefits, it also impacts the environment and the citizens health. For the first time this impact has been accessed in a close cooperation between the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA) (EMSA & EEA, 2021). The report presents up-to-date information, points out trends, identifies data gaps, and highlights both the challenges and opportunities facing the shipping sector, which are of relevance to fostering cooperation at European level. The analysis is focusing on European waters and do therefore not include specific data and results for the Arctic region. However, since it is the first time such an impact analysis is performed the key findings will be presented here to provide an idea on the possible environmental implications of an increased maritime activity in the Arctic with its vulnerable environment but additionally also to provide indications on which observations are needed to include in an Arctic Observing System in order to perform a proper environmental assessment in the future.

5.1. Pressures on the environment produced by the maritime transport sector.

Shipping is one of the modes of transport with the lowest CO_2 emissions per distance and weight carried. In spite of this, pollution derived from maritime shipping activities has profound implications for air and water quality and marine and estuarine biodiversity. Different ship types, operational profiles, cargoes carried, fuels consumed, materials used, arrangements and control systems make vessels highly complex systems. As they move on the surface of the sea, both their impacts on air and water need to be addressed to achieve sustainability. The diagram below shows the different types of pollutant emissions possible from a generic ship.

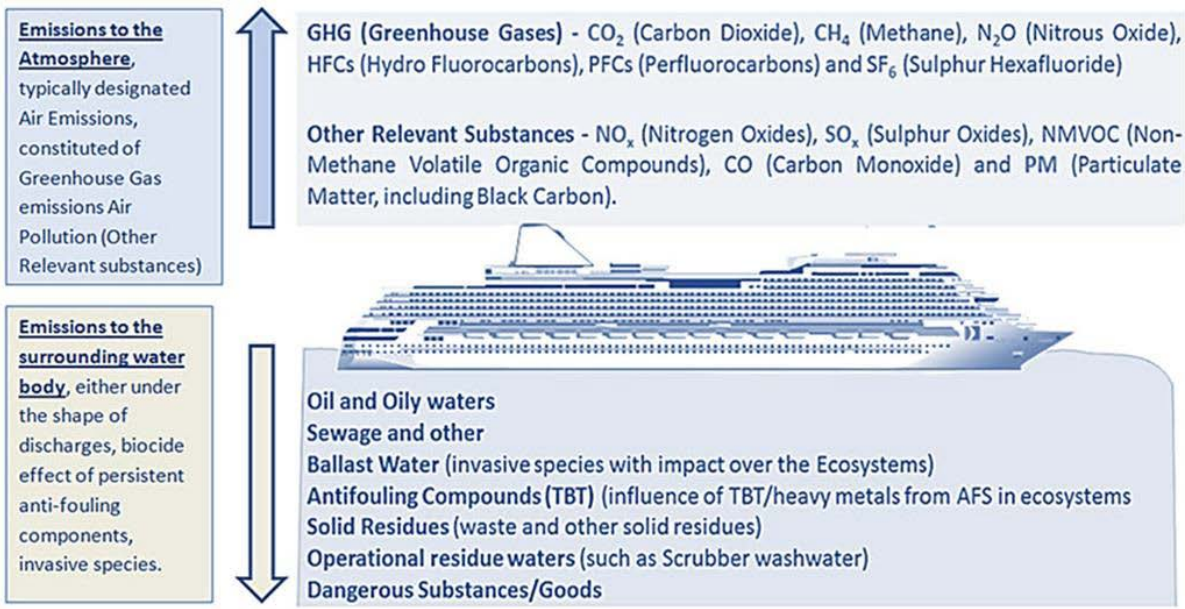


Figure 5.1 Pollutant emissions to the atmosphere and water body from a generic ship. (Source: EMSA)

The key findings of the analysis on the various effects on the environment was in the report presented as follows (EMSA & EEA, 2021):

Greenhouse gases and air pollution

- In 2018, maritime transport contributed 13.5% to EU's total GHG emissions from the transport sector (including international transport), which puts it roughly at the same level as aviation.
- In 2018, CO_2 emissions from ships calling in EU/EEA ports were roughly 140 Mtns, representing 18% of the global CO_2 emissions from international shipping. Of the total CO_2 emitted on an annual basis, 40% corresponds to voyages between EU ports or while at berth. Container ships account for around one third of the fleet CO_2 emissions in the EU.
- In 2018, air pollutant emissions produced by the maritime transport sector in the EU, including international, domestic and inland waters navigation, represented 24% for NO_x, 24% for SO_x and 9% of PM2.5 as a proportion of national EU emissions from all sectors. In 2019, emissions from ships calling in EU/European Economic Area (EEA) ports represented 20% for NO_x, 14% for SO_x and 18% for PM2.5 of the worldwide emissions from international shipping.
- During 2014-2019, air pollutant emissions from the maritime transport sector have generally stabilized in all regions. However, SO_x emissions have largely decreased from 2015 in the North and the Baltic Sea although not in the Mediterranean Sea. Similarly, NO_x emissions have remained stable in all regions except in the Baltic Sea, where a reduction was observed in 2019.
- Since 2015, SO_2 concentrations in the North and Baltic Sea have dropped down to 60% due to the introduction of SO_x Emission Control Areas. As of January 2021, NO_x Emission Control Areas will also be applied in these regions, although effective reductions are expected to materialise at a slow pace since the requirements only apply to new ships.
- Estimates show that black carbon was responsible for 6.85% of the global warming contribution from shipping in 2018, while CO_2 contributed 91.32%.

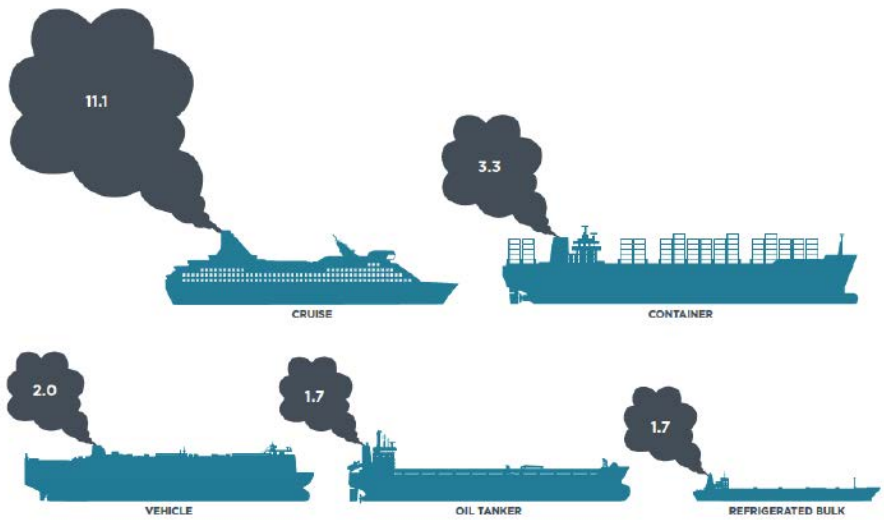


Figure 5.2 Annual global Black Carbon emissions per ship type in tonnes (Comer, Mao, Roy, & Rutherford, 2017)

Water Discharges and Pollution

- While the amount of oil transported by sea has been steadily growing for the last 30 years, with a consequent increase of the risk of potential oil spills, the total amount of accidental oil spills has been constantly declining. During 2010-2019, out of the total 44 medium size oil spills (7-700 tonnes) in the world, only 5 were located in EU waters (11%), and out of a total of 18 large oil spills (>700 tonnes), only 3 were located in the EU (17%).
- In 2019, a total of 7939 possible small size oil spills (<7 tonnes) were identified using satellite monitoring. From these spills, approximately 2400 (30%) were verified in-situ by the relevant authorities, 1000 (42%) of these confirmed as illegal discharges of various sizes (within a 3-hour verification time period). Despite an increase in the area monitored by satellites, the 2019 average number of detections per Mkm2 decreased to 2017 values, confirming a positive declining trend in illegal discharges.
- The current largest water discharges from ships in terms of volume, excluding ballast water discharges, is estimated to come from open-loop scrubbers (78%), followed by grey waters and sewage. The release of discharge waters from open-loop scrubbers has significantly increased since 2015 and is expected to continue growing.
- Nitrogen discharges from sewage from roll-on-roll-off passenger ships are on the rise since 2014, reaching approximately 1910 tons per year, and are the largest contributor to Nitrogen discharges in sea-water.

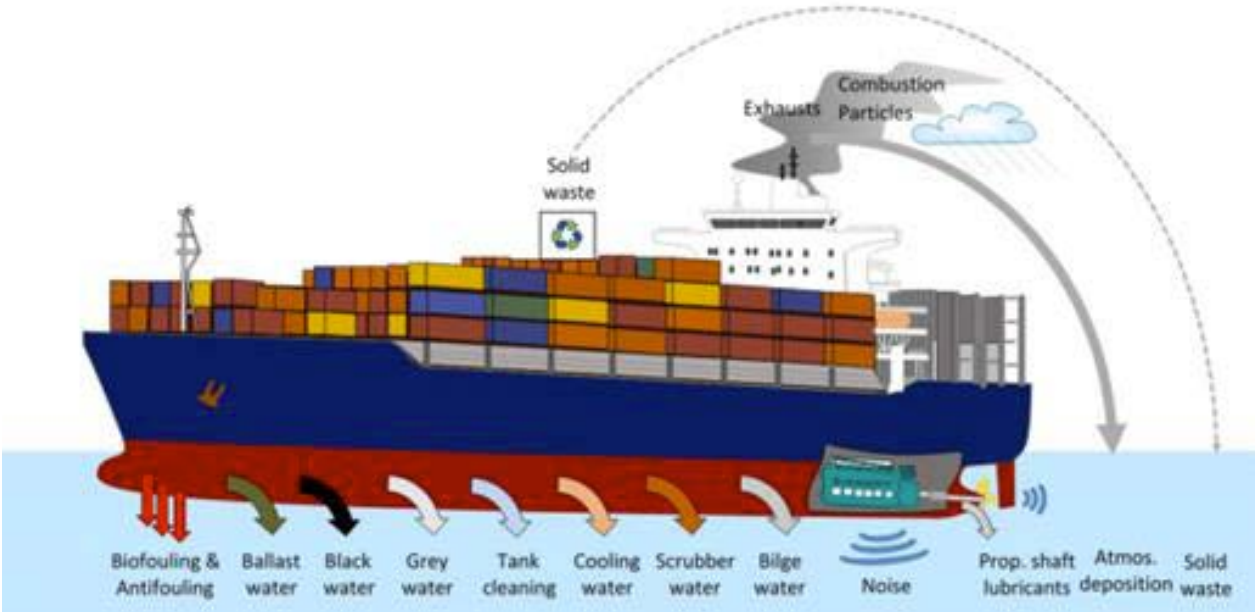


Figure 5.3 Subsystems onboard ships that produce water pollution. (Source: Scientific final report from the BONUS SHEBA project. (SHEBA Project, 2015))

Marine Litter

- There is currently limited knowledge on the bearing of the maritime sector on marine litter. An analysis made on beach litter data from 2015 and 2016 indicates a higher proportion of sea-based litter on the Atlantic and North Sea coast compared to the Mediterranean Sea.

- Estimates of the percentage of total waste released through lost containers at sea are considered low and negligible in the EU, with an average of 268 containers lost per year (i.e., one thousandth of 1% of 226 million packed and empty containers worldwide shipped on average each year).
- 2018 calculated waste generated on board ships compared to the waste actually delivered in port reception facilities in the EU, provided an estimation on the potential ship generated waste which may be illegally discharged at sea ranging around 2.5% for oily waste, 10% for sewage and 7-34% for garbage.

Underwater Noise

- The main sources of underwater noise from ships are caused by the propeller, machinery (including engines), and the movement of the hull through the water.
- During 2014-2019, the total accumulated underwater radiated noise energy have doubled in EU waters. Container ships followed by passenger ships and tankers, are responsible for the highest noise energy emissions resulting from the operation of the propeller, although this pattern varies between sea basins.

Non-Indigenous Species

- The maritime transport sector accounts for the largest proportion of Non-Indigenous Species (NIS) introductions in seas around the EU (almost 50%) since records exist, although the rate of new introductions has slowed down since 2005. The 51 species introduced by maritime transport in the EU are considered to have a high impact, which means they can affect ecosystems, influence native species and cause economic loss.
- The Mediterranean Sea is the area where the highest numbers of NIS introduced by maritime transport are found.
- Container ships and tankers are responsible for most of ballast water discharges in EU waters. The volume of these discharges is estimated to have remained relatively stable during 2014-2019, both in total volume and per ship type. The Mediterranean Sea accounts for the greatest volumes of ballast water.
- Spreading of biofouling NIS by recreational boats is estimated to be significant in regions such as the Mediterranean Sea.

Physical disturbance of the seabed

- Habitats most affected by dumping of dredged material are those with sedimentary bottoms, such as sand or mud, which in general are more diverse and considered to be the more productive.
- The marine regions with the highest extent of estimated area potentially disturbed by ship wakes are the North and the Baltic Sea, where respectively 63% and 40% of these regions fall within Natura 2000 sites.
- The development of port infrastructures produces changes in the coastal morphology with the corresponding alteration of the local hydrographical conditions and the loss of seabed habitats. During 2000-2018, port developments have steadily increased in the EU. Ports have grown in size by 10% while their relative cargo handled by 100%.

Impacts of maritime transport on marine and coastal ecosystems and human health

- While the various pressures from maritime transport are well documented, information on their impacts on human health, the environment or climate change are more difficult to establish.
- GHGs from maritime transport contribute to climate change, representing a threat to the marine environment and human health, producing changes in temperature, increasing CO_2 levels, and decreasing pH in waters and soils, changes in nutrients and dissolved oxygen due to changes in circulation and stratification, as well as extreme weather events and sea level rise.
- Maritime transport air pollutant emissions have the potential to reach the shoreline and adversely impact almost 40% of the European population that lives within 50 km from the sea.
- Contaminants released in the environment can also produce various effects on the marine fauna at individual and population level. For instance, marine litter can produce the entanglement of animals, leading to injuries, reduced mobility or death.
- The habitats for which the greatest number of maritime transport related pressures have been reported by EU Member States in 2019 are estuaries, large shallow inlets and bays, and sandbanks slightly covered by sea water.
- The ecological and chemical status of water bodies surrounding the Trans-European Transport Network (TEN-T) ports shows little improvement from 2010 to 2016.

The EMSA&EEA, 2021 report clearly demonstrates that maritime activities produce significant pressures to the atmosphere and the marine environment:

- Greenhouse gases and air pollutant emissions
- Water discharges from maritime transport affect the marine environment due to their hazardous nature.
- Leaches from antifouling biocides can reach concentrations which may be harmful.
- Accidental or intentional oil spills can have severe consequences to many different environments and habitats.
- Introduction and spread of non-indigenous species
- Marine litter
- low frequency noise energy.

These pressures are well described and documented in the report for European Seas, but in the perspective of increased maritime activity in Arctic Region it would be advisable to perform similar monitoring of environmental pressures for this region whose environment is different and more vulnerable than the European seas.

Measuring the environmental pressures impacts on human health, the environment, climate change and the economy is another challenging task that requires attention and will according to EMSA & EEA, 2021 involve comprehensive, integrated and timely monitoring and outlook programmes. This effort would entail, for instance, the evaluation and insight on cases of respiratory problems which can be associated with emissions from ships, changes in the distribution, abundance or behavior of species due to continuous underwater noise, monitoring injuries or death produced by collision with the vessels, assessing burial of

organisms produced by dumping of dredged material, identifying changes in the food webs due to the introduction of non-indigenous species or intoxication and monitoring the potential death of organisms due to harmful substances.. Finally, port activities such as enlargements and developments which support a transition to a more circular blue economy, can also lead to a loss of vulnerable habitats, as well as to hydrographical changes at the local level, which may affect coastal ecosystems.

6. Conclusions

Three important components of the Arctic Blue Economy –i.e. maritime transport via the Arctic Ocean, cruise industry in the Svalbard area and fishery in the Barents Sea – were selected as demonstration cases for a more detailed study of their business development potentials under a warming Arctic climate. Entering into operations in the harsh Arctic environment requires good knowledge and understanding of the physical environmental conditions to ensure a sound decision process on economy, efficiency, safety of ship, crew and cargo and protection of the vulnerable Arctic environment. Therefore, examples of statistical analysis of relevant environmental parameters like sea ice, wind, waves, temperature and salinity has been performed.

Generally, it can be concluded that the three selected business areas have potential for further economic developments in the coming years but, at the same time, there also severe challenges regarding security and environmental protection in the Arctic region than other parts of the world ocean that will influence economy and efficiency and therefore requires attention.

Key finding of the analysis of the three business sectors are:

- **Maritime transport sector:**
  - The Transpolar Sea Route is the most advantageous but is not realistic in a foreseeable future due to year-round ice cover in the central Arctic;
  - For ship traffic between Europe and Asia the Northeast Passage route gives best savings in time (33%) and expenses (22%).
  - Increased use of the Northeast Passage for maritime transportation will result in:
    - Liberation of maritime transport capacity leading to either increased ship-based transportation or reduction in ship capacity;
    - Possible reduction in freight rates;
  - Analysis of AIS data demonstrates that use of the Northeast Passage is already increasing
  - There is an environmental impact to be considered:
    - The reduction in travel time and fuel consumption of the individual voyage will reduce the impact on the environment, but if the freed transport capacity is fully utilised the environmental impact will be the same,
    - The environmental impact will however be moved geographically from low to high latitudes
- **Cruise industry:**
  - The Arctic Cruising Industry has developed since the 1960's and during the past couple of decades luxury cruise lines have begun to venture into the high Arctic waters
  - The increase in the number of cruise passengers in the Arctic region has over the past 1-2 decades been substantial. Business prognoses foresee this increase to continue also in years to come
  - The latest trend is to deviate from the normal cruising season during the few summer months (June to September) and also organise cruises late-winter/early spring period.

  - The Covid-19 pandemic outbreak in early 2020 has however changed this development patter, reducing the Arctic cruise traffic in 2020 and 2021 markedly and it is expected that it will take several years before the Arctic Cruise Industry is back to normal.
- **Barents Sea Fishery.**
  - Most important fish stock in the Barents Sea fishery are: capelin, deep-water shrimp, cod, haddock, saithe, red king crab and snow crab.
  - Landings of the various stocks fluctuate over time reflecting changes in the physical environment
  - There are currently 12 nations with fisheries targeting the stocks in this ecoregion. The country with the highest landings is Norway, followed by Russia. Lower landings are made by Denmark, Estonia, Faroe Islands, France, Germany, Iceland, Poland, Portugal, Spain, Belarus, and the UK
  - Climate-induced changes in seasonal sea ice extent and thickness and ocean stratification will alter marine primary production which will impact the ecosystem by affecting regional species composition, spatial distribution, and abundance of marine species. These changes together with human introduction of non-native species will expand the range of temperate species and contract the range of polar fish and ice-associated species.
- **Risk and safety**
  - Increased maritime activity in the Arctic Ocean will increase the risks for accidents and oil spills in general due to the presence of sea ice and related visibility problems, which is of particular concern due the vulnerability of the Arctic environment and the lack of oil spill combatting preparedness in the area.
  - The harsh Arctic environment raise special demands to secure a safe journey for the ship and its crew e.g.:
    - Construction of the ship
    - Education of the crew
    - Operating procedures on the ship
    - High quality operational meteorological and oceanographic products and services.
  - Search and rescue facilities in the Arctic are minimal

Statistical analysis of environmental physical parameters important for planning and implementing maritime operations in the Arctic has been performed using data from satellite observations (OSI-SAF) or numerical models (CMEMS). The analysis shows:

- There exists a clear positive trend in the number of open water days in the Northeast Passage for the period 1990 to 2020, which is consistent with the trend of ice retreat in the region reported in the literature. There no indications in the analysis nor in climate projections that the positive trend in open water days will decrease or stop in the coming years.
- There is a clear seasonal cycle in wind speed with strongest winds during the winter season. The strongest winds are found to the west of Svalbard where winds of storm strength appear regularly. Within the Arctic Basin wind speeds are more moderate.
- The most stable wave climate and highest waves are found in regions with little or no sea ice e.g., Norwegian-, Greenland- and Barents Sea; while ocean areas with sea ice

parts of the year experience an increase of wave heights over time due to the retreating sea ice providing an increased wind fetch area.

- A clear warming trend for the Barents Sea watermasses is demonstrated, which is believed to generate a migration of existing fish and marine mammals as well as an invasion of fish stocks from lower latitudes in search of their preferred habitats and food sources. Some species are gaining habitat, while others are being squeezed out by new arrivals and habitat loss.
- Salinity is decreasing in the surface layer in the southern part of the Barents Sea reflecting an increased presence of fresh water due to melting sea ice and melting land ice/glaciers. Below the surface layer a positive trend in salinity is observed - most markedly in the bottom layer – reflecting that these layers are dominated by inflowing North Atlantic Water. In the northern part the salinity trends are more diffuse.

Satellite observations and outputs from numerical models are important sources of data to gain knowledge and understanding of the Arctic Ocean physical environment and its variability; but the trustworthiness of the information's from these two data sources depends critically on the availability of in situ observations of key variables for assimilation in the models and especially for validation of quality of the generated data products. Unfortunately, timely availability of enough relevant and high-quality in situ observations of oceanographic and meteorological variables from the Arctic Region is far from satisfactory for this purpose.

It is therefore crucial to design and implement a fit-for-purpose Arctic Observing System to ensure the timely availability of high-quality in situ data needed for model assimilation as well as validation of the quality of model and remote sensing products used both for statistical trend analysis and particularly operational purposes.

The European Maritime Transport Environment Report (EMTER) (EMSA&EEA, 2021) describe and document how maritime activities produce significant pressures to the environment in European Seas:

- Greenhouse gases and air pollutant emissions
- Water discharges from maritime transport affect the marine environment due to their hazardous nature.
- Leaches from antifouling biocides can reach concentrations which may be harmful.
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References

Buch Erik, Marianne Sloth Madsen, Jun She, Martin Stendel, Ole Krarup Leth, Ann Mari Fjæraa, Mikael Rattenborg, 2019. Arctic In-Situ Data Availability. https://insitu.copernicus.eu/library/reports/CopernicusArcticDataReportFinalVersion2.1.pdf

Comer, B. O., Mao, X., Roy, B., & Rutherford, D. (2017). *Black Carbon Emissions And Fuel Use In Global Shipping, 2015.* The International Council on Clean Transportation

Drinkwater, K., Loeng, H., Titov, O.V., Boitsov, V.D., 2011. Global warming and climate change. In: Jakobsen, T., Ozhigin, V.K. (Eds.), The Barents Sea - Ecosystem, Resources, Management. Half a Century of Russian-Norwegian Cooperation. Tapir Academic Press, Trondheim, pp. 777–807 (Chapter 15).

Dyrcz, C., 2017. Safety of navigation in the Arctic. Zeszyty Naukowe Akademi i Marynarki Wojennej (Scientific Journal of Polish Naval Academy) https://www.researchgate.net/publication/321687663_Safety_of_Navigation_in_the_Arctic

EMSA & EEA, 2021. European Maritime Transport Environment Report -EMTER. Link ????

Eriksen E., H. Gjøsæter, D. Prozorkevich, E. Shamray, A. Dolgov, M. Skern-Mauritzen, J.E. Stiansen, Yu. Kovalev, K. Sunnanå, 2017. From single species surveys towards monitoring of the Barents Sea ecosystem. Progress in Oceanography www.elsevier.com/locate/pocean

Gorshkov, S.G. (Ed.), 1980. Atlas of the Oceans. Arctic Ocean. USSR Ministry of Defense. Voenno-Morskoy Flot Press, Moscow, pp. 184 (in Russian).

ICES, 2019. ICES Fisheries overview s, Barents Sea Ecoregion. https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2019/2019/EcosystemOverview_BarentsSea_2019.pdf

Ingvaldsen, R., Loeng, H., Ådlandsvik, B., Ottersen, G., 2003. Climate variability in the Barents Sea during the 20th century with focus on the 1990s. ICES Mar. Sci. Symp. 219, 160–168.

Khon V.V, Mokhov I.I, Pogarskiy F.A. , Babanin A. , Dethloff K., Rinke A., Matthes H. , 2014. Wave heights in the 21st century Arctic Ocean simulated with a regional climate model. Geophys Res Lett 41(8):2956–2961. https://doi.org/10.1002/2014GL059847

Lind, S., Ingvaldsen, R., 2012. Variability and impacts of Atlantic Water entering the Barents Sea from the north. Deep Sea Res Part I (62), 70–88.

Liu Q., A. V. Babanin, S. Zieger, et al. (2016), Wind and Wave Climate in the Arctic Ocean as Observed by Altimeters. J. Clim. 29, 7957–7975. DOI: https://doi.org/10.1175/JCLI-D-16-0219.1

Loeng, H., 1991. Features of the physical oceanographic conditions of the Barents Sea. Polar Res. 10, 5–18.

Meredith, M., M. Sommerkorn, S. Cassotta, C. Derksen, A. Ekaykin, A. Hollowed, G. Kofinas, A. Mackintosh, J. Melbourne-Thomas, M.M.C. Muelbert, G. Ottersen, H. Pritchard, and E.A.G. Schuur, 2019. Polar Regions. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press

Ozhigin, V.K., Ingvaldsen, R.B., Loeng, H., Boitsov, V.D., Karsakov, A.L., 2011. The Barents Sea. In: Jakobsen, T., Ozhigin, V.K. (Eds.), The Barents Sea – Ecosystem, Resources, Management. Half A Century of Russian-Norwegian Cooperation. Tapir Academic Press, Trondheim, pp. 39–76 (Chapter 2).

PAME, 2020. Arctic Shipping Status Report #1. https://www.pame.is/projects/arctic-marine-shipping/arctic-shipping-status-reports/723-arctic-shipping-report-1-the-increase-in-arctic-shipping-2013-2019-pdf-version/file

SHEBA Project. (2015). Sustainable Shipping and Environment of the Baltic Sea region. Retrieved from SHEBA: https://www.sheba-project.eu/

Smedsrud, L.H., Ingvaldsen, R., Nilsen, J.E.Ø., Skagseth, Ø., 2010. Heat in the Barents Sea: transport, storage and surface fluxes. Ocean Sci. 6 (1), 219–234.

Smedsrud, L.H., I. Esau, R.E. Ingvaldsen, Y. Eldevik, P.M. Haugan, C. Li, V.S. Lien, A.Olsen, A.M. Omar, B. Risebrobakken, A.B. Sandø, V.A Semenov, S.a Sorokina, 2013. The role of the Barents Sea in Arctic Climate System.Rev. Geophys. S1, 415-449

Stopa, E, F. Ardhuin and F.G. Ardhuin, (2016). Wave Climate in the Arctic 1992-2014: seasonality and trends. The Cryosphere, 10, 1605-1629, 2016. https://tc.copernicus.org/articles/10/1605/2016/tc-10-1605-2016.pdf

Vespe M., Greidanus H., Santamaria C., Barbas T. (2018) Knowledge Discovery of Human Activities at Sea in the Arctic Using Remote Sensing and Vessel Tracking Systems. In: Hildebrand L., Brigham L., Johansson T. (eds) Sustainable Shipping in a Changing Arctic. WMU Studies in Maritime Affairs, vol 7. Springer, Cham. https://doi.org/10.1007/978-3-319-78425-0_9

Vinje, T., 2001. Anomalies and trends of sea-ice extent and atmospheric circulation in the Nordic Seas during the period 1864–1998. J. Clim. 14 (3), 255–267

Waseda, T., Webb, A., Sato, K. *et al.* Correlated Increase of High Ocean Waves and Winds in the Ice-Free Waters of the Arctic Ocean. *Sci Rep* **8,** 4489 (2018). https://doi.org/10.1038/s41598-018-22500-9

Wergeland, T., 2010. Arctic Shipping Routes – Cost comparisons with Suez. www.arctis-search.com

Wienerroither R., Johannesen E., Dolgov A., Byrkjedal I., Bjelland O, Drevetnyak K., Eriksen KB., Høines Å., Langhelle G., Langøy H., Prokhorova T., Prozorkevich D., Wenneck T., 2011. Atlas of the Barents Sea Fishes. IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828.

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