WMU Journal of Maritime Affairs (2020) 19:219–234
https://doi.org/10.1007/s13437-020-00200-4

ARTICLE

Polar Code application areas in the Arctic

Meric Karahalil[1] · Burcu Ozsoy[1] · Ozgun Oktar[1]

Received: 4 January 2020 / Accepted: 23 April 2020 / Published online: 20 May 2020

Abstract
The improvement of the International Code for Ships Operating in Polar Waters (Polar Code) has been a long process and is based on the previous International Maritime Organization (IMO) instruments. It aims at mitigating the risks of harsh environments and weather conditions for safe operations and the prevention and control of maritime pollution from ships in the polar regions. It is essential to understand the challenges pertaining to polar circumstances and reasons for maritime casualties in order to mitigate future risks. While maritime activities are increasing in the Arctic, little attention is being paid to some of the northernmost regions that are greatly influenced by the Arctic climate and are excluded from the Polar Code. The marine boundaries of the Arctic region have been defined differently by the Arctic Council Working Groups based on physical, geographical, and ecological characteristics. However, the boundaries of the Polar Code are not compatible with any of them. In this study, we analyze the extent of sea ice changes and the maritime traffic in the high north and also evaluate maritime safety in the frame of the application of the Polar Code boundaries in the Arctic.

Keywords Polar Code · Arctic sea ice extent · Arctic shipping · Polar Code application boundaries · Maritime safety

1 Introduction

The Arctic region consists of the Arctic Ocean and its contiguous seas. It is surrounded by landmasses including Canada, Greenland (Denmark), Iceland, Norway, Russia, Alaska (the USA), Finland, and Sweden (Council 2019). However, there are a variety of opinions regarding what exactly constitutes the boundaries of the Arctic.

✉ Meric Karahalil
merickrhll@gmail.com

[1] Maritime Faculty, Maritime Transportation Engineering, Istanbul Technical University, Istanbul, Turkey

The decreasing sea ice extent due to global climate change has been a growing concern in recent years. The National Snow and Ice Data Center (NSIDC) has recorded record lows. For instance, the Arctic sea ice extent for September 2019 is the third lowest in the last 41 years (Serreze et al. 2019). However, owing to this event, some potential opportunities have emerged regarding maritime activities such as tourism, fishing, and trans-polar passages in the Arctic waters. Nevertheless, while maritime activities have increased, so have the risks in the region. The existence of sea ice and its thickness are important factors affecting navigational performance, and a vessel's hull, propeller, and/or rudder may incur damages under significant forces from them.

On the other hand, the melting of ice shelves has increased the risk of floating sea ice, which presents a significant danger for navigation**.** Compared with the open-water incident rate, the probability of a maritime accident is 19 times higher in the Arctic (Loughnane et al. 1995). Unfortunately, several accidents have occurred in this region in recent years. In this manner, IMO brought to its agenda guidelines for ships that operate in Arctic ice-covered waters in 2002. Afterward, in 2010, the agenda was changed to include Antarctic waters as well. Finally, the development of the regulations from guidelines to binding legal obligations re-emerged on the IMO agenda (Jensen 2016). On 1 January 2017, IMO adopted the Polar Code, aiming to supply safe and environmentally friendly ship operations in both the polar regions (Marine Environment Protection Committee n.d.).

During its development, several concerns from a variety of foundations (International Fund for Animal Welfare (IFAW), Friends of the Earth International (FOEI), World Wildlife Fund (WWF), and Pacific Environment were addressed to include in the Polar Code. However, when the Polar Code was evaluated according to maritime casualties and seasonal sea ice extent, it was found to be insufficient and left much to be desired. Even though the number of maritime activities is predicted to increase in the Arctic, little attention has been paid to the rest of the sea-ice-covered waters that lie beyond the Polar Code Arctic boundary and how this lack of attention affects maritime safety. In this article, we will assess the sea-ice-covered northern waters that are excluded from the Polar Code. Additionally, maritime traffic density in these regions will be evaluated, and suggestions will be made about the actions that can be taken to improve maritime safety.

2 Study area

2.1 Arctic region: differing boundaries

Some definitions of the Arctic region boundaries have emerged in terms of physical, geographical, and ecological characteristics. In this frame, some Arctic Council bodies such as the Arctic Monitoring and Assessment Program (AMAP), Emergency Prevention, Preparedness and Response (EPPR) Working Group, and Conservation of Arctic Flora and Fauna (CAFF) have different boundaries illustrated in Fig. 1 (Arctic Council 2019).

The most intimate definition of the Arctic region is north of 66° 33′N latitude where the polar night and the midnight sun are observed. Another approach at definition involves the region where the average temperature of the warmest month of July temperature is 10 °C (Stonehouse 2001; Przybylak et al. 2003). There is, also, a

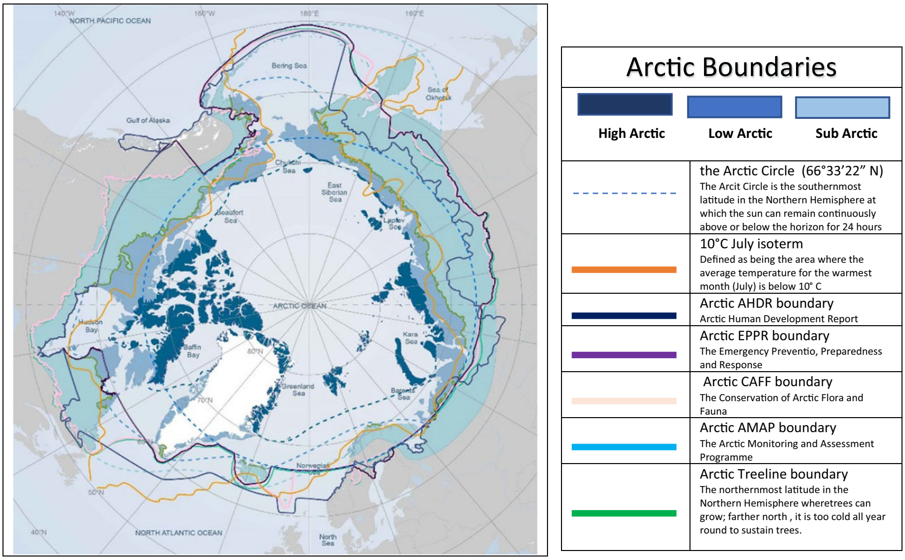


Fig. 1 Arctic boundaries. Source: Grid-Arendal, ADHR, EPPR, NSIDC, AMAP, CAFF

boundary determined by the vegetation, according to which the Arctic is the region where trees do not grow (Walker et al. 2005). Yet another definition pertains to the presence of permafrost (Serreze and Barry 2014).

Boundaries of Arctic Council bodies differ regarding their assessment activities. For the AMAP assessment and recognizing other factors which may be used to define the Arctic marine area, such as Arctic marine biology and sea ice cover, the AMAP marine area to the south of the region also includes the Labrador Sea and Hudson Bay; the Greenland, Iceland, Norwegian, Barents, Kara Sea; and Bering Sea (AMAP 1998).

The marine boundary of the Arctic is based on oceanographic characteristics whereby the warm and less dense waters from the south meet the Arctic Ocean. This region starts approximately at about 63°N in the Canadian shore or 65°N near the coast of Greenland. The warm waters of the Atlantic Current may alter this boundary up to 80°N, west of Spitsbergen, then to the Russian shore (Stonehouse 2001). Recognizing the difficulty of assigning a distinct boundary separating the Pacific water from the Arctic water, the boundary has been arbitrarily drawn across the Bering Strait as the point at which modification is likely to commence (Stonehouse 1989). Defining the Arctic marine boundary by a direct line across the Bering Sea may give rise to a debate as it excludes fundamental areas with comparable environmental characteristics to higher latitudes. For instance, sea ice extends well below 60°N in the Pacific Ocean, while the waters may be ice free in many parts of the Arctic Ocean.

2.2 Polar Code application areas in the Arctic

In the 1980s, different national implementations regarding the structure of vessels operating in polar waters started to be developed. Nevertheless, this created confusion because there was a variety of national regulation (Jensen 2016). On 1 January 2017, the mandatory Polar Code was enforced. The Polar Code amends SOLAS 74 and MARPOL 73/78 with binding regulations. It has been structured into three parts: Introduction, Part I-A (Ship Safety), Part II-A (Pollution), Additional Guidances: Part I-B, and Part II-B. Part I addresses a wide range of safety measures such as operational manual, ship structure, the safety of navigation, life-saving appliances and arrangements, communication, voyage planning, manning, training, etc. Part II addresses pollution from ships (Marine Environment Protection Committee n.d.).

The Working Group on the Development of a Mandatory Polar Code defined the Arctic and Antarctic waters as in the Guidelines for Ships Operating in Polar Waters. However, there are potential conflicts between the Polar Code and Article 234 of the United Nations Convention for the Law of the Sea (UNCLOS). According to Article 234 of UNCLOS, sea ice must be present "most of the year" (Thorén 2014). We think that sea ice extent should also be the determiner of the Polar Code boundary in the Arctic as it is in UNCLOS Article 234. Nevertheless, there is nothing changed in terms of marine boundaries during the development of Polar Code. It has already been defined in existing IMO mandatory instruments, e.g., Antarctic in MARPOL (51). As regards geographical application of Guidelines 2010, "Arctic ice-covered waters" is defined in Section G-3.3 as "[waters] … and thence by the northern shore of the Asian Continent eastward to the Bering Strait and thence from the Bering Strait westward to latitude 60° North as far as Il'pyrskiy and following the 60th North parallel eastward as far as and including Etolin Strait and thence by the northern shore of the North American continent as far south as latitude 60° North…" (Jensen 2007). In Polar Code's Introduction section, there is a definition and a figure which demonstrate the boundaries of the Arctic waters (Fig. 2) (Marine Environment Protection Committee n.d.).

However, some areas which sea ice present and which pose a structural risk to ships have been excluded in Polar Code. For instance, these areas are North Atlantic Ocean to part of the Norwegian Sea along the shore of Norway and the adjacent part of the Barents Sea to the Kola Peninsula in Russia. The exclusion of these areas is partially acceptable because sea ice concentration is not a big deal in these areas. However, sea ice temporarily exists beyond the 60°N part of the Bering Sea, Sea of Okhotsk, Strait of Tartary, and the Sea of Japan. It is important to describe some of these regions to understand the situation briefly.

The Bering Strait is 44 nautical miles wide at the narrowest point, which is between the Bering Sea and the Arctic Ocean. Vessel traffic through the Bering Strait has been increasing steadily and sharing with Arctic wildlife. The growth in shipping operations is expected to continue due to resource development as decreasing sea ice. Bering Strait transit ship number in total was 220 in 2008 and increased to 540 in 2015 (Boylan and Elsberry n.d.). Although shipping activity is low compared with other parts of the world, the capacity to provide aid for vessels in the strait is limited compared with elsewhere (Bering Sea Elders Advisory Group 2011; Communities 2014; McFarland et al. 2018). IMO approved to designate to six two-way shipping lanes to protect the marine environment and the people of the region (Rosen n.d.).

The Bering Sea, a northern extension of the Pacific Ocean, which is over 2 million km^2 is surrounded by Russia, Kamchatka Peninsula, Aleutian Islands, Alaska, and ends in the Bering Strait. Ship traffic through the Bering Sea with the opening of Yamal LNG and the future Arctic LNG 2 facility will see more than 1000

Fig. 2 Maximum extent of Arctic water application. Source: Polar Code, Introduction, Fig. 2

transit large vessels carrying hydrocarbon resources within the next 5 years. In addition to that, there is a large number of smaller non-fishing and fishing vessels. Together with these vessels, there were more than 110,000 individual voyages in the waters between Russia and Alaska in 2014 and 2015 (Humpert n.d.).

The Okhotsk Sea, the northwestern extension of the Pacific Ocean, has an approximately 1.6 million km^2 area and 10,460 km coastline (Alekseev et al. 2006). The Sea of Okhotsk is an economically important region that includes oil and gas fields (Tkachenko 2008). While oil and gas exploration and exploitation are increasing, the possibility of oil spills as well (Miller et al. 2004). Due to the presence of one of the wealthiest fisheries of the world, the fishing industry plays a significant role in the local economy and results in the distribution of fishing fleets from not only Russia and Japan but also other parts of the world (Elferink 1995).

3 Maritime safety and ship accidents caused by sea ice in the high north

According to the Polar Code Introduction section, sources of hazards, especially ice, create a structural risk to ships. Severe weather conditions and low temperatures also affect the working environment and human performance, both of which are crucial. Remoteness, lack of correct hydrographic data, and crew experience are other sources of hazards observed in these areas. Determining the particular level of ice extent is not easy, but it is evident that sea ice temporarily exists beyond the 60°N. Furthermore, weather conditions beyond the 60°N are quite like in the Arctic region (Alekseev et al. 2006).

In challenging the fragile Arctic region, maritime activities are growing as sea ice extent and volume are decreasing. Thus, it is imperative to analyze the maritime incidents caused by sea ice. There are a variety of factors, ranging from humans to the environment, that cause ship accidents, such as the state of the sea, wind, current, weather, and sea ice along the polar waters. Moreover, the melting of ice shelves raises the risks of drifting pack ice. This, together with the factor of the wind can create dangerous icing conditions (Şahin 2015). Sea ice existence and thickness are important factors for navigational performance that the vessel's hull, propeller, and rudder may be damaged under significant forces. On the other hand, the lack of marine infrastructure and accurate charting and the limitations of radio and satellite communications present significant risks of ice damage or getting stuck in the ice, groundings, machinery failures, etc. Compared with the open-water incident rate, the probability of a maritime accident is 19 times higher in the Arctic region (Loughnane et al. 1995).

An analysis of ship accidents in the Arctic over the previous century shows that a majority of casualties were related to sea ice. The cases categorized such as ice floe hit, trapping by ice, and ice jet show the real danger posed by sea ice to shipping (Marchenko 2013). Generally, it is possible to rescue a vessel trapped in ice using modern equipment and technique. However, the problem is time and money involved in conducting that kind of rescue operations. On the other hand, if any oil spills occur, there are serious concerns about how to clean oil-polluted icy waters. Most pollution prevention methods are based on open-water conditions in coastline environments. Emergency Prevention, Preparedness and Response (EPPR) released oil spill response guidance which is specific to the unique climatic and geographic conditions of the polar environment (Owens et al. 1998). Unfortunately, even though many countries surround it, the vast area of the Arctic region is insufficient for emergency preparedness for maritime accidents in the Arctic insufficient (Sakhuja 2014). Thus, while making significant investments to protect the environment, binding rules concerning maritime safety standards must also be developed.

The Protection of the Arctic Marine Environment (PAME)'s comprehensive Arctic Marine Shipping Assessment 2009 (Council 2009) (Fig. 3) demonstrates that the majority of shipping incidents have taken place in the coastal waters. The various colored dots demonstrate the nature of these incidents in the Arctic. On the other hand, when recent marine incidents were studied to identify the cases caused by sea ice beyond the Polar Code application areas, there were too many cases that occurred between the Gulf of Alaska and Northern China coasts/Yellow Sea and between the Labrador Sea and Baltic Sea (LMAlloyds). Some examples of accidents in these regions are given below.

The fishing vessel *Destination* which was 33.5-mt length and 196-gross ton, sank in remote waters 2.6 mi northwest of St. George Island, Alaska, on February 11, 2017. None of the six crew members aboard were found in the accident. According to the US National Transportation Safety Board investigation report, while the exact nature of the accident is unknown because there were no survivors, no witnesses, and no mayday call from the *Destination*, evidence indicates it capsized and sank after an accumulation of ice on the vessel and its fishing gear after encountering forecasted heavy freezing spray conditions (NTSB 2013).

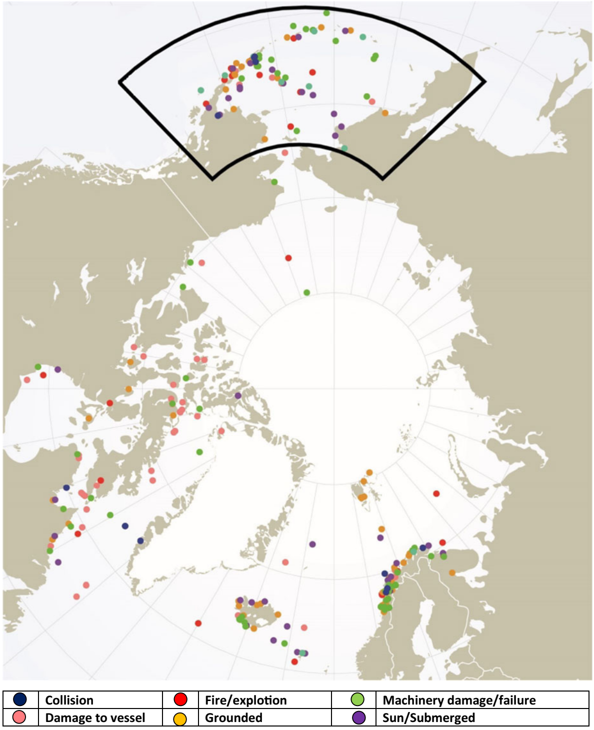


Fig. 3 Shipping incidents in the Arctic. Source: Arctic Marine Shipping Assessment 2009

In December 2010, 10 fishing vessels (675 crew) had been trapped by a vast sheet of drifting sea ice while fishing in Sea of Okhotsk, Sakhalin Gulf. The sea ice was up to 30-cm thick, and its temperature was −22C. The ships needed icebreaking assistance to be rescued. More than 6 h later, nobody was injured, and all the fishermen were rescued (BBC News 2010; Leon 2012). As Far East Shipping Company reported, the rescue operation took a month and cost approximately 5 ml USD. Fortunately, none of the vessels had been damaged. The first vessel had been escorted 23.6 nm, second 62 nm, and third 150 nm. Towing ropes were broken several times due to severe ice conditions (Marchenko 2014).

In December 2013, 6030 GT general cargo ship, *Diomid*, while navigating from Magadan to Vladivostok, drifted to the shore due to adverse weather conditions. The vessel sheltered in Sakhalin Bay and waited for the excellent weather conditions (LMAlloyds 2013).

4 Methodology

The maps of sea ice extent and concentrations in the Arctic and surrounding waters were developed using brightness temperature imagery in the passive microwave wavelengths collected by satellites (Emery and Camps 2017). Satellite remote sensing provides sea ice data to estimate the total extent where sea ice concentration is more than 15%. Data from 1978 to 1987 were collected using the Scanning Multichannel

Microwave Radiometer on board the Nimbus-7 Pathfinder (Nimbus-7 SMMR) satellite and afterward series of Special Sensor Microwave/Imager (SSM/I) instruments used which have been carried onboard Defense Meteorological Satellite Program (DMSP) satellites (Foster et al. 2009). In 2008, the Special Sensor Microwave Imager/Sounder (SSMIS) replaced the SSM/I as the source for sea ice products (Epa and Change Division n.d.). Remote Sensing Systems generates SSM/I and SSMIS data products using a unified, physically based algorithm to simultaneously retrieve the products' season (Kern and Ozsoy-cicek 2018). These instruments also provide data regarding surface temperature and surface water which helps to determine the start and end dates of the melt. The National Snow and Ice Data Center (NSIDC)'s data are derived from satellite imagery collected and processed by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). However, some of the instruments past its lifetime, and some of these instruments failed that significantly increased the risk of a gap in coverage in the next years (Gerland et al. 2019). On the other hand, NASA Goddard produces sea ice thickness estimates based on data from the European Space Agency CryoSat-2 radar altimeter. While direct estimates of sea ice thickness can be obtained from airborne and satellite systems using laser and radar altimeters, as well as from submarines using sonar, these data sources cannot provide sufficiently long and consistent time series to be used as an indicator (Gerland et al. 2019).

Traffic Density Maps are a simple and effective way of displaying vessel movement patterns, which contribute to a better understanding of maritime traffic. The Automatic Identification System (AIS) produces massive amounts of maritime data daily. It transmits vessel information, such as location, speed, and heading via VHF to other vessels and terrestrial or satellite receivers. Terrestrial receivers are land-based stations that receive messages from vessels within their line of sight, while Satellite receivers do not require line of sight. The working principle of both receivers is similar, by transmitting the received AIS message to a computer for data storage, processing, and visualization. Several studies attempt to understand maritime behavior by generating density maps for supporting decision-making (Willems et al. 2009; Tsou 2010). The main shipping lanes and what type of vessels navigating on which routes can be seen via the created density maps. Most of the existing methodologies are based on the same approach to generate density maps where the area to be monitored is divided into cells to create a spatial grid. This method rebuilds the track of each type of vessel from the recorded positions and counts how many routes are crossing each cell of the grid during the selected time period (Zissis et al. 2020).

The archived monthly and daily concentration and extent data are available on the NSIDC website, and Traffic Density Maps are available on the Marine Traffic website. We analyze, in particular, the Bering Sea and Sea of Okhotsk sea ice extent data provided via satellite records from 1978 to 2019, based on the NSIDC datasets, and the density of maritime traffic provided by the Marine Traffic.

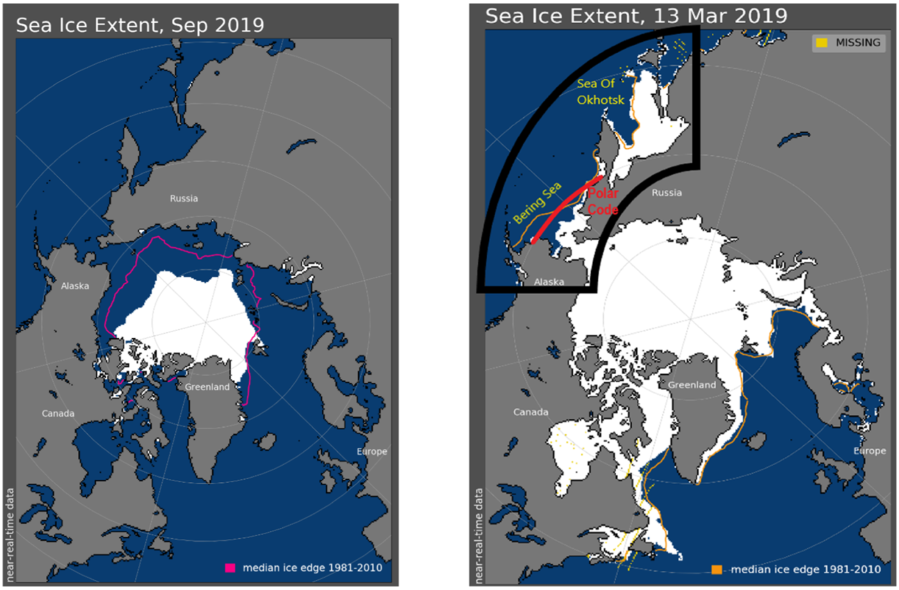
5 Results

The Arctic sea ice extent reaches its annual minimum in September that has decreased approximately 33% since 1979, and it is estimated that it will be ice free during the summer months of 2050 (Gerdes and Köberle 2007; Screen and Williamson 2017).

According to NSIDC, this year's minimum Arctic sea ice extent averaged 4.32 million km^2 (Fig. 4a. This extent is 2.09 million km^2 below the 1981 to 2010 average. Arctic sea ice extent reached its maximum for 2019 at 14.78 million km^2. Furthermore, it is 860,000 km^2 below 1981 to 2010 average maximum (Fig. 4b) (Serreze et al. 2019). In the northernmost part of the world, the seawater freezes during the winter months (min. extent in September to max. extent in March) and melts during the summer, but in some areas, sea ice cover is retained throughout the year. Moreover, sea ice can exist as far south as 38 °N, Bohai Bay, China (Liu and Horton 2016). In this study, we focus on beyond the Polar Code boundary of the Arctic, the Bering Sea, and the Sea of Okhotsk. Thus, the sea ice extent data is evaluated, which is provided via satellite passive microwave records from 2018 to 2019 by the NSIDC. In Fig. 4b, median sea ice edge 1981–2010, March 2019 sea ice extent, and Polar Code boundary are showed.

In March 2019, sea ice coverage was far below average in the Bering Sea, but it was slightly above average in the Sea of Okhotsk (Fig. 5b). Given are some figures (Fig. 5 a–f) to illustrate the sea ice extent in the Bering Sea, Sea of Okhotsk, and the Sea of Japan over the last 2 years, spanning the months December to May.

In Fig. 6 a–b, the graphs show Bering Sea and Sea of Okhotsk sea ice extent data for previous years. Although the maximum sea ice extent in the Bering Sea and the Sea of Okhotsk shows significant interannual variations because of changes in regional air temperature, wind, and sea surface temperature, the maximum sea ice extent in these regions follows a long-term trend of reduction from 1979 to 2019 (Fig. 7). The annual ice period lasts for an average of 260 days in the northwest and for 190–200 days in the north and the Sakhalin coasts (Alekseev et al. 2006).



a Arctic sea ice extent at minimum for 2019 **b** Arctic sea ice extent at maximum for 2019

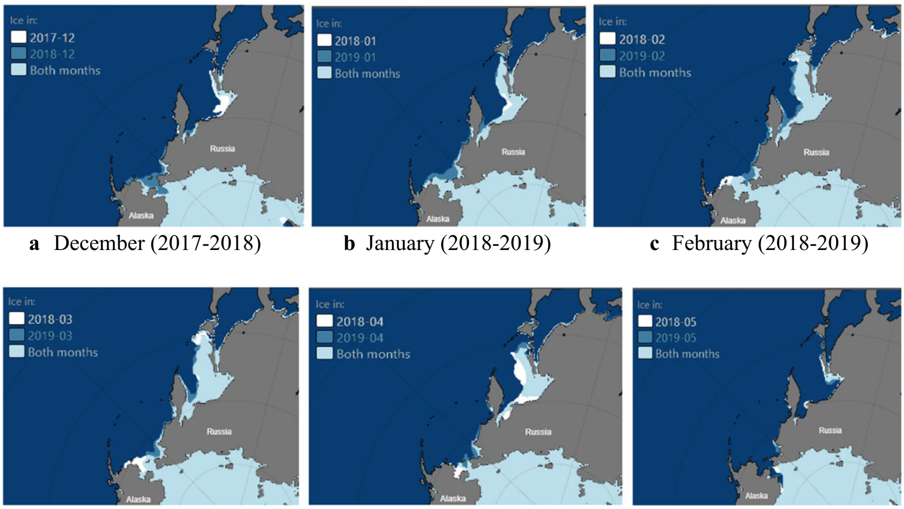
Fig. 4 **a** Arctic sea ice extent at minimum for 2019. **b** Arctic sea ice extent at maximum for 2019. Source: NSIDC at the University of Colorado Boulder

The northern part of the Okhotsk Sea is greatly influenced by the Arctic climate, and its average January temperature ranges between 8 and −32 °C. The cold period lasts 210–220 days in the north of the region. In general, the surface water temperatures of −1.0 to −1.8 °C in February and March sea ice extent can cover up to 99% of the water area during severe winters and, in milder winters, about 65%. The sea ice form is both stagnant and drifting, which is comparable with the Arctic ocean (Alekseev et al. 2006). Time series of sea ice extents in the Sea of Okhotsk and the Bering Sea from March 1979 to 2019 are showed in Fig. 7.

5.1 The density of ship traffic in the region

The availability of instant information from ships is provided by the Automatic Identification System (AIS). Following the SOLAS rules set by IMO, AIS systems are compulsory in any cargo ship > 500 GT transiting within national waters, all passenger ships, and all vessels > 300 GT transiting international routes (Marine Traffic n.d.).

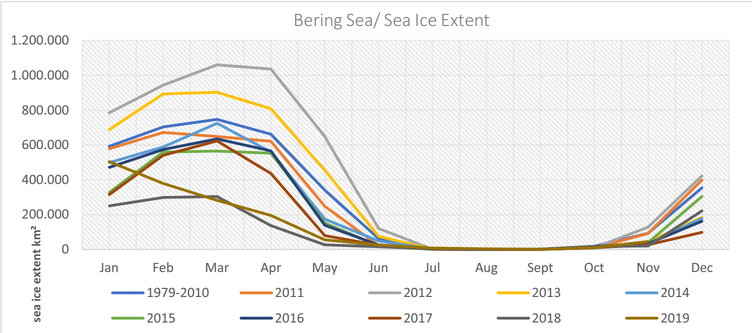
In 2014, Arctic shipping was found to occupy between 57 and 80% of ice-free waters (Eguíluz et al. 2016). In the Arctic, shipping will continue to increase as the ice coverage decreases (Smith and Stephenson 2013; Stephenson et al. 2013). Density maps of the regions are illustrated in Fig. 8, taken from marine traffic application, which is widely used by mariners, and supply a variety of data related to shipping activities. It is based on the AIS track of vessels (Marine Traffic n.d.). The colors of lines show routes according to vessel type as in Fig. 8 a–h, the red for tankers, light green for cargo vessels, blue for passenger ships, orange for fishing vessels, purple for pleasure crafts, dark green for container ships, yellow for gas carriers, and light blue for tugs and special craft.



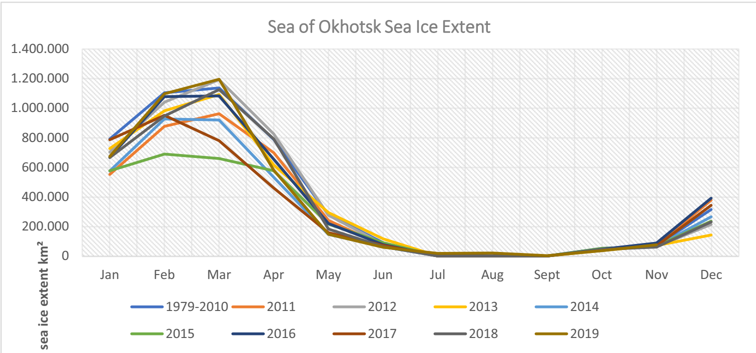
a December (2017-2018) **b** January (2018-2019) **c** February (2018-2019)

d March (2018-2019) **e** April (2018-2019) **f** May (2018-2019)

Fig. 5 **a-f** Sea ice extent in the Bering Sea, Sea of Okhotsk, and the Sea of Japan over the last 2 years



a Bering Sea monthly average sea ice extents from 1979 to 2019.



b Sea of Okhotsk monthly average sea ice extents from 1979 to 2019.

Fig. 6 **a** Bering Sea monthly average sea ice extents from 1979 to 2019. **b** Sea of Okhotsk monthly average sea ice extents from 1979 to 2019

There is a metric bar that the numbers refer to distinct vessels daily and count positions per square km. The numbers on the bottom right indicate the number of routes within every 382 km2. The "colder" colors show less dense routes. Moreover, the "hotter" the colors are, the higher the number of routes. These ship density maps are created based on the 2017 AIS datasets (Marine Traffic n.d.).

As seen in Fig. 8 a–h, according to vessel types cargo vessels, tankers, and fishing vessels, density for the total year rate is quite high. There are a large number of routes preferred in the areas focused on in this study. No significant accidents have occurred in these regions, but it is obvious that there is a high risk depending on a large number of ships. On the other hand, the ship sizes also matter. Figure 9 a–d demonstrate the density of ships according to their size that are categorized into four different types. Figure 9a shows small size of vessels which are below 500 GT, and the other figures are medium size (500 GT–25 K), large size (GT 25–60 K), and very large size (GT 60 K>) of vessels, respectively.

These figures provide essential tips. As it is seen, while small and mainly medium size of ships operate more often in these areas, a large and extensive size of ships slightly operate beyond the Aleutians Islands. When we take ship sizes into account, which must comply with SOLAS, Fig. 9b is vital to analyze the Polar Code application areas and the size of ships.

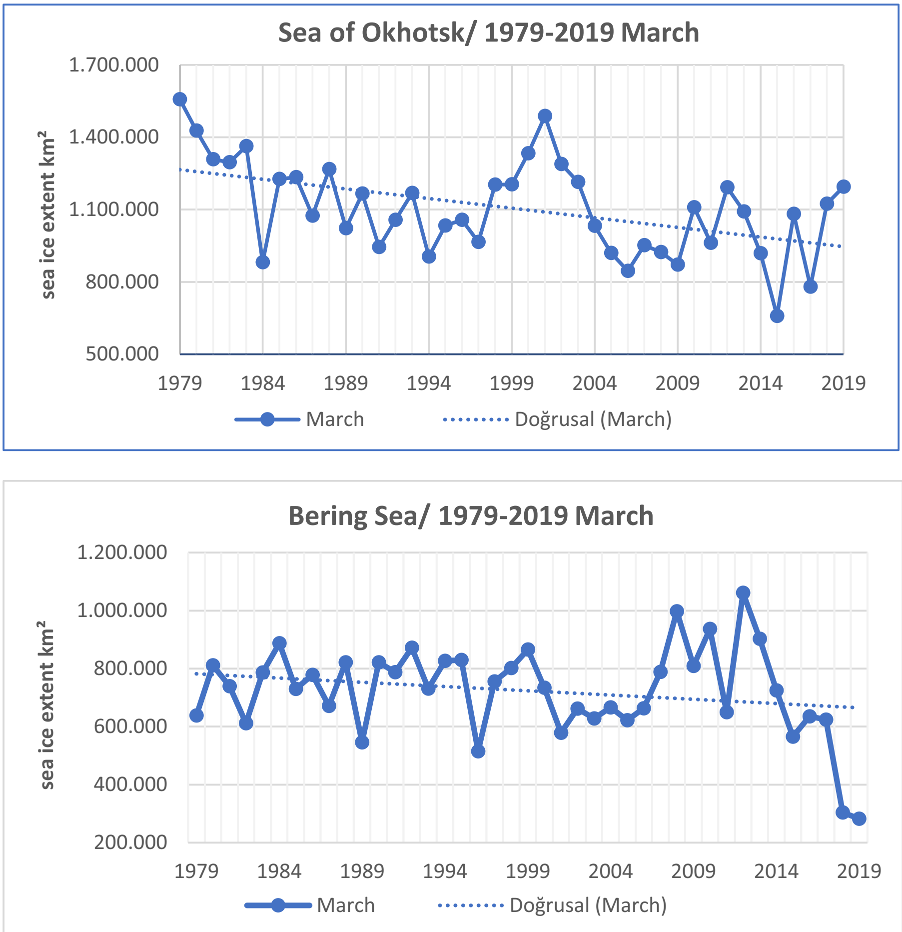


Fig. 7 Time series representation of March sea ice extents in the Sea of Okhotsk and the Bering Sea from 1979 to 2019

6 Discussion and conclusion

The decreasing sea ice extent in Arctic waters due to global climate change offers opportunities by opening Arctic waters as shipping lanes, fishing ground, and potential cruise tourism destination with the potential risks for more incidents. In this study, we compared the boundaries of Arctic Council bodies regarding their assessment activities to the Polar Code implementation areas. Therefore, we investigated the maritime safety issues and ship accidents caused by sea ice in the 60°N and beyond the 60°N. Furthermore, we examined the sea ice extent changes in the Northern Hemisphere based on NSIDC datasets. After examining the 41-year satellite records of sea ice extent in the Arctic area, including the Bering Sea and the Sea of Okhotsk, our analysis concluded that the interannual variations of sea ice extent resulted in outcomes that were a long-term trend of reduction 1979 to 2019. Although previous findings indicated that trend of reduction outcomes, our study followed a specific approach concerning

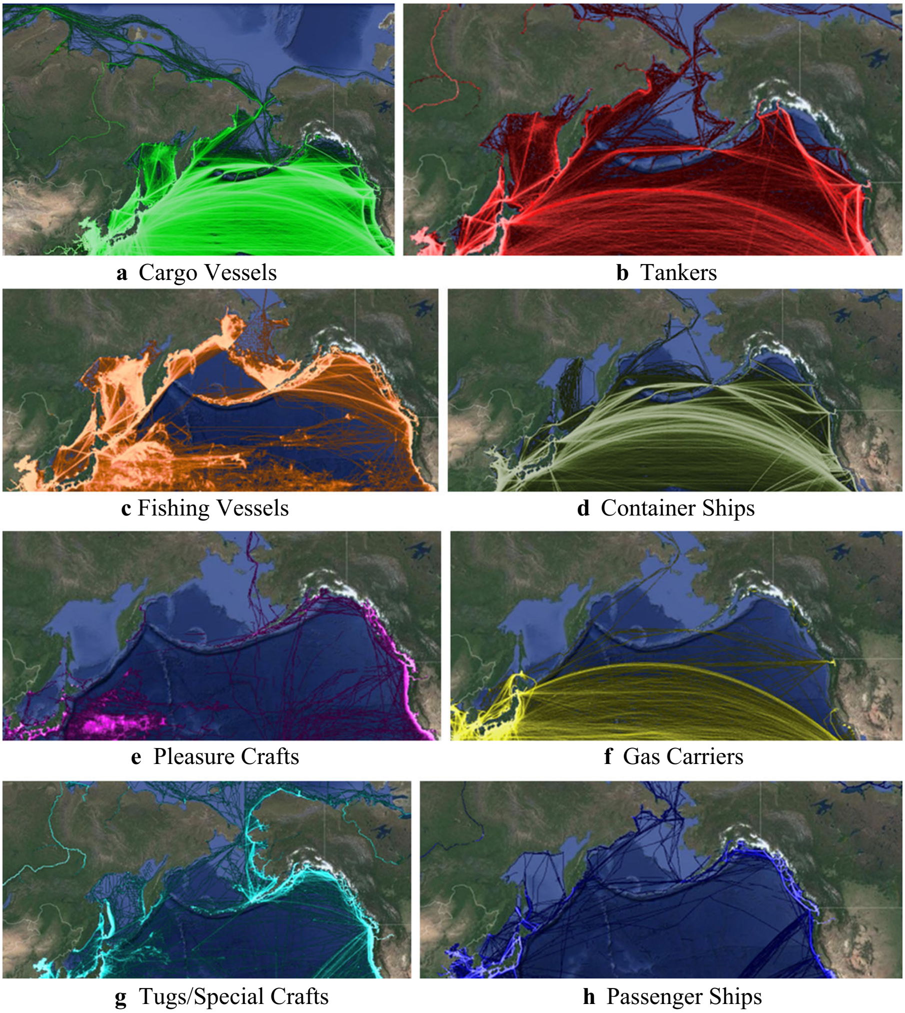


Fig. 8 Traffic density maps by vessel types

maritime traffic density and maritime safety than those in major studies conducted previously. The risk level regarding maritime activities within polar waters differs according to location, season, temperature, weather, sea conditions, remoteness, ice coverage, type of ice, etc. The measures to address specific hazards in polar waters are included in the Polar Code, which is imposed in 2017. However, this is an important finding in the understanding of the Polar Code that it does not cover all sea ice–covered areas as specifying hazards in the Introduction section. Thus, the present findings confirm that Polar Code's application boundary might be modified in the Pacific according to the sea ice period and the sea ice extent records of the last decades. Additionally, in a long period of sea ice extent in specific areas, if ship traffic density and recent maritime incidents are taken into account, the development of the Polar Code would be beneficial. Although there have been few incidents that there is a considerable risk of oil spills in these regions due to rising oil extraction operations, the potential consequences of an accident are considerable when the ecological and

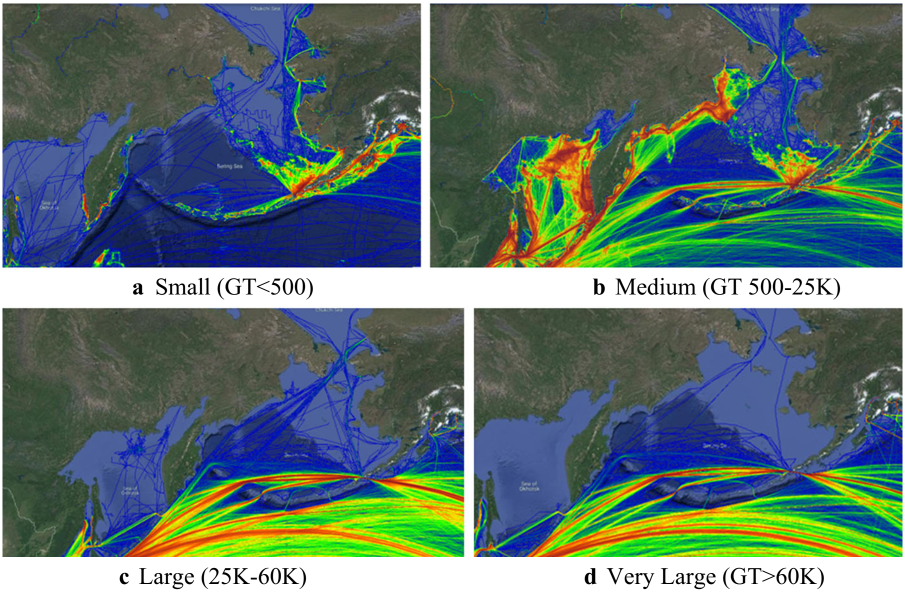


Fig. 9 Traffic density maps by vessel sizes beyond the Polar Code region

economic importance of the Arctic region is taken into account. This assumption might be addressed in future studies. Future researchers also should consider investigating the impact of decreasing sea ice extent and increasing maritime activities in these regions. Regardless, our research points to the need for revision of the boundaries of the Polar Code to cover the part of the Bering Sea and the Sea of Okhotsk to sea ice edge 1981–2010 line instead of an arbitrary line in order to prevent terrible consequences.

Acknowledgments This study was carried under auspices of Presidency of Republic of Turkey, supported by the Ministry of Industry and Technology, and coordinated by TUBITAK MRC Polar Research Institute.

References

Alekseev A, Baklanov P, Arzamastsev I et al (2006) Sea of Okhotsk: GIWA Regional assessment 30:71

AMAP (n.d.) Arctic boundaries (physical). https://www.amap.no/documents/doc/arctic-boundaries-physical/380. Accessed 6 Nov 2019

AMAP A (1998) Assessment report: Arctic pollution issues. Arct Monit Assess Program (AMAP), Oslo, Norw 12:859

Arctic Council (2019) Working groups - Arctic council. In: Arct. Counc. Homepage. https://arctic-council.org/index.php/en/about-us/working-groups. Accessed 5 Nov 2019

BBCnews (2010) Ten ships, 600 crew trapped in frozen Sea of Okhotsk - BBC news. In: BBC News. https://www.bbc.com/news/world-europe-12099928. Accessed 7 Nov 2019

Bering Sea Elders Advisory Group (2011) The Northern Bering Sea: our way of life. A Proj Bering Sea Elders Advis Group, with Support from Alaska Mar Conserv Counc 54

Boylan BM, Elsberry DT Increased maritime traffic in the Arctic: implications for international cooperation and security

Communities I (2014) Arctic vessel traffic in the Bering Strait

Council A (2019) A quick guide to the Arctic Council

Council A (2009) Arctic marine shipping assessment 2009 report

Eguíluz VM, Fernández-Gracia J, Irigoien X, Duarte CM (2016) A quantitative assessment of Arctic shipping in 2010–2014. Sci Rep 6:30682
Elferink AGO (1995) Fisheries in the Sea of Okhotsk high seas enclave-the Russian Federation's attempts at coastal state control. Int J Mar Coast L 10:1–18
Emery W, Camps A (2017) Introduction to satellite remote sensing: atmosphere, ocean, land and cryosphere applications. Elsevier
Epa U n.d.Change Division C (n.d.) Technical documentation: Arctic Sea Ice
Foster JL, Hall DK, Kelly REJ, Chiu L (2009) Seasonal snow extent and snow mass in South America using SMMR and SSM/I passive microwave data (1979–2006). Remote Sens Environ 113:291–305
Gerdes R, Köberle C (2007) Comparison of Arctic Sea ice thickness variability in IPCC climate of the 20th century experiments and in ocean–sea ice hindcasts. J Geophys Res Ocean 112
Humpert M IMO (n.d.) Approves new shipping corridors in Bering Sea to improve safety. In: highnorthnews https://www.highnorthnews.com/en/imo-approves-new-shipping-corridors-bering-sea-improve-safety. Accessed 7 Nov 2019
IMO (2011) Development of a mandatory code for ships operating in polar waters. In: IMO sub-committee on ship design & equipment, de 55/12/X, 55th session, Agenda item 12. IMO, London
Jensen Ø (2016) The International Code for Ships Operating in Polar Waters: finalization, adoption and law of the sea implications. Arct Rev Law Polit 7:60–82. https://doi.org/10.17585/arctic.v7.236
Jensen Ø (2007) The IMO guidelines for ships operating in Arctic ice-covered waters: from voluntary to mandatory tool for navigation safety and environmental protection
Kern S, Ozsoy-cicek B (2018) Remote sensing
Leon W (2012) Russian emergency services rescue 675 fishermen stranded on a sheet of ice drifting out to sea | daily mail online. In: Dailymailnews. https://www.dailymail.co.uk/news/article-2123696/Russian-emergency-services-rescue-675-fishermen-stranded-sheet-ice-drifting-sea.html. Accessed 7 Nov 2019
Liu J, Horton RM (2016) Arctic Sea ice and its role in global Change. In: Our Warming Planet. World Scientific, pp 295–307
LMAlloyds (2013) Recent Incidents Archive. In: lmalloyds. http://www.lmalloyds.com/lma/underwriting/marine/JHC_Nav_Limits/Recent_Incidents_Archive.aspx. Accessed 7 Nov 2019
Loughnane D, Judson B, Reid J (1995) Arctic tanker risk analysis project. Marit Policy Manag 22:3–12
Marchenko N (2013) Navigation in the Russian Arctic: sea ice caused difficulties and accidents. In: ASME 2013 32nd international conference on ocean, offshore and arctic engineering. American Society of Mechanical Engineers Digital Collection
Marchenko N (2014) 22nd IAHR international symposium on ice
Marine Environment Protection Committee (n.d.) MEPC 68/21/Add.1, Annex: International Code for Ships Operating in Polar Waters (Polar Code). 1:3–56
Marinetraffic MarineTraffic(n.d.): Global Ship Tracking Intelligence | AIS Marine Traffic. https://www.marinetraffic.com/en/ais/home/centerx:176.7/centery:61.8/zoom:3. Accessed 5 Nov 2019
McFarland HR, Eicken H, Thoman R, et al (2018) Bering Strait: an overview of winter 2018 sea ice conditions
Miller AJ, Chai F, Chiba S, Moisan JR, Neilson DJ (2004) Decadal-scale climate and ecosystem interactions in the North Pacific Ocean. J Oceanogr 60:163–188
NTSB (2013) National Transportation Safety Board Railroad Accident Brief: Metro-North Railroad Derailment. pp 1–24
Owens EH, Solsberg LB, West MR, McGrath M (1998) Field guide for oil spill response in Arctic waters. Emergency Prevention, Preparedness and Response Working Group (EPPR)
Przybylak R, Sadourny R, Mysak LA (2003) The climate of the Arctic. Springer
Rosen Y (n.d.) With marine traffic growing, international shipping agency approves US-Russia plan for Bering Strait shipping lanes - ArcticToday. https://www.arctictoday.com/marine-traffic-growing-international-shipping-agency-approves-us-russia-plan-bering-strait-shipping-lanes/. Accessed 7 Nov 2019
Şahin B (2015) Risk assessment and marine accident analysis in ice-covered waters
Sakhuja V (2014) The polar code and arctic navigation. Strateg Anal 38:803–811
Screen JA, Williamson D (2017) Ice-free Arctic at 1.5° C? Nat Clim Chang 7:230
Gerland S, Barber D, Meier W, Mundy CJ, Marika Holland SK, Li Z, Michel C, Donald K, Perovich TT (2019) Essential gaps and uncertainties in the understanding of the roles and functions of Arctic Sea ice. Environ Res Lett 14
Serreze MC, Barrett AP, Crawford AD, Woodgate RA (2019) Monthly variability in Bering Strait oceanic volume and heat transports, links to atmospheric circulation and ocean temperature, and implications for sea ice conditions. J Geophys Res Ocean 2019JC015422. https://doi.org/10.1029/2019JC015422

Serreze MC, Barry RG (2014) The Arctic climate system. Cambridge University Press
Smith LC, Stephenson SR (2013) New trans-Arctic shipping routes navigable by midcentury. Proc Natl Acad Sci 110:E1191–E1195
Stephenson SR, Smith LC, Brigham LW, Agnew JA (2013) Projected 21st-century changes to Arctic marine access. Clim Chang 118:885–899
Stonehouse B (2001) Polar environments. Encycl ecotourism 219
Stonehouse B (1989) No title. Springer US
Thorén AM (2014) Article 234 UNCLOS and the Polar Code-the interaction between regulations on different levels in the Arctic region
Tkachenko G (2008) Estimation and development of oil-gas resources in the Okhotsk Sea basin and sustainable development in Northeast Asia. Energy Environ Slav Eurasia Towar Establ Netw Environ Stud Pan-Okhotsk Reg 67
Tsou M-C (2010) Discovering knowledge from AIS database for application in VTS. J Navig 63:449–469. https://doi.org/10.1017/S0373463310000135
Walker DA, Raynolds MK, Daniëls FJA, Einarsson E, Elvebakk A, Gould WA, Katenin AE, Kholod SS, Markon CJ, Melnikov ES, Moskalenko NG, Talbot SS, Yurtsev BA, The other members of the CAVM Team (2005) The circumpolar Arctic vegetation map. J Veg Sci 16:267–282
Willems N, Van De Wetering H, Van Wijk JJ (2009) Visualization of vessel movements. In: Computer Graphics Forum. Wiley Online Library, pp 959–966
Zissis D, Chatzikokolakis K, Spiliopoulos G, Vodas M (2020) A distributed spatial method for modeling maritime routes. IEEE Access 8:47556–47568