Navigating Arctic Waters
A Summary of Ship Activities and Ice-Ship Interactions in Alaskan Waters

Peel, Grant J; Gedikli, Ersegun D; Hendrikse, Hayo

Publication date
2023

Document Version
Final published version

Published in
Proceedings of the 27th International Conference on Port and Ocean Engineering under Arctic Conditions

POAC'23
Glasgow, United Kingdom

Proceedings of the 27th International Conference on
Port and Ocean Engineering under Arctic Conditions
12-16 June 2023, Glasgow, United Kingdom

Navigating Arctic Waters: A Summary of Ship Activities and Ice-Ship Interactions in Alaskan Waters

Grant J Peel[1], Ersegun D Gedikli[1], Hayo Hendrikse[2]
[1] Department of Ocean and Resources Engineering, University of Hawaii at Manoa, Honolulu, HI USA, 96822
[2] Department of Hydraulic Engineering, Delft University of Technology, Delft, the Netherlands

ABSTRACT

Climate change is affecting global weather patterns, but nowhere is this more apparent than in the Arctic. The Arctic is an extreme environment going through rapid climate change, resulting in the opening of new shipping lanes and leading to less multiyear ice formation. This increases the risk of collision with the sea ice making it difficult to make long term voyage plans based on sea ice predictions. The Automatic Identification System (AIS) provides important services for marine domain awareness. For safe and effective ship traffic management and the development of new artificial intelligence (AI) marine algorithms, precise AIS readings for hull size and type are typically required. In this paper, we provide a summary of ship activities as well as relevant ice information in Alaskan waters that may result in ice-ship interactions and discuss them. AIS ship data was used to determine the ship speed distribution in different areas in the Alaskan waters. Ship movement in ice infested regions was compared with sea ice data from the Copernicus Reanalysis Products and sea ice thickness was estimated using empirical equations to identify potential ship-sea ice interactions. Data from 2015 to 2020 was analyzed to determine if there is an increase in maritime activity that can be linked to a decline in sea ice extent in Alaskan waters. The AIS data was also sorted by ship hull types to see how the different sectors of the Alaskan maritime industry are changing over time in ice-covered areas.

KEY WORDS : Ice-ship interactions; Alaska; Sea ice; Maritime activities; AIS

BACKGROUND

Automatic Identification System (AIS) is a radio-based system used to track and monitor vessel movements. It is mandated by the International Maritime Organization (IMO) in international waters for all vessels over 300 gross tons engaging in an international transit and by the US Coast Guard in US waters for all commercial vessels 65 feet or longer and all towing vessels 26 feet or longer to carry and transmit AIS information to other vessels and shore-based monitoring stations. AIS data includes information such as the vessel's position, course, speed, and identification information. This data is transmitted via VHF radio waves and can be received by satellite or ground-based stations.

AIS data provides a wealth of information on vessel traffic, including vessel location, speed, and course. It can be used to identify high traffic areas, detect potentially hazardous situations, and support effective maritime management. AIS data is often used to monitor vessel movements, identify patterns of behavior, and enforce regulations. It can also be used to support search and rescue operations and to provide valuable information in the event of an accident or incident at sea [1]. It is frequently used in cold regions for safe navigation, to inform ice-structure interaction modeling, and decision making, among other things. However, while much research is done for the Baltic Sea[2][3][4][5] and the Northern Sea Route, little research is done for Alaskan waters.

Despite its benefits, AIS data alone may not be sufficient to fully understand vessel behavior in areas with challenging navigational conditions, such as Alaskan waters[6]. Factors such as sea ice, narrow channels, and strong currents can significantly impact vessel movements and behavior. Therefore, combining AIS data with other sources of information, such as satellite-based remote sensing, can provide a more comprehensive understanding of vessel traffic patterns and environmental conditions [7] [8].

Satellite-based remote sensing techniques, such as those used by the Copernicus satellite system, have enabled us to collect large amounts of sea ice data, including information on ice extent, thickness, and concentration. By combining AIS data with sea ice data from the Copernicus missions, we can gain a better understanding of vessel behavior in challenging navigational conditions and support the safe and sustainable use of Alaskan waters.

The framework that was developed to identify potential ice-ship interactions is based on the combination of ice concentration and ship positions in Alaskan waters. This framework uses satellite-based remote sensing to collect information on ice concentration, and AIS data to track vessel movements. By combining this information, the framework can identify areas of high ice concentration where vessels are present, and assess the potential for ice-ship interactions. This type of framework can be used to support effective decision-making around vessel routing and operations in areas with challenging navigational conditions.

DATA SOURCES

The AIS data was obtained from the Marine Cadastre [9] website which is a collaborative effort between the National Oceanic and Atmospheric Association (NOAA), the Bureau of Ocean Energy Management (BOEM) and the US Coast Guard (USCG). The data obtained was all of the AIS data for the territorial waters of the United States which was collected through a network of AIS ground station receivers and satellites. The AIS system is based on the registered Maritime Mobile Service Identity (MMSI) number which is a unique nine-digit number assigned to a vessel’s radio equipment. As the MMSI number is not tied directly to the vessel’s hull like the International Maritime Organization (IMO) number, but rather the radio the MMSI number does not always transfer with the sale of the vessel and so it is an imperfect method of identifying unique vessels throughout time. The AIS data consists of 15 variables, including ship identification information such as the MMSI number, vessel name, call sign, and IMO number. It also contains vessel characteristics, such as length, beam, draft, registered vessel type, and transceiver class. In addition, the data includes voyage information, such as cargo registration and voyage status, as well as trip information such as time, latitude, longitude, speed over ground (SOG), course over ground (COG), and heading. The vessel characteristics, ship identification information, and voyage information are input by the vessel's owners/operators, and their recording requirements may vary depending on where the vessel is registered and operating. As a result, some of these variables may not be available for all vessels in the data set.

The Ice Concentration data was obtained from the Copernicus Climate Change Service [10]. The dataset consists of 2 different products that report the daily sea ice concentration in the arctic based on satellite imagery. Prior to 2017 the data is from the European Space Agency Climate Change Initiative (ESA CCI) medium-resolution data from Advanced Microwave Scanning Radiometer Earth Observing System (AMSR-E/AMSR2) missions. After 2017 the data was from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Ocean and Sea Ice Satellite Application Facility (OSI SAF) course-resolution data from the Special Sensor Microwave Imager/Sounder (SSMIS) mission. Both of these products have the same grid resolution (25 km) but the sensors on the AMSR missions had a more refined spatial resolution than the SSMIS mission. This means that the AMSR product had a much more detailed view of the sea ice cover then the SSMIS product, particularly in the marginal ice zone [10].

METHODS

Dealing with such large data sets, 1.74 terabytes of AIS data and 67.2 gigabytes of Sea Ice data, requires limiting the data using multiple layers of filters(i.e. limiting the data geospatially and setting minimum ice concentration thresholds). The AIS data and the Copernicus data was limited spatially from the latitudes 53º to 75º North and longitudes 180º to 120º West so that the framework had the same base starting geography (see Fig. 1). The AIS systems continuously updates when the vessels electronics systems are powered on, which leads to a lot of data points where the vessel is not underway, be it moored to the dock or at anchor. To filter out these points when the vessel wasn't moving under its own power, a minimum speed filter of 3 knots was applied to the recorded Speed Over Ground (SOG) in the AIS data, and then all the data was binned and stored by month. This initial filter reduced the size of the data files from the original 1.74 TB down to 4.17 GB or .24% of the size of the total data.

These limited AIS and Sea Ice concentration monthly data files were then entered into our framework. The framework utilizes the UTM Grid Zones, a system that divides the earth into 60 Longitudinal zones each 6º wide and 20 Latitude zones each 8º tall (Note that this system does not include the poles above 84º N or below 80º S). Using the 7 horizontal longitude zones 1 through 7 and 4 vertical latitude zones U to X, the framework first identifies which of the 28 zones, which can be seen in Figure 1, all the AIS and Ice concentration data points are in. The framework then goes through zone by zone and identifies if there were ships in that zone that month and also ice concentration above the specified limit (ice concentration > 30,60,90 percent respectively). If both of those conditions are met, the framework checks to see if any potential ice ship interactions above the limit occurred.

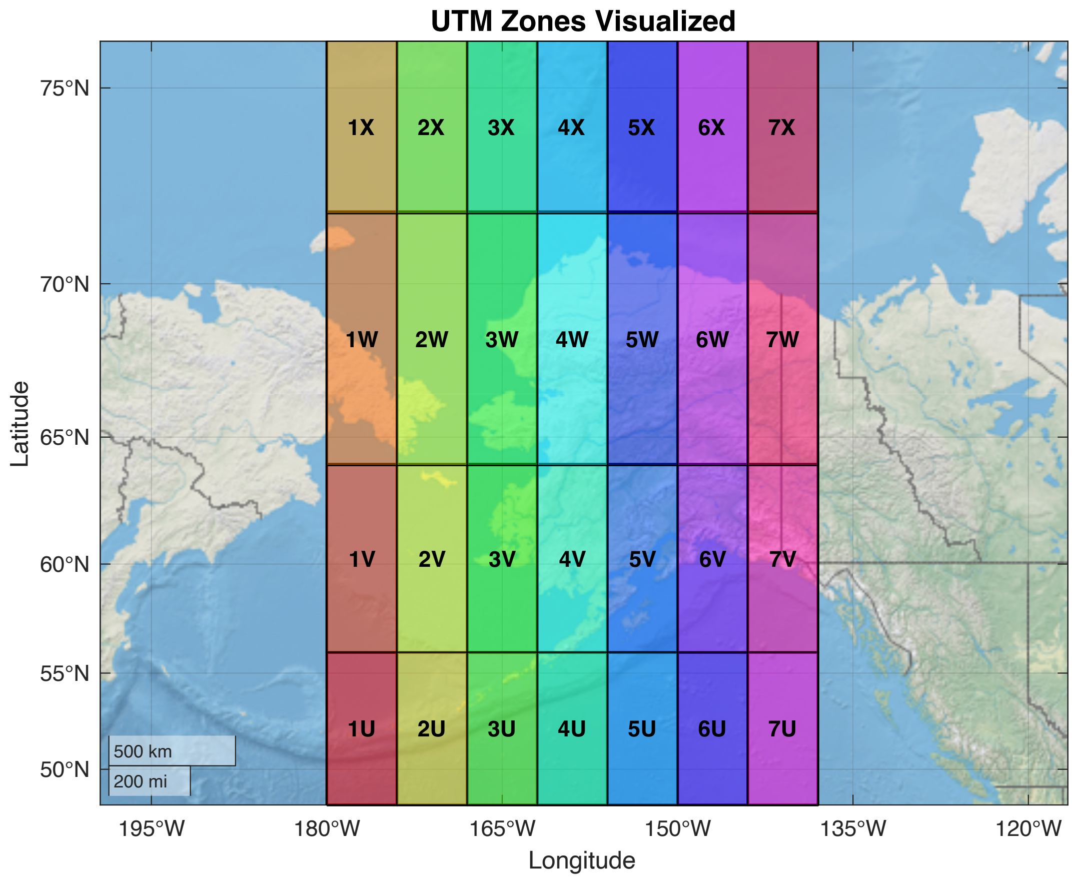

Figure 1. A visual depiction of the UTM Zones utilized in the Framework and their color coding for the figures

The lowest latitude where the ice concentration is above the minimum specified value for the month is identified, and then the indices of all the AIS points above the minimum ice line are identified. As the Ice Concentration data is binned daily, we next use the index of saved points to identify the day each potential interaction occurred. With the ship data limited to points worth comparing, the remaining points are stepped through and the closest Copernicus grid point for ice concentration is identified. If that points ice concentration is above the minimum specified value then the AIS data for that point is kept along with the ice concentration and some general information from the framework. The framework was run at 30, 60 and 90 percent ice concentration to compare the differences in ship distributions in the various ice conditions.

The next step was analyzing the framework output at different ice concentration limits, which involved taking all the unique MMSI numbers identified in the 30 percent ice concentration framework run and researching the individual ships. Through this research it was discovered that many of the 568 unique identified MMSI numbers were not necessarily marine vessels. There were points that were found over land, MMSI numbers registered to aircraft and a large amount of MMSI numbers that only occurred a few times over the 6 years of data. It became clear that further filtering was needed to eliminate some of the erroneous framework results. It was clear that categorizing the different ships was an important factor in the analysis, so one of the filter conditions was that the vessel had to have a defined Vessel Type Code [11] for at least one of its occurrences. Another filter condition was based on the SOG. To eliminate the aircraft all MMSI numbers with an occurrence with the SOG over 50 knots was eliminated and any MMSI numbers without an occurrence with the SOG under 25 knots was also eliminated. The final filter eliminated all the MMSI numbers with less than 10 occurrences. This reduced the number of unique MMSI numbers from 567 to 242 for the 30 percent ice concentration run, 329 to 105 for the 60 percent ice concentration and 136 to 5 for the 90 percent ice concentration.

It is important to note that there were some corrections made to the vessel types based on the research done. All of the vessels with ‘CG’ in the vessels reported names were assigned to the ‘US Coast Guard/Military’ category, along with the ‘Sir Wilfred Laurier’ and ‘Admiral Makarov’. The following vessels were changed to the ‘Fishing’ category; ‘Farrar Sea’, ‘Gulfwinds’, ‘Lady Helen’, ‘Roberta M’, ‘Rolfy’, ‘Seamac’, ‘Grace C’, ‘Pacific Star’, ‘SBS Provider’, ‘Westward Wind’, ‘Tempest’, ‘Dolphin’, ‘Eastern Wind’, ‘Hallo Bay’ and ‘Eastern Hunter’. The following vessels were designated as the ‘Tug or Tow’ category; ‘Aiviq’, ‘Big Dipper’, ‘Camden Bay’, and ‘Fireweed’. The ‘David Thompson’ and the ‘Sikuliaq’ were redesignated as ‘Research/Law Enforcement’. Finally the ‘Camai’ and the ‘Nunaniq’ were redesignated as ‘Cargo/Supply Vessel’.

It is important to note that one of the most important parameters in ice-structure interactions is the ice thickness which helps us to develop methods to estimate loads on structures and ships. The same information can also be used to estimate the ice resistance. For a comprehensive overview see Erceg and Ehlers (2017)[12]. Therefore, the next step is to calculate the ice thickness using the updated Zubov equation [13], [14], which factors in air temperature, wind speed, and ocean temperature. This equation assumes that the ice is in thermal equilibrium with the surrounding water, and therefore the heat flux through the ice is constant. Although the Zubov equation is a useful tool for estimating ice thickness, it should be noted that it is based on empirical data and may not always provide accurate results.

As a follow-up to this work, we plan to obtain ice thickness data at high-density ship locations in Alaskan waters. Using the empirical equation proposed and validated against experiments by Huang et al. (2021, 2022)[15] [16], we will integrate the framework with ice resistance and develop a cost-benefit analysis for ice-going ships in Alaskan waters. Additionally, we are working on AIS data from 2009 to 2014 to get a better picture of the longer trend in the Alaskan maritime industry.

RESULTS

Figure 2 shows the number of unique MMSI numbers found in each zone per month for four conditions : 1) no ice limit, 2) Ice Concentration greater than 30 percent, 3) Ice Concentration greater than 60 percent, and 4) Ice Concentration greater than 90 percent. Seeing how many unique ships are active in each zone per month, above a given ice concentration, gives insight into which regions may be strategically important to focus further resources on. Seeing how many ships are operating in various ice conditions helps us to identify areas of interest to local stakeholders.

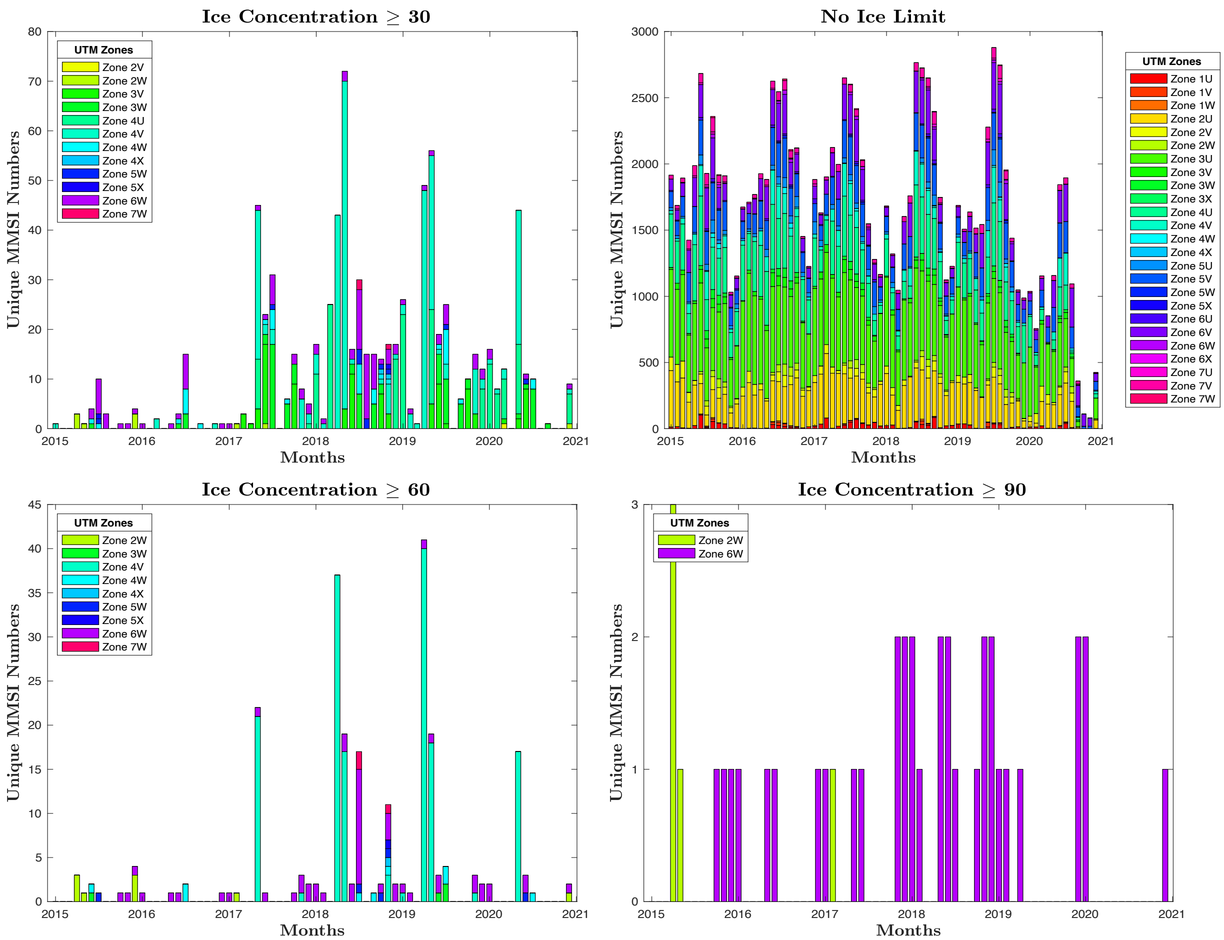

Figure 2. Shows the number of unique MMSI numbers found in each Zone per month

In Figure 2, x-axis shows the months and y-axis shows the unique MMSI numbers. It should be noted that Figure 2 can be a bit misleading on the y-axis, as it tells you how many unique ships were active in each zone in a given month, which it accurately shows for each zone individually, but as a collective whole it doesn't take into account that the same ship can be active in multiple zones over the course of a month.

Figure 3 shows the number of occurrences in each zone per month with the same 4 conditions seen in Figure 2: 1) no ice limit, 2) Ice concentration greater than 30 percent, 3) Ice concentration greater than 60 percent and 4) Ice concentration greater than 90 percent. An occurrence is a potential ice interaction above the set ice concentration limit identified by the framework. It shows how active the ships in each zone are, with the higher the number of occurrences corresponding to a greater potential risk for dangerous ice-ship interactions. With more ship activity in icy conditions it increases the chances of changing environmental conditions moving the ice floes in a hazardous way.

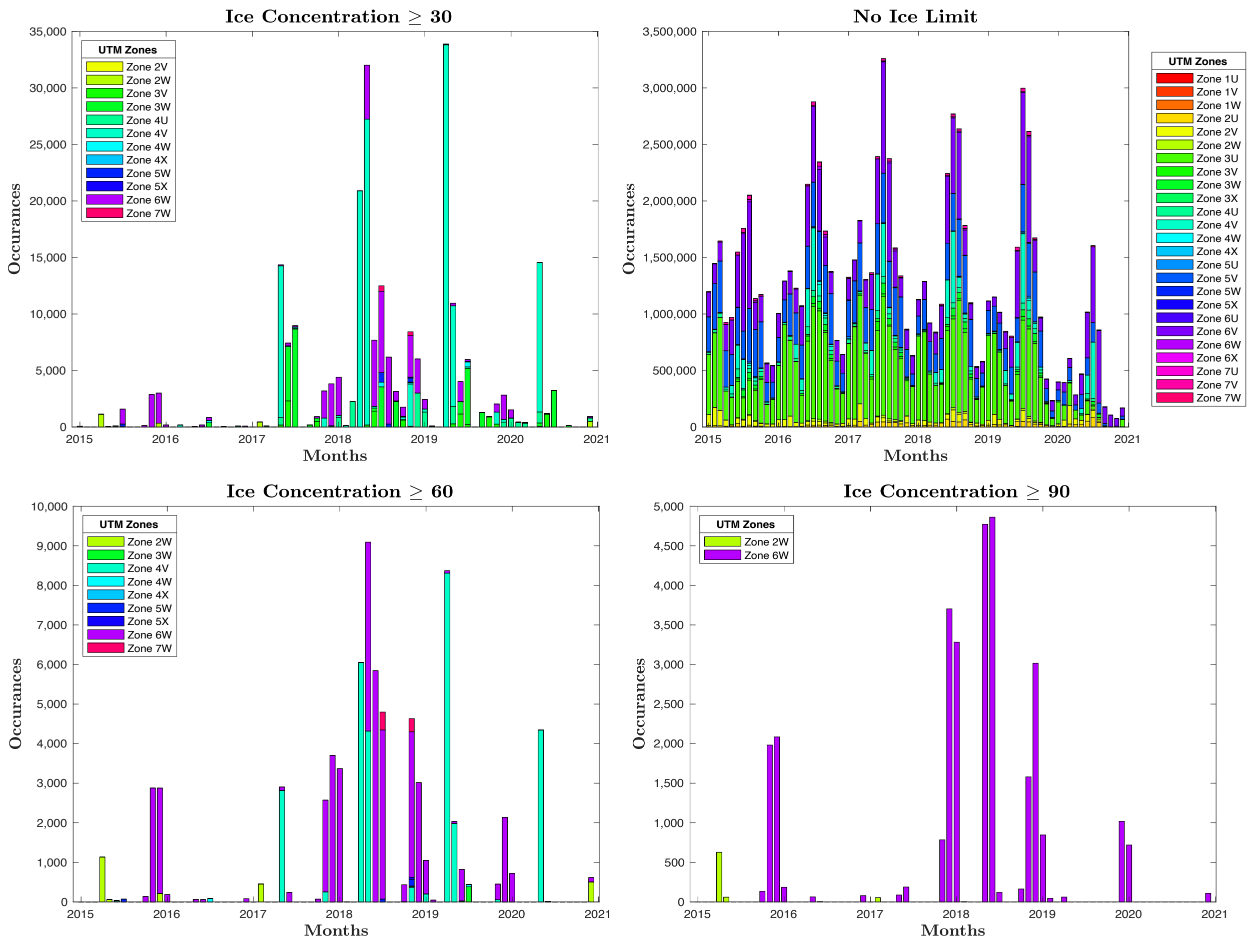

Figure 3. Shows the number of occurrences, or potential ice interactions above the limit, in each Zone per month

Figure 4 and 5 follow the same 4 quadrant layout of Figures 2 and 3 and also each represent the unique MMSI numbers and total occurrences respectively. But while Figures 2 and 3 inform us about the geospatial distribution of Alaskan vessels, Figures 4 and 5 show the composition of the ships categorical types. Categorizing the ships is not just important to help inform policy makers decisions on various maritime industries but is also important to understanding the risk levels for ships operating in ice. Every ship is built with a hull shape optimized for its primary usage and these various hull shapes have varying degrees of ice capabilities (or no ice capability at all). While Figure 2 has a potential for over sampling the number of unique ships active in a month, Figure 4 is an accurate representation of the total number of unique ships active in each month.

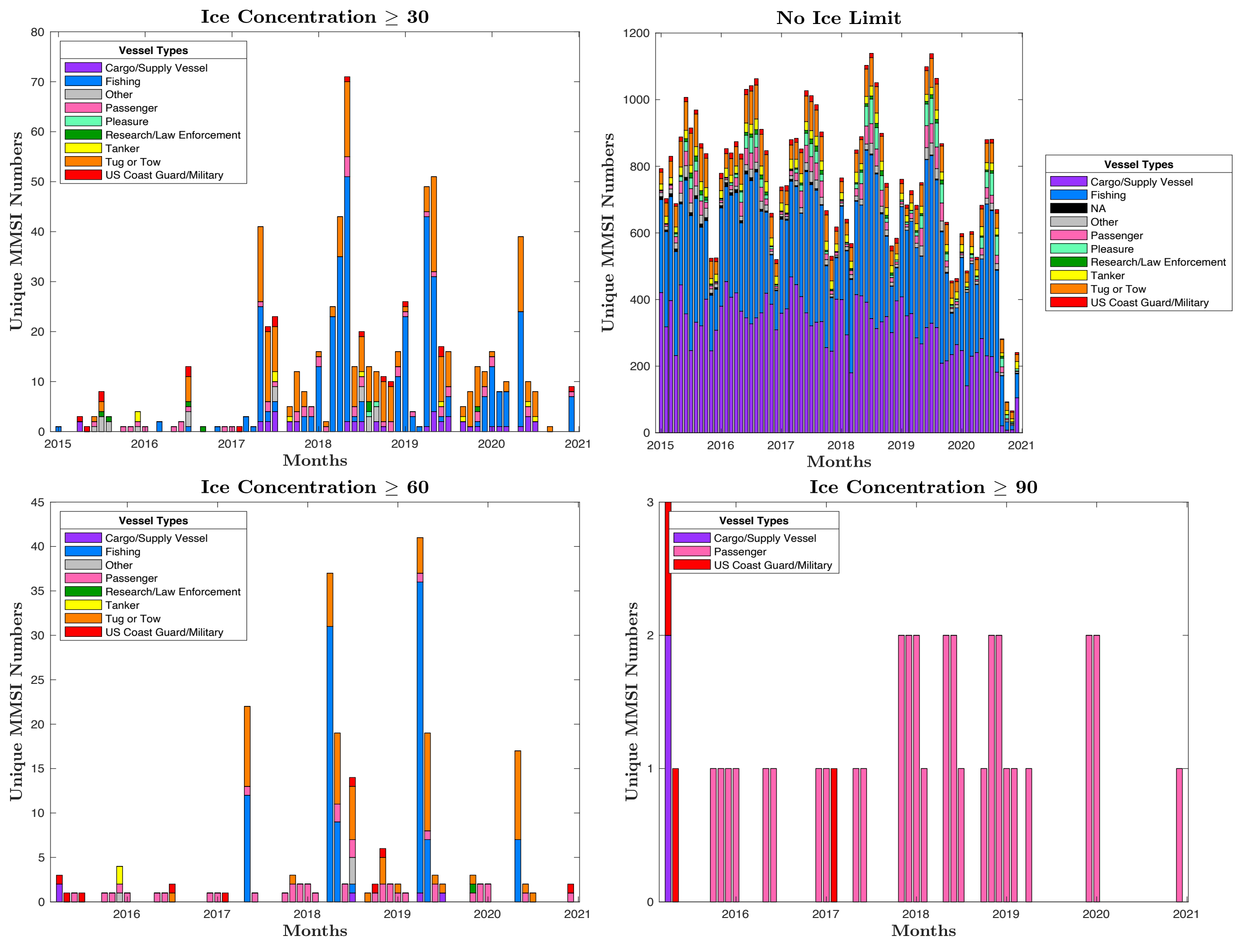

Figure 4. The number of unique MMSI numbers of each vessel type per month

As seen in the top right quadrant of Figure 4, Fishing and Cargo/Supply Vessels represent the majority of the year round industry in Alaskan waters, with around 83% of the total vessels observed over the 6 years falling into one of these 2 categories. And while fishing vessels seem to maintain a larger presence when ice is present, the cargo/supply vessels are all but absent when there is ice present. This may be in part due to the fact that the fishing industry is more widely distributed across the state compared to the cargo industry.

There are many different fisheries all around Alaskan waters that have a wide variety of different opening season dates, while the majority of cargo throughput in Alaska is routed through the Port of Anchorage and then distributed from there[17]. Though Alaska has many port spread across the state, most do not have the infrastructure to handle bulk cargo shipments and those that do are mostly located in the South Central and South Eastern regions of Alaska which sees limited ice. Much of the cargo that does get delivered to the remote Northern communities is sent by tug and barges, which accounts for its increased representation in both number of ships in Figure 4 and number of interactions in Figure 5.

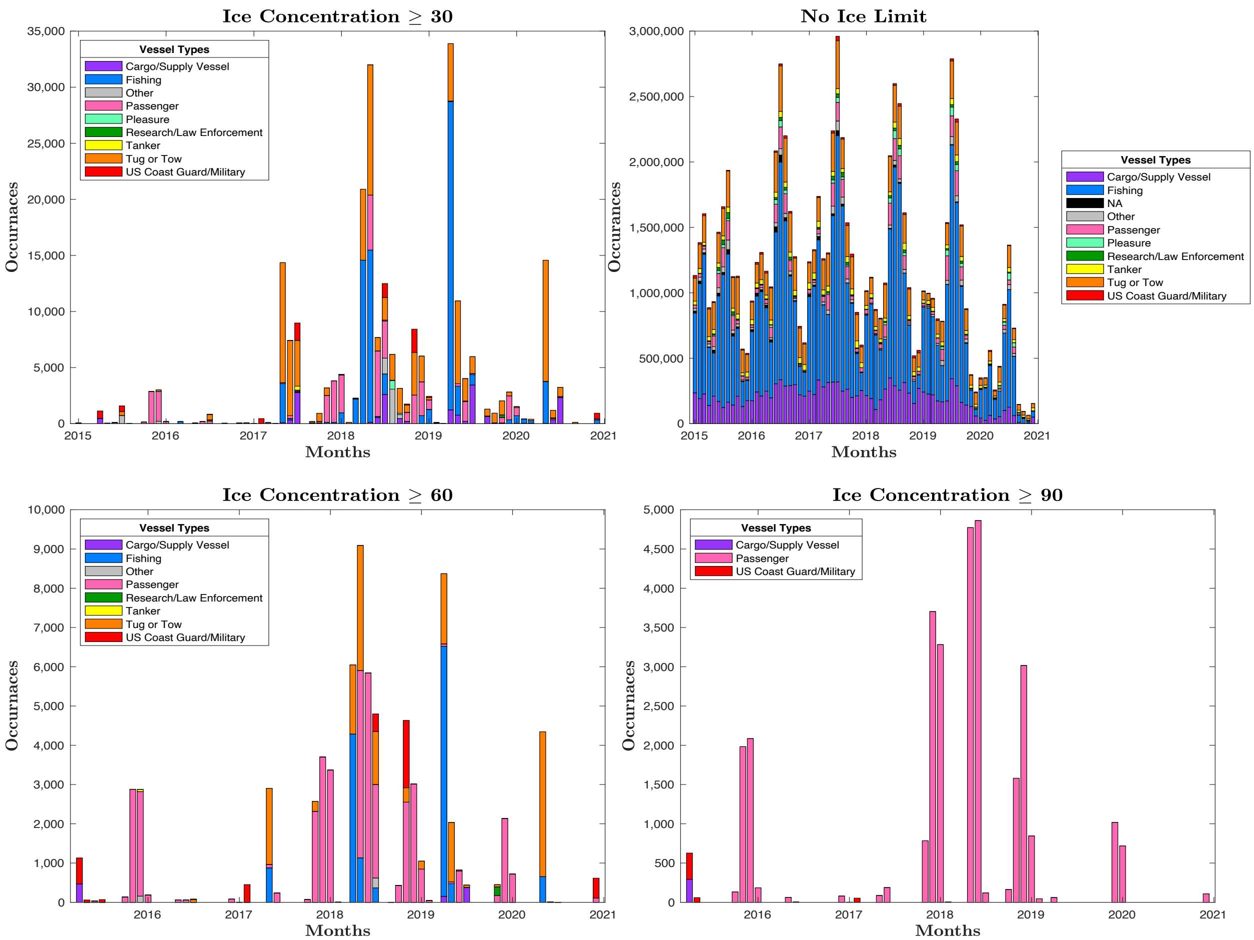

Figure 5. The number of occurrences for each vessel type per month

DISCUSSION AND CONCLUSION

As seen across the higher ice concentration runs, 60 and 90 percent, in Figures 2 and 3 the two most active zones as far as unique ships and how active the ships were are Zones 4V and 6W. These zones are rather far away from each other and represent 2 very different Alaskan communities. The Zone 4V is centered around Bristol Bay watershed which supports the largest Sockeye Salmon run in the world, producing about 46 percent of the worlds wild sockeye harvest. Conversely, Zone 6W is centered around Prudhoe Bay Oil Field, which contains the largest oil field in North America covering 213,543 acres. This difference in usage and latitude is highlighted by the typical seasonality of each zone, with Zone 4V having most of its occurrences in April and May, which is the lead up to the start of the summer fishing season. Conversely, the oil fields are operating year round so the occurrences and number of active vessels is more evenly distributed over the year. These two zones also experience different ice types. Comparing the monthly averaged Copernicus sea ice thickness for each zone (shown in Figure 6), which is only recorded from October to April due to the melt ponds, the average ice thickness across Zone 6W is still trending upwards in April while the average ice thickness across Zone 4V generally peaks around December/January and is trending downwards in April.

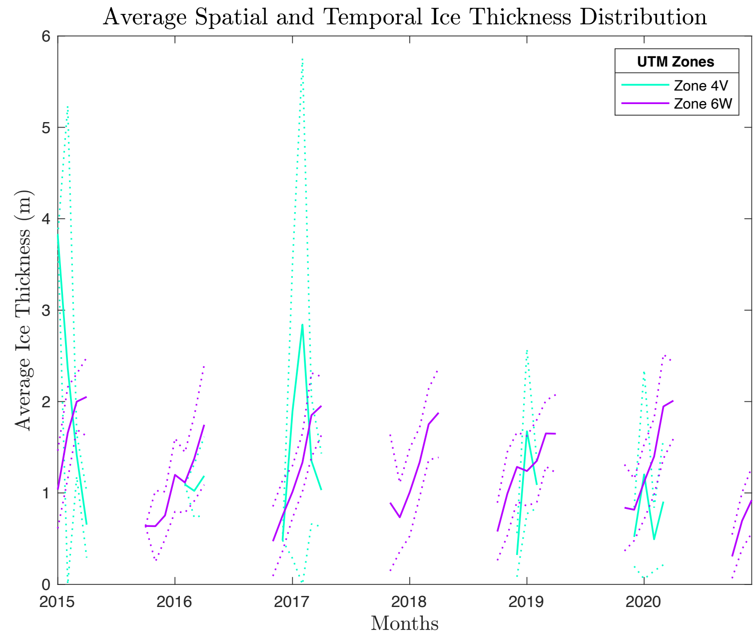

Figure 6. The monthly ice thickness averaged over the entire Zone

When looking at the 90 percent ice concentration runs in Figures 2 through 5 it is clear that the majority of the potential ice-ship interactions are occurring in the winter months from one singular Passenger vessel in Zone 6W. This seemed anomalous as the only vessels that should be able to operate at 90% ice concentration are vessels that are ice class or ice breakers. After digging deeper it was found that vessel AP1-88-8701 is a Lynden Hovercraft transporting oil field workers on the North Slope and as such is not actually breaking the ice but riding atop it. Three of the other identified ships were from a Russian ice breaking convoy with 2 cargo ships being escorted by the Russian military Ice Breaker the Admiral Makarov.

When looking at Figures 4 and 5 there are 2 different general trends in both the number of vessels per month and the total occurrences per month. Before 2017 there are significantly fewer occurrences and unique ships then after. This is in part because the Coast Guard passed new regulations in March of 2015 requiring the adoption of AIS by all boats longer than 65 feet by March of 2016. This ramp up of occurrences and unique ships can be seen in both figure 4 and 5. Another interesting feature is the relative collapse of ship activity in 2020. This coincides with the COVID 19 global pandemic that the World Health Organization identified January 10^{th} of that year.

Looking at the 2^{nd} quadrant of Figure 4, the ice concentration above 30 percent, there is a clear jump in the number of fishing vessels being reported after 2017. This seems to suggest that, in accordance with the new regulations, the Alaskan fishing fleet began implementing AIS systems. The jump in the number of fishing vessels interacting with ice isn't limited to the late spring/early summer lead in to the summer salmon season. There are consistently 3 to 13 fishing vessels interacting with at least 30 percent ice concentration in the winter months, November to January which coincides with the Alaskan King Crab and Opolio Crab (Snow Crab) seasons which are typically open during the coldest time of the year, October through January. The dangers of crabbing as an industry has been well documented since the early 2000's due to the rise in popularity of the Discovery TV show ‘The Deadliest Catch’[18], but one of the main hazards for the boat and crew is the ice floes they fish close to. The crabs like to gravitate towards the supercooled briny water found under the ice floes as it offers protection for juvenile crabs from predation and lowers their metabolic stress. This leads to fishermen playing a dangerous game of trying to fish close to the ice while trying to keep their vessels and gear safely out of harms way.

SUMMARY

This study summarizes the recent ship and ice-structure interactions in Alaskan waters. More specifically, we discuss the geospatial distribution of Alaskan vessels as it relates to their risk levels when operating in icy conditions. To summarize, we show that:

- Fishing and cargo/supply vessels are the majority of the year-round industry in Alaskan waters, with fishing vessels maintaining a larger presence when ice is present.
- The cargo/supply vessel are absent when there is ice present due to limited access and infrastructure in remote communities.
- Majority of potential ice-ship interactions with 90% ice concentration or above occur in winter months.
- Before 2017, there were significantly fewer occurrences and unique ships in Alaskan waters, partly due to the U.S. Coast Guard’s new regulations on AIS adoption in March 2015 (with enforcement beginning in 2016).
- After 2017, the jump in the number of fishing vessels interacting with ice isn’t limited to the late spring/early summer lead-in to the summer salmon season. There are fishing vessels interacting with at least 30 percent ice concentration in the winter months, which coincides with the Alaskan King Crab and Opolio Crab seasons.

In summary, categorizing ships and marine activities is a critical process that informs policymakers' decisions on various aspects of the maritime industry, such as regulation, sustainability, and safety. By doing so, policymakers can ensure that the maritime industry operates efficiently, responsibly, and sustainably.

ACKNOWLEDGEMENT

The authors gratefully acknowledge funding from the National Science Foundation (PM: Mamadou Diallo) under award no. 2127095.

REFERENCES

[1] R. J. Bye and A. L. Aalberg, “Maritime navigation accidents and risk indicators: An exploratory statistical analysis using AIS data and accident reports,” *Reliability Engineering & System Safety*, vol. 176, pp. 174–186, Aug. 2018, doi: 10.1016/j.ress.2018.03.033.

[2] G. Peel and E. D. Gedikli, “Investigating the dominant force distributions in ice-induced vibrations using multivariate analysis,” *26th IAHR International Symposium on Ice*, Jul. 2022, Accessed: Apr. 27, 2023. [Online]. Available: https://par.nsf.gov/biblio/10393869-investigating-dominant-force-distributions-ice-induced-vibrations-using-multivariate-analysis

[3] K. V. Høyland *et al.*, “Fatigue damage from dynamic ice action – The FATICE project”.
[4] V. Hornnes, K. Høyland, J. Turner, E. Gedikli, and M. Bjerkås, *Combined distribution of ice thickness and speed based on local measurements at the Norströmsgrund lighthouse 2000-2003*. 2020.
[5] H. Hendrikse and A. Metrikine, “Ice-induced vibrations and ice buckling,” *Cold Regions Science and Technology*, vol. 131, pp. 129–141, Nov. 2016, doi: 10.1016/j.coldregions.2016.09.009.
[6] E. D. Gedikli, V. Groeschel, G. Peel, J. Behnen, O. Francis, and H. Hendrikse, “Navigating the New Arctic through Investigating Ice-Structure Interactions”.
[7] D. Yang, L. Wu, S. Wang, H. Jia, and K. X. Li, “How big data enriches maritime research – a critical review of Automatic Identification System (AIS) data applications,” *Transport Reviews*, vol. 39, no. 6, pp. 755–773, Nov. 2019, doi: 10.1080/01441647.2019.1649315.
[8] R. Berglund, V. Kotovirta, and A. Seinä, “A system for icebreaker navigation and assistance planning using spaceborne SAR information in the Baltic Sea,” *Canadian Journal of Remote Sensing*, vol. 33, no. 5, pp. 378–387, Oct. 2007, doi: 10.5589/m07-042.
[9] V. Lehtola, J. Montewka, F. Goerlandt, R. Guinness, and M. Lensu, “Finding safe and efficient shipping routes in ice-covered waters: A framework and a model,” *Cold Regions Science and Technology*, vol. 165, p. 102795, Sep. 2019, doi: 10.1016/j.coldregions.2019.102795.
[10] Copernicus Climate Change Service, “Sea ice concentration daily gridded data from 1979 to present derived from satellite observations.” ECMWF, 2020. doi: 10.24381/CDS.3CD8B812.
[11] “VesselTypeCodes2018.pdf.” Accessed: Mar. 30, 2023. [Online]. Available: https://coast.noaa.gov/data/marinecadastre/ais/VesselTypeCodes2018.pdf
[12] S. Erceg and S. Ehlers, “Semi-empirical level ice resistance prediction methods,” *Ship Technology Research*, vol. 64, no. 1, pp. 1–14, Jan. 2017, doi: 10.1080/09377255.2016.1277839.
[13] 14:00-17:00, “ISO 19906:2019,” *ISO*. https://www.iso.org/standard/65477.html (accessed Apr. 04, 2023).
[14] G. of C. N. R. C. Canada, “Predicting ice thickness for engineering applications - NRC Publications Archive,” Apr. 04, 2023. https://publications-cnrc.canada.ca/eng/view/object/?id=fce1c616-994a-4f9f-8634-6d20be17c19d (accessed Apr. 04, 2023).
[15] L. Huang, F. Li, M. Li, D. Khojasteh, Z. Luo, and P. Kujala, “An investigation on the speed dependence of ice resistance using an advanced CFD+DEM approach based on pre-sawn ice tests,” *Ocean Engineering*, vol. 264, p. 112530, Nov. 2022, doi: 10.1016/j.oceaneng.2022.112530.
[16] “Ice resistance equation_MS_accepted manuscript.pdf.” Accessed: Apr. 04, 2023. [Online]. Available: https://discovery.ucl.ac.uk/id/eprint/10130627/1/Ice%20resistance%20equation_MS_accepted%20manuscript.pdf
[17] “PortofAlaska_benefits_McDowell_Oct2020_sm.pdf.” Accessed: Mar. 31, 2023. [Online]. Available: https://www.portofalaska.com/wp-content/uploads/PortofAlaska_benefits_McDowell_Oct2020_sm.pdf
[18] “*Deadliest Catch*,” *Wikipedia*. Mar. 27, 2023. Accessed: Apr. 04, 2023. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Deadliest_Catch&oldid=1146904489