Quantifying Linkages between Navigational Conditions and Maritime Traffic in the Arctic

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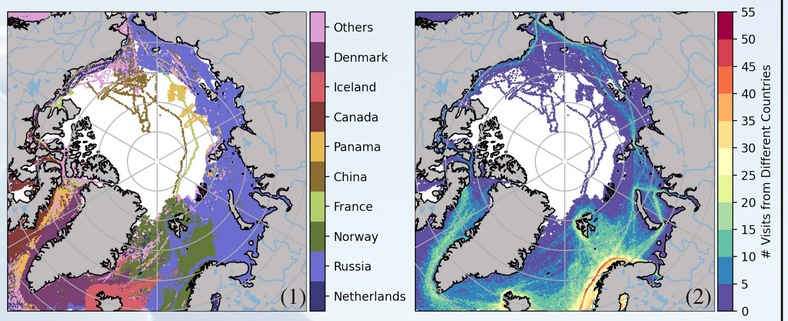
Introduction

The Arctic is undergoing profound environmental changes at a time of increasing geopolitical interests. Loss of the Arctic sea ice is one of the most prominent signatures of global climate change. As a result, the Arctic is becoming more accessible, revealed by the increasing shipping traffic. For example, A polar route has the potential to reduce transit time of traditional shipping routes by up to two weeks. Opportunities for potential resource extraction and expanding Arctic tourism offer new economic prospects for countries including US, Russia, Canada, and China.

The spatio-temporal patterns of vessel traffic in the Arctic and the geopolitical implications have been investigated in the literature [1, 2]. This research focuses on assessing the maritime traffic simulation and Arctic accessibility. It utilizes an eight-year observational dataset of Arctic vessel traffic from 2013 to 2021, together with sea ice and atmospheric reanalysis products, to understand the linkages between observed maritime traffic and sea ice changes. Spatial features and temporal trends of model simulations are compared with observations. This policy and security-relevant research aims to improve our understanding of recent and future Arctic environmental changes and its impacts on maritime transport.

Data and Method

Arctic Ship Traffic Data (ASTD)



The ASTD [3] System contains historical ship-related information across the Arctic from 2013 to 2021. Ship records are reported on a minute basis. It includes ship categories, the associted Finnish-Swedish ice classes, GPS locations, detailed measurements on emissions by ships, and fuel consumption by ships.

Figure (1) shows a map of the Arctic with colors corresponding to the country that visits the particular grid most frequently during the 8 year period. Figure (2) shows the same map but the color corresponds to the number of countries that ever visted a particular grid.

Arctic Transportation Accessibility Model (ATAM)

The ATAM [4] is a modelling framework that adapts different transportation modes, including over sea and land. This research utilizes the maritime modeling component to simulate the accessibility of the Arctic. Specifically, the ability of a ship to safely navigate ice-covered waters is given by the ice numeral (IN):

$$IN = (C_a * IM_a) + (C_b * IM_b) + \ldots + (C_n * IM_n)$$

- C_a is the concentration in tenths of ice type a
- IM_a is the predefined ice multiplier of ice type a

IMs, which are based on ice type and vessel class, are a series of nonzero integers ranging from −4 to 2, with higher values denoting lower risk. A negative IM signifies that the ice regime presents significant hazard and should be avoided.

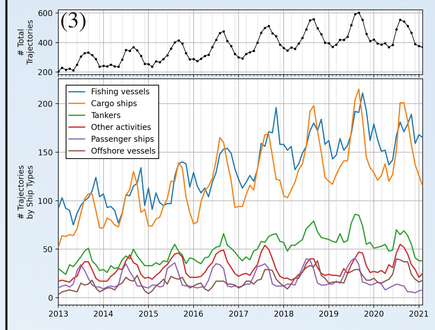
The calculated IN can be an indicator for accessibility, with negative INs meaning inaccessible. A larger IN can be associated with faster travel speed. We use this calculation to generate an IN raster for the Arctic to compare with the observed ship location map from the ASTD.

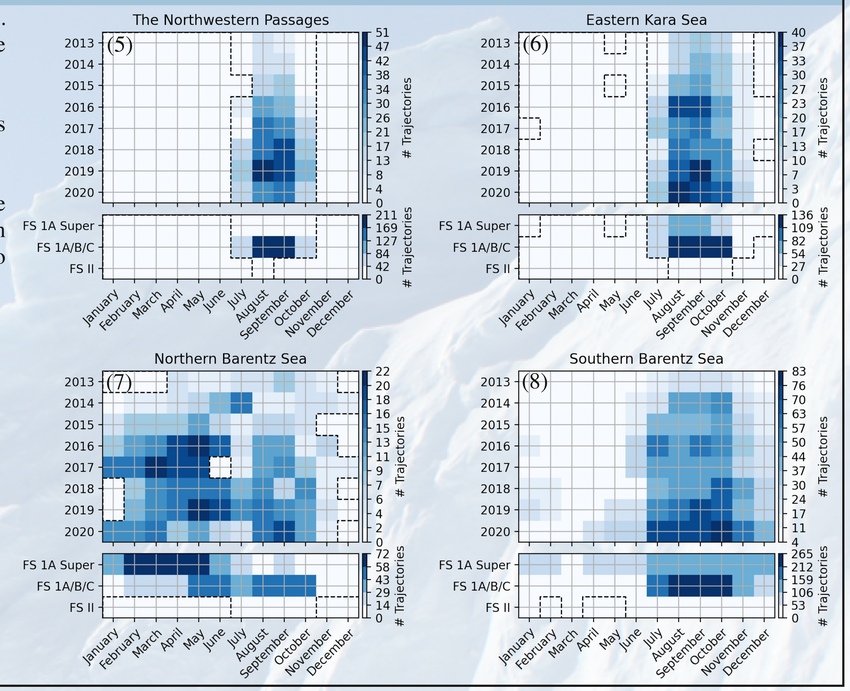
Arctic Accessibility Trend Analysis

Figure (3) shows the number of trajectories by different ship types from 2013 to 2021. The Arctic has seen increasing visits during the recent decade. The major factor is the increase of fishing vessels and cargo ships.

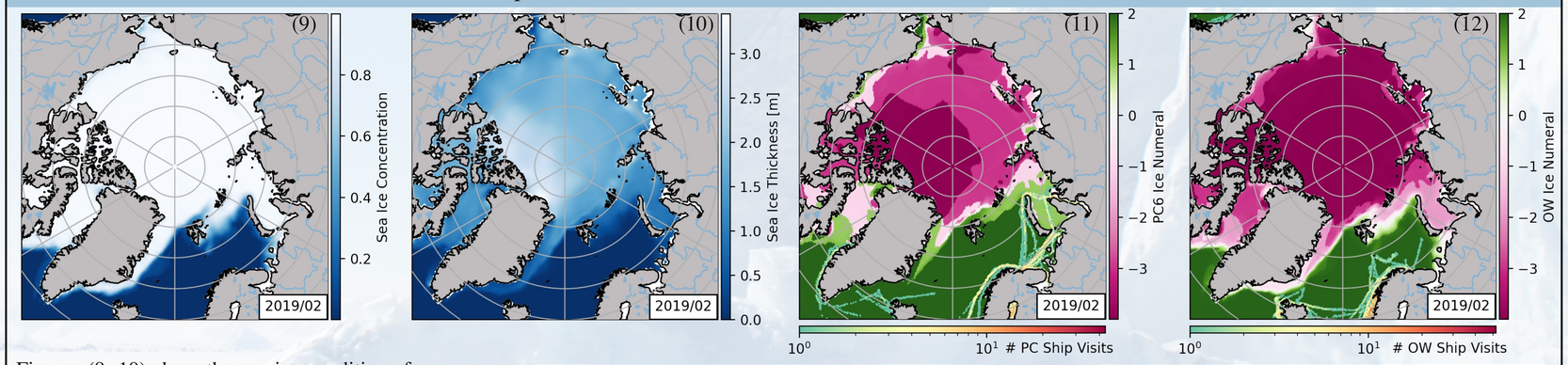
Figure (4) shows a map of the Arctic with the regions of interest annotated for this research.

Figures (5 ~ 8) show the number of trajectories recorded within four regions in the Arctic. Generally, the Northern Sea Route has seen a greater increase in ship visits than the Northwestern Passages. The dashed lines separate time periods having zero trajectories and at least one trajectory.





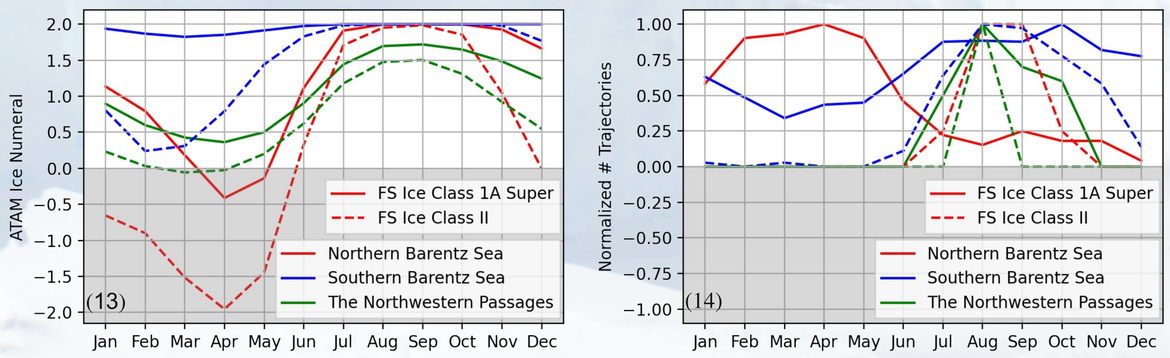
Comparison between Arctic Traffic Simulation and Observation



Figures (9, 10) show the sea ice conditions from PIOMAS [5] dataset averaged for Feburary, 2019.

Figures (11, 12) show the calculated ice numerals from ATAM overlayed with the heatmap of ship visits. PC 6 corresponds to FS Ice Class 1A Super and OW corresponds to FS Ice Class II.

Figures (13, 14) compare the average INs and the number of trajectories. Trajectory counts are summed across years for a particular month, and then nomalized by the month with the most visits. IN correlates well with the observed ship visits, except for FS Ice Class 1A Super (red solid).



Conclusions

The maritime traffic in the Arcitc has doubled since 2013, with preferences over the Northern Sea Route over the Northwestern Passages. This is partly due to the less sea ice coverage over the Eastern Arctic, but also because of the larger portion of ice-strengthening vessels traveling through the Eastern Arctic. This increase in maritime traffic can be well captured using PIOMAS and ATAM. However, improvements can be made to better model traffic involving multiple ship types given an economic context and navigational conditions.

[1] Bennett, Mia M., et al. "The opening of the Transpolar Sea Route: Logistical, geopolitical, environmental, and socioeconomic impacts." Marine Policy 121 (2020): 104178.
[2] Chen, Jin-Lei, et al. "Variation of sea ice and perspectives of the Northwest Passage in the Arctic Ocean." Advances in Climate Change Research (2021).
[3] Secretariat, Arctic Council. "Arctic Ship Traffic Data (ASTD) project: Cover Letter: Information Paper; and MOU regarding Data Sharing." (2017). https://www.pame.is/index.php/projects/arctic-marine-shipping/astd
[4] Stephenson, Scott R., Laurence C. Smith, and John A. Agnew. "Divergent long-term trajectories of human access to the Arctic." Nature Climate Change 1.3 (2011): 156-160.
[5] Schweiger, A., R. Lindsay, J. Zhang, M. Steele, H. Stern, Uncertainty in modeled arctic sea ice volume, J. Geophys. Res., doi:10.1029/2011JC007084, 2011