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Preliminary Study on the Applicability of the POLARIS Methodology for Ships Operating in Lake Ice

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ABSTRACT

A preliminary study was performed to assess the applicability of the Polar Operational Limit Assessment Risk Indexing System (POLARIS) for ships operating in lake ice. POLARIS provides guidance regarding operational limits for ships operating in polar waters, which was developed in association with the IMO Polar Code in 2014. POLARIS uses a Risk Index Outcome (RIO) value based on a ship's ice class and specific ice conditions, which is calculated using a Risk Index that reflects the ship's operational capability in ice. The Risk Index contains a set of Risk Index Values (RIVs) corresponding to different stages of sea ice development for each ice class. AIS records for ships operating in the North American Great Lakes region for ice seasons between 2010 and 2019 were analysed to compare historical vessel operations to the recommendations prescribed by POLARIS, by applying the POLARIS methodology to operations in lake ice instead of its normal application for polar operations. Ice condition information was extracted from the Canadian Ice Service digital charts. RIVs for lake ice types were assigned based on the closest equivalent sea ice types within POLARIS by thickness. Results from this study suggest that Great Lakes shipping operations are generally consistent with POLARIS guidelines and icebreaker support is observed to correspond well with regions where vessels most frequently encounter negative RIO values. While these results indicate that the development of modified POLARIS guidelines for the Great Lakes seem feasible, this work also highlights the need for additional information and further analysis. Areas requiring further investigation include assessing potential for ship damage from lake ice versus sea ice of equivalent thickness, establishing POLARIS Risk Index Values specific to lake ice stages-of-development, and assessing suitable RIVs that reflect operations in freshwater ice. Additional information needed to support this work includes documentation of the ice class of all vessels operating in this region, details of local operational ice conditions (rather than general ice conditions obtained from ice charts), and information about the extent and frequency of traffic that uses shipping lanes in broken ice channels. Additional areas to be explored include evaluation of optimum speed limits for different operational scenarios and the degree to which icebreaker support is necessary to operate a given class of vessel in particular ice conditions.

KEY WORDS: Ice; Ice-Class; POLARIS; Shipping

INTRODUCTION

The North American Great Lakes are a high-traffic shipping waterway for both Canada and the United States, which is enabled by an extensive system of locks and canals along the Great Lakes-St. Lawrence Seaway. Shipping in the region slows during winter months due to the severe ice conditions seen in the lakes. The Seaway between Lake Erie and Montreal is closed for an annual winter shutdown from January to mid-March, and the Soo Locks between Lake Superior and the other lakes are typically closed for a slightly shorter duration. It is during this time that the majority of the Seaway's critical infrastructure maintenance is scheduled (Transport Canada et al, 2007).

During the winter lay-up, ships still operate within the Great Lakes in reduced numbers. Ice frequently remains in the lakes once shipping has fully resumed, sometimes in significant quantities, beyond the winter season into April and occasionally early May. There is significant year-to-year variability in the length of the ice season as well as the degree of ice coverage seen in the lakes. There is also significant regional variation of ice coverage due to differences in the individual lakes' geography, including water depth and mean ambient air temperature (Assel, 2005). Additionally, a downward trend in total ice coverage has been seen across the lakes in recent decades (Wang, et al., 2012), which suggests poor predictability for forecasting the severity of upcoming ice seasons.

Numerous media publications and anecdotal experiences from operators indicate that ships are known to occasionally experience damage due to operations in ice within in the Great Lakes, and cases where ships have become trapped due to unexpectedly severe ice conditions are not uncommon. Measures such as icebreaker assistance are considered essential in order to maintain traversable passages through regions that experience the most consistently severe ice conditions such as Lake Erie, especially during spring breakup following the shutdown period (U.S. Army Engineer District Detroit, 1979).

For ship operations in freshwater ice, such as within the Great Lakes, it is important for operators to have consistent guidelines regarding ice conditions that can be safely navigated and appropriate measures for mitigating such risks. This is essential for ensuring the safety of personnel and the environment, while also helping reduce the number of ice-related delays and incidents requiring repairs.

Under the Polar Code, the Polar Operational Limit Assessment Risk Indexing System (POLARIS) can be used as a means of providing guidance regarding operational limits in ice for ships operating in polar waters. As a preliminary study into the feasibility of adapting the POLARIS methodology for ships operating in freshwater ice, this work attempts to address the following questions:

1. If the POLARIS methodology were to be applied on the Great Lakes using the closest lake ice equivalents, what range of Risk Index Outcomes are observed?
2. What insights can be gained about the nature of current ship operations in ice in the Great Lakes based on the POLARIS methodology?
3. What additional information and further research would be needed to support the development of a modified POLARIS methodology for the Great Lakes?

It is noted that design standards for ice class ships and guidelines for ship operations in ice, such as the Polar Code, focus on sea ice and glacial ice hazards for ocean-going vessels rather than freshwater lake ice. While the impact of differences in material properties between freshwater ice versus sea ice in terms of the potential for damage to a vessel is a highly important consideration, this topic is beyond the scope of the present work.

BACKGROUND

The POLARIS methodology was first adopted into the IMO Polar Code by the Maritime Safety Committee in 2014. The Polar Code requires a ship operating in polar waters should possess a valid Polar Ship Certificate that establishes its operational limitations, as well as a ship-specific Polar Water Operational Manual (PWOM), which identifies procedures to support the decision-making process for operations during both routine and emergency circumstances. Operational limitations recommended through the POLARIS methodology may be referenced by a Polar Ship Certificate, and its guidelines are intended to support ship-specific information contained within a ship's PWOM. It was developed through the incorporation of operator experience and established best practices from Canada's Arctic Ice Regime Shipping System, the Russian Ice Certificate, and other existing methodologies. (IMO, 2016)

The POLARIS methodology uses a Risk Index Outcome (RIO) value to classify a ship's operational capability in specific ice conditions. Under POLARIS, each ship is assigned a Risk Index based on its ice class, which contains a set of Risk Index Values (RIVs) for the different stages of sea ice development. An alternative set of Risk Indices has been developed for decayed *Medium* and *Thick First Year Ice* that are intended for operations during higher ambient temperatures in order to reflect an associated reduction in risk. The ice-classes with Risk Indices in POLARIS include the IACS Polar Class ice classes and ice classes assigned equivalence to Finnish-Swedish Ice Class Rules under HELCOM. A ship's RIO value for a given set of ice conditions is calculated by the summation of the concentration (in tenths) of each ice type present multiplied by their corresponding RIVs. (IMO, 2016)

Based on the range an RIO falls into, POLARIS recommendations address three operational categories: *normal operation*, *elevated operational risk*, and *operation subject to special consideration*. An RIO equal to or greater than 0 indicates *normal operation,* with no additional POLARIS guidelines. For Polar Class ships, an RIO equal to or greater than -10 and less than 0 indicates *elevated operational risk*. POLARIS provides speed limit recommendations ranging from 3 to 11 knots depending on the specific Polar Class for this category. Additional watch keeping or the use of icebreaker support are also suggested measures, as is avoiding areas likely to fall into this category if possible while voyage planning. The remaining category, *operation subject to special consideration*, applies to Polar Class ships for RIO values less than -10 and for all other vessels (with or without an assigned ice class) for RIO values less than 0. Ice regimes with an RIO identifying *operation subject to special consideration* merit extreme caution when navigating, and POLARIS recommendations suggest rerouting to avoid such conditions when possible. Otherwise, further reduction in speed is recommended beyond that outlined for *elevated operational risk,* as well as any other ship-specific risk mitigating special measures that are outlined in its PWOM. In short, the POLARIS methodology provides guidelines that aim to reduce the level of risk of structural damage to a given ship in particular ice conditions. (IMO, 2016)

It is important to note that ice conditions considered in the Polar Code correspond to ice types (sea ice and glacial ice) encountered by ocean-going vessels, rather than freshwater lake ice. While it is essential to assess the impact of differences in ice conditions and properties in terms of operational risk and the potential for ship damage from freshwater lake ice versus sea ice/glacial ice, this topic is beyond the scope of this preliminary study. This highly important topic requires detailed consideration and is recommended as a separate topic for future investigation, since such information would be required to assess the need for revised risk index values specific for lake ice.

DECRIPTION OF DATA

The basis of this study was the analysis of historical AIS records for ships operating in the North American Great Lakes region for ice seasons between 2010 and 2019, along with ice condition information from corresponding archived ice charts. The data processing procedure for the analysis included the following steps: acquire AIS data for all ships in the region during the specified time intervals, extract historical ice conditions at the time and location of each AIS data point, verify ship ice classes to allow for selection of appropriate POLARIS risk indices, and filter out the relevant subset of data to be used in the analysis.

AIS Dataset

Given the focus of the present work on ships transiting through ice, AIS records for stationary ships (with speeds equal or less than 0.1 knots) were excluded from this dataset. The initial dataset consisted of a total of 262,945 individual AIS records. Historical ice condition information was then compiled for the times and locations of each AIS data point. Analysis of these data revealed that 139,287 AIS records corresponded to open water conditions. These were removed from the dataset, leaving 123,630 records for ice operations.

In total, 390 unique ships were identified that have operated in ice conditions with 1/10 or greater coverage. Ice-class information was obtained for these ships on a ship-by-ship basis, primarily through classification society information available via http://www.equasis.org or from ship specifications provided by operators. Since knowledge of a ship's ice class is required to apply the POLARIS methodology, it was necessary to parse the data such that only the subset corresponding to ships of verified ice class were used. Of the identified ships, 114 were verified to have a POLARIS ice class, while 14 others possessed alternative ice classes and the remaining 262 were either unclassed, could not be verified, or possessed an ice class lower than the lowest outlined within POLARIS ("IC"). While no Polar Class ships were identified in these data, five Canadian Coast Guard ships and four US Coast Guard ships were identified with comparable icebreaking capabilities to Polar Class ships. The final subset of data corresponding to ice operations of transiting POLARIS ice class ships consisted of 15,072 records, summarized below by ice season in Table 1. It should be noted that the number of available AIS records increased substantially between 2012 and 2014. This is largely the result of increases in AIS coverage over the Great Lakes region during this period.

Table 1. Summary of AIS records used for this analysis.

Ice Season	All Ships		POLARIS Ice Class Ships	
	Total	Ice Present	Total	Ice Present
January 1, 2010 to March 31, 2010	454	219	141	113
December 15, 2010 to April 15, 2011	34	0	2	0
January 1, 2012 to March 31, 2012	2328	512	237	50
January 1, 2013 to April 30, 2013	13,082	4,699	2,249	670
December 1, 2013 to May 15, 2014	41,756	22,977	7,367	3,787
January 1, 2015 to May 15, 2015	50,378	25,457	4,663	2,193
January 1, 2016 to March 31, 2016	5,654	3,284	753	430
December 15, 2016 to April 15, 2017	55,296	28,852	5,780	2,880
December 5, 2017 to May 15, 2018	38,654	18,227	5,739	2,424
January 1, 2019 to April 30, 2019	55,309	19,403	7,722	2,525

Historical Ice Conditions

The ice condition information used for this analysis was extracted from the Canadian Ice Service (CIS) digital chart archive. These charts are published in an "egg-code" format using WMO terminology, and describe regional ice concentration, stage of development, and ice form. As this analysis is limited to the available ice chart information, it assumes unbroken level ice, and does not consider degraded ice conditions, rubble buildup or ridging effects, and local variations in ice conditions such as shipping lanes. While these charts do include ice form information, floe size is not considered in the POLARIS methodology. CIS ice charts are typically published daily, though there are occasional gaps of up to 3 days. For the analysed data, the mean absolute difference between each AIS timestamp and the publication of the nearest ice chart was approximately 0.3 days, with the largest gap being 2.5 days.

Historical ice conditions for each AIS point were taken from the region encompassing them on the closest available ice chart. CIS ice chart regions are classified as either *ice*, *open-water*, or *land*. AIS points within *land* regions, such as ships transiting a canal, were omitted from the study. A substantial portion of the remaining AIS records described ship operations in *open-water* regions due to variation in year-to-year ice season duration and regional variation in the distributions of ice throughout the lakes. In this analysis, only AIS points within *ice* regions were considered for statistical analysis of historical ship operations. This also encompasses trace ice conditions, where CIS provides an ice concentration of 0.1 tenths (occasionally without a corresponding ice type).

Lake ice types were assigned RIVs from the closest first-year sea ice equivalent by thickness within POLARIS, which uses WMO terminology for sea ice types. Most lake ice types have clear sea ice equivalents for which CIS assigned the same ice chart egg codes. However, while the thickness range for *Thick Lake Ice* (30-70cm) best corresponds to *Thin First-Year Ice* (30-70cm), POLARIS only provides RIVs for the first and second stage subcategories with thicknesses of 30-50cm and 50-70cm, respectively. To account for this, RIVs were chosen for *Thick Lake Ice* assuming an even split between the two subcategories. Similarly, POLARIS differs from WMO nomenclature in providing an additional RIV subcategory for *Medium First-Year Ice* (normally 70-120cm) for ice known to be less than 100cm thick. The corresponding lake ice category, *Very Thick Lake Ice*, applies for all lake ice greater than 70cm thick (Canadian Ice Service, 2016). As ice thicknesses in the Great Lakes are known to exceed 100cm (U.S. Army Engineer District Detroit, 1979), RIVs for this category were conservatively taken from the broader *Medium First-Year Ice* category. Mappings for the chosen ice type equivalencies are shown in Table 2.

Table 2. Table of equivalencies used to map POLARIS RIVs to CIS lake ice types.

CIS Stage-of-Development for Lake Ice	Equivalent POLARIS Ice Type
New Lake Ice (<5cm)	New Ice (<10cm)
Thin Lake Ice (5-15cm)	Grey Ice (10-15cm)
Medium Lake Ice (15-30cm)	Grey-White Ice (15-30cm)
Thick Lake Ice (30-70cm)	50% Thin First Year Ice, 1st Stage (30-50cm), 50% Thin First Year Ice, 2nd Stage (50-70cm)
Very Thick Lake Ice (>70cm)	Medium First Year Ice (70-120cm)

RESULTS AND DISCUSSION

Using the historical ice condition information and known ice classes of the studied vessels, the POLARIS methodology was applied to calculate RIO values corresponding to each AIS record in the dataset. The distribution of calculated RIO values covers a wide range, with the majority of records (89%) having positive RIO values that would correspond to *normal operations* under POLARIS guidelines. Of these data, a total of 5,784 (39%) points correspond to ice conditions resulting in an RIO between 0 and 29 and 7,491 (50%) points were in trace ice conditions that would result in an RIO between 29 and 30. The remaining 1,684 points (11%) had an RIO less than 0, for which the POLARIS methodology would recommend *operation subject to special consideration*. The histogram in Figure 1 shows the distribution of calculated RIO values. Note that the bin width for the 29 to 30 range was modified to highlight the comparatively high percentage of data in trace ice conditions.

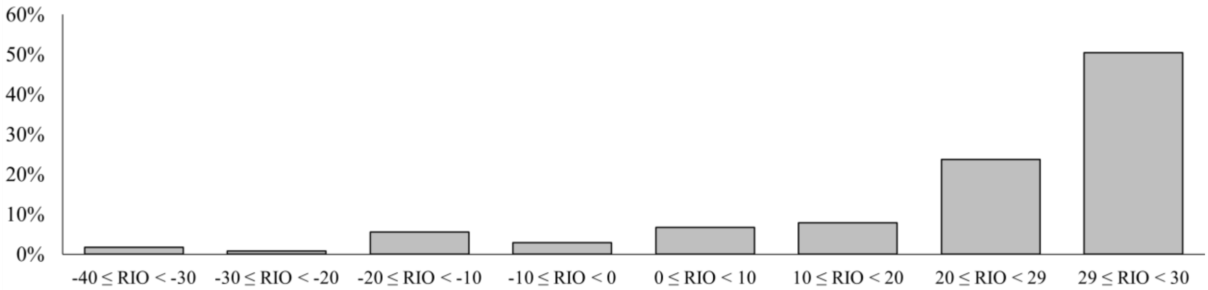

Figure 1. Distribution of RIO values for all ships with known ice class in the dataset.

Overall, only a small percentage of cases correspond to lower RIO ranges below 0, with a few instances of highly negative RIOs below -20. While these results provide insight into general trends, caution should be exercised in reading too much into the highly negative RIO values in this preliminary study. The current approach cannot directly account for icebreaker support, navigation through broken ice channels, differences between actual local ice conditions versus general ice chart conditions (e.g. possible navigable leads through heavy ice), or other mitigating actions that may have been employed (e.g. speed reductions). While a detailed analysis of individual instances of highly negative RIO values is beyond the scope of this study, general trends in the data are discussed in the sections below.

Analysis of Ship Operating Speed

Probability Density Functions of ship speed were generated for each RIO range as a means of comparing ship operations to POLARIS guidelines. While POLARIS recommendations make no distinction between RIO values between 0 and -10 versus those below -10 for non-Polar Class ships, separate distributions were generated for each range in order to highlight possible differences in operations for highly negative RIO values. Similarly, an additional distribution was generated for RIO values between 29 and 30 in order to provide a reference probability distribution for normal operations when there is only trace ice present. Histograms with a bin width of 1 knot were used to generate these distributions, and a scaling factor was applied to each bin count to address differences in exposure at different speeds, assuming uniform AIS reporting rates. This was achieved by multiplying the raw count in each bin by a factor equal to the bin's centroid speed prior to generating the distributions. These distributions are shown in Figure 2.

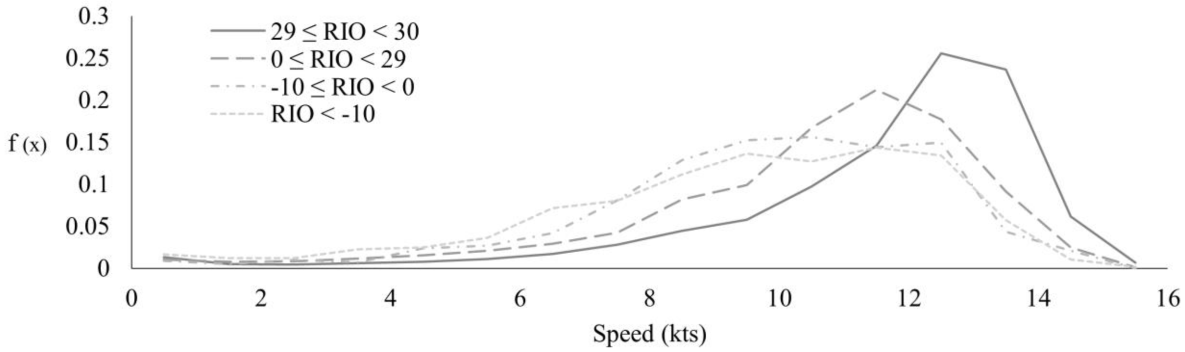

Figure 2. Probability Density Functions of ship speed, scaled to account for exposure.

The probability distributions of ship speed demonstrate a clear trend of speed reduction with decreasing RIO values, both for mild ice conditions versus trace ice and further reduced speed in increasingly severe ice (as indicated by negative RIO values). Factors that affect the extent of speed reduction include local variations in ice conditions that may allow ships to transit along relatively ice-free passages through the more heavily ice-covered regions described by the available ice charts. In addition, current practices during ice operations involve close coordination between commercial ships and both the Canadian and US coast guards, who perform ice management with dedicated icebreaking ships to maintain safe passages. Both coast guards are also known to provide ice-routing recommendations or operational restrictions such as daylight-only navigation in particularly hazardous ice conditions (English, et al., 2014). The data presented here suggest Great Lakes operators take a flexible approach and reduce their speeds to reflect unfavorable ice conditions, although the degree of speed reduction differs from current POLARIS recommendations for ships in similar ice conditions (IMO, 2016). While further work is needed to assess the magnitude of speed reduction that is appropriate for the Great Lakes, the main observation in the context of the present research is that operators currently employ speed reduction as an ice risk mitigation approach. A more complete assessment of local ice conditions and operational risk mitigations are necessary to inform speed restriction assessments.

Regional Analysis of Ship Operations

In order to identify particularly challenging regions and provide further context for the analysis, the positions of analyzed AIS data have been plotted over maps of the Great Lakes. These maps are shown in Figures 3 through 6, grouped by month from January through April. Three categories of AIS data are plotted on these maps: ice class ship records are shown as red dots for those locations where negative RIO values occur and as green dots for locations corresponding to positive RIO values, and icebreaker records are depicted as blue "x" markers. Data for ships in trace ice conditions (with RIO values between 29 and 30) have been omitted from these plots for clarity. It is important to note that these maps depict aggregate data taken across multiple ice seasons. As such, the presence of icebreaking ships only highlights the regions in which they have operated, and do not necessarily mean they were operating as an escort at the specific times when negative RIO values were calculated.

Few negative RIO values were observed for ship operations in January, presumably because the heavier ice conditions that would produce them do not tend to develop until later in the ice season. The negative RIO values that were calculated are restricted to Lake Erie and the adjacent Lake St. Clair and St. Clair River. There have been icebreaker operations in January near these locations, and it is also apparent that icebreakers maintain passages between Lake Huron and Lakes Superior and Michigan, which corresponds to a shipping lane of operations with positive RIO values. Icebreaker operations can also be seen around Manitoulin Island in Lake Huron, and near major ports in Lake Superior and Lake Michigan (which include Thunder Bay and Duluth in Lake Superior, and Green Bay, Milwaukee and Chicago in Lake Michigan).

A greater number of negative RIO values were calculated for February versus January, which remain isolated to the same general region that includes Lake Erie, the Detroit River, Lake St. Clair, and the St. Clair River. Icebreaker operations can be seen within Lake Erie alongside the locations of negative RIO values, and it appears that icebreakers also maintain a passage between Lake Huron and Lake Michigan, on at least one occasion through to Chicago. No AIS records are contained within Lake Superior during February, which is likely a result of heavy ice conditions that preclude ship operations as well as the closure of the Soo Locks.

Substantially more data is available for March versus previous months as the Seaway tends to reopen from winter lay-up by the middle of the month. A dense cluster of negative RIO values is again present in the general region comprising Lake Erie, the Detroit River, Lake St. Clair, and the St. Clair River. Unlike previous months, clusters of negative RIO values can also be seen between Lake Huron and Lakes Superior and Michigan. However, there also appears to be heavy icebreaker support during March in all three regions. Additional negative RIO values can be seen in the ports of Thunder Bay and Duluth in Lake Superior, with corresponding icebreaker operations.

The distribution of negative RIO values is fairly similar between March and April. However, there is a lower ratio of positive RIO values, indicating that the majority of ice operations during April are within persisting patches of unavoidable heavy ice and rubble buildup. A large cluster of negative RIO values can be seen in the eastern half of Lake Erie, which is a known problem area following spring breakup (U.S. Army Engineer District Detroit, 1979). Additional clusters of negative RIO values exist between Lake Huron and Lakes Superior and Michigan, along the St. Lawrence River, and again near Thunder Bay and Duluth in Lake Superior. Icebreaker support is apparent at each of these locations.

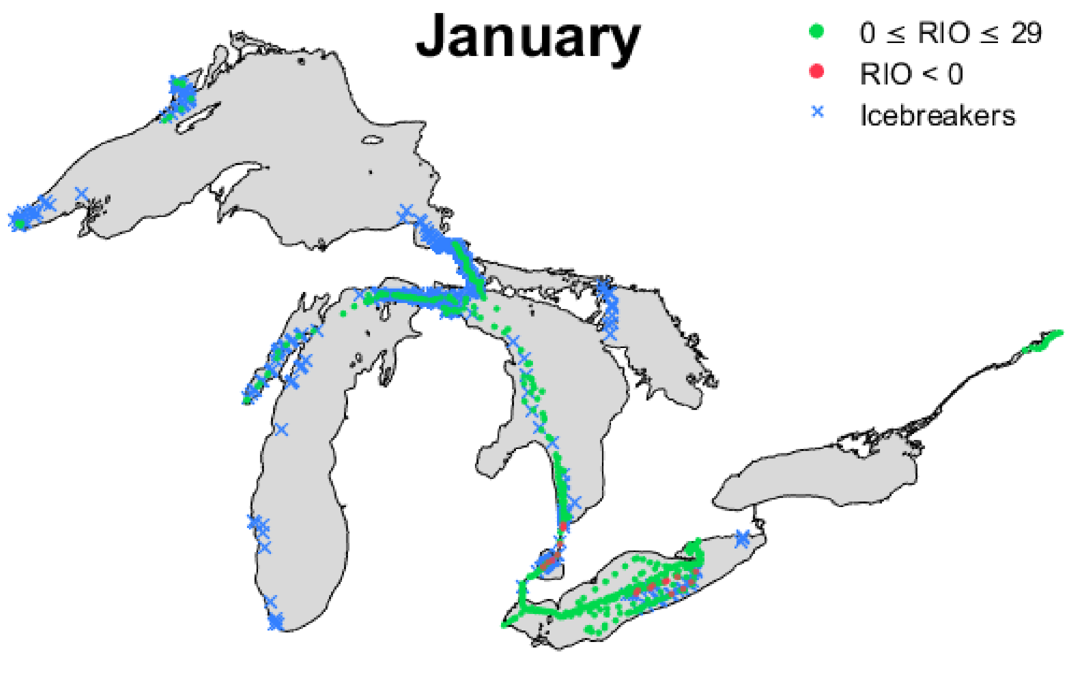

Figure 3. Distribution of calculated RIO values for ice class ships and icebreaker positions in 1/10 or greater ice concentrations during the month of January from 2010 to 2019.

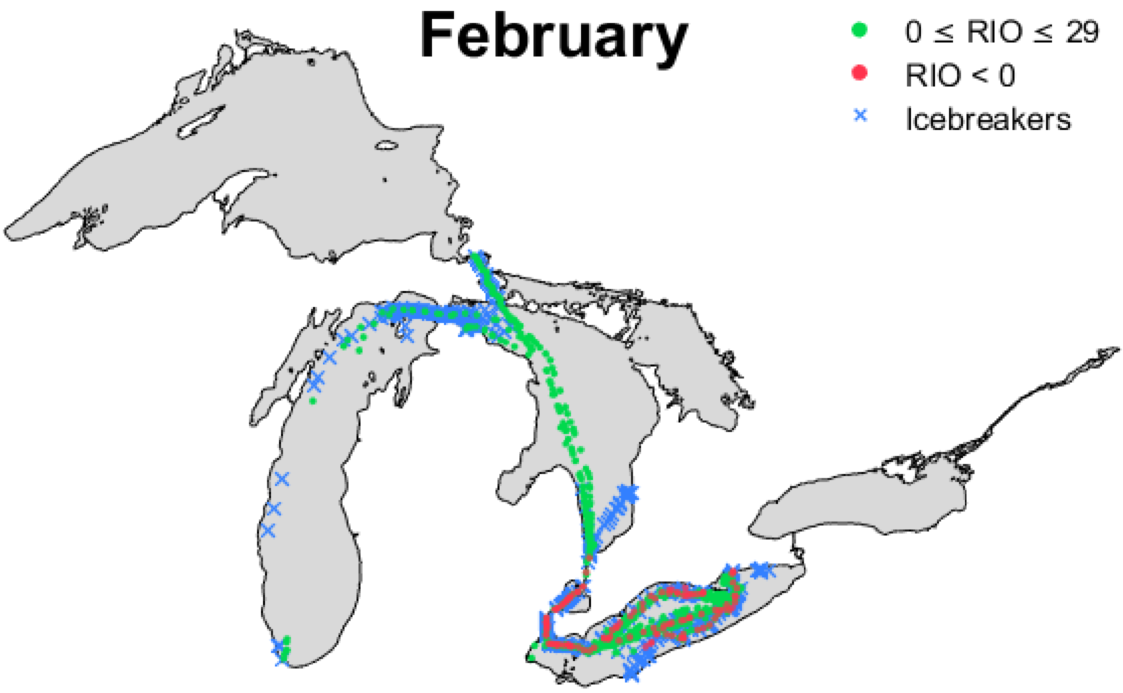

Figure 4. Distribution of calculated RIO values for ice class ships and icebreaker positions in 1/10 or greater ice concentrations during the month of February from 2010 to 2019.

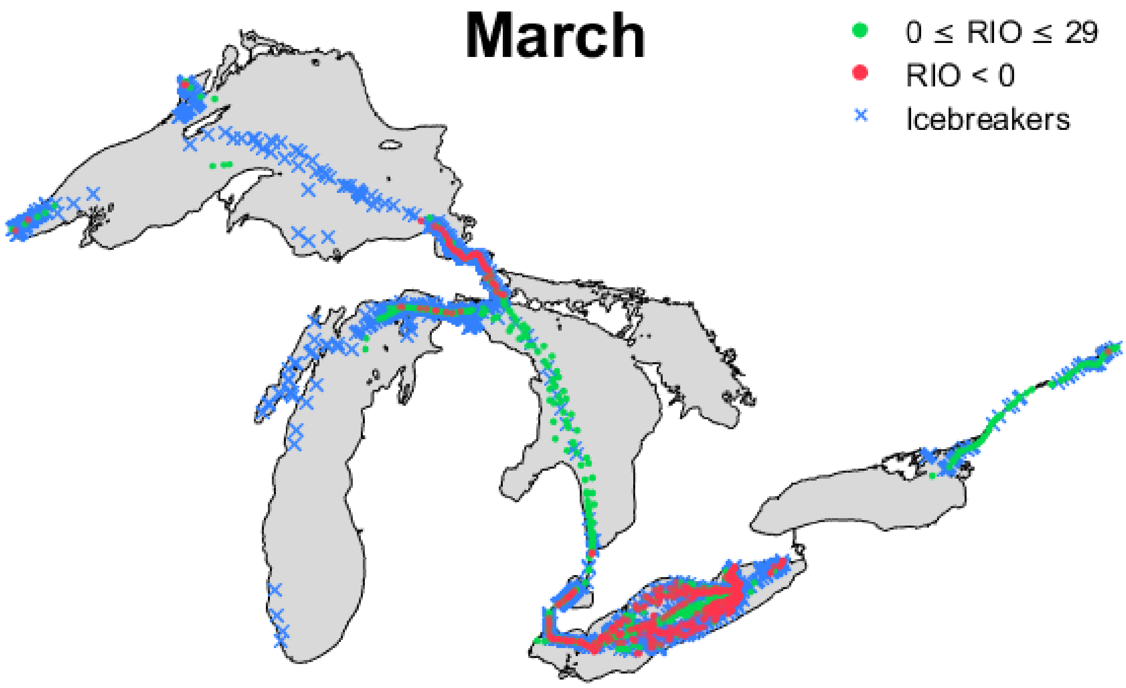

Figure 5. Distribution of calculated RIO values for ice class ships and icebreaker positions in 1/10 or greater ice concentrations during the month of March from 2010 to 2019.

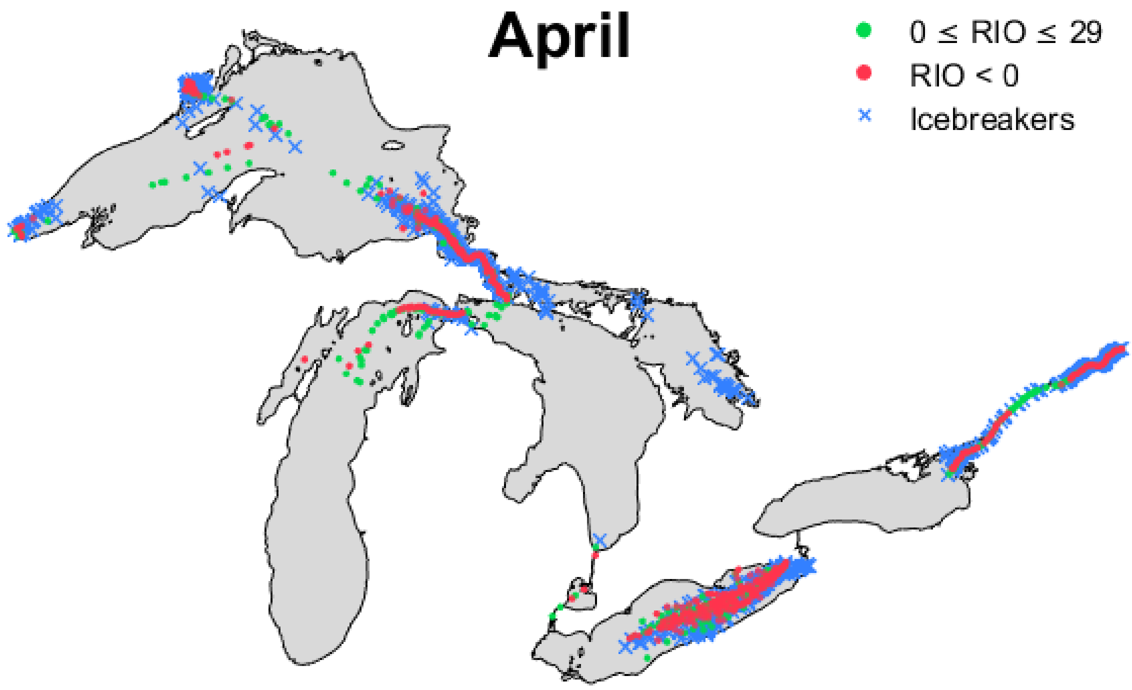

Figure 6. Distribution of calculated RIO values for ice class ships and icebreaker positions in 1/10 or greater ice concentrations during the month of April from 2010 to 2019.

In general, it is observed that negative RIO values tend to occur in specific regions throughout the lakes. In particular, Lake Erie can be seen to experience consistently heavy ice conditions that result in negative RIO values throughout the entire ice season. The passages between Lake Huron and both Lake Michigan and Lake Superior demonstrate similar trends with heavy ice conditions later in the ice season. The distributions of RIO values seen over the studied period from 2010 to 2019 align with earlier studies of ice cover in the Great Lakes, although these are based purely on ice coverage and do not consider thickness (Wang, et al., 2012; Assel, 2005). In brief, Lake Erie and Lake Huron have been reported to consistently experience heavy ice coverage due to their relatively shallow depths compared to the other Great Lakes, at 19m and 58m, respectively. Lake Superior is also known to experience heavy ice coverage despite being the deepest of the lakes with a mean depth of 148m. However, it does not typically develop significant ice coverage in milder winters, largely due to its high heat capacity resulting from its depth and water volume. This is reflected by the distribution of both positive and negative RIO values throughout Lake Superior in April, which would indicate year-to-year variability in ice severity. Lake Ontario and southern Lake Michigan are stated to not typically develop extensive ice coverage due to comparatively milder winter air temperatures and high mean depths at 85m and 86m, respectively (Assel, 2005). Correspondingly, few ice operations are apparent in either region.

Overall, these distributions of calculated RIO values and icebreaker operations appear to align with the aforementioned operational practices of Canadian and US coast guards (English, et al., 2014). Icebreaking ships have frequently operated in the areas with the highest density of negative RIO values, and few negative RIO values occur in areas where no icebreaker has operated across the studied period. This would imply that many of the negative RIO values that were calculated may not accurately reflect the actual local ice conditions ships were operating in if one assumes they were operating with an icebreaker escort or travelling along maintained shipping routes. Future work is recommended to explore if it is possible to better correlate specific individual instances of negative RIO values with the presence of icebreaker escorts.

CONCLUSION AND RECOMMENDATONS

A preliminary study of ice class ship operations in lake ice within the North American Great Lakes between 2010 and 2019 has been completed. In this investigation, the POLARIS methodology has been applied to calculate RIO values for ships of known ice-class operating in ice conditions based on ice charts corresponding to historical ship tracks obtained from AIS data. As a starting point, approximate ice thickness equivalences between lake ice and ice types used in POLARIS have been assumed.

Results obtained from this study provide valuable insights into the nature of current ship operations in ice in the Great Lakes as viewed through the lens of the POLARIS method. Overall, the trends observed from historical operations suggest that current practices are well aligned with POLARIS guidelines (89% of ice operations are in positive RIO values) and risk mitigating measures used in the Great Lakes (e.g. icebreaker support, speed reductions) are compatible with the approaches recommended in POLARIS.

Given the preliminary nature of this study, it is recommended that a more detailed analysis of the correlation between historical ship operations and ice breaking activity in specific regions be conducted to provide a better understanding of the degree to which ships operate in managed ice conditions. Further exploration of the POLARIS guidelines in the context of adapting mitigating measures into operational guidance for the Great Lakes is also recommended. The use of a unified ice-class system for ships operating in the Great Lakes would be required to allow for the calculation of RIO values for all vessels in the region. Clarifying vessel ice classes would furthermore allow for the inclusion of verifiable unstrengthened (non-ice class) ships which in turn would expand the available dataset for future analysis.

Since ice conditions used in this study reflect general ice chart conditions rather than the specific ice conditions encountered by ships in transit, opportunities to obtain detailed local ice condition information should be explored where possible (e.g. from ship logs or other ice records).

While it is well known that lake ice and sea ice/glacial ice (as considered in the Polar Code) have different properties, it is not evident how such differences in ice types would translate into differences between the current POLARIS method and a modified "Freshwater POLARIS". To this end, research is needed to assess the impact of differences in ice properties in terms of potential for ship damage and appropriate speed limits, as well as assessing the need for possible modification of Risk Index Values for lake ice.

In summary, the results of this preliminary study suggest that a modified POLARIS method suitable for operations in the Great Lakes represents a promising approach. The potential to codify current best-practices for shipping operations in the Great Lakes into such a modified method would help ensure consistency in the assessment of operational capabilities and limitations for different classes of vessels operating in lake ice. This in turn would provide greater clarity regarding expected mitigating measures and would help support effective decision-making relating to ship operations in ice. Further work to advance this approach represents an exciting direction for continued research and development.

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