ICE RISK MANAGEMENT

Entering the "white space" on the map

BY NIGEL GREENWOOD AND IVANA KUBAT

The historical means of prudent navigation in unknown regions ("operational risk management" in modern terms) has been to follow directions and advice in the written pilot books of those who have been there before. In northern, ice-covered seas, many centuries of such experience identified windows of favorable opportunity for successful passages for vessels of limited strength and power during short navigational seasons. Even then, anomalous years of unusually harsh conditions could catch voyagers by surprise, as Franklin experienced in the difficult ice years of 1845-1847.

The traditional approach to polar navigation was captured in the early arctic pilots of Canada through general discussion of favorable dates in different channels and straits. This was incorporated in a more detailed, but still fundamentally empirical fashion, in the Zone-Date System (ZDS), which was introduced with the Arctic Shipping Pollution Prevention Regulations (ASPPR) in 1972. In that system, the Canadian Arctic has been divided into 16 zones, to which access dates were determined based on a vessel ice class—nine arctic classes and five type (Baltic) ships.

In modern times, however, the availability of detailed climatological records, satellite observation of meteorological and ice conditions, global telecommunications, and advanced analysis of different ice-classed vessels' performance in ice permit more deliberate risk calculation solutions. Key among these are the Canadian Arctic Ice Regime Shipping System (AIRSS), the International Maritime Organization's (IMO) Polar Operational Limitation Assessment Risk Index System (POLARIS), and the Russian Ice Certificate system (Ice Passport). In addition, the National Research Council of Canada (NRC) has undertaken a significant effort to consolidate years of research and data on sea ice conditions, ice hazards, physical properties,

The availability of detailed climatological records, satellite observation of meteorological and ice conditions, global telecommunications, and advanced analysis of different ice-classed vessels' performance in ice permit more deliberate risk calculation solutions. Photo by Nigel Greenwood.

Risk assessment is still a matter of correct identification of ice: FY or old, decayed or ridged? Photo by Nigel Greenwood.

met-ocean and other data into a supportive integrated system called the Canadian Arctic Shipping Risk Assessment System (CASRAS).

The objective of all of this development has been to replace the empirical system of risk management by coastal maritime administrations (i.e., access control) with something that is more adaptable to the effects of climate change; more flexible to accommodate observation of actual ice conditions; better tailored to recognize differences in ship capabilities and operational risk mitigation; and more scientifically based, particularly concerning the probability of actual damage to ships. Our purpose here will be to review recent efforts and solutions aimed at developing accurate and practical risk assessment tools for polar navigators.

Zone–Date and its alternative

The ZDS was introduced with the 1972 ASPPR, and with minor modifications, has remained the primary means of regulating traffic in the Canadian Arctic. Vessels reporting entry and progress under Transport Canada's northern marine traffic reporting and communications services system are free to proceed through any of the 16 zones if they conform to the open dates for their class and intended movement.

With amendment of the ASPPR in 1989, AIRSS was proposed as an alternate to the ZDS. AIRSS represents risk as a summation of numbers representing ice types, weighted by concentration and modified by ice multipliers appropriate to the ship's ice class. The resulting

Through the 1990s, a number of studies examined AIRSS in the light of practical experience.

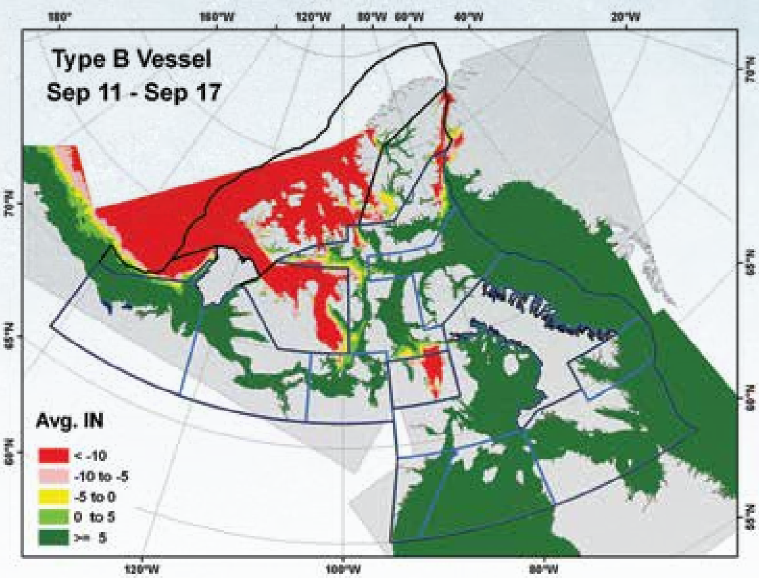
number determines allowable entry; an ice numeral (IN) thus calculated would indicate a GO if positive or a NO-GO if negative. This calculation is based on reported ice conditions along the route, modified by skilled observation and interpretation of conditions at the vessel's current location. Therefore, a condition of using this system is the requirement for the vessel's master and mates to be experienced in arctic ice navigation, or otherwise to carry a suitably qualified ice navigator.

A large effort was expended in the early days to ensure that this alternate system was not only compatible with the ZDS but also a reliable predictor of safe conditions of passage for various ships. Through the 1990s, a number of studies examined AIRSS in the light of practical experience. Vessel damage and non-damage events that occurred in ice in the Arctic were analyzed to validate the AIRSS. The AIRSS also was validated by analyzing voyages of vessels of Fednav, the Canadian Arctic shipping company.

Potential problems, however, were seen with AIRSS: there was no connection between the IN and speed or maneuverability of the vessel, and the calculated IN was very sensitive to differences in the recognized ice class of the vessel. In addition, some users felt the AIRSS system was overly complex and bureaucratic, and the definition of "ice regimes" was too indefinite, possibly leading to inordinate repetition of the calculations.

While the ice multipliers for each ice type were developed empirically to reflect navigability and performance in ice of each class of vessel, researchers at NRC were tasked to place the calculation of AIRSS INs on an irrefutable scientific basis. Accordingly, a set of 7 tasks was developed in 1998 to study the relationship of ship damage and corresponding IN, and to guide further development of AIRSS. A related study of more than 1,000 ship incidents in ice determined a good correlation between negative IN and ship damage. AIRSS was further tested during the regular deployment of CCG vessels in the Arctic. Observations of ice conditions were recorded alongside the masters' judgments of risk, showing generally good agreement between CIS ice charts and bridge observations. However, CIS ice charts were seen to over-predict the IN; that is, CIS charts under-estimated the amount of old (strong) ice and thus generated an erroneously favorable result. This finding underlines the value of having constant, careful and experienced observation of ice types from onboard the ship. Another observation of the damage study was to note greater incidence of damage at IN between 0 and +5 than between 0 and -5; this is either a result of the preceding point (conditions being worse than predicted) or possibly the use of excessive speed due to the mariner's lack of experience.

Further examination of the NWP-transit implications of AIRSS in mild and severe ice years determined that an ice regime system was essential for coping with the increasing variability of ice conditions due to climate change—the ZDS was too rigid for the climate changes being seen. Alongside these developments, work by the NRC investigated ice strength and provided a guide to the proper identification of old ice in summer. Michelle Johnston and Gary Timco's 2008 guide is a key element of in-situ risk management as the ice navigator must recognize and avoid strong ice that may not be observed by remote sensing and then use this visual input in AIRSS calculations.



Modern risk calculation for ice navigation shows that zone access is not a matter of simple open-and-closed dates. Image courtesy NRC.

Ice multipliers

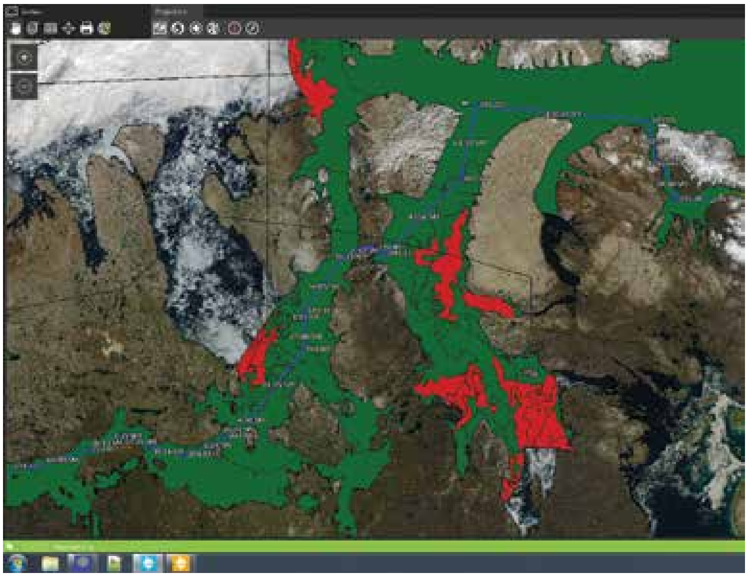
The outcome of the preceding work was the recommendation for a hybrid system composed of the ZDS combined with the ice regime system at the beginning and end of the shipping season. Comparison of calculated IN based on many years of ice records provided a statistical argument for lengthening the navigational season in some areas. Further work in 2011 validated the applicability of the ice regime system by examining the probability of positive IN for three type and five Polar class vessels in all 16 zones, based on multiple years of recorded ice conditions.

These studies illustrated the value of the ice regime approach through the examination of hypothetical routes and vessel types. Quantifying ice regimes for safe navigation has provided a recognized methodology for a variety of numerical approaches to examine arctic navigation: past, present, and future. This extends to digital evaluation, which automatically determines shortest-safest routes.

Still, concerns raised earlier remain unaddressed in the current version of AIRSS. The ice multipliers (IM) assigned to vessel classes for the different types of ice may not go far enough in recognizing salient factors that contribute to mitigating risk. Those factors include speed of the vessel; experience of the operators; the ability of the ship to access accurate ice information onboard; availability of ice detection equipment onboard; ice floe size; and visibility.

Studies in 2002 identified four approaches for moving forward:

1. Status-quo: maintain the use of the existing table of IM, using adjustments for rough (ridged) or decayed ice conditions
2. Modification to the IN: adding a modifier to the calculated ice numeral to account for mitigating factors such as slower speed
3. Integer bonus to the IM: add factors to the IM to credit available mitigations
4. Non-integer multipliers: providing tailored and more precise IM to each ship, corresponding to the particular ship and voyage.



IceNav: an immediate depiction of GO (green)/NO-GO (red) calculated in AIRSS from shapefiles of CIS ice charts. Image by Nigel Greenwood.

The production of the ice certificate is a significant undertaking, which is carried out by the Central Marine Research and Design Institute of Saint Petersburg.

For various reasons relating to the complexity and difficulty of definition, none of these change options were further developed for implementation.

POLARIS and the Russian Ice Passport

Notwithstanding the preceding critiques of AIRSS, it is a practical system that establishes prudent limits. A similar system, the IMO's POLARIS, which is closely modeled on AIRSS, is an element of the Polar Code that came into effect in January 2017. For Canada, with adoption of the Polar Code, POLARIS becomes a third acceptable means of determining navigational access to the Canadian Arctic.

POLARIS addresses some of the shortfalls of AIRSS. Similar to AIRSS, it aggregates the products of numbers representing ice types and concentrations with ice multiplier related to the class of ship. Importantly, its risk index values (equivalent to IM in AIRSS) are oriented to IMO polar classes and Baltic ice classes, and thus avoid the difficulty of establishing equivalence with Canadian Arctic classes.

POLARIS differs from AIRSS in the interpretation of the resulting ice numeral (called risk index outcome, or RIO, in POLARIS). Whereas AIRSS presents the result as a strict GO/NO-GO decision, POLARIS permits a range of responses to RIO between 0 and (-)10. These responses vary according to ice class. For vessels of classes PC1 to PC7, this domain of elevated operational risk requires speed reductions according to class. The reduced speed ranges from 11 kts for PC1 to 3kts for PC4 and below. For vessels below PC7 (those not assigned an ice class), operations in such conditions are subject to special consideration, which means consideration of rerouting and/or escort by icebreaker, along with speed reductions. In the case of such escorted operations, a bonus of 10 is given to the RIO of the escorted ship. For all classes of ship, a RIO of less than (-)10 requires

LEFT: Co-author Nigel Greenwood worked on this article onboard RV *Xue Long* as it completed its circum-polar voyage of the Arctic with a transit of the Northwest Passage. Image by Nigel Greenwood.

RIGHT: From co-author Greenwood's voyage on RV *Xue Long*, a view of the ship's system displaying a feed from the University of Bremen's remote sea ice observation program. The resolution is very coarse and not of much help for tactical ice navigation. Image by Nigel Greenwood.

special consideration of the operation, and in most cases a recommendation not to proceed.

For application to the Northern Sea Route between the Barents and the Chukchi Seas, the Russian Ice Certificate (formerly Ice Passport) follows an approach similar to the AIRSS improvement option number 4 with added specific information. The ice certificate is produced for each unique ship design and amounts to a detailed operational guide for the use of that ship in ice. Through examination of design parameters and construction strength (capability to operate under conditions of elastic deformation), the ice certificate defines attainable, admissible and safe speeds. These quantities are presented in tabular and graphical form for a range of different conditions of ice thickness, ridging and ice pressure, floe size, and ship loading. Additional graphs indicate safe following distances for escorted ships based on speed, ice thickness and ice concentration.

The production of the ice certificate is a significant undertaking, which is carried out by the Central Marine Research and Design Institute of Saint Petersburg. The ice certificate provides very detailed information to the navigator for a closely defined range of conditions. While such an approach is very precise, it would not be practical for the multitude of possible conditions to be encountered in the Canadian Arctic. Moreover, the effort and cost would not be warranted for a ship making a rare single transit. For such uses, the AIRSS/POLARIS methodology may provide a more easily adaptable tool for practical risk assessment of ice navigation options.

Supporting data and tools

Whatever system of ice navigation control is adopted, the ice navigator (or shipping company planner) must access relevant information from a wide variety of sources. The temporal nature of the data ranges from stable, fixed data (for example, some hydrographic and ship parameters) to established records (such as ice climatology) to transient conditions (for example, actual ice parameters in the vicinity of the ship). Additionally, compliance with constraints of regulation and defined protected areas requires verifiable up-to-date information.

Accessing the large volume of available necessary data in a manageable form can be a challenge. The National Research Council of Canada has addressed this need by developing a comprehensive integrated risk assessment system that aims at serving the needs of voyage planners for Canada's Arctic. This dynamic system, CASRAS, combines a vast amount of information concerning climatological, hydrographic, ice dynamics, marine protected regions, places of refuge, and other relevant geographical information. The system incorporates more than 100 datasets (with memory exceeding 300GB) in a platform that provides advanced visualization responses to a large range of geographic-based queries. The users can define their queries and also probe through the response to access the underlying data.

For route planning in Canadian Arctic navigation, CASRAS can present the results from any of the ZDS, AIRSS, or POLARIS methods as well as comparisons between these. It also allows hypothetical substitution of different classes of ship. The extensive range of databases permits analysis of inter-annual variability to calculate probability of success for different windows and areas of prospective transit. CASRAS constitutes an effective tool for both shore-side and ship-based risk analysis.

In contrast to CASRAS, which provides extensive historical and present datasets, other systems provide displays of a limited number of present datasets and calculations of IN. For example, an effective approach to onboard risk assessment was taken by Enfotec (a subsidiary of Fednav). Their system, IceNav, combines the strength of GIS technology to layer the ship's route

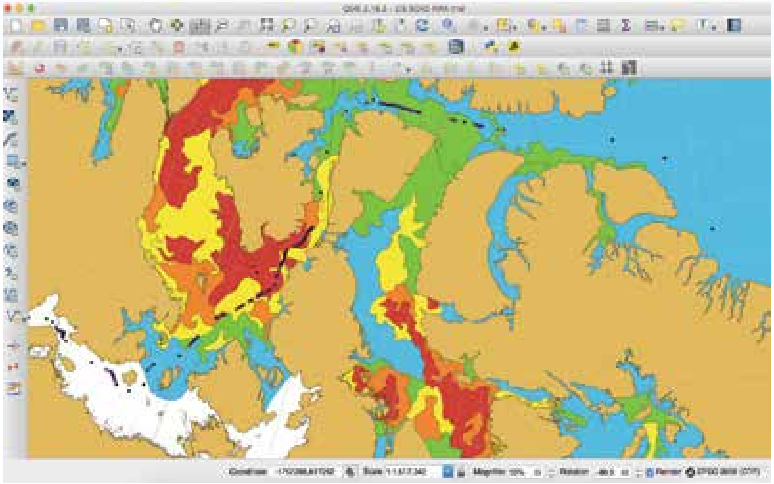
The practical execution of passages in ice-covered waters with the tools we have outlined still relies on continuous robust connectivity.

over available ice imagery, either CIS ice charts, satellite imagery (visual or Radarsat), or even the ship's radar input. That provides excellent support for tactical ice avoidance and also route planning. With the selection of geo-referenced CIS charts, IceNav calculates the ice numeral and may present the transit area as a dia-chromatic plot of GO or NO-GO areas. In addition, IceNav manages the AIRSS calculations to automatically format the ice regime routing message, which is required as a condition of accessing the Canadian Arctic outside of the Zone-Date system.

The navigator and safety

The understanding of nautical risk management has greatly advanced in the past few decades. The precision of navigation has been enhanced by substantial access to detailed information at almost any point on the globe. These advances, however, are becoming ever more necessary to meet the increasing demands for safe performance, close to the margins, coupled with regulatory and public risk tolerance tending toward zero.

Polar navigation poses additional formidable challenges due to the harsh and complex Northern environment. Not only is the climate severe, but it is also extremely variable; climate change is evident when seen in historical perspective, but the general warming trend can be hidden in the unpredictability from year to year. The inaccessibility of the region means that any incident would be too far from help for a prompt rescue. This is especially a concern with ships that are built to operate in mild ice conditions and which are bringing large numbers of tourists to "see the ice before it disappears."



A layering of Canadian Ice Service weekly regional ice charts on a GIS system. This is scalable and the ship's planned track can be plotted accurately on the ice chart, but it doesn't have the fidelity of CIS daily ice charts. Image by Nigel Greenwood.

Practical, effective risk management tools are therefore—more than ever—a requirement of safe navigation. The evolution of ice-classed ships is steadily improving the survivability of vessels to cold and recurrent ice impacts. The methodology of AIRSS and POLARIS provides a more reliable guide to the safe operation of such ships than the previous ZD system, and data repositories and visualization tools such as CASRAS and IceNav enable useful access to the broad base of available knowledge.

However, to close on a cautionary note—the practical execution of passages in ice-covered waters with the tools we have outlined still relies on continuous robust connectivity. Apart from the preparatory voyage planning, the operation of AIRSS and POLARIS relies on constant accessibility to current satellite reconnaissance and the work of skilled analysts at national ice services. But as much as it is possible to call home to Shanghai from 75 North, it is still possible for a ship to be without satellite service for a week in the middle of the Northwest Passage. In such a situation, one also hopes that the onboard resources, training and skill of the ice navigator are sufficient to guide the ship safely through the surrounding conditions. **MT**

__Nigel Greenwood__ is a retired rear admiral of the Royal Canadian Navy and a currently licensed master mariner. He worked on this article onboard RV Xue Long *as it completed its circum-polar voyage of the Arctic with a transit of the Northwest Passage. __Ivana Kubat__ has worked at the National Research Council of Canada on ice engineering issues since 1998. Currently, she is leading the development of a Canadian Arctic Shipping Risk Assessment System for marine transportation in the Canadian North.*