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ICE REGIMES ENCOUNTERED DURING THE USCGC HEALY ICE TRIALS

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ABSTRACT

Part of the Canadian contribution to the USCGC Healy Ice Trials was to provide complete documentation of the ice regimes encountered during the first stage of the Ice Trials. During its voyage from Halifax, Canada to Nuuk, Greenland the ship transited 118 different ice regimes. An overview of the voyage is presented using eight of those regimes. A photograph of the ice regime is given, along with a summary of the total ice concentration, constituent ice types, climatic conditions and ship speed. The ice severity in each regime is indicated by the Ice Numeral, which is calculated based upon the requirements outlined in the Arctic Ice Regime Shipping System (AIRSS).

RATIONALE FOR THE PROJECT

The ice regimes and associated Ice Numerals that were encountered during the USCGC Healy Ice Trials were documented to provide a continuous record of the ice conditions encountered over the three-week voyage. Although this type of information has been documented previously (e.g. Norland Science, 1994a; 1994b), few papers have focused upon describing ice regimes and their corresponding Ice Numerals. This paper was structured so that the reader could easily relate the total (and partial) ice concentration(s) of an ice regime to a photograph of that regime and the corresponding Ice Numeral.

ARCTIC ICE REGIME SHIPPING SYSTEM (AIRSS)

At present, the Zone/Date System is used to regulate navigation in Canadian waters above 60° North latitude. This system divides the Canadian Arctic into 16 zones. Ship access to those zones depends upon the ice severity for a particular time of year (obtained from historical records) and the ice class of the vessel. Transport Canada has proposed the *Arctic Ice Regime Shipping System* (AIRSS) that uses actual ice conditions instead of historical ice conditions (AIRSS, 1996; ASPPR, 1989; Canadian Gazette, 1996). The Ice Regime System defines different areas of ice using *ice regimes* and grants (or denies) access to those regimes according to actual ice conditions and the ship type or class. Currently, the Ice Regime System is being tested outside the Zone-Date system, with "after-action" reports submitted to Transport Canada. Provided due diligence is maintained, AIRSS is intended to be a more flexible system for vessels navigating in the Canadian Arctic.

Ice regimes are defined as a homogeneous area of ice having component ice types of proportionate ice thickness and concentration. An Ice Numeral (IN) is used to determine whether a vessel can enter a particular ice regime. For each regime, the Ice Numeral will be either positive, zero or negative. A regime that has a positive or zero Ice Numeral would permit a vessel to enter that regime. Conversely, a vessel would be denied access to a regime with a negative Ice Numeral. AIRSS (1998) states that an Ice Numeral is calculated as the product of ice concentration and its respective Ice Multiplier, as shown by Equation (1)

$$IN = \sum_{i=1}^{n} [C_i](IM_i) \tag{1}$$

where

IN = Ice Numeral

i = used to indicate ice type, denoted as open water (OW) to multi-year ice (MYI)

C_i = concentration of ice type i

IM_i = Ice Multiplier for ice type i

An individual ice regime is based upon nine ice types, as defined by the World Meteorological Organization (WMO, 1985, see Figure 1). The ice types in a regime each have a partial concentration, expressed in terms of 10^{ths} and denoted as C_i in Equation (1). The sum of the partial ice concentrations must equal $10/10^{ths}$ coverage, including the open water component. The manner in which Ice Numerals are calculated for regimes with a given ice type and concentration is discussed subsequently.

The importance of ice type on vessel class is weighted using an Ice Multiplier. The value of the Ice Multiplier for a particular type of ice ranges from 2 to –4, depending upon the class of vessel. Figure 1 shows the Ice Multipliers relevant to the Healy, classified (for these Ice Trials) as being able to operate with a CAC4 Ice Numeral. The Ice Multipliers shown in Figure 1 are valid for a CAC4 only. Figure 1 shows that the most severe ice types, such as multi-year ice and second year ice, are represented by negative Ice Multipliers (-3 and -2 respectively). Thick first-year ice is assigned an Ice Multiplier of 1 and a CAC4 has an Ice Multiplier of 2 for the thinner ice types.

The Ice Multipliers may be adjusted, depending upon the state (i.e. ridging or decay) of the ice in the regime. If the total ice concentration in a regime is at least 6/10^{ths} and at least 3/10^{ths} of an ice type is deformed (ridges, rubble or hummocked) then the Ice Multiplier for only the deformed ice is decreased by one. Once the ice has deteriorated significantly, it can be classified as decayed and the Ice Multiplier may be increased by 1 (for the decayed ice component).

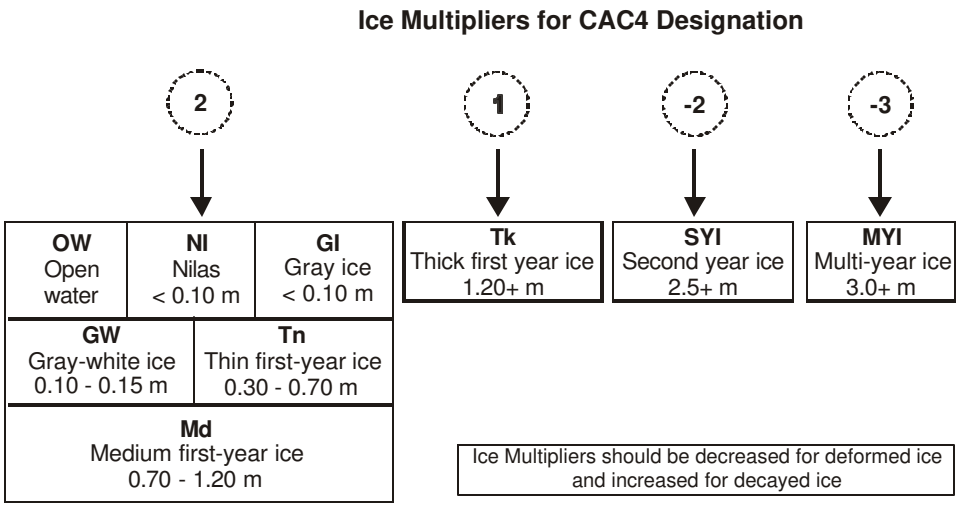


Figure 1 Ice Multipliers for a CAC4 designation, based upon ice type

DESCRIPTION OF VESSEL ROUTING

Ice regimes are best characterized from a shipboard observation program that continuously monitors ice conditions in the vicinity of the vessel with supplementary information from ice charts, reconnaissance flights and satellite images. The USCGC Healy Ice Trials provided an excellent opportunity to continuously document ice regimes over a three-week period. The first stage of the Ice Trials (referred to as Phase IIIa) extended from 2 April to 25 April, during which time the ship travelled from Halifax, Canada to Nuuk, Greenland.

During the northward voyage of Phase IIIa the ship travelled through the Gulf of St. Lawrence, along the Labrador Coast, into Davis Strait and across to Nuuk, Greenland (Figure 2). From 2 April to 4 April the ship crossed open water in the Gulf of St. Lawrence. On 4 April the ship encountered its first measurable concentration of ice (5/10^{ths}) in Ice Regime 2, north of the Strait of Belle Isle. Due to inclement weather and high seas the ship travelled in the marginal ice zone for most of the voyage north. When the ship was parallel with the tip of Labrador on 8 April, it altered course (into the pack ice) in search of level, first year sea ice for the test program. From 9 April to 23 April, the ship remained in the pack ice of Davis Strait, where performance tests were conducted in five regimes between Ice Regime 76 and Regime 111. The remaining regimes in Davis Strait were traversed en route to the various test sites. Phase IIIa concluded on 24 April in Nuuk, Greenland.

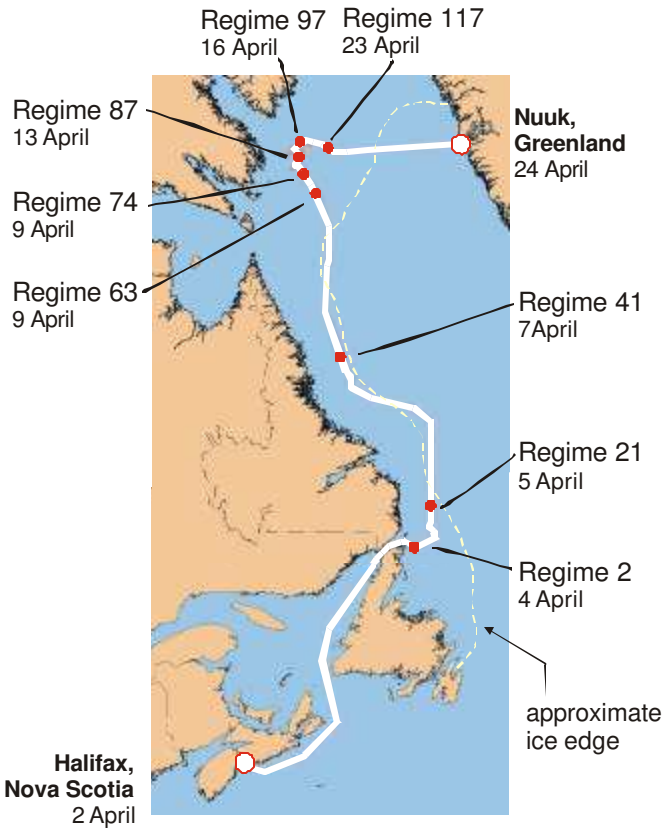


Figure 2 Routing of USCGC Healy during Phase IIIa of Ice Trials

ICE REGIMES ENCOUNTERED DURING THE VOYAGE

A total of 118 ice regimes were encountered during Phase IIIa. Figure 2 shows the location of the eight, quite different regimes that were selected as highlights of a wide range of ice conditions traversed during the voyage. A more thorough description of the regimes observed during Phase IIIa is given in Johnston and Gorman (2000). The numbering system used for the eight regimes described in this paper is based upon that report.

Regime 2: East Newfoundland, south of Belle Isle

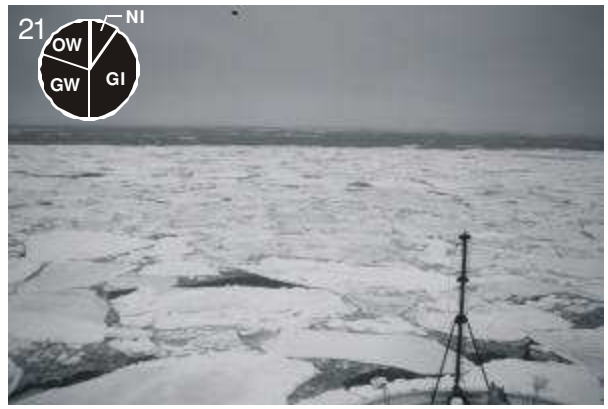
The ship encountered trace concentrations of young ice until it entered Regime 2 (51°33.27'N, 54°31.78'W) on 4 April. By that point, the vessel had passed through the Strait of Belle Isle where it encountered higher ice concentrations. Ice Regime 2 had a total ice concentration of 5/10^{ths} with some strips and patches of 8/10^{ths} concentration. The ice cover was comprised of medium (Md) to thick (Tk) first year ice cakes, from 2 to 10 m in

diameter. The air temperature was –2°C and the visibility was excellent. The along-track length of the regime was 7.7 n.mi, through which the USCGC Healy maintained an average speed of 9.0 kts (determined from digital output of the ship speed). A regime-related Ice Numeral of +17 was calculated for the Healy.

IN = +17 = {[5_{OW}] ? 2} + { [2_{Md}] ? 2 } + { [3_{Tk}] ? 1 }

Regime 21: Southern Labrador Sea

The ship entered Regime 21 (52°41.90'N, 53°42.60'W) on 5 April. The total ice concentration of 8/10^{ths} of Regime 21 was comprised of three primary ice types (nilas - NI, gray ice - GI and white-white ice - GW) and had trace concentrations of thin to medium first year ice. The ice cover classified as open pack ice with individual floes of 10 to 30 m diameter. The ship maintained an average speed of 8.1 kts throughout the along-track distance of 2.9 n.mi. The air temperature was –2°C, with fair visibility. A regime-related Ice Numeral of +20 was calculated for the Healy.



IN = + 20 = {[2_{OW}] ? 2} + {[1_{NI} + 4_{GI} + 3_{GW}] ? (2)}

Regime 41: Labrador Sea

Ice Regime 41 (57°20.20'N, 59°04.40'W) was selected to provide an example of an ice regime with 4/10^{ths} total ice concentration, comprised of equal concentrations of medium (Md) and thick (Tk) first-year ice and trace concentrations of glacial ice and multi-year ice. The first year floes were 10 to 20 m in diameter and showed some evidence of ridging. The multi-year floes had a diameter of about 20 m. The air temperature was –4°C and there was excellent visibility. Ice Regime 41 had an along-track distance of 10.4 n.mi, throughout which the ship maintained an average speed of 9.1 kts. A regime-related Ice Numeral of +18 was calculated for the Healy.

IN = + 18 = {[6_{OW}] ? 2} {[2_{Md}] ? 2} + [2_{Tk}] ?1}

Regime 63: Davis Strait

On 9 April, the ship entered Regime 63 (62°34.00' N, 60°39.00'W) in the pack ice of Davis Strait. The 9+/10^{ths} total concentration of ice consisted mostly of thin first-year ice (Tn) with some nilas (NI) and medium (Md) first-year ice. The regime also had trace concentrations of thick first-year ice and glacial ice. On average, the floes in Regime 63 ranged from 5 to 20 m in diameter. The air temperature was –16°C and the visibility was excellent. The average speed throughout the 4.2 n.mi. along-track distance of the regime was 7.3 kts. A regime-related Ice Numeral of +20 was calculated for the Healy.

IN =+20 = {[1_{NI} + 7_{Tn} + 2_{Md}] ? 2}

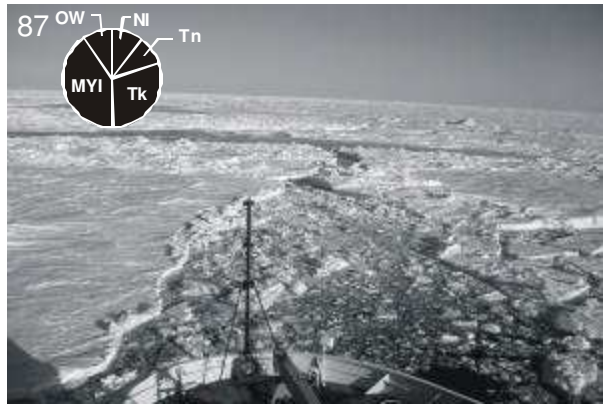
Regime 74: Davis Strait

Ice Regime 74 (63°16.30'N, 61°49.20'W) was encountered when the ship impacted a 5 km diameter, heavily ridged, first-year floe of medium thickness (Md). A considerable amount of backing and ramming was required in that regime. Consequently, it took just under one hour to progress through the along-track distance of 1.1 n.mi. The air temperature was –14°C and there was excellent visibility. Transit of the ridged floe required a substantial amount of backing and ramming therefore the average ship speed was only 2.4 kts. The Ice Multiplier was adjusted to account for the presence of ridged medium first year ice, as shown in the Equation below, resulting in an Ice Numeral of +10 for the Healy.

IN = +10 = {[10_{Md}] ? (2 – $1_{ridging}$)}

Regime 87: Davis Strait

On 13 April, the USCGC Healy entered the 9/10^{ths} total concentration of Regime 87. This regime was comprised of thick first year ice (Tk) and multi-year ice (MYI), with lesser amounts of nilas (NI) and thin first-year ice (Tn). The first year floes were from 50 to 500 m in diameter and were moderately ridged. The multi-year floes were over 3 m thick, about 500 m in diameter and had surface features that ranged from level to hummocked. Regime 87 had trace concentrations of glacial ice.



About two hours after entering Regime 87 the vessel rammed a 3 m thick multi-year floe and came to a full stop. The ship remained stationary until backing and ramming were resumed, seven hours later. Then, after about five minutes of ramming, the ship entered a wide lead. The average ship speed was 1.4 kts during the backing and ramming. The air temperature was –15°C and the visibility was excellent. Due to the high concentration of multi-year ice, Regime 87 was the first negative-numeral regime (IN of –3 for the Healy) encountered during the voyage.

IN = -3 = $\{[1_{OW}] ? 2\} + \{[1_{NI} + 1_{Tn}] ? 2\} + \{[3_{Tk}] ? 1\} + \{[4_{MYI}] ? -3\}$

Regime 97: Davis Strait

On 16 April the USCGC Healy impacted a 2 km wide, multi-year floe at about 3 kts. Reduced visibility and the smooth surface – thick snow cover of the multi-year floe made it extremely difficult to identify the ice as a multi-year floe. The homogeneous 10/10^{ths} coverage of Regime 97 consisted of one large, multi-year floe (MYI). The ice was under significant pressure, as shown by a ridge building event that occurred in the thinner ice (about 10 m from the starboard side of the vessel) and the rapid closing of the ship's track. Backing and ramming were required, repeatedly, to transit the severe ice conditions of Regime 97. The average ship speed in the regime was 1.8 kts. During transit, the air temperature was –4°C and there was fair visibility. Ice Regime 97 was the second negative-numeral Ice Regime that was encountered by the Healy during the voyage.

IN = -30 = $\{[10_{MYI}] ? -3\}$

Regime 117: Davis Strait

Upon completion of the performance tests on 23 April, the ship navigated towards the ice edge, where Regime 117 was encountered. The 9/10^{ths} total concentration in that regime consisted of mostly thin first year ice (Tn), with lesser concentrations of white-white ice (GW) and nilas (NI). Regime 117 also had trace concentrations of glacial ice. The ice cover consisted of 20 to 50 m diameter, level ice floes. The Healy had an average speed of 8.6 kts throughout the 20.3 n.mi along-track distance of the regime. The air temperature was –4°C and there was good visibility. A regime-related Ice Numeral of +20 was calculated for the Healy.

IN = +20 = {[1_{NI} + 3_{GW} + 6_{Tn}] ? 2}

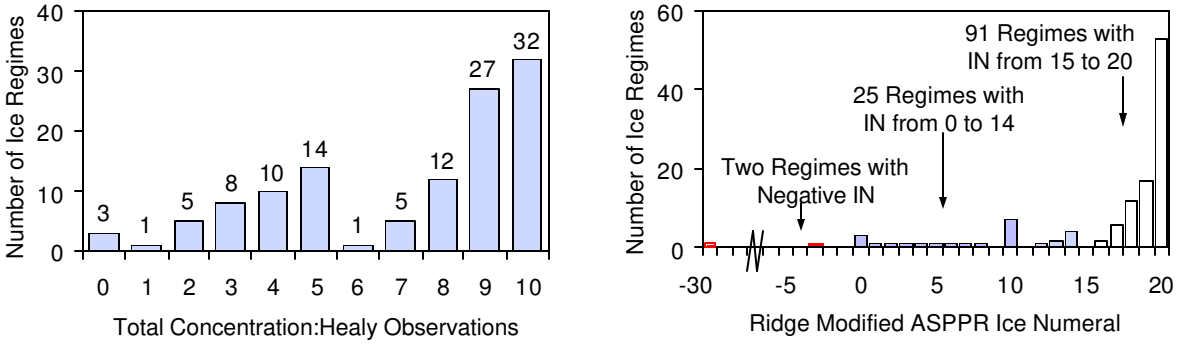
DISCUSSION

When vessels are normally transiting from their point of origin to destination they move as quickly, and safely as ice conditions and vessel capabilities permit. In comparison, the purpose of the Ice Trials was to ensure that the USCGC Healy was operating smoothly and that the ship satisfied its icebreaking capability of 3 kts in first year ice, 1.4 m (4.5 ft) thick. Due to the circuitous route of the USCGC Healy in searching for specific ice types, the frequency of encounter of "severe" ice types was not representative of actual conditions. Therefore it is difficult to compare the ice conditions encountered by (and vessel performance of) the USCGC Healy with those of a commercial vessel. In addition, the ship speed through the different ice regimes was not limited by ice conditions but rather by operational requirements and performance limitations that are inherent in a maiden voyage. Consequently, the data from Phase IIIa do not show a logical correlation between the ice type and ship speed.

Due to the above-mentioned limitations, the following discussion gives an overview of the wide range of ice conditions encountered during Phase IIIa. A total of 916 n.mi was travelled between Halifax, Canada and Nuuk, Greenland. The ship was in open water for 16% of the voyage (147 n.mi). During approximately 31% of the voyage (286 n.mi) the regimes had a total ice concentration of 9/10^{ths} or greater. Individual ice regimes ranged from 0.4 to 69.7 n.mi.

Figure 3-a shows the distribution of total concentration for the 118 regimes. Over 50% of those regimes had total ice concentrations that exceeded 9/10^{ths}. Thin, medium and thick first year ice occurred most frequently in the regimes (63%, 77% and 50% of the regimes, respectively). Grease ice, nilas and white-white ice were noted in fewer than 35% of the regimes. Multi-year ice was noted in 6% of the regimes in concentrations from 2/10^{ths} to 10/10^{ths}. Second year ice was not observed in any of the ice regimes.

Figure 3-b shows that about 77% of the total number of regimes encountered during Phase IIIa had Ice Numerals that ranged from 15 to 20 (91 regimes). About 21% of the regimes had Ice Numerals that ranged from 0 to 14 (25 regimes). Due to the a high proportion of positive Ice Numeral and the relatively low strength of the first year ice (calculated mean strength of 315 kPa/ 46 psi, per Jones et al., 2001) most of the regimes encountered by the USCGC Healy did not prove difficult for navigation. regimes with negative Ice Numerals were encountered less than 2% of the time (two regimes) during the three-week voyage.



(a) total ice concentration (b) Ice Numerals

Figure 3 Ice regimes encountered during Phase IIIa of the Ice Trials

CONCLUSIONS

The ice regimes encountered by the USCGC Healy during Phase IIIa of the Ice Trials 2000 were documented to broaden knowledge of ice regimes and their corresponding Ice Numerals. Most of the ice regimes traversed during this field program were characterized by relatively light ice conditions and had Ice Numerals that were zero or positive. Two ice regimes however were comprised of predominantly multi-year ice, as illustrated by their negative Ice Numerals. It should be noted that work is currently underway to develop a scientific basis (Timco and Kubat, 2001) for the Arctic Ice Regime System. Those developments take into account other aspects of the ice regime (such as overall visibility and vessel speed) that can have significant implications for vessel performance.

ACKNOWLEDGEMENTS

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