Ice Regimes Encountered during the Transit of the USCGC Healy: 2 April to 25 April 2000.

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http://dx.doi.org/10.4224/12340950

CHC CANADIAN HYDRAULICS CENTRE
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Technical Report HYD-TR-059

November 2000

National Research Council Canada | Conseil national de recherches Canada

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ABSTRACT

This report presents a synopsis of the ice conditions encountered by the United States Coast Guard Cutter Healy during Phase III of the Ice Trials. Phase III was conducted from 31 March to 25 April 2000 in the in the Eastern Canadian Arctic. During that voyage, 118 Ice Regimes were traversed. This report includes a detailed description of 20 of those Ice Regimes. Particulars about the ice conditions, vessel routing, ship operations and climatic conditions are given. An Ice Numeral is calculated for each Ice Regime using the methodology outlined in the Arctic Ice Regime Shipping System (AIRSS) Regulations. A brief evaluation of AIRSS is given, whereby the calculated Ice Numeral is correlated with the relative ease or difficulty experienced by the Healy in each Regime.

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1. INTRODUCTION

Navigation in Canadian waters under Canadian jurisdiction north of 60° North latitude is governed by the Arctic Shipping Pollution Prevention Regulations (ASPPR). Since the introduction of ASPPR ships of different classes or type have their access to the Arctic governed by the Zone/Date System. That system divides the Arctic into 16 zones, ranging from the most severe ice conditions (Zone 1) to the least severe conditions (Zone 16). Since the Zone/Date system relies upon the time of year to grant or deny access to areas of the Arctic, it does not take into account the inter-annual differences in ice severity. As a result, shipping regulations for Zone/Date System rely upon historical data of the ice conditions, rather than the actual ice conditions.

A new set of shipping regulations, the Arctic Ice Regime Shipping System (AIRSS) has been proposed to augment and eventually replace the Zone/Date system. AIRSS uses the actual ice conditions, rather than historical data, to describe *Ice Regimes*. An Ice Regime is defined as a homogeneous area of ice with component ice types of proportionate ice thickness and concentration. Since AIRSS is tailored to the ice conditions reported from passing ships and inferred from remotely sensed imagery it is more “route-specific” than the Zone/Date system. As a result, AIRSS provides a more flexible and safe system for vessels navigating the Canadian Arctic.

A fundamental component of AIRSS is the calculation of an Ice Numeral, which is used to advise a vessel whether it should enter or avoid a particular Ice Regime. The Ice Numeral is determined by ice severity of the Regime, the ability of the vessel to circumnavigate potentially dangerous ice and the ice strengthening capability of the vessel. To provide further data on AIRSS, the 118 Ice Regimes traversed during Phase III of the Healy Ice Trials were documented.

2. PLANNED ROUTE OF THE USCGC HEALY

The USCGC HEALY is a 16,000 LT vessel that was designed as a high latitude research platform. Some of the particulars of the Healy are listed in Table 1. The Healy was classified as a Canadian Arctic Class 4 (CAC4) vessel for this study although, strictly speaking, the Healy does not satisfy all requirements for a CAC4 vessel.

The Healy was delivered to the United States Coast Guard on 10 November 1999. On 26 January 2000 the vessel departed New Orleans, Louisiana on her maiden voyage to Seattle, Washington via the Northwest Passage. A set of dedicated Ice Trials was conducted during this maiden voyage. This report focuses upon Phase III of the Ice Trials entitled “Ice Breaking Performance in the Eastern Arctic”.

Table 1 Particulars of the USCGC Healy

Owner:	United States Coast Guard
Registry:	American Bureau of Shipping (ABS)
Length:	128 m
Beam width (maximum):	25 m
Draft:	8.9 m
Displacement:	16,000 LT
Propulsion:	Diesel Electric, AC/AC cyclo-converter
Shaft Horsepower:	30,000 HP
Propellers:	2 fixed pitch, 4 blade
Speed:	17 kts at 147 rpm
Ice Class:	CAC4: Capable of navigating in any thickness of first-year ice found in the Canadian Arctic, including first-year ridges. Avoid multi-year ice; if impossible, proceed by pushing or ramming at very low speeds.

The Healy departed Halifax, Nova Scotia on 31 March en route to the Eastern Canadian Arctic where tests were conducted to evaluate the ice breaking performance of the vessel. The performance evaluation required a range of ice types and thickness, resulting in an erratic navigation pattern, as shown in Figure 1. Clearly, the routing of the Healy did not represent the typical routing from point of origin to destination. The Healy first encountered ice near the Strait of

Belle Isle, on 4 April (Ice Regime 1 in Figure 1). The last observed Regime of Phase III (Ice Regime 118) was characterized by the ice edge/open water transition en route to Nuuk, Greenland on 24 April.

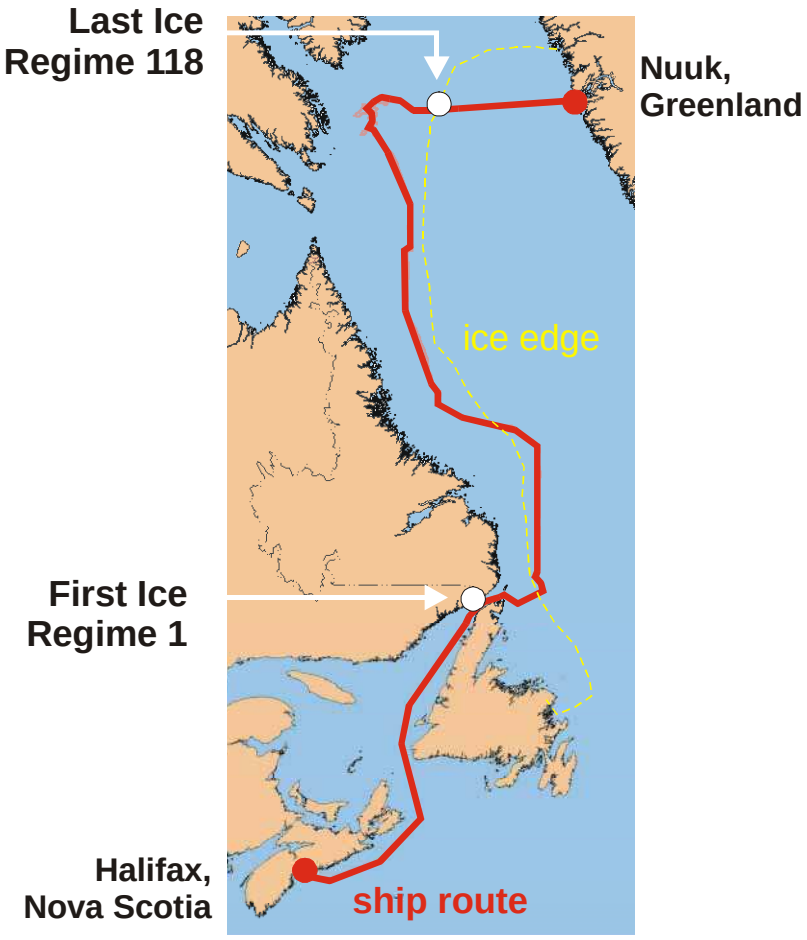

Figure 1 Route of the Healy during Phase III of the Ice Trials

3. METHODOLOGY FOR CHARACTERIZING ICE REGIMES

Ice Regimes are best characterized from shipboard ice observations. A thorough observation program requires continual monitoring of the along-track ice conditions. During the voyage of the Healy the following four categories were used to characterize an Ice Regime, as discussed below.

- Route Information
- Voyage Information
- Climatic Conditions
- Ice Conditions

3.1 Route Information

During the voyage, the Ice Regime was numbered consecutively and its general geographic location was noted. The beginning of a new Ice Regime occurred when there were changes in the ice type and ice concentration. Also documented were the vessel mode of operation (transit in open water, continuous transit in level ice, backing and ramming, etc.) and the person at the helm.

3.2 Voyage Information

Voyage information included the geographic coordinates and the time of entry/exit to the Ice Regime. That information was used to calculate the along-track distance of the Regime. The average speed and the maneuvering speed of the vessel during a Regime were determined from continuous speed profiles from the onboard instrumentation system. The average speed through a Regime did not consider occasions when it was necessary to stop for the night or when engine failure occurred. The maneuvering speed was the minimum speed required when negotiating the ice and, typically, coincided with the minimum speed in an Ice Regime (except for the above-noted stops). The overall ship performance and noteworthy features of the Ice Regime were also recorded.

3.3 Climatic Conditions

Documentation of the climatic conditions included noting the air temperature and wind speed by glancing periodically at the shipboard instrumentation system. The general visibility was described qualitatively, as supplemented by an estimate of the range of visibility (in nautical miles).

3.4 Ice Conditions

The ice conditions were characterized by estimating the total ice concentration and noting the component ice types in an Ice Regime. This information was then used to compute an Ice Numeral based upon AIRSS regulations. Following is a classification of the different ice types and the AIRSS methodology used in computing the Ice Numeral.

3.4.1 Ice Types

Ice type was categorized into eight classes, as defined by the World Meteorological Association (WMO, 1985).

Nilas (NI) – A thin elastic crust of ice, that easily bends on the swell and under pressure. Nilas forms a pattern of interlocking fingers, has a matte surface and can be up to 0.10 m thick.

Grease ice (GI) – Freezing stage at which ice crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, resulting in a matte appearance and can be up to 0.10 m thick.

Grey-white ice (GW) – Young ice (0.10 to 0.15 m thick) that is less elastic than nilas and breaks on the swell. Grey-white ice usually rafts under pressure.

Thin first-year ice (Tn) – First-year ice 0.30 to 0.70 m thick.

Medium first-year ice (Md) – First-year ice 0.70 to 1.20 m thick.

Thick first-year ice (Tk) – First-year ice over 1.20 m thick.

Second year ice (SYI) – Old ice which has survived only one melt season. Second year ice typically has a thickness of 2.5 m (sometimes more).

Multi-year ice (MYI) – Old ice up to 3 m or more thick that has survived at least two melt seasons.

3.4.2 Ice Thickness

The ice thickness was estimated by comparing an object of known dimensions (such as the sidelights that extended from the side of the hull) to the thickness of overturned ice pieces. The photograph in Figure 2, taken over-the-side from the top deck, shows an ice cusp as it overturned along the side of the hull. Figure 3 shows a 3 m thick piece of multi-year ice that was overturned in Ice Regime 87.

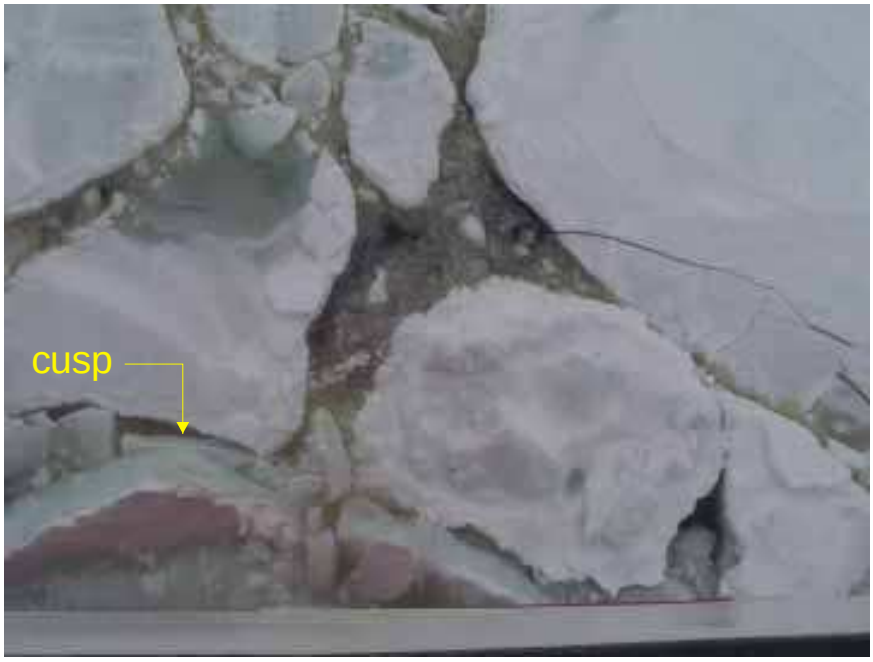

Figure 2 Cusp of First-year ice used to Estimate Ice Thickness

Figure 3 Cusp of Multi-year ice overturned in Ice Regime 87

3.4.3 Ice Numeral Calculations

AIRSS regulations were used to calculate an Ice Numeral for the Ice Regimes encountered during Phase III of the Ice Trials. AIRSS (1998) defines an Ice Numeral as the product of the ice concentration and the ice multiplier, as shown by Equation (1)

$$IN = \sum_{i=1}^{n} C_i \, IM_i \qquad (1)$$

where

IN = Ice Numeral
C_i = concentration of ice type i
IM_i = Ice Multiplier for ice type i
n = total number of ice types, i = 1 to n

An individual Ice Regime can be comprised of a maximum of ten ice types, ranging from open water (considered an "ice type") to multi-year ice. The ice types in a Regime each have a concentration, expressed in terms of 10^{ths} and denoted as C_i in Equation (1). When the sum of the partial ice concentrations does not equal $10/10^{ths}$ coverage, the remaining portion of the coverage is assumed to be open water.

The importance of ice type on vessel class is reflected in the Ice Multiplier, which ranges from 2 to –4. The value of the Ice Multiplier for a *particular type of ice* depends upon the *class of vessel*. Table 2 shows the Ice Multipliers relevant to the Healy, which was classed as a CAC4 vessel for these Ice Trials. **The Ice Multipliers shown in Table 2 are valid for a CAC4 vessel only.** The most severe ice types, such as multi-year ice and second year ice, are represented by negative Ice Multipliers (-3 and -2 respectively). An Ice Multiplier of 1 is assigned to thick first-year ice. Ice types thinner than thick first-year ice have an Ice Multiplier of 2. The calculation for the Ice Numerals in this report follows the notation of [ice type](Ice Multiplier).

The Ice Multipliers may be adjusted, depending upon the state of the ice in the Regime. When the total ice concentration in a Regime is $6/10^{th}$ or greater and $3/10^{th}$ or more of an ice type is deformed by ridges, rubble or hummocking the specified Ice Multiplier for that *particular ice type(s)* shall be decreased by one. In this report, when the Regime-related Ice Multipliers have been adjusted to account for ridging the modified Ice Numeral is referred to as a Ridge Modified Ice Numeral. In the case of decayed ice, the Ice Multiplier may be increased by 1. Calculation of an Ice Numeral will result in either a positive or negative number for a particular Regime. A positive Ice Numeral permits a vessel to enter the Regime and proceed with caution. A negative Ice Numeral advises the vessel to select an alternate route.

Table 2 Ice Multipliers for the Healy

Ice Type	CAC4 Ice Multiplier
Nilas, bergy water, open water (NI)	2
Grey ice (GI)	2
Grey-white ice (GW)	2
Thin first-year ice (Tn)	2
Medium first-year ice (Md)	2
Thick first-year ice (Tk)	1
Second year ice (SYI)	-2
Multi-year ice (MYI)	-3

4. ICE REGIMES ENCOUNTERED BY THE HEALY

A total of 118 Ice Regimes were encountered during Phase III of the Healy Ice Trials. A summary of the 118 Ice Regimes encountered by the Healy during Phase III of the Ice Trials is included in Appendix A. Particulars such as the latitude, longitude and start time of entry to the Regime are noted, along with the total and partial ice concentrations, the Ice Numeral and the general visibility during the Regime.

The following is a discussion of the most representative Ice Regimes, presented in chronological order. Figure 4 shows the selected Regimes according to the endpoint of their route segment lengths.

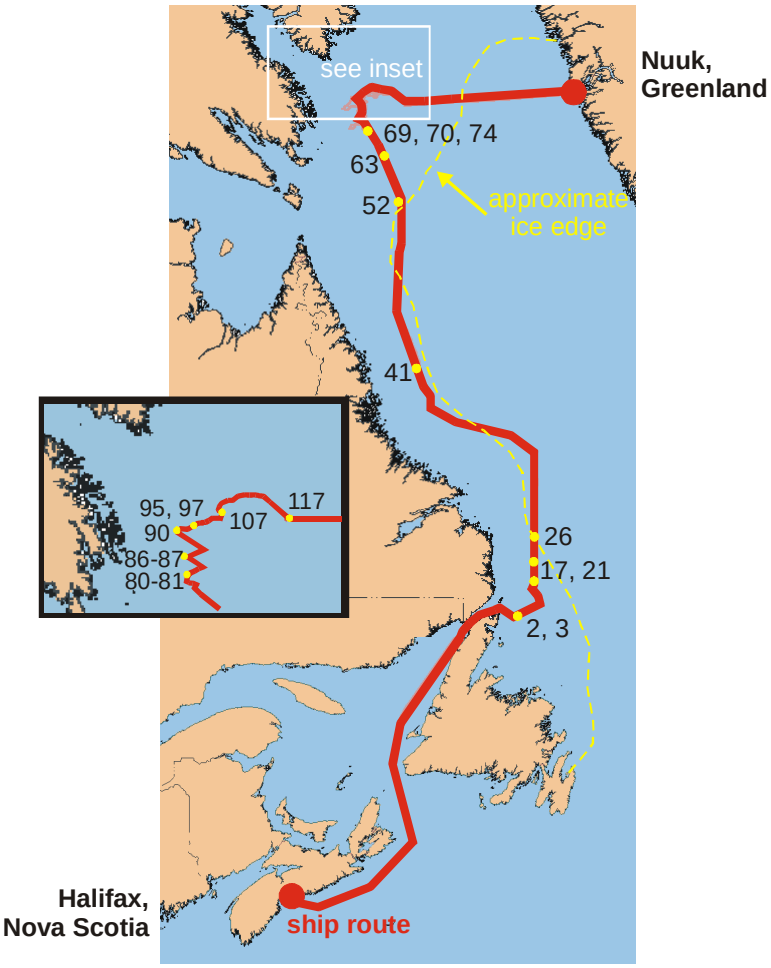

Figure 4 Selected Ice Regimes and their Route Segments

4.1 Regime 2: East Newfoundland, south of Belle Isle

Route Information

	Regime Entry	Regime Exit
Date:	4 April 2000	4 April 2000
Time:	19:07:00 UTC	20:00:22 UTC
Coordinates:	51°33.27'N, 54°31.78'W	51°36.60'N, 54°20.39'W
Total Distance:	7.7 n.mi	
Average Ship Speed	9.0 kts	
Maneuvering Speed	6.0 kts	

Climatic Conditions

Air Temperature:	-1.9°C
Wind Speed:	6.7 kts
Sources of Ice Information:	03 April RADARSAT (09:58, 21:22 UTC)
Visibility:	Excellent (10+ n.mi)
	04 April daily ice chart

Ice Conditions

Total Ice Concentration: 5/10^{ths}

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	2
Tk	3
SYI	0
MYI	0

Ice Numeral: **+17** = [5 + 2](2) + [3](1)

Description of Regime

Ice Regime 1 was characterized by the 69.7 nmi of open water between Halifax and the Strait of Belle Isle. The Healy traversed Ice Regime 1 from 2 April to 4 April. Although Regime 1 had trace concentrations of young ice, the Healy did not encounter any appreciable amount of ice until Ice Regime 2 (Figure 5). In Regime 2, the Healy traversed 5/10^{ths} total concentration of ice, with strips and patches of 8/10^{ths} concentration. The ice was medium to thick first-year ice in

the form of rough ice cakes, about 2 to 10 m in diameter. The floes in Regime 2 split easily and showed some surface decay. The Healy had an average speed of 9.0 kts and a maneuvering speed of 6.0 kts through Ice Regime 2.

The notation [Ice type](Ice Multiplier) was used to compute the Ice Numeral, which requires a total coverage of $10/10^{ths}$. Since the total ice concentration of Ice Regime 2 equaled $5/10^{ths}$, the remainder of the $10/10^{ths}$ coverage was open water. Open water, nilas, grey ice, grey white ice, thin and medium first-year ice all have an Ice Multiplier of 2 for a CAC4 vessel. The Ice Numeral of +17 for Ice Regime 2 was calculated as:

[$5/10^{ths}$ OW + $2/10^{ths}$ Md] (Ice Mulitplier of 2) + [$3/10^{ths}$ Tk] (Ice Multiplier of 1).

Figure 5 Ice Regime 2

4.2 Regime 3: East Newfoundland

Route Information

	Regime Entry	*Regime Exit*
Date:	4 April 2000	4 April 2000
Time:	20:00:00 UTC	21:29:00 UTC
Coordinates*:*	51°36.30'N, 54°20.39'W	51°41.24'N, 54°04.45'W
Total Distance*:*	10.7 n.mi	
Average Ship Speed	11.7 kts	
Maneuvering Speed	9.6 kts	

Climatic Conditions

Air Temperature:	-2.3°C
Wind Speed:	6.9 kts
Visibility:	Excellent (10+ n.mi)
Sources of Ice Information:	03 April RADARSAT (09:58, 21:22 UTC) 04 April daily ice chart

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	TR
Tn	3

Ice Type	Concentration
Md	5
Tk	1
SYI	0
MYI	0

Ice Numeral: **+19** = [1 + 3 + 5](2) + [1](1)

Description of Regime

Ice Regime 3 had a total ice concentration of 9/10^{ths} that was comprised of thin, medium and thick first-year ice interspersed with trace concentrations of grey-white ice. The cover was mostly roughened ice cake and open pack, with individual floes from 2 to 100 m in diameter (Figure 6). The ship had an average speed of 11.7 kts and a maneuvering speed of 9.6 kts through Regime 3.

Ice Regime 3 had an associated Ice Numeral of +19.

Figure 6 Ice Regime 3, forward of Healy

Figure 7 Ice Regime 3, along ship track from stern

4.3 Regime 17: East Newfoundland

Route Information

	Regime Entry	*Regime Exit*
Date:	5 April 2000	5 April 2000
Time:	15:30:00 UTC	16:30:00 UTC
Coordinates*:*	52°21.30'N, 53°45.20'W	52°29.60'N, 53°41.90'W
Total Distance	8.4 n.mi	
Average Ship Speed	8.5 kts	
Maneuvering Speed	6.5 kts	

Climatic Conditions

Air Temperature:	-2.2°C
Wind Speed:	20.0 kts
Visibility:	Fair (2 n.mi)
Sources of Ice Information:	04 April daily ice chart

Ice Conditions

Total Ice Concentration: **7/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	1
Tn	3

Ice Type	Concentration
Md	3
Tk	0
SYI	0
MYI	0
Glacial	✔

Ice Numeral: **+20** = [3 + 1 + 3 + 3](2)

Description of Regime

Ice Regime 17 had a 7/10^{ths} total concentration of grey-white ice and thin to medium first-year ice. The cover was comprised of ice cakes, 10 to 20 m in diameter (Figure 8) with some ridges, leads and glacial ice. Throughout Ice Regime 17 the Healy had an average speed of 8.5 kts and a maneuvering speed of 6.5 kts. Three fishing boats were encountered in Ice Regime 17.

Figure 8 Ice Regime 17

4.4 Regime 21: Southern Labrador Sea

Route Information

	Regime Entry	*Regime Exit*
Date:	5 April 2000	5 April 2000
Time:	17:57:00 UTC	18:18:00 UTC
Coordinates*:*	52°41.90'N, 53°42.60'W	52°44.80'N, 53°42.70'W
Total Distance*:*	2.9 n.mi	
Average Ship Speed	8.1 kts	
Maneuvering Speed	6.3 kts	

Climatic Conditions

Air Temperature:	-1.8°C
Wind Speed:	24.0 kts
Visibility:	Fair (2 n.mi)
Sources of Ice Information:	04 April daily ice chart, DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **8/10^{ths}**

Ice Type	Concentration
NI	1
GI	4
GW	3
Tn	TR

Ice Type	Concentration
Md	TR
Tk	0
SYI	0
MYI	0

Ice Numeral: **+20** = [2 + 1 + 4 + 3](2)

Description of Regime

Ice Regime 21 had a total ice concentration of 8/10^{ths}, most of which consisted of grey ice and grey white ice, with a lesser amount of nilas. Regime 21 had trace concentrations of thin to medium first-year ice. Ice cakes and open pack characterized the Regime, with individual floes from 10 to 30 m in diameter. The Healy maintained an average speed of 8.1 kts and a maneuvering speed of 6.3 kts. Figure 9, taken just before exiting Regime 21, shows the well-defined transition zone between Regime 21 and Regime 22.

Ice Regime 21 had an associated Ice Numeral of +20.

Figure 9 Ice Regime 21 (Regime 22 on horizon)

4.5 Regime 26: Labrador Sea

Route Information

	Regime Entry	*Regime Exit*
Date:	5 April 2000	5 April 2000
Time:	22:02:00 UTC	22:17:00 UTC
Coordinates*:*	53°16.60'N, 53°43.20'W	53°18.20'N, 53°42.70'W
Total Distance*:*	1.6 n.mi	
Average Ship Speed	6.3 kts	
Maneuvering Speed	3.0 kts	

Climatic Conditions

Air Temperature:	-0.8°C
Wind Speed:	8.0 kts
Visibility:	Fair (1 n.mi)
Sources of Ice Information:	05 April daily ice chart RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	2
Tn	0

Ice Type	Concentration
Md	3
Tk	4
SYI	0
MYI	0

Ice Numeral: **+16** = [1 + 2 + 3](2) + [4](1)

Description of Regime

Grey-white ice and medium to thick first-year ice comprised the 9/10^{ths} total concentration of Ice Regime 26. The ice floes were from 5 to 50 m in diameter and showed evidence of ridging. The average speed of the Healy was 6.3 kts throughout the Regime and the maneuvering speed was 3.0 kts. The 4/10^{ths} component of thick first-year ice and the reduction in visibility (Figure 10) necessitated that the Healy proceeded cautiously.

Ice Regime 26 had an associated Ice Numeral of +16.

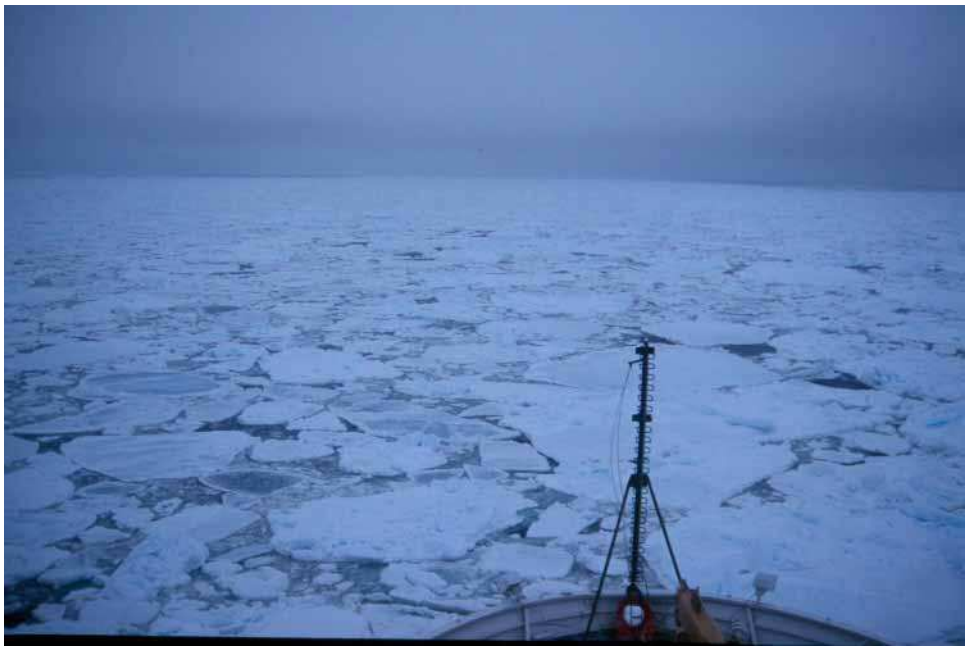

Figure 10 Ice Regime 26

4.6 Regime 41: Labrador Sea

Route Information

	Regime Entry	*Regime Exit*
Date:	7 April 2000	7 April 2000
Time:	15:37:00 UTC	16:45:00 UTC
Coordinates*:*	57°20.20'N, 59°04.40'W	57°30.48'N, 59°06.80'W
Total Distance*:*	10.4 n.mi	
Average Ship Speed	9.1 kts	
Maneuvering Speed	5.7 kts	

Climatic Conditions

Air Temperature:	-3.9°C
Wind Speed:	23.0 kts
Visibility:	Excellent (10+ n.mi)
Sources of Ice Information:	06 April daily ice chart for Labrador Sea RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **4/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	2
Tk	2
SYI	0
MYI	TR
Glacial	✔

Ice Numeral: **+18** = [6 + 2](2) + [2](1)

Description of Regime

The 4/10^{ths} total concentration of Regime 41 was comprised of equal concentrations of medium and thick first-year ice. The 10 to 20 m diameter, first-year floes showed evidence of ridging. Regime 41 also had trace concentrations of glacial ice and multi-year ice. The multi-year ice floes were about 20 m in diameter and 3 m thick. Ice Regime 41 had an along-track distance of 10.4 n.mi, throughout which the Healy maintained an average speed of 9.1 kts. The maneuvering speed of the Healy during Regime 41 was 5.7 kts.

Ice Regime 41 had an associated Ice Numeral of +18.

Figure 11 Ice Regime 41, along the Marginal Ice Zone

4.7 Regime 52: Northern Labrador Sea

Route Information

	Regime Entry	*Regime Exit*
Date:	8 April 2000	9 April 2000
Time:	13:40:00 UTC	00:50:00 UTC
Coordinates*:*	60°13.10'N, 60°07.20'W	61°20.00'N, 59°57.00'W
Total Distance*:*	67.0 n.mi	
Average Ship Speed	11 kts	
Maneuvering Speed	10 kts	

Climatic Conditions

Air Temperature:	-7.4°C
Wind Speed:	20 kts
Visibility:	Fair (3 n.mi)
Sources of Ice Information:	07 April daily ice chart for Labrador Sea RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration (Open Water): **0/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	0
Tk	0
SYI	0
MYI	0

Ice Numeral: **+20** = [10](2)

Description of Regime

Ice Regime 52 was encountered on 8 April as the Healy exited the pack ice and entered open water. The intent was to follow the edge of the Marginal Ice Zone as far north as possible to allow for rapid transit. The Healy traversed open water from 13:00 on 8 April to 00:50 on 9 April; a distance of 67 n.mi (see Figure 4 for the route segment). Occasionally, the Healy would encounter strips and patches with 9+/10^{ths} ice concentration (Figure 12). The average ship speed throughout Regime 52 was 11 kts, with a slightly lower maneuvering speed of 10 kts. The average speed and the maneuvering speed do not take into account the frequent stops made in Regime 52.

Ice Regime 52 had an associated Ice Numeral of +20.

Figure 12 Ice Regime 52, mostly open water with occasional strips and patches of ice (as shown here)

4.8 Regime 63: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	9 April 2000	9 April 2000
Time:	10:22:00 UTC	10:50:00 UTC
Coordinates*:*	62°34.00'N, 60°39.00'W	62°38.00'N, 60°43.10'W
Total Distance*:*	4.2 n.mi	
Average Ship Speed	7.3 kts	
Maneuvering Speed	4.4 kts	

Climatic Conditions

Air Temperature:	-15.7°C
Wind Speed:	12 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	08 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9+/10^{ths}**

Ice Type	Concentration
NI	1
GI	0
GW	0
Tn	7

Ice Type	Concentration
Md	2
Tk	TR
SYI	0
MYI	0
Glacial	✓

Ice Numeral: **+20** = [1 + 7 + 2](2)

Description of Regime

The 9+/10^{ths} total concentration of Ice Regime 63 consisted mostly of thin first-year ice with some nilas and medium first-year ice. The Regime also had trace concentrations of thick first-year ice (Figure 13) and glacial ice (Figure 14). On average floes in Regime 63 ranged from 5 to 20 m in diameter. The Healy maintained an average speed of 7.3 kts throughout the Regime, with a maneuvering speed of 4.4 kts.

Ice Regime 63 had an associated Ice Numeral of +20.

Figure 13 Ice Regime 63, thick first-year floe

Figure 14 Ice Regime 63, iceberg on horizon

4.9 Regime 69: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	9 April 2000	9 April 2000
Time:	16:32:00 UTC	17:20:00 UTC
Coordinates*:*	62°59.20'N, 61°17.20'W	63°04.00'N, 61°26.60'W
Total Distance*:*	6.4 n.mi	
Average Ship Speed	8.4 kts	
Maneuvering Speed	0.2 kts	

Climatic Conditions

Air Temperature:	-13.2°C
Wind Speed:	16 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	08 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **5/10^{ths}**

Ice Type	Concentration
NI	1
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	2
Tk	2
SYI	0
MYI	0
Glacial	✓

Ice Numeral: **+18** = [5 + 1 + 2](2) + [2](1)

Description of Regime

The 5/10^{ths} total concentration of Ice Regime 69 was comprised of equal parts medium and thick first-year ice, with a lesser amount of nilas. Trace concentrations of glacial ice were noted. Figure 15 shows a fairly level, unconfined floe in Regime 69 in which cracks were able to propagate easily from the ship. The floes in Regime 69, were about 500 m in diameter. The ship maintained an average speed of 8.4 kts throughout the Regime. Backing and ramming was required to penetrate the more difficult ice, as illustrated by the maneuvering speed of 0.2 kts.

Ice Regime 69 had an associated Ice Numeral of +18.

Figure 15 Ice Regime 69 medium first-year floes

4.10 Regime 70: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	9 April 2000	9 April 2000
Time:	17:20:00 UTC	17:43:00 UTC
Coordinates*:*	63°04.20'N, 61°26.60'W	63°04.00'N, 61°23.80'W
Total Distance*:*	1.3 n.mi	
Average Ship Speed	3.8 kts	
Maneuvering Speed	0.4 kts	

Climatic Conditions

Air Temperature:	-12.0°C
Wind Speed:	12 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	08 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **10/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	0
Tk	10
SYI	0
MYI	0
Glacial	✓

Ridge Modified Ice Numeral:	**0** = [10](1 - 1)

Description of Regime

Ice Regime 70 was a giant floe of heavily ridged, thick, first-year ice (Figure 16). When the Healy first impacted the floe it penetrated about one half of a ship length and came to a halt. Rather than attempt to penetrate the floe further, it was decided to circumnavigate the floe by chipping along its edge (Figure 17). The along-track distance of Regime 70 was 1.3 n.mi, during which the Healy maintained an average speed of 3.8 kts. The maneuvering speed of the Healy was 0.4 kts during Regime 70.

The Ice Numeral reported for Regime 70 was adjusted to account for the significant extent of ridging in the thick first-year ice. AIRSS (1998) states that when greater than $3/10^{ths}$ of an ice type is deformed by ridges, the Ice Multiplier should be decreased by one. Consequently, the Ice Multiplier of 1 for thick first-year ice was reduced to 0, resulting in an Ice Numeral of 0 for Regime 70.

Figure 16 Initial impact of thick first-year floe of Regime 70

Figure 17 Ice Regime 70: circumnavigating the giant floe

4.11 Regime 74: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	9 April 2000	9 April 2000
Time:	20:46:00 UTC	21:44:00 UTC
Coordinates*:*	63°16.30'N, 61°49.20'W	63°17.30'N, 61°48.40'W
Total Distance*:*	1.1 n.mi	
Average Ship Speed	2.4 kts	
Maneuvering Speed	0.0 kts	

Climatic Conditions

Air Temperature:	-13.6°C
Wind Speed:	9 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	09 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **10/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	10
Tk	0
SYI	0
MYI	0

Ridge Modified Ice Numeral:	**+10** = [10](2 - 1)

Description of Regime

In Ice Regime 74 the Healy impacted heavily ridged, first-year floe of medium thickness. The floe was about 5 km in diameter. A considerable amount of backing and ramming was required in Regime 74, as demonstrated by the ship's progress of 1.1 n.mi in just under one hour. Figure 18 shows a typical bow print made during a backing and ramming cycle. Figure 19 shows Regime 74 as pictured along the broken ice track. The average ship speed throughout the Regime was 2.4 kts. The maneuvering speed of 0.0 kts indicated that the Healy was (frequently) brought to a full stop during the backing and ramming process. The Ice Numeral of +10 that was reported for Regime 74 was modified to account for the heavy ridging.

Figure 18 Ice Regime 74, typical bow print after ram

Figure 19 Ship track through Regime 74 as seen from the stern

4.12 Regime 80: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	12 April 2000	12 April 2000
Time:	09:35:00 UTC	10:32:00 UTC
Coordinates*:*	63°22.80'N, 62°59.70'W	63°27.20'N, 61°56.70'W
Total Distance*:*	4.6 n.mi	
Average Ship Speed	2.4 kts	
Maneuvering Speed	0.0 kts	

Climatic Conditions

Air Temperature:	-10.8°C
Wind Speed:	11.8 kts
Visibility:	Good (6 n.mi)
Sources of Ice Information:	11 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9+/10^{ths}**

Ice Type	Concentration
NI	3
GI	0
GW	0
Tn	4

Ice Type	Concentration
Md	3
Tk	0
SYI	0
MYI	0

Ridge Modified Ice Numeral: **+17** = [3 + 4](2) + [3](2 – 1)

Description of Regime

The 9+/10^{ths} total concentration of Ice Regime 80 consisted of nilas and thin and medium first-year ice. The floes were from 0.1 to 2 km in diameter some of which were heavily ridged and showed evidence of pressure (Figure 20). Leads were noted in the Regime, as were trace amounts of glacial ice. Backing and ramming was required in the highly ridged and rafted ice, particularly at the beginning of the Regime. The average ship speed was 2.4 kts during backing and ramming (first 30 minutes, time for which the speed record is available). The vessel had a maneuvering speed of 0.0 kts, as is typical of the ramming process.

To account for the significant amount of ridging in the medium-thick first-year ice, the reported Ice Numeral for Regime 80 was modified to +17.

Figure 20 Ice Regime 80, substantial ridging and pressure

4.13 Regime 81: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	12 April 2000	12 April 2000
Time:	10:32:00 UTC	11:25:00 UTC
Coordinates*:*	63°27.20'N, 61°56.70'W	63°29.70'N, 61°45.70'W
Total Distance*:*	5.5 n.mi	
Average Ship Speed	6.7 kts	
Maneuvering Speed	0.5 kts	

Climatic Conditions

Air Temperature:	-11.0°C
Wind Speed:	10 kts
Visibility:	Good (6 n.mi)
Sources of Ice Information:	11 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	2
GI	0
GW	0
Tn	5

Ice Type	Concentration
Md	1
Tk	1
SYI	0
MYI	0
Glacial	✓

Ice Numeral: **+19** = [1 + 2 + 5 + 1](2) + [1](1)

Description of Regime

Regime 81 had a total concentration of 9/10^{ths} that was comprised of mostly of nilas and thin first-year ice, with some medium and thick first-year ice. Individual floes were from 0.5 to 1.0 km in diameter and frequently were separated by leads. Ridged ice was observed, although the ice did not appear to be under pressure. There was a trace concentration of glacial ice in Regime 81. The Healy had an average speed of 6.7 kts and a maneuvering speed of 0.5 kts during most of the Regime (speed records not available for first 30 minutes of transit).

Ice Regime 81 had an associated Ice Numeral of +19.

Figure 21 Ice Regime 81, predominantly thin first-year ice

4.14 Regime 86: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	13 April 2000	13 April 2000
Time:	08:30:00 UTC	10:20:00 UTC
Coordinates*:*	63°38.29'N, 61°50.22'W	63°38.70'N, 61°57.90'W
Total Distance*:*	9.0 n.mi	
Average Ship Speed	4.5 kts	
Maneuvering Speed	--	

Climatic Conditions

Air Temperature:	-14.5°C
Wind Speed:	1.3 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	12 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9+/10^{ths}**

Ice Type	Concentration
NI	1
GI	1
GW	0
Tn	4

Ice Type	Concentration
Md	4
Tk	0
SYI	0
MYI	0
Glacial	✓

Ice Numeral: **+20** = [1 + 1 + 4 + 4] (2)

Description of Regime

The 9+/10^{ths} total concentration of Ice Regime 86 consisted of equal concentrations of nilas and grey-white ice, with larger percentages of thin and medium first-year ice. The moderately ridged floes had diameters of 20 to 500 m (Figure 22). Leads and glacial ice characterized Regime 86. The Healy maintained an average speed of 4.5 kts throughout the Regime. Due to the frequent stops that were made for engine work and helicopter launches, the maneuvering speed was not reported for Regime 86.

Ice Regime 86 had an associated Ice Numeral of +20.

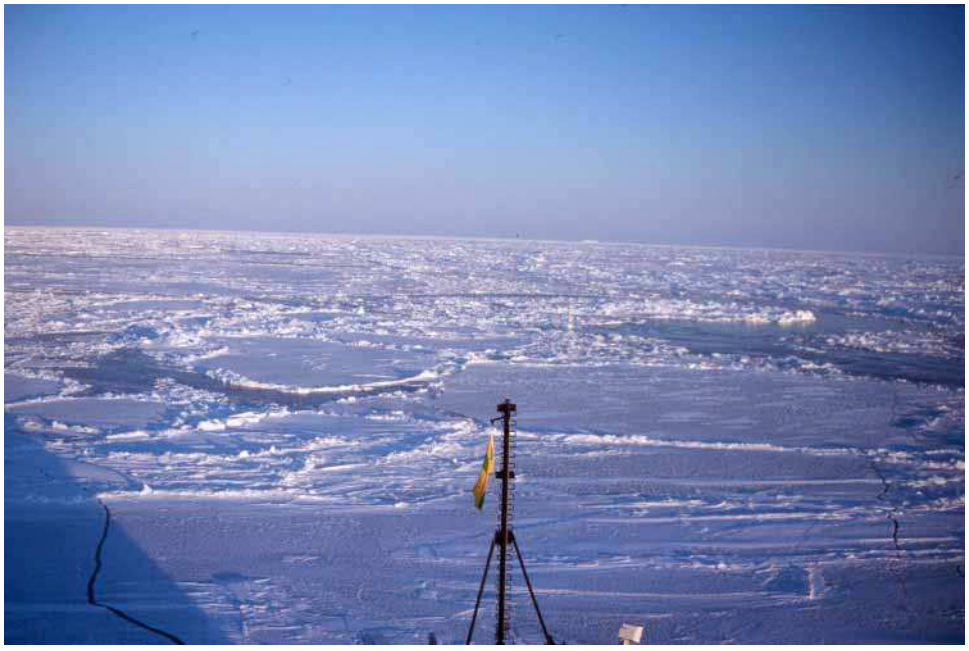

Figure 22 Regime 86, thin and medium first-year ice

4.15 Regime 87: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	13 April 2000	13 April 2000
Time:	10:20:00 UTC	19:46:00 UTC
Coordinates*:*	63°38.70'N, 61°57.90'W	63°38.65'N, 62°01.03'W
Total Distance*:*	1.4 n.mi	
Average Ship Speed	1.4 kts	
Maneuvering Speed	0.0 kts	

Climatic Conditions

Air Temperature:	-14.9°C
Wind Speed:	4.3 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	12 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	1
GI	0
GW	0
Tn	1

Ice Type	Concentration
Md	0
Tk	3
SYI	0
MYI	4
Glacial	✓

Ice Numeral: **-3** = [1 + 1 + 1](2) + [3](1) + [4](-3)

Description of Regime

The 9/10^{ths} total concentration of Regime 87 was comprised of mostly thick first-year ice and multi-year ice, with lesser amounts of nilas and thin first-year ice. The first-year floes were from 50 to 500 m in diameter and were moderately ridged (Figure 23). The multi-year floes were about 500 m in diameter, over 3 m thick and had a surface topography that ranged from level to hummocked ice. Regime 87 had a trace concentration of glacial ice.

The Healy made frequent stops to check the engine throughout Regime 87. The most noteworthy stop resulted from an ice impact at 12:20, about 2 hours after entering Regime 87. At that point, the Healy rammed a 3 m thick multi-year floe that brought the vessel to a full stop. The propulsion system of the Healy failed and remained down from about 12:20 to 19:37. At 19:37 the Healy regained power and once again began backing and ramming. After about five minutes of ramming the Healy entered a wide lead that terminated Regime 87. The average ship speed during the backing and ramming of Regime 87 was 1.4 kts and the maneuvering speed was 0.0 kts.

Ice Regime 87 had an associated Ice Numeral of –3, due to the high concentration of multi-year ice. Regime 87 was the first negative Ice Regime encountered by the Healy during Phase III of the Ice Trials.

Figure 23 Ice Regime 87

4.16 Regime 90: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	13 April 2000	14 April 2000
Time:	22:10:00 UTC	00:48:00 UTC
Coordinates*:*	63°44.41'N, 61°36.14'W	63°57.24'N, 62°13.24'W
Total Distance*:*	20.8 n.mi	
Average Ship Speed	9.3 kts	
Maneuvering Speed	1.1 kts	

Climatic Conditions

Air Temperature:	-11.4°C
Wind Speed:	6 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	13 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9+/10^{ths}**

Ice Type	Concentration
NI	7
GI	0
GW	0
Tn	3

Ice Type	Concentration
Md	0
Tk	0
SYI	0
MYI	0

Ice Numeral: **+20** = [7 + 3](2)

Description of Regime

Ice Regime 90 was characterized by a recently-frozen lead. Most of the 9+/10^{ths} total concentration of Regime 90 consisted of nilas, with a lesser amount of thin first-year ice. The thin first-year ice floes were about 30 m in diameter. The Healy was able to maintain an average speed of 9.1 kts through Regime 90 and a maneuvering speed of 1.1 kts. The ship stopped for the night at 00:48, which terminated Regime 90. By morning, the Healy had entered a new Ice Regime (a result of ice movement).

Ice Regme 90 had an associated Ice Numeral of +20.

Figure 24 Ice Regime 90, nilas and thin first-year ice

4.17 Regime 95: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	16 April 2000	16 April 2000
Time:	14:38:90 UTC	18:25:00 UTC
Coordinates*:*	63°43.90'N, 62°22.20'W	63°46.41'N, 62°19.84'W
Total Distance*:*	2.71 n.mi	
Average Ship Speed	2.9 kts	
Maneuvering Speed	0.0 kts	

Climatic Conditions

Air Temperature:	-5.3°C
Wind Speed:	10.1 kts
Visibility:	Fair (1 n.mi)
Sources of Ice Information:	15 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	1

Ice Type	Concentration
Md	7
Tk	1
SYI	0
MYI	0

Ice Numeral: **+19** = [1 + 1 + 7](2) + [1](1)

Description of Regime

The 9/10^{ths} total concentration of Ice Regime 95 consisted of mostly of medium thick, first-year ice with lesser amounts of thin and thick first-year ice. The floes were about 5 km in diameter and were moderately ridged. The most noteworthy feature of Ice Regime 95 was that the ice was under a significant amount of pressure. The Healy first started to experience the effects of increased pressure at 16:50, when the track of the ship began closing within minutes of forming (Figure 25). Ten minutes later there was ridge-building in the ice off the port side of the bow. The ridge-building process continued until distinct "fingers" of ice were formed in the thick first-year (Figure 26). At 17:05, the Healy lost a cyclo-converter on the port shaft and remained stationary until the pack ice pressure subsided, about 40 minutes later. The Healy maintained an average speed of 2.9 kts throughout Ice Regime 95 (excepting the stationary period). A significant amount of backing and ramming was required to transit the Regime, as evidenced by the maneuvering speed of 0.0 kts.

Ice Regime 95 had an associated Ice Numeral of +19.

Figure 25 Closed Ship Track

Figure 26 Ridge-building Event

4.18 Regime 97: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	16 April 2000	16 April 2000
Time:	19:28:00 UTC	22:04:00 UTC
Coordinates*:*	63°46.37'N, 62°16.90'W	63°46.35'N, 62°16.01'W
Total Distance*:*	0.4 n.mi	
Average Ship Speed	1.8 kts	
Maneuvering Speed	0.1 kts	

Climatic Conditions

Air Temperature:	-4.2°C
Wind Speed:	8.1 kts
Visibility:	Fair (1 n.mi)
Sources of Ice Information:	16 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **10/10^{ths}**

Ice Type	Concentration
NI	0
GI	0
GW	0
Tn	0

Ice Type	Concentration
Md	0
Tk	0
SYI	0
MYI	10

Ice Numeral: **-30** = [10](-3)

Description of Regime

On 16 April (19:28) the Healy impacted a 2 km wide, multi-year floe at a speed of about 3 kts. Recognition of the multi-year floe was extremely difficult, due to the reduced visibility (fog) and the fact that the multi-year floe had a smooth surface and a thick snow cover, as shown in Figure 27. The large multi-year floe alone constituted the 10/10^{ths} coverage of Regime 97.

The ice in Regime 97 was under substantial confinement, as evidenced by the ridge building event that occurred in the thinner ice about 10 m from the starboard side at 21:16 (Figure 28). In addition, the ship's track closed within minutes of forming. Repeated cycles of backing and ramming were required to

transit the severe ice conditions of Regime 97. The Healy maintained an average speed of 1.8 kts and a maneuvering speed of 0.1 kts in Regime 97. This Regime terminated when the Healy entered an area of small floes with little confinement.

Ice Regime 97 had an associated Ice Numeral of –30, due to the 10/10^{ths} coverage of multi-year ice. Regime 97 was the second Regime encountered with a negative Ice Numeral during Phase 3 of the Ice Healy Trials.

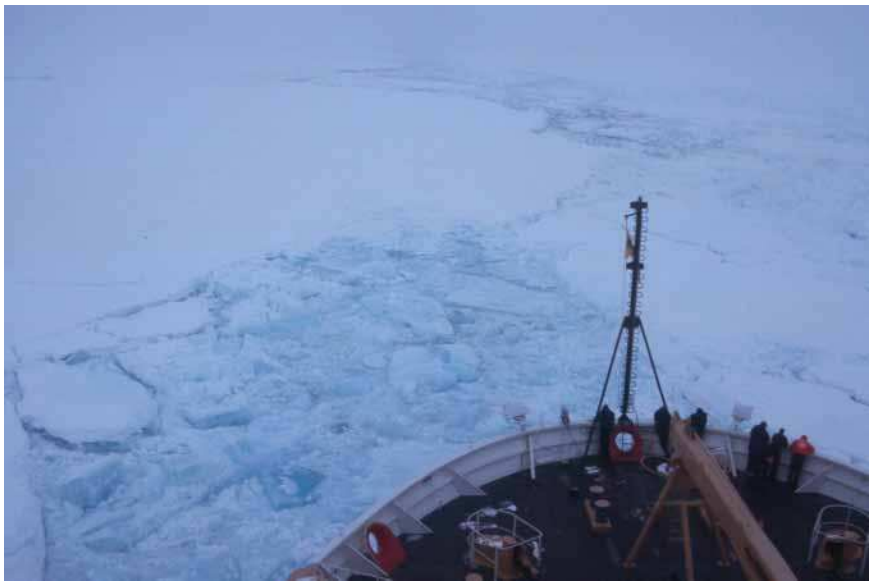

Figure 27 Ice Regime 97, Bow Print after Ram

Figure 28 Pressure Ridge in Regime 97

4.19 Regime 107: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	18 April 2000	18 April 2000
Time:	16:33:00 UTC	19:19:00 UTC
Coordinates:	63°51.72'N, 61°38.39'W	63°53.29'N, 61°38.94'W
Total Distance:	2.1 n.mi	
Average Ship Speed	2.9 kts	
Maneuvering Speed	0.0 kts	

Climatic Conditions

Air Temperature:	-5.8°C
Wind Speed:	6.0 kts
Visibility:	Excellent (10 n.mi)
Sources of Ice Information:	17 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9+/10^{ths}**

Ice Type	Concentration
NI	TR
GI	0
GW	0
Tn	1

Ice Type	Concentration
Md	2
Tk	7
SYI	0
MYI	0

Ice Numeral: **+13** = [1 + 2](2) + [7](1)

Description of Regime

The 9+/10^{ths} total concentration of Ice Regime 107 consisted of mostly thick first-year ice, with lesser amounts of thin and medium first-year ice. The 20 to 200 m diameter floes were mixed with trace concentrations of nilas. Frequently, ice along the margin consisted of ridged ice (Figure 29). The ridges along the periphery of the floes appeared to be less consolidated than ridges embedded in the floes.

During Ice Regime 107 the Healy alternated between continuous ice breaking (in the thinner ice types) and backing and ramming (floes of thick first-year ice, shown in Figure 30). The average ship speed was 2.9 kts (excepting the frequent stops made for engine work). The maneuvering speed of the Healy was 0.0 kts.

Ice Regime 107 had an associated Ice Numeral of +13.

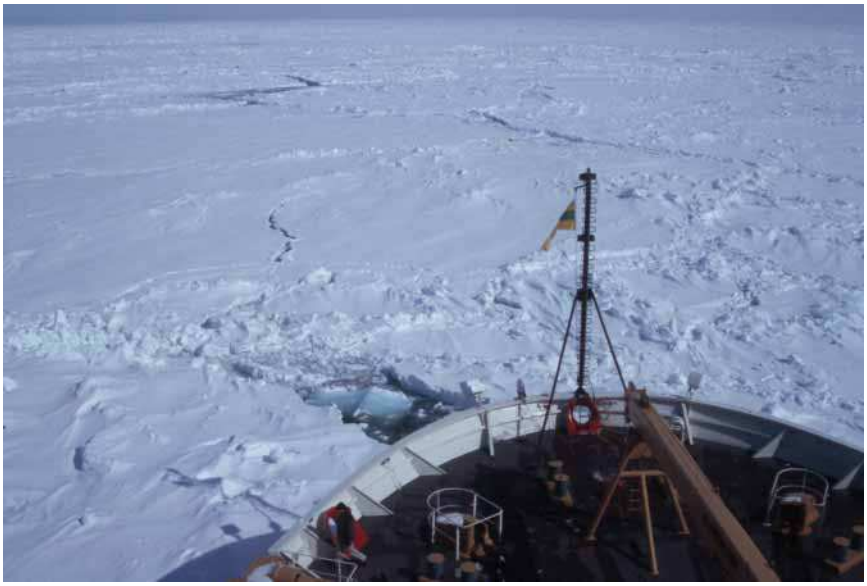

Figure 29 Ice Regime 107, unconsolidated ridges along the floe perimeter

Figure 30 Ice Regime 107, ramming through a thick first-year floe

4.20 Regime 117: Davis Strait

Route Information

	Regime Entry	*Regime Exit*
Date:	23 April 2000	24 April 2000
Time:	21:50:00 UTC	00:15:00 UTC
Coordinates*:*	64°02.45'N, 60°25.14'W	63°49.00'N, 59°51.38'W
Total Distance*:*	2.1 n.mi	
Average Ship Speed	8.6 kts	
Maneuvering Speed	4.7 kts	

Climatic Conditions

Air Temperature:	-4.4°C
Wind Speed:	1 kts
Visibility:	Good (6 n.mi)
Sources of Ice Information:	23 April daily ice chart for Davis Strait RADARSAT imagery DMSP Operational Linescan System (OLS)

Ice Conditions

Total Ice Concentration: **9/10^{ths}**

Ice Type	Concentration
NI	1
GI	0
GW	3
Tn	6

Ice Type	Concentration
Md	0
Tk	0
SYI	0
MYI	0
Glacial	✓

Ice Numeral: **+20** = [1 + 3 + 6](2)

Description of Regime

Ice Regime 117 was one of the last Regimes encountered by the Healy during Phase III of the Ice Trials. The 9/10^{ths} total concentration of Regime 117 consisted of mostly thin first-year ice, with some grey-white ice and nilas. The ice was a homogeneous matrix of 20 to 50 m diameter, level ice floes. Comparison of Figure 31 and Figure 32 shows that the floe size decreased as the ice edge was approached. Glacial ice was noted in Regime 117. The Healy had an average speed of 8.6 kts throughout the 20.3 n.mi distance of Regime 117. The maneuvering speed of the Healy was 4.7 kts.

Ice Regime 117 had an associated Ice Numeral of +20.

Figure 31 Larger floes of Ice Regime 117

Figure 32 Smaller floes of Ice Regime 117

5. DISCUSSION

During its transit from Halifax, Nova Scotia to Nuuk, Greenland the USCGC Healy encountered 118 Ice Regimes, a summary of which is listed in Appendix A. Examination of the total number of Ice Regimes revealed that 50% had a total ice concentration that exceeded 9/10^{ths} (Figure 33). Comparison of the different ice types in each of the 118 Regimes indicated that thin, medium and thick first-year ice occurred most frequently (in 63%, 77% and 50% of the Regimes, respectively). Grease ice, nilas and grey-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.

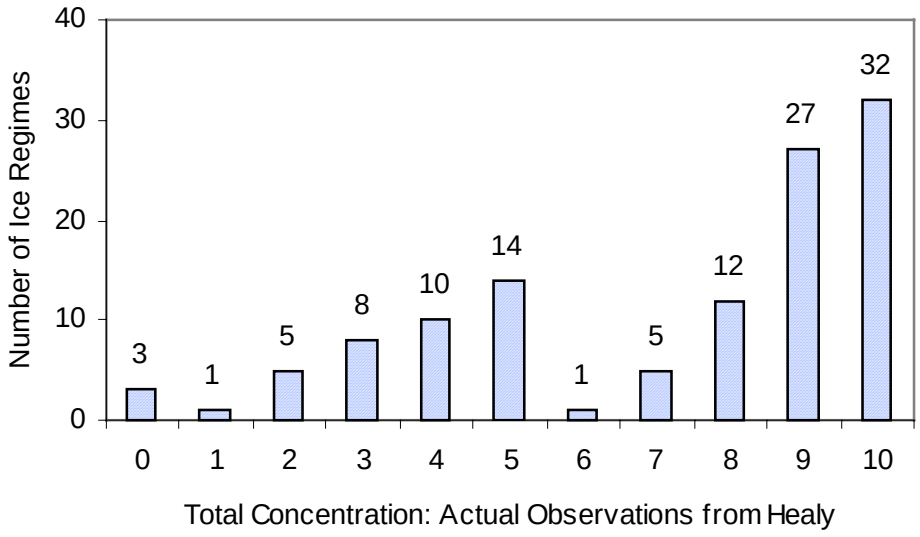

Figure 33 Total Ice Concentration of Regimes encountered by the Healy

The Ice Numeral associated with the Regime provided a good indication of the ice severity (as applies to a particular ship class). For this study, the Healy was classed as a Canadian Arctic Class 4 (CAC4) vessel. As such the Ice Numerals were computed using the Ice Mulitpliers appropriate for that vessel class. About 77% of the total number of Regimes encountered by the Healy during Phase III had Ice Numerals from 15 to 20 (91 Regimes, Figure 34). About 21% of the Regimes had Ice Numerals that ranged from 0 to 14 (25 Regimes). The high proportion of positive Ice Numerals indicated that most of the Regimes encountered by the Healy during the voyage did not prove problematic for navigation. Regimes with negative Ice Numerals were encountered less than 2% of the time (2 Regimes) during the three-week voyage.

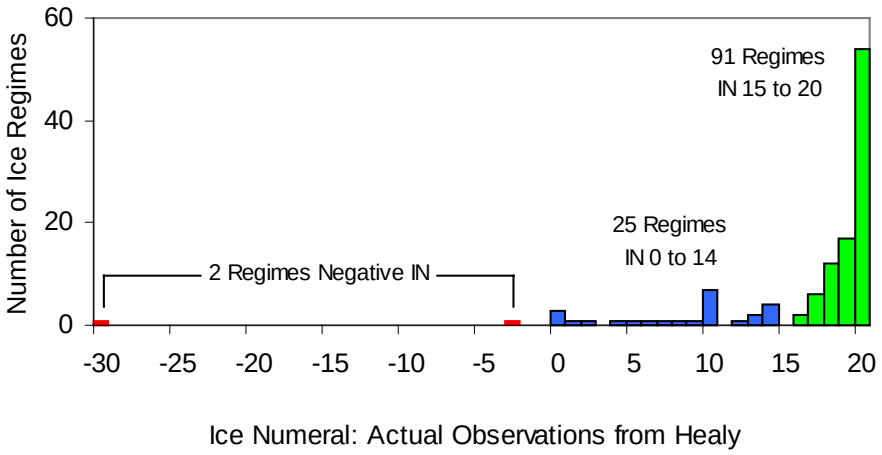

Figure 34 Ice Numerals of Regimes encountered by the Healy

The twenty Ice Regimes that were selected for this report are summarized in Table 3. Ice Regime 52 was the least severe Regime, since it was characterized by open water and had only trace amounts of first-year ice. The most severe ice conditions were encountered in Ice Regime 97 since that Regime consisted of a 10/10^{ths} cover of multi-year ice.

Table 3 Chronology of Selected Ice Regimes

Date	Ice Regime	Total Concentration	Ice Numeral	Predominant Ice Types
04 April	2	5/10^{ths}	17	Md and Tk FYI.
04 April	3	9/10^{ths}	19	Md FYI
05 April	17	7/10^{ths}	20	Tn and Md FYI
05 April	21	8/10^{ths}	20	NI, GI and GW ice
05 April	26	9/10^{ths}	16	Md and Tk FYI
07 April	41	4/10^{ths}	18	Md and Tk FYI
08 April	52	Open Water	20	Open water, strips of 9+/10ths
09 April	63	9+/10^{ths}	20	Tn FYI
09 April	69	5/10^{ths}	18	Md and Tk FYI
09 April	70	10/10^{ths}	10	Tk FYI only
09 April	74	10/10^{ths}	20	Md FYI only
12 April	80	9+/10^{ths}	20	NI, Tn and Md FYI
12 April	81	9/10^{ths}	19	Tn FYI
13 April	86	9+/10^{ths}	20	Tn and Md FYI
13 April	87	9/10^{ths}	-3	Tk FYI and MYI
13 April	90	9+/10^{ths}	20	NI
16 April	95	9/10^{ths}	19	Highly pressured Md FYI
16 April	97	10/10^{ths}	-30	MYI
18 April	107	9+/10^{ths}	13	Tk FYI
23 April	117	9/10^{ths}	20	Tn FYI

6. CONCLUSIONS

The Ice Regimes encountered by the Healy during Phase III of the Ice Trials 2000 were documented to broaden the knowledge base associated with Ice Numeral calculations hence the Arctic Ice Regime Shipping System. Most of the Ice Regimes traversed by the Healy during this field program had Ice Numerals that did not present a problem for the Healy, which was classified as a CAC4 vessel. However, two Ice Regimes had negative Ice Numerals indicating severe ice conditions that could, potentially, result in damage to the vessel. The avoidance of damage in those two Ice Regimes was a direct result of the manner in which the vessel was operated. Examination of the Ice Numerals for the Ice Regimes showed that there are additional aspects, besides the ice severity, that can have significant implications for vessel performance in an Ice Regime. AIRSS would benefit from consideration of factors such as the overall visibility, vessel speed and the amount of ice pressure in calculating the Regime-related Ice Numeral.

7. ACKNOWLEDGEMENTS

This study was conducted with the financial support of Transport Canada. The assistance and support of the United States Coast Guard during field operations on the Healy are also much appreciated.

8. REFERENCES

AIRSS (1998) User Assistance Package for the Implementation of Canada's Arctic Ice Regime Shipping System (AIRSS), May 1998, Transport Canada Prairie and Northern Region, Report No. TP 12819, 41 pp.

WMO Sea Ice Nomenclature (1985) Report issued by World Meteorological Association, March 1985, Report No. 259, Supplement No. 4.

Appendix A:

Summary of Total Number of Ice Regimes

Ice Regimes Transited during Healy Ice Trials: Phase III

Regime	Date	Start lat.	Start long.	Start UTC	Total Conc.	NI	GI	GW	Tn	Md	Tk	SYI	MYI	IN	Visibility
1	4-Apr	51°33	56°24	13:20	OW	0	0	0	0	0	0	0	0	20	excellent
2	4-Apr	51°33.27	54°31.78	19:07	5	0	0	0	0	2	3	0	0	17	excellent
3	4-Apr	51°36.60	54°20.39	20:00	9	0	0	TR	3	5	1	0	0	19	excellent
4	4-Apr	51°41.26	54°04.85	21:29	9	1	0	2	4	1	1	0	0	19	good
5	4-Apr	51°45	53°3	22:30	4	0	0	0	2	2	0	0	0	20	fair
6	4-Apr	51°46.81	53°45.90	23:09	9	0	0	1	2	6	0	0	0	20	darkness
7	4-Apr	51°47.92	53°42.31	23:29	3	0	0	0	1	2	TR	0	0	20	darkness
8	4-Apr	51°48	53°39	23:44	5	0	0	0	0	3	2	0	0	18	darkness
9	5-Apr	51°56.7	53°36.5	11:00	5	0	0	1	1	3	0	0	0	20	good
10	5-Apr	52°04.7	53°42.5	13:20	8	0	0	2	2	4	0	0	0	20	fair
11	5-Apr	52°05.04	53°46.23	13:48	5	0	0	0	3	2	0	0	0	20	fair
12	5-Apr	52°08.7	53°46.5	14:12	4	0	0	0	3	1	0	0	0	20	fair
13	5-Apr	52°09.54	53°46.12	14:20	4	0	0	1	3	0	0	0	0	20	fair
14	5-Apr	52°11.24	53°46.12	14:30	5	0	0	1	2	2	0	0	0	20	fair
15	5-Apr	52°15.36	53°46.12	14:55	2	0	0	0	1	1	0	0	0	20	fair
16	5-Apr	52°19.6	53°45.2	15:18	5	0	0	1	3	1	0	0	0	20	fair
17	5-Apr	52°21.3	53°45.2	15:30	7	0	0	1	3	3	0	0	0	20	fair
18	5-Apr	52°29.5	53°41.9	16:30	9+	2	2	2	2	2	TR	0	0	20	fair
19	5-Apr	52°31.3	53°42.0	16:44	5	0	0	1	1	2	1	0	0	19	fair
20	5-Apr	52°37.70	53°42.50	17:25	4	0	0	0	2	2	0	0	0	20	fair
21	5-Apr	52°41.90	53°42.60	17:57	8	1	4	3	TR	TR	0	0	0	20	fair
22	5-Apr	52°44.80	53°42.70	18:18	3	0	1	2	TR	0	0	0	0	20	fair
23	5-Apr	52°47.40	53°42.10	18:34	5	0	1	3	1	TR	TR	0	0	20	fair
24	5-Apr	52°55.20	53°42.20	19:29	9	TR	0	2	2	2	3	0	0	17	fair
25	5-Apr	53°03.80	53°42.30	20:30	7	0	0	2	1	2	2	0	0	18	good
26	5-Apr	53°16.60	53°43.20	22:02	9	0	0	2	0	3	4	0	0	16	fair
27	5-Apr	53°18.20	53°42.70	22:17	5	0	0	0	1	2	2	0	0	18	fair
28	5-Apr	53°32.60	53°43.90	23:58	8	0	0	1	1	4	2	0	0	18	good
29	6-Apr	53°38.50	53°44.20	0:41	9+	0	0	1	3	3	3	0	0	17	good
30	6-Apr	53°41.00	53°42.50	1:00	9	0	0	2	1	2	3	0	1	12	good
31	6-Apr	53°54.30	53°42.60	3:30	2	0	0	0	0	1	1	0	0	19	good
32	7-Apr	56°08.00	57°18.00	1:40	9	0	0	0	2	1	5	0	1	10	good
33	7-Apr	56°11.00	57°19.00	2:19	3	1	0	0	1	1	0	0	0	20	good
34	7-Apr	56°12.36	57°28.54	3:04	4	0	0	0	0	2	2	0	0	18	good
35	7-Apr	56°12.70	57°32.60	3:19	9+	0	0	0	0	3	4	0	3	1	good
36	7-Apr	56°12.80	57°35.90	3:39	7	0	0	0	0	1	4	0	2	6	good
37	7-Apr	56°13.80	57°39.30	4:01	3	0	0	0	0	3	0	0	0	20	good
38	7-Apr	56°15.00	57°41.00	4:19	4	0	0	0	0	4	0	0	0	20	good
39	7-Apr	56°37.10	58°37.10	11:25	2	0	0	0	0	1	1	0	0	19	fair
40	7-Apr	57°08.10	58°55.80	13:55	4	0	0	0	0	2	2	0	0	18	excellent
41	7-Apr	57°20.20	59°04.40	15:37	4	0	0	0	0	2	2	0	TR	18	excellent
42	7-Apr	57°30.48	59°06.80	16:45	5	0	0	0	0	3	2	0	TR	18	excellent
43	7-Apr	57°38.30	59°08.10	17:43	5	0	0	0	0	3	2	0	TR	18	excellent
44	7-Apr	58°07.15	59°29.67	21:18	9+	0	0	0	0	7	3	0	0	17	excellent
45	7-Apr	58°14.20	59°35.20	22:11	3	0	0	0	0	2	1	0	0	19	excellent

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Regime	Date	Start lat.	Start long.	Start UTC	Total Conc.	NI	GI	GW	Tn	Md	Tk	SYI	MYI	IN	Visibility
46	7-Apr	58°14.20	59°31.20	23:29	4	0	0	0	1	2	1	0	0	19	good
47	8-Apr	59°21.50	60°08.30	8:50	1	1	0	0	0	0	0	0	0	20	good
48	8-Apr	59°25.50	60°08.30	9:19	4	0	0	0	0	4	TR	0	0	20	good
49	8-Apr	59°30.00	60°07.00	9:50	2	0	0	0	0	2	0	0	0	20	excellent
50	8-Apr	59°50.20	60°03.14	11:39	OW	0	0	0	0	0	0	0	0	20	excellent
51	8-Apr	60°00.00	60°03.30	12:28	3	0	0	0	0	3	0	0	0	20	good
52	8-Apr	60°13.10	60°07.20	13:40	OW	0	0	0	0	0	0	0	0	20	fair
53	9-Apr	61°20.00	59°57.00	0:50	5	0	0	0	2	2	1	0	0	19	poor
54	9-Apr	61°24.40	59°56.40	1:21	9	0	1	0	6	1	1	0	0	19	fair
55	9-Apr	61°35.70	60°01.30	2:51	7	0	0	0	5	1	1	0	0	19	poor
56	9-Apr	61°39.80	60°03.50	3:20	9	0	0	1	7	1	TR	0	0	20	fair
57	9-Apr	61°42.50	60°04.90	3:37	6	0	0	0	6	0	0	0	0	20	good
58	9-Apr	61°44.50	60°06.70	3:57	9	0	0	3	6	0	0	0	0	20	good
59	9-Apr	61°48.00	60°09.44	4:27	5	0	0	0	5	0	0	0	0	20	good
60	9-Apr	61°54.80	60°13.40	5:10	8	1	0	0	7	0	0	0	0	20	fair
61	9-Apr	62°15.27	60°26.59	7:39	8	1	0	2	2	2	1	0	0	19	good
62	9-Apr	62°29.30	60°35.80	9:35	9+	1	1	0	5	2	1	0	0	19	excellent
63	9-Apr	62°34.00	60°39.00	10:22	9+	1	0	0	7	2	TR	0	0	20	excellent
64	9-Apr	62°38.00	60°43.10	10:50	9+	1	0	0	5	4	0	0	0	20	excellent
65	9-Apr	62°41.90	60°46.90	11:34	9+	0	0	0	2	5	3	0	0	7	excellent
66	9-Apr	62°50.21	60°59.90	13:46	9	1	0	0	0	4	4	0	0	8	excellent
67	9-Apr	62°51.80	61°02.81	14:36	9+	0	0	0	0	5	5	0	0	5	excellent
68	9-Apr	62°55.60	61°09.30	15:15	8	TR	0	0	2	4	2	0	0	18	excellent
69	9-Apr	62°59.20	61°17.20	16:32	5	1	0	0	0	2	2	0	0	18	excellent
70	9-Apr	63°04.00	61°26.60	17:20	10	0	0	0	0	0	10	0	0	0	excellent
71	9-Apr	63°04.00	61°23.80	17:43	9+	2	1	0	1	2	4	0	0	10	excellent
72	9-Apr	63°08.20	61°30.70	18:47	2	1	0	0	1	0	0	0	0	20	excellent
73	9-Apr	63°08.30	61°33.80	19:00	9	2	0	2	4	1	0	0	0	20	excellent
74	9-Apr	63°16.30	61°49.20	20:46	10	0	0	0	0	10	0	0	0	10	excellent
75	9-Apr	63°17.30	61°48.40	21:44	9+	9+	0	0	0	0	0	0	0	20	excellent
76	9-Apr	63°18.90	61°46.70	22:03	8	1	0	0	1	5	1	0	0	19	excellent
77	12-Apr	63°18.90	62°10.70	0:55	8	1	2	0	3	1	1	0	0	19	good
78	12-Apr	63°20.40	62°08.20	1:20	9+	0	0	0	0	0	9+	0	0	0	good
79	12-Apr	63°20.90	62°05.70	8:50	9	2	1	0	5	1	0	0	0	20	good
80	12-Apr	63°22.80	62°59.70	9:35	9+	3	0	0	4	3	0	0	0	10	good
81	12-Apr	63°27.20	61°56.70	10:32	9	2	0	0	5	1	1	0	0	19	good
82	12-Apr	63°29.70	61°45.70	11:25	9	1	0	0	1	7	0	0	0	10	good
83	12-Apr	63°30.70	61°44.30	12:30	9	1	0	0	5	3	0	0	0	20	excellent
84	12-Apr	63°31.72	61°36.51	20:30	9+	0	1	0	7	2	0	0	0	20	excellent
85	12-Apr	63°33.21	61°41.89	21:15	9	1	1	0	1	2	4	0	0	16	excellent
86	13-Apr	63°38.29	61°50.22	8:30	9+	1	1	0	4	4	0	0	0	20	excellent
87	13-Apr	63°38.70	61°57.90	10:20	9	1	0	0	1	0	3	0	4	-3	excellent
88	13-Apr	63°38.65	62°01.03	19:46	10	10	0	0	0	0	0	0	0	20	excellent
89	13-Apr	63°40.15	61°56.90	20:04	9	4	0	0	1	2	2	0	TR	14	excellent
90	13-Apr	63°44.41	61°36.14	22:10	9+	7	0	0	3	0	0	0	0	20	excellent

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Regime	Date	Start lat.	Start long.	Start UTC	Total Conc.	NI	GI	GW	Tn	Md	Tk	SYI	MYI	IN	Visibility
91	14-Apr	63°57.24	62°13.24	0:48	9+	6	0	0	2	1	1	0	0	19	good
92	15-Apr	63°42.66	62°41.50	21:35	10	0	0	0	0	0	10	0	0	10	fair
93	16-Apr	63°42.40	62°43.30	9:30	9+	0	0	TR	1	2	7	0	0	4	good
94	16-Apr	63°41.60	62°29.60	13:50	8	0	0	0	0	2	6	0	0	14	fair
95	16-Apr	63°43.90	62°22.20	14:38	9	0	0	0	1	7	1	0	0	19	fair
96	16-Apr	63°46.41	62°19.84	18:25	9	1	0	0	3	3	2	0	0	18	fair
97	16-Apr	63°46.37	62°16.90	19:28	10	0	0	0	0	0	0	0	10	-30	fair
98	16-Apr	63°46.35	62°16.01	22:04	8	0	0	0	0	1	4	0	3	0	poor
99	16-Apr	63°46.35	62°16.01	22:04	8	0	0	0	3	5	0	0	0	20	good
100	16-Apr	63°46.79	62°01.44	23:20	9	0	0	0	0	2	7	0	0	13	good
101	17-Apr	63°47.37	62°04.19	9:07	9	0	1	0	0	5	3	0	0	9	fair
102	17-Apr	63°50.08	61°53.24	15:45	9	1	1	3	0	1	3	0	0	17	fair
103	17-Apr	63°52.04	61°53.14	17:00	9+	0	0	0	0	0	9+	0	0	10	poor
104	18-Apr	63°49.14	61°57.28	10:25	9	0	0	0	7	2	0	0	0	20	fair
105	18-Apr	63°49.00	61°44.46	14:02	9+	1	0	0	0	0	9	0	0	2	excellent
106	18-Apr	63°49.83	61°42.03	15:42	9+	1	0	0	6	0	3	0	0	14	excellent
107	18-Apr	63°51.72	61°38.39	16:33	9+	TR	0	0	1	2	7	0	0	13	excellent
108	18-Apr	63°53.29	61°38.94	19:19	10	0	0	0	1	3	6	0	0	14	excellent
109	19-Apr	63°55.59	61°44.64	9:38	9+	1	1	0	7	1	TR	0	0	20	excellent
110	19-Apr	64°00.88	61°40.90	10:45	9+	1	3	0	3	3	0	0	0	17	excellent
111	20-Apr	64°03.66	61°35.47	10:50	8	0	0	0	4	4	0	0	0	20	excellent
112	23-Apr	63°58.93	61°14.57	17:48	3	3	0	0	0	0	0	0	0	20	excellent
113	23-Apr	64°01.86	61°04.99	18:15	3	1	0	0	0	2	TR	0	0	20	good
114	23-Apr	64°05.23	60°57.46	18:53	9	1	0	0	6	2	0	0	0	20	good
115	23-Apr	64°04.58	60°50.91	19:12	9	0	0	0	1	8	0	0	0	20	excellent
116	23-Apr	64°04.46	60°39.56	21:11	7	0	0	0	2	5	0	0	0	20	excellent
117	23-Apr	64°02.45	60°25.14	21:50	9+	1	0	3	6	0	0	0	0	20	good
118	24-Apr	63°49.00	59°51.38	0:15	9+	4	0	0	6	0	0	0	0	20	excellent