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Scientific Basis for the Ice Regime System: March 2000 Update

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ABSTRACT

This report provides an update on the work being carried out by the Canadian Hydraulics Centre of the NRC, to put the Arctic Ice Regime Shipping System (AIRSS) on a scientific basis. Although the project is not complete, significant progress has been made towards its intended goal. This report is meant to highlight the progress, and to lead to a focused discussion in the marine community on the final form for the ice regime system.

The process of putting the ice regime system on a scientific basis involves a systematic approach using empirical data in a pragmatic format. The report provides details of vessel damage, and shows the agreement of the current definition of the Ice Numeral with available full-scale data. It has been found that although the system reasonably well reflects the observations, there are numerous instances where the agreement is poor.

An advanced scheme has been proposed which takes into account the “interaction” aspects of vessels in ice-covered waters. Using this approach, a significant improvement in the definition of the ice numeral can be achieved. This approach further “rewards” high ice class vessels with experienced Ice Navigators operating in a prudent manner, and still “penalizes” low ice class vessels, especially in the presence of multi-year ice.

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LIST OF ACRONYMS

Acronym	Description
AES	Atmospheric Environment Service
AIRSS	Arctic Ice Regime Shipping System
ASPPR	Arctic Shipping Pollution Prevention Regulations
C_a	Ice Concentration
CAC	Canadian Arctic Class
CHC	Canadian Hydraulics Centre
DS	Damage Severity (Number)
FY	First-year sea ice
IM	Ice Multiplier
IN	Ice Numeral
PPD	Potential Pollution Damage
MY	Multi-year sea ice
NRC	National Research Council
SY	Second-year sea ice
WMO	World Meteorological Organization

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1.0 INTRODUCTION

Navigation in Canadian waters north of 60°N latitude is regulated by the Arctic Shipping Pollution Prevention Regulations (ASPPR). These regulations include the date Table in Schedule VIII and the Shipping Safety Control Zones Order, made under the Arctic Waters Pollution Prevention Act. Both of these are combined to form the "Zone/Date System" matrix that gives entry and exit dates for various ship types and classes. It is a rigid system with little room for exceptions. It is based on the premise that nature consistently follows a regular pattern year after year.

Transport Canada, in consultation with stakeholders, has proposed extensive revisions to the Arctic Shipping Pollution Prevention Regulations (ASPPR 1989; Canadian Gazette 1996; AIRSS 1996). The changes are designed to reduce the risk of structural damage in ships which could lead to the release of pollution into the environment, yet provide the necessary flexibility to shipowners by making use of actual ice conditions, as seen by the Master. In this new system, an "Ice Regime", which is a region of generally consistent ice conditions, is defined at the time the vessel enters that specific geographic region, or it is defined in advance for planning and design purposes. The Arctic Ice Regime Shipping System (AIRSS) is based on a simple arithmetic calculation that produces an "Ice Numeral" that combines the ice regime and the vessel's ability to navigate safely in that region. The Ice Numeral (IN) is based on the quantity of hazardous ice with respect to the ASPPR classification of the vessel (see Table 1). The Ice Numeral is calculated from

$$IN = [C_a X\ IM_a] \quad + \quad [C_b X\ IM_b] \quad + \ldots \qquad \textbf{(2-1)}$$

where
IN = Ice Numeral
C_a = Concentration in tenths of ice type "a"
IM_a = Ice Multiplier for ice type "a" (from Table 1)

The term on the right hand side of the equation (a, b, c, etc.) is repeated for as many ice types as may be present, including open water. The values of the Ice Multipliers are adjusted to take into account the decay or ridging of the ice by adding or subtracting a correction of 1 to the multiplier, respectively (see Table 1).

The Ice Numeral is therefore unique to the particular ice regime and ship operating within its boundaries.

Table 1 Table of Ice Multipliers for AIRSS

Table Of Ice Multipliers By Ship Category

AES / WMO Ice Codes	Ice Types		Ice Multipliers for each Ship Category: Type E	Type D	Type C	Type B	Type A	CAC 4	CAC 3
7• or 9•	Old / Multi-Year Ice........... (MY)		-4	-4	-4	-4	-4	-3	-1
8•	Second Year Ice .... (SY)		-4	-4	-4	-4	-3	-2	1
6 or 4•	Thick First Year Ice .... (TFY)	> 120 cm	-3	-3	-3	-2	-1	1	2
1•	Medium First Year Ice .... (MFY)	70-120 cm	-2	-2	-2	-1	1	2	2
7 9	Thin First Year Ice .... (FY) Thin First Year Ice - 2nd Stage	30-70 cm 50-70 cm	-1	-1	-1	1	2	2	2
8	Thin First Year Ice - 1st Stage	30-50 cm	-1	-1	1	1	2	2	2
3 or 5	Grey-White Ice.................. (GW)	15-30 cm	-1	1	1	1	2	2	2
4	Grey Ice............................ (G)	10-15 cm	1	2	2	2	2	2	2
2	Nilas, Ice Rind	< 10 cm	2	2	2	2	2	2	2
1	New Ice .... (N)	< 10 cm	“	“	“	“	“	“	“
	Brash (ice fragments < 2 m across)		“	“	“	“	“	“	“
⇨Δ	Bergy Water		“	“	“	“	“	“	“
⊕⊕⊕⊕	Open Water		“	“	“	“	“	“	“

Notes: Decayed Ice: For the following ice types: MY, SY, TFY, and MFY that are ‘decayed’, add 1 to the Ice Multiplier.

Ridged Ice: For floes of ice that are over 3/10ths ‘Ridged’ and in an overall concentration that is greater than 6/10ths, subtract 1 from the Ice Multiplier.

The ASPPR deals with vessels that are designed to operate in severe ice conditions for both transit and Icebreaking (CAC class) as well as vessels designed to operate in more moderate first-year ice conditions (Type vessels). The System determines whether or not a given vessel should proceed through that particular ice regime. If the Ice Numeral is negative, the ship is *not* allowed to proceed. However, if the Ice Numeral is zero or positive, the ship is allowed to proceed into the ice regime. Responsibility to plan the route, identify the ice, and carry out this numeric calculation rests with the Ice Navigator who could be the Master or Officer of the Watch. Due care and attention of the mariner, including avoidance of hazards, is vital to the successful application of the Ice Regime System. Authority by the Regulator (Pollution Prevention Officer) to direct ships in danger, or during an emergency, remains unchanged.

At the present time, there is only partial application of the ice regime system, exclusively outside of the “zone-date” system.

Credibility of the new system has wide implications, not only for ship safety and pollution prevention, but also in lowering ship insurance rates and predicting ship performance. Therefore, there is a need to establish a scientific basis for the system. To this end, Transport Canada approached the Canadian Hydraulics Centre of the National Research Council of Canada in Ottawa to assist them in developing a methodology for establishing a scientific basis for AIRSS. This led to a "road map" approach that is based on 7 Tasks (Timco and Frederking 1996; Timco et al. 1997).

Different approaches were looked at to put the system on a scientific basis. For a variety of reasons, it was decided that an empirical approach would provide the most confidence in establishing a scientific basis. That is, the approach is not based on first-principle calculations of potential ice damage. Instead, the approach makes use of the large number of different vessels that have traveled through a wide range of ice and environmental conditions. It investigates the actual conditions that have caused vessel damage in ice.

There are many things to consider with the ice regime system. First, it is based on the Pollution Prevention Regulations and is, therefore, safety (not operational) oriented. Any suitable system must meet the needs of Transport Canada as the Regulator, but must not unduly penalize ship operators from operating in ice-covered waters. In developing a scientific basis, there are a number of key components that can be used as input into the scientific approach. Based on this analysis, Timco and Frederking (1996) prepared the Context Diagram, as shown in Figure 1, for this work. This Diagram presents a summary overview of the main factors driving this work.

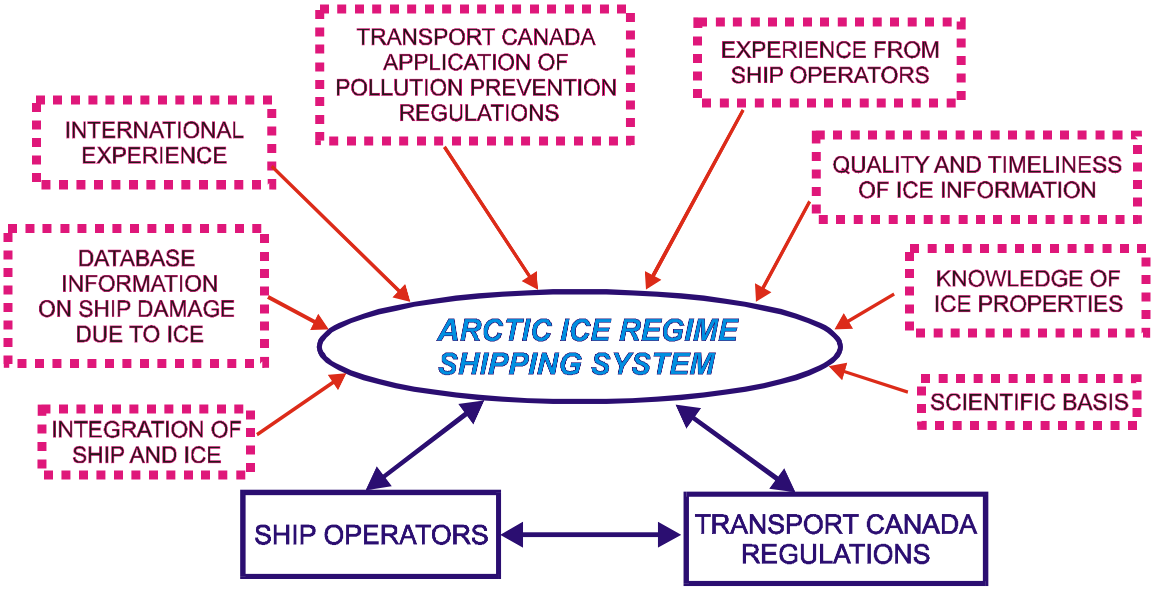

Figure 1 Context diagram for the scientific basis for the ice regime system

In developing the methodology, a very straightforward approach was employed. The approach centers on asking and answering seven basic questions. Each question is a logical extension to the answer of the previous question. The basic questions are:

1. What problems can happen to a ship in ice?
2. What are specific examples of problems that have occurred that could be used for a deterministic development? i.e. specific case-histories that can be used to identify and understand the problems.
3. Would the current ice regime system have predicted these problems?
4. If not, how can the problem conditions be better defined?
5. Can the current ice detection methods identify the problem ice conditions?
6. If not, how can the ice detection systems be improved in a pragmatic manner to be able to detect the problem ice?
7. How can this information be communicated to the ship to implement the Ice Regime System?

These questions led to the following 7 Tasks:

1. Define Safety-Related Issues
2. Definition of Specific Problems with the Corresponding Ice Conditions
3. Assess the Adequacy of the AIRSS
4. Definition of Problem Ice and Operation Conditions
5. Identification of Problem Ice

6. Detection of Problem Ice
7. Implementation of AIRSS

The progress made in addressing these Tasks, and in answering the 7 basic questions is presented in this report. It should be noted that the work done on this project is not complete. However, the work has made significant progress towards its intended goal. This report is meant to highlight the progress, and to lead to a focused discussion in the marine community on the final form for the ice regime system.

2.0 TASK 1 - SAFETY-RELATED ISSUES

A large number of vessels have been damaged by ice. The damage primarily relates to hull deformation or fractures due to impacts with ice, damage to propellers or steering gears, vessel immobilization due to pressured-ice conditions, and ice overtopping the deck and damaging critical elements. For the present purpose, it is necessary to categorize the types of damage, and damage extent, in terms of their potential to cause pollution. To quantify the damage in this way, **Damage Severity (DS) Numbers** were defined as presented in Table 2.

Table 2 Definition of Damage Severity Numbers

Damage Severity Number	Description
0	No damage
1	High measured stress
2	slight deformation of hull, denting, propeller
3	small puncture or fracture, extensive denting
4	large hole
5	vessel sank

It should be noted that this damage description is not based on the cost of repair, nor downtime for a vessel. It is based strictly on the pollution potential of a particular type of damage. With this definition, it can be seen that Damage Severity of 3, 4 or 5, which represent breaching of the hull, have the highest probability for causing pollution. In subsequent analysis in this report, these damage events have been termed **Potential Pollution Damage (PPD).**

A listing of vessel damage should be related to the class of the vessel. The AIRSS is based on several different vessel categories, which are primarily sub-divided into the new (1995) Canadian Arctic Class (CAC) and Type vessels. The ice regime system was developed using the concept of "limiting" ice. This is the thickest ice type in which a properly navigated ship can operate without risk of structural damage (ASPPR, 1989). Each ship category is designed to withstand impacts with all ice types at and below the "limiting" ice type. The "limiting" ice type and ship category are presented in Table 3 (from ASPPR, 1989). These ice types are related to the AES/WMO ice types listed in Table 1. Note that, in this table, the Ice Multipliers are 1 for the "limiting" ice type for each class.

Table 3 “Limiting” Ice Type versus Ship Category

Ship Category	Limiting Ice Type
CAC1	None
CAC2	Multi-year Ice
CAC3	Second-year Ice
CAC4	Thick First-year Ice
Type A	Medium First-year ice
Type B	Thin First-year ice - 2nd stage
Type C	Thin First-year ice - 1st stage
Type D	Grey-White Ice
Type E	Grey Ice

To date, there have not been any CAC vessels designed and built exactly to the new vessel classes defined in the proposals for the revision to the pollution prevention regulations (ASPPR, 1989). Therefore, for the present purposes, ships used in this analysis have been assigned, using a “best estimate of the equivalency” into one of these categories. This assignment of individual vessels was based on discussions with several people including Robert Wolfe of Transport Canada, Andrew Kendrick of Fleet Technology, Bob Gorman of Enfotec, and Capt. Peter Dunderdale, as well as using the Table of Equivalency from Schedule 5 to the ASPPR.

Damage information was obtained from several sources including the Transportation Safety Board, the Norland/AKAC Damage database (Norland & AKAC 1993), B. Wright of Wright & Associates, Neil Denis of Braden Marine, as well as numerous individual reports of vessel damage. From this information, a large number of different damage events were obtained. The vast majority of the damage events occurred in Canadian waters. The results are summarized in Table 4 to Table 10 for CAC3 to Type E vessels respectively. Note that the tables provide information on the vessel damage, cause of damage, and the Damage Severity number for each Event. The wording used to describe the damage and cause of damage is taken from the original source.

Table 4 Damage Events for CAC 3 vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
2	Minor damage to propeller	vessel struck MY ice following an escort icebreaker
2	Denting of hull bottom	transiting shallow water, grounding on ice pieces
2	Some (medium)	transiting through heavy MY ice
2	Minor	hitting FY ice
2	Minor denting at lower bow.	ice management, high speed ramming
2	Problems with the vessel's impressed current systems.	cause unknown (9+/10 Y)
2	Damage to the port and starboard propellers	icebreaking operation in severe ice conditions
2	Propeller damage.	jammed ice in the propellers (10/10 SY)
1	high stress	3 impacts with MY floes, weaving through rough ice.
1	high stress	impacted MY floe; ship rode up unto floe and then slid off

Table 5 Damage Events for CAC4 vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
4	starboard damage - ripped, gaping hole 6 m long 1.5 m high	high speed in OW hitting MY growler
3	cracks and frame deformation including buckling	transiting through area of MY ice
3	port side damage,	struck MY ice when attempting to follow turn made by escort
3	cracks and plate dishing/denting	vessel beset in MY ice
3	cracks - location unknown	vessel rocking in MY while beset
3	1 m crack Port side bow shell plating	vessel engaged in trials - ramming MY ice floe
3	cracks - midship	MY ice floe, vessel unable to move due to heavy pressure
2	Ice damage Minor	port shield plate damaged in ice
2	Minor	vessel struck 7/10 MY ice
2	Propeller damage	damage due to ice (10/10 SY)
2	Stearing gear, damage to rudder	ice damage
2	Propeller damage	ice damage while proceeding through ice (3/10 SY and 5/10 FY)
2	Shell plating, buckled frames	while transitting Baffin Bay (1/10 MY and 9/10 FY)
2	Minor	deflecting an iceberg
2	Minor	ice damage while escorting other vessel in old ice (MY & SY)
2	Plate dishing/denting	exact cause unkown
2	4 damaged propeller blades.	unknown (4/10 SY and 6/10 FY)
2	Propeller damaged	unknown (5/10 SY)
2	vessel struck 30x30m floe, no holes were developed	vessel damaged while trying to avoid MY ice
2	2 bent blades, 1 blade scored, 1 blade with upper third part broken	while freeing a vessel in pressured ice
2	suspect indentation of hull plates at ice draft.	transiting through 10/10 ice with heavy rafting, vessel trapped in ice

Table 6 Damage Events for Type A vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
5	Vessel holed and sank	- vessel rolled sideways into an old ice floe
4	Holed in port side, engine room flooded	- struck MY floe
3	Port side shell plating indented and cracked 8 ft. below waterline	- cause unknown (3/10 MY and 7/10 FY)
3	All three rudder stocks twisted and bent	- cause unknown (3/10 MY and 7/10 FY)
3	Small leak near stern post / Holed	- presumed to be due to ice (10/10 FY)
3	Vessel damaged on startboard bow, apparently holed	- following too close to escort in pressure conditions
3	hull plating ruptured and supporting frames collapsed	- cause unknown (4/10 MY and 2/10 FY)
3	Holed - leakage in one small ballast tank	- proceeding through MY floe
3	small puncture in bow - frame deformation including buckling	- cause unknown (9+/10 total: 7/10 MY and 2/10 FY)
3	small puncture in bow - frame deformation including buckling	- cause unknown (9+/10 total: 2/10 MY and 7/10 FY)
2	Minor plating and frame damage, Propeller cones damaged	- backing and ramming in multi-year ice
2	Dent in hull on port side near deck level	- unknown (1/10 MY and 7/10 FY)
2	Damage to shell/bottom plating, propeller blades & rudders	- vessel beset in close pack ice (FY)
2	Indentation of shell plating	- following track of icebreaker
2	Hull damaged	- impact with heavy ice pieces (FY)
2	Minor	- severe ice conditions (1/10 MY and 4/10 FY)
2	denting - stern; frame deformation	- vessel beset in pressured ice (8/10 MY and 2/10 FY)
2	some damage to plating, deflections of transverse frames	- vessel under heavy compression of ice (9/10 FY)
2	buckling of frames	- vessel in compressive ice (9/10 FY)
2	frames buckling	- vessel in compressive ice (9/10 FY)
1	high stress	- continuous ramming (9+/10 FY)

Table 7 Damage Events for Type B vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
4	Bow thruster compartment holed	old ice piece broke off from submerged floe and rose up forcefully
4	.15 m hole, considerable damage to plating and frames,	while beset in ice, the ice rafted, nipped and crushed vessel port quarter.
4	Bulbous bow holed on port side, forepeak tank open to sea	vessel was stricken in 8/10 ice (4/10 old ice, 4/10 FY)
4	Holed in both bows, forepeak tank open to sea	heavy impact with MY ice (9/10)
4	Holed in starboard bow.	sheered into heavy ice while manoeuvering in icebreaker track (10/10 MY)
4	holed in port bow	sheered into heavy ice while manoeuvering in escort track (5/10 MY and 3 FY)
4	Forepeak port side holed, No.1 cargo hold open to sea;	excessive speed; ship master attributes cause to darkness & bad weather
4	Hole in #1 Bower hold -Starboard site	hitting MY ice while being escorted
4	Forepeak tank holed	impact with hidden multi-year piece or growler
4	Vessel damaged hull on port side.	impacted ice (1/10 MY, 9/10 FY)
4	Damaged area 6 sq.m., holed and flooded No.1 ballast tank	vessel pushing ahead into multi-year ice
4	Port side bow fractured, 2 sq.m., forepeak and cofferdam flooded	track filled with heavy pieces of ice (5/10 MY and 3/10 FY)
4	Ice damage at stern, port side, forepeak holed	uknown (2/10 MY and 8/10 FY)
3	Vessel holes near stern	unknown (1/10 MY and 5/10 FY)
3	Bow plating holed below waterline / Minor	unknown (6/10 SY)
3	Holed	proceeding through heavy (9-10/10) FY ice
3	Holed	proceeding through very close pack ice (10/10 FY)
3	Port side cracked near stern in way of forepeak ballast tank	struck several ice floes during escort
3	Holed	impacted ice piece going through a strip
3	Vessel holed forward	contact with ice (3/10 MY and 7/10 FY)
3	Holed, minor pollution	impact with MY ice
3	Bow plating holed 2 m below waterline	unknown (9/10 FY)
3	4-5 frames buckled in forepeak area, small weld cracks	entered fog bank at 4 knts, 2 medium MY floes left no room to manoeuvre
3	Holed	proceeding through very close pack ice (MY) and striking MY floe
3	Damage to port side shell plating and internal structure	contact with floe of MY ice
3	Holed	forward transit in ice (3/10 MY and 5/10 FY)
3	cracks in bow	damage in 8/10 ice
3	small puncture in bow	damage due to ice (9+/10 FY)
3	18" - 24" gash, frames badly buckled	hit piece of SY ice
2	Minor ice damage	ice damage
2	Minor	while transiting through 2/10 MY and 1/10 FY
2	Bow and side plating damage	struck a heavy floe (FY)
2	Damage to propellers; stbd. nozzle, rudder stock and skeg	transiting through a track being thightly packed with ice (10/10 FY)
2	Small indent in bow	unknown (5/10 MY and 4/10 FY)
2	Minor	ice damage
2	Minor	ice damage during escort
2	Dent	sustained damage while navigating in ice
2	Minor	transiting through 6/10 MY and 3/10 FY
2	Minor	ice damage (1/10 MY and 2/10 FY)
2	dent on the hull plate of F.P.T. and the bent on the frame	unable to follow path of escort due to vessel sudden veering at the wide angle
2	Minor	minor ice damage found in drydock inspection (9/10 FY)
2	hull dented	shell damage discovered on dry docking (10/10 FY)
2	Slight damages on the propeller blade tips.	steering gear damaged while operating in ice (9/10 FY)
2	Starboard side shell plating.	very hard pressure on ship's sides (10/10 FY).
2	Port and starboard side shell plating and internals, and propeller.	unknown (10/10 FY)
2	Shell plating and internals, bow thruster compartment & cargo tanks	vessel beset in ice (9/10 FY)
2	Starboard shell plating and in way of the bow thruster compartment.	unknown (7/10 FY)
2	Outboard half of starboard kort nozzel and rudder damaged.	ice thrust back by escort,
2	Port prop damaged in heavy ice	Propellor damaged in heavy old ice (5/10 SY)
2	Starboard side caved-in	while beset, ice rafted on both sides subjecting vessel hull to intense pressure
2	Damages on the shell plating	heavy ice compression - 7th vessel of an icebreaker convoy
2	Five areas damaged; deck plating buckled	vessel stuck in compressive ice (10/10 FY)
1	high stress	medium impact with a small floe at slow speed
1	high stress	ship beset 3 times in old ice (3/10 SY)
1	high stress	moderate ice impact
1	high stress	two direct, moderate impacts with old ice (2/10 MY)
1	high stress	three moderate impacts with small decayed MY floe at speed of 2 knots
1	high stress	lost the track of escort; stuck between two big floes of multi-year ice
1	high stress	vessel impacted a multi-year floe that had drifted into the track

Table 8 Damage Events for Type C vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
3	small puncture in outer hull	ice (1/10 MY and 9/10 FY)
2	Some shell plating set in, some fractured welds	unknown
2	Hull plating and frames damaged; no pollution	unknown (9/10 MY)
2	Concave marks on hull; nicks on propeller	squeezed on several occasions
2	Shell plating damage on the forward port and starboard sides.	direct result of operating in ice

Table 9 Damage Events for Type D vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
4	Very severe damage along starboard extending along #1 and #2 holds.	vessel further north than normal route
3	Indentations on bulbous bow; dents and fracture on port side	unknown (5/10 FY)
3	Port and starboard shell plating. Indented and fractured port and starboard shell plating and internals.	damage attributable to ice (10/10 FY)
3	0.6 m crack	vessel beset in ice under heavy pressure (9+/10 FY)
3	cracks & plate denting	vessel beset in ice under heavy pressure (9/10 FY)
2	damage to plating on bow - pushed-in plating on stern port side.	encountered heavy floes of drift ice (7/10 FY)
2	External damage to starboard propeller and shaft	propeller impacted ice
2	Hull damaged at various places (bow, forepeak, engine room)	unknown (1/10 MY and 8/10 FY)
2	Propeller lost - Minor	lost starboard propeller contacting 4/10 ice; bergy waters
2	Damage to propeller	while attempting to dock, port propeller severely damaged (9/10 FY)
2	Stern rudder twisted by approx. 32 deg.	unknown (10/10 FY)
2	Damages were sustained to the propeller shafts and rudder	entered ice floes and subsequently noticed the vessel vibrating
2	shell plating	unknown (9+/10 FY)
2	Damage to shell plating noted during diver's inspection	presumed caused by the build up of ice pressure (10/10 FY)
2	Areas of shell plating heavily set in; frame buckled and distorted.	vessel beset in ice under heavy pressure (9+/10 FY)

Table 10 Damage Events for Type E vessels

DS	DAMAGE DESCRIPTION	CAUSE OF DAMAGE
5	Holed in starboard bow; vessel sank when watertight compartment was inadvertantly open to the sea	presumed impact with ice (7/10 MY)
4	severe damage to hull bottom of bulbous bow	unknown (1/10 MY and 4/10 FY)
4	Extensive damage to forefoot of bulbous bow; forepeak tank holed	unknown, CCGS reports strips and patches of 9/10 in area
4	Holed bulbous bow at waterline	direct impact with ice
4	Bulbous bow and starboard hull holed	passing through patches of heavy ice at very slow speed
4	Holed shell and buckled frames	forward transit in heavy pack
3	Bow plating damaged at waterline, 1sq.m. area, craking at forepeak	attributed to difficult movement behind icebreaker
3	Crack in plating at starboard bow 3 m back from stern; propeller blade bent at tip	unknown (1/10 MY and 7/10 FY)
3	Damaged both sides of forepeak	following in icebreaker track which was closing quickly
3	3 rudders sheared off, 1 bent and jammed; frames damaged both sides; plating dented.	heavy ice conditions behing icebreaker
3	Cracked hull and damaged frames	while under escort
3	Port gearbox damaged; both port and starboard propellers leaking oil	propeller and gerabox damage contacting ice (7/10 FY)
3	Damage to forepeak compartment	track was filled with thick FY ice pieces (1/10 MY and 9/10 FY)
3	Sides of vessel. Also propeller and rudder. Shell dented, buckled frames	vessel beset in pressure, sides squeezed in extreme pressure
3	3rd plate below sheer set in and distorted over lower 1 m full length.	unknown (9/10 FY)
3	Extensive damage sustained in way of the bow, shell plating and propellers.	violent contact with ice (9/10 MY)
3	Bow plates damaged at water level with some plates cracked in forepeak	vessel transmiting through heavy ice (9+/10 FY)
2	Minor indents at breast hook area	unknown (1/10 MY and 3/10 FY)
2	Plating damaged on both sides, not holed	unknown
2	damage to the propeller and rudder	unknown (5/10 MY and 4/10 FY)
2	Vessel reports light damage to 5 frames at forepeak	unknown (9/10 FY)
2	Minor damage below the buoyancy line.	
2	Indentation 0.15 m for a length of 10 frames. No leakage or cracks.	violent contact with ice while following icebreaker
1	high stress	unknown (6/10 FY)

3.0 TASK 2 - SPECIFIC PROBLEMS WITH CORRESPONDING ICE CONDITIONS

In this task, it is necessary to collect, in a very systematic manner, information on both damage Events and non-damage Events. In this case, an Event is described as ship transit through a known ice regime. The Event must include all relevant information about the transit including the vessel characteristics, route, climate, ice conditions and resulting damage (or no damage). It is important to include both damage and non-damage events to ensure that the analysis has a fair balance between the restrictions to limit damage (i.e. Regulators viewpoint) and the ability to travel through ice (Operators viewpoint) [see Figure 1].

The CHC developed a very comprehensive database that combines all of the key elements in a systematic manner (Timco and Morin 1997, 1998a, 1998b; Timco et al. 1999). Since the details of the database have been extensively discussed in these references, they will not be described here. However, it is important for the reader to understand a number of salient features of the database:

- It contains 1125 Events related to occurrences of both damage and non-damage. The database contains 934 non-damage Events and 191 Damage Events (see Figure 2). About 3% of the (damage) Events did not have full information on the damage or detailed ice conditions. These Events were not used in any analysis of the data, but they were included in the database for completeness;
- The database is very comprehensive. Each specific Interaction Event is characterized by 79 fields that relate to vessel characteristics, route, climate, ice conditions and damage;
- The Events cover vessel classes from CAC3 to Type E. Figure 3 shows the breakdown of Events for each class. Note that on this figure, there is an additional breakdown of information in terms of damage (D) and non-damage (ND) Events for each class.
- All of the damage Events were categorized according to the Damage Severity Number described in Table 2. The breakdown of these Events is shown in Figure 4;
- Information for the database came from a wide number of sources;
- The database contains Events related to 131 different vessels. Care was taken to ensure that a large number of vessels were used so that a single vessel would not bias the database;
- Bob Gorman of Enfotec and Capt. Peter Dunderdale of Dunderdale & Associates independently reviewed the Events in the database.

It should be noted that although the present description of the database is very brief, the database is very comprehensive. It can be used in numerous ways to verify and/or improve the ice regime system, and put it on a scientific basis.

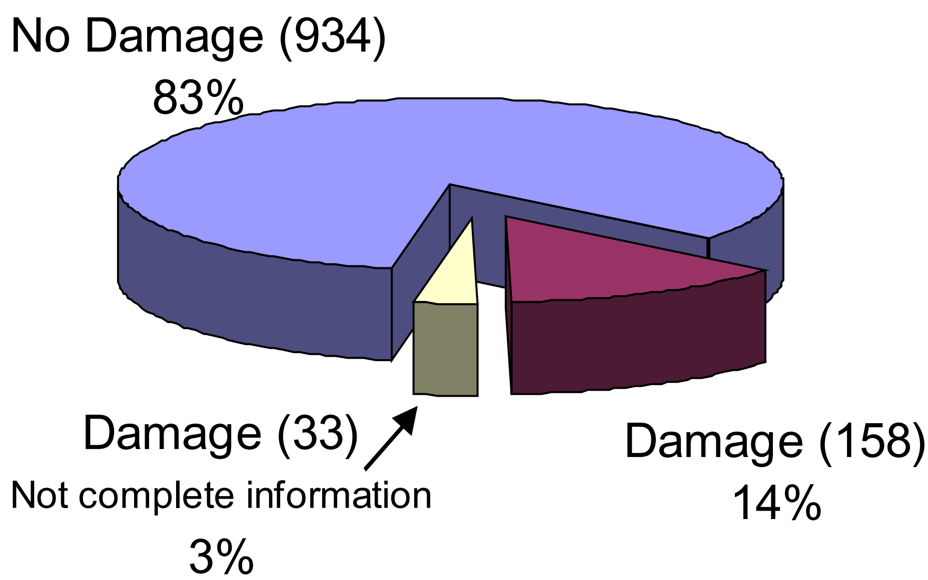

Figure 2 Pie chart showing the breakdown of Events between damage and non-damage Events in the CHC database.

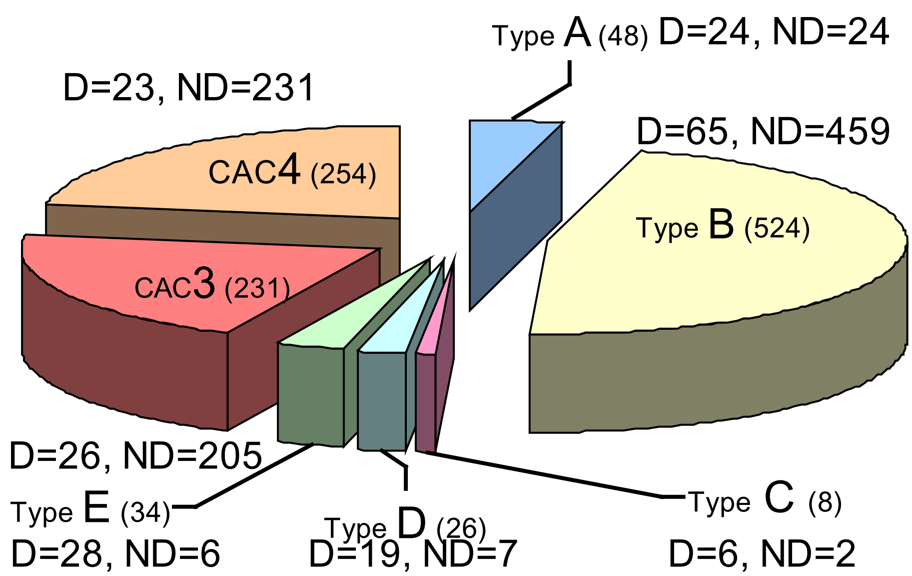

Figure 3 Pie chart showing the breakdown of the Events in the CHC database according to vessel class and damage (D) and non-damage (ND) Events.

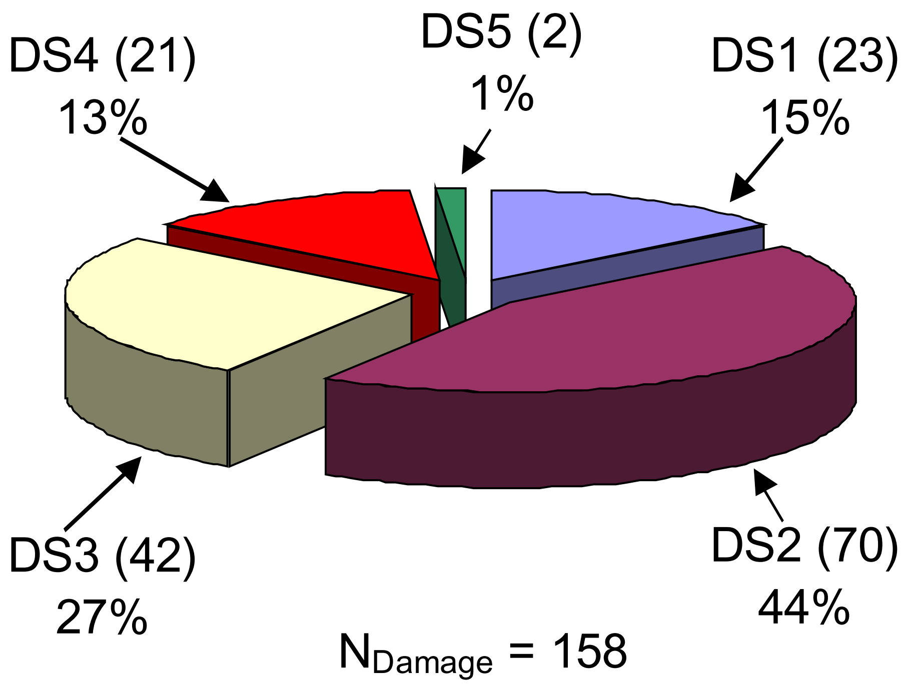

Figure 4 Pie chart showing the number of damage events according to the Damage Severity (DS) as defined in Table 2.

4.0 TASK 3 – ADEQUACY OF THE ASPPR DEFINITION

It is possible to use the database to determine if the definition for the Ice Numeral (IN) proposed in the ASPPR agrees with documented empirical data.

For ease of presentation and understanding, the information has been compiled into a series of 3 pie charts, according to the Damage Severity (DS) Number. These pie charts, as shown in Figure 5, are described as follows:

Damage Severity (DS) ≥ 3
These Events represent ship damage situations where there was hull fracture or cracking, holes in the hull, or large hull deformations. This category represents the damage that could result in pollution, and as discussed previously, is designated as Potential Pollution Damage (PPD). For an ideal Ice Regime System, all of these damage Events should have a **negative** Ice Numeral.

Damage Severity (DS) = 1 or 2
These Events represent either minor damage, or damage to propellers or steering gears, etc. (DS = 2), or high measured stress on the hull in ship trials (DS = 1). It could be considered that these Events are the "transition" Events between no damage and PPD damage. For an ideal Ice Regime System, these Events should have an Ice Numeral close to zero, with an even split of positive and negative Ice Numerals.

Damage Severity (DS) = 0
These Events represent no damage Events, where the vessel has traversed an ice regime without any damage. For an ideal Ice Regime System, these Events should all have **positive** Ice Numerals.

The ideal Ice Regime System should have only negative numbers for PPD, an even split between positive and negative Ice Numerals for minor damage and only positive Ice Numerals for no damage situations. Because of the great complexity and the large number of factors that influence a vessel in ice-covered waters, it is not realistic to expect that an ideal system could be obtained. However, it is realistic to expect that the definition of the Ice Numeral accurately represent the situation to minimize the number of positive Ice Numerals for the PPD situation (while still capturing the PPD Events), and minimize the negative Ice Numeral situations where the damage risk is lower. These trends are shown schematically in Figure 5 in the pie chart representation of the data.

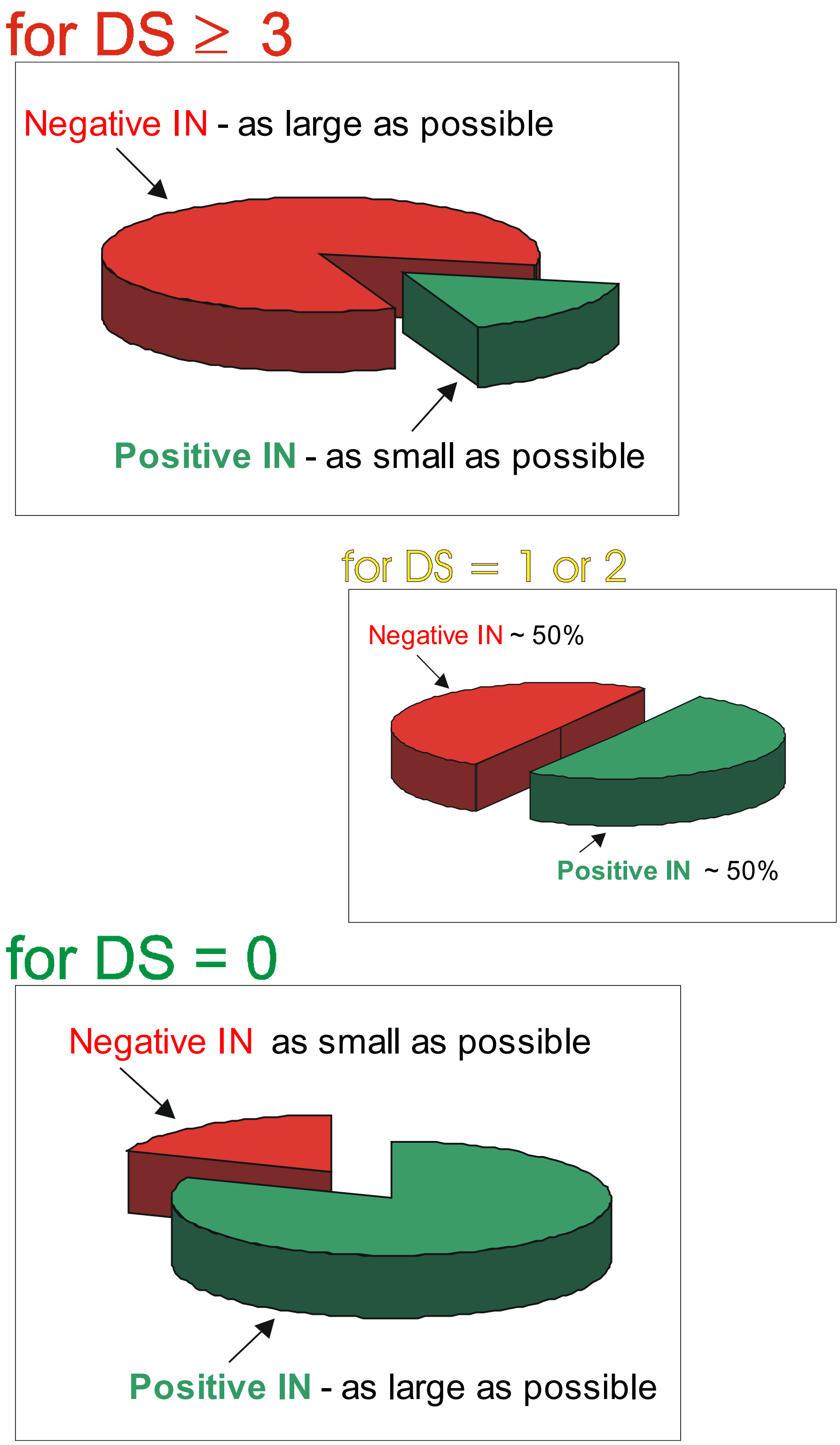

Figure 5 Illustration of the pie chart analysis of the data. An ideal Ice Numeral would maximize the negative Ice Numerals for DS ≥ 3, and maximize the positive Ice Numerals for DS=0.

Task 3 investigates the fit of the empirical data to the current definition of the ASPPR Ice Numeral, as defined in Section 1.0 and Table 1. Using this definition, the pie chart analysis of the data is shown in Figure 6. There are a number of important issues to note:

1. The current definition of the Ice Numeral captures 83% of the PPD Events, but it misses 17% of these Events.
2. There is a good 50-50 split for DS = 1 or 2
3. The current definition of the Ice Numeral allows passage for 81% of the no damage Events in the database, but it would have restricted 19% of the Events, even though there was no resulting damage[1].

According to this analysis, although the current definition of the Ice Numeral captures the general desired trend, the definition does miss several damage Events, and it does significantly restrict access to transportation in situations in which there was no resulting damage. Task 4 will examine other possibilities for the definition in an attempt to improve the fit to the data.

[1] It should be kept in mind that the present analysis is based on a limited amount of data and with Events that were selected to test the limits of the Ice Regime System. Therefore it is important to realize that the analysis does not imply that the current definition of IN would restrict access for 19% of the non-damage cases. That is, the CHC database cannot be used or viewed as a Risk Database.

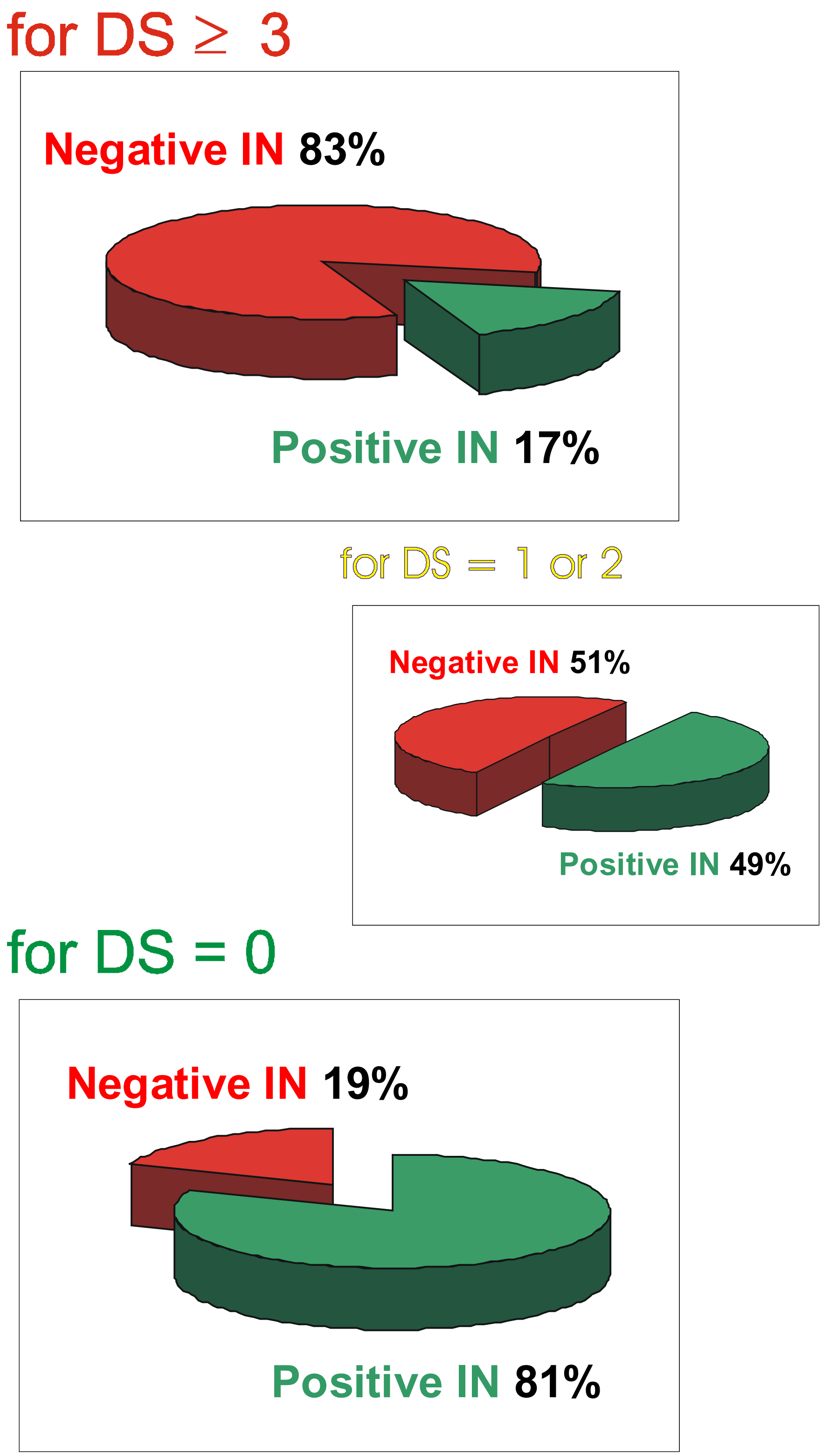

Figure 6 Pie chart analysis for the ASPPR Ice Numeral as calculated using the current definition of IN in the Arctic Ice Regime Shipping System.

5.0 TASK 4 - DEFINITION OF PROBLEM ICE AND OPERATION CONDITIONS

Improving the definition of the Ice Numeral is not a simple task. Initially, a fundamental decision must be made.

The existing approach to the Ice Numeral considers the vessel as being characterized solely by an "Ice Class", and the ice regimes to be characterized by a few ice properties (see Figure 7). In reality, however, this is not the case. There are several important aspects that must be considered, the main one being that the whole process is one of the interaction of the ship with the ice regime. Viewed in this way, several other factors come into play (see Figure 8). These factors **must** be considered to improve the definition of the Ice Numeral.

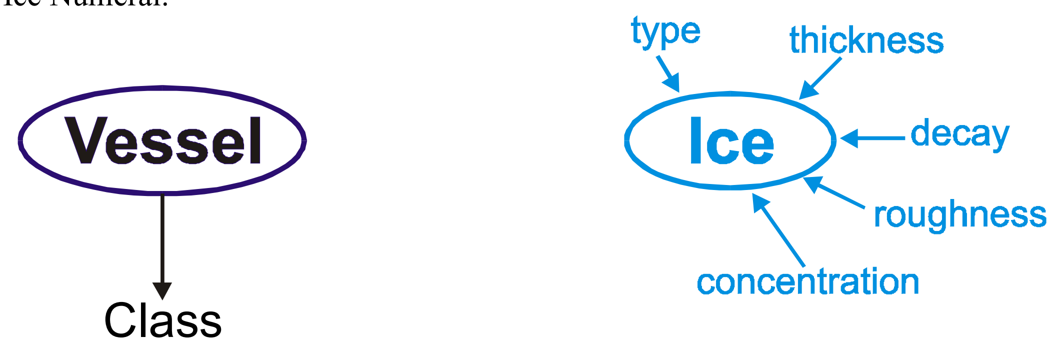

Figure 7 Illustration of the existing approach for defining the ASPPR Ice Numeral.

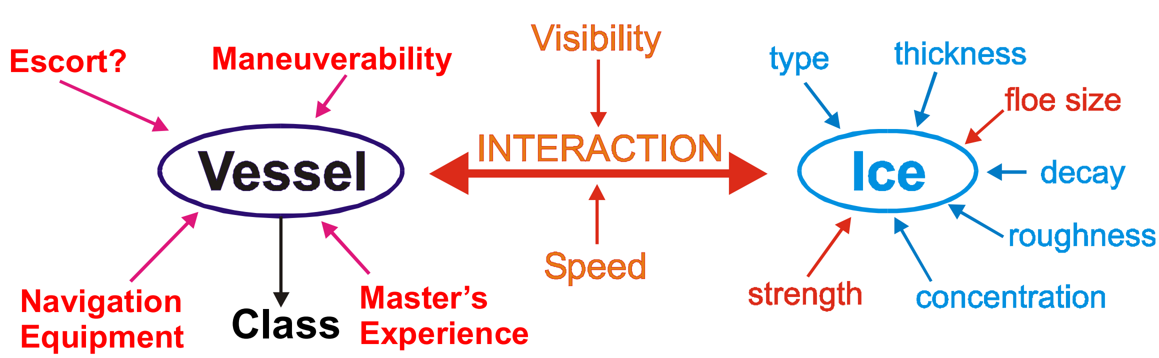

Figure 8 Illustration of the "Interaction" approach for defining the Ice Numeral. This approach could take into account more of the realistic and important factors affecting ships operating in ice-covered waters.

How can this be done? Fortunately, the CHC database described in Section 3.0 allows testing of different hypothesis based on actual field data. The CHC have used the database to investigate a large number of different combinations of factors[2]. By using an *interaction* approach with reasonable assumptions, the definition of the Ice Numeral can be considerably improved.

A proposed methodology for refining the definition of the Ice Numeral is presented in this chapter.

5.1 Base Case Situation

At the start of this Task, the following question was posed:

What conditions should give an Ice Numeral of Zero?

To answer this question, one could consider the "limiting" ice type for each vessel class, as outlined in Table 3. If one considers this to indeed be the limiting ice type, then it is reasonable to assume that the Ice Numeral should be zero when the vessel is in 10/10s concentration of its limiting ice type. With the present definition of the ASPPR Ice Numeral, the Ice Multipliers for the limit ice type are 1 in all cases (see Table 1). Therefore, in 10/10s concentration of limit ice, using Equation 2-1, the ASPPR Ice Numeral would be 10 (i.e. C = 10, and IM = 1). It is proposed that:

- *Ice Multiplier should be defined to be **zero** at the limit ice type for each vessel;*
- *Ice Multiplier for ice below the limit ice type should be treated equally, and given a value of **2**.*

The latter is now the case except for a few categories for Type C and Type B vessels. The revised Multipliers are presented in Table 11. The changes from Table 1 are indicated in red. These Ice Multipliers are considered for *worst case conditions*, and they are designated as **BaseCase Ice Multipliers**.

It should be noted that the interaction approach to calculating the Ice Numeral is considerably more complex than the simple approach used now in AIRSS. In the following sections, different factors that could influence travel through ice-covered waters are discussed. For each case, a modification to the Ice Numeral is suggested. In some cases, the modification would *add* to the Ice Numeral, whereas in other cases, the modification would *subtract* from the Ice Numeral. After considering all factors, the final Ice Numeral would then be calculated.

[2] Summaries of a number of these analyses are given in Appendix A.

Table 11 BaseCase Ice Multipliers

Ice Types	Vessel Class						
	Type					CAC	
	E	D	C	B	A	4	3
Old / Multi-Year Ice	-4	-4	-4	-4	-4	-3	-1
Second-Year Ice	-4	-4	-4	-4	-3	-2	0
Thick First-Year Ice	-3	-3	-3	-2	-1	0	2
Medium First-Year Ice	-2	-2	-2	-1	0	2	2
Thin First-Year Ice - 2nd Stage	-1	-1	-1	0	2	2	2
Thin First-Year Ice - 1st Stage	-1	-1	0	2	2	2	2
Grey-White Ice	-1	0	2	2	2	2	2
Grey Ice	0	2	2	2	2	2	2
Nilas, Ice Rind	2	2	2	2	2	2	2
New Ice	2	2	2	2	2	2	2
Brash	2	2	2	2	2	2	2
Open Water	2	2	2	2	2	2	2

5.2 Summer Conditions

There are 3 important differences between summer and winter navigation in the Arctic:

1. During the summer months, there is generally better visibility due to the daylight conditions;
2. The strength of the ice is significantly reduced during the summer months (see Figure 9);
3. The higher air temperatures in summer result in a more ductile (i.e. less brittle) material properties for the steel hulls.

To account for these factors, it is proposed that:

- *during the summer months (June 1 to September 30), a value of **10** is added to the Ice Numeral, with a few exceptions as noted below.*

5.3 Visibility

Visibility is considered to be an extremely important consideration for safe travel. In summer months, the visibility is generally good due to the abundant amount of daylight. However, blowing snow and fog can seriously affect visibility. Thus, it is proposed that:

- *if the visibility were poor, the summer bonus of increasing the Ice Numeral by 10 would not be granted.*

In this case, poor visibility would be defined as less than one-half kilometre in front of the vessel.

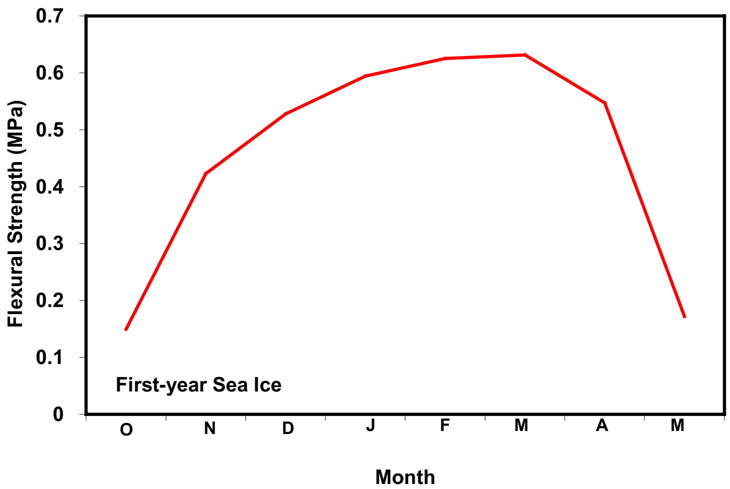

Figure 9 Flexural strength of first-year sea ice versus date (October to May) for the Canadian Arctic (after Timco and O'Brien 1994)

5.4 Vessel Speed

Examination of the damage incidences described in Section 2.0 clearly shows that speed is often a factor in causing damage. In this proposal, low speed is rewarded and high speed is penalized. This is done by adding a value to, or subtracting a value from, the Ice Numeral. This criterion is further defined according to the class of the vessel. For the present analysis:

- *Add **5** to the Ice Numeral if the speed is less than 3 knots for the CAC and Type A & B vessels (i.e. no reward for low class Type vessels (i.e. Type C, D & E) even if the speed is low).*
- *Subtract **5** from the Ice Numeral if Multi-year ice is present and the speed is greater than 7 knots (only for Type C, D, & E vessels).*

It is suggested that further guidance in this area could be obtained by examining the Russian Passport System.

5.5 Experience of Master or Ice Navigator

The experience of the Master or Ice Navigator plays an extremely important role in the safe operation of a vessel in ice-covered waters. This fact should be recognized. For the present analysis, this was included in the following way:

- *Subtract **3** from the Ice Numeral if the Master or Ice Navigator has limited experience in ice.*

For this, recommendations from Transport Canada on the threshold limit for experience (i.e. Master of a vessel for over 200 hours in ice-covered waters with no damage incidents) must be clearly defined.

5.6 Maneuverability of Vessel

The maneuverability of the vessel can play an important role in the safe operation of a vessel in ice-covered waters. However, this factor has not been taken into account in this proposal. It is suggested that this factor be considered and discussed amongst Stakeholders for an acceptable approach for including it.

5.7 Navigational Equipment

Navigation equipment that provides good detailed information on the near and far-field ice regimes can play an important role in the safe operation and routing through difficult waters. For this analysis, this factor was considered, but no changes to the Ice Numeral were implemented. It is suggested that discussions be held on a method for incorporating this into the ice regime system.

5.8 Ships under Escort

Ships under escort are treated in the same manner as in the current ice regime system. That is, the ice regime encountered by the escorted vessel is not based only on the ice regime in its general region. Instead, it is based on the general ice regime taking into account the track of the escort vessel. This is a modified ice regime compared to the regime in the general region. It should be mentioned that there are several instances of vessel damage during escort, and the issue of ships under escort should be considered in some manner.

5.9 Presence of Multi-year Ice

Collision with multi-year ice is often the cause of damage to vessels in the Arctic (see Table 4 to Table 10). Therefore, it is especially important that this fact be considered in a more pro-active manner, especially for the low ice class vessels. It is proposed that:

- *if there is multi-year or glacial ice present in the ice regime in concentrations of 1/10th or higher, there is no summer bonus of 10 for Vessels with an ice class of Type C, D & E. This restriction would not apply to the Type B vessels and higher class.*

5.10 Ridging

For the present proposal, ridging was taken into account in the same manner as used in the current definition of the Ice Numeral. That is,

- *Subtract **1** from the **BaseCase Ice Multipliers** for ice floes that are over 3/10^{s} ridged and in an overall ice concentration that is greater than 6/10^{s}.*

5.11 Decay

Decay is treated here differently than in the current ASPPR approach. For this proposal, the effect of low ice strength is already considered in summer adjustment to the Ice

Numeral. However, it is also recognized that during the summer months the ice can decay to such an extent that it presents little chance of damaging a vessel. Thus, it is proposed that

- *Add **3** to the Ice Numeral if the ice is significantly decayed (probably only in late summer).*

5.12 Floe Size

Floe size can influence the safe passage of a vessel through ice, primarily due to increased maneuverability of the vessel. To accommodate this factor, it is proposed that:

- *Add **3** to the Ice Numeral if the floe size is less than 50 m and the ice is not under pressure.*

5.13 Bergy Bits

The strength of bergy bits is essentially the same as that for multi-year ice. Therefore it is proposed that:

- *Bergy bits (glacial ice) should be considered in the same way as multi-year ice.*

That is, the presence of bergy bits should be included in with the concentration of multi-year ice in the ice regime. It should be noted that the BaseCase Ice Multipliers do not contain a separate line of multipliers for bergy waters (as is now the case in the Ice Regime System – see Table 1). Bergy waters should not be considered the same as open water, or a less severe ice regime, as is implied in the current Ice Regime table of Ice Multipliers. Inexperienced Masters may not appreciate the damage that can be caused by the collision of their vessel with a piece of (even small) glacial ice.

5.14 The Revised Ice Numeral

What happens if all of the above-mentioned interaction factors are taken into account? Figure 10 shows the pie chart diagram with the consideration for the interaction and external factors. In comparing it to Figure 6, it can be seen that using the interaction approach, more of the PPD damage Events are captured. Using the ASPPR definition, 17% of the PPD Events were missed whereas only 12% were missed using the revised definition. Further, a significant number of non-damage Events, which previously had a negative Ice Numeral, now have a positive Ice Numeral. Using the ASPPR Ice Numeral, passage would have been restricted for non-damage Events for 19% of the database Events. With the revised Ice Numeral, restriction of passage of non-damage Events would have only been 7%. In both cases, these are significant improvements.

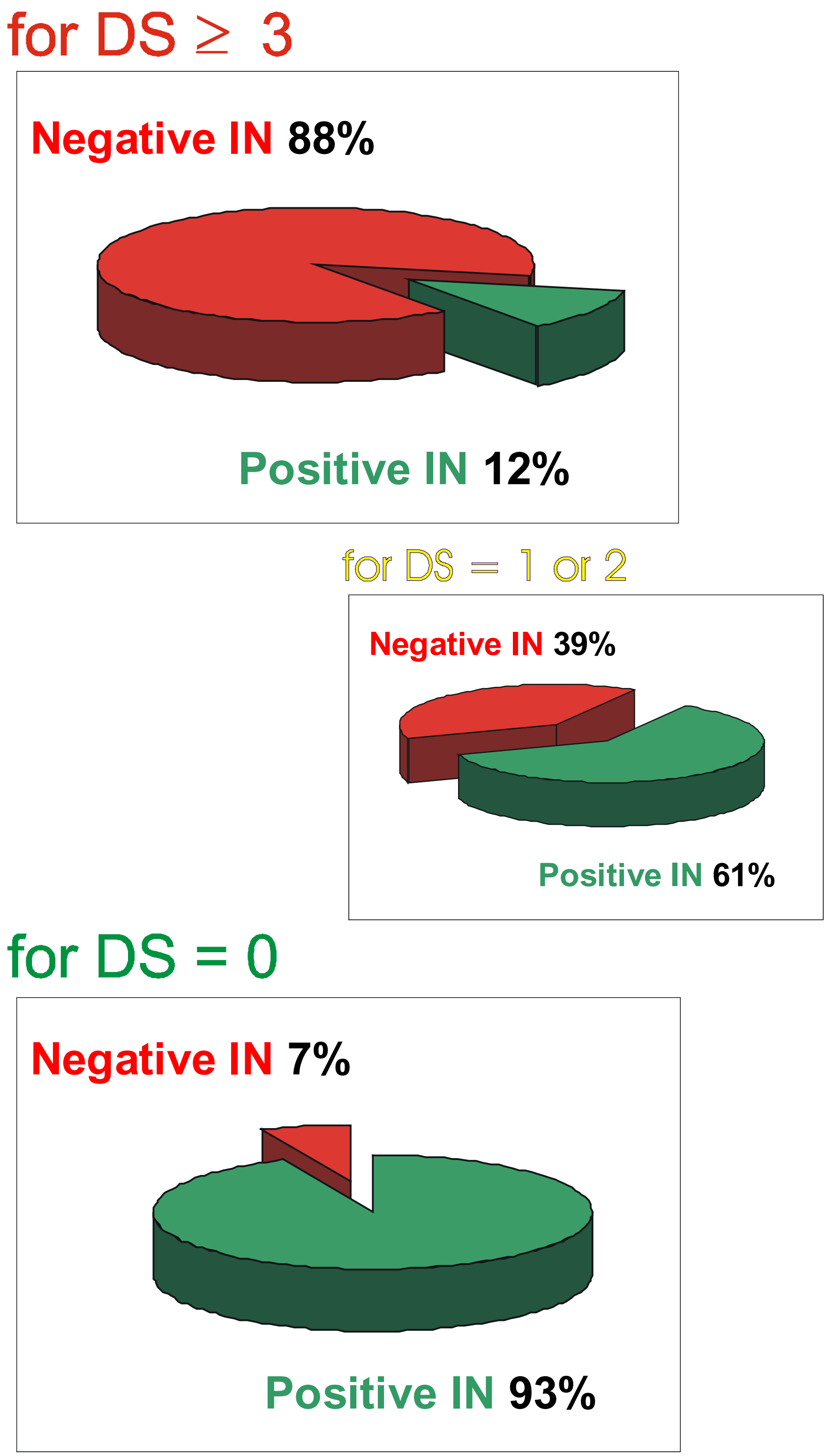

Figure 10 Pie chart illustration showing the improvement that can be achieved using the Interaction approach to define the Ice Numeral.

5.15 Missed Damage Events

It is instructive to examine the PPD Events that gave a positive Ice Numeral to see why the Ice Regime System did not "capture" these Events. Table 12 provides the details of the 8 PPD Events that had a positive Ice Numeral using the proposed scheme. Examination of these Events shows that the vessel classes ranged from Type E to CAC 4. In almost all cases, the damage occurred due to an isolated incidence of impact with multi-year ice, usually in fairly open ice conditions. In a few cases, the exact time and location of the damage occurrence are not known, and the ice conditions listed are representative ice conditions for the transit. These Events appear to represent somewhat unique Events that probably would not be captured with any ice regime format without unduly penalizing vessel operators.

Table 12 Summary of PPD Events that had a Positive Ice Numeral.

CHC Ice Numeral	Vessel Class	Ice Conc. FY	Ice Conc. MY	Desription of Damage	Cause of Damage
11	Type A	5	2	Holed in port side, engine room flooded	Struck multi-year floes on port bow
6	Type B	9	0	Bow plating holed below waterline / Minor	Exact time/cause unknown, navigated similar conditions in past without incident / VSL damaged while proceeding through very close pack first year ice
12	Type A	0	3	Holed - leakage in one small ballast tank	VSL suffered a crack after proceeding through a multi-year ice floe
8	Type E	0	2	Holed bulbous bow at waterline	Direct impact with ice
21	Type B	1	2	Damage to port side shell plating (50cm crack) and internal structure (bow thruster compartment)	contact with floe of MY ice.
0	CAC 4	6	4		Transiting through area of MY ice
10	CAC 4	8	2	port side damage	vessel struck MY ice when attempting to follow a turn made by icebreaker
7	Type D	5	0	Indentations on bulbous bow and starboard side; dents and fracture on port side	Exact time/cause unknown

5.16 Speed Variation

It is instructive to look at the empirical data as a function of vessel speed to compare the ASPPR and the Proposed definition of the Ice Numeral. This is done in the following three figures:

Figure 11 shows the speed versus the ASPPR and Proposed Ice Numeral for different damage severity numbers. Note that the Proposed definition gives a significantly larger number of "no damage" Events with a positive Ice Numeral. (This is especially obvious in the IN range of –10 to 0).

Figure 12 shows the speed versus the ASPPR and Proposed Ice Numerals showing damage and no damage Events for the cases where there is only first-year ice, and the case where is a mix of both first-year and multi-year ice. This data is plotted for Type vessels only. Note the damage Events represent Events with Damage Severity greater than zero (i.e for all types of damage).

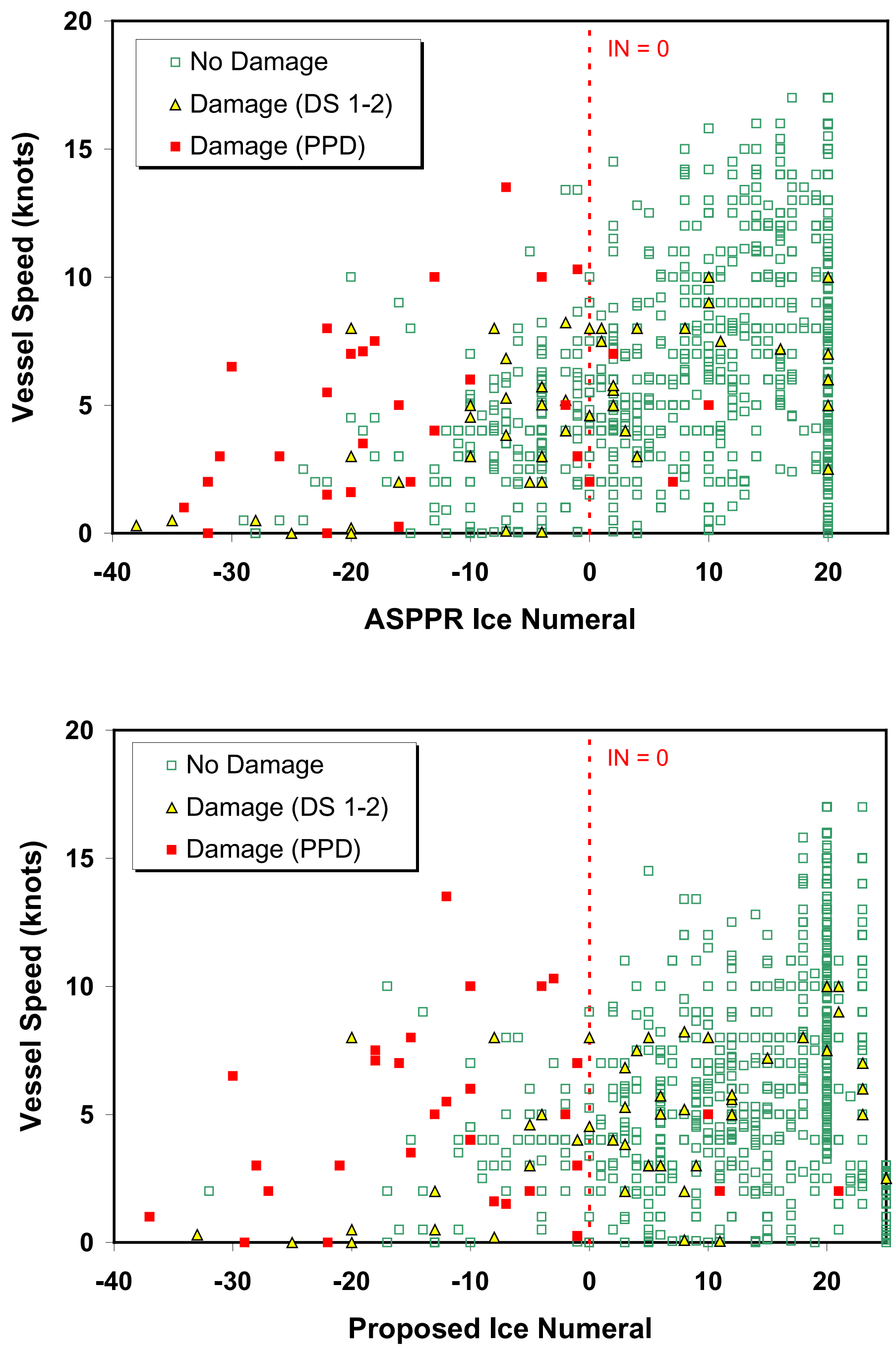

Figure 11 Plots of vessel speed verus the ASPPR and Proposed Ice Numeral for all vessel classes.

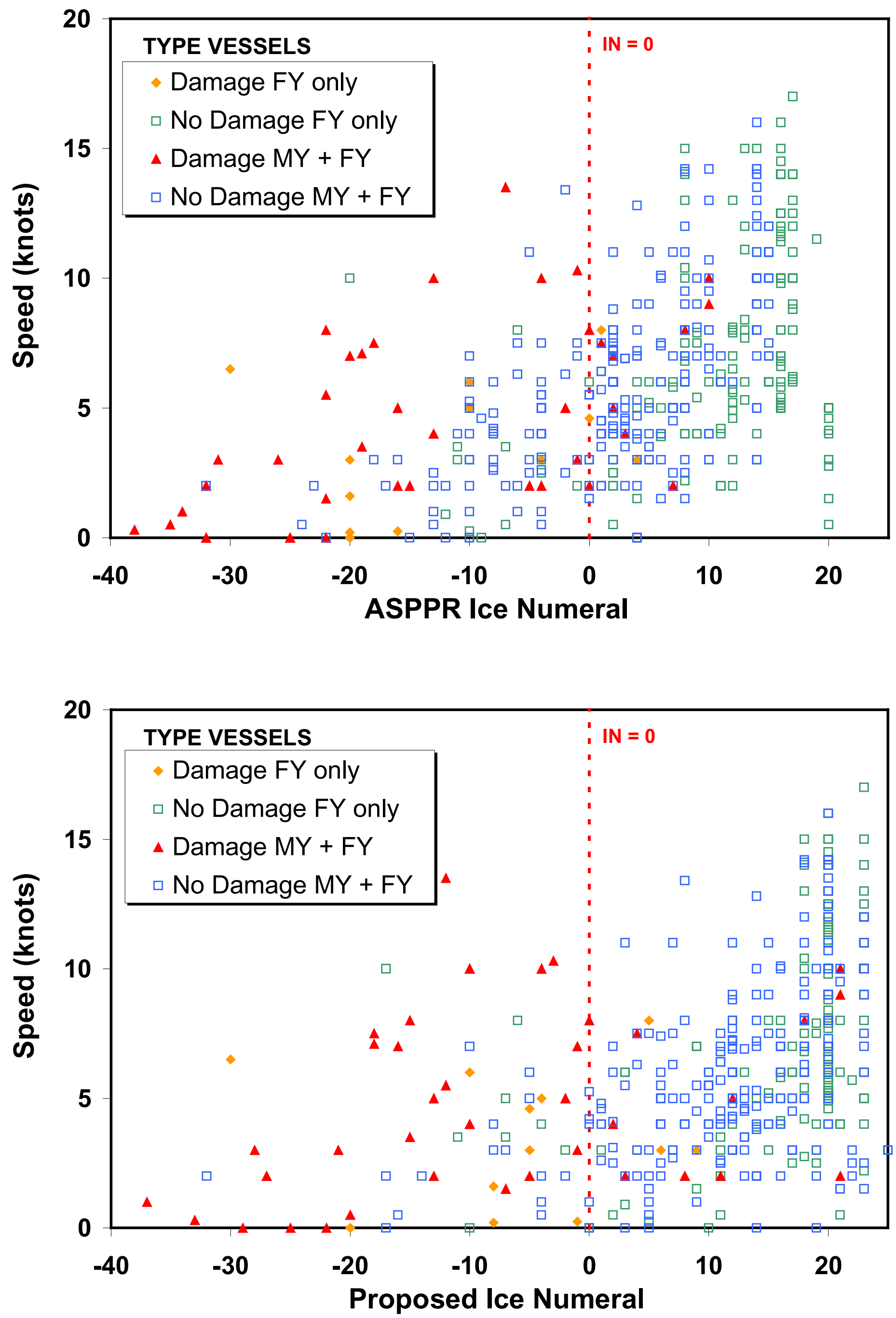

Figure 12 Plot of speed versus ASPPR and Proposed Ice Numeral for Type vessels. The data shows damage and no damage Events where there is only first-year ice and when there is a mix of first-year and multi-year ice.

Figure 13 shows a plot of the speed versus the ASPPR and Proposed Ice Numeral for PPD damage and no-damage Events for different ice conditions. The data is plotted only for Type vessels. Note that both definitions of the Ice Numeral capture the vast majority of PPD Events, but the Proposed definition has many more non-damage Events with positive Ice Numerals.

5.17 Summary

The methodology proposed here takes into account a large number of factors that are important in assessing a ship moving through ice-covered waters. Although it may appear complicated, there are 2 basic underlying principles driving it:

1. Ship Operators are rewarded when they use a high ice-strengthened vessel (CAC or Type A, B) operating with experienced Masters who proceed carefully through difficult ice and navigation conditions.
2. Ship Operators are severely penalized when they use poor ice-strengthened vessels and less experienced personnel.

It is proposed that a Workshop be organized with invitations to the key Stakeholders to examine and discuss the proposed approach. A comparison of Figure 6 and Figure 10 shows that this approach offers significant improvements for both capturing damage Events and allowing passage when historically there has been no damage.

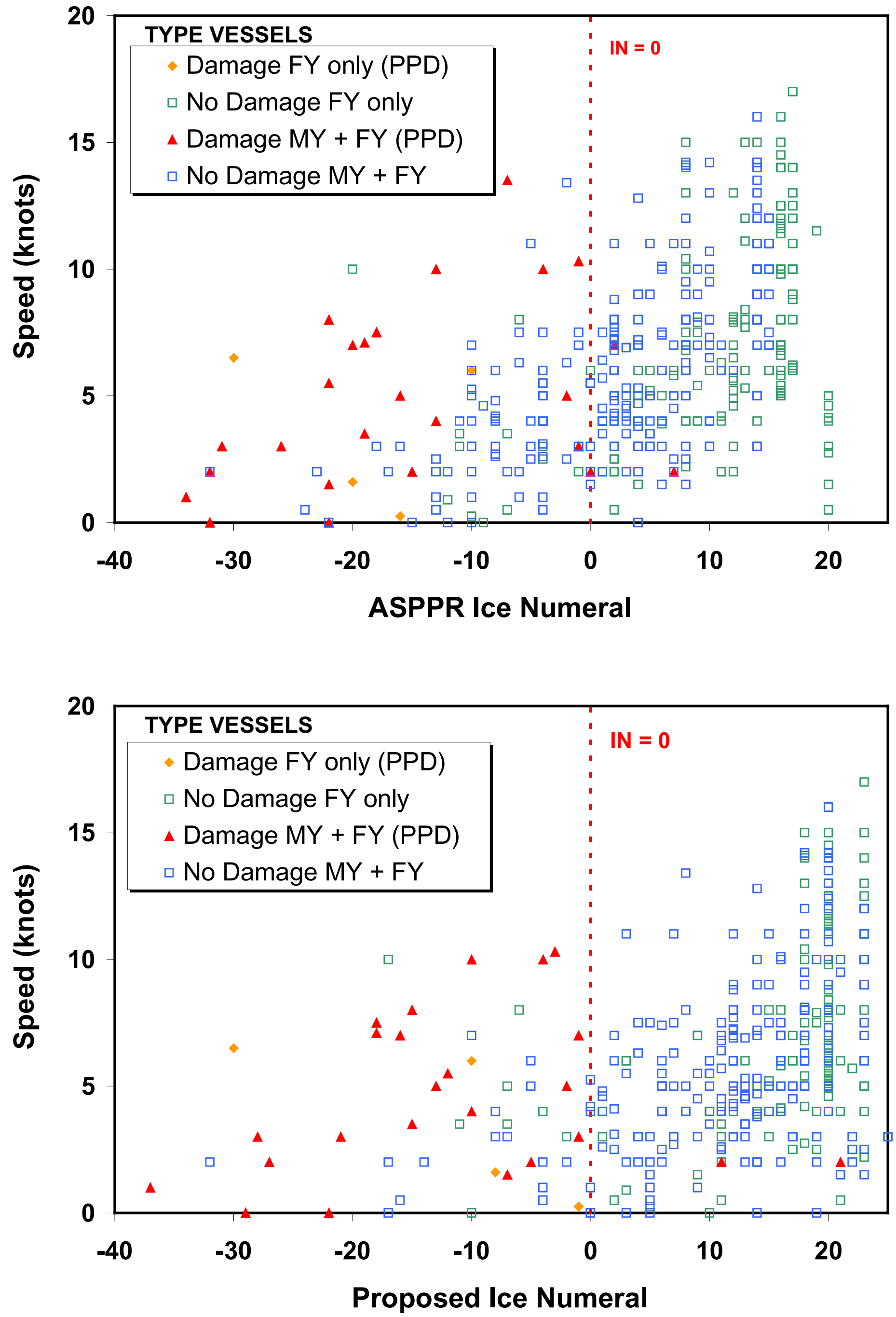

Figure 13 Plot of speed versus the ASPPR and Proposed Ice Numeral for Type vessels showing the PPD damage Events and no-damage Events for different ice conditions.

6.0 TASK 5 - IDENTIFICATION OF PROBLEM ICE

This task will examine the ability of current ice detection systems to accurately predict the ice conditions. Clearly, if remote sensing techniques do not provide a reliable method for estimating ice conditions, then the Ice Regime approach would less accurate, especially for route planning purposes.

Work in this Task has begun, by comparing the “predicted” ice conditions from Canadian Ice Services (CIS) Ice Charts to those ice conditions observed on board a vessel. The CHC has collected only a limited amount of data in this area to date, but this aspect will be investigated in detail using some newly-acquired information as well as the information that will be collected during the trials of the USCG Healy in the Arctic this spring.

Figure 14 and Figure 15 examine the predicted ice concentrations versus the observed ice concentrations for the all ice types (Figure 14) and the sum of multi-year and thick first-year ice concentrations (Figure 15) for 52 different observations. The data is plotted as histograms showing the variation of the predicted ice concentration from the observed ice concentration. It can be seen that in both cases, the predicted concentration agrees reasonably well with the observed conditions. The data show that the predicted conditions agree with the observed conditions in 2 out of 3 cases, to within a concentration of ± 1.

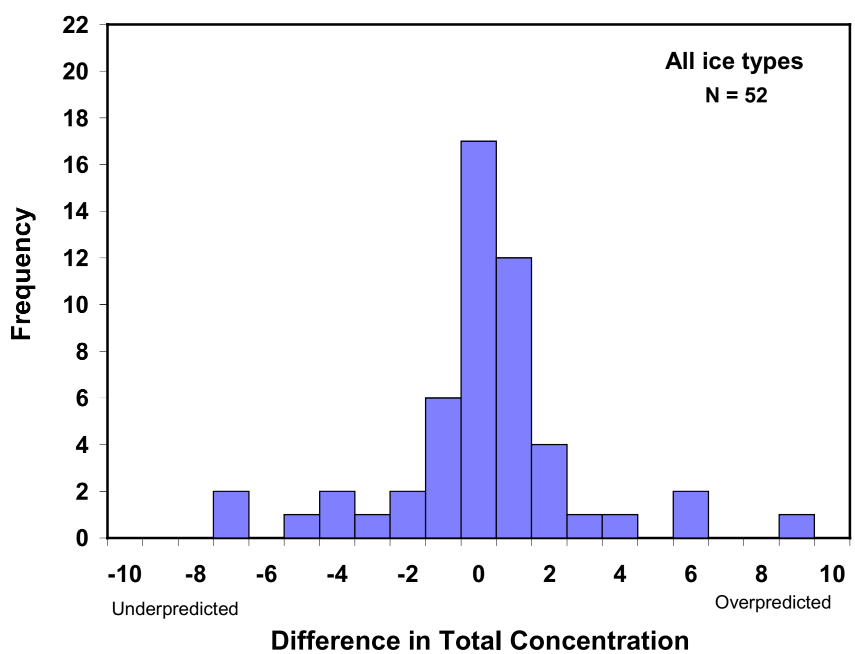

Figure 14 Histogram showing the difference in the predicted ice concentrations versus the observed ice concentration for all ice types.

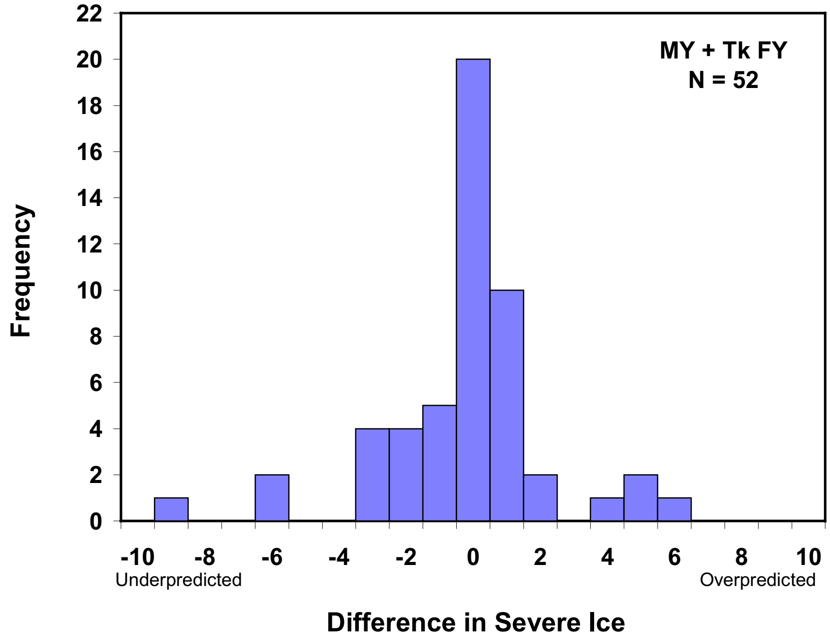

Figure 15 Histogram showing the difference in the predicted ice concentrations versus the observed ice concentration for severe ice conditions.

7.0 TASK 6 - DETECTION OF PROBLEM ICE

Task 6 will look at the techniques for detecting ice, and provide some insight into the information that each technique provides, as well as the reliability of each technique. The intent of this Task is not to develop new techniques; rather it will focus on a pragmatic study of the type of improvements that could be made to better predict the ice conditions. The level of effort in this Task will be a direct reflection of the results of Task 5. This task will rely heavily on the collaboration of people with knowledge of ship operations, remote sensing, and ice properties.

8.0 TASK 7 - IMPLEMENTATION OF AIRSS

Although it may appear that the implementation of the proposed system would be difficult, it would be a relatively straightforward calculation given the proliferation of today's inexpensive computers. A simple interface program could be written that would consider all factors, based on the input of the existing conditions.

To complete this task, discussions would initially be held with several of the Ship Operators to understand the computer equipment on board, and the level of knowledge of the Master, Ice Navigator and crew in using standard software packages.

9.0 SUMMARY AND CONCLUSIONS

This report has presented an update on the work being carried out to put the ice regime system on a scientific basis. An empirical approach has provided good insight into the usefulness and limitations of the current ice regime definitions. It has been found that although the system reasonably well reflects the observations, there are several instances where the agreement is poor.

An alternate scheme has been proposed which takes into account the "interaction" aspects of vessels in ice-covered waters. Using this approach, a significant improvement in the definition of the ice numeral has been developed. This approach "rewards" high ice class vessels with experienced Ice Navigators operating in a prudent manner, and "penalizes" low ice class vessels, especially in the presence of multi-year ice.

It was proposed that a Workshop take place with all interested Stakeholders to discuss this revised approach. Work will continue to complete the remainder of Tasks 5 to 7 to put the ice regime system on a scientific basis.

10.0 ACKNOWLEDGEMENTS

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Appendix A

Summary of Database Queries

ASPPR (IN):

	IN positive	%	IN negative	%	Sum
DS ≥ 3	11	17	54	83	65
DS 1 - 2	46	49	47	51	93
DS = 0	756	81	178	19	934

ASPPR – two below (IN-TB): One for limiting ice type modifiers and two below (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	9	14	56	86	65
DS 1 - 2	43	46	50	54	93
DS = 0	763	82	171	18	934

Base Case: BaseCase Ice Multipliers (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	7	11	58	89	65
DS 1 - 2	40	43	53	57	93
DS = 0	731	78	203	22	934

Case 2: BaseCase Ice Multipliers + add 10 to IN for summer (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	17	26	48	74	65
DS 1 - 2	60	65	33	35	93
DS = 0	873	93	61	7	934

Case 2ND: BaseCase Ice Multipliers + add 10 to IN for summer (ice ridging as per Table 1 applied to BaseCase Multipliers, but no adjustment for decayed ice)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	17	26	48	74	65
DS 1 - 2	58	62	35	38	93
DS = 0	849	91	85	9	934

Case 3: BaseCase Ice Multipliers + add 1 to IM for summer only to FY ice multipliers (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	16	25	49	75	65
DS 1 - 2	49	53	44	47	93
DS = 0	812	87	122	13	934

Case 4: BaseCase Ice Multipliers + add 10 to IN for summer (if vessels are CAC3 → Type B & concentration of old ice (MY or SY) < 3/10) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	11	17	54	83	65
DS 1 - 2	43	46	50	54	93
DS = 0	769	82	165	18	934

Case 5: BaseCase Ice Multipliers + add 1 to IM for summer only for limiting ice type modifiers and below (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	14	22	51	78	65
DS 1 - 2	48	52	45	48	93
DS = 0	791	85	143	15	934

Case 6: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 - 2	59	63	34	37	93
DS = 0	861	92	73	8	934

Case 7: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 3 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 - 2	60	65	33	35	93
DS = 0	873	93	61	7	934

Case 8: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 - 2	60	65	33	35	93
DS = 0	879	94	55	6	934

Case 9: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 3 to IN if speed ≤ 3 knots (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 - 2	60	65	33	35	93
DS = 0	873	93	61	7	934

Case 10: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 – 2	60	65	33	35	93
DS = 0	879	94	55	6	934

Case 11: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	12	18	53	82	65
DS 1 - 2	60	65	33	35	93
DS = 0	879	94	55	6	934

Case 12: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	11	17	54	83	65
DS 1 – 2	59	63	34	37	93
DS = 0	879	94	55	6	934

Case 13: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	10	15	55	85	65
DS 1 – 2	59	63	34	37	93
DS = 0	879	94	55	6	934

Case 14: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add **5** to IN if speed ≤ 3 knots (for all vessels) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	12	18	53	82	65
DS 1 – 2	60	65	33	35	93
DS = 0	879	94	55	6	934

Case 15: BaseCase Ice Multipliers + add 10 to IN for summer except for events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add **5** to IN if speed ≤ 3 knots (for all vessels) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	11	17	54	83	65
DS 1 – 2	59	63	34	37	93
DS = 0	879	94	55	6	934

Case 16: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for all vessels) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	10	15	55	85	65
DS 1 - 2	59	63	34	37	93
DS = 0	879	94	55	6	934

Case 17: BaseCase Ice Multipliers + add 1 to IM for summer only to FY ice multipliers but those events when visibility = poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 - 2	48	52	45	48	93
DS = 0	802	86	132	14	934

Case 18: BaseCase Ice Multipliers + add 10 to IN for summer (if vessels are CAC3 → Type B & concentration of old ice (MY or SY) < 3/10) but those events when visibility = poor (all vessels) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	9	14	56	86	65
DS 1 - 2	43	46	50	54	93
DS = 0	763	82	171	18	934

Case 19: BaseCase Ice Multipliers + add 1 to IM for summer (only for limiting ice type modifiers + below) but those events when visibility = poor (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	11	17	54	83	65
DS 1 - 2	47	51	46	49	93
DS = 0	783	84	151	16	934

Case 20: BaseCase Ice Multipliers + add 10 to IN for summer (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + subtract 3 from IN if visibility = poor

	IN positive	%	IN negative	%	Sum
DS ≥ 3	12	18	53	82	65
DS 1 – 2	61	66	32	34	93
DS = 0	886	95	48	5	934

Case 21: BaseCase Ice Multipliers + add 10 to IN for summer (ice decaying and ridging as per Table 1 applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + subtract 5 from IN if visibility = poor

	IN positive	%	IN negative	%	Sum
DS ≥ 3	12	18	53	82	65
DS 1 – 2	61	66	32	34	93
DS = 0	885	95	49	5	934

Case 22: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice ridging as per Table 1 but no adjustment for decayed ice applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	9	14	56	86	65
DS 1 – 2	56	60	37	40	93
DS = 0	859	92	75	8	934

Case 23: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) (ice ridging as per Table 1 but no adjustment for decayed ice applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + add 3 to IN if Decaying = yes

	IN positive	%	IN negative	%	Sum
DS ≥ 3	10	15	55	85	65
DS 1 – 2	58	62	35	38	93
DS = 0	871	93	63	7	934

Case 24: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) or events where old ice is present (low class vessels = Type C -> E) (ice ridging as per Table 1 but no adjustment for decayed ice applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + add 3 to IN if Decaying = yes

	IN positive	%	IN negative	%	Sum
DS ≥ 3	8	12	57	88	65
DS 1 – 2	57	61	36	39	93
DS = 0	871	93	63	7	934

Case 25: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) or events where old ice is present (low class vessels = Type C -> E) (ice ridging as per Table 1 but no adjustment for decayed ice applied to Base Case) + add 5 to IN if speed ≤ 3 knots (all vessels) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + add 3 to IN if Decaying = yes

	IN positive	%	IN negative	%	Sum
DS ≥ 3	9	14	56	86	65
DS 1 – 2	57	61	36	39	93
DS = 0	871	93	63	7	934

Proposed Case: BaseCase Ice Multipliers + add 10 to IN for summer except of events when visibility is poor (all vessels) or events where old ice is present (low class vessels = Type C -> E) (ice ridging as per Table 1 but no adjustment for decayed ice applied to Base Case) + add 5 to IN if speed ≤ 3 knots (for high class vessels = CAC3 → Type B) + subtract 5 from IN if MY ice is present & speed ≥ 7 knots (for low class vessels = Type C → Type E) + subtract 3 from IN if Ice Navigator's experience is low (for all vessels) + add 3 to IN if Decaying = yes + add 3 to IN if FY floe size < 50m

	IN positive	%	IN negative	%	Sum
DS ≥ 3	8	12	57	88	65
DS 1 – 2	57	61	36	39	93
DS = 0	871	93	63	7	934

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Case 27: BaseCase Ice Multipliers + add 4 to IN for summer (Type vessels only) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	13	20	52	80	65
DS 1 – 2	46	49	47	51	93
DS = 0	760	81	174	19	934

Case 28: BaseCase Ice Multipliers + add 4 to IN if speed ≤ 4 knots & no MY ice is present (Type vessels only) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	7	11	58	89	65
DS 1 – 2	41	44	52	56	93
DS = 0	737	79	197	21	934

Case 29: BaseCase Ice Multipliers + add 3 to IN if FY Floe size < 50 m (Type vessels only) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	7	11	58	89	65
DS 1 – 2	40	43	53	57	93
DS = 0	731	78	203	22	934

Case 30: BaseCase Ice Multipliers + add 1 to IN if Ice Navigator's experience = high (for Type vessels only) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	7	11	58	89	65
DS 1 – 2	40	43	53	57	93
DS = 0	731	78	203	22	934

Case 31: BaseCase Ice Multipliers + subtract 1 from IN if visibility = poor (For Type vessels only) (ice decaying and ridging as per Table 1 applied to Base Case)

	IN positive	%	IN negative	%	Sum
DS ≥ 3	7	11	58	89	65
DS 1 - 2	40	43	53	57	93
DS = 0	730	78	204	22	934