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A Process for Producing Ice Coverage Marine Information Objects (MIOs) in IHO S-57 Format

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Article

A Process for Producing Ice Coverage Marine Information Objects (MIOs) in IHO S-57 format

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Abstract

While global warming may be opening up more Arctic waters in the summer, ice still infests key shipping lanes in the northern hemisphere during the winter months. To safely navigate these areas, mariners rely on daily ice coverage charts produced by national governmental agencies. Ice charts are primarily issued in paper format or as a fax. However, there is increased interest to ice coverage information on vessel navigation systems such as an Electronic Chart and Display Information Systems (ECDIS). However, to do so, the ice information must be provided as a separate layer of information to the Electronic Navigational Chart (ENC).

Résumé

Bien que le réchauffement global puisse faire enfler les eaux arctiques en été, les glaces envahissent toujours les principaux couloirs de navigation dans l'hémisphère, pendant la saison hivernale. Afin de naviguer en toute sécurité dans ces zones, les navigateurs se fient aux cartes des glaces produites quotidiennement par les agences gouvernementales nationales. Les cartes des glaces sont essentiellement communiquées sous forme imprimée ou de télécopie. On note cependant un regain d'intérêt pour les informations sur la couverture des glaces, dans des systèmes de navigation maritime tel que l'ECDIS (système de visualisation des cartes électroniques et d'information). Toutefois, pour ce faire, les renseignements sur les glaces doivent être transmis, en tant que « niveau » d'information distinct, aux Cartes électroniques de navigation (ENC).

Resumen

Mientras que un calentamiento global puede aumentar la extensión de las aguas árticas en verano, el hielo sigue infestando las derrotas marítimas en el hemisferio septentrional durante los meses de invierno. Para navegar en estas zonas de forma segura, los navegantes confían en las cartas de cobertura diaria del hielo producidas por agencias gubernamentales nacionales. Las cartas del hielo son editadas principalmente en formato impreso o como fax. Sin embargo, hay un interés creciente por la información de cobertura del hielo en los sistemas de navegación de los buques, como por ejemplo en los Sistemas de Presentación de las Cartas Electrónicas y de Información (ECDIS). Sin embargo, para producirlas, tiene que proporcionarse la información sobre el hielo como una serie de información separada para la Carta Electrónica de Navegación (ENC).

Introduction

Sea ice occurs along more than 90% of the Canadian coast line (Climate Change Indicators Task Group, 2003). Lake and river ice also cover much of the Great Lakes and the St. Lawrence Seaway. In all, up to four million square kilometres of Canada's navigable waterways are covered by ice. In the open waters of Canada's eastern coast, roughly 40,000 icebergs appear annually. Ice is present in Canada's navigable waters year-round. The potential danger that ice poses is so great that a single iceberg report can cause tens of thousands of square kilometres of ocean to be declared unsafe for shipping (IICWG, 2004). Ice can cause varying degrees of damage to ships, such as the 1912 *Titanic* disaster when over 1500 lives were lost.

To assist marine navigation, many ice-affected nations have government-run ice charting agencies. These organisations, along with the International Ice Patrol, provide operational ice information to mariners. The information provided by these ice services enables year-round operations of major ports (such as Montreal, Halifax, Helsinki, or St. Petersburg), provides tactical ice information to national militaries, and provides logistical and safety support to offshore structures in ice-infested waters (such as the Baltic Sea and the Grand Banks). In Canada, the Canadian Ice Service (CIS) helps ensure the safe transit of 1500 ships through the Gulf of St. Lawrence each winter (IICWG 2004).

The electronic chart is a new technology that provides significant benefits in terms of navigation safety and improved operational efficiency. More than simply a computer display, an electronic chart is a real-time navigation system that integrates a variety of information that is displayed and interpreted by the Mariner. As an automated decision aid capable of continuously determining a vessel's position in relation to land, charted objects, aids-to-navigation, and unseen hazards, the electronic chart represents an entirely new approach to maritime navigation (Hecht et al, 2006).

For an electronic chart to be considered an ECDIS, it must comply with the Performance Standards for ECDIS established by the International Maritime Organization (IMO). The IMO Performance Standards for ECDIS specify the components, features, functions of a system in which the primary function is to contribute to safe navigation (IMO 1995). By displaying selected information from an electronic navigational chart (ENC) and positional information from navigation sensors ECDIS should "*assist the mariner in route planning and route monitoring, and if required, display additional navigation-related information.*" If provided in suitable format, ice coverage information could be a form of "additional navigation-related information."

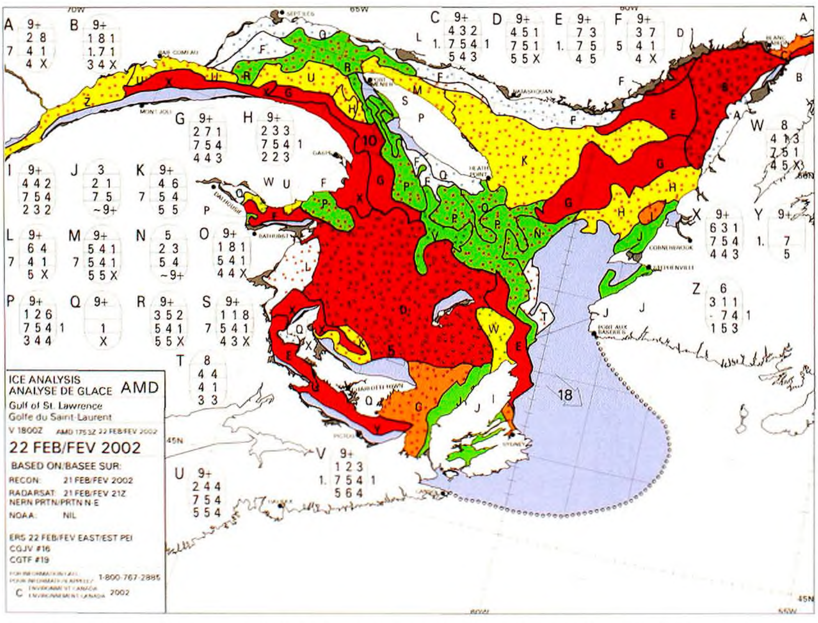

Figure 1: CIS's February 22, 2002, daily ice chart for the Gulf of St. Lawrence.

An electronic navigational chart (ENC) is specifically defined in the IMO Performance Standards for ECDIS (Sec. 2.2), and must conform to IHO S-57 data standards (IHO 2000). Appendix B.1 of IHO S-57 contains the ENC Product Specification. In short, an ENC is comprised almost entirely of chart-related information. There are rigid specifications as to what an ENC does (and does not contain), and how it is produced/issued by a national hydrographic office. Any information that is not specified as part of the ENC Product Specification must be regarded as supplemental, and separate from the ENC. This includes ice information.

Marine Information Objects (MIOs) consist of chart and navigation-related information that supplement the minimum information required by ECDIS (Alexander 2003). As it relates to the use of Electronic Navigational Chart (ENC) data, MIOs are additional, non-mandatory information not already covered by existing IMO or IHO standards. Currently, this includes ice coverage, tide/water level, current flow, meteorological, oceanographic, and marine habitats. The supplemental information contained in MIOs is usually in the form of IHO S-57 objects/attributes (IHO 2005).

This paper discusses the process of converting ice coverage information currently issued by the Canadian Ice Service into an IHO S-57 format to use in conjunction with ENCs in ECDIS.

Mapping ArcInfo vector data into S-57 data

As shown in Figure 1, daily Ice Charts are issued by the Canadian Ice Service.

Produced using ESRI ArcInfo E00 exchange format, typical examples of the ArcInfo datasets are listed in Table 1.

The starting point for the conversion process is to convert the points, lines, and annotations of ArcInfo dataset into an IHO S-57 exchange set consisting of points, lines, and polygons. When discussing S-57, the terms "spatial record" and "vector record" are often used interchangeably. A spatial record technically is a vector, raster, or matrix record. However, only the vector record type has to date been formally defined in the current S-57 specifications (IHO, 2000). Since a vector record describes geometry, it does not have any meaningful, real-world attributes. A "feature record" describes an object and points to one or more vector records to represent it spatially. ArcInfo has four types of geometric features: nodes, points, lines, and polygons (ESRI 1995). The equivalent S-57 vector records are shown in Table 2.

ArcInfo Geometry	S-57 Vector Record
Point	→ Isolated node
Node	→ Connected node
Line	→ Edge
Polygon	→ Face

Table 2: S-57 Geometric equivalents of ArcInfo geometry (after Cheung, 1997).

In Version 3.1 of the S-57 standards, chain-node topology is specified. As such, polygons are represented as closed loops of edges, and edges that can cross each other.

S-57 has four types of feature records: points,

File Name	Region	Date
EXPANGULF_i20010209.e00	Gulf of St. Lawrence	9 February 2001
EXPANGULF_i20010210.e00	Gulf of St. Lawrence	10 February 2001
EXPANGULF_i20010211.e00	Gulf of St. Lawrence	11 February 2001
EXPAGL_20030305.e00	Great Lakes	5 March 2003
EXPAGULF_20030318.e00	Gulf of St. Lawrence	18 March 2003
EXPAHA_20031021.e00	High Arctic	21 October 2003
EXPAMID_20031102.e00	Mid Arctic	2 November 2003
EXPANFLD_20030318.e00	Newfoundland and Labrador	18 March 2003
EXPAWA_20031023.e00	West Arctic	23 October 2003
EXPAEA_20031124.e00	East Arctic	24 November 2003
EXPAFOXE_20031112.e00	Foxe Basin	12 November 2003

Table 1: Examples of daily ice charts produced by the CIS.

nodes, lines, and areas. While these types of feature records appear to be just like ArcInfo's geometries, they are not. S-57 allows one edge to be part of many features (lines or areas), and one face to be part of many areas. Also, each edge need not be part of a line as long as it is part of an area. The feature point and node relate directly to ArcInfo's point and node. The feature line and area relate to ArcInfo's extended data model, specifically the route and the region. A route is a collection of one or more arcs, just as a feature line is represented by one or more edges. A region is one or more polygons, as a feature area is one or more faces. The relationship between S-57 feature records and ArcInfo features is shown in Table 3.

S-57 Feature Record	ArcInfo Geometry
Feature point	→ Point
Feature node	→ Node
Feature line	→ Route
Feature area	→ Region

Table 3: ArcInfo Equivalents of S-57 Features (after Cheung 1997).

To create an S-57 cell from ArcInfo coverage, the paths shown in Table 4 must be taken for each ArcInfo data type:

ArcInfo	S-57 Vector Record	S-57 Feature Record
Point	→ Isolated node	Feature point
Node	→ Connected node	Feature node
Line	→ Edge	-
Route	→ -	Feature line
Polygon	→ Face	-
Region	→ -	Feature area

Table 4: Translating ArcInfo data to S-57 data (after Cheung 1997).

Mapping CIS chart data to the proposed ECDIS ice objects

Complete definitions of all proposed IHO S-57 Ice Objects can be found in *ECDIS Ice Objects Version 3.0* (CIS 2001). A full description of the ISIS output coverage is in *CIS Daily Chart (Sea Ice) ISIS Format Data Description* (CIS, 2003). The ice chart coverage points and lines (and their associated attributes) were compared with the existing and proposed S-57 object and attribute definitions. Then each spatial LINE_TYPE value in the arc coverage and each spatial PNT_TYPE value in the point coverage is matched with S-57 objects and attributes. Table 5 shows the mapping of each PNT _TYPE value to an S-57 object. Table 6 shows the same for each LINE _TYPE value. In some cases, a value may map to an object, but have no attribute value (i.e., coastline or land). This is not a problem since IHO S-57 objects may exist with no attribute values.

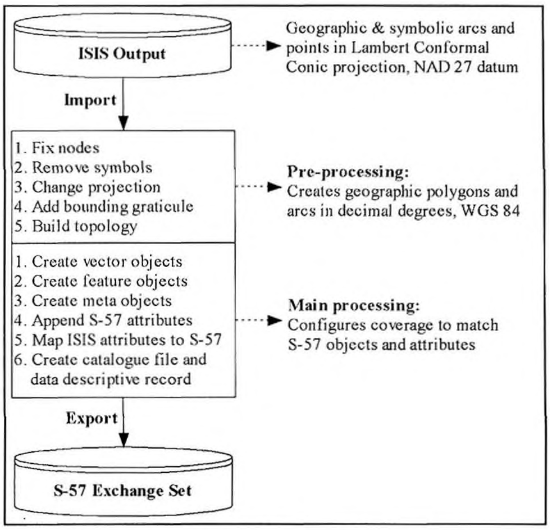

Figure 3: Application workflow of the developed solution.

Solution workflow

Figure 3 shows the workflow of the solution developed for converting ice information to S-57 ice objects.

Pre-processing

Prior to 2004, the ESRI ARCS57 software could not create the proposed S-57 ice objects. As the objects do not officially exist, ARCS57 did not "know" the values to be coded. ARCS57 uses lookup tables to convert from a named feature in the coverage (such as a LNDARE region for a land area) to a numeric code. These lookup tables were modified in this study to include the ice objects and attributes. The additional information to be included in the lookup tables was created using Microsoft Access 2000 and then exported to three

PNT_TYPE	Description	Object	Attribute(s)	Value(s)
101	Bergy water	BRGARE	-	-
		SEAICE or LACICE	ICECVT	12
106	Fast ice	SEAICE or LACICE	ICECVT	2
107	Open water	SEAICE or LACICE	ICECVT	11
115	Ice free	SEAARE	-	-
117 118 120 122	Ice with Egg Code	SEAICE or LACICE	ICEACT ICEAPC ICESOD or ICELSO ICEFLZ ICECVT	In EGG_ATTR
140	Ice area (with attributes)	SEAICE or LACICE	ICEACT	
143 144 145	Ice area (no attributes)	SEAICE or LACICE	ICEACT	
400	Land	LNDARE	-	-

Table 5: Ice Object Equivalents of ISIS PNT_TYPE Values

LINE_TYPE	Description	Object	Attribute(s)	Value(s)
117	Fast ice edge	ICELIN	ICELNC	2 or 5
122	Ice edge			
133	Open water edge			
140	Coastline	COALNE	-	-
141	Inland lake edge			
150	Iceberg edge (topological)	ICELIN	ICELNC	7
151	Iceberg edge (non-topological)			
162	Estimated ice edge	ICELIN	ICELNC	6
171	Crack	ICEFRA	ICEFTY	1
183	Open water lead	ICELEA	ICELTY	1 to 3
			ICELST	1
190	Frozen water lead	ICELEA	ICELTY	1 to 3
			ICELST	2
201	Radar limit	ICELIN	ICELNC	3
218	Undercast limit	ICELIN	ICELNC	1
222	Visual limit	ICELIN	ICELNC	4

Table 6: Ice Object Equivalents of ISIS LINE_TYPE Values.

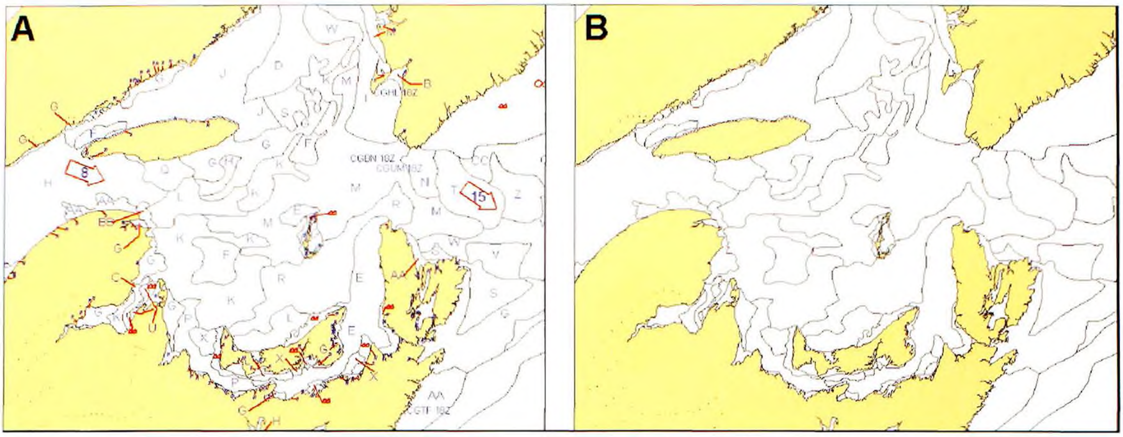

Figure 4: Ice chart with symbology removed. Land is shown in beige to assist viewing. (A) shows all arcs and annotations (text in blue) in the input coverage. Arcs to be deleted are in red. (B) shows the coverage after deletion.

files in dBASE IV file (DBF) format. AML code was developed to import the information in these files and make the modifications.

The first step after importing the coverage is to create (or recreate if it exists) the input file's Node Attribute Table (NAT). The NAT has sometimes been found to be incomplete. All special cartographic symbols must be removed. Such features include, but are not limited to, leader lines, arrows indicating flow direction, and symbols indicating strips and patches of ice (CIS, 2003). All these features are non-geographic, i.e., they do not represent any real features. Using ArcEdit®, all arcs that have a non-zero value for the EGG_ID attribute are deleted (all geographic features have a value of zero). Each of the non-geographic features has an associated point. These points are distinguished from other points by their PNT_TYPE attribute values. They are also deleted. The annotations are also deleted, as they have no information that is required by the tool.

Figure 4 shows a "before-and-after" example of the symbology removal. Adjacent arcs with identical LINE_TYPE values are dissolved into each other (LINE_TYPE is the only arc attribute that is used by the tool, so losing the values of all other attributes is of no consequence).

All ice charts produced by CIS use the Lambert Conformal Conic projection. Also, they are referenced to the North American Datum of 1927 (NAD 27), which is based on the Clarke 1866 spheroid (CIS, 2003). Since ENCs must reference the WGS 84 datum, and no projection may be applied (IHO,

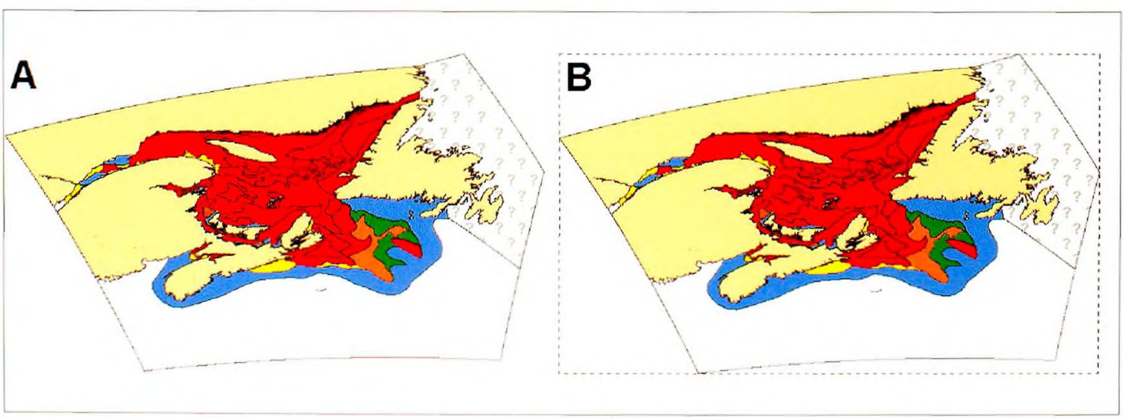

Figure 5: Ice chart with bounding graticule added. (A) shows the chart before the graticule is added, (B) shows the graticule as a dashed line.

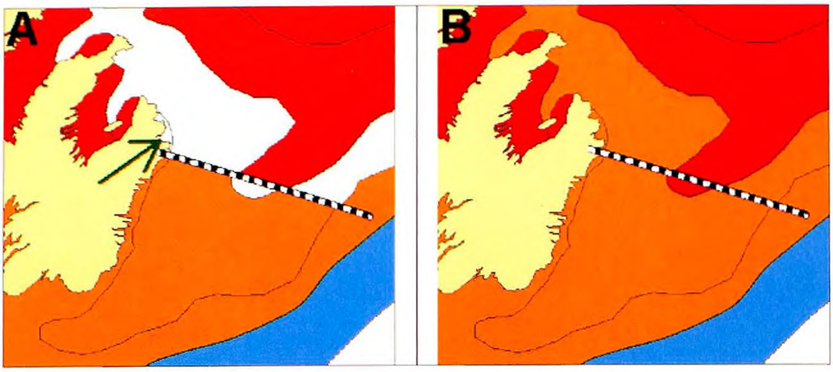

Figure 6: Non-topological LINE_TYPE 151. This is the thick line that alternates between black and white. (A) shows how polygon attributes are lost after building topology (in white). (B) shows the fixed polygons.

2000), the Ice coverage data must therefore be transformed to meet these requirements. S-57 data are distributed in graticule-based cells defined by two meridians and two parallels (IHO, 2000). When projected using a Mercator projection, the cells appear rectangular. A bounding rectangle must therefore be added to the coverage. Figure 5 shows the transformed chart with the addition of the bounding graticule.

The final step before processing begins is to build polygon topology. The point attribute values are automatically transferred to the polygon that contains them. There is one unique situation in the data that requires special attention. Arcs with a LINE_TYPE value of 151 are described as, "Iceberg Edge (Non-Topological)." When polygon topology is built, parts of the polygons that the arcs split have no attribute values (Figure 6A). The relationship between the Arc Attribute Table (AAT) and the Polygon Attribute Table (PAT) in the ESRI logical data structure is used to help solve this problem. Each arc's left and right polygon numbers are stored in the AAT, thus "connecting" each arc to its surrounding polygon(s). To assign attribute values to the polygons that are missing them, each polygon that borders one of the (LINE_TYPE = 151) arcs and is missing attribute values is selected. The arcs are then assigned the attribute values of their counterpart polygons (Figure 6B).

Creating feature objects, meta objects, and vector records

The coverage is now formatted so that vector records, feature objects, and meta objects can be exported correctly into S-57 format. To create S-57 feature objects. Four lines are created corresponding to coastline (COALNE), ice line (ICELIN), ice fracture (ICEFRA), and ice lead (ICELEA). All but coastline are proposed ice objects. Regions are then created to represent five feature areas: land area (LNDARE), depth area (DEPARE), sea area (SEAARE), iceberg area (BRGARE), and either sea ice (SEAICE) or lake ice (LACICE). Only the latter three are proposed ice objects; the first three are existing objects. The Meta objects, coverage (M_COVR) and quality of data (M_QUAL) are created next.

It is also necessary to create a route (called VENAME) for each arc in the coverage (using the Arc command ARCROUTE). S-57 specifications stipulate that each vector record requires a unique identifier. This identifier is its NAME attribute. NAME is composed of two letters followed by exactly 10 digits. The two letters are "VC" (for connected nodes), "VE" (for edges), or "VI" (for isolated nodes) (IHO, 2000). After various required fields are added in Tables, a cursor moves through each record in the VENAME route, the AAT, and the NAT. For each record, the letters are concatenated with the internal identification number, with the appropriate number of zeros inserted between them. For example, a route with the internal number 269 would have a NAME value of "VE0000000269".

"Set A" attributes in S-57 are attributes that are unique to each object type (or at least they do not apply to all object types, as some attributes do apply to more than one object type). These attributes are added to the route and region tables in Tables. Like the vector records, each feature and vector object also requires a unique identifier. Each feature is assigned a name that begins with "FE" and is followed by ten digits [IHO, 2000]. The so-called "Egg Code" values then are copied from the field EGG_ATTR to the proposed ice attribute fields. "Set B" and "C" attributes are attributes that apply to each object. They are stored in a separate INFO file.

Creating other required elements

There are two other elements of the exchange set that also still be created. They include the catalogue file and the Data Descriptive Record. The catalogue file describes the contents of the exchange set, specifically the files contained in the set and the geographic bounds of the data. The catalogue file contains one record, the Catalogue Directory record, which is composed of one field (table in ArcInfo), the Catalogue Directory field (CATD). The CATD is created and populated in Tables. All values are hard-coded except for the geographic bounds of the data and the Cyclic Redundancy Check (CRC) value.

The data set file is composed of a Data Set General Information record, a Data Set Geographic Reference record, vector records, and feature records. The Data Set General Information record is composed of two fields: Data Set Identification (DSID) and Data Set Structure Information (DSSI). Except for the issue date of the data and an optional comment, all the DSID values are hard-coded and it is unlikely that they would need to be modified by the user. The DSSI contains a count of each type of record in the data set. The Data Set Geographical Reference record contains only one field, Data Set Parameter (DSPM). The field is used to describe the datums and units of measurement used. The only subfield that the user controls is the Compilation Scale of Data (CSCL). This is set by the user in the GUI; however if the information exists in the input data look-up table, the user's input is overridden with that value.

Exporting to S-57

The coverage is exported using the ARCS57 command. This creates a catalogue file and an S-57 cell file. The catalogue file does not have the correct CRC value for the cell. The catalogue is re-exported using the ENCREVISION command. This can be used to export a catalogue file with correct CRC values. When complete, the log file created by ARCS57 is displayed (with the appended list).

Benefits

With detailed ice information provided in suitable format for use in ECDIS, mariners will benefit by being able to plot safer courses through ice-infested waters. Increasing the likelihood of safe passage will have several economic benefits: a decrease in travel time and insurance costs, and possibly the number of workers required could all be reduced. Less travel time means savings are found in operational costs (fuel, daily wear) and personnel costs. Because vessels will have better routing information, shipping seasons could be lengthened, thus creating further economic benefits. Shorter trips are also beneficial to the environment as less fuel is required. Safer passage is also a benefit for the environment because the risk of accidental spillage of contaminants due to collision with ice is reduced. Another benefit of integrating detailed ice information into ECDIS is that emergency personnel may be better prepared to deploy when required.

Conclusion

This paper described the process of converting ice coverage information currently issued by the Canadian Ice Service into an IHO S-57 format to use in conjunction with ENCs in ECDIS. Ideally, this process can be used by other ice information services as well.

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