On the Integration of Sea Ice Information into ECDIS

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Key words: Electronic Nautical Chart (ENC), ECDIS, Ice Objects, S-57, S-52, Integration, CARIS HOM, ArcInfo, e00 format. Canadian Hydrographic Service, Canadian Ice Service, Navigation, Marine Information Objects.

ABSTRACT

Electronic Chart Display and Information System (ECDIS) is a computerized navigation system, consisting mainly of a computer processor and display, a standardized database, and navigation sensors. ECDIS is not only capable of displaying the navigation-related information in real-time but also supporting other advanced functions, such as route planning, route monitoring and automatic alarms.
In ice-infested waters, the use of ECDIS as a standalone information system would not provide sufficient information for safe navigation. Safe and efficient marine navigation in ice-infested waters require comprehensive and timely information on the sea ice conditions. To enhance the safety of marine navigation in ice-infested waters, the Canadian Ice Service (CIS) uses remote sensing techniques to extract the sea ice information in the form of daily ice charts. The availability of the ice charts enables the mariners to make critical decisions regarding the selection of the best possible navigation routes.

While highly useful in providing the mariners with comprehensive ice information, ice charts may not fulfill the requirements for safe and efficient marine navigation, even if they are used side-by-side with ECDIS. Canadian research funded by CRESTECH now underway at Ryerson University and the University of New Brunswick proposes that, in ice-infested waters, an integrated navigation chart system may be developed which integrates vital ice information into an ECDIS in a formal, standards-based manner.

This paper discusses a production approach demonstrating how Canadian ice chart and standardized ice object attribute data could be integrated into an ECDIS using three commercially available software packages. A prototype production flowchart is explained, and both results and challenges of the proposed approach are described in detail.

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1. INTRODUCTION

Electronic Chart Display and Information Systems (ECDIS) are a part of modern navigation style developed as part of the integrated bridge. ECDIS systems have hardware and software components. The hardware part consists of a computer processor, a display, and navigation sensors.
The software component consists of a standardized database and processing software package. ECDIS has evolved through out the last decade to ensure safe and efficient navigation is the safe and efficient navigation. This is done by integrating Electronic Nautical Chart (ENC) together with real time radar and other types of information. ECDIS makes life easier for the navigator as it processes real time navigation information and warn for collision and other hazards and help optimize the navigation process through out the navigation phases including planning and monitoring. In ice-infested waters, however, ECDIS cannot be used alone as a safe navigation tool as it lacks the important ice information input to safe navigation information.

Off Canada's Atlantic coast and in northern regions, a great deal of navigable water freezes in winter and imposes a great hazard to safe navigation. In order to overcome this danger, ice charts are prepared and updated daily to help the mariners avoid collision and plan their routes accordingly. This requires manual work to be done on the ice charts and to be checked with ECDIS electronic output. When (potential) hazards are encountered, a manual action from the mariner is needed, which jeopardizes the automation of the navigation process and may not be optimal. Even if all the work is done in an accurate and timely fashion, the amount of effort and concentration can be extremely reduced for cheaper and safer computerised navigation. In order to overcome this problem, the integration of sea ice information within ECDIS has been proposed. One of the major challenges to achieving this goal that is that ice information is not always produced by hydrographic offices and is usually not in a format compliant with ECDIS standards.

The aim of a research project now underway in Canada at Ryerson University in Toronto and the University of New Brunswick in Fredericton [El Rabbany, 2001] is to develop appropriate methods and techniques to ensure accurate and safe integration of sea ice information within ECDIS. This paper introduces that research project and summarizes early results and challenges.

2. BACKGROUND

Electronic Chart Display and Information Systems (ECDIS) are a part of modern navigation style developed as part of the integrated bridge [Bowditch, 1995]. In this navigation style, various kinds of navigation information aids are integrated within one navigation system [Alexander, 2000] in order to provide optimal navigation aid to mariners. These include Electronic Nautical Chart (ENC) database, system display, planning station, control system, navigation sensors, and radar. The ENC database includes the navigational chart in digital format. The display has the capability of displaying navigational chart components in color and should provide the capability of displaying a basic subset of information all the time and selected extra information at the mariner's discretion. It has also the capability of displaying the ship's position in real-time through GPS navigation sensors. The radar provides important input to avoid collision with other objects in the radar range and alerts the mariner for action. These various components work together to perform certain functions necessary for safe navigation like route planning, route monitoring, and voyage recording. The most important part of ECDIS is the Electronic Nautical Chart (ENC).

An Electronic Navigational Chart (ENC) is the softcopy equivalent to the paper navigational chart and it is basically a database that can be read and displayed on the screen by ECDIS. In order for a chart to be considered as an ECDIS, it should comply with the standards established by the International Maritime Organisation (IMO), a UN agency responsible for regulating the international navigation and consists of all UN member countries [IMO, 2001]. In addition, the International Hydrographic Organisation's special publication S-57 Edition 3.0 defines the standards for an electronic chart to be considered as an ENC compliant with the IMO specifications. The IHO special publication S-52, on the other hand, defines the display standards for an electronic chart display system to be considered as an ECDIS [Alexander, 2000]. The ultimate purpose of all these standards is to ensure safe and efficient navigation all the times and under all circumstances.

In ice-infested waters, however, the use of ECDIS alone jeopardizes the safety of navigation. This is because neither of the current standards supports ice objects in ice-infested waters. In order to overcome this drawback, various government agencies produce and publish different ice publications in order to avoid hazards arise from the ice objects. In Canada, the Canadian Ice Service (CIS) is the government body responsible for producing and publishing ice information for the mariners. The CIS uses different kinds of technologies in order to produce daily ice charts. These technologies include aircraft side looking airborne radar (SLAR), and RADARSAT, synthetic aperture radar (SAR) and visual observation. After proper processing, the CIS produces daily ice charts in form of images and bulletins [CIS,2001c]. These charts are then used by the mariners in conjunction with ECDIS in order to ensure safe navigation.

This requires dealing with two types of information systems simultaneously, which may not always be safe. A safe route identified on the ice chart may not be a valid navigation route on the ECDIS as a result of a shallow water depth for example. This suggests that a greater, more timely effort should be put in by the mariner in order to reach the correct navigation decision in a critical time. Even if it could provide safe navigation, this approach is absolutely not efficient.

A better approach to supporting safe and efficient navigation is to have the ice objects integrated within ECDIS. This will enable the mariners from dealing only with one system that is capable of alerting them in case of hazards and ensure advanced route planning for both, safe and efficient navigation. This will help the mariners to make correct and informed decision regarding the selection of the best possible navigation routes. This can also help extend the shipping season for maximum income return.

3. PRODUCTION AND FORMAT OF ICE CHARTS

The Canadian Ice Service is responsible for providing the ice information in the Canadian waters, mainly through its daily ice charts (Figure 1). To do this, the CIS uses various space-borne and airborne remote sensing sensors, shore station observations and shipboard ice observations (Canadian Ice Service, 1994). The charts are based on the North American Datum 1927 (NAD 27) and the Lambert Conformal Conic Projection. The World Meteorological Organization (WMO) symbolization for ice information, frequently referred to as the "Egg Code", is used to describe the ice conditions (Figure 1). Boundaries are drawn around the ice areas with different concentrations; with the relevant attributes of each area represented by an egg code (Canadian Ice Service, 1994).

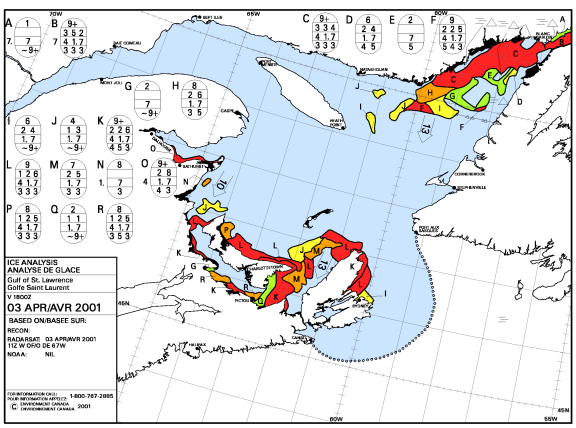

Figure 1: CIS Ice Chart for the Gulf of St. Lawrence , April 3, 2001.

An egg code is an oval shaped symbol containing three components that collectively describe the concentration of the ice, the stage of development (age) of the ice concentration and the predominant form of ice (floe size). These parameters are expressed by up to 12 numerical values. The concentration of the ice represents the ratio between the area of the water surface covered by ice and the total area, and is expressed in tenths. The value of the ice concentration varies from 10/10 for consolidated ice to 1/10 for open water. The single uppermost parameter in the egg code represents the total concentration, which includes all stages of development. The second row in the egg code matrix contains the partial concentration for the thickest (left), the second thickest (middle) and the third thickest (right) ice types. The partial concentration field may contain two numbers, if only two ice types are present in the area (see Figure 2). If there is one ice type only, the partial concentration field will be left blank, as the attribute will be represented by the total concentration (Figure 2). The third field in the ice code contains the stages of development (age) for the ice types reported in the partial concentration field. Thicker ice refers to older ice, and vice versa. Various codes are used, depending of the stage of development. For example, a code of "1" is a assigned to the *new ice* (less than 10 cm in thickness), while a code of "9" is assigned to the *second stage thin first-year ice* (50-70 cm in thickness). "Medium/thick first-year ice", as well as "areas classified as old ice", are assigned a dot (·) as part of their code. The last field in the code represents the predominant forms of the sea ice (floe sizes) corresponding to the stages of development identified in the previous field. Various codes are given to various floe size, which vary from "0" for the *pancake ice* to "7" for the *giant floe* (width greater than 10 km). Fast ice and icebergs are given the codes of "8" and "9", respectively. Undetermined ice form, unknown or no form is assigned the code of "X".

4. ICE CHARTS AND ECDIS:

As mentioned above, the current standards for the production and displaying of ENCs and ECDIS do not support ice objects. A great deal of attention has been paid to integrating sea ice information within ECDIS. A list of ice objects and attributes was developed in the *"Workshop on International Standards for Ice Information in ECDIS"* held in Ottawa, Canada in 1995. The results of this workshop were reviewed in another workshop *"The Use of ECDIS in Ice Navigation"* held in Hamburg, Germany in May 1996. A proposed version 2.0 of the ECDIS Ice Objects presented in a third workshop *"Ice in ECDIS"* held in St. John's, Newfoundland, Canada, in 2000. In March 2001, the CIS produced the version 3.0 of the ECDIS Ice Objects. The use of these objects as an international standard pending the approval of the IHO, which then can be used as a guide for the IMO's work on ice [CIS, 2001]. It is worth mentioning that the IHO has frozen the S-57 standard Edition 3.0 until 2003 [Ramsay, 2000]. It is worth mentioning that this catalogue defines how ice objects are represented in the database but doesn't define how the objects are displayed. There are two main ways for representing ice objects: the egg code and the hash code. The egg code is used mainly in North America and is recognized by the World Metrological Organization (WMO). The hash code, on the other hand, is used mainly in North Europe and Baltic Sea and is relatively simpler than the egg code. With this in hand, the integration of sea ice information within ECDIS requires the optimal use of ice representation amongst both of the systems and may suggest another better approach.

5. METHODOLOGY AND APPROACH FOLLOWED

The purpose of this research is to integrate the digital ice information within ECDIS. ECDIS is basically an information system that has a spatial attribute. Therefore, it is one kind of Geographical Information Systems (GIS). As with any information system, the Software Development Life Cycle should be followed when designing or modifying parts of it. The Software Development Life Cycle (SDLC) suggested by Layzell[] was followed by the senior author as it is deemed appropriate for the tasks encountered in this modification in order to put the project on the right track. An adapted version of the SDLC is shown in Figure 2. The current position of the project within this cycle is marked with (1) because the ECDIS system already exists and a new functionality is required to be added to the system.

In this endeavor, the CIS ice charts make a new input to the system. A new functionality should be added in order to perform the desired requirement, which is the integration of ice objects within ECDIS. The desired result is to display the sea ice object on the screen and to support the use of these objects in ECDIS functionality like route planning and monitoring. The ultimate purpose is the safe and efficient navigation practices. The Object-Oriented approach will be followed as the initial system used this approach.

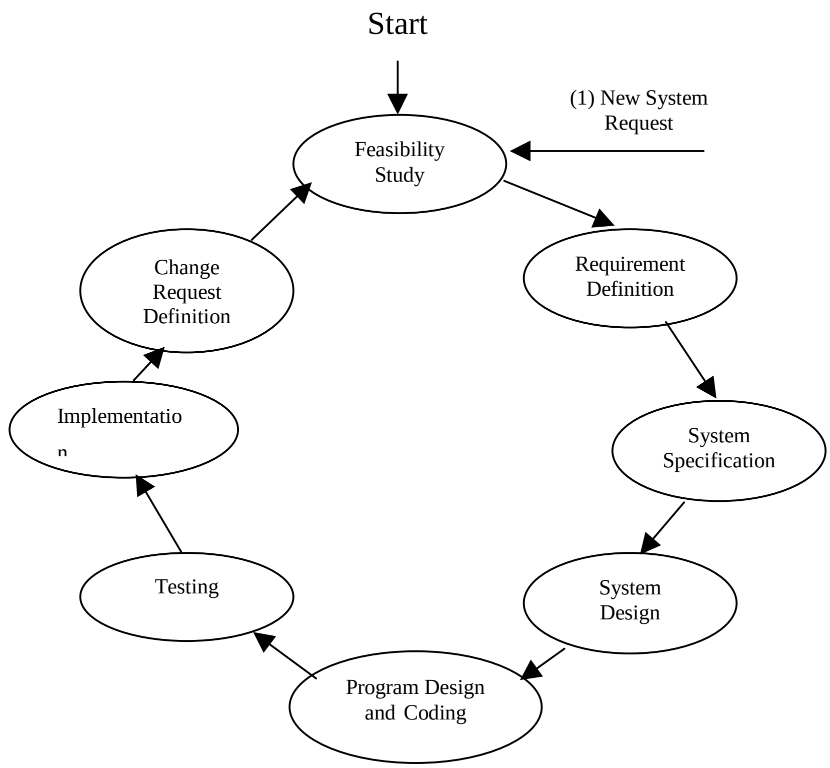

Figure 2: Software Design Life Cycle after Layzell[]

6. SOFTWARE EMPLOYED

The solution that was initially examined used the *ArcView* GIS, *CARIS* GIS, and *Hydrographic Object Manager* (or *HOM*)software to move the ice data into an ECDIS-readable form [Lapointe, 2001]. The GIS software packages employed — *ArcView* and CARIS — allow a user to assemble, store, manipulate, and display the geographically-referenced ice boundaries. For more information on the capabilities of *ArcView* GIS and *CARIS* GIS, the reader should consult the Web sites *http://www.esri.com* and *http://www.caris.com* respectively.

HOM is also software developed by CARIS which lets the user produce an ENC that is compliant to the S-57 data standard ([CARIS, 2001]; [Pais, 1999]). This is done by associating S-57 object and attributes to features in the CARIS *DES* file. The modified *DES* file continues to store the spatial features while the objects and attributes are stored in the Hydrographic Object (HOB) file. Both files can then be used to create an ENC.

7. APPROACH EMPLOYED

The initial approach to the project is illustrated in Figure 3.

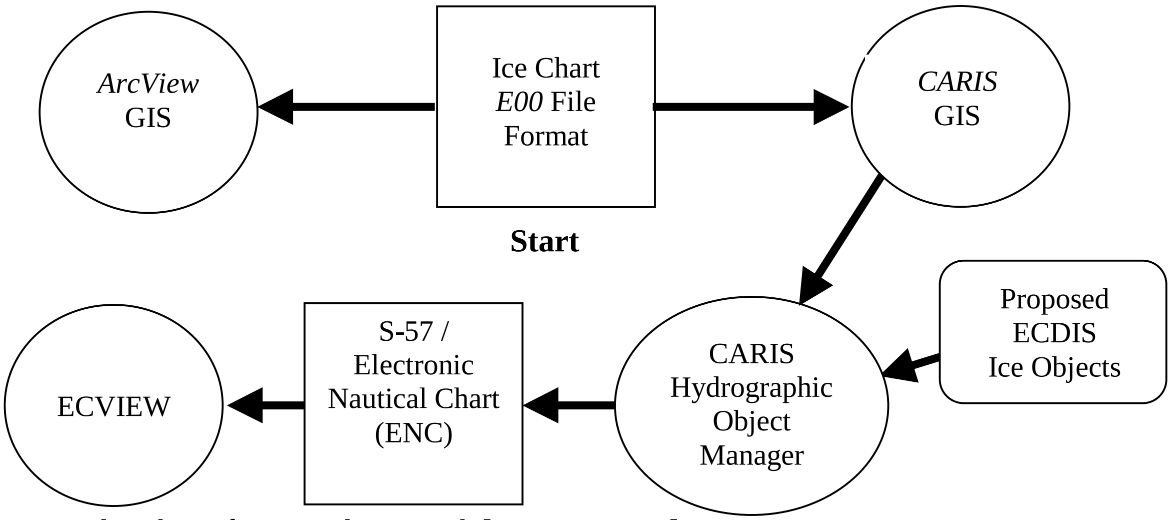

Figure 3: Flowchart of Proposed Approach [Lapointe, 2001]

Ice data originally collected within *ArcInfo* was structured and symbolized primarily with hardcopy cartographic display purposes in mind. (Such data is typically faxed out to weather offices, shipping firms, mariners, etc. Before any major conversions took place, the original ice data (in E00 format) was first imported into *ArcView* in order to be viewed and queried easily. Also, when the data is subsequently imported into *CARIS*, the resulting *CARIS* file can be checked against the *ArcView* shape file. Figure 4 illustrates one such E00 file so imported into *ArcView*.

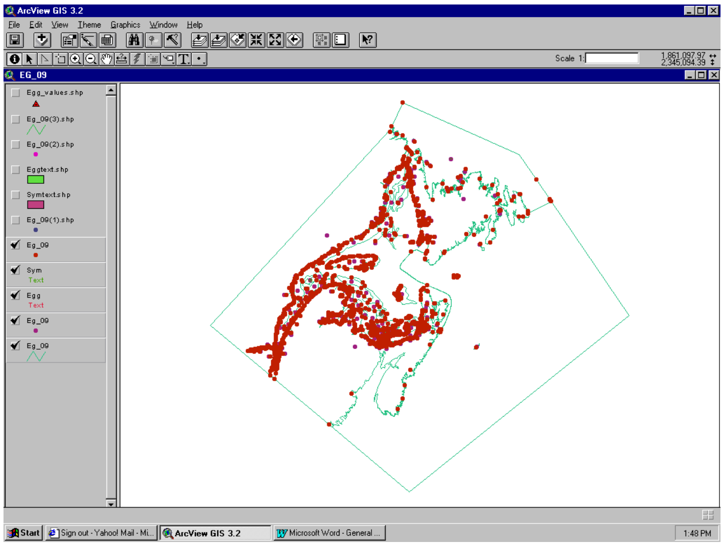

Figure 4: Coverage of the Test Area.

A *CARIS*-internal routine was employed to import the E00 files directly into *CARIS* GIS. Since the file translation process was not semantic in nature, the data subsequently had to be re-layered onto different themes and text labels had to be moved or replaced. In addition, since the ice data coordinates were originally related to the Lambert Conformal Conic projection referenced to the North American Datum 1927 (NAD 27), they had to be transformed to Universal Transverse Mercator (UTM) projection referenced to the WGS84 ellipsoid. Finally, the topology of the various ice areas had to be rebuilt in accordance with the *CARIS* structuring specifications.

The restructured ice data file (now in *CARIS* internal format) was imported into the *CARIS Hydrographic Object Manager* (HOM) software to build an S-57-compliant dataset. A metadata layer was created, ice areas were associated with corresponding S-57 compliant objects, Ice Catalogue-compliant attributes were attached to these objects, and the S-57 ECDIS-readable file was prepared.

8. EARLY RESULTS

Although the early conversion work from *E00* to S-57 completed by Lapointe [2001] was successful, yet it was impractical. Ideally, the only interaction from the user should be to input the *E00* file in some application that would process all the steps of the transformation explained in Section 3.2. Such an elaborate transformation would be semantic in nature because the application would know both the *E00* and S-57 data structures are organized, and how the two are related to each other. Essentially, the *E00* file structure would get mapped to an equivalent S-57 file structure. The transformation in Section 3.2 is not semantic and thus the user is left to convert the data utilizing features from three different software packages.

The only insurmountable problem is that the non-standard S-57 objects (ECDIS Ice Objects) do not get displayed in the ENC. A method to expand the S-52 standard (display standard) will have to be determined and implemented to solve this problem.

Nevertheless, the initial transformation process developed by Lapointe for this project does have advantages, including:

1. An ENC can be created from the CIS' *E00* data.
2. The information about the ice areas is stored as per the S-57 data standard.
3. The S-57 data standard can be expanded. This is particularly useful for a user that wishes to create new S-57 objects that do not currently exist.

This process also has the following disadvantages:

1. The use of *ArcView* in the process is not justified as the data can be viewed and queried in *CARIS* GIS. This represents an additional burden for the user.
2. The time required to perform the transformation as developed by Lapointe was still too long. There was still too much interactive editing required, with the operator performing the same task over and over. Given the time involved, the proposed

process as developed would still result in a backlog with much of the ice information already be out of date and meaningless.

3. The process involved operations using three different GIS software packages. Besides operator learning-curve considerations, important information might be lost during the various transformation processes and the user may have no idea where the loss occurred. A more desirable approach will use one software package to do all necessary conversions before it is transformed to another one.

9. STEAMLINING THE CONVERSION PROCESS

Advanced development work now underway by the senior author is directed towards steamlining the conversion process and minimizing the interactive editing still present in the initial effort.

Since these ice charts were originally prepared for hardcopy distribution, selected features within the mapping are superfluous to the needs of an ECDIS. One such example dealt with the label lines used by the CIS to create the ice charts. In the case of very small polygons, a line was employed to ”link” a given ice area to its corresponding ”egg code” attributes. While useful on hardcopy products, these lines were interpreted as ”dangling arcs” by the software at the topology-contruction stage – thereby producing a significant number of errors requiring interactive editing. In addition, the majority of these small ice polygons contained more than one label in them while a few apparently contained no label at all- conditions which also hampered topology construction of the GIS file.

The solution developed by the senior author was to develop a batch script within *ArcInfo*— run prior to any other transformations -- which performed necessary projection and datum transformations, cycled through all polygons, removed any extra labels if more than one existed, and added a label where necessary. The use of *ArcInfo* was important as the original CIS’ ice charts are produced using it. (See Figure 5.)

Figure 5: Polygon Labelling Problems when Building Topology in the Ice Charts

Another related problem involved determining how best to deal with ice information lines and symbols originally added to the chart to convey information about the ice conditions. An example is an arrow with a number written on it. This arrow shows the direction of the movement of the ice object and the number inside it represents the speed (knots/24 hours) of motion. These lines and symbols carry important information even though they are not ice objects. Therefore, the solution for this problem was to move these symbols to another layer to be manibulated in future work if need be. The original work completed by Lapointe [2001] did not deal with these symbols. In subsequent work completed by the senior author, these symbols were dealt with in batch mode using a script in *ArcInfo*. (See Figure 6.)

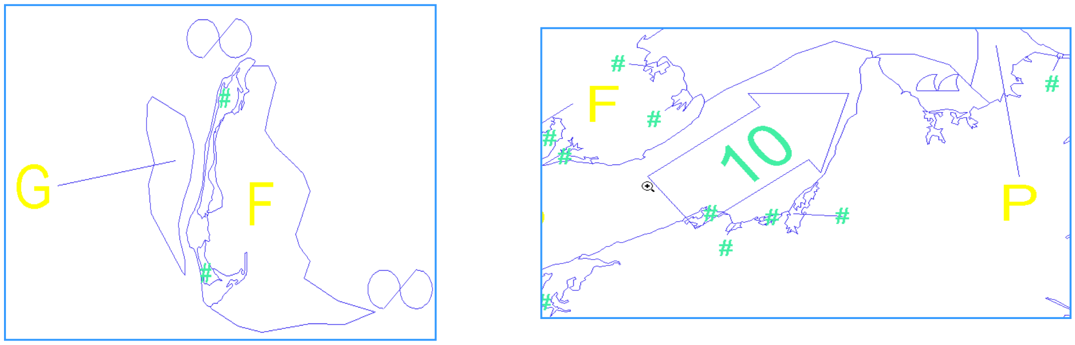

Figure 6:Moving Symbology in the Ice Charts onto Different Theme Levels in the GIS

Finally, when topology was built, manual testing was performed on each one of these polygons to ensure quality of AML script developed. The testing performed showed that the results are correct and accurate. The restructured files are shown below in Figures 7, 8 amnd 9. The final stage of the script involved exporting the cleaned and structured file into *CARIS* for subsequent immediate transfer into HOM.

10. EVALUATION AND FUTURE WORK

The development work completed to date by the senior author has been extremely successful. Advantages of the new refinements include the following:

- The refined approach is totally automated – all necessary pre-processing can be done "on-the-fly" to ensure timely and accurate data conversion and there is no need for the user to know any functionality of *ArcInfo*..
- No interactive editing is required from the user and therefore the process is less prone to error.
- Rather than using both *ArcView* and *CARIS*, only one software package *(ArcInfo)* was employed for all necessary pre-processing of the data, which eliminates any possibility of errors resulting from data conversion. Since *ArcInfo* was the software originally used to produce this data, the resulting data should be accurate and compatible with the original data.

The work has also opened the door to new challenges, including the following:

- The automatic mapping of the ice objects after they are imported to HOM remains to be addressed. Different ice objects should be mapped to their counterpart ice objects already appended to the database.

- The process of extracting the ice objects' attributes needs to be examined in order that they also be mapped to their correct place in the database. This is necessary so that these objects can be used for different types of navigation processes.
- A more general research challenge involves examining, developing and testing alternate approaches to the display of a wider set of time-varying objects within the ECDIS. Various methods need to be reviewed in order to reach the best way for this process, which is not necessarily mimic what is being done manually.

Recognizing that poor planning produces poor results, various involved stakeholders should be interviewed in order to define their requirements, needs, and expectations from the resulting system. The mariners' needs in particular, should be given proper notice. The work environment must be studied in order to define proper Human Computer Interaction (HCI) requirements in order to suggest the best approach for the ice object display taking into consideration the requirements, needs, and expectations of the other stakeholders like the CIS and WMO.

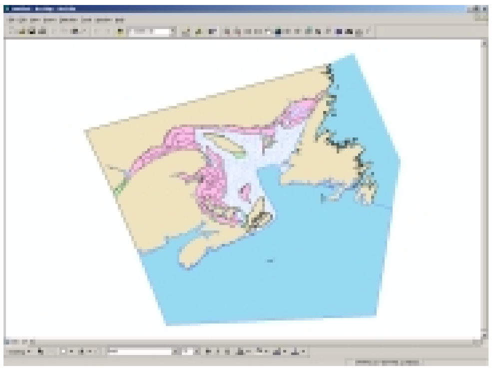

Figure 7:
Ice Objects after Extraction
and Layering

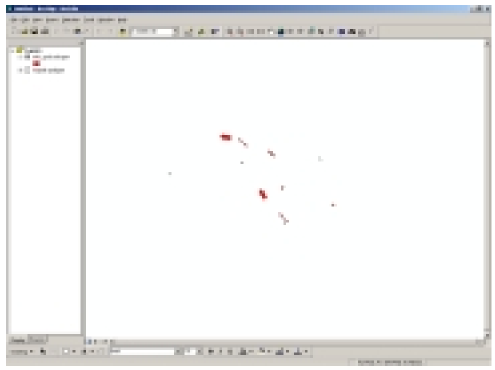

Figure 8:
Ice Information Symbols
as Polygons on a Separate Layer

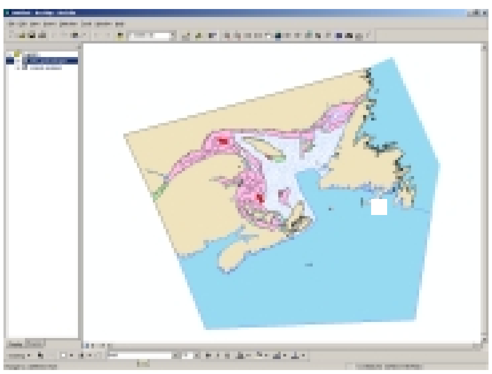

Figure 9
Ice information symbols Superimposed on the Ice Objects

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