TransCanada Pipelines Ltd. (TCPL)

A Summary of Ice Conditions at the Gros Cacouna LNG Terminal Site & in the Gulf of St. Lawrence

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Prepared By: ______________________________ 10 December 2004

B. Wright - B. Wright & Associates Ltd.

Reviewed By: ______________________________ 10 December 2004

D. Masterson - Project Manager - Sandwell Inc.

Executive Summary

This report provides a summary of ice conditions that are relevant for the design and operation of the LNG terminal at Gros Cacouna, and for LNG tanker transit operations through the Gulf of St. Lawrence. The main focus of the report is on site-specific ice conditions at Gros Cacouna, for use in various ice-related LNG terminal design and operability assessments. However, a brief description of ice conditions in the Gulf of St. Lawrence is also provided, as background for various tanker transit considerations.

This summary is based upon a review and analysis of existing ice information. The ice data sources that are currently available for the area of interest are varied, in terms of the ice parameters they describe, as well as the resolution they provide in space and time. Because of this, the nature of these ice data sources is described in some detail.

The level of information about site-specific ice parameter details at the Gros Cacouna terminal site, which will be required for in-depth design and operability assessments, is presently limited. As such, the information that is presented in this report should be recognized as being a preliminary summary. New ice data acquisition programs are planned for the upcoming winter that should improve the current ice data base for the Gros Cacouna terminal site. These studies are also highlighted in this report.

In contrast, a broad range of relatively detailed ice information is now available for the Gulf of St. Lawrence region, plus an extensive experience base from past shipping operations in the area. This type of information about ice conditions in the Gulf is only briefly highlighted in the report, but can be accessed should more specific details be required for various tanker design and in-ice transit considerations.

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1 Introduction

TransCanada Pipelines (TCPL) is planning to build and operate an LNG import terminal at the Gros Cacouna site, which is located on the southern shore of the St. Lawrence River near the river's entranceway to the Gulf of St. Lawrence (Figure 1.1). The scope of this project includes the LNG terminal facility, frequent LNG tanker transits to the terminal through the waters of the Atlantic and Gulf of St. Lawrence (from Russian and/or African LNG sources), and a pipeline distribution system to move the imported gas within Quebec and to the north-eastern US states.

TCPL's Gros Cacouna LNG terminal will be located in the estuarine waters that separate the St. Lawrence River from the Gulf of St. Lawrence. For eight to nine months of the year, this region is characterized by open water. These conditions will present a relatively conventional operating environment for the LNG terminal, and for any tanker transits to and from it.

During the winter period, however, the St. Lawrence River and Gulf of St. Lawrence are covered by ice. It is this seasonal presence of ice that makes TCPL's project unique, when compared to other LNG projects world-wide. In this regard, the LNG terminal facility at Gros Cacouna, the tanker and support vessel operations that will be carried out at the terminal, and the tanker fleet that will be used for transits to and from the terminal site will all have to be designed to contend with expected ice conditions in a safe and efficient manner.

Figure 1.1: Geographical reference map showing the Gros Cacouna location.

This report provides a summary of ice conditions that are relevant for the design and operation of the LNG terminal at Gros Cacouna, and for tanker transit operations through the Gulf of St. Lawrence. The main focus of the report is on site-specific ice conditions at the Gros Cacouna terminal site. However, a brief description of ice conditions along the transit route through the Gulf of St. Lawrence and lower St. Lawrence estuary is also given.

The summary is based upon a review and analysis of existing ice information. Because many decades of experience has been gathered with vessel transits through the Gulf of St. Lawrence and St. Lawrence River in winter, the ice data base that is available for LNG tanker transit considerations is quite good. At the Gros Cacouna site, however, the level of ice information that is currently available is more limited, particularly in terms of the site-specific ice parameter details that are needed for various terminal design and operability considerations.

Because of this, several field programs have been planned to obtain additional ice information at the Gros Cacouna site this winter (2004/05). A model-based hindcast study of ice conditions and ice movements at the location is also underway to provide relevant site-specific ice information over a longer period. The new field and hindcast ice data for the Gros Cacouna terminal site will be used to augment and improve this summary, as it becomes available.

2 Objectives

The primary objective of this report is to provide a summary of expected ice conditions at the Gros Cacouna terminal site, for use as a preliminary basis in the assessment of key ice-related design and operability issues. Secondary objectives of the work are:

- To assess the consistency of different data sets that give certain ice parameter values for the Gros Cacouna site on different time and space scales.
- To blend these data sets together to form longer term ice parameter records and broader based ice statistics, where appropriate.
- To describe ice conditions along the transit route through the Gulf of St. Lawrence to the terminal in less detail than the ice conditions summary for Gros Cacouna, but one that gives a feel for:
  - the regional distribution of pack ice in the Gulf of St. Lawrence, and the manner in which it varies over the freeze-up, winter and spring periods
  - the nature and magnitude of differences in ice conditions between normal, good and poor ice years in the Gulf of St. Lawrence
  - some important but less obvious factors to recognize for tanker transits through the Gulf, for example, ice pressure occurrences, marine icing events, and the occasional presence of “extreme” ice features in certain areas

The approach that has been taken in this report is to present ice information for the terminal site and transit route separately, in a self-contained way. Attempts have also been made to lead the reader through various aspects of the ice environment that will influence design and operations, in a fairly basic manner. In this regard, comments about application areas for the ice data that is given in this summary are provided throughout the text. Where possible, illustrations of various ice conditions and ice features are also included, to give the reader a physical feel for what is described in graphical and tabular form. For those experienced with ice design and operations problems, much of the discussion will be obvious. However, for those who have not dealt with ice problems as extensively before, some of the background and perspectives that are given may be of more use.

3 Key Ice-related Considerations

There are broad range of ice-related considerations that should be recognized in the basic design of the LNG terminal and LNG tanker fleet, and in related assessments of the operability of the overall system. In order to properly address all of these considerations, many facets of the ice environment must be understood and quantified, preferably in statistical form, and on the basis of long term data records. There are also a large number of different ice parameters that are of importance. These parameters often have to be considered jointly, to define appropriate design and operational scenarios.

A few comments about key ice-related considerations for the design and operation of the LNG terminal at Gros Cacouna, and the LNG tanker fleet, are briefly outlined as follows.

3.1 Terminal Design

Obviously, all elements of the terminal structure will have to be designed to withstand the ice loads and effects that can be experienced at the Gros Cacouna site, both normal and extreme. This includes factors such as:

- Global ice loads on the individual dolphins (or cells) that comprise the sub-structure for the LNG terminal (see Figure 3.1), and local ice loads (if relevant).
- The possibility of ice action on a tanker that is berthed at the terminal (e.g.: a cross river ice movement that loads the vessel's long-side) increasing global ice load levels on the individual dolphins.
- The manner in which ice might move around and through the terminal's sub-structure, including the potential for ice jamming between the dolphins.
- The possibility of ice pile-up and ice ride-up against the dolphins, and the above-water clearances that may be required for the trestle structure.

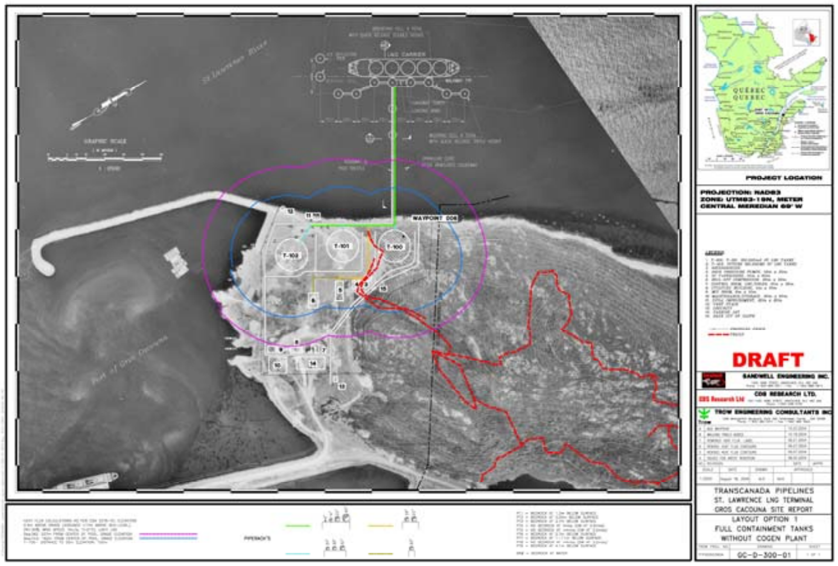


Figure 3.1: Conceptual layout of the Gros Cacouna LNG terminal.

Extreme ice features and interaction events will govern design ice loads for the LNG terminal. The types of extreme features that should be recognized in design ice load calculations include:

- Thick level ice that can form in both fresh and brackish water areas of the river.
- Thicker features within the ice cover such as rafted ice, ridges, and floating rubble fields.
- The consolidated layer within ridges and ice rubble fields, which is generally thicker (but weaker) than the surrounding level ice areas.
- Drifting ice battures that may be of considerable thickness and extent (these ice features can form as the result of repeated tidal flooding of shoreline inter-tidal shallows in winter, and are seen drifting free in the St. Lawrence River and Gulf of St. Lawrence albeit on rare occasions, after becoming ungrounded).

There are a variety of mechanisms that may limit the load levels that these types of extreme ice features could generate on the terminal (i.e.: limit momentum or limit force, versus a limit stress load). Whether or not these load limiting mechanisms will occur depends on factors such as the size and drift speed of the extreme feature, the concentration and make-up of the general ice cover around it (e.g.: the distribution of ice types and floe sizes), and the wind and current forces at play at the time of the interaction event. These additional ice parameters will have to be mixed into design ice load calculations for the terminal as important ingredients, to ensure that the ice loading scenarios developed are realistic. Their inclusion would be particularly insightful in the case of a probabilistic design ice load calculation methodology, should the sophistication of this approach be required.

3.2 Terminal Operability

Along with these basic ice design considerations for the terminal structure itself, it is clear that the facility should be configured to minimize any adverse ice effects relating to tanker operations at the terminal in winter. In this regard, the following points are noted.

- The terminal layout should allow for adequate tanker manoeuvring room, in terms of the final approach and berthing operations of LNG vessels, in various ice situations.

- The layout of the terminal should be designed to minimize any ice forces on the tanker while it is moored at berth, recognizing that ice drift directions will be seen against both its bow and stern over the time frame of the LNG offloading operation (about 18 hours), but may also occur against the vessel's long-side during shoreward (to the south) ice drift situations.

- The terminal should be configured to minimize the need for ice management support during tanker approach, berthing, station-keeping and departure operations, although this ice management capability will be present in the form of an ice capable tug support fleet (3 to 4 tugs).

- The terminal facility, mooring arrangements, and LNG transfer systems should also be designed to allow for emergency disconnects and move-offs of the offloading tanker, should an adverse ice situation begin to arise, or "come-on" unexpectedly.

For in-ice operability considerations at the terminal site, the normal range of ice conditions that are expected at Gros Cacouna is a question of more importance than extreme ice conditions. When faced with an adverse ice situation, a tanker can delay or suspend its operations, in accordance with an ice alert procedure, until the ice conditions improve. Some of the ice parameters that are most important for various terminal and tanker operability considerations are highlighted as follows.

- The ambient ice regime at the site at any point in time, including ice concentrations, ice types, ice roughness and ice floe sizes.

- The ice drift speed and direction at any point in time, and the potential for (or realization of) ice pressure events on site.

- The other environmental factors that may be associated with these ice conditions such as winds, currents, air temperatures, precipitation (snow, freezing rain, etc.) and visibility.

It is important to note that these ice factors typically vary over time scales of a few minutes to several hours at the Gros Cacouna terminal site. Since the existing ice data base does not provide information on short time scales, judgements regarding various operability issues will be required. Here, It should also be noted that the presence of the terminal structure will probably modify the type of ice zonation and ice movement patterns seen in the local area, and will likely extend the shore-fast ice zone outwards from the coastline to the inner edge of the terminal's sub-structure dolphins, and a few hundred metres upstream.

3.3 Tanker Fleet

The LNG tanker fleet that is used to supply the Gros Cacouna terminal will have to be designed to contend with all of the ice conditions expected along the transit route through the Gulf of St. Lawrence and lower St. Lawrence River estuary in winter, as well as those at the terminal site. Some of the key ice-related considerations that should be kept in mind with regard to the LNG tankers are highlighted as follows.

- The transit speeds of the LNG tankers will be reduced along the transit route to the Gros Cacouna site through eastern Canadian waters in winter, due to the presence of ice.

- The ice conditions that will be encountered along the transit route have the potential to cause damage to the hull, propulsion and steerage systems of the LNG tankers that will be used.

- Accordingly, the LNG tankers should be designed with an appropriate level of powering, strengthening and manoeuvrability to operate with safety and efficiency in the range of ice conditions that are expected.

- Icebreaker escort from the Canadian Coast Guard (CCG) may be available to aid with the transit of LNG tankers through the Gulf of St. Lawrence in winter ice conditions, but should not be counted upon.

- Hence, the tankers should be capable of independent operations in the expected range of ice conditions.

- The tankers should also be designed to operate with a good level of manoeuvrability and efficiency at the Gros Cacouna terminal, including their ability to quickly suspend LNG transfer operations and move-off, should ice conditions require.

- The size and number of LNG carriers in the tanker fleet should also be well matched to the land-based storage capacity at the Gros Cacouna terminal, to ensure that any ice-related downtime experienced during the operation of the overall LNG system can be accommodated.

The normal range of ice conditions that can be expected along the tanker transit route are of most importance for various LNG tanker transit performance considerations in winter. The more extreme ice conditions that may be encountered are of higher importance for specific aspects of vessel design. The type of ice information that is required to assess tanker transit issues includes parameters such as ice concentrations by type along the route, ice roughness, and snow cover. Two of the more innocuous factors that are seldom recognized but are of high importance in terms of impeding tanker transits in winter include:

- Ice pressure occurrences.

- Marine icing events.

4 Ice Information Sources

A substantial amount of information has been obtained about ice conditions in the St. Lawrence River and Gulf of St. Lawrence, over many years. As noted earlier, the level of ice data that is available for assessments of tanker transit through the Gulf of St. Lawrence is generally better than the ice data base required for detailed design and operational considerations at the Gros Cacouna terminal location, where site-specific details about some of the the characteristics and dynamics of the ice environment are lacking.

Existing ice data sources for the terminal site and transit route are varied. They include a wide range of different types of ice information that has been acquired by different means, and over different time periods. Some of this data can be used to describe ice conditions and develop statistics directly, while other data requires interpretation and analysis to be applicable. The key data sources that have been used in this work are briefly outlined below.

4.1 CIS Ice Charts

The Canadian Ice Service (CIS) has provided ice information to support marine operations in the Gulf of St. Lawrence and St. Lawrence River areas since the late 1960s. This ice information is based on visual observations taken during aircraft over-flights, reports from transiting vessels, and more recently, from various forms of satellite imagery and companion information generated by ice growth and ice movement models. It is provided to users in the form of bulletins and ice charts in near real time, and is also maintained as a historical data archive.

Several types of CIS ice chart products have been used as primary data sources for describing ice conditions in this summary work, and for related tanker transit simulation studies that have and are now being done. They are highlighted as follows.

4.1.1 Regional Weekly Ice Charts

These ice charts are issued by CIS on a weekly basis, and provide a time averaged description of ice conditions over a large area of the East Coast and St. Lawrence River for the particular week. An example is shown in Figure 4.1. Some points to note are listed below.

- 30 years of weekly ice chart data has been used in this work, covering the 1970/1971 to 1999/2000 winter periods. These charts provide quantitative information about the ice distribution patterns and different ice regimes seen in the chart area, including the total ice concentration, ice concentrations by type, and the floe sizes observed within each ice regime. However, they do not provide any information about specific ice characteristics such as thickness, ridging, ice movements, and so forth.

- It should also be recognized that the quality of these ice charts is generally better over the past 15 years or so, than in the earlier years, largely due to recent advances made in satellite remote sensing technologies, as well as the use of numerical ice models that are now run to provide input to the charts.

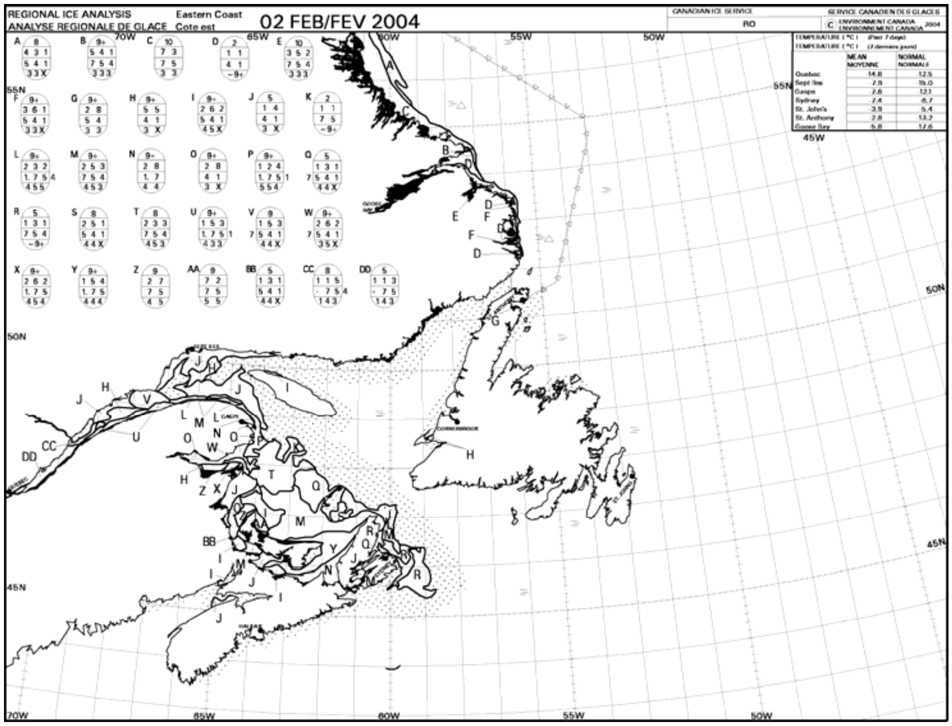


Figure 4.1 Example of a CIS regional weekly ice chart. The “egg codes” that are shown on the ice chart are described in section 4.1.4.

- Although the basic CIS ice charts are analogue in nature, the ice data they contain has been digitized at 1/4˚ latitude by 1/4˚ longitude grid points across the chart area. The results of this digitization process, which was carried out by Environment Canada in the early 1990’s, were transferred into a commercially available software package that was developed by Canatec. This “Canatec ice data base” includes information about total ice concentrations and ice concentrations by type, but does not have entries that describe ice floe sizes, the degree of roughness of the ice cover and so forth. It contains weekly ice data from 1969 to 2000, but has not been updated to include the last 4 winters (2001 to 2004).

- The Canatec data base has been used to develop information about some aspects of the ice cover around the Gros Cacouna site in this work, and for input to related in-ice tanker transit simulations through the Gulf of St. Lawrence. However, this data base should be appreciated as a fairly low resolution data source. The ice information from it is viewed as being appropriate and representative for regional tanker transit assessments, but more limited in terms of defining specific ice conditions at the Gros Cacouna terminal location. In this regard, it only provides weekly ice data that is representative for grid areas of about 15nm (nautical miles) by 10 nm in size.

- Figures 4.2 and 4.3 show examples of the gridded ice information from the Canatec data base on regional and local scales, to provide some perspective.

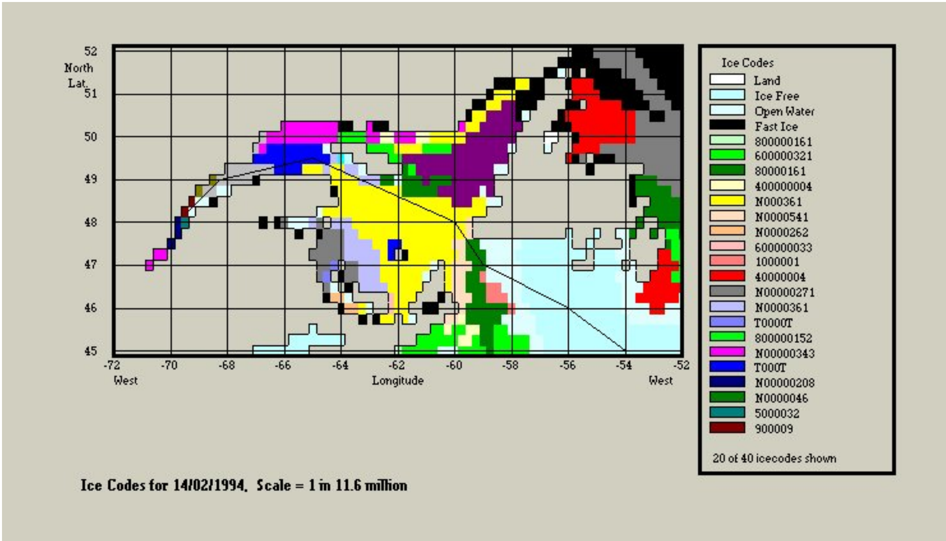


Figure 4.2: Example of a digitized regional ice chart from the Canatec data base. The black line is the tanker transit route from Cabot Strait to Les Escoumins.

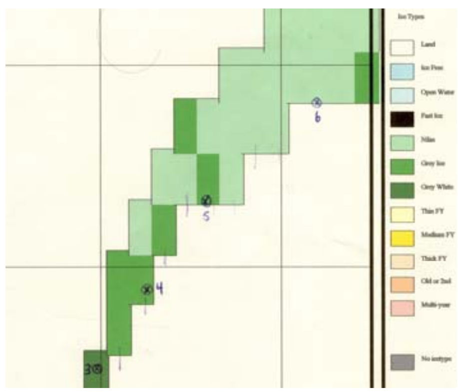


Figure 4.3: Example of digitized ice data on a local scale in the St. Lawrence River estuary (about 20 grid points). Here, Gros Cacouna is denoted at site # 4.

- Despite these resolution limitations, the Canatec data base (and the CIS regional weekly ice charts that underlie it) provides the only long term ice data source available. For the purposes of this work, ice information has been extracted from the Canatec data base for the 1970 to 2000 period (30 winter seasons), and used to develop some relevant ice statistics.

4.1.2 Daily Gulf of St. Lawrence Ice Charts

These ice charts are issued by CIS on a daily basis, and have been routinely produced since the 1990s. Like the weekly charts, they provide a description of ice conditions over the Gulf of St. Lawrence and St. Lawrence River areas, but for the particular day. An example is shown in Figure 4.4. Although these charts are produced on a smaller scale than the regional charts (i.e.: apparently more detailed), they do not actually contain ice information that has any better spatial resolution than what is contained in the regional charts. However, their temporal resolution is better.

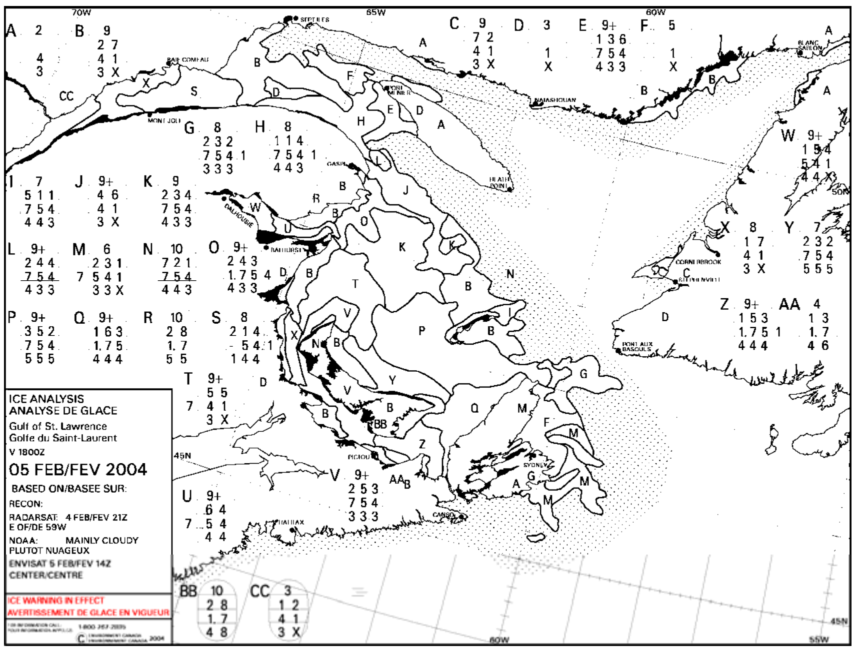


Figure 4.4: Example of a CIS daily ice chart for the Gulf of St. Lawrence.

A few points to note about these daily CIS ice charts are outlined below.

- The daily ice charts are based on periodic visual observations from aircraft, ship based reports and satellite imagery, but rely quite heavily on recently developed ice models to “fill in the ice picture” during the time frames (typically several days) on which these more direct (but intermittent) ice information sources are acquired.
- The ice models are run on a 5 km x 5 km grid across the Gulf of St. Lawrence and St. Lawrence River areas, and are sophisticated state-of-the-art models in terms of their ability to reflect the physics of ice growth and movement processes.
- The grid cells that are contained in the CIS model (and the DFO version of it now being run on an operationally basis for CCG out of Mont Joli), which cover the Gros Cacouna area, are shown in Figure 4.5.

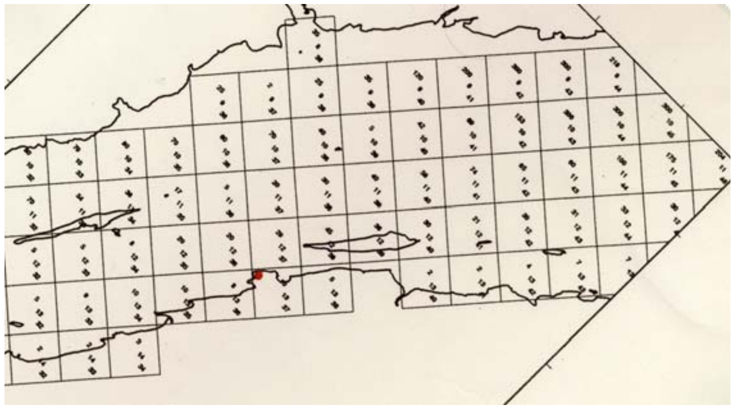


Figure 4.5: A view of the 5 km x 5 km grid in the Gros Cacouna area that is used in the CIS ice model (note: the proposed LNG terminal location is denoted by the red point).

- The basic ice data that is provided on the daily ice charts is available in digital form from the 1996 to 2003 period, including ice concentrations by type and floe sizes. This ice data was obtained from the University of Quebec at Rimouski (who have the personnel that run the model operationally) for the grid areas shown in Figure 4.5.
- This 7 years of digitized ice information that is associated with the daily ice charts, for the four grid areas nearest to Gros Cacouna, has also been used to develop ice statistics for the terminal site in this work.

4.1.3 St. Lawrence River Ice Charts

The St. Lawrence River ice charts are another CIS ice product that are issued an “as-acquired” basis. They are local charts of different segments of the river, and provide a more detailed view of ice conditions in particular areas of the river than the regional weekly or daily Gulf ice charts. An example of a river ice chart that covers the Gros Cacona terminal site is shown in Figure 4.6. A few points to note are highlighted as follows.

- These river charts have much better spatial resolution than the other CIS chart products, but are only issued intermittently during the river’s ice season, with typical frequencies of several times per week (rather than every week or every day like the regional and Gulf of St. Lawrence chart series, respectively).
- The river charts are also based on visual observations from aircraft (usually helicopters) and satellite imagery, but generally include a larger observational component from CCG icebreakers operating in the area. The charts provide information on ice concentrations by type, floe sizes, shorefast ice edges, sometimes on ice thickness and roughness, and occasionally include notes on battures. There is a special inset for ice conditions in the Gros Cacouna harbor that is sometimes filled out on the river charts for the area.

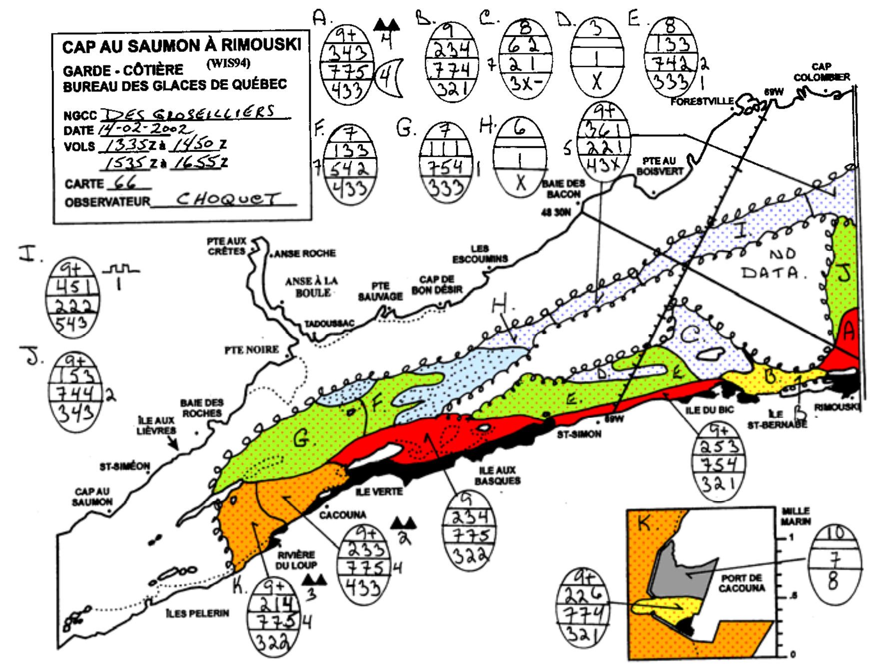
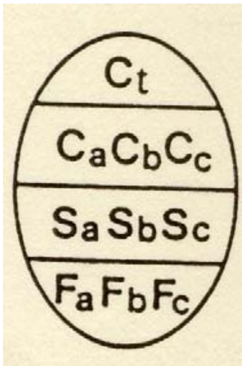


Figure 4.6: Example of a St. Lawrence River ice chart issued by CIS for the Cap au Saumon to Rimouski segment of the river, including the Gros Cacouna site. Note the inset of specific ice conditions within the Gros Cacouna harbour and its entryway.

- For the purposes of this work, 15 years of river ice charts covering the winters of 1990/91 through 2003/04 were obtained from CIS for the Gros Cacouna area. Information on ice concentrations and floe sizes by ice type were manually extracted from these charts for the specific terminal location, along with ice roughness and measured ice thickness data (within the harbor) when available. This data was used to develop ice statistics for the terminal site, and for comparisons with the longer term but coarser regional ice chart information.

4.1.4 Ice Chart Codes

The ice information that is contained in all of CIS's ice chart products is presented in the form of an "egg code". This code specifies the make up of an ice regime in terms of the concentrations of different ice types and the floe sizes of these ice types, as shown in Figure 4.7. Both the ice type and floe size codes involve numerical values, and are summarized in Tables 4.1 and 4.2. A more complete explanation of the overall egg code system is given in the CIS website (www.cis.ec.gc.ca). An important point to note is that the egg codes provides an indication of the thickness of the ice types that comprise an ice regime, but only in broad ranges. It should also be noted that these ranges are simply visual estimates and are not the result of direct ice thickness measurements. In this regard, the thinner ice types are better defined than the thicker ice types, which have a wider spread of thicknesses within the code.



C_t is the total ice concentration (on a scale of 1 to 10)

C_a is the partial concentration of the thickest ice type, C_b is the partial concentration of the second thickest ice type, and C_c is the partial concentration of the third thickest ice type

S_a is the code for the thickest ice type, S_b is the code for the second thickest ice type, and S_c for the third thickest ice type

F_a is the floe size code for the thickest ice type, F_b is the floe size code for the second thickest ice type, and F_c for the third thickest ice type

Figure 4.7: A brief summary of what the egg code indicates.

Description	*Thickness (cm)*	*Code*
New & Nilas Ice	<10	1 & 2
Young Ice	10 – 30	3
Grey Ice	10 – 15	4
Grey-White Ice	15 – 30	5
First Year Ice	>30	6
- thin first-year ice	30 – 70	7
- medium first-year ice	70 – 120	1●
- thick first-year ice	>120	4●

Table 4.1: Ice types, their thickness ranges and the codes used to describe them on the ice charts.

Description	*Floe Size (m)*	*Code*
Pancake & Brash	< 2	0 & 1
Ice Cakes	< 20	2
Small Floes	20 - 100	3
Medium Floes	100 - 500	4
Big Floes	500 - 2000	5
Fast Ice	-	8
No Form	-	X

Table 4.2: Floe size terms, their size ranges and the codes used to describe them on the ice charts.

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4.1.5 Ice Thickness Stations

The Canadian Ice Service has also acquired ice thickness information at various near-shore measurement stations over the years. These ice thickness stations are scattered throughout southern Canada and the Arctic, and include a few locations along the St. Lawrence River and on Gulf of St. Lawrence coastlines. An example of the type of information they provide is shown in Figure 4.8 for a location about 60 km upstream of Gros Cacouna.

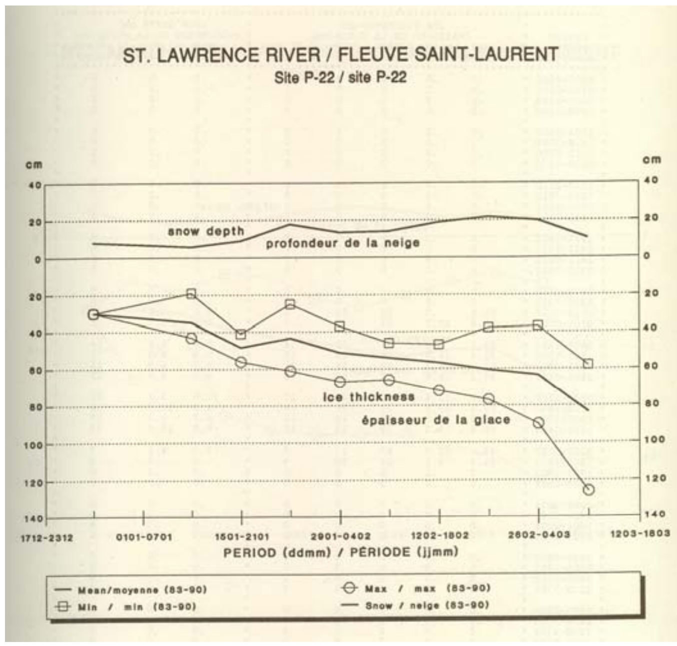

Figure 4.8: Example of CIS ice thickness data from a measurement station on the shoreline of the St. Lawrence River.

Several related comments are given as follows.

- These ice thickness measurements were typically taken at CIS stations over the 1961 to 1990 period, and provide information on ice cover growth versus time, and on the mean, minimum and maximum observed ice thicknesses (plus the snow cover). Although there are some stations along the St. Lawrence River, one was never established at the Gros Cacouna site.

- The thickness data from other St. Lawrence River locations is of some relevance and is representative of the thickness of fast ice near the shoreline, but not of the thicknesses of most of the drifting ice in the river. Some of this ice thickness station data, plus air temperature records (freezing degree-days) from Environment Canada has been used to estimate extreme ice thickness values for the Gros Cacouna terminal site, as described later in this report.

4.2 Previous Ice Field Studies

There have also been a number of field studies carried out to document specific aspects of the ice cover that is found in the Gros Cacouna area. However, these studies are few and far between, and were all conducted to provide ice-related input to the Arctic Pilot Project (APP) that was under consideration in the late 1970s and early 1980s. The type of ice information that was collected in these field studies is primarily visual. It is available in the form of a limited number of air and surface photographs of general ice conditions around the terminal site, which are spread out sporadically in time. Although this information does not form a systematic ice data source, it is useful in terms of giving a physical feel for certain aspects of the ice cover. The type of data acquired in these previous field studies is briefly highlighted as follows.

4.2.1 General Observations

A few general photos of ice conditions in the Gros Cacouna area that were taken in 1976, along with two air photos from earlier years, were included in an ice-related study entitled "Dynamics and Characteristics of Ice in the Gros Cacouna Area", prepared for the University of Quebec (at Rimouski) by D. Carter. Examples of these two types of "visual" ice data sources extracted from the U of Quebec report are given in Figures 4.9 and 4.10. There are eight handheld surface photographs from February and March of 1976 contained in this report, and two air photos taken in late February and early March of 1972.

Figure 4.9: Photograph of the ice cover taken off Gros Cacouna looking to the NE from the harbour's outer breakwater, towards the planned LNG terminal site. The ice in the river was pressed against the shoreline under the influence of winds and currents at the time, and appears to be heavily deformed and present in the form of ice rubble.

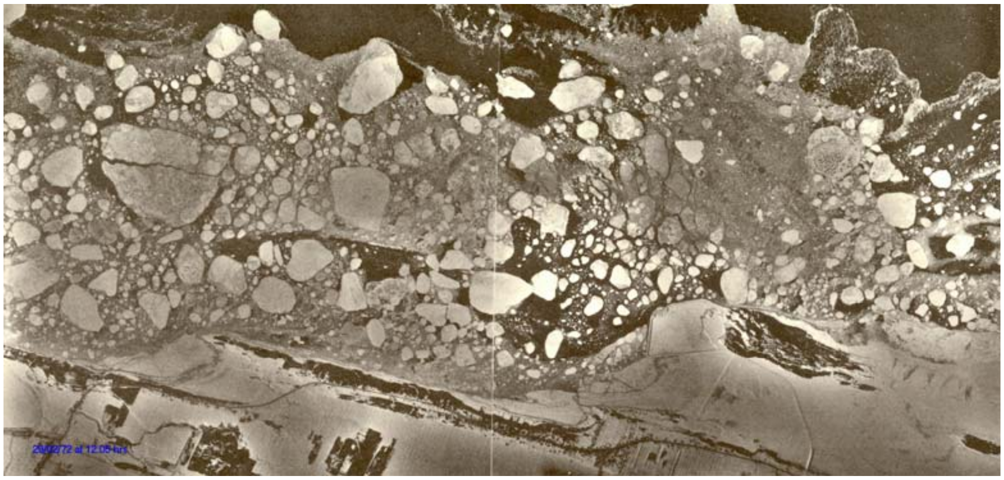

Figure 4.10: An air photo showing ice floes of various sizes together with brash ice and shore-fast in the Gros Cacouna area, taken during the winter of 1972.

4.2.2 Air Photos

A series of air photos that are similar to the one shown in Figure 4.10 were also taken during the winter of 1982, as part of a study entitled “Ice Studies at Gros Cacouna”. This field work was carried out for the Arctic Pilot Project, and documented in a report authored by D. Berenger. In addition to the air photos, this report contains ice cover schematics derived from the photos, like the example shown in Figure 4.11. There are five such schematics which provide snapshots of ice conditions in the Gros Cacouna area over the February and March period in 1982. Some ice drift trajectories and speeds were also extracted from this data as part of the Berenger study.

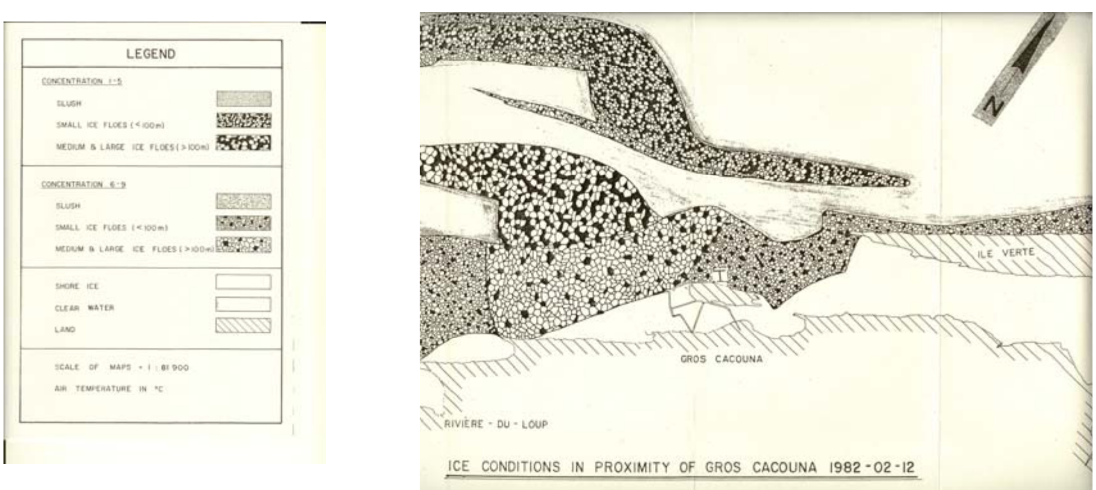

Figure 4.11: Schematic of ice conditions around Gros Cacouna derived from air photos.

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4.3 Planned Ice Field Studies

The foregoing data sources are sufficient to provide a reasonable (albeit preliminary) description of ice conditions at the Gros Cacouna site, and along the LNG tanker transit route through the Gulf of St. Lawrence. However, recognizing that more detailed ice data will be required as the terminal design work proceeds, several ice-related projects have been planned for the winter of 2004/05. These new ice data acquisition projects are briefly highlighted as follows.

4.3.1 Upward Looking Sonar

Arctic Sciences Limited (ASL) deployed an upward looking sonar system on the seafloor at the Gros Cacouna terminal site during the fall of 2004. This system is comprised of an Ice Profiling Sonar (IPS) and an Acoustic Doppler Current Profiler (ADCP). These sonars will collect data on the following ice parameters over the course of the winter, and will also provide data on water currents at the terminal site.

- ice drafts passing over the terminal site (i.e.: level ice thicknesses, ridge and rubble keels, and keel geometries) with an accurate spatial resolution
- ice drift speeds and directions at the terminal site on time scales of a few minutes
- ice concentrations and floe sizes inferred from the ice draft time series over short time scales

A photo of the sonar instrumentation and a typical output of measured ice drafts from the IPS (obtained further up the St. Lawrence River) is given in Figure 4.12. The results of these sonar measurements at Gros Cacouna should become available during the May time frame in 2005.

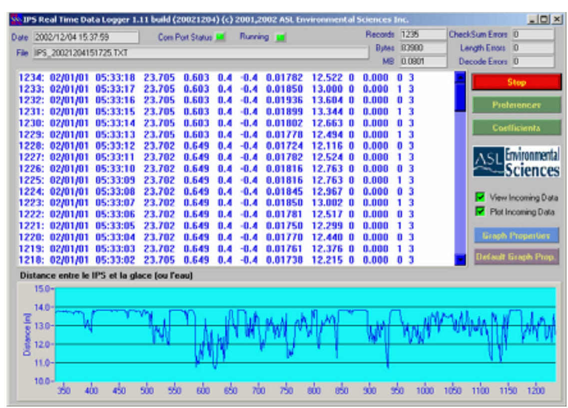

Figure 4.12: The type of upward looking sonar system that has been deployed at the Gros Cacouna terminal site, and an example of the keel draft output data it provides. Note that ice keels in the range of 3m to 4m on this particular ice draft trace are indicated, at a location in Lac St. Pierre which is up-river of Gros Cacouna.

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4.3.2 Time Lapse Video Coverage

A time lapse video camera system will also be deployed to document the ice and ice movement conditions experienced at the Gros Cacouna site over the winter of 2004/05, at an ongoing recording time scale of several seconds. This work is being conducted by personnel from the University of Quebec (at Rimouski) and will provide a detailed visual time series of:

- ice concentrations by type that are moving over the site, and the surface roughness characteristics of the ice cover
- ice movement patterns (and speeds) in the area of interest over short time scales
- ice compression (pressure) events in the terminal area and their duration, and the amount of ridging and rubbling that may occur (which is an indication of ice pressure event severity)

Figure 4.13 shows the time lapse video camera scheme that is now planned, and its deployment location on a cliff that is about 80m in elevation above the river. The video recordings will be collected at roughly 2 week intervals throughout the winter and as such, will be available across the 2004/05 winter period.

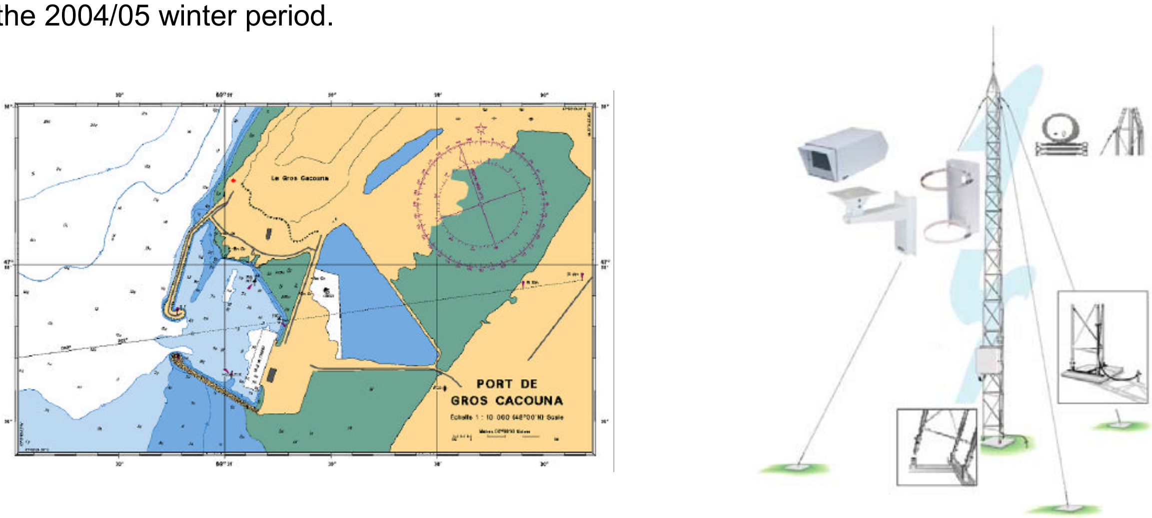

Figure 4.13: An illustration of the time lapse video arrangement. This system will be deployed at the “red dot location” on the Gros Cacouna area reference map.

4.3.3 Ice Conditions Hindcast Study

A hindcast study of ice, weather and current conditions at the Gros Cacouna site over the past 8 winters (1996/97 to 2002/03) is also being carried out by the University of Quebec at Rimouski. This study involves running the CIS ice model on a 400m x 400m grid (much higher resolution than that shown in Figure 4.5), and providing ice parameter time series (at 3 hour intervals) and statistics on factors such as ice concentration, ice thickness, ice movements and ice pressure events. The results will become available over the late January to May period in 2005.

5 Ice Conditions at the Gros Cacouna Site

Data from the foregoing ice information sources has been gathered together, interpreted, and analyzed, to provide a preliminary summary of ice conditions at the Gros Cacouna terminal site. These conditions are summarized in this section of the report, with relevant data and statistics presented in the following ice topic areas.

- ice season, including freeze-up dates, break-up dates, and ice season lengths
- ice zones, including the shore-fast and drifting ice areas
- ice coverage, including total ice concentrations and ice concentrations by type
- ice characteristics, including ice thickness, floe sizes by ice type, and ice roughness
- extreme ice features, including rafted ice, ridges and ice battures
- ice dynamics, including ice drift speeds, ice drift directions, and ice pressure events

Before providing more detailed information about these various ice parameters, a few overview comments are given below, to give a general feel for ice conditions in the St. Lawrence River.

- Ice starts forming in the upstream portions of the St. Lawrence River between Montreal and Quebec City earlier than in the estuarine waters between Quebec and Matane, and well before ice formation in the Gulf of St. Lawrence. Typical time frames for freeze-up in these areas are early December, mid December and early January, respectively.

- The normal period of maximum ice extent and severity in the St. Lawrence River (and around Gros Cacouna) is from late January to early March, but this can vary from year to year. In the Gulf of St. Lawrence, this period of maximum ice extent and severity is later, usually from mid February to early April.

- The winter ice cover along the north shore of the St. Lawrence River, where ship transits are normally made, is generally less severe than the ice cover along the southern shore, including the type of ice that is seen near Gros Cacouna. Here, ice concentrations are often high, in the range of 7 to 9/10ths, although the ice cover is frequently comprised of thin ice types (< 30 cm). In the river, brash ice and small floes are common but larger floes in the order of hundreds of metres to several kilometres in size can also be found.

- The ice in the St. Lawrence River is quite dynamic, and typically moves downstream at an average drift speed in the range of 1 knot. Tidal influences can increase this speed several fold in some areas, and cause reversals in short term ice movements twice a day. Rafted ice areas, pressure ridges and rubble accumulations that form as the result of differential movements and compression within the river ice cover are not uncommon but generally, are not particularly severe. When strong winds from the northwest or northeast occur, ice pressure events can be experienced at various locations within the river, including the Gros Cacouna terminal site area.

- The ice in the St. Lawrence River normally begins to break-up, melt and clear in the mid to late March period, with the ice clearance pattern generally progressing from west to east. In the Gulf of St. Lawrence, ice break-up and clearance typically lags that in the river by about one month, and is normally seen over the mid to late April time frame.

5.1 Ice Season

Ice freeze-up dates, ice clearance dates, and the length of the ice (and open water) season are all factors of interest for different operating considerations at the Gros Cacouna terminal site. Information about these three factors is presented here. The criterion that has been used to define the ice season is simple, namely the presence or absence of any ice, regardless of its concentration or thickness.

The information and statistics that have been developed in this work are primarily based on the Canatec ice data base (30 winters of data from 1970/71 to 1999/2000), but also include data from more recent daily and river ice charts (to the winter of 2002/03). As a result, they reflect 33 years of ice observations in total.

5.1.1 Ice Freeze-up

Figure 5.1 shows the dates of first ice occurrence at the Gros Cacouna terminal site (not inside the harbor) over the past 33 years in time series form. This plot shows a considerable amount of variability, with the freeze-up dates ranging from early December to mid January, and having an average value of December 19th. The linear regression line (dotted blue) that has been fit to the data shows no statistically significant trends in the freeze-up date time series, hence, any comments that may arise about the possible effect of climate change appear to be unwarranted.

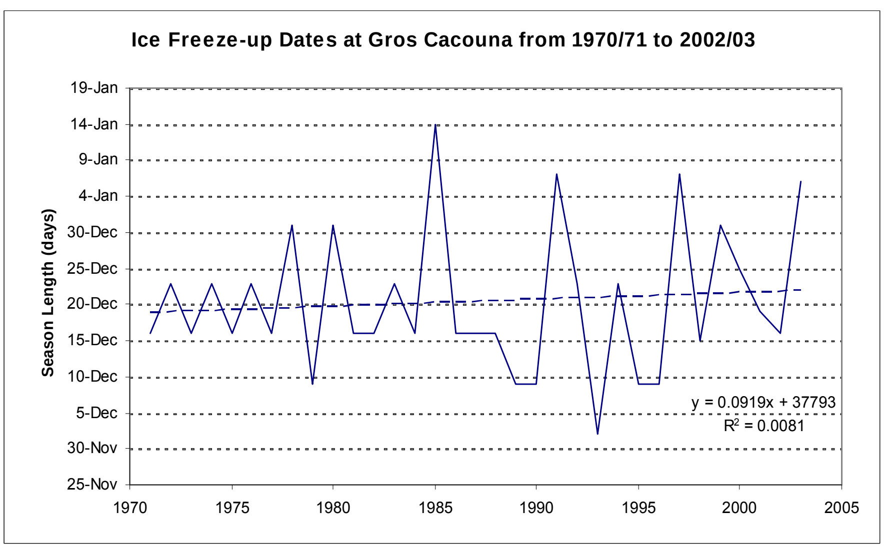

Figure 5.1: Ice freeze-up date time series for the Gros Cacouna terminal site.

Figure 5.2 shows the 33 years of ice freeze-up date data for the Gros Cacouna terminal location in the form of a cumulative probability distribution. This plot illustrates the probability of first ice occurrence on or later than the date shown. For example, there is a 100% chance that freeze-up will be seen on or later than December 1st, a 40% chance it will be on or later than December 21st and 0% chance it will be on or after January 15th, based on the 33 years of historical ice data.

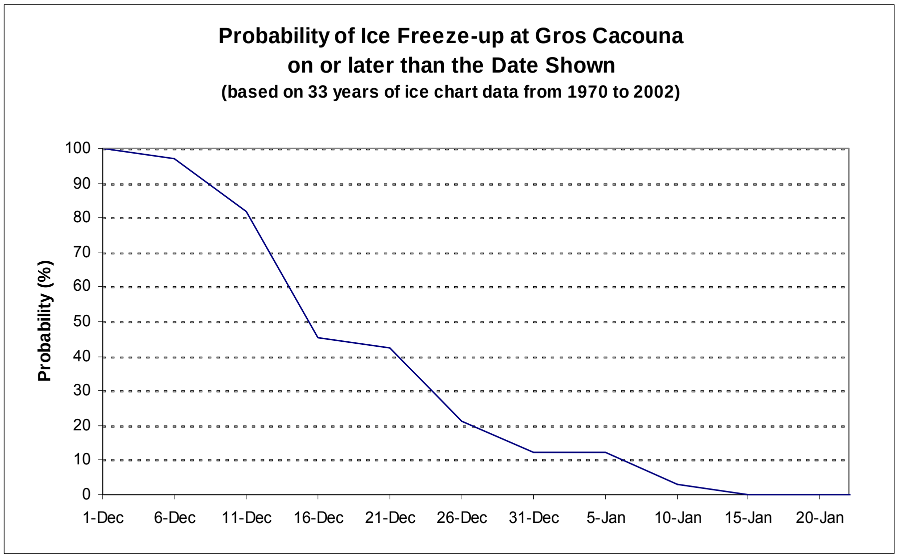

Figure 5.2: Cumulative probability distribution for freeze-up dates at the terminal site.

Ice freeze-up dates that are representative of a normal, poor and good year (in terms of first ice formation) have been determined from Figure 5.2, and are summarized as follows.

- a median freeze-up date (50% value) of Dec 15
- an earliest 1 in 5 year date (80% value) of Dec 11
- a latest 1 in 5 year date (20% value) of Dec 26

A check was also made of ice freeze-up dates indicated by the three CIS ice chart data sources (i.e.: the weekly regional, daily Gulf and St. Lawrence River charts) to assess their compatibility. The results are shown in Figure 5.3 where freeze-up dates from these different data sets are compared, when possible. This scatter plot indicates a reasonable level of agreement between the three data sources, although the river ice charts sometimes suggest an ice freeze-up date that is a week or so earlier (or later) than the CIS regional weekly and daily Gulf of St. Lawrence ice chart series.

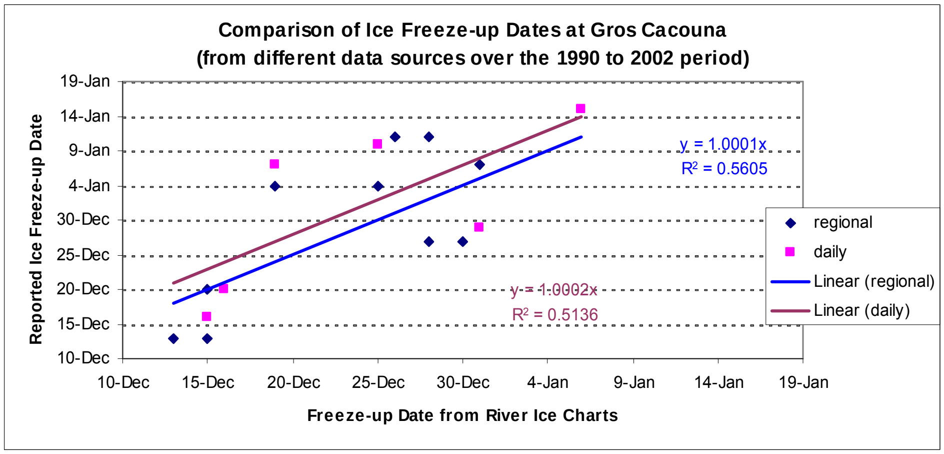

Figure 5.3: Scatter plot of freeze-up dates from three different CIS ice chart products.

5.1.2 Ice Clearance

The same type of plots as those given for ice freeze-up dates has been generated for ice clearance dates at the Gros Cacouna terminal site, based on the same 33 years of historical ice chart data. These plots are given in Figures 5.4 through 5.6, with a few related points outlined as follows.

- The ice clearance date time series that is contained in Figure 5.4 shows a considerable amount of variability from year to year, and a visually trend toward later ice clearance in recent years. However, this trend is not statistically significant.

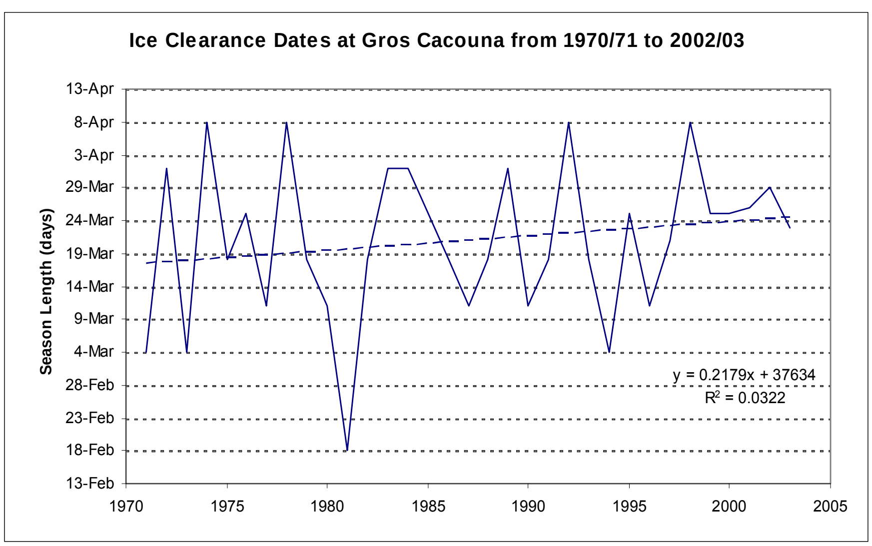

Figure 5.4: Ice clearance date time series for the Gros Cacouna terminal site.

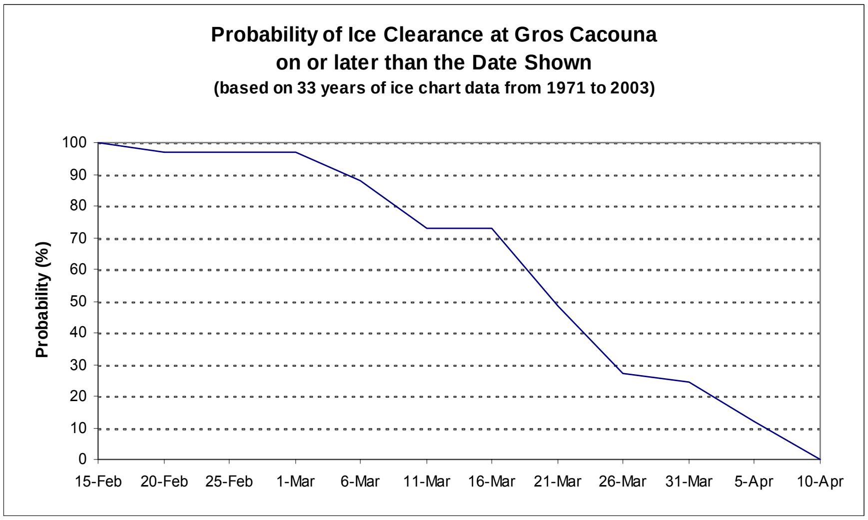

Figure 5.5: Cumulative probability distribution for ice clearance dates at the terminal site.

- The cumulative probability distribution of ice clearance dates that is shown in Figure 5.5 shows a median ice clearance date (50% value) of March 21, an earliest 1 in 5 year date (80% value) of March 9, and a latest 1 in 5 year date (20% value) of April 2.

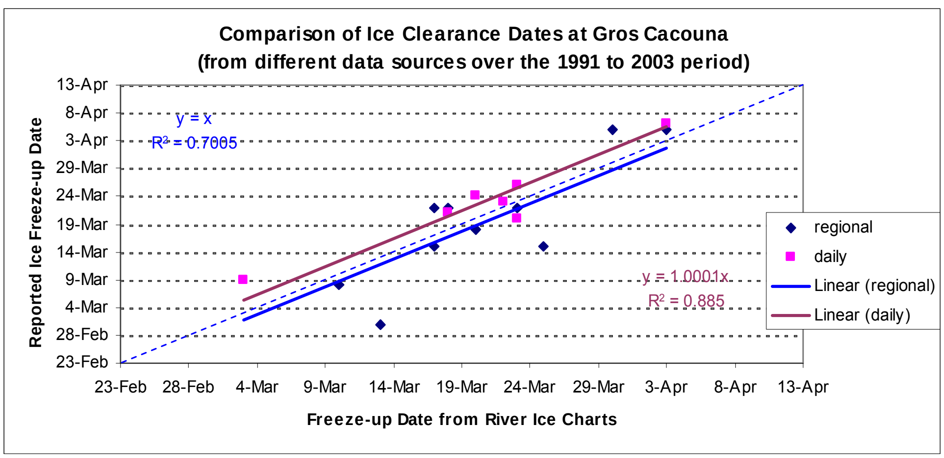

Figure 5.6: Scatter plot of ice clearance dates from three different CIS ice chart products.

- As shown in Figure 5.6, there are fewer discrepancies in the clearance date comparisons between the three different CIS ice chart data sources than in the case of freeze-up dates. In fact, the level of agreement is actually very good.

5.1.3 Ice Season Lengths

The length of the ice season was calculated for each of the 33 winters considered here, as the number of days between first and last ice occurrence. Time series and cumulative probability distribution plots were developed from this season length data, as shown in Figures 5.7 and 5.8.

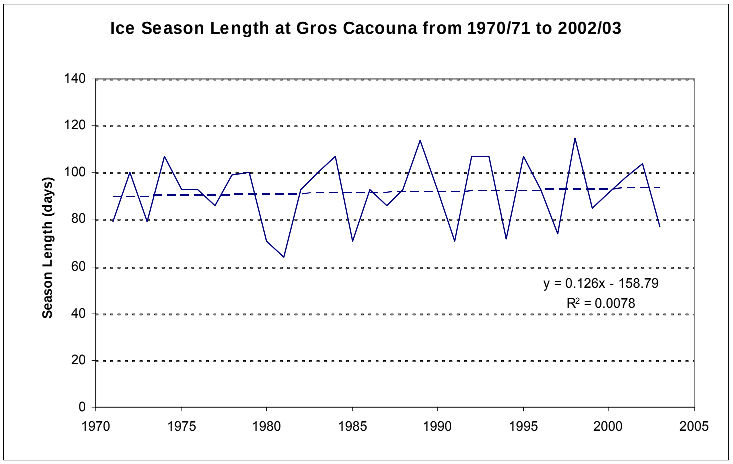

Figure 5.7: Ice season length time series for the Gros Cacouna terminal site.

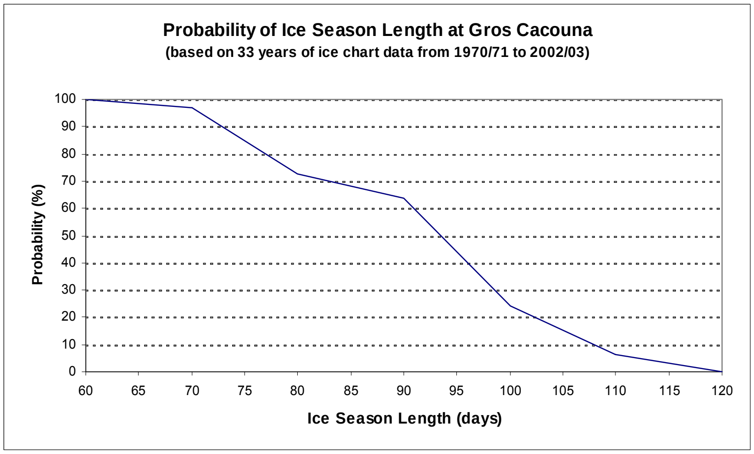

Figure 5.8: Cumulative probability distribution for ice season length at the terminal site.

- The time series plot of ice season length at the Gros Cacouna site in Figure 5.7 shows some variation in ice season length from year to year, but no real trends over the past several decades (i.e.: towards either shorter or longer ice seasons). The probability distribution shown in Figure 5.8 indicates a median season length (50% value) of 93 days, a severe season length (worst 1 in 5 years, or the 20% value) of 102 days, and a mild season length (best 1 in 5 years, or the 80% value) of 77 days.

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5.2 Ice Zones

Before presenting more detailed information about various ice parameters at the Gros Cacouna terminal site, it is useful to provide a short description of the general ice zones that are seen in the area. In this regard, there are only two zones of importance, the moving ice zone and the shore-fast ice zone. As its name implies, the moving ice zone is simply that, with the ice in this zone being in near continuous motion, albeit at varying drift speeds and directions. Shore-fast ice, in contrast, is very stable once it forms, except for its outer reaches which may break-off from time to time.

5.2.1 Shore-fast Ice

Shore-fast ice is normally seen in the near-shore shallows of the St. Lawrence River out to water depths of several meters (Roger Provost - CIS ice observer, personal communication), in inlets and bays, in protected areas that lie between near-shore islands and the coastline, and within enclosures like the present Gros Cacouna harbor. There is nothing unique about this particular ice zone, other than the fact that it is stable and typically quite smooth, except near its outer edges. Because it is stable (undergoing displacements that are likely no more than a meter or so over the course of the winter), it grows in place to its full winter thickness (see, for example, Figure 4.8). By way of comparison, the ice in the moving zone has a wide range of thicknesses, with most of it often being very thin. The reason for this relates to the open water areas that are continually introduced due to ice movements, with new ice then forming in these open areas and then drifting away.

There does not appear to be much (if any) detailed information available about the shore-fast ice that forms in the Gros Cacouna area. However, some feel for this ice zone can be obtained from the river ice charts, and from sporadic air photos that have been taken over the general area. Figure 5.9 shows a schematic of ice conditions derived from an air photo flight made in early March 1982. This figure seems to represent the type of shore-fast ice pattern that should be expected around Gros Cacouna quite well. A few related comments are given below.

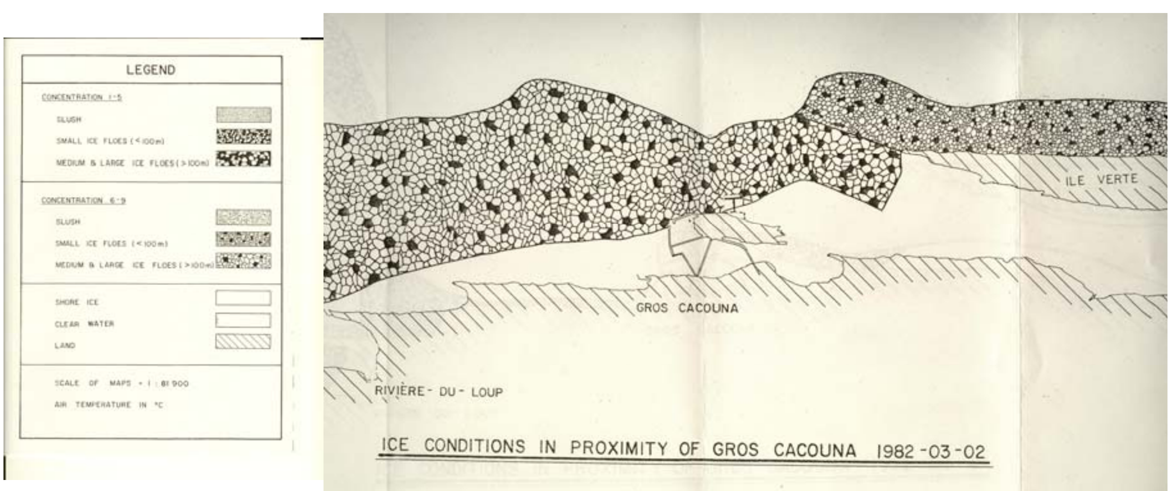

Figure 5.9: Typical shore-fast ice distribution (near-shore white areas) around Gros Cacouna.

- The terminal site is not in the shore-fast ice zone, but lies in an area that is continually within the moving ice zone (as shown on this and other schematics and air photos, from different times in February and March of 1982, and in earlier years).

- There is an area of shore-fast ice in an embayment just to the east of Riviere du Loup, a second fast ice area running eastwards to the Gros Cacouna harbor's break water, and a more extensive fast ice area between Isle Verte and the coastline. These shore-fast ice areas (as well as the stable fast ice within the present Gros Cacouna harbor) are likely to start forming slightly earlier and start clearing somewhat later, relative to the moving ice in the river.

- Shore-fast ice appears to be consistently present in these three areas, but its extent can vary from month to month and from year to year, with the fast ice zone to the southwest of Isle Verte sometimes coming quite close to the terminal site (see, for example, Figure 4.11). This latter fast ice shoreward of Isle Verte, and the island itself, actually provides some protection for the terminal site against ice movements from the east.

- In the river ice charts and air photo data, there is evidence of large sections of the outer edge of the shore-fast ice in near-shore areas to the west of the Gros Cacouna terminal site breaking off in large sections (a few hundred meters in width and several kilometers [or more] in length), then drifting down the river.

- The fast ice just to the east of the terminal site that is anchored by Isle Verte appears to be less susceptible to break-offs, although they can be seen but usually involve relatively small fragments (several hundred meters in size).

- It is not unlikely that shore-fast ice formation between the LNG terminal's outer dolphins, its trestle supports, and the shoreline may be encouraged from time to time, due to their presence. However, support tugs could break-up and clear any stable (fast) ice that may begin to form, should it become an operational nuisance.

5.2.2 Moving Ice

The moving ice zone in the St. Lawrence River lies offshore, typically in water depths of 4m to 5m or more, and is well represented by Figure 5.9 and some of the illustrative figures given in Section 4. Here, the main point to note is that the Gros Cacouna terminal site should always be located in a moving ice regime, as mentioned above. However, there are three different types of moving ice conditions that will be encountered at this location. They include:

- pack ice moving up and down the river, without any lateral confinement
- pack ice pressed against the coastline under the influence of NW or NE winds
- open water or very loose ice on site due to winds from the southerly quadrants

Over the course of the winter, all of these moving ice conditions will be experienced at the Gros Cacouna terminal site, intermittently.

5.3 Ice Coverage

The amount of ice coverage at the Gros Cacouna terminal site is a very important consideration for various marine operations. It is expressed in terms of an ice concentration, on a scale of 1 to 10 tenths, and represents the proportion of the river's surface that is covered by ice (e.g.: 1/10th means that 10% of the water surface is ice covered, 5/10^{ths} means that 50% is covered, and so forth). The make-up of the ice within a particular ice regime (i.e.: an area of ice with the same general characteristics) is also an important factor. For example, an ice regime that has a total ice concentration of 9/10^{ths} but is comprised of very thin ice would usually be easier to contend with than an ice regime with a total concentration of 7/10th that is comprised of thicker ice types. Hence, information about the distribution of ice concentrations by ice type within a particular ice regime, as described in Section 4.1.4, is also fundamentally important.

5.3.1 Total Ice Concentrations

Information about the total ice concentrations that are seen at the Gros Cacouna terminal site has been developed from all three of CIS's ice chart products. Inter-comparisons have been made between the resultant statistics from these different ice chart products that show they are all in reasonably good agreement, despite the different temporal and spatial scales of the data sources.

Figure 5.10 provides a cumulative probability distribution of total ice concentrations for different monthly periods over the course of the ice season, based on the seven years (1996 to 2003) of gridded daily ice chart data provided by the University of Quebec (Rimouski) in digital form. This plot is representative, and is similar to the total ice concentration distributions derived from the regional weekly and river ice charts.

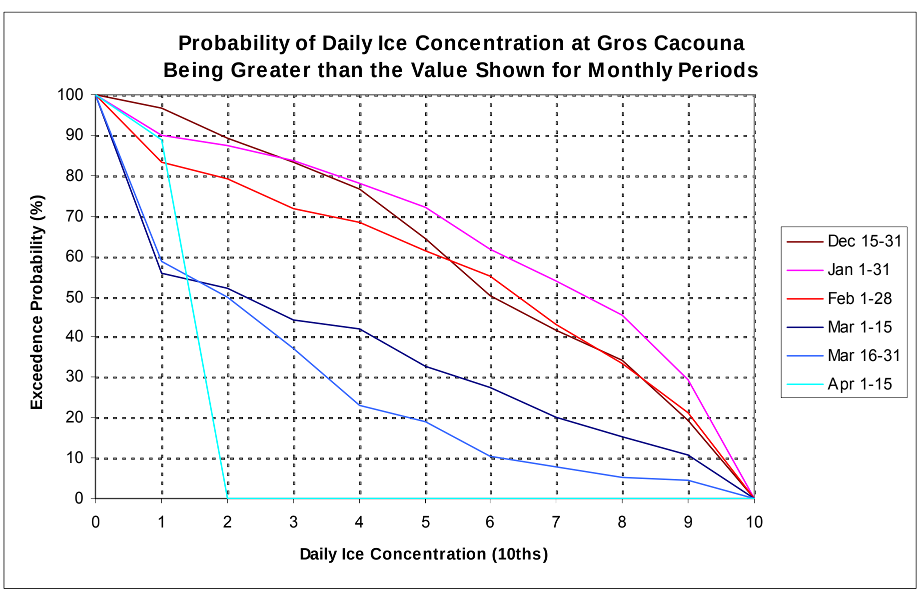

Figure 5.10: Cumulative probability distribution of total ice concentrations at the Gros Cacouna terminal site for different monthly periods, from 7 years of daily ice chart data.

This total ice concentration plot makes good sense in relation to the progression and demise of ice coverage that should be expected with time. For example, in the colder winter months (December, January and February), the total ice concentration is in the range of 6-9/10^{ths} for at least half of the time. In March and early April, ice concentrations in this range are less frequent, when the ice is typically thicker.

Although this probability plot of total ice concentrations is useful, it tends to mask some ice conditions that are of equal or more concern from a terminal operability standpoint, in particular, the percentage occurrence of different ice types. Also, this plot does not reflect the variability in ice concentrations that occur over short time scales, which are of high operational relevance. In this regard, total ice concentrations can vary widely over time scales of a few minutes, to hours, to days. Two examples of the type of day to day variations that should be expected in total ice concentrations are given in Figures 5.11 and 5.12, extracted from the river and daily ice chart data sources, respectively.

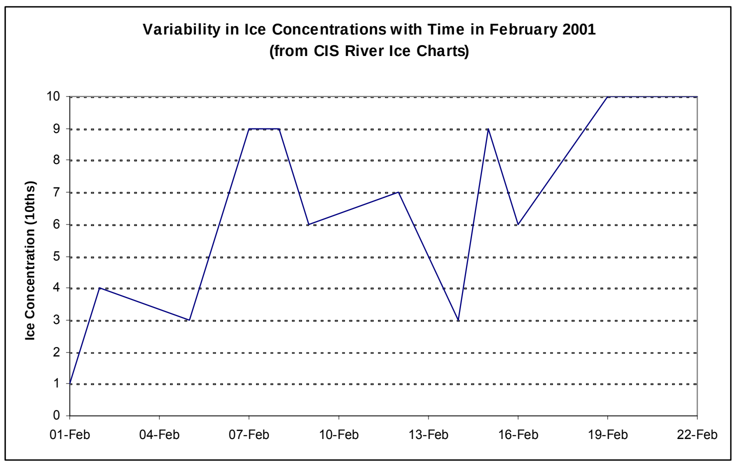

Figure 5.11: Data from St. Lawrence River ice charts.

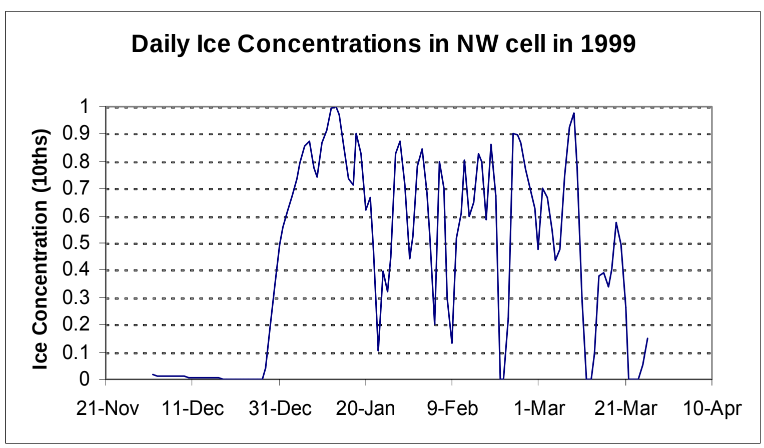

Figure 5.12: Data from digitized CIS daily ice charts.

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5.3.2 Ice Concentrations by Type

Information about ice concentrations by ice type has also been obtained from the three CIS ice chart data sources. Again, inter-comparisons between these data sources show that they are in good agreement, in terms of the ice type distributions they portray. A statistical analysis of the ice type data from the daily ice charts is representative of all three data sets, and is shown in the form of the relative occurrence of different ice types by month in Figure 5.13.

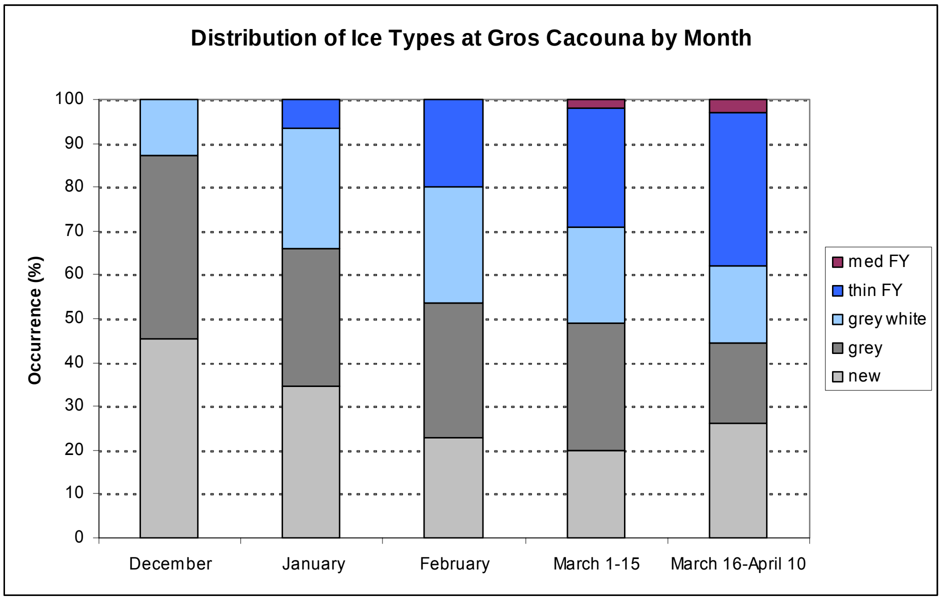

Figure 5.13: Relative occurrence of different ice types at the Gros Cacouna terminal site for different monthly periods, from 7 years of daily ice chart data.

A few points about the information that is provided in Figure 5.13 are given as follows

- The ice type distribution for the Gros Cacouna site shows that the following thin ice forms are prevalent in all months
  - new ice (0 to 10 cm thick)
  - grey ice (10 to 15 cm thick)
  - grey white ice (15 to 30 cm thick)
- There is an increasing proportion of ice in the thin first year ice category (30 cm - 70 cm thick) reported as winter progresses (in the range of 30 - 35% of the ice cover in March)
- There are few ice charts that report the occurrence of any ice in the medium first year ice thickness category (70 - 120 cm).

One question of interest relates to the concentrations of ice exceeding the new, grey and grey-white categories (i.e.: > 30 cm in thickness) that may be encountered at the terminal site at any point in time. Obviously, if a large thick ice floe drifts across the site, the concentration of thick ice will be 10/10[ths] during the time period of its passage. However, on slightly longer time scales of a day or two, the question becomes much more reasonable, for example, in terms of potential ice management requirements.

Figure 5.14 shows a probability distribution for the occurrence of ice concentrations involving ice in the thin (30 cm - 70 cm) first year ice category (and greater) at the Gros Cacouna site. This plot is based on 30 years of historical ice data that was obtained from CIS's weekly regional ice charts. The results derived from the daily Gulf of St. Lawrence and river ice charts are similar. On the basis of this figure, the main point to note is that when ice of more than 30 cm does occur at the terminal site (in combination with thinner ice types), it is usually present in relatively low ice concentrations, with "thicker" ice concentrations being less than 3/10[ths] for almost 90% of the time .

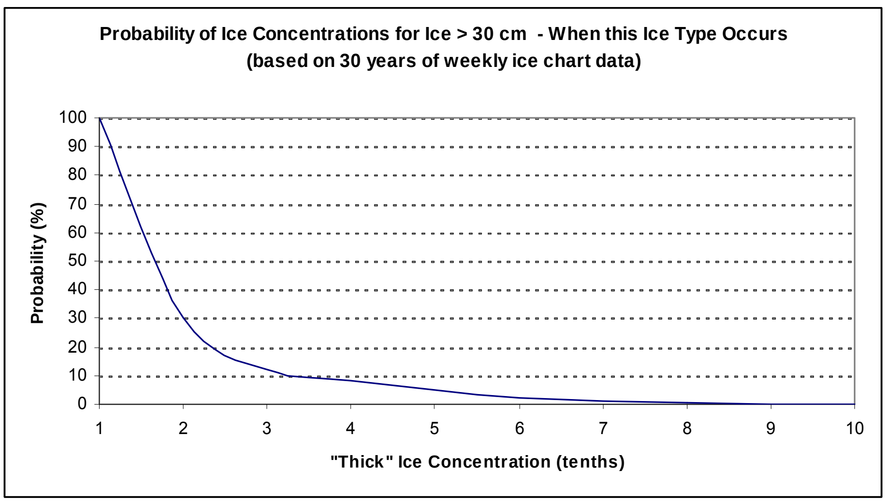

Figure 5.14: Cumulative probability of ice concentrations involving "thick ice", when this ice type occurs.

5.4 Ice Characteristics

In addition to information about total ice concentrations and ice concentrations by type, data about more specific characteristics of the ice cover at the terminal site is required. This includes parameters such as ice thickness (more detailed than the broad ice type thickness ranges), ice floe sizes, and ice roughness. With the exception of floe size information from the ice charts (and corroborated by the sporadic air photos), there is very little data concerning the actual ice thicknesses and roughness ranges that should be expected at the Gros Cacouna terminal site. A summary of the information that has been found, or derived, for these ice characteristics topic areas is given as follows

5.4.1 Ice Thickness

One parameter that is of considerable interest for the design of the terminal structure, from an ice loading perspective, is the maximum thickness that level ice may grow to in the area of interest. Sandwell has addressed this question in some detail, based on freezing degree-days, with a summary of their analysis work presented in Appendix 1. The basic result suggests that a 100 year maximum level ice thickness value of 1.22m should be used for any ice load analyses associated with the LNG terminal design. No further information has been found in the CIS ice charts or in any other data sources to indicate that this design level ice thickness value is not appropriate.

However, for terminal operability considerations, this extreme level ice thickness value has little relevance. In this regard, the ice type information that was given in Section 5.3.2 provides a better feel for what should be anticipated and planned for, from a marine operations point of view. To provide some sense for the spatially averaged ice thicknesses that will be commonly encountered at the Gros Cacouna site, blended ice thickness values have been calculated by combining ice concentrations by type into a mean thickness for the observed ice regime (from the daily and weekly charts). This ice thickness data is more representative for considerations relating to the type of ice conditions that various marine operations will have to contend with, tanker approaches to the terminal and ice management support activities, for example.

Figure 5.15 shows a cumulative probability distribution of spatially averaged ice thicknesses at the Gros Cacouna site by month, based on 30 years of CIS's regional weekly ice chart data. These monthly distributions of blended ice thickness values are in good agreement with those derived from the digital daily ice chart data and the river ice charts. From this figure, it is clear that mean ice thicknesses averaged over space scales of a few kilometers are generally quite thin, and show a logical progression from "thin to thick" as the ice season goes on.

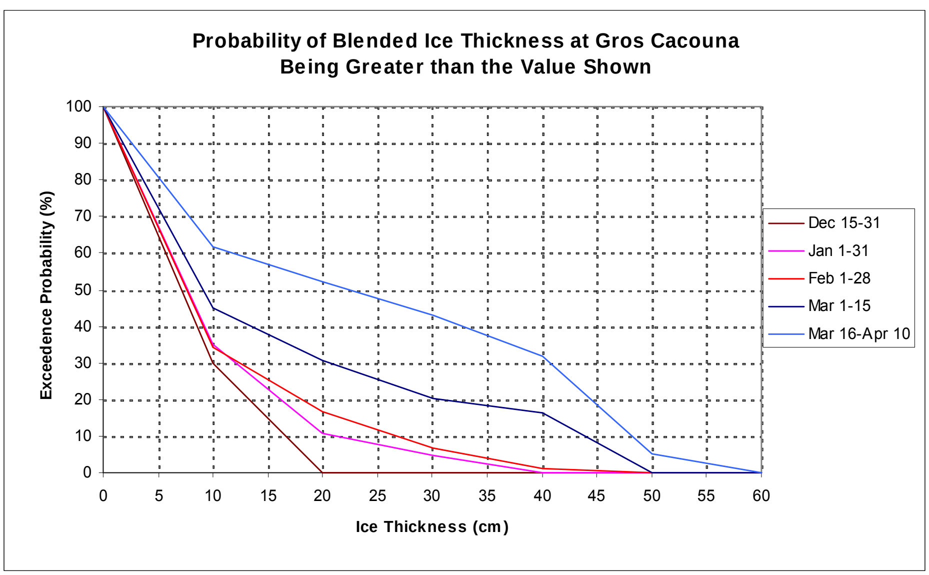

Figure 5.15: Cumulative probability of mean ice thicknesses around Gros Cacouna by month.

5.4.2 Floe Size

Ice floe sizes are another important factor for various operational considerations, and also for the kinetic energy and driving force determinations that may be associated with design ice load calculations for the LNG terminal structure itself. Floe size data has been obtained from the three CIS ice chart sources, and analyzed to provide floe size statistics by month. Figure 5.16 shows the relative occurrence of floes within various size categories, as determined from the daily ice chart data. This figure indicates that a large portion of the ice cover is present in the form of small floes (< 100m in size) and brash ice accumulations. However, larger ice floes in the range of 500m to several kilometers size can also been found in the Gros Cacouna area, across all ice type categories. This point is illustrated by the air photo shown in Figure 5.17.

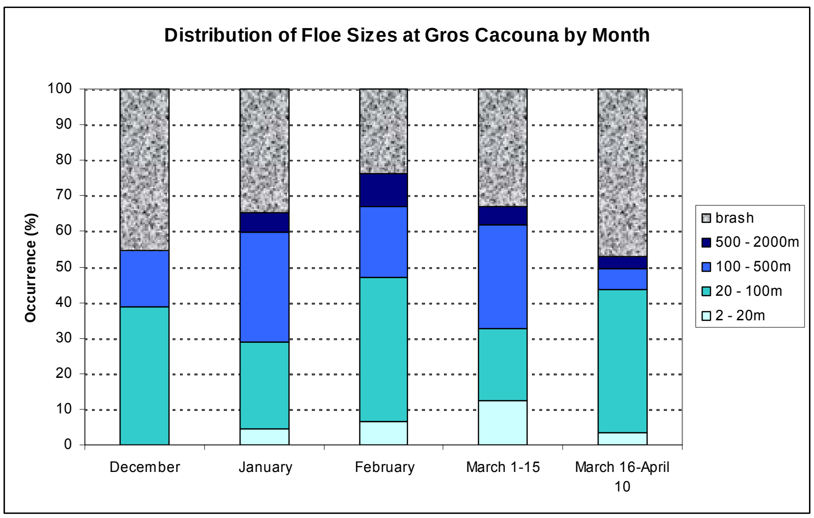

Figure 5.16: Relative occurrence of ice floe sizes, based on 7 years of daily ice chart data.

Figure 5.17: Air photo showing a wide range of floe sizes around the Gros Cacouna site.

5.4.3 *Ice Roughness*

There are a variety of ice roughness features in the ice cover that is found in the St. Lawrence River, including rafted ice, pressure ridges, rubbled ice areas, and brash ice accumulations. Although substantial ridges and rubble fields (some grounded) have been reported on the south side of the river (George Comfort, personal communication), there does not appear to be any well documented quantitative information available about them. A few photographs of surface ice conditions around the Gros Cacouna site were taken in the mid 1970s, which are reproduced in Figures 5.18 and 5.19 below. These photos provide a feel for surface ice roughness when the river's ice cover is compacted against the shoreline, but are likely not typical of the surface morphology of the ice floes (which are undoubtedly less rough) that normally drift across the terminal site.

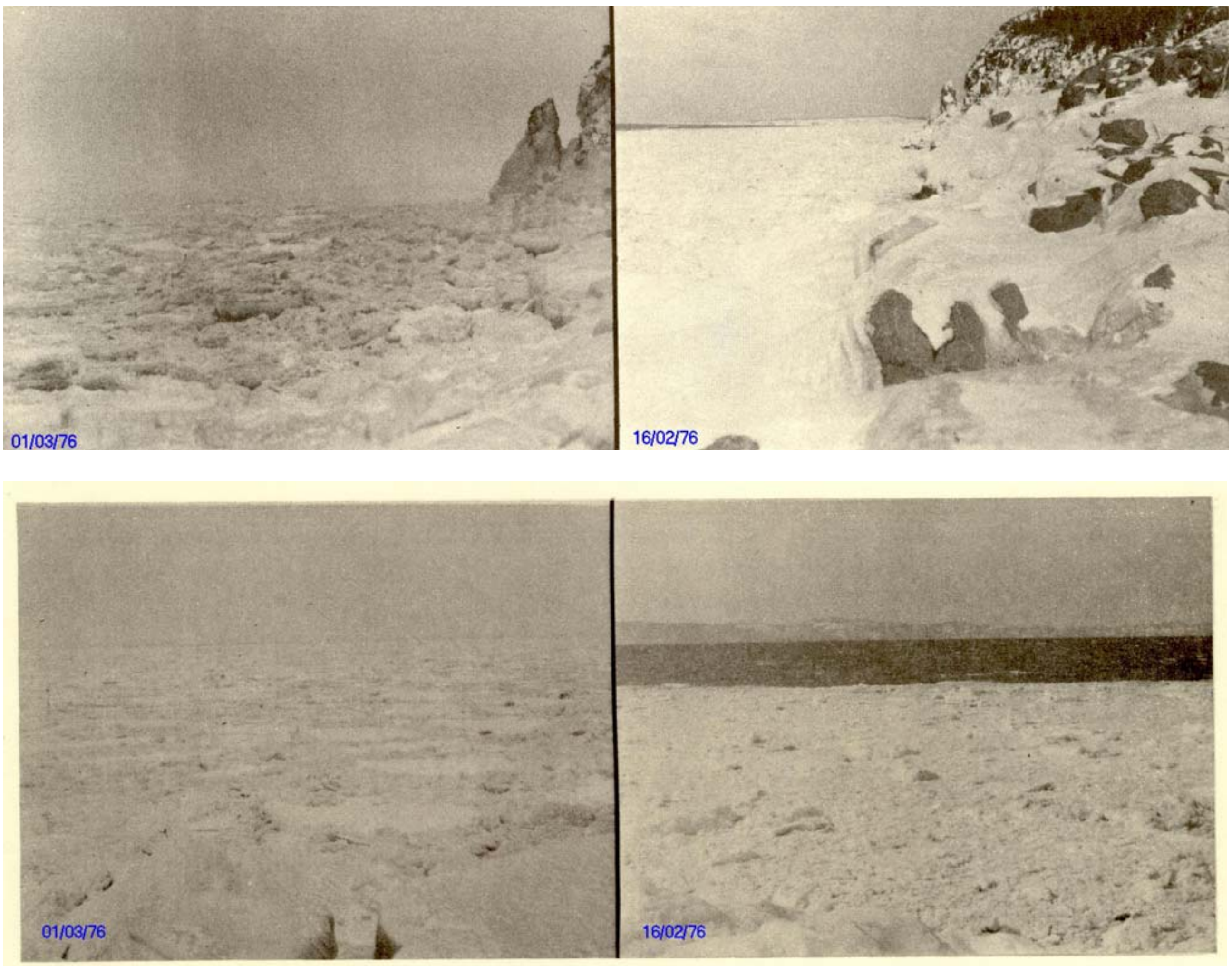

Figure 5.18: Representative photos of the surface of the ice cover at Gros Cacouna when it is pressed against the shoreline.

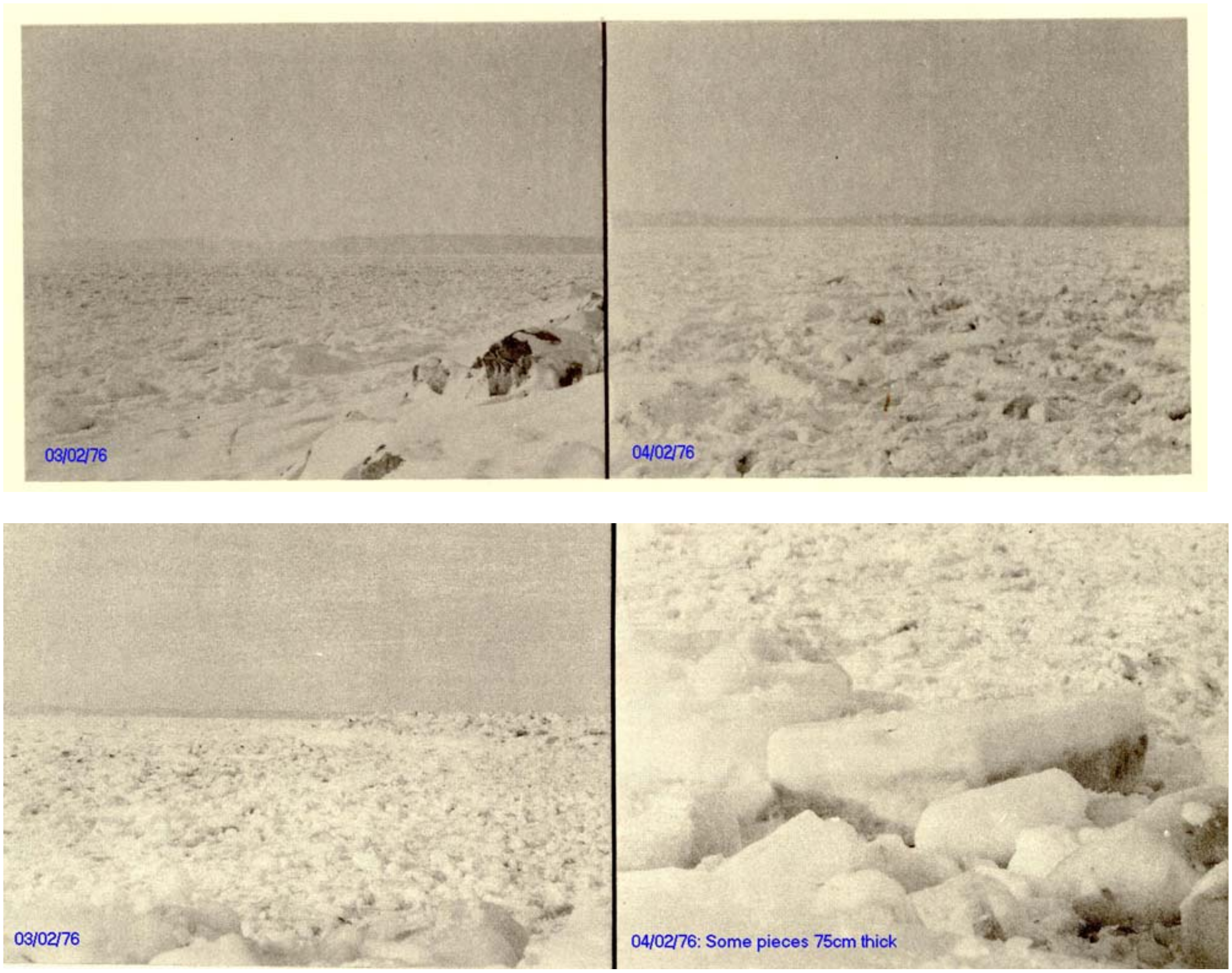

Figure 5.19: Additional photos of the ice cover at Gros Cacouna when it is pressed against the shoreline. Ice blocks up to 60 cm thick were reported in the lower right photo.

In the absence of any hard data, it is difficult to provide any substantive comments about the surface (and subsurface) roughness of the ice cover that may drift over the Gros Cacouna site. However, the following comments are given, largely based on past experience.

- Any ridges and rubbled ice that may drift over the terminal site should normally have a small sail height (likely less than a meter) and keel draft (likely less than 4 to 5m). Keel draft data collected further up the river (see Figure 4.12) tends to support this view.

- The ice that should be expected at the terminal site will normally be thin and smooth, except for cases in which the river's ice cover is pushed against the shoreline by winds and currents, and becomes heavily rubbled (see photos).

- On rare occasions, the degree of ridging near the entrance to the Gros Cacouna harbour is reported on the CIS St. Lawrence River ice charts. These observations are sporadic but suggest that the ice cover can be ridged over 20% to 40% of its surface area, when the ice is pressed against the shoreline.

5.5 Extreme Ice Features

Extreme ice features are of more importance in relation to calculations of design ice loads on the terminal structure, than for the marine operations that will be carried out at the terminal. In this section of the report, experienced based judgements about extreme ice features are given, since there does not appear to be any hard data available about them. Further information about extreme ice features should be acquired this winter as part of the field data acquisition programs highlighted in Section 4.3, and some ancillary winter visits that are being planned at the terminal site.

- *Thick level ice*
  - the 100 year maximum level ice thickness of 1.22m cited in Section 5.4.1, and detailed in Appendix 1, seems appropriate.
- *Thick rafted ice*
  - a rafted ice thickness of twice the maximum ice thickness, or about 2.5m should be expected.
  - however, this type of rafted ice thickness should only be seen over distance scales of a few meters, and are of little real relevance from both a design and operational point of view (for the LNG terminal and tanker vessels systems envisioned).
- *Ridges and rubble*
  - extreme ridges (see Figure 5.20) should be expected to have maximum keel depths of no more than 10m to 15m, which would correspond to a maximum sail height of about 3m (with an expected sail to keel ratio in the order of 1:4 to 1.5)
  - they should be no more than several tens of meters in width, with a mean keel slope angle of about 30˚.
  - rubbled ice areas will have lesser drafts, typically in the range of several meters, but may be wider in extent, up to a hundred meters (or more)
- *Consolidated layers*
  - ridges and rubbled ice areas will have a refrozen (or consolidated) layer at the waterline, which will often be thicker than the surrounding level ice thickness

- this consolidated layer in these features can be in the range of 1.5 to 2 times the surrounding level ice thickness, but should be weaker than the level ice
- the consolidated later of a large pressure ridge, plus the keel of such a feature, will likely govern design ice loads on the terminal structure

Figure 5.20: A photo of the sail of a pressure ridge. A consolidated layer forms between the rubble in the ridge's sail and its underwater keel as the result of refreezing.

- Ice Battures
  - these ice features are defined by the Canadian Ice Service as:

    "*large, thick, uneven and discolored floes often up to 8 km or more across. Form on the upstream side of shoals and islets in the St. Lawrence River when cold weather precedes or accompanies neap tides. They are composed of ice of different thicknesses formed under pressure during ebb tide, the whole mass freezing together, and gradually increasing in size with each successive tides. As the tidal range increases between the neaps and springs, large sections of ice break away and drift down the river."*
  - this description of ice battures appears to be more ominous than in reality. According to ice observers and CCG icebreaker captains that work on the St. Lawrence River (Roger Provost of CIS and Capt. Tremblay of CCG, personal communication), these ice batture features are only 1m to 2m in thickness.
  - They are also reported as being comprised of brash ice and rubble, and as such, are quite porous and weak. This is somewhat at odds with other anecdotal descriptions of battures, which suggest ice batture thicknesses of several meters (or more), and a composition of intact granular ice.

- Although they should be recognized, battures are likely a minor design ice feature, and of less importance for routine marine operations at the Gros Cacouna terminal site. Nevertheless, battures and their fragments are sometimes identified as features of note on the St. Lawrence River ice charts. An example of one of the charts that reports battures just to the east of the Gos Cacouna terminal site (past Isle Verte) is shown in Figure in Figure 5.21.

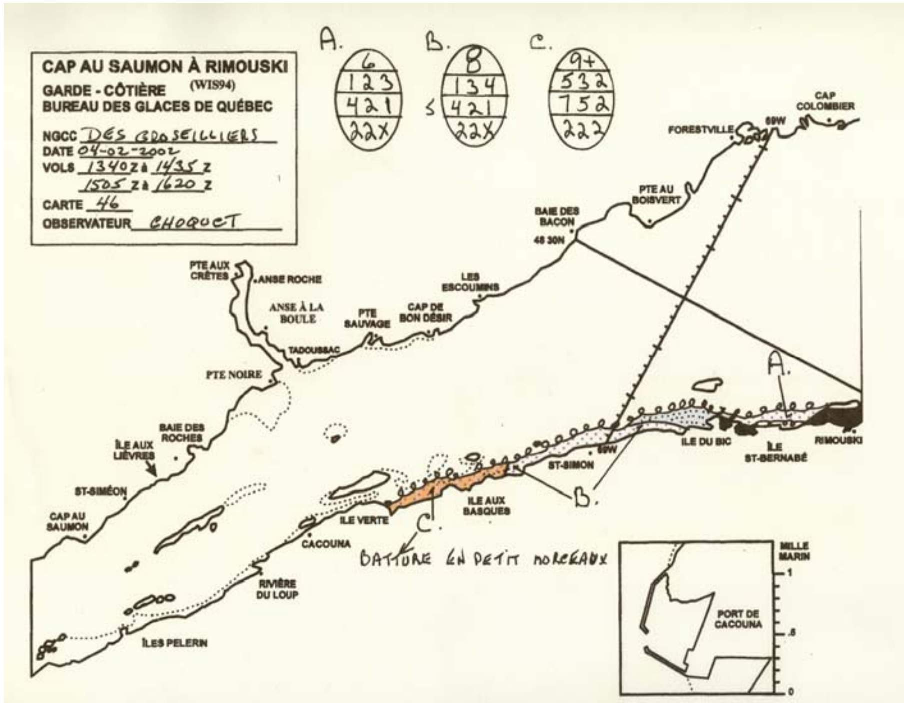

Figure 5.21: Small fragments of an ice batture drifting just to the east of the Gros Cacouna terminal site, as reported on a CIS river ice chart.

5.6 Ice Dynamics

Ice dynamics, including ice drift speeds, ice drift directions, and ice pressure events are all very important considerations in relation to marine operations at the Gros Cacouna terminal site, and for in-ice operability assessments. However, there seems to be very little data available about these aspects. A few comments about ice dynamics, based upon "snippets" of data and past experience are given as follows. Despite the paucity of data, a key point to note is that is ice movements can vary substantially over time scales of a few tens of minutes to several hours. This can bring different ice regimes that may be located either upstream or downstream of the terminal site over the location very quickly, and certainly within the time frame of a tanker approach, berthing, offloading and departure cycle. The ice management services provided by the support tugs will have to deal with these rapid changes in ice conditions that are associated with ice dynamics, on an as-required basis.

5.6.1 Ice Motions

- The only ice drift speed values that have been found for the area of interest are in a 1982 report (4 observations taken from sequential tracking of ice floes over time periods of 20 to 45 minutes on air photos). The values reported near the Gros Cacouna terminal site are 0.11, 0.64, 2.54 and 1.56 km/hour.
- The ice drift is primarily driven by tidal (and other) currents, and also by winds (at about 3% of wind speed).
- Drift speeds in the range of 0 to 2 knots should be expected, with higher extremes, likely up to 3 knots or slightly more.
- Ice drift directions will be primarily up and down the river, with two reversals every 12 (or so) hours, under the influence of the semi-diurnal tides.
- Cross river ice drift events that may pack ice tightly against the south shore of the St. Lawrence will also occur at times, under the influence of winds from the northerly quadrants.

5.6.2 Ice Pressure

- Ice pressure events will occur at the Gros Cacouna terminal site from time to time.
- The ingredients needed to create an ice pressure event include:
    - high ice concentrations
    - wind and current forces that pack the ice together and/or push it tightly against the coastline
- Ice modeling work is now being done by U of Quebec at Rimouski that should define the frequency, severity and duration of pressure events at the Gros Cacouna site.
- It is likely that heavy ice pressure events will only occur a few times per winter, and last anywhere from a few hours to a day or two.
- From an operational point of view, ice pressure events (and other ice factors such as concentrations and motions) should be predictable, and therefore can be anticipated and avoided.

6 Ice Conditions in the Gulf of St. Lawrence

Although it is not be main focus of this report, a few comments about ice conditions in the Gulf of St. Lawrence are given here, to provide some feel for range of conditions that LNG tankers will have to contend with during winter transits to and from the Gros Cacouna terminal site. Should more detailed information be required for various ice-related tanker design and in-ice transit considerations, it should be recognized that there is an extensive ice data base to draw upon, along with a broad experience base that has been developed through many years of shipping operations in the area.

6.1 Ice Coverage

6.1.1 Freeze-up

The typical time frame for first ice occurrence in the western portion of the Gulf of St. Lawrence, in the shipping lane into the river near the Gaspe Peninsula and Anticosti Island, is over early to mid January period. As noted earlier, this is several weeks later than typical ice freeze-up dates further to the west, in the St. Lawrence River. Figure 6.1 shows several types of ice cover distribution maps for the Gulf of St. Lawrence region on January 8th. These maps have been produced by the Canadian Ice Service as part of their "Ice Atlas for the East Coast of Canada", based on 30 years of data (1971 to 2000) from CIS's regional weekly ice charts. The following points should be noted about the information contained in this figure.

- Figure 6.1(a) shows the frequency of the presence of any ice in the Gulf on January 8th. It indicates that many areas of the Gulf will be ice free at this time, in most years. In the St. Lawrence River estuary and near the coast of the Bay de Chaleur, some ice is present in the majority the years. However, the area well east of the Gaspe Peninsula and to the southeast of Anticosti only experiences ice in 2 to 3 of 10 years.

- Figure 6.1(b) shows the median ice concentration in the Gulf area on January 8, based on 30 years of data. It indicates no ice (i.e.: a zero concentration value) in all areas of the Gulf, except for the river estuary and Bay de Chaleur. In these areas, moderate to high median ice concentration values (4 to 9/10^{ths}) are shown. These concentrations are also lower on the north shore of the St. Lawrence River estuary (and within the river) due to prevailing winds from the NW at this time.

- Figure 6.1(c) shows the median of predominant ice type when ice is present in the Gulf of St. Lawrence, on January 8th. It can be seen that, when ice is present, the median values indicated it will all be very thin along the transit route to Gros Cacouna (i.e.: new and grey ice types, which include ice < 10 cm thick).

Freeze-up in the Gulf of St. Lawrence continues throughout the month of January, with sea ice spreading over most of the region. However, ice thicknesses during this period rarely exceed the grey and grey white stages with new ice predominating along the lee side of land masses, particularly the north shore of the mainland, and south shores of Newfoundland and Anticosti.

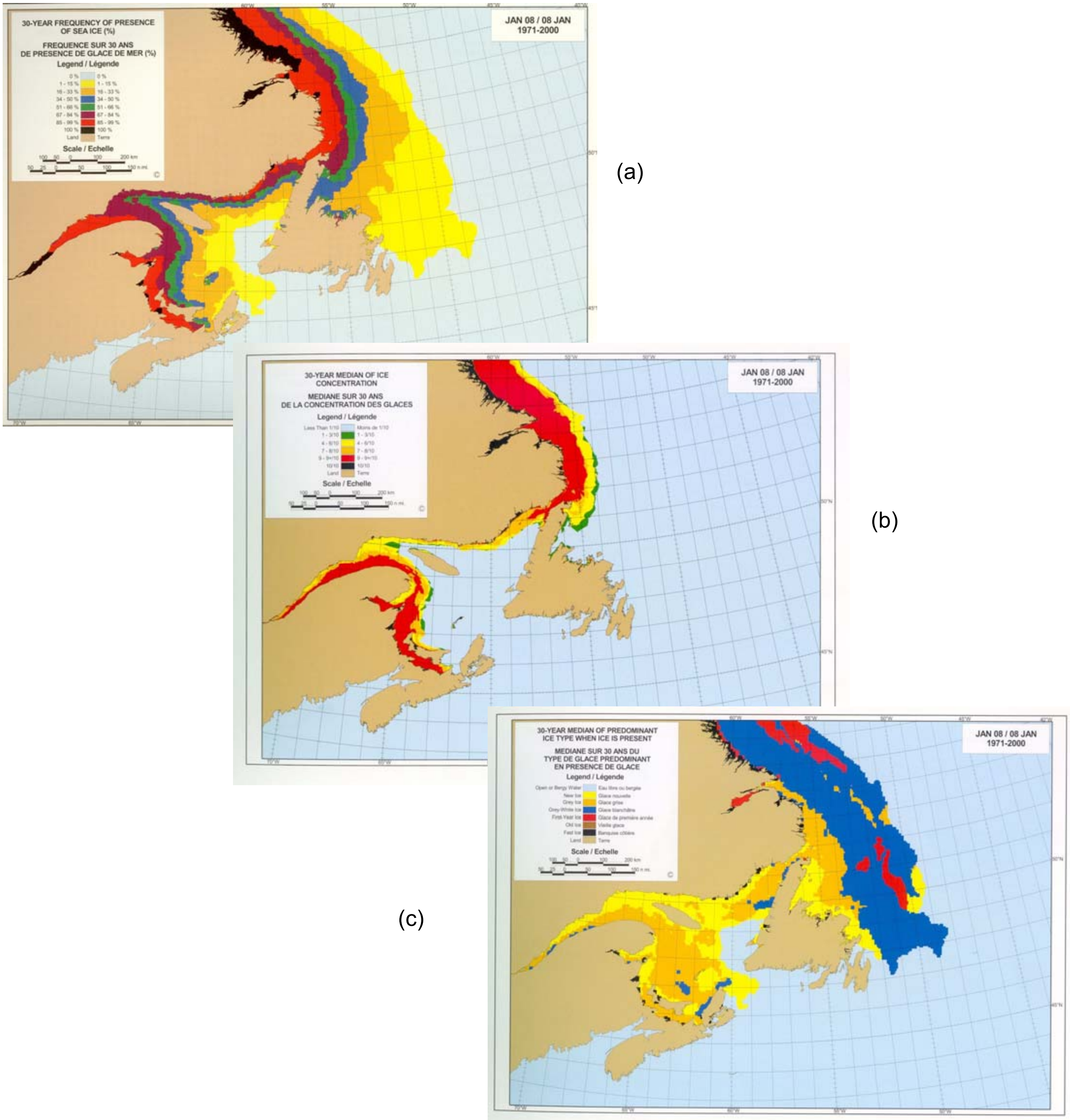

Figure 6.1: Regional ice distribution information for the Gulf of St. Lawrence on January 8th.

Figure 6.2 shows a NOAA image of typical ice conditions in the Gulf of St. Lawrence toward the end of the freeze-up period. This image (from Enfotec's website) is representative, and provides a visual feel for the typical distribution pattern of ice in the region around in the late January to early February time frame.

Figure 6.2: Typical distribution of sea ice in the Gulf of St. Lawrence towards the end of the freeze-up period, in the late January to early February time frame.

6.1.2 Mid Winter

The typical period of maximum ice extent in the Gulf of St. Lawrence is from mid February to mid March, with the ice progressively becoming thicker over this time frame, and into early April. Figure 6.3 shows the type of ice cover distribution maps that were provided in Section 6.1.1 for January 8th, but for February 19th in this case.

These CIS ice climatology maps illustrate the extent of the ice cover in the Gulf of St. Lawrence in mid February (see Figure 6.3), with ice typically reaching eastwards to the Cabot Strait at this time. As indicated by Figure 6.3(b), ice concentrations are normally high throughout the area, with median values of 9 to 9^{+}/10^{ths}. However, the predominant ice type in the region is still grey white (15 to 30 cm), as shown by the median values of predominant ice type given in Figure 6.3(c). The general extent of the ice cover and its typical concentrations do not change much over the next month or so, until the mid to late March period. However, the ice does continue to grow in thickness, with thin first year ice (30 to 70 cm) becoming the predominant ice type, and some area of medium (70 to 120 cm) (and occasionally thick first year ice > 1.2m) being seen.

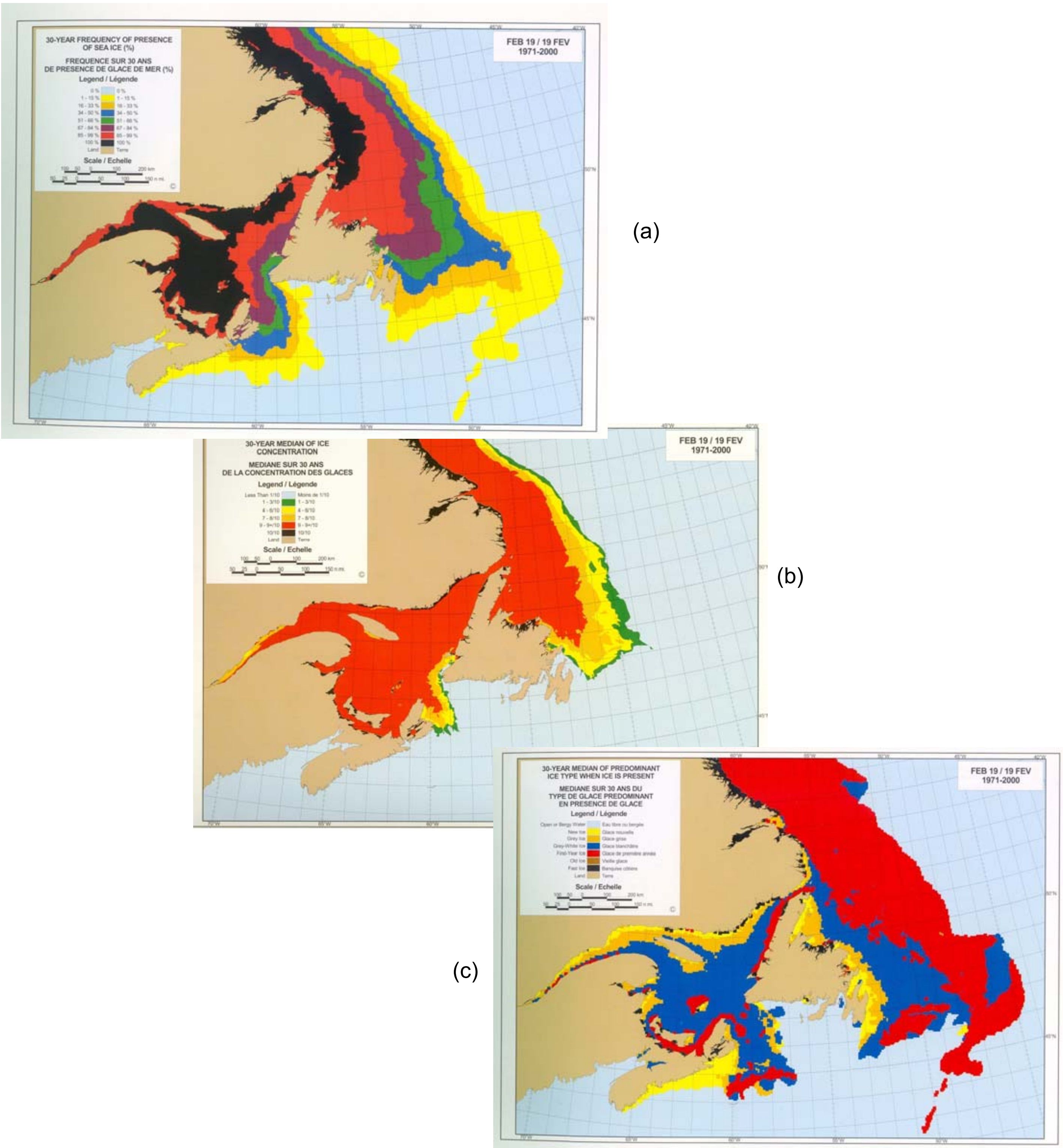

Figure 6.3: Regional ice distribution information for the Gulf February 19th.

Figure 6.3 shows a representative NOAA image of ice conditions in the Gulf of St. Lawrence in mid winter. This image, also from Enfotec's website, provides a typical view of the type of ice distribution pattern that should be expected in mid winter in a normal year. In a colder than average year, the ice edge can extend past the Cabot Strait years and southwards, occasionally reaching as far as Halifax and the Scotian Shelf. In warmer winters, the extent of the ice cover can be quite limited, extending no further east than the Magdalen Islands in the central Gulf.

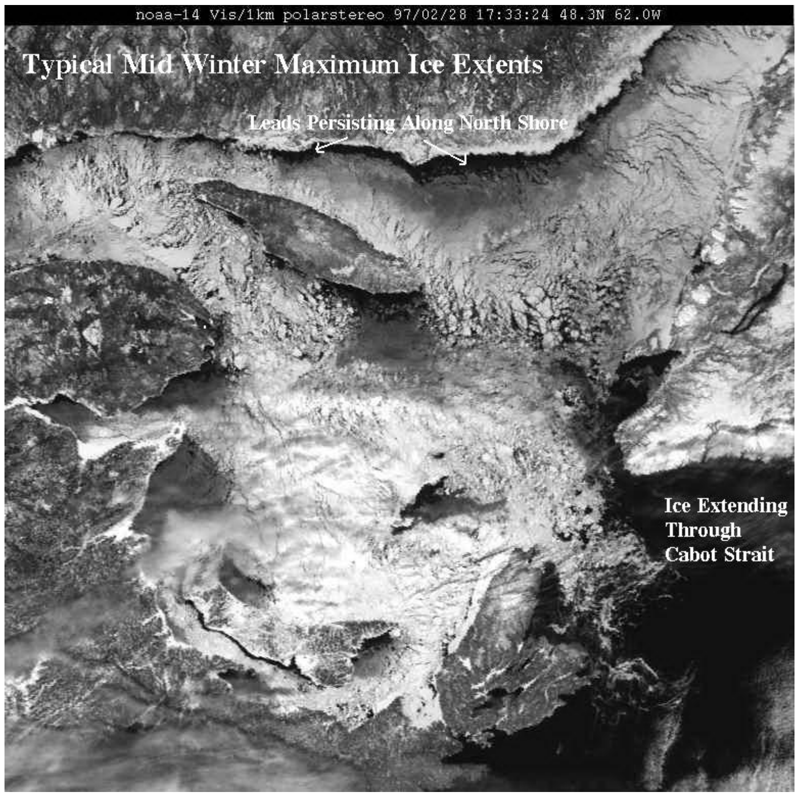

Figure 6.4: NOAA image of typical winter ice conditions in the Gulf, from February 28, 1997.

This image can be used to illustrate a couple of additional points.

- Ice floes from the St. Lawrence River are continually introduced into the waters of the Gulf as they drift down the river, and are swept towards the SW by the strong Gaspe current. Many of these floes are comprised of fresh water ice which is "harder" than the sea ice formed in the Gulf. Some ice battures can also drift into the Gulf area this way.

- The central and southern parts of the Gulf are often more ice-congested than the area's north and north central portions. Ship transits are usually routed through these northerly parts of the Gulf, where leads and open water areas are frequently seen along the SW coast of Newfoundland, the south shore of Anticosti and the north shore of the mainland.

- The thicker ice in the Gulf of St. Lawrence is generally found in the areas around the Magdalen Islands, around PEI and off the western coastline of Cape Breton. Here ridges and ice pressure events are very common.

- The thinner ice in the Gulf is generally seen along the south facing shorelines of its north coast and Anticosti Island, as noted above. Although this northerly part of the Gulf is the is the preferred shipping channel to the St. Lawrence River in winter, thick ice, pressure ridges and ice pressure event can also be encountered in this more northerly region, due to changing winds and ice dynamics in the area.

6.1.3 Break-up

The ice cover in the Gulf of St. Lawrence begins to break-up and retreat in terms of its overall extent in the mid to late March period. The onset of the ice break-up process in the region is first seen in the St. Lawrence River and the river estuary, where loose ice and open water areas begin to occur. By the end of March, large expanses of open water are generally found in the western and central portions of the Gulf, with heavier ice conditions persisting in the more southerly part of the region that are bounded by Cape Breton, PEI and the Magdalen Islands. At this time, higher ice concentrations also tend to remain in the Strait of Belle Isle which lies to the west of Newfoundland. A representative view of ice conditions mid way through the break-up process is illustrated by the NOAA image that is provided in Figure 6.5. The CIS ice distribution maps in Figure 6.6 for April 2nd give further information about ice break-up conditions. By mid to late April, any remnant ice that may remain in the Gulf is usually well clear of the main shipping lane to the St. Lawrence River.

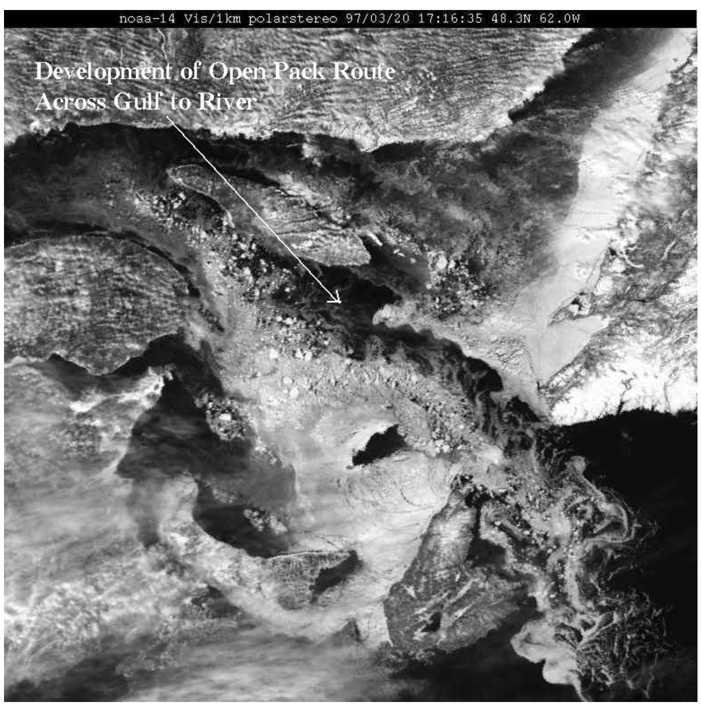

Figure 6.5: NOAA image of the mid stage of break-up in the Gulf, from March 20, 1997.

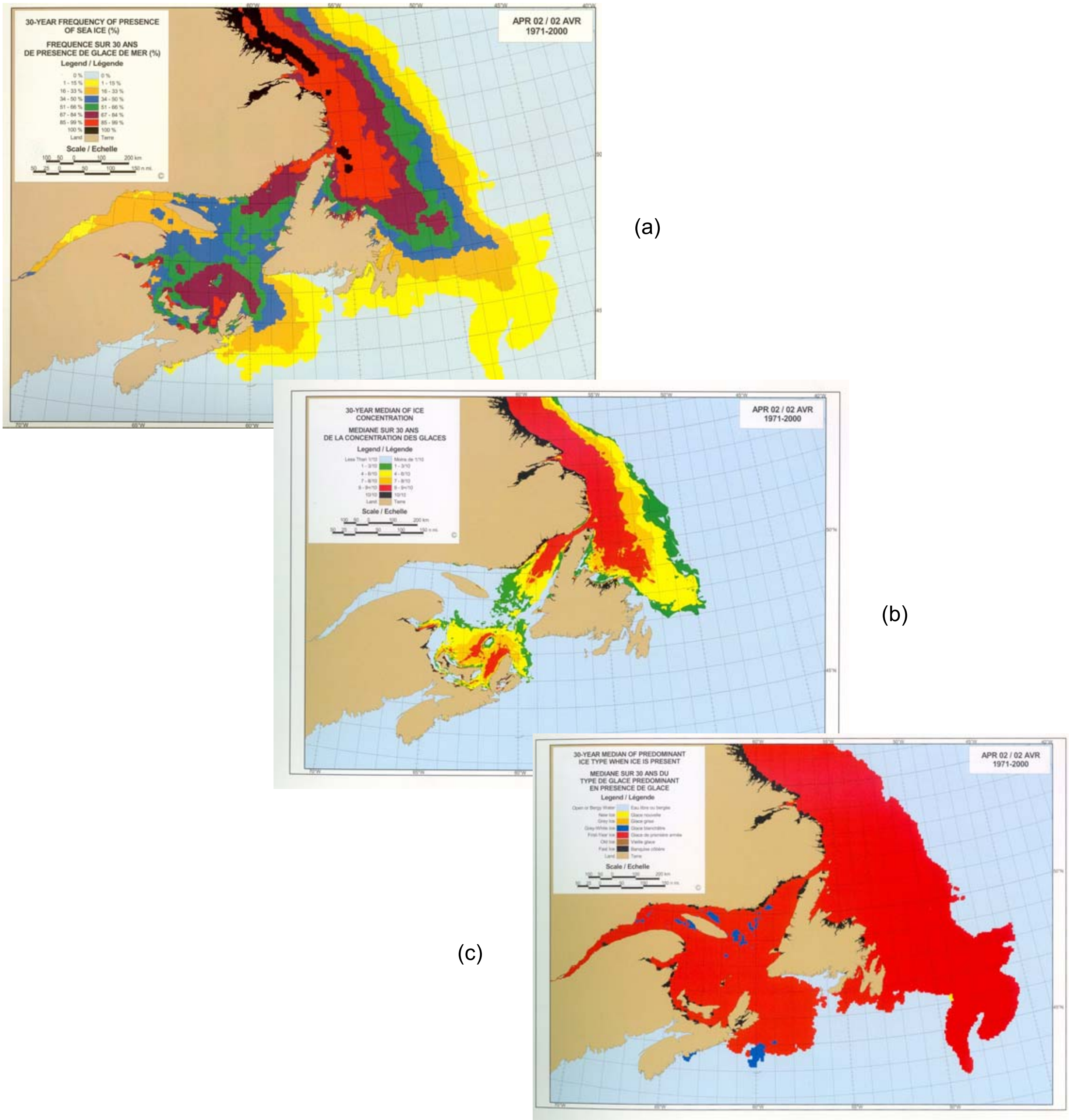

Figure 6.6: Regional ice distribution information for the Gulf of St. Lawrence on April 2nd.

6.2 Ice Characteristics

Details about the ice characteristics that can be found in the Gulf of St. Lawrence are not provided here. However, a few summary points are briefly highlighted as follows.

- Ice concentrations in the Gulf are generally quite high, in the range of 7/10^{ths} to 9/10^{ths}, but can be quite variable over relatively short distances (tens of kilometres). Open water leads are often frequent along the north central shipping lane through the Gulf of St. Lawrence, particularly when winds are from the NW.

- Ice thicknesses are typically quite variable in the Gulf, with predominant ice types being in the thin first year ice category (30 cm to 70 cm) in winter, as outlined in Section 6.1. However, thicker level ice floes together with rafted, ridged and rubbled ice areas can be encountered on any ship transit, resulting in considerably thicker ice encounters (mean ice thicknesses of a meter or more) over some portions of the route.

- Floe sizes in the Gulf are also variable, but will typically be much larger than those seen at the Gros Cacouna terminal site. Mean floe sizes that are in the order of several km are not unreasonable to expect in mid winter, with slightly smaller floe sizes being more common during the freeze-up and break-up periods.

- The frequency of pressure ridges that will be encountered in the Gulf will normally not be high, in the range of several ridges per kilometre. However, more heavily ridged and rubbled areas will also be encountered at times. Most of these ridges will be relatively small, with sail heights of less than a meter and keels in the order of 4m to 5m in depth. However, more sizable ridges will be encountered on occasion, with sail heights of several meters and keel depths in the 10m to 15m range. Extensive areas of rubbled ice many kilometres in extent should be rare along the main shipping route, unless a voyage is exposed to a severe and sustained ice pressure event (or its aftermath).

- Small icebergs, bergy bits, growlers and old ice fragments sometimes drift into the area to the north of Anticosti Island during the late winter and break-up periods, through the Strait of Belle Isle. However, their occurrences are rare and they are usually detected, and noted as “hazards to avoid” for any ships that may be operating in the area.

- Figures 6.7 and 6.8 have been included with this text, to provide the reader with a visual feel for the type of ice conditions that should be expected in the Gulf of St. Lawrence in winter.

- The photo shown in Figure 6.7 is representative of the range of fairly smooth and relatively thin ice conditions that will normally be encountered during vessel transits. Figure 6.8 is representative of the type of rougher and thicker ice areas that may sometimes be encountered on a transit voyage through the Gulf.

Figure 6.7: Typical winter ice conditions in the Gulf of St. Lawrence.

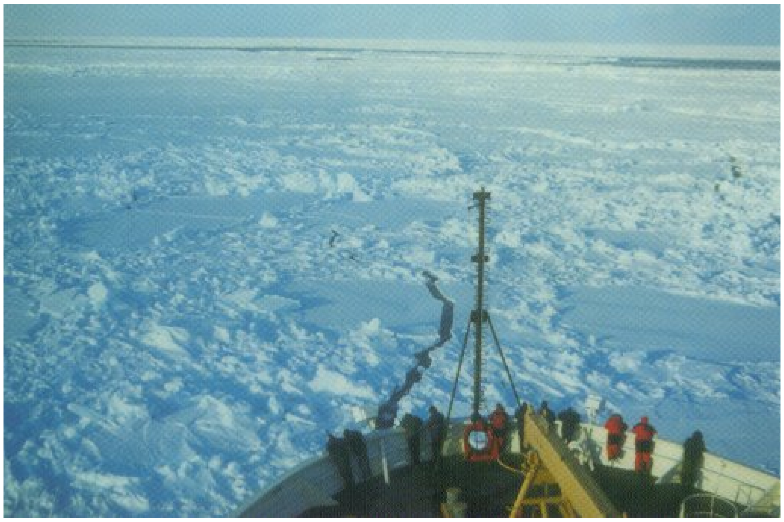

Figure 6.8: Rougher pack ice conditions that will sometimes be encountered in the Gulf.

6.3 Ice Dynamics

Details about the range of ice dynamics that are experienced in the Gulf of St. Lawrence are not outlined here. However, some brief summary points are highlighted as follows. Should further information about specific ice conditions or dynamics be required for tanker transit evaluations, data on various ice parameters (concentrations, ice types, drift speeds and directions, pressure events, etc.) are available in digital form from the University of Quebec at Rimouski from 1996 to present. This information has been developed from a combination of observations and numerical modelling work, and can be made available on a day by day basis at 5 km x 5 km grid points throughout the Gulf of St. Lawrence.

- Ice motions in the Gulf of St. Lawrence are caused by winds, currents and tides, and show significant variations in space and time. The prevailing ice drift direction in the main shipping lane from Cabot Strait to the St. Lawrence River is from west to east, but ice movements in any direction can be seen at any time, depending on wind direction.

- Ice drift speeds in most parts of the Gulf are in the range of 0.5 knots to 1 knot, which is considerably slower than typical ice drift speeds in the St. Lawrence River. However, there are areas in the Gulf where ice drift speeds are generally higher, for example, to the E and SE of the Gaspe Peninsula and in the Northumberland Strait, where strong currents and tidal influences (respectively) can drive the pack ice at considerably higher speeds. During storms with strong winds, higher drift speeds can also be experienced.

- Ice pressure events that can slow or stop vessel transits for time periods of a few hours to a day (or more) are also experienced in the Gulf of St. Lawrence. Although they are more common in the southern portion of the Gulf, away from the main shipping lane, ice pressure events are also seen in the north central part of the Gulf, particularly when winds from the southerly quadrants push the ice cover against Anticosti Island. In these situations, vessels are often routed to the north of Anticosti, where thin ice conditions are usually present on the island’s lee side (under these wind conditions).

- In order for significant ice pressure events to occur, a near continuous pack ice cover (i.e.: high ice concentrations) is required, along with ice types that for the most part, are thicker than the new, grey and grey white ice stage categories. Because of this, ice pressure event are less frequent during the freeze-up and break-up periods than in mid winter, when this prerequisite mix of ice conditions is usually met.

- Although it is not related to ice dynamics, marine icing is another factor that is important to mention here. In this regard, there may be leads and open water areas in the ice cover that permit high vessel transit speeds, but in low air temperatures, sea spray that is generated by these speeds can quickly to significant icing (see example in Figure 6.9).

Figure 6.9: Marine icing is common in the Gulf of St. Lawrence and is a factor that can limit vessel transit speeds in light ice conditions, when air temperatures are low.

7 Closure

This report has provided a summary of ice conditions that are relevant for the design and operation of the LNG terminal at Gros Cacouna, and for LNG tanker transit operations through the Gulf of St. Lawrence. The main focus of the report has been placed on site-specific ice conditions at the Gros Cacouna location, for use in various ice-related LNG terminal design and operability assessments. However, a brief description of ice conditions in the Gulf of St. Lawrence has also been provided, as background for various tanker transit considerations.

This summary has been based upon a review and analysis of existing ice information. The ice data sources that are currently available for the area of interest are varied, in terms of the ice parameters they describe, as well as their resolution they provide in space and time. Because of this, the nature of these ice data sources has been described in some detail.

The level of information about site-specific ice parameter details at the Gros Cacouna terminal site, which will be required for in-depth design and operability assessments, is presently limited. As such, the information that has been presented in this report should be recognized as being a preliminary summary. New ice data acquisition programs are planned for the upcoming winter that should improve the current ice data base for the Gros Cacouna terminal site. These studies have also been highlighted in this report.

In contrast, a broad range of relatively detailed ice information is now available for the Gulf of St. Lawrence region, plus an extensive experience base from past shipping operations in the area. This type of information about ice conditions in the Gulf has only been briefly highlighted in the report, but can be accessed should more specific details be required for various tanker design and in-ice transit considerations.

Sandwell

Appendix 1

Ice Thickness Analysis

by

P. Spencer

Sandwell Engineering

Introduction

This review is based upon the analysis of weather and ice thickness records for selected sites in the Gulf of St. Lawrence and the St. Lawrence Seaway. The thickness and coverage of the first year ice is needed for LNG service planning, primarily for the calculation of the design force for the terminal piers, etc. at Gros-Cacouna.

Ice thickness data are available from a number of sources. Some are directly applicable and some require interpretation and analysis. The Canadian Ice Service provides historical daily and weekly ice charts for the Gulf of St Lawrence. These charts use data from aircraft over-flights and satellite remote sensing. They are not the result of direct thickness measurements although the Canadian Ice Service has expended effort to calibrate the charts against ground truth data. The data on these charts quantify the ice thickness, but only in broad ice type ranges.

The Canadian Ice Service has also maintained a number of ice thickness measurement stations. These stations cover a limited number of sites and years. Most stations ceased operation by 2002 but a small number of sites resumed operation to provide data for climate change studies. Unfortunately for the present study, all of the stations that resumed operation in 2002 are located in the Arctic regions of Canada north of 60°N.

Approach

These measured ice thickness data are used together with weather data to estimate, for example, the 100-year return period maximum level ice thickness. This process is described as follows.

- The data from a particular ice measurement station is retrieved. The ice thickness and date when the measurements were taken are used. The Environment Canada database is searched for a closely located weather station.

- The close weather station data is retrieved and a Freezing Degree Day (FDD) index is calculated for the days on which the ice thickness measurements were taken. The ice thickness data are plotted as function of FDD.

- Various models for predicting the ice thickness as a function of FDD are compared with the data.

- The most appropriate model is selected. The Environment Canada database is then used to predict 100-year FDD index for the region for which the 100-year ice thickness is required.

The results of the analysis are illustrated below for selected sites.

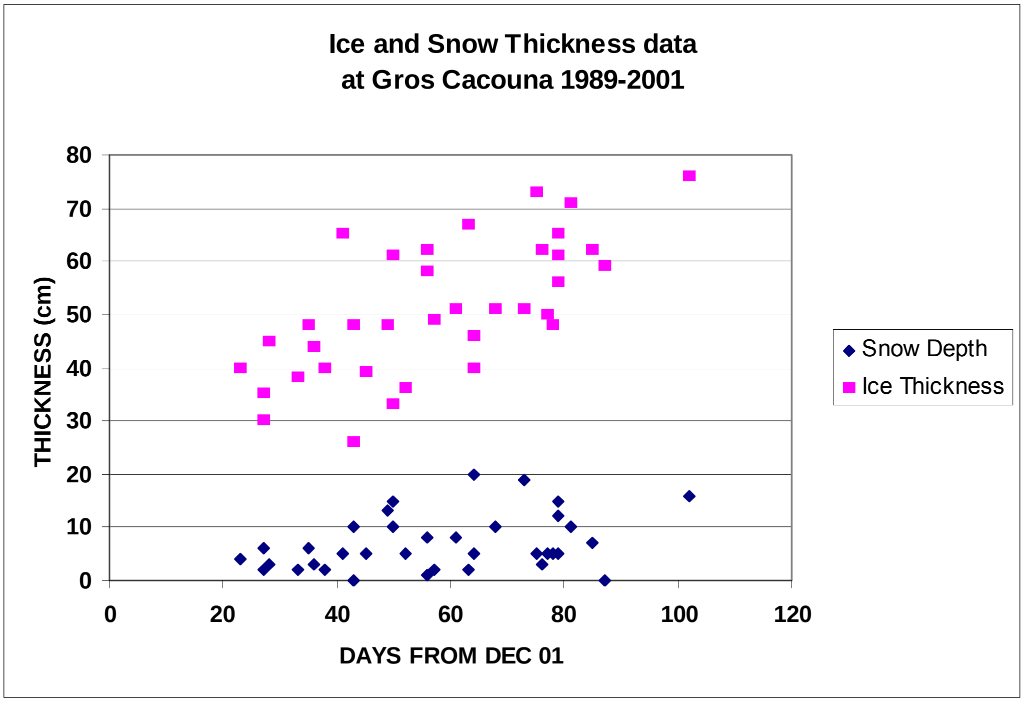

Figure 2 - Gros-Cacouna Ice and Snow Thickness

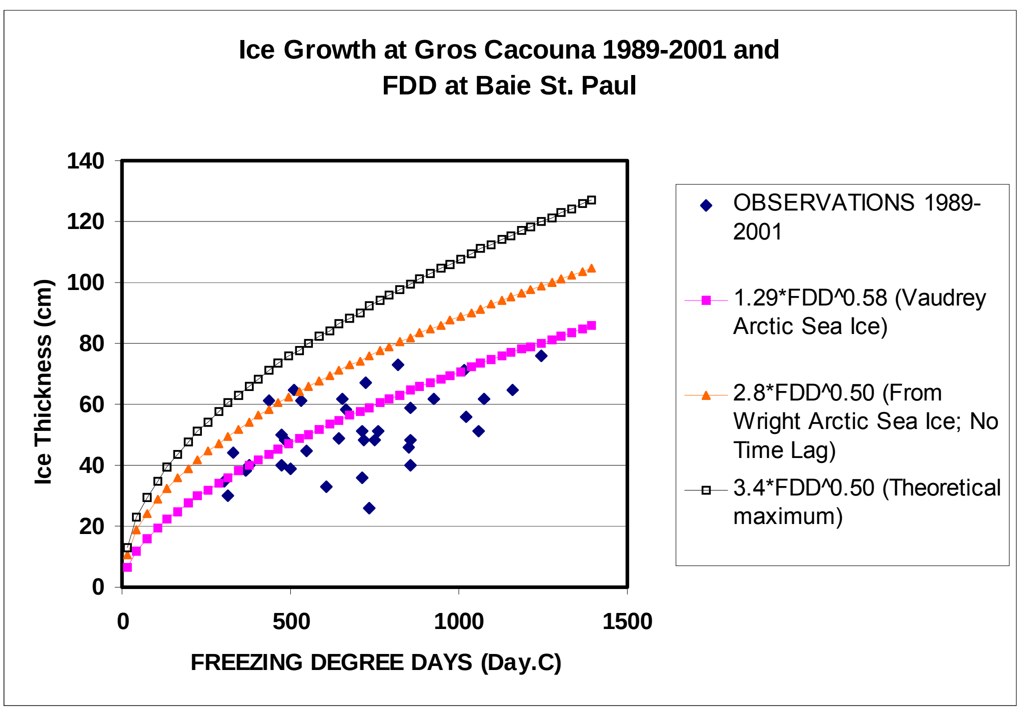

Figure 3 - Gros-Cacouna Ice Thickness Versus FDD for Baie St. Paul

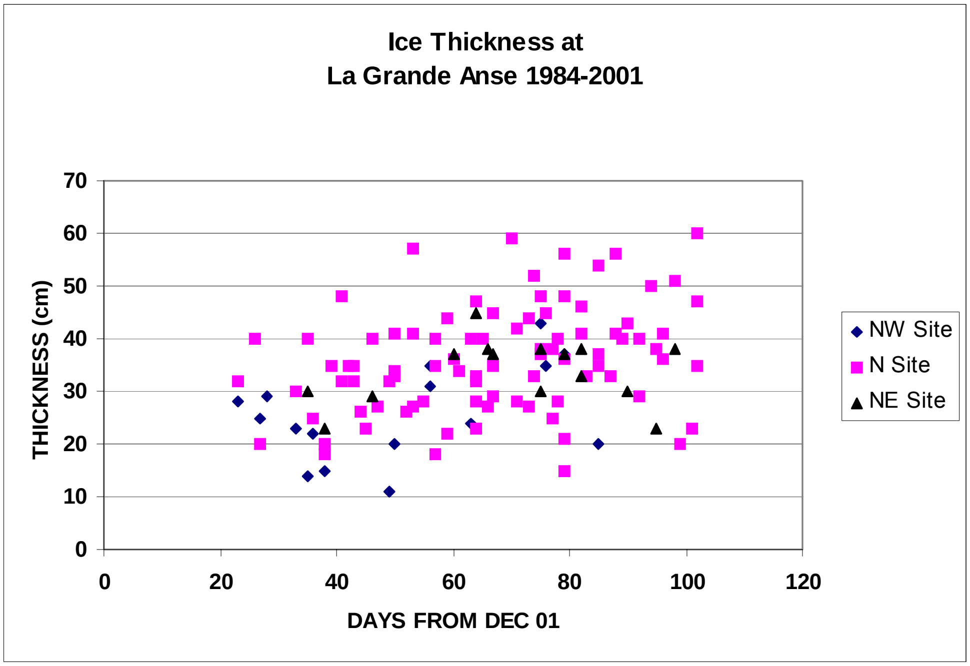

Figure 4 - La Grand Anse - Ice Thickness

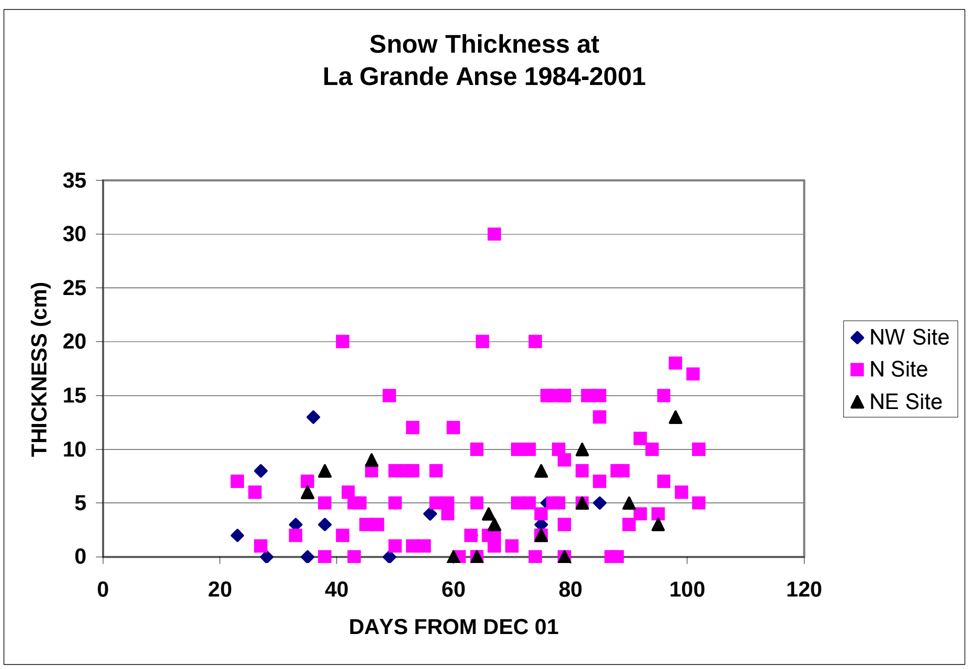

Figure 5 - La Grande Anse Snow Cover Thickness

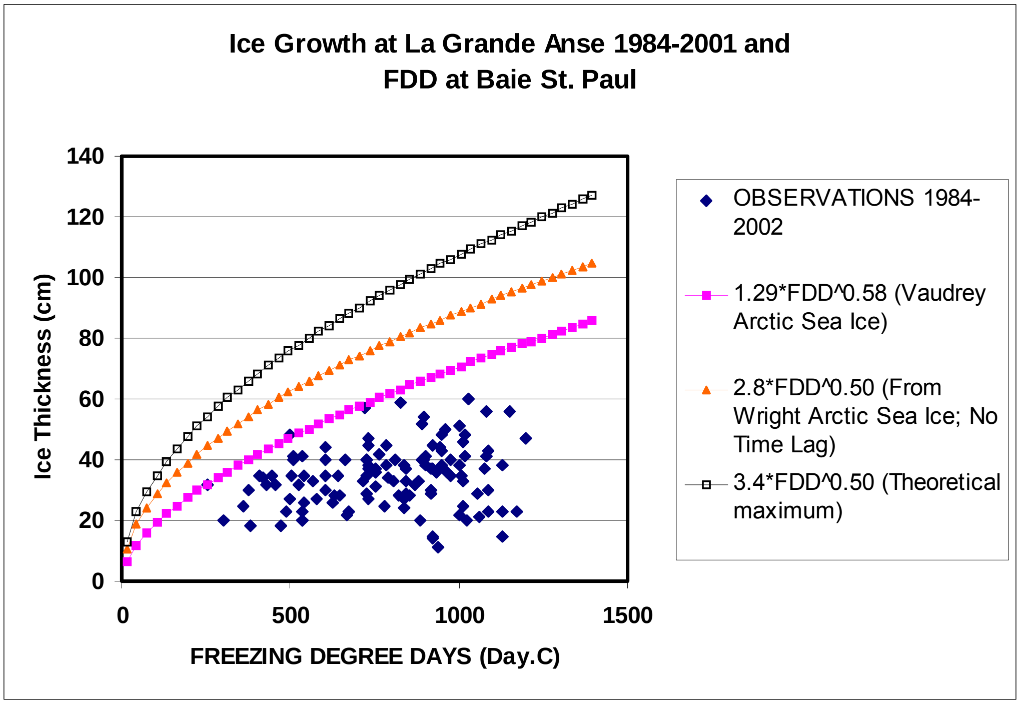

Figure 6 - La Grande Anse Ice Thickness Versus FDD for Baie St. Paul

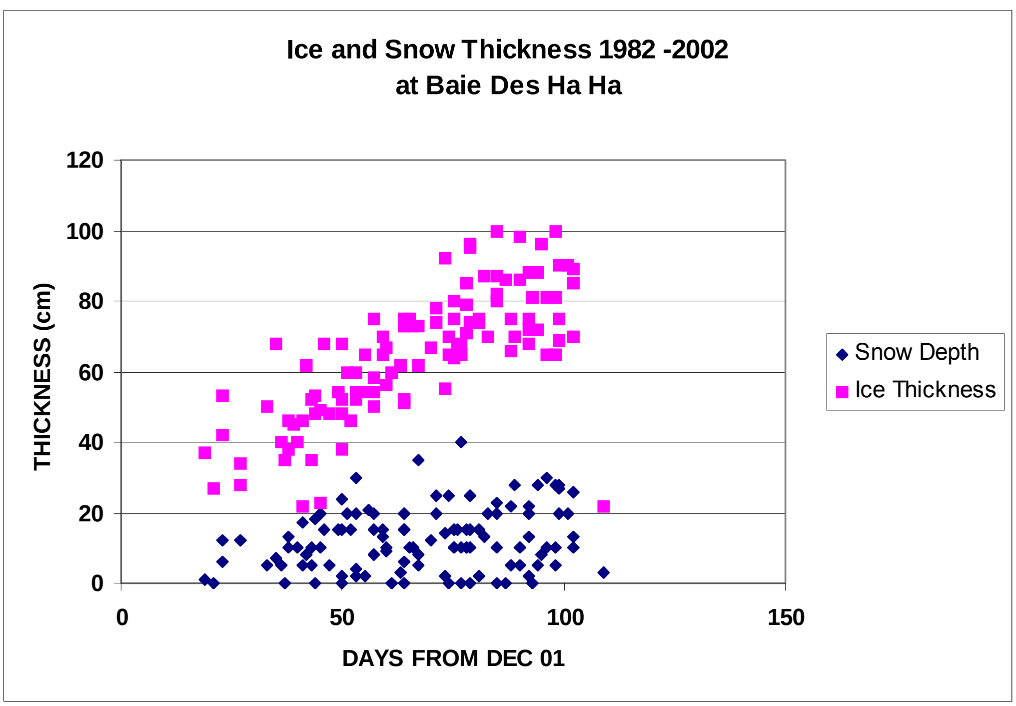

Figure 7 - Baie Des Ha Ha Ice and Snow Cover Thickness

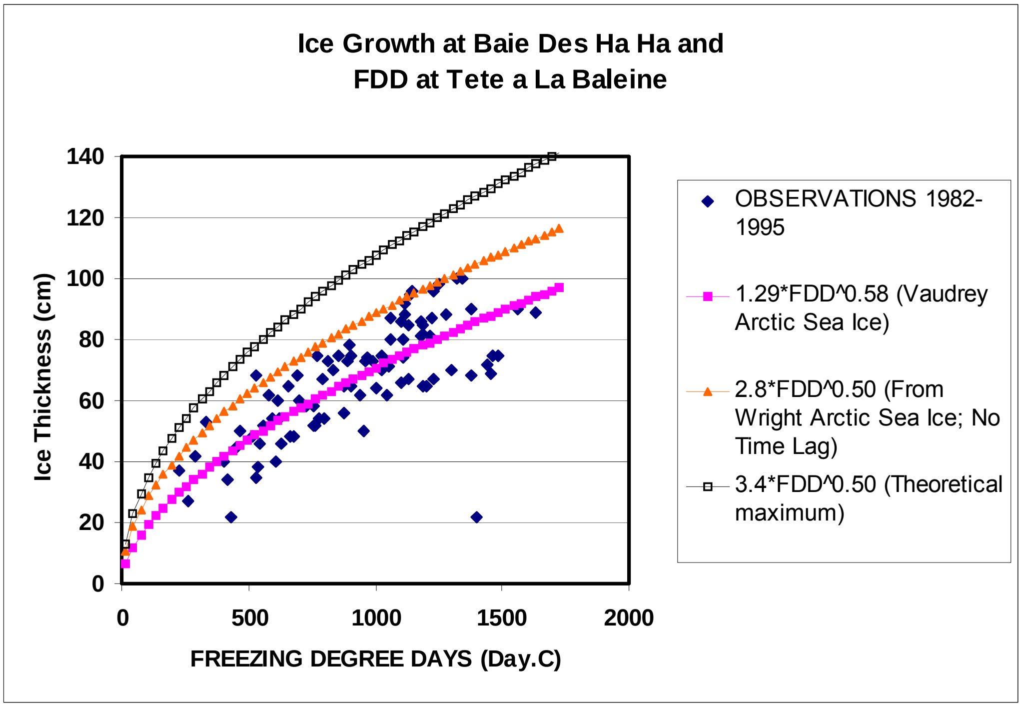

Figure 8 - Baie Des Ha Ha Ice Thickness Versus FDD for Tete a la Baleine

For the data sets presented, the Vaudrey expression is a reasonable fit through the data. Note however that in these formulae, the depth of the snow cover is not explicitly included. The actual ice thickness will be affected by the amount of snow cover. For the purpose of estimating the maximum thickness of the ice sheet the Wright formula is more appropriate. The theoretical maximum ice growth is for the case of zero snow cover and the upper ice surface has the same temperature as the ambient air. The reason for the lower ice thickness at La Grande Anse compared with Gros-Cacouna and Baie des Ha Ha is not known. The data from Baie Des Ha Ha is from the north shore of the St Lawrence further east than Gros-Cacouna and is included to investigate the ice growth in colder areas that may be representative of the extreme ice growth conditions.

The 100-year or other return period FDD is determined using a Gumbel extrapolation that uses the mean and the standard deviation of the annual FDD.

$$\text{Gumbel}(\text{Data}, \text{Years}) := \text{mean}(\text{Data}) - \frac{\sqrt{6}}{\pi} \cdot \left(0.5772156649 + \ln\left(\ln\left(\frac{\text{Years}}{\text{Years} - 1} \right) \right) \right) \cdot \text{stdev}(\text{Data})$$

The ice thickness h as a function of FDD is given by:

$$h = 2.8 \times (FDD)^{0.5}$$

Where

h ice thickness (cm)

FDD freezing degree day index (day.°C below 0C

The Environment Canada database was used to obtain weather data for station locations in the Gulf of St Lawrence from which the mean and standard deviation of the winter FDD were calculated. The data in Table 1 were calculated from daily mean temperature at the stations indicated. The period of the data was the winters starting in 1968 to 1993 as this period had all listed stations recording. This same data along with some complimentary values from West Dock Prudhoe Bay Alaska is shown in Figure 9.

Table 1: FDD Data for St Lawrence and Newfoundland Stations

Location	Latitude (deg N)	Longitude (deg W)	FDD Mean (day.°C)	FDD StdDev (day.°C)
Baie St Paul	47.417	70.500	1195	117
Ile aux Coudres	47.383	70.383	1095	120
Rimouski	48.450	68.517	1145	120
Tete a la Baleine	50.700	59.317	1434	254
Ste Anne des Monts	49.133	66.467	1158	139
Cap Madeleine	49.780	65.317	1418	249
Stephenville A	48.533	58.550	714	178
Port aux Basques	47.567	59.150	572	145
Cartwright	53.700	57.033	1679	301
Plum Point	51.067	56.883	1092	236
Corner Brook	48.950	57.950	683	180
Nain	56.550	61.683	2229	309

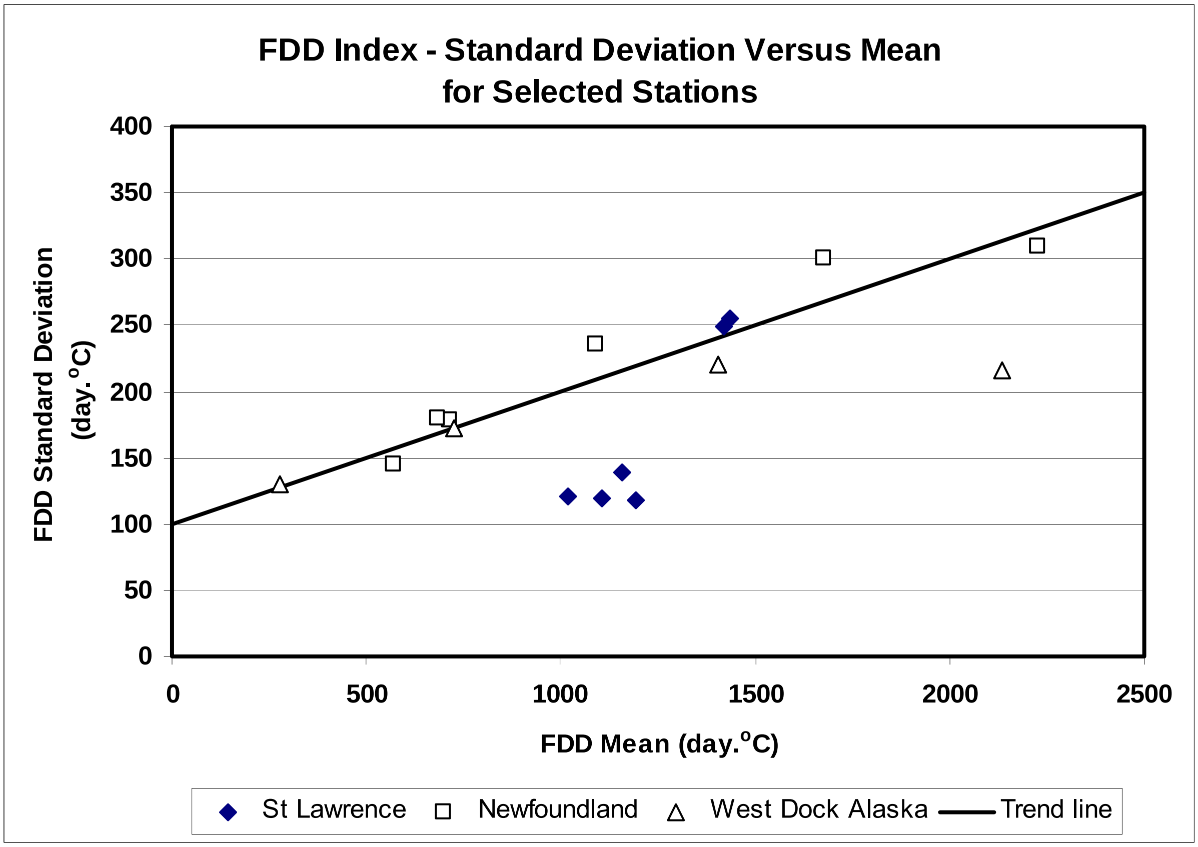

Figure 9 - FDD Index - Standard Deviation Versus Mean

Further inspection of the data on the standard deviation of the FDD indicated that small changes in the selection of years that were included in the St Lawrence data set had large changes in the standard deviation. Thus the low values of the standard deviation of the FDD may be anomalous. The trend line for the standard deviation of the FDD is given in terms of the mean FDD by:

$$FDD\_std = 100 + FDD\_mean/10$$

Summary of Extreme Level Ice Thickness Data

For ice that has formed in the region of the Gros-Cacouna terminal, climate data for Baie St Paul is appropriate. For ice that forms in the colder regions of the Gulf of St Lawrence climate data from Tete a la Baleine is appropriate. The Gumbel extrapolation has used to determine the 100-year return period FDD. The Wright formula is recommended for calculating the maximum level ice thickness from the FDD.

These data are summarized in Table 2.

Table 2: Recommended Extreme Ice Thickness

Location	FDD Mean (day.^{o}C)	FDD StdDev (day.^{o}C)	100-Year FDD (day.^{o}C)	100-Year Ice Thickness (cm)
Gros-Cacouna	1195	220	1885	122
North Shore	1434	243	2196	131