Rabaska

RABASKA PROJECT

CONSTRUCTION OF A LNG TERMINAL ON THE SAINT LAWRENCE RIVER
DETAILED ASSESSMENT OF CLIMATIC CONDITIONS AT PROPOSED SITES

FINAL REPORT

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1. MANDATE

1.1 INTRODUCTION

A pre-feasibility study was conducted by Roche Ltd, Consulting Group, in 2003 to develop a LNG maritime terminal on the south shore of the Saint Lawrence River. Three potential project sites were then proposed by the Rabaska project proponents, Gaz Metro / Enbridge / Gaz de France (Figure 1.1):

- Lévis-Beaumont, located about 10 km east and across the river from Quebec City, in front of Île d'Orléans. The site is situated within the limits of the port of Quebec City;

  Note: The name of this site was changed from Ville Guay to Lévis-Beaumont shortly after completion of this pre-feasibility study.

- Pointe Saint-Denis, located near the municipality of Rivière-Ouelle, approximately 120 km north east of Quebec City;

- Gros Cacouna, a small village located some 15 km east of the city of Rivière-du-Loup, at 220 km north east of Quebec City.

The geographic coordinates of the three sites are indicated in the following table:

Site	**Latitude**	**Longitude**
Lévis-Beaumont (Ville Guay)	N 46° 50.2′	W 71° 06.5′
Pointe Saint-Denis	N 47° 35′	W 69° 58′
Gros Cacouna	N 47° 58′	W 69° 32′

On the basis of this preliminary technical assessment, the project proponents decided to develop a LNG receiving terminal in the Lévis - Beaumont area.

The current study is complementary to the pre-feasibility report. It is still part of the project site selection process. It aims at documenting the conclusions reached in the pre-feasibility analysis by defining with more accuracy the climatic and hydrodynamic conditions encountered at the proposed sites, particularly Lévis-Beaumont and Gros Cacouna.

1.2 PRE-FEASIBILITY STUDY

The 2003 Roche pre-feasibility report presented a description of the various climatic and hydrodynamic conditions (wind, wave, tidal current, ice and visibility) with a view to defining navigation conditions to be faced by LNG carrier ships.

It was then concluded that the Lévis-Beaumont area would offer easier and more favourable conditions than the Gros Cacouna site considering the various operational rules generally applied by the LNG industry worldwide. The third site considered in the study, Pointe-Saint-Denis, was rejected for technical and environmental reasons.

Although Gros Cacouna was not rejected as a potential site, one of its main drawbacks was its potential for occasional difficult navigation conditions. The following points drawn from the pre-feasibility report summarize the comparative analysis between Lévis-Beaumont and Gros Cacouna:

- based on a statistical assessment of wind data recorded at the Île Rouge weather station, located some 16 km offshore from Gros Cacouna, over a period of 16 years (1988-2003), it was concluded that wind would exceed a 25 kn operational limit established by the project proponent about 7,7 % of the time on a yearly basis; during the winter season, this limit is exceeded 16% of the time. Assuming one ship call per week at the LNG terminal (= 1 arrival + 1 departure, considered as two statistically independent events), this wind frequency would mean that berthing/unberthing manoeuvres would have to be interrupted or delayed about 8 times per year;

- the ice conditions were also taken into consideration in the analysis. From comments obtained in the course of an ice study conducted prior to the pre-feasibility study (Paul Croteau and Associates, 2003), it was understood that a northerly or west-northerly wind could cause ice to remain packed along the south shore of the river for some time, thus having a negative impact on navigation conditions in the Gros Cacouna port sector. In the absence of accurate or well documented data on this issue, the approach taken in the pre-feasibility analysis consisted of relating this behaviour to the cumulative frequency of the winds incoming from the N and NW directions during the months of January, February and March. This lead to the conclusion that downtime due to ice accumulations could occur 3 to 4 times per year;

- the visibility conditions (fog) were also known as being a potentially limiting factor for berthing / unberthing manoeuvres considering that a minimum visibility distance of one nautical mile is a basic requirement applied by the LNG industry in general. Due to the scarcity of data on this issue, only a rough indication could be given: it was estimated that visibility conditions could result in terminal downtime for a maximum of 3 to 4 times per year;

- the global situation of the Gros Cacouna site, considering all the elements described previously, was that interruption of the berthing / unberthing operations could be expected a maximum of 14 to 16 times every year. This numberwas believed to give a reliable picture of the Gros Cacouna site, considering the preliminary level of the study;

- from a similar analysis, a downtime frequency of 2 to 3 times per year was estimated for Lévis-Beaumont.

1.3 SCOPE OF STUDY

The current study comprises a more detailed analysis of the three main topics described previously, i.e. wind, ice and visibility, and aims at better documenting the comparison between the Gros Cacouna and Lévis-Beaumont sites.

In order to carry out this work, wind and visibility data have been obtained from Environment Canada for different meteorological stations located along the Saint Lawrence River and the Gulfe of Saint Lawrence. These weather stations are listed in Table 1.1 and shown on Figure 1.1. Additional analysis of river ice data was also carried out.

1.4 IMPORTANCE OF CLIMATIC CONDITIONS

In order to determine the effect of climatic elements on the operational conditions of the future LNG receiving terminal, it is important to recall the main marine operational rules generally applied by the LNG industry at similar facilities worldwide. These can then be compared with conditions encountered at the sites considered in the present project.

Berthing or unberthing manoeuvres are generally performed under the following requirements:

- wind velocity must not exceed 25 knots (= 46 km/h) from any direction due to the important windage area of LNG carriers;

- visibility distance must be at least 1 nautical mile (= 1,852 km);

- manoeuvres can be performed either at day time or night time as long as appropriate lighting conditions are in place;

- regarding the particular aspect of ice, which is specific to this project (no other LNG terminal worldwide exists in ice conditions as severe as the ones encountered in the Saint-Lawrence River), it is clear that the ice conditions must be manageable to allow berthing / unberthing manoeuvres safely.

No restriction applies on tidal current velocities to allow berthing / unberthing manoeuvres. However, the Saint Lawrence pilots have expressed a preference for docking ships with currents in the range of 2-3 knots in a stable direction. Considering the maximum current velocities occurring in the berthing area with large tides, this means that manoeuvres can be performed any time with respect to this criterion.

In addition to these rules applying to navigation manoeuvres, particular operational rules apply to the LNG unloading operation once the ship has been moored securely:

- LNG unloading is stopped if winds exceed 35 knots (=65 km/h);
- the LNG unloading arms which connect the ship and the terminal must be disconnected if wind velocity exceeds 40 knots (= 74 km/h);
- The ship must be capable of making an emergency departure from the terminal at all times. This issue is to be the object of a thorough examination with respect to the prevailing environmental conditions (not included in this study).

Table 1.1 - Environment Canada Meteorological Stations located along the Saint Lawrence River and the Gulfe of Saint Lawrence

No	Station	ID Number	Latitude	Longitude	Élévation	Wind		Visibility	
						Record period	Record duration (years)	Record period	Record duration (years)
1	SYDNEY A, NS	8205700	46.17	-60.05	61.9 m	---	---	1989-2004	15.6
2	PORT AUX BASQUES, NFLD	8402975	47.57	-59.15	39.7 m	---	---	1989-2004	15.6
3	ILES DE LA MADELEINE A, QUE	705C2G9	47.42	-61.78	10.4 m	---	---	1989-2004	15.6
4	PORT-MENIER, QUE	7056202	49.84	-64.29	55.2 m	---	---	1994-2002	8.5
5	NATASHQUAN A, QUE	7045400	50.18	-61.82	10.7 m	---	---	1989-2004	15.6
6	SEPT-ILES A, QUE	7047910	50.22	-66.27	54.9 m	---	---	1989-2004	15.6
7	BAIE-COMEAU A, QUE	7040440	49.13	49.13	21.6 m	---	---	1989-2004	15.6
8	GASPE A, QUE	7052605	48.78	-64.48	32.9 m	---	---	1989-2004	15.6
9	MONT-JOLI A, QUE	7055120	48.60	-68.22	52.4 m	1988-2003	16.0	1989-2004	15.6
10	ILE BICQUETTE, QUE	705LKPQ	48.25	-68.53	7.0 m	1994-2003	10.0	---	---
11	CHARLEVOIX A, QUE	7041310	47.60	-70.23	298.0 m	---	---	1994-1996	2.8
12	ILE ROUGE, QUE	7043BP9	48.07	-69.56	5.9 m	1988-2003	16.0	1994-1996	2.4
13	RIVIERE-DU-LOUP, QUE	7056616	47.81	-69.55	146.5m	1988-2003	16.0	1994-2001	7.7
14	ILE D'ORLEANS, QUE	70132G9	47.00	-70.81	5.2 m	1991-2003	13.0	---	---
15	LAUZON, QUE	702MKNL	46.50	-71.10	20.0 m	1991-2003	13.0	---	---
16	QUEBEC/JEAN LESAGE INTL A, QUE	7016294	46.80	-71.38	74.4 m	1991-2003	13.0	1989-2004	15.6

Figure 1.1 - Location of project sites considered and Environment Canada weather stations along the Saint Lawrence.

2. WIND CONDITIONS

One of the main purposes of the present study is to determine the most suitable meteorological station that should be used to establish the wind conditions at each site under study. A comparative analysis has therefore been carried out between the various wind records available from stations located in the vicinity of each site.

Detailed reports of the comparative analyses are presented in appendix A. The present chapter summarizes these analyses.

2.1 Lévis-Beaumont

2.1.1 Comparison of wind data

Three Environment Canada meteorological stations have been compared to establish the most representative data for the Lévis-Beaumont site:

a) Quebec airport, located on the north shore of the Saint Lawrence, approximately 25 km west of the Lévis-Beaumont site;

b) Lauzon, located on the south shore of the Saint Lawrence, about 6 km upstream from the project site;

c) Île d'Orléans, located at the east end of Île d'Orléans about 30 km downstream from the site proposed for the LNG terminal.

The comparison has been done for the period of January 1991 to December 2003 that is common to the three data sets. Tables 2.1, 2.2 and 2.3 and Figure 2.1 summarize the comparison.

Table 2.1 shows mean velocities and occurrence frequencies according to 8 and 4 cardinal directions. The three stations indicate that the W-SW and E-NE sectors are the prevailing wind directions.

As to the velocities, Île d'Orléans appears as the most windy among the three stations followed by Lauzon and Quebec. Depending on the specific directions considered, mean velocities may be relatively similar (N, W) or may show more important differences (NE) between the three stations.

Table 2.2 gives a different presentation of the comparison of wind velocities. It shows the distribution of wind velocities observed simultaneously at Lauzon and Quebec (top table), Lauzon and Île d'Orléans (middle section), and Quebec and Île d'Orléans (bottom table). The numbers in the diagonal cells are observations with equal simultaneous velocities at both stations being compared. The numbers above and below the diagonal correspond to observations with wind velocities higher at one of the two stations compared. General conclusions can be drawn by cumulating all the data above or all the data below the diagonal, as shown below each table. For instance, from the top table, it can be concluded that Quebec and Lauzon show similar wind velocities 53,4 % of the time; Quebec presents velocities higher than Lauzon 14,4 % of the time whereas the opposite is observed 32,2 % of the time. This is an indication that the Lauzon station generally presents higher wind velocities than the Quebec station.

Similar analyses are presented in the two other sections of Table 2.2 for Lauzon – Île d'Orléans and Québec – Île d'Orléans. The following table summarizes the results:

	>	=	<	
Québec	14,4%	53,4%	32,2%	Lauzon
Lauzon	16,1%	38,9%	44,9%	Île d'Orléans
Québec	12,5%	35,8%	51,7%	Île d'Orléans

Figure 2.1 is a graphic representation of the previous analysis focusing on wind velocities. General velocity ratios can be approximated from the probability curves:

Île d'Orléans / Lauzon	=	1,2 to 1,3 +/-
Lauzon / Quebec	=	1,1 to 1,2 +/-

Table 2.3 shows a comparison of the directions of simultaneous winds. The numbers located along the diagonal of each table correspond to observations with similar direction at both stations; it is an indication of the degree of similarity of the two regimes being compared. For Lauzon and Quebec, this comparison indicates that wind directions are similar for 52,9 % of the total number of observations (89 273 data). As explained in the detailed report (see Appendix), this ratio is increased to 64,2% if wind velocities below 10 km/h are excluded from the comparison (52 555 data compared), and to 67,9% if velocities below 20 km/h are removed from the calculation (20 072 data compared). These results indicate that the level of agreement between the two stations

increases with wind velocities; this can be explained by the fact that low velocity winds are often more irregular and not as well defined as stronger winds.

Similar comparisons between Lauzon and Île d'Orléans and between Québec and Île d'Orléans give the results presented hereafter. It can be seen that, as far as the wind directions are concerned, the degree of agreement between these stations is lower than for velocities, which can be expected to some extent due tolocal topographic and geographic conditions at each station.

	Considering all data		Excluding velocities < 10 km/h		Excluding velocities < 20 km/h	
Percentage of simultaneous wind data in the same direction	%	Number of data	%	Number of data	%	Number of data
Lauzon – Québec	52,9%	89 273	64,2%	52 555	67,9%	20 072
Lauzon – Île d'Orléans	34,2%	89 862	38,0%	54 958	33,0%	24 933
Québec – Île dOrléans	30,4%	95 427	34,2%	55 412	32,7%	21 618

2.1.2 Conclusion

The preliminary assessment of wind conditions presented at the pre-feasibility stage was based on the use of data from the Lauzon weather station. This station had been selected on the basis of the consultant's general experience in similar studies carried out in the past and on his good knowledge and understanding of the geographic and topographic conditions specific to the Lévis-Beaumont area.

The comparison of the three stations available in the vicinity of the project site has lead to confirm that the Lauzon station is indeed the most relevant one for the purpose of the present climatic study for the following reasons:

- The Lauzon station is much closer to the project site and is located at the upstream end of the same stretch of the river. Beyond Lauzon in the upstream direction and beyond Beaumont in the downstream direction, the river changes direction and it is likely that wind conditions are different past these points. This conclusion is reinforced by comments obtained from the Lower Saint Lawrence pilots who indicated that there is usually a noticeable change in the wind conditions in front of Saint-Laurent (Île d'Orléans) corresponding to a change in the seaway orientation: downstream from this point the wind is often noticeably stronger than further upstream;

- The Île d'Orleans station cannot be considered representative of the Lévis-Beaumont area due to its rather important distance to the project site and its exposure to wind that has definitely less in common with the Lévis-Beaumont area than the Lauzon station which is located in the immediate vicinity of the project site;
- The Quebec airport station is also located too far from the project site to be representative. Moreover, as most on-land stations, it is less windy than at-sea stations.

Appendix B presents monthly wind velocity and direction statistics established from the Lauzon wind records over a period of 13 years (1991 - 2003). This data file is to be used as the reference to establish the wind conditions at the project site. It is in fact the same data set as the one used in the pre-feasibility study.

Results extracted from this data set indicate that wind velocities in excess of 25 knots or 46 km/h - this condition is considered an important operational limit for berthing / unberthing manoeuvres, as explained previously - may occur with the following probabilities:

Complete year:	1,165 %	or	102 h / yr	(= 0,01165 x 365 x 24)
December:	1,490 %	or	11,1 h / month	(= 0,01490 x 31 x 24)
January:	1,336 %	or	9,9 h / month	(= 0,01336 x 31 x 24)
February:	1,635 %	or	11,0 h / month	(= 0,01635 x 28 x 24)
March	2,322 %	or	17,3 h / month	(= 0,02322 x 31 x 24)
Winter	1,697 %	or	49,3 h / season	

As to the 35 knot (= 64,8 km/h) limit applicable to the LNG unloading operation, the following probabilities can be extracted from the same data base:

Complete year:	0,030 %	or	2,6 h / yr	(= 0,00030 x 365 x 24)
December:	0,023 %	or	0,2 h / month	(= 0,00023 x 31 x 24)
January:	0,024 %	or	0,2 h / month	(= 0,00024 x 31 x 24)
February:	0,027 %	or	0,2 h / month	(= 0,00027 x 28 x 24)
March	0,190 %	or	1,4 h / month	(= 0,00190 x 31 x 24)
Winter	0,067 %	or	1,9 h / season	

Table 2.1 – Comparison of wind frequencies and mean velocities
for 8 and 4 directions – Lévis-Beaumont

- **between Quebec, Lauzon and Île d'Orléans weather stations**
  Period: January 1991 to December 2003

i) 8 directions

January-December 1991-2003	Québec		Lauzon		Île d'Orléans	
Direction	**Mean velocity (km/h)**	**Frequency (%)**	**Mean velocity (km/h)**	**Frequency (%)**	**Mean velocity (km/h)**	**Frequency (%)**
calm	0	8.9	0	1.8	0	0.7
N	9.6	9.8	9.7	4.0	12.6	6.6
NE	10.9	8.9	18.0	8.9	30.8	26.8
E	17.3	19.7	21.9	23.8	13.5	2.6
SE	8.3	1.4	5.5	1.5	7.9	0.8
S	8.5	2.2	7.0	3.4	16.4	4.6
SW	16.4	16.3	14.4	20.1	21.3	34.9
W	17.5	25.4	16.7	32.4	13.5	16.7
NW	15.0	7.4	15.1	4.0	10.7	6.2
Total		100.0		99.9		99.9

ii) 4 quarters

January-December 1991-2003	Québec		Lauzon		Île d'Orléans	
Direction	**Mean velocity (km/h)**	**Frequency (%)**	**Mean velocity (km/h)**	**Frequency (%)**	**Mean velocity (km/h)**	**Frequency (%)**
calm	0	8.9	0	1.8	0	0.6
NNE,NE,ENE,E	14.8	30.3	20.9	32.4	28.9	30.2
ESE,SE,SSE,S	8.5	3.5	7.0	5.0	13.5	4.2
SSW,SW,WSW,W	17.0	40.2	15.6	51.8	19.0	51.7
WNW,NW,NNW,N	13.0	17.2	13.9	8.9	11.3	13.2
Total		100.1		99.9		99.9

Table 2.2 – Distribution of wind velocities observed simultaneously – Lévis-Beaumont

a) Quebec and Lauzon weather stations - Period: January 1991 to December 2003

Wind velocity (km/h)		Québec 0-9	10-19	20-29	30-39	40-50	>50	total
Lauzon	**0-9**	26255	5646	615	46	4	0	32566
	10-19	11683	15601	4921	374	8	0	32587
	20-29	2114	8811	8364	2071	113	6	21479
	30-39	378	2396	4010	2531	408	48	9771
	40-49	41	342	805	858	247	51	2344
	>50	2	30	120	217	149	74	592
	total	40473	32826	18835	6097	929	179	99339

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	53.4%	
Quebec superior to Lauzon (above diagonal)	14.4%	
Lauzon superior to Québec (below diagonal)	32.2%	100.0%

b) Île d'Orleans and Lauzon weather stations - Period: January 1991 to December 2003

Wind velocity (km/h)		Île d'Orléans 0-9	10-19	20-29	30-39	40-50	>50	total
Lauzon	**0-9**	14262	11744	3345	670	76	22	30119
	10-19	5907	11297	8607	3955	437	67	30270
	20-29	1231	4734	6260	6069	1477	276	20047
	30-39	149	853	1471	3074	2502	1095	9144
	40-49	12	69	125	264	587	1169	2226
	>50	0	6	10	22	57	475	570
	total	21561	28703	19818	14054	5136	3104	92376

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	38.9%	
Île d'orleans superior to Lauzon (above diagonal)	44.9%	
Lauzon superior to Île d'Orléans (below diagonal)	16.1%	100.0%

c) Quebec and Île d'Orleans weather stations - Period: January 1991 to December 2003

Wind velocity (km/h)		Québec 0-9	10-19	20-29	30-39	40-50	>50	total
Île d'orléans	**0-9**	17792	5570	1159	112	12	1	24646
	10-19	16538	11685	4040	527	33	1	32824
	20-29	6037	9458	5717	1324	78	7	22621
	30-39	2256	5868	5458	2140	267	27	16016
	40-49	398	1594	2257	1279	252	45	5825
	>50	168	588	1189	1114	347	117	3523
	total	43189	34763	19820	6496	989	198	105455

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	35.8%	
Québec superior to Île d'orleans (above diagonal)	12.5%	
Île d'Orleans superior to Québec (below diagonal)	51.7%	100.0%

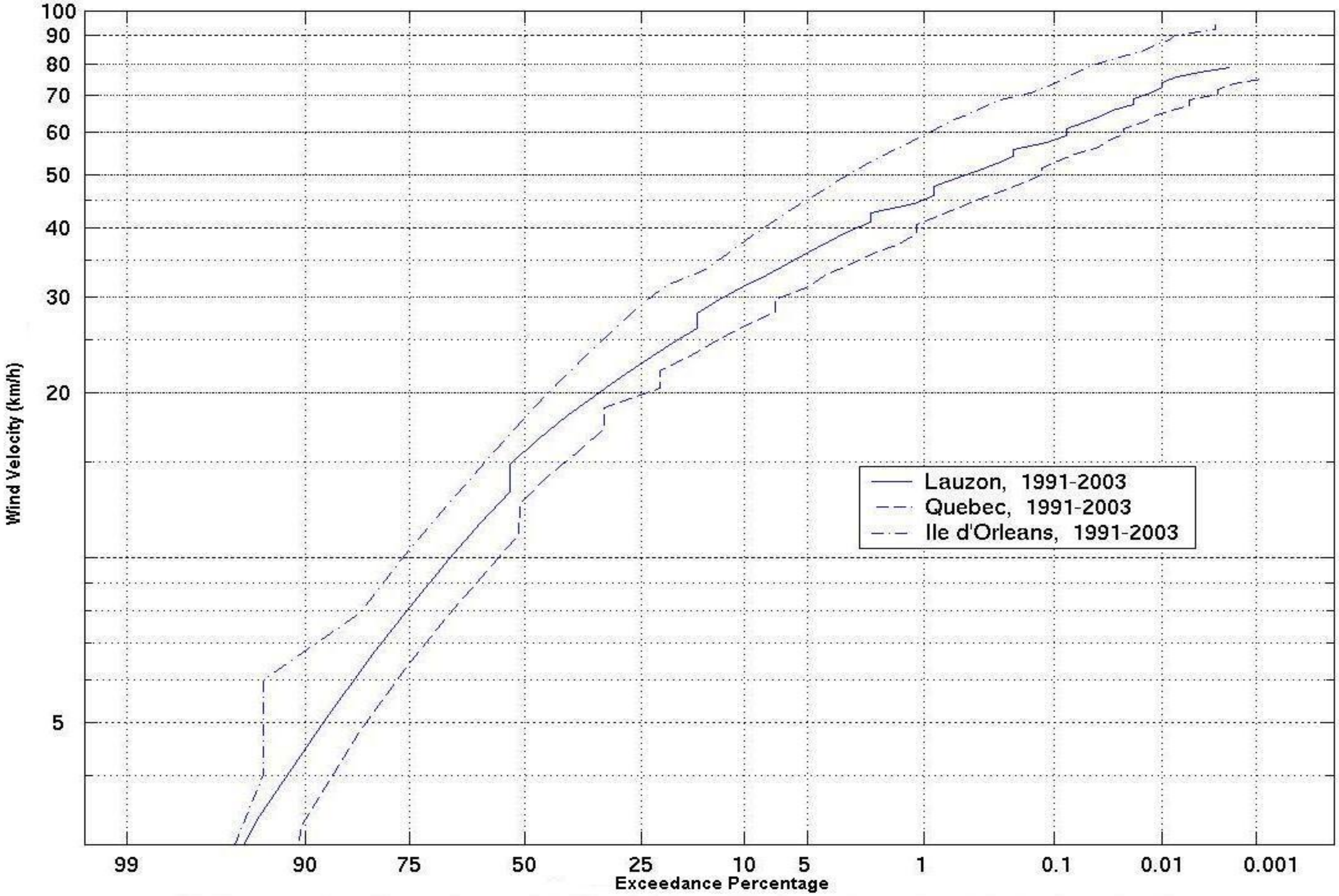


Figure 2.1 – Comparison of exceedance probabilities of wind velocities from various meteorological stations – Lévis-Beaumont.

Table 2.3 – Distribution of directions observed simultaneously at Québec, Lauzon and Île d'Orléans weather stations – Period: January 1991 to December 2003.

a) Québec and Lauzon

	Station No 2 : Québec								
Station No 1 : Lauzon	N	NE	E	SE	S	SW	W	NW	Total
N	2.2	0.7	0.3	0.1	0.1	0.1	0.2	0.4	3.9
NE	1.8	3.0	4.0	0.1	0.1	0.1	0.2	0.2	9.4
E	1.3	4.5	16.9	0.8	0.5	0.5	0.4	0.3	25.3
SE	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.0	1.3
S	0.4	0.2	0.1	0.1	0.5	0.9	0.4	0.1	2.9
SW	0.7	0.3	0.2	0.1	0.7	9.7	7.6	0.6	20.0
W	2.2	0.5	0.2	0.1	0.4	6.1	18.8	4.9	33.3
NW	1.4	0.2	0.1	0.0	0.1	0.2	0.4	1.6	4.0
Total	10.4	9.7	22.0	1.6	2.5	17.6	28.1	8.2	100.0

b) Île d'Orléans and Lauzon

	Station No 2 : Île d'Orléans								
Station No 1 : Lauzon	N	NE	E	SE	S	SW	W	NW	Total
N	1.1	0.6	0.2	0.1	0.2	0.3	0.6	0.9	4.0
NE	1.3	5.7	0.3	0.1	0.1	0.3	0.5	0.8	9.1
E	1.6	18.9	1.2	0.2	0.4	0.7	0.7	0.5	24.3
SE	0.2	0.3	0.1	0.1	0.1	0.3	0.3	0.1	1.4
S	0.1	0.2	0.1	0.0	0.3	1.6	0.8	0.2	3.4
SW	0.3	0.6	0.2	0.1	1.6	14.4	2.9	0.3	20.5
W	1.1	0.8	0.3	0.2	1.6	16.7	10.3	2.3	33.3
NW	1.0	0.3	0.1	0.1	0.2	0.5	0.8	1.1	4.0
Total	6.7	27.6	2.6	0.8	4.6	34.8	16.8	6.1	100.0

c) Québec and Île d'Orléans

	Station No 2 : Québec								
Station No 1 : Île d'Orléans	N	NE	E	SE	S	SW	W	NW	Total
N	2.3	1.1	1.1	0.1	0.1	0.2	0.6	1.3	6.8
NE	1.7	5.0	18.1	0.7	0.5	1.0	0.9	0.7	28.5
E	0.5	0.4	0.8	0.1	0.1	0.2	0.2	0.3	2.6
SE	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.8
S	0.3	0.2	0.2	0.2	0.4	1.7	1.2	0.4	4.6
SW	1.7	0.9	0.5	0.3	1.0	12.3	16.3	1.2	34.1
W	2.1	1.1	0.5	0.1	0.2	2.1	7.7	2.4	16.3
NW	2.0	0.8	0.4	0.1	0.1	0.2	1.0	1.8	6.3
Total	10.7	9.7	21.7	1.5	2.4	17.9	28.0	8.1	100.0

2.2 GROS CACOUNA

2.2.1 Comparison of wind data

Data from five meteorological stations have been compared with the objective of establishing the conditions applicable to the Gros Cacouna site (see Figure 1.2):

a) Rivière-du-Loup, located at the airport, about 20 km south of the Gros Cacouna harbour ;

b) Mont-Joli, about 110 km downstream from the project site,

c) Île Bicquette, located offshore from Rimouski, about 65 km from Gros Cacouna;

d) Île Rouge, situated in the middle of the Saint Lawrence, approximately 14 km north of Gros Cacouna ;

e) Rivière-du-Loup ferry wharf, 11 km south of Gros Cacouna.

It is important to notice that, unlike all the others, the latter station (Rivière-du-Loup ferry wharf) is not an official Environment Canada meteorological station. This station is in fact located on board the Rivière-du-Loup / St-Siméon ferry ship and the corresponding data set was collected by the captain of the ship in the course of the ferry regular activities during the years 2001, 2002 and 2003. This data set therefore covers only the period from April to December of these three years. It comprises velocities and directions taken regularly at 4 hour intervals every day, i.e. 6 data per day (0h, 4h, 8h, 12h, 16h, 20h). The observations were done systematically when the ship was at the Rivière-du-Loup berth. Only a few data are missing.

Detailed reports of these comparative analyses are presented in Appendix A. Tables 2.4, 2.5 and 2.6 and Figure 2.2 summarize the results.

From an assessment similar to the one presented for Lévis-Beaumont, a number of conclusions can be drawn.

Wind velocities are generally higher at the Île Rouge and Île Bicquette stations, followed by Mont-Joli and Rivière-du-Loup (airport). This can be seen in Table 2.4 where mean velocities from all stations are compared by direction (top tables) and by quarter (bottom tables).

Table 2.5 also illustrates this conclusion by presenting various comparisons of frequencies of simultaneous velocities. In each table, as already explained, the diagonal numbers are the number of observations with equal simultaneous velocities at both stations being compared. The numbers above and below the diagonal correspond to observations with velocities higher at one station or the other. The following table summarizes the various comparisons presented in Table 2.5.

Period	Station	>	=	<	Station
1988-2003	Île Rouge	74,2%	22,1%	3,7%	Rivière-du-Loup
	Île Rouge	54,1%	31,3%	14,6%	Mont-Joli
	Mont-Joli	53,0%	38,4%	8,6%	Rivière-du-Loup
1994-2003	Île Bicquette	37,8%	36,7%	25,5%	Île Rouge
	Île Rouge	39,7%	32,8%	27,5%	Mont-Joli
	Île Bicquette	44,8%	35,0%	20,3%	Mont-Joli
2001-2003	R-du-L ferry	31,5%	38,5%	30,0%	Île Rouge

As to the data set obtained from the ferry ship, it has to be used with some reserve considering its short duration. It is also important to mention that, due to the particular method of collecting data in this case, the definition of “calm condition” is different from all the other stations: in this particular case, “calm” means a wind velocity below 7-8 km/h (perceived as a gentle breeze by the observer). According to the international standards used by Environment Canada, “calm” means a wind velocity below 1 km/h. This difference explains the apparent higher frequency of calm conditions at the ferry wharf (see Table 2.4). However, the ferry ship data show good agreement with the Île rouge and Île Bicquette velocity records.

The probability curves presented in Figure 2.2 (a, b and c) give another illustration of these conclusions. Approximate wind velocity ratios between these curves can be estimated as follows:

- from Figure 2.2 a:
  - o Mont-Joli / Rivière-du-Loup (airport) = 1,5
  - o Île rouge / Mont-Joli = 1,3
  - o Île rouge / Rivière-du-Loup (airport) = 2

- from Figure 2.2 b :

  Île Rouge = Île Bicquette = 1,25 x Mont-Joli

- from Figure 2.2 c :

  Île Rouge = Rivière-du-Loup ferry wharf

The comparison of wind directions is somewhat more difficult. As can be seen in Table 2.4, differences from one station to another are sometimes relatively minor (SW, S, E) but can be rather important (W, NW). A comparison by quarter is easier since it gives less consideration to minor differences in wind directions. A few general conclusions can be drawn from this assessment:

- For all the stations except Île Rouge, prevailing winds come from the 3rd quarter (SSW, SW, WSW, W) with frequencies in the range of 32% to 48%;

- The Île Rouge predominant quarter is the 4th one (WNW, NW, NNW, N) with a cumulative frequency of 32,1% but it is followed closely by the 3rd quarter with a frequency of 30,8%. The explanation for this difference with other stations would probably be the proximity of the Saguenay River in the NW direction from the station which would increase the frequency of corresponding winds;

- The 2nd quarter (ESE, SE, SSE, S) is generally among the least frequent quarters for most stations (generally ranked 3rd or 4th except for Mont-Joli);

- The 1st quarter usually ranks second or third (except at Rivière-du-Loup). It is interesting to mention that winds from this quarter (particularly NE) usually correspond to bad weather conditions (rain, snow storms...).

The following table, similar to the one presented for the Lévis-Beaumont assessment, summarizes results presented in Table 2.6. Each line gives, for the two stations being compared, the percentages of simultaneous wind records having the same direction within a data set comprised of the number of data indicated. Three cases are treated. In the first one, all available data have been used in the comparison; in the two others, velocities below 10 km / h and 20 km/h respectively have been excluded from the calculation. As can be seen, the data correlate better and better as only higher velocities are considered. However, the results barely exceed 60% in the best case. This gives some indication of the degree of wind direction variability between the stations that is not really surprising considering the topographic and physical features of each station and the distance between each.

	Considering all data		Excluding velocities < 10 km/h		Excluding velocities < 20 km/h	
Percentage of simultaneous wind data in the same direction	%	Number of data	%	Number of data	%	Number of data
1988 – 2003						
Île Rouge – Riv-du-Loup	38,4%	113 479	48,1%	53 190	56,7%	12 088
Mont-Joli – Île rouge	35,8%	123 951	43,7%	82 448	53,4%	38 227
Mont-Joli – Riv-du-Loup	37,0%	117 453	45,7%	52 034	50,9%	10 983
1994 – 2003						
Mont-Joli – Île Rouge	35,1%	81 718	41,4%	59 053	50,1%	31 772
Île Bicquette – Île Rouge	42,7%	67 584	48,6%	50 101	52,7%	30 630
Île Bicquette – Mont-Joli	45,1%	66 865	52,9%	49 290	60,7%	20 072
2001 – 2003						
Île Rouge – ferry wharf	46,2%	4 024	51,4%	3 175	57,8%	1 857

2.2.2 Conclusion on the comparison of wind data sets

The comparison of data obtained from five wind recording stations has shown significant variability in velocities as well as directions. The level of accuracy and reliability of each data set for the purpose of this study is variable from one station to another; it depends on the physical environment or the geographic location of each station (on-land vs at-sea stations, topography, etc).

The Île Rouge station, already used as the reference station in the pre-feasibility assessment, still appears to be more representative than the others for the purpose of establishing the wind regime in the area proposed for the future LNG receiving port. The comparison with the Île Bicquette station which is also located at sea (compared to on-land stations) shows good agreement at least for velocities. The velocity data collected at the Rivière-du-Loup ferry wharf, even if they cover a relatively short period of time, also show good agreement with the Île Rouge data.

As to the wind directions, the Île Rouge station might present a bias toward the 4th quarter in comparison with the other stations where the 3rd quarter is prevalent. However this bias would not necessarily be of major importance since the 3rd quarter ranks second, close behind the 4th . This station presents good correlation with the Rivière-du-Loup (airport) or the ferry wharf stations, at least as good as the correlation between any of the other stations. The degree of variability is relatively high between all stations and Île Rouge is neither better nor worse than any of the other stations available as far as directions are concerned.

Knowledge of the wind climate is important in two different ways within the present scope:

a) to determine down time frequency due to occurrence of the 25 and 35 knot operational rules already explained;

b) to determine the effect of wind on the movement of floating ice.

As to the first objective, the Île Rouge station definitely appears as the most relevant source of data to be used since the wind direction does not matter with these requirements.

As to the second objective, wind direction is more important. There is no reason to believe that a station other than Île Rouge (Mont-Joli or Île Bicquette, for instance) could be more accurate or reliable. Being closest to the project area and located at sea, Île Rouge is probably the most representative one for this assessment although it must be kept in mind that it is probably affected by the proximity of the Saguenay River.

Table 2.4 - Comparison of wind frequencies and mean velocities for 8 and 4 directions - Gros Cacouna

a) between Riviere-du-Loup, Mont-Joli and île Rouge weather stations
Period: January 1988 to December 2003

i) 8 directions

January-December 1988-2003	Rivière-du-Loup		Mont-Joli		Île Rouge	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	0	9.6	0	4.2	0	0.6
N	13.0	17.3	15.8	5.7	18.4	8.6
NE	11.7	6.6	20.5	11.5	21.6	16.7
E	5.7	3.9	11.5	6.2	12.8	5.0
SE	7.8	3.7	14.8	8.3	12.1	2.6
S	10.2	17.7	15.4	14.0	23.6	14.8
SW	13.5	19.6	17.2	21.0	24.9	16.2
W	8.4	8.9	21.1	21.4	25.9	13.8
NW	11.5	12.8	19.9	7.7	31.1	21.6
Total		100.1		100.0		99.9

ii) 4 quarters

January-December 1988-2003	Rivière-du-Loup		Mont-Joli		Île Rouge	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	0	9.6	0	4.2	0	0.6
NNE,NE,ENE,E	11.4	13.6	17.5	18.0	19.9	23.6
ESE,SE,SSE,S	8.8	16.5	14.6	18.6	19.3	12.8
SSW,SW,WSW,W	12.1	32.4	18.7	44.0	24.9	30.8
WNW,NW,NNW,N	11.7	27.9	19.1	15.2	28.4	32.1
Total		100.0		100.0		99.9

b) between île Rouge and Île Bicquette weather stations
Period: January 1994 to December 2003

i) 8 directions

January 1994-December 2003	Île Rouge		Île Bicquette	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	0	0.4	0	0.9
N	18.1	8.8	20.1	9.2
NE	21.3	16.8	21.6	14.1
E	12.5	5.3	15.1	8.5
SE	11.8	2.6	11.8	2.5
S	23.7	14.6	19.2	7.0
SW	24.6	15.6	31.5	33.5
W	25.7	14.0	28.5	14.6
NW	31.1	21.8	28.5	9.7
Total		99.9		99.1

ii) 4 quarters

April-December 2001-2003	Île Rouge		Île Bicquette	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	0	0.4	0	0.9
NNE,NE,ENE,E	19.6	24.3	19.1	23.9
ESE,SE,SSE,S	18.2	11.4	15.8	8.3
SSW,SW,WSW,W	24.7	30.7	30.3	47.9
WNW,NW,NNW,N	28.4	33.2	25.8	19.1
Total		100.0		100.1

c) between the Riviere-du-Loup ferry wharf and île Rouge weather station
Period: April to December, 2001 to 2003

i) 8 directions

April-December 2001-2003	Rivière-du-Loup Ferry wharf		Île Rouge	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	4.0	16.2	0	0.4
N	22.2	7.4	15.5	8.1
NE	20.7	17.8	19.8	17.4
E	10.0	2.0	11.2	5.3
SE	14.9	2.2	11.3	2.6
S	23.1	3.5	23.6	15.7
SW	25.6	33.9	23.6	18.2
W	26.0	3.4	23.4	13.0
NW	30.5	13.6	28.8	19.6
Total		100.0		100.3

ii) 4 quarters

April-December 2001-2003	Rivière-du-Loup Ferry wharf		Île Rouge	
Direction	Mean velocity (km/h)	Frequency (%)	Mean velocity (km/h)	Frequency (%)
calm	4.0	16.2	0.0	0.4
NNE,NE,ENE,E	20.0	21.3	17.9	24.9
ESE,SE,SSE,S	19.0	5.0	17.0	10.4
SSW,SW,WSW,W	25.6	37.6	23.7	34.1
WNW,NW,NNW,N	27.8	19.9	26.2	30.2
Total		100.0		100.0

Table 2.5 - Distribution of wind velocities observed simultaneously - Gros Cacouna

Period: January 1988 to December 2003

a) Rivière-du-Loup and Île Rouge weather stations

Wind velocity (km/h)		Île Rouge 0-9	10-19	20-29	30-39	40-50	>50	total
R.-du-Loup	**0-9**	17966	23565	15824	7813	2001	987	68156
	10-19	3399	7804	11997	12810	4975	2718	43703
	20-29	260	757	1579	3622	3053	2252	11523
	30-39	17	37	102	281	482	632	1551
	40-49	2	3	6	7	14	52	84
	>50	0	1	2	0	0	4	7
	total	21644	32167	29510	24533	10525	6645	125024

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	22.1%	
Île Rouge superior to Rivière-du-Loup (above diagonal)	74.2%	
Rivière-du-Loup superior to Île rouge (below diagonal)	3.7%	100.0%

b) Mont-Joli and Île Rouge weather stations

Wind velocity (km/h)		Île Rouge 0-9	10-19	20-29	30-39	40-50	>50	total
Mont-Joli	**0-9**	13014	13357	7216	3135	768	267	37757
	10-19	7147	13953	12878	8291	2270	823	45362
	20-29	1642	4765	7668	8752	3654	2022	28503
	30-39	454	1094	2475	4661	3246	2406	14336
	40-49	69	120	238	609	844	976	2856
	>50	10	27	46	92	143	395	713
	total	22336	33316	30521	25540	10925	6889	129527

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	31.3%	
Île Rouge superior to Mont-Joli (above diagonal)	54.1%	
Mont-Joli superior to Île Rouge (below diagonal)	14.6%	100.0%

c) Rivière-du-Loup and Mont-Joli weather stations

Wind velocity (km/h)		Mont-Joli 0-9	10-19	20-29	30-39	40-50	>50	total
R.-du-Loup	**0-9**	30688	28583	10954	3238	276	26	73765
	10-19	8135	16186	14062	7034	1204	223	46844
	20-29	743	2243	4248	3825	1044	249	12352
	30-39	20	96	310	621	387	207	1641
	40-49	0	3	9	19	23	34	88
	>50	0	0	2	2	1	2	7
	total	39586	47111	29585	14739	2935	741	134697

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	38.4%
Mont-Joli superior to Rivière-du-Loup (above diagonal)	53.0%
Rivière-du-Loup superior to Mont-Joli (below diagonal)	8.6%

Table 2.5 - Distribution of wind velocities observed simultaneously - Gros Cacouna
Period: January 1994 to December 2003

d) Île Bicquette and Île Rouge weather stations

Wind velocity (km/h)		Île Rouge 0-9	10-19	20-29	30-39	40-50	>50	total
Île Bicquette	0-9	6038	4002	1187	454	104	60	11845
	10-19	3982	6533	3604	1247	186	57	15609
	20-29	1474	4034	4791	2744	621	226	13890
	30-39	812	2862	4384	4714	1467	675	14914
	40-49	203	847	1825	2795	1646	806	8122
	>50	25	101	362	1023	1170	1381	4062
	total	12534	18379	16153	12977	5194	3205	68442

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	36,7%	
Île Rouge superior to Île Bicquette (above diagonal)	25,5%	
Île Bicquette superior to Île rouge (below diagonal)	37,8%	100,0%

e) Mont-Joli and Île Rouge weather stations

Wind velocity (km/h)		Île Rouge 0-9	10-19	20-29	30-39	40-50	>50	total
Mont-Joli	0-9	6381	6056	2930	1255	311	116	17049
	10-19	5839	8966	6673	3473	866	298	26115
	20-29	1840	4807	5808	4868	1613	714	19650
	30-39	557	1650	3124	4133	1931	1238	12633
	40-49	198	448	1063	2181	1598	1200	6688
	>50	57	100	208	530	695	868	2458
	total	14872	22027	19806	16440	7014	4434	84593

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	32,8%	
Île Rouge superior to Mont-Joli (above diagonal)	39,7%	
Mont-Joli superior to Île Rouge (below diagonal)	27,5%	100,0%

f) Île Bicquette and Mont-Joli weather stations

Wind velocity (km/h)		Mont-Joli 0-9	10-19	20-29	30-39	40-50	>50	total
Île Bicquette	0-9	6023	4244	1207	401	116	48	12039
	10-19	5137	7095	2768	750	141	34	15925
	20-29	2012	5582	4333	1784	390	56	14157
	30-39	828	3610	5002	4021	1482	220	15163
	40-49	298	1075	2268	2330	1811	465	8247
	>50	46	228	654	944	1172	1075	4119
	total	14344	21834	16232	10230	5112	1898	69650

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	35,0%
Mont-Joli superior to Île Bicquette (above diagonal)	20,3%
Île Bicquette superior to Mont-Joli (below diagonal)	44,8%

Table 2.5 - Distribution of wind velocities observed simultaneously - Gros Cacouna
Period: April to December, 2001 to 2003

g) Rivière-du-Loup ferry wharf and Île Rouge weather station

Wind velocity (km/h)		Riv-du-Loup ferry wharf						
		0-9	**10-19**	**20-29**	**30-39**	**40-50**	**>50**	**total**
Île Rouge	**0-9**	588	446	170	37	10	0	1251
	10-19	263	470	314	121	19	6	1193
	20-29	87	280	356	214	40	23	1000
	30-39	29	84	211	239	70	14	647
	40-49	3	20	89	170	107	33	422
	>50	1	4	24	89	87	91	296
	total	971	1304	1164	870	333	167	4809

Frequency of simultaneous wind velocities

equal at both stations (diagonal):	38.5%
Riv-du-Loup wharf superior to Île Rouge (above diagonal)	31.5%
Île Rouge superior to Riv-du-Loup wharf (below diagonal)	30.0%

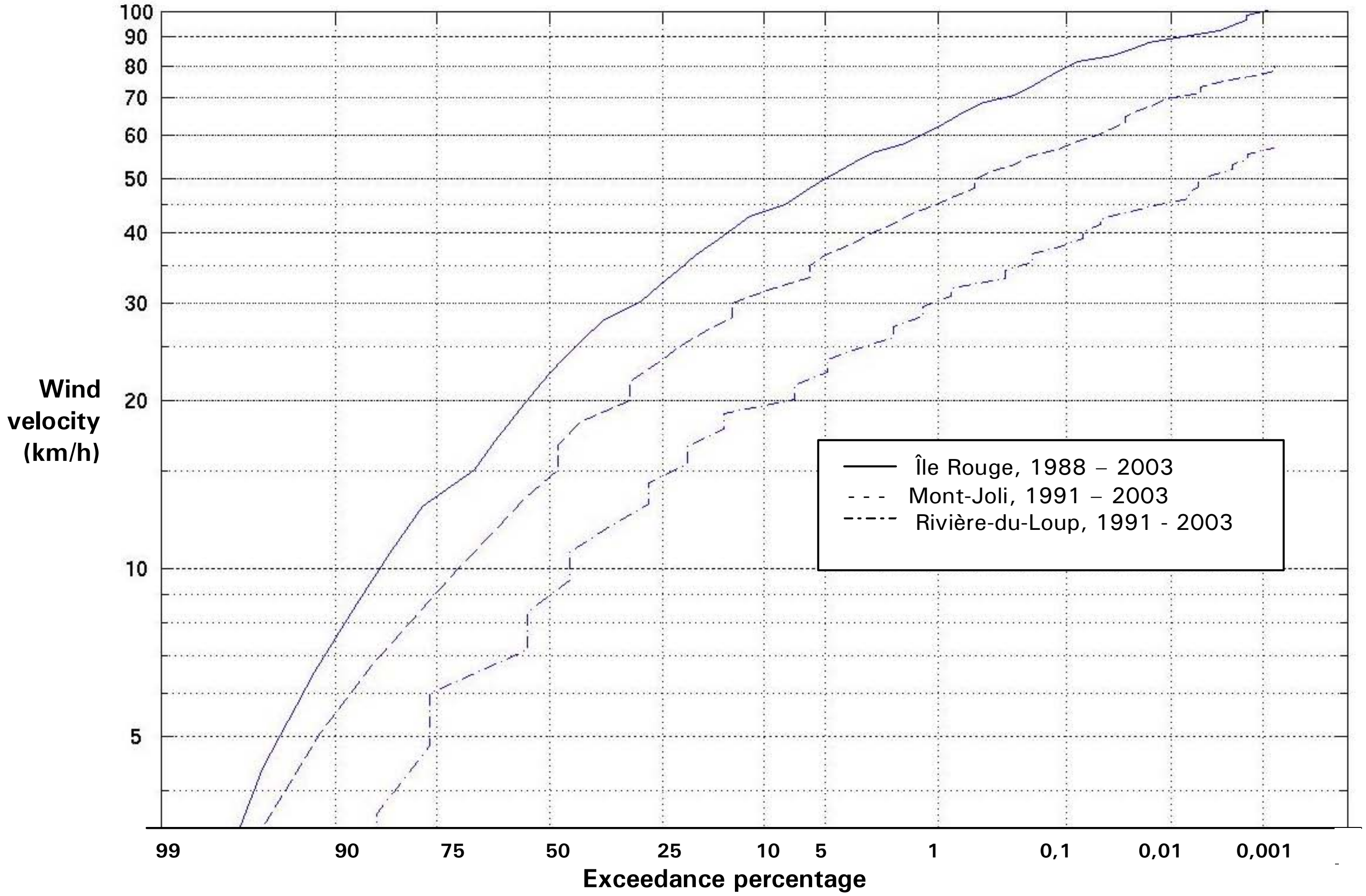


Figure 2.2a – Comparison of exceedance percentage of wind velocities – Île Rouge, Mont-Joli, Rivière-du-Loup

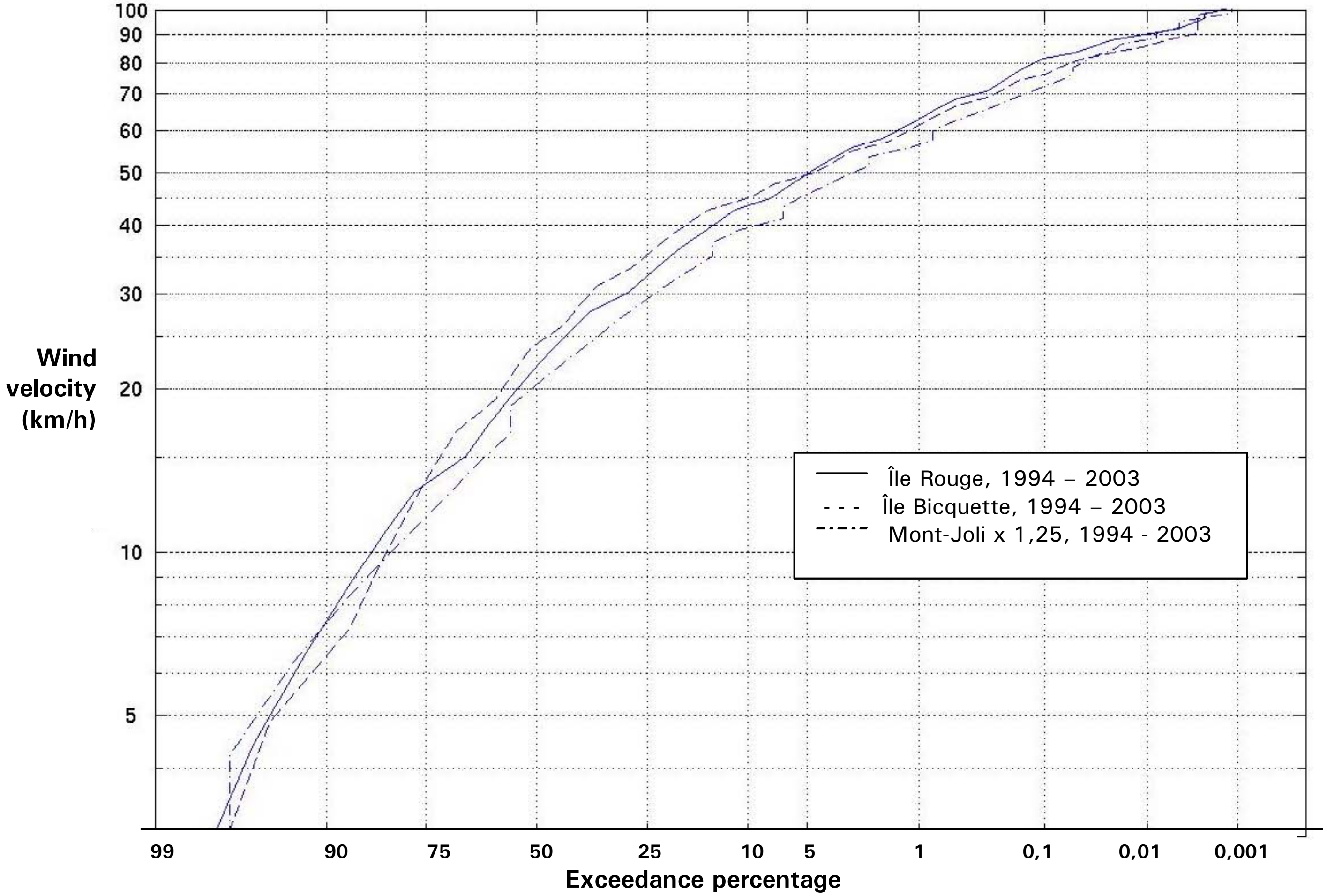


Figure 2.2b – Comparison of exceedance percentage of wind velocities – Île Rouge, Île Bicquette, Mont-Joli

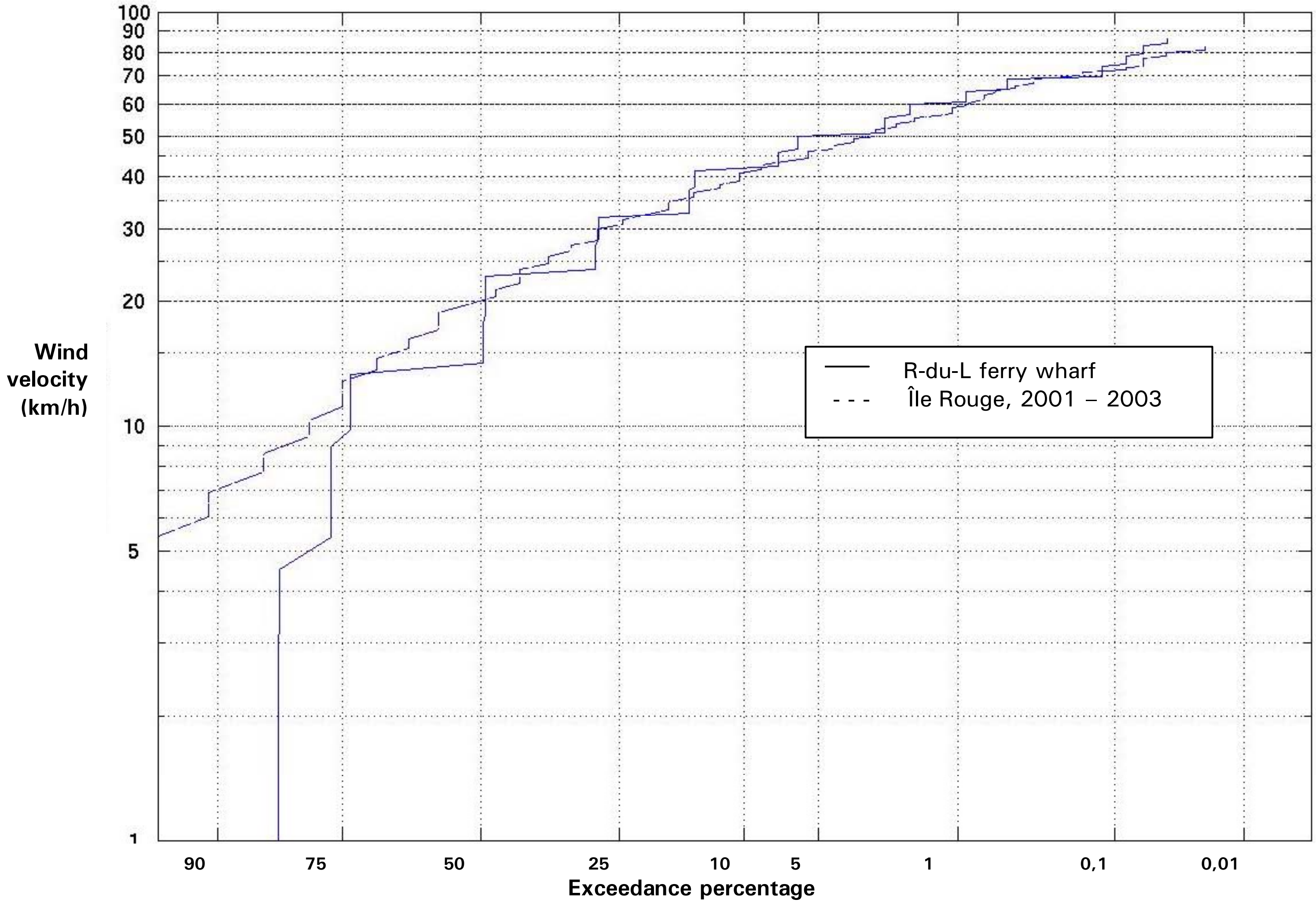


Figure 2.2c – Comparison of exceedance percentage of wind velocities – Rivière-du-Loup ferry wharf, Île Rouge.

Table 2.6 – Distribution of directions observed simultaneously at Rivière-du-Loup, Île Rouge, Mont-Joli, Île Bicquette and Rivière-du-Loup ferry wharf.

a) Île Rouge and Rivière-du-Loup, 1988-2003

	Station No 2 : Île Rouge								
Station No 1 : ivière-du-Loup	N	NE	E	SE	S	SW	W	NW	Total
N	4,6	6,2	0,7	0,2	0,2	0,2	0,8	6,3	19,2
NE	1,3	4,3	0,7	0,1	0,0	0,0	0,1	0,8	7,3
E	0,5	1,5	1,0	0,3	0,1	0,0	0,1	0,8	4,3
SE	0,3	1,0	0,6	0,6	0,6	0,2	0,2	0,6	4,1
S	0,5	1,1	0,6	0,9	6,9	5,7	1,9	1,9	19,4
SW	0,3	0,5	0,4	0,3	6,5	9,2	2,9	1,6	21,6
W	0,2	0,5	0,3	0,1	1,2	1,6	3,9	2,1	9,9
NW	0,7	0,9	0,2	0,1	0,2	0,3	4,1	7,8	14,3
Total	8,4	16,0	4,6	2,5	15,7	17,2	14,0	21,6	100,0

b) Île Rouge and Mont-Joli, 1988 – 2003

	Station No 2 : Mont-Joli								
Station No 1 : :ivière-du-Loup	N	NE	E	SE	S	SW	W	NW	Total
N	3,4	6,7	1,8	0,6	0,4	0,9	2,6	2,8	19,1
NE	0,7	3,1	1,5	0,5	0,3	0,3	0,4	0,3	7,1
E	0,1	0,5	0,9	1,2	0,6	0,3	0,3	0,2	4,2
SE	0,1	0,2	0,5	1,6	0,9	0,3	0,3	0,1	4,0
S	0,2	0,2	0,5	2,8	8,3	5,6	1,6	0,4	19,4
SW	0,4	0,4	0,4	0,6	3,4	10,8	5,2	0,5	21,8
W	0,4	0,3	0,2	0,2	0,4	2,4	5,4	0,6	10,0
NW	0,9	0,7	0,4	0,2	0,2	1,6	6,9	3,5	14,4
Total	6,2	12,2	6,0	7,8	14,5	22,1	22,8	8,4	100,0

c) Mont-Joli and Rivière-du-Loup, 1988 - 2003

	Station No 2 : Île Rouge								
Station No 1 : Mont-Joli	N	NE	E	SE	S	SW	W	NW	Total
N	1,6	1,2	0,4	0,1	0,3	0,2	0,2	1,9	5,9
NE	2,6	7,6	0,7	0,1	0,2	0,1	0,1	0,5	12,0
E	1,1	3,4	1,0	0,2	0,2	0,2	0,1	0,3	6,5
SE	1,0	2,5	1,2	0,9	1,3	0,6	0,3	0,7	8,5
S	0,7	1,1	0,6	0,7	4,8	4,0	1,0	1,6	14,5
SW	0,3	0,2	0,2	0,2	4,8	7,6	4,6	4,0	21,9
W	0,4	0,3	0,3	0,2	2,9	3,5	7,1	7,7	22,5
NW	0,6	0,3	0,3	0,1	0,4	0,3	0,9	5,3	8,2
Total	8,4	16,6	4,8	2,6	14,9	16,5	14,3	22,0	100,0

Table 2.6 – Distribution of directions observed simultaneously at Rivière-du-Loup, Île Rouge, Mont-Joli, Île Bicquette and Rivière-du-Loup ferry wharf.

d) Île Rouge and Île Bicquette, 1994-2003

Station No 1 : Île Bicquette	Station No 2 : Île Rouge N	NE	E	SE	S	SW	W	NW	Total
N	2,8	1,8	0,6	0,1	0,2	0,2	0,3	3,2	9,2
NE	2,8	9,1	1,1	0,1	0,3	0,2	0,1	0,6	14,2
E	1,4	4,0	1,7	0,3	0,3	0,2	0,2	0,4	8,5
SE	0,2	0,6	0,5	0,5	0,3	0,1	0,1	0,2	2,5
S	0,3	0,7	0,6	0,7	2,7	1,2	0,4	0,5	7,1
SW	0,4	0,2	0,3	0,4	10,3	12,9	5,4	3,8	33,7
W	0,3	0,2	0,2	0,1	1,2	1,7	6,2	5,0	14,8
NW	0,5	0,2	0,2	0,1	0,2	0,2	1,7	6,8	9,9
Total	8,7	16,8	5,2	2,4	15,5	16,6	14,2	20,5	100,0

e) Île Rouge and Mont-Joli, 1994-2003

Station No 1 : Mont-Joli	Station No 2 : Île Rouge N	NE	E	SE	S	SW	W	NW	Total
N	1,7	1,3	0,5	0,1	0,4	0,2	0,2	2,1	6,5
NE	2,6	7,4	0,8	0,1	0,2	0,1	0,1	0,6	11,9
E	1,1	3,3	1,0	0,2	0,2	0,2	0,1	0,3	6,5
SE	1,0	2,6	1,3	0,9	1,2	0,6	0,3	0,7	8,7
S	0,8	1,2	0,7	0,7	4,6	3,8	1,0	1,7	14,5
SW	0,3	0,2	0,2	0,2	4,5	6,9	4,5	3,8	20,6
W	0,5	0,3	0,4	0,2	3,1	3,6	7,1	7,6	22,8
NW	0,7	0,4	0,3	0,1	0,4	0,3	0,9	5,3	8,4
Total	8,7	16,8	5,2	2,5	14,6	15,8	14,3	22,1	100,0

f) Mont-Joli and Île Bicquette, 1994-2003

Station No 1 : Île Bicquette	Station No 2 : Mont-Joli N	NE	E	SE	S	SW	W	NW	Total
N	3,0	1,4	0,6	0,7	0,9	0,3	0,6	1,6	9,0
NE	1,4	7,5	2,5	1,4	0,7	0,2	0,3	0,4	14,1
E	0,7	2,3	2,4	1,8	0,5	0,1	0,2	0,2	8,3
SE	0,1	0,1	0,3	1,3	0,5	0,1	0,1	0,0	2,5
S	0,2	0,1	0,2	1,8	3,3	0,6	0,7	0,2	7,0
SW	0,4	0,2	0,2	0,9	6,5	15,6	9,8	0,7	34,2
W	0,2	0,1	0,1	0,4	1,4	3,9	8,1	0,8	14,9
NW	0,4	0,1	0,1	0,3	0,5	0,7	3,9	3,9	9,9
Total	6,3	11,7	6,3	8,6	14,4	21,4	23,5	7,8	100,0

Table 2.6 – Distribution of directions observed simultaneously at Rivière-du-Loup, Île Rouge, Mont-Joli, Île Bicquette and Rivière-du-Loup ferry wharf.

g) Île rouge and Rivière-du-Loup ferry wharf, 2001 - 2003

Station No 1 : Île Rouge	Station No 2 : Quai N	NE	E	SE	S	SW	W	NW	Total
N	2,2	3,7	0,4	0,2	0,1	0,4	0,1	0,6	7,6
NE	3,4	11,9	0,4	0,3	0,1	0,9	0,0	0,4	17,5
E	0,6	2,3	0,3	0,4	0,1	0,5	0,0	0,2	4,4
SE	0,1	0,3	0,2	0,3	0,3	0,7	0,0	0,0	1,9
S	0,0	0,2	0,1	0,6	1,5	13,7	0,2	0,2	16,5
SW	0,0	0,2	0,1	0,3	1,3	16,7	0,2	0,1	19,1
W	0,3	0,5	0,2	0,1	0,4	4,9	2,5	4,0	13,0
NW	2,2	1,8	0,7	0,4	0,4	2,6	1,1	10,8	20,0
Total	8,9	20,9	2,4	2,6	4,2	40,5	4,1	16,4	100,0

2.3 WIND CONDITIONS AT THE SITES UNDER STUDY

2.3.1 Exceedance probabilities of 25 and 35 knot winds

The wind data sets used in this assessment are presented in Appendix B. Statistics of the Lauzon weather station cover a period of 13 years, from 1991 to 2003; those of the Île Rouge station include 16 years, from 1988 to 2003. The tables shown in the appendix give monthly results as well as annual summaries of the wind velocities and directions based on hourly records.

Statistics on 25 knot and 35 knot velocities have been extracted from these tables and are presented in Table 2.7 hereafter. The numbers in the table represent exceedance probabilities of these wind velocities for all directions combined. These wind speeds are particularly important since they represent operational limits generally in use in LNG terminals to ensure safety of the activities. The first velocity (25 knots) is used as a limit beyond which berthing or unberthing manoeuvres are generally not allowed; the second limit (35 knots) corresponds to a requirement to interrupt unloading operation before disconnecting the unloading arms between the ship and the terminal. For both stations winter conditions are significantly more severe than conditions on an annual basis.

Table 2.7 - Probabilities (%) of 25 knot and 35 knot wind velocities

Lauzon	**Annual (%)**	**Winter (%)**				
(Lévis-Beaumont Site)		December	January	February	March	Season
25 knots (46 km/h)	1.165	1.490	1.336	1.635	2.322	1.697
35 knots (66 km/h)	0.030	0.023	0.024	0.027	0.190	0.067

Île Rouge	**Annual (%)**	**Winter (%)**				
(Gros Cacouna Site)		December	January	February	March	Season
25 knots (46 km/h)	7.917	19.097	18.397	17.903	11.872	16.790
35 knots (66 km/h)	0.634	2.001	1.922	1.407	0.945	1.573

2.3.2 Durations of Wind Episodes

The duration of the wind episodes is also an important parameter in the assessment of the operating conditions of the terminal. Tables 2.8 and 2.9 summarize the statistics of durations of sustained winds in excess of 25 and 35 kn at Lauzon ant Ïle-Rouge; the analysis is presented on an full-year basis, and for winter months only. From these tables it is interesting to notice that the longest annual 25 knot episodes are in the range of 30-40 hours at the Lauzon station and can reach 60 hours at Île Rouge. The longest durations for the 35 knot velocity are in the range of 8-12 hours and 20-30 hours respectively. Only rare events obviously have such long durations.

It is also clear that for any given duration of down-time due to wind, the probabilities are in all cases much higher at Gros Cacouna than at Lévis-Beaumont, between 6 and 25 times approximately .

Table 2.8 – Comparison of Wind Episode Durations – 25 knot Velocity

Annual

Lévis-Beaumont Duration (hours)	Lévis-Beaumont Ann. Cumul. Nb. Hours	Lévis-Beaumont Exceedance prob. (%)	Gros Cacouna Duration (hours)	Gros Cacouna Ann. Cumul. Nb. Hours	Gros Cacouna Exceedance prob. (%)
1	120,7	1,1649	1	701,3	7,9174
6	72,8	0,7024	6	503,7	5,6862
9	57,2	0,5517	9	398,7	4,5011
12	42,8	0,4136	12	308,5	3,4828
15	29,8	0,2881	15	237,3	2,6785
18	24,9	0,2406	18	170,2	1,9216
21	17,5	0,1693	21	119,7	1,3517
24	9,0	0,0869	24	95,1	1,0739
27	7,1	0,0683	27	73,3	0,8276
30	2,9	0,0282	30	55,7	0,6285
33	2,9	0,0282	33	45,7	0,5157
36	2,9	0,0282	36	34,7	0,3921
39	0,0	0,0000	39	34,7	0,3921
			42	29,9	0,3372
			45	21,5	0,2428
			48	13,2	0,1494
			51	10,4	0,1168
			54	3,7	0,0420
			57	3,7	0,0420
			60	3,7	0,0420
			62	3,7	0,0420

Winter

Lévis-Beaumont Duration (hours)	Lévis-Beaumont Ann. Cumul. Nb. Hours	Lévis-Beaumont Exceedance prob. (%)	Gros Cacouna Duration (hours)	Gros Cacouna Ann. Cumul. Nb. Hours	Gros Cacouna Exceedance prob. (%)
1	55,9	1,6978	1	498,3	16,7883
6	36,5	1,1093	6	387,6	13,0587
9	28,8	0,8734	9	316,6	10,6685
12	21,3	0,6469	12	246,2	8,2952
15	16,2	0,4928	15	190,4	6,4167
18	13,8	0,4204	18	138,2	4,6562
21	10,9	0,3316	21	96,0	3,2347
24	4,2	0,1261	24	79,6	2,6808
27	4,2	0,1261	27	59,4	2,0006
30	0,0	0,0000	30	45,4	1,5289
			33	35,6	1,2004
			36	29,3	0,9856
			39	29,3	0,9856
			42	24,2	0,8150
			45	18,7	0,6297
			48	10,1	0,3391
			51	7,1	0,2380
			54	3,9	0,1306
			57	3,9	0,1306
			60	3,9	0,1306
			62	3,9	0,1306

Table 2.9 – Comparison of wind Episode Durations - 35 knot Wind Velocity

Annual					
Lévis-Beaumont			Gros Cacouna		
Duration (hours)	Ann. Cumul. Nb. Hours	Exceedance prob. (%)	Duration (hours)	Ann. Cumul. Nb. Hours	Exceedance prob. (%)
1	4,7	0,0300	1	68,8	0,6335
6	2,7	0,0172	6	33,3	0,3064
9	1,7	0,0108	9	18,1	0,1670
12	0,9	0,0059	12	12,8	0,1181
			15	6,3	0,0576
			18	3,3	0,0299
			21	2,0	0,0184
			24	2,0	0,0184
			27	2,0	0,0184
			30	2,0	0,0184
			32	2,0	0,0184

Winter					
Lévis-Beaumont			Gros Cacouna		
Duration (hours)	Ann. Cumul. Nb. Hours	Exceedance prob. (%)	Duration (hours)	Ann. Cumul. Nb. Hours	Exceedance prob. (%)
1	2,3	0,0672	1	57,9	1,5723
6	1,0	0,0291	6	28,6	0,7777
9	0,0	0,0000	9	15,3	0,4143
			12	9,9	0,2700
			15	4,3	0,1155
			18	1,3	0,0340
			21	0,0	0,0000

3. ICE CONDITIONS

3.1 INTRODUCTION

The ice conditions at the proposed sites on the South shore of the St. Lawrence River were investigated primarily by an extensive analysis of river ice charts gathered by Environment Canada over the last 20 years, interviews of ship masters, pilots, ice breaker commanders and ice observers, and some analysis of relevant weather data (PCAI, 2003). These studies were intended to provide input to the preliminary site selection process.

In the pre-feasibility study, the specific issue of assessing the probable delays to marine operations was raised, and this issue has become one of the key decision factors in the selection of the site to establish the future marine terminal.

This complementary ice study is intended to analyse the data in more detail with a specific focus on this important issue. Only Lévis-Beaumont and Cacouna are considered at this stage of the project. As before, the same three information sources are examined in this complementary analytical investigation, namely ice chart data, weather data and interviews. As mentioned in earlier studies, the analytical results will need to be verified by ground proofing in the field during subsequent winters.

In an earlier study of ice conditions near Quebec City, the conditions having caused an ice jam which paralysed winter navigation for 4 consecutive days in March 1984 were examined. Correlation among meteorological data indicated that conditions similar to those existing at the time of this rare event are likely to occur once in 20 to 25 years. This rare extreme event actually paralyzed navigation in the Quebec Bridge area, some 20 km upstream from the current project site. From testimonies received from CCG De-Icing Service officers, it appears that there has never been any interruption of the commercial navigation activities in the Lévis-Beaumont area since 1957, starting date of the ice managing activities. It is therefore believed that ice is not a controlling factor on navigation in this sector, as long as the active de-icing program is maintained by the Canadian Coast Guard (CCG) every year. Therefore the emphasis in this complementary climatological study is on the Cacouna site, although Pointe-de-la-Martinière is also discussed, for comparison. Ice data from Pointe-de-la-Martinière (PM) is considered representative of the conditions at Lévis-Beaumont, which is located only 3 km downstream in the same channel on the south side of Île d'Orléans.

Although there is no anecdotic information describing any specific extreme ice condition off the Island of Gros Cacouna, the ice charts do indicate that sustained conditions of very high ice coverage and thick ice are frequent. However, resulting impact on navigation cannot be ascertained other than by educated opinions, including those of pilots and navigators who are familiar with the general area.

In this chapter, the assessment of delays to navigation at Cacouna is obtained by several approaches:

- comparison between ice data statistics between PM and Cacouna;
- visual examination of representative ice charts to provide insight into the dynamics of the ice cover;
- statistical analysis of wind data;
- statistical analysis of ice chart data.

3.2 ICE CONDITIONS STATISTICS AT POINTE-DE-LA-MARTINIÈRE AND CACOUNA

The symbols used to identify the ice cover are explained in Figure 3.1. The main parameters, and limiting values at the site, are as follows:

- ice concentration C, usually expressed in tenths (0 is no ice, 10 is full cover),
- stage of development S or thickness, coded from 1 for new ice to 7 for 30-70 cm ice and 1• ("1 dot") for 70-120 cm ice,
- and floe size F, coded 1 for brash ice to 5 for big floes of 500 to 2000 m.

The histograms presented in Figures 3.2 to 3.4 summarize the statistical distribution of these key parameters at PM and at Cacouna for each winter month. The data was extracted from the analysis of 1322 and 651 ice charts collected respectively at these locations between 1982 and 2003 (PCAI, 2003 – see Appendix D).

It has been noted that the ice data used in this study has not been collected to analyse conditions at the specific locations of interest, nor have they been obtained by random sampling. The ice charts are prepared only when an ice patrol is needed, in response to the objectives and constraints of the CCG ice management program, whose mission is to keep navigation going everywhere along the St. Lawrence. Consequently, the data set is not perfectly objective or scientific. Because of this, the ice conditions described in the data set are likely to be biased on the conservative side, tending to show somewhat more severe conditions.

Figures 3.2a and b illustrate the distribution of ice concentrations at the two sites. In Figure 3.2b, we note that ice concentrations of 9 and above are prevalent in 40% of the charts at Cacouna. It is also noted that the most frequent concentration at PM is 8 tenths (23%), while at Cacouna, concentrations of 1 or less and 9 and more are about equally frequent (27%). This illustrates the fact that the ice cover comes and goes at Cacouna.

Figures 3.3a and b illustrate the distribution of ice thickness (or development stage S) at the two sites. The distribution of the thickest fraction of ice identified in the egg code is shown. This is therefore not an indication of the average ice thickness but only of the thickest parts of the ice cover. 30 cm and thicker ice is identified in about 35% of ice charts at Cacouna, 45% at PM.

Figures 3.4a and b illustrate the distribution of floe sizes at the two sites. Here again this is not an average size, but the largest size of any fraction of the ice cover. Floes 100 m and larger occur in 40% of the charts at Cacouna, only 12% at PM.

3.3 ICE DYNAMICS AT CACOUNA

The ice climate near the Gros Cacouna site is characterized by the presence of a highly variable ice cover, which can be very heavy at times, but can also move rapidly with changing atmospheric conditions.

Since winds have a very important component from the NW sector, ice normally tends to concentrate along the South shore, but remains very dynamic because of strong tidal currents (figures 3.5 a, b, c). The net and predominant flow direction for ice is to the Northeast. The presence of Île Verte causes some convergence of the ice on the north shore. Moving ice can be slowed or even trapped in the triangular area formed by the Western tip of Cacouna Island, the Eastern tip of Île Verte and the shoreline. As reported in early work on the site (Robitaille, 1957), winds from the N and NW can cause ice to form a belt fringing the NW shore of the island, stopping temporarily the net progression of the ice cover. This scenario is investigated here by examining relevant historic records of ice and weather data.

But first, we examine Figure 3.6 in order to identify the severity of historical ice seasons. The graph shows the cumulative freezing-degree-days (FDDs) computed from the weather records at Mont-Joli from 1980 to 2002. Winter seasons 1992, 1993 and 1994 have clearly been severe ice seasons. 1994 is selected to illustrate the ice processes, since weather data is not available at all relevant stations for previous years.

Three similar graphs are included in Figure 3.7a, b and c, in which the hourly variation of wind speed, wind direction and air temperature is plotted for weather stations Mont-Joli, Rivière-du-loup and Île Rouge respectively. The records are plotted for the months of February and March 1994. The wind direction is expressed as the azimuth in degrees, and therefore it varies between 0 and 360 degrees. Wind speed is plotted as a yellow line where zero velocity has been plotted at the 36 ordinate, so that speed and direction are not overlapped.

There is no significant difference in the temperature variation among the sites. For winds, as expected from the conclusions of the previous chapter, wind speeds are very high at Île Rouge (peak is 82 km/h), lowest at Rivière-du-loup (36 km/h) and somewhere in between at Mont-Joli (59 km/h). Wind directions follow similar patterns at the three sites. Winds from the NW sector (azimuth 270 to 360), which are of a particular interest for ice, are clearly more predominant at Rivière-du-loup and Île Rouge (see Table 2.4). We also note that the periods of sustained winds from this sector are more persistent at Île Rouge. This station, located on the river, provides the wind data set most closely correlated to that collected at the Rivière-du-loup wharf, and therefore most representative of the site under study at Cacouna.

Focusing now on Figure 3.7c, where all total ice concentrations read from all ice charts prepared during the period (see Appendix C) are shown, it is quite remarkable that conditions of 9 to 10 tenths of ice concentrations always follow periods of sustained winds from the NW sector. Conversely, conditions with little or no ice (concentration < 1) typically occur when winds are weak or from another direction.

Also worthy of notice in Figure 3.7c is the fact that there is no ice data in the last portion of March. Although winds from March 16 to 21 were strong and from the NW, ice conditions were not of concern because of the mild temperatures experienced in the first two weeks of the month.

We are therefore lead to the observation that severe ice conditions at Cacouna are correlated to persistent winds from the NW, and sustained temperatures below –5 degrees for several days before and during these persistent winds.

3.4 Analysis of wind data, as relevant to ice

A first cut conservative estimate of unfavourable ice conditions at Cacouna can be derived from the analysis of wind data at Île Rouge. However, we must not double count wind conditions in excess of 25 kn (46 km/h) which are already attributed to delays due to wind conditions. The following table summarizes the combined frequency of winds from the WNW, NW, NNW and N at this station. Wind velocities above 15 knots are considered in this assessment since it is assumed that lower velocity winds are not powerful enough to initiate movement of ice floes toward the south shore. This assumption is somewhat arbitrary but still appears more realistic than considering all velocities. Another conservative assumption behind this assessment is that temperatures are always cold enough throughout all winter months to generate ice on the river. However, the month of December has been excluded since ice thickness is not important at the beginning of the season.

NW winds (Île Rouge Station, 1988-2003)	**January**	**February**	**March**	**Winter months**	**All year**
All velocities	42.1%	42.8%	31.3%	38.8%	32.1%
Velocities > 15 kn (27 km/h)	31.9%	31.3%	19.0%	27.4%	17.9%
Velocities > 25 kn (46 km/h)	10.9%	11.2%	6.6%	9.6%	7.9%
Velocities 15 to 25 kn	21.0%	20.1%	12.4%	17.8%	10.0%

We would conclude from this preliminary assessment that there is a 20 to 30 % probability that any single marine operation (berthing, unberthing) during the 3 winter months would be delayed due to ice.

3.5 Analysis of ice data, as relevant to berthing/ unberthing manoeuvres

According to our discussions with many navigators, pilots and ice observers, commercial ships are essentially unaffected by ice less than 15 cm thick. For a large and powerful LNG carrier, much thicker ice would probably not affect its capability to sail.

Current practice at Ultramar is to have open water in front of the dock for berthing so that no ice becomes entrapped between the ship and the structures. This approach is assumed to be valid for the LNG terminal as well. At Ultramar, berthing and unberthing are done with a current. At almost any time during the winter, ice conditions are such that clearing the dock front from ice can be done using tug boats, using the current to move ice along; the dock can then be shielded from incoming ice during berthing by a tug boat anchored up-current onto the protective ice dolphin.

We will assume that ice can become an obstacle to the operation of a marine terminal when the ice concentration equals or exceeds 9 and ice thickness is more than 15-30 cm.

From the database generated during the study of ice conditions at selected sites along the St. Lawrence River (PCAI, 2003), all ice charts showing total ice concentrations of 9 tenths and above and in which at least some portion of the ice cover is 30 cm and thicker were identified. The tables included in Appendix D provide these events for three locations, Cacouna, Pointe-de-la-Martinière and the Ultramar marine terminal.

By then computing the proportion of these ice events to the total number of charts in the sample, the following probabilities can be obtained:

	Number of ice charts with C > 9 and S > 7	**Total number of ice charts**	**Frequency**
Cacouna	129	651	19.8%
Pointe-de-la-Martinière (PM)	107	1322	8.1%
Ultramar terminal	156	1436	10.9%

These frequencies are somewhat conservative due to the selection bias discussed earlier, due to the fact that de-icing operations (and sampling of ice conditions) must address the worst conditions. In addition, we have been able to verify that marine operations at the Ultramar terminal have not been stopped a single time due to ice since the inauguration of the facility in 1971, largely due to a very effective de-icing program by the CCG and the know-how of the pilots of the Lower-St. Lawrence.

On this basis, we would conclude that there should not be any delay to navigation due to ice at Lévis-Beaumont, where ice conditions are similar to those at PM, since these conditions very similar to those at the Ultramar terminal.

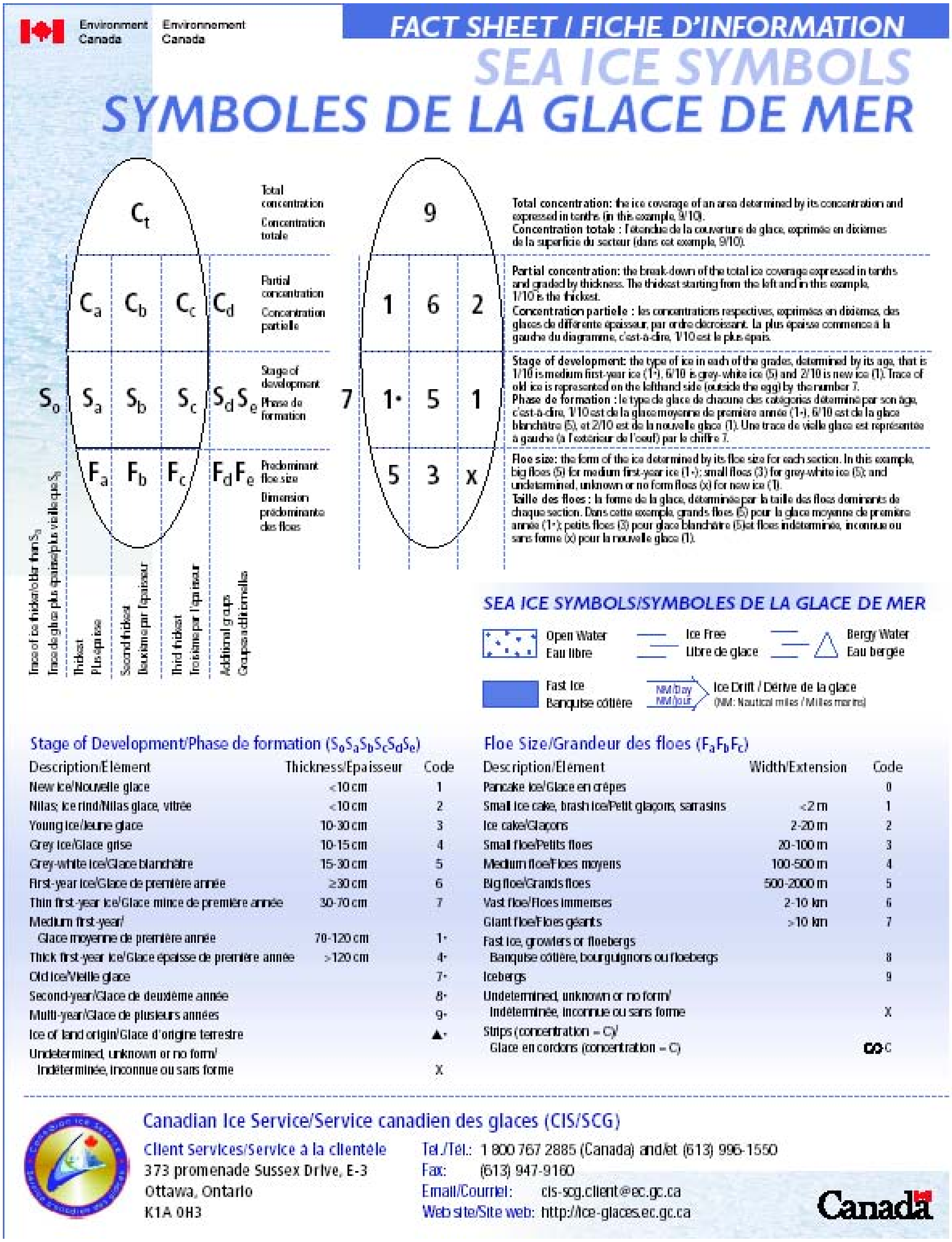
For Cacouna, the presence of a dense cover of thick ice occurs twice as frequently compared to PM and Ultramar.. We believe 10% to 15% is a reasonable estimate of down time frequencyThis estimate is in agreement with the educated guess made by the pilots during our interview.

On the other hand, ice tends to encroach onto the site in short periods of time but can also clear the site rapidly when wind shifts directions. It is probable that the construction of new facilities near the Island would tend to stabilize the ice cover between the dock and the shoreline, and perhaps capture more ice in the area for longer periods than in the current conditions. The shear zone (or 'chariot') which develops between shorefast ice and moving ice floes can create a barrier of piled-up broken ice, which adds to the difficulty of navigation. Therefore the hydraulic conditions have to be considered carefully in the design of the wharf. Once again, de-icing operations would also be essential.

3.6 CONCLUSION ON THE EFFECT OF ICE IN GROS CACOUNA

Determining the effect of ice on the marine operations of the future LNG terminal in Gros Cacouna is not a straightforward task: some subjective judgment is involved, using on the one hand objective data and, on the other hand, subjective information from LNG or oil carrier navigators, ice observers, pilots, and other specialists. A few analytical approaches have been proposed in the current chapter. This work leads us to believe that between 10 % and 30 % of the LNG deliveries might be delayed during the winter period, for durations that may exceed a few days in some cases since they are related to west-northerly winds. These winds are very frequent during the winter season, with a prevalence of approximately 40%.

There is still a lack of knowledge on the ice issue in Gros Cacouna since the existing shipping activity during winter is low compared to other places such as Quebec City. Manoeuvering at night in the Cacouna area in presence of large floes may also raise questions. Based on comments received from St.Lawrence pilots, it appears quite clearly that delays due to ice are to be expected at Cacouna. For Lévis-Beaumont the conditions are much more predictable and navigation there is much easier compared to Gros-Cacouna, in the presence of ice; it is difficult to give better quantitative results on these conclusions.



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FACT SHEET / FICHE D'INFORMATION

SEA ICE SYMBOLS
SYMBOLES DE LA GLACE DE MER

Total concentration: the ice coverage of an area determined by its concentration and expressed in tenths (in this example, 9/10).
Concentration totale : l'étendue de la couverture de glace, exprimée en dixièmes de la superficie du secteur (dans cet exemple, 9/10).

Partial concentration: the break-down of the total ice coverage expressed in tenths and graded by thickness. The thickest starting from the left and in this example, 1/10 is the thickest.
Concentration partielle : les concentrations respectives, exprimées en dixièmes, des glaces de différente épaisseur, par ordre décroissant. La plus épaisse commence à la gauche du diagramme, c'est-à-dire, 1/10 est le plus épais.

Stage of development: the type of ice in each of the grades, determined by its age, that is 1/10 is medium first-year ice (1•), 6/10 is grey-white ice (5) and 2/10 is new ice (1). Trace of old ice is represented on the lefthand side (outside the egg) by the number 7.
Phase de formation : le type de glace de chacune des catégories déterminé par son âge, c'est-à-dire, 1/10 est de la glace moyenne de première année (1•), 6/10 est de la glace blanchâtre (5), et 2/10 est de la nouvelle glace (1). Une trace de vielle glace est représentée à gauche (à l'extérieur de l'oeuf) par le chiffre 7.

Floe size: the form of the ice determined by its floe size for each section. In this example, big floes (5) for medium first-year ice (1•); small floes (3) for grey-white ice (5); and undetermined, unknown or no form floes (x) for new ice (1).
Taille des floes : la forme de la glace, déterminée par la taille des floes dominants de chaque section. Dans cette exemple, grands floes (5) pour la glace moyenne de première année (1•); petits floes (3) pour glace blanchâtre (5)et floes indéterminés, inconnue ou sans forme (x) pour la nouvelle glace (1).

SEA ICE SYMBOLS/SYMBOLES DE LA GLACE DE MER

Open Water / Eau libre
Ice Free / Libre de glace
Bergy Water / Eau bergée
Fast Ice / Banquise côtière
NM/Day NM/Jour — Ice Drift / Dérive de la glace (NM: Nautical miles / Milles marins)

Stage of Development/Phase de formation ($S_oS_aS_bS_cS_dS_e$)

Description/Élément	Thickness/Epaisseur	Code
New ice/Nouvelle glace	<10 cm	1
Nilas; ice rind/Nilas glace, vitrée	<10 cm	2
Young ice/Jeune glace	10-30 cm	3
Grey ice/Glace grise	10-15 cm	4
Grey-white ice/Glace blanchâtre	15-30 cm	5
First-year ice/Glace de première année	≥30 cm	6
Thin first-year ice/Glace mince de première année	30-70 cm	7
Medium first-year/ Glace moyenne de première année	70-120 cm	1•
Thick first-year ice/Glace épaisse de première année	>120 cm	4•
Old ice/Vieille glace		7•
Second-year/Glace de deuxième année		8•
Multi-year/Glace de plusieurs années		9•
Ice of land origin/Glace d'origine terrestre		▲•
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X

Floe Size/Grandeur des floes ($F_aF_bF_c$)

Description/Élément	Width/Extension	Code
Pancake ice/Glace en crêpes		0
Small ice cake, brash ice/Petit glaçons, sarrasins	<2 m	1
Ice cake/Glaçons	2-20 m	2
Small floe/Petits floes	20-100 m	3
Medium floe/Floes moyens	100-500 m	4
Big floe/Grands floes	500-2000 m	5
Vast floe/Floes immenses	2-10 km	6
Giant floe/Floes géants	>10 km	7
Fast ice, growlers or floebergs Banquise côtière, bourguignons ou floebergs		8
Icebergs		9
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X
Strips (concentration = C)/ Glace en cordons (concentration = C)		∞C

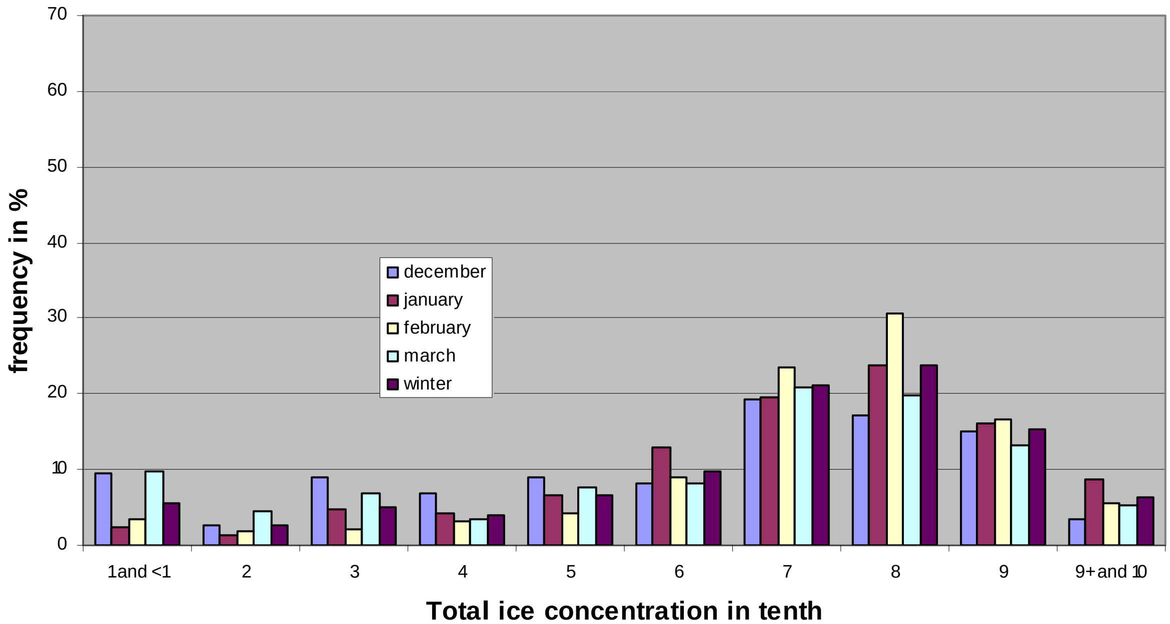
Canadian Ice Service/Service canadien des glaces (CIS/SCG)

Client Services/Service à la clientèle
373 promenade Sussex Drive, E-3
Ottawa, Ontario
K1A 0H3

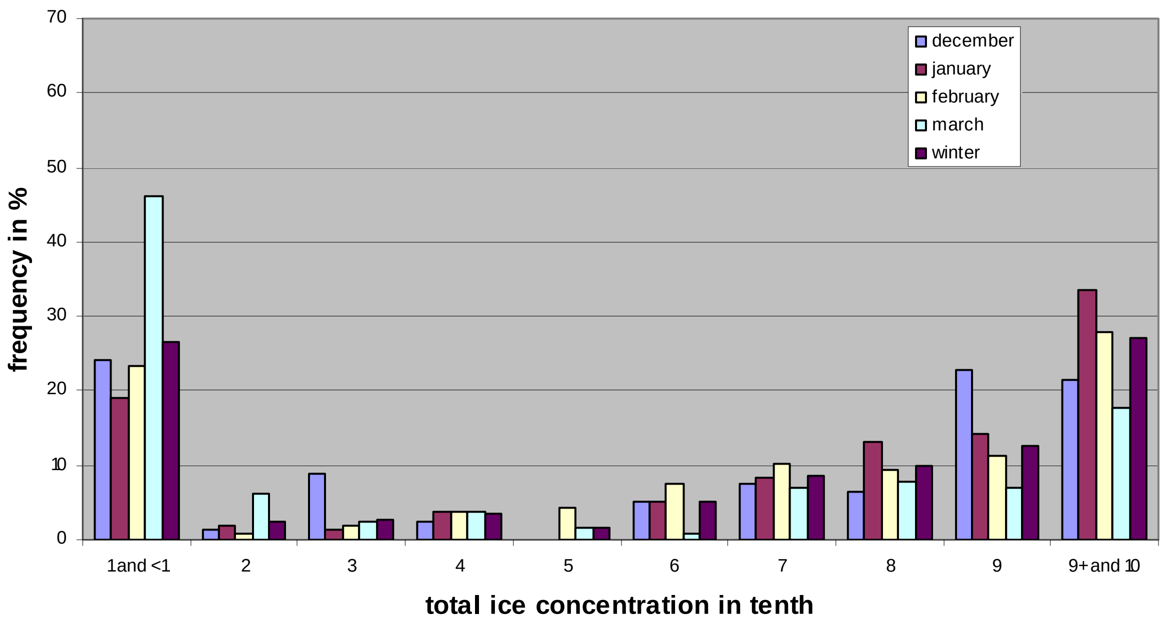
Tel./Tél.: 1 800 767 2885 (Canada) and/et (613) 996-1550
Fax: (613) 947-9160
Email/Courriel: cis-scg.client@ec.gc.ca
Web site/Site web: http://ice-glaces.ec.gc.ca

Canada

Figure 3.1 - Identification of ice using the "egg" code

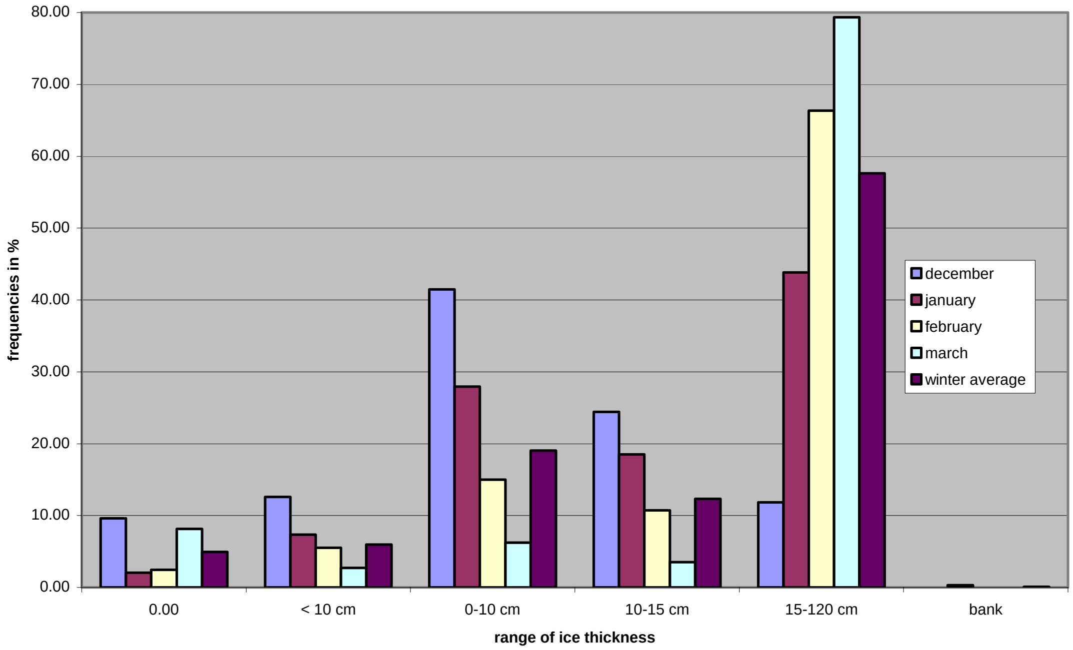


a) Pointe-de-la-Martinière

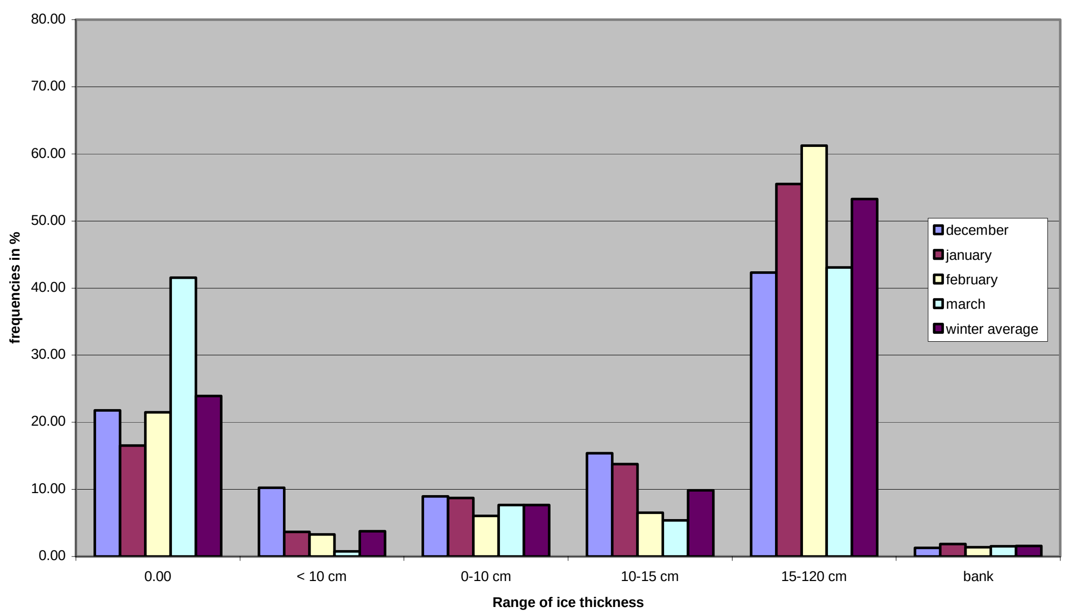


b) Cacouna

Figure 3.2 - Frequencies of total ice concentrations by month

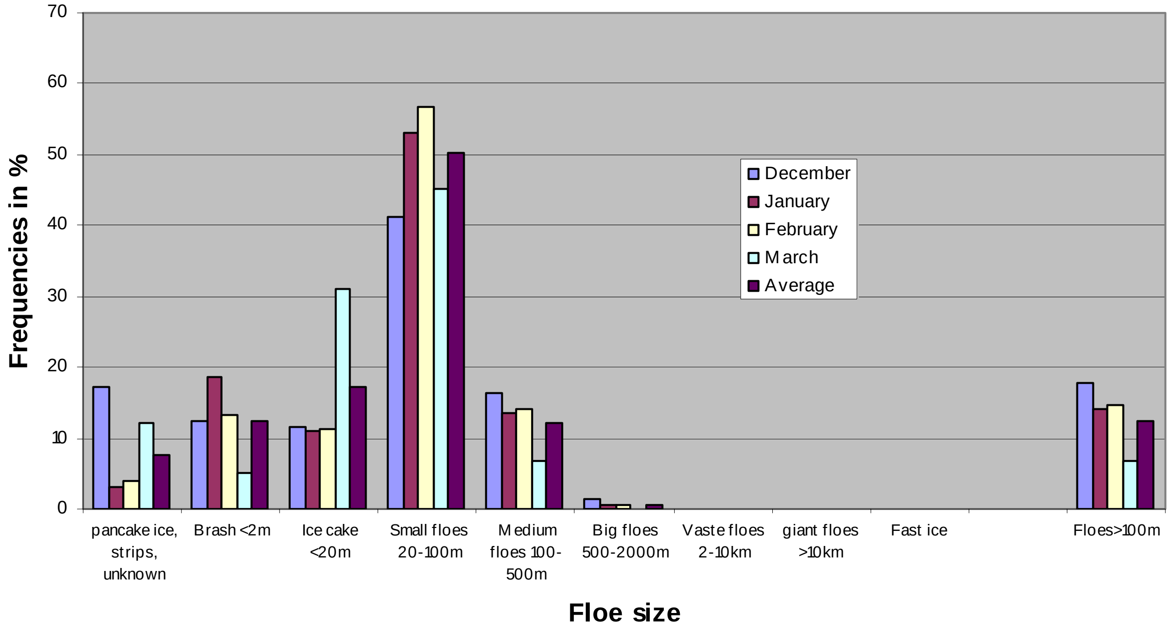


a) Pointe-de-la-Martinière

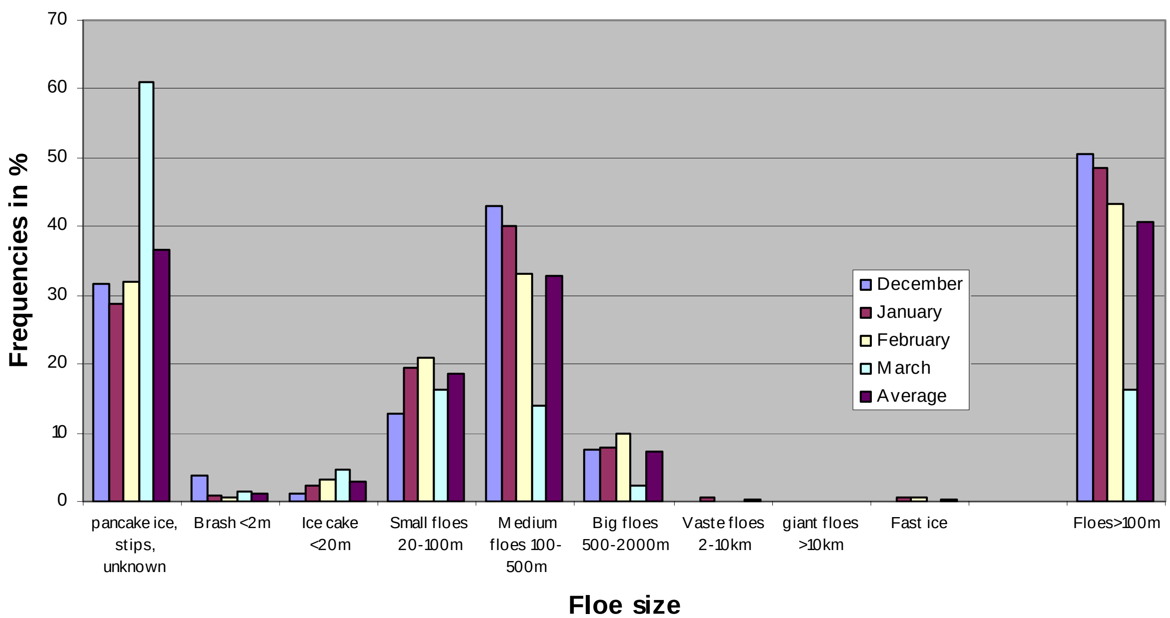


b) Cacouna

Figure 3.3 - Frequencies of maximum ice thickness by month

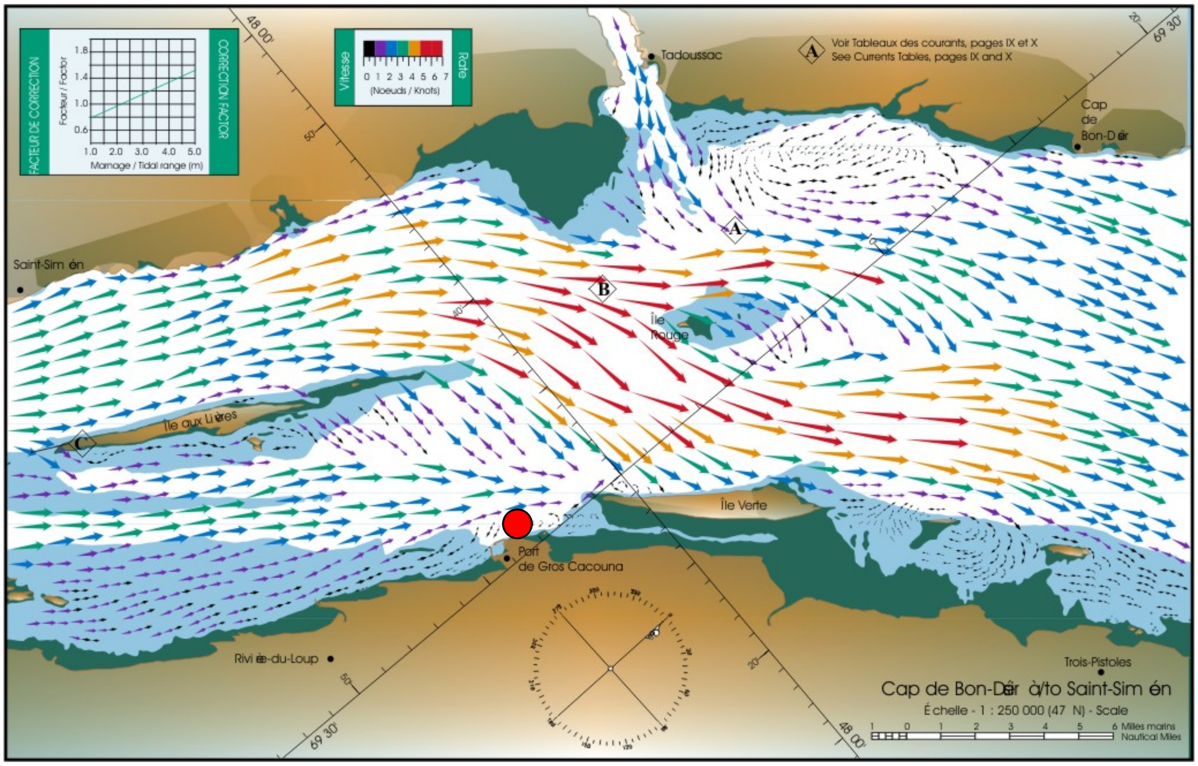


a) Pointe-de-la-Martinière

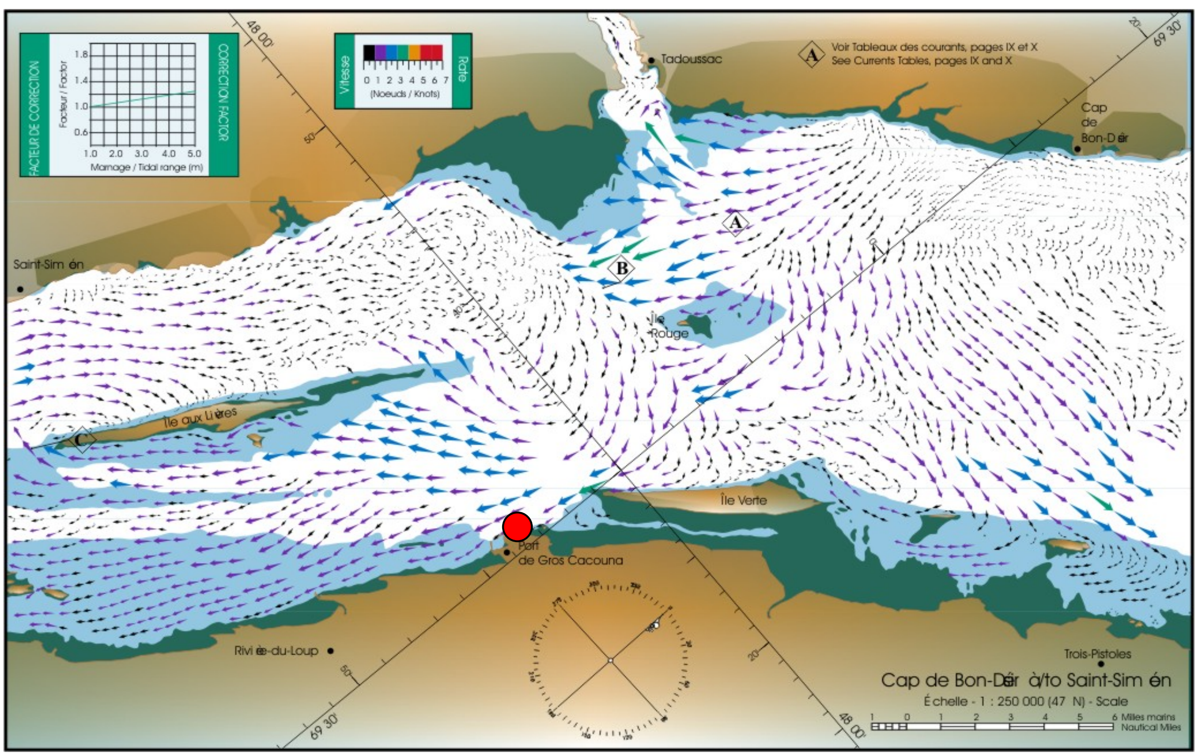


b) Cacouna

Figure 3.4 - Frequencies of maximum floe size by month

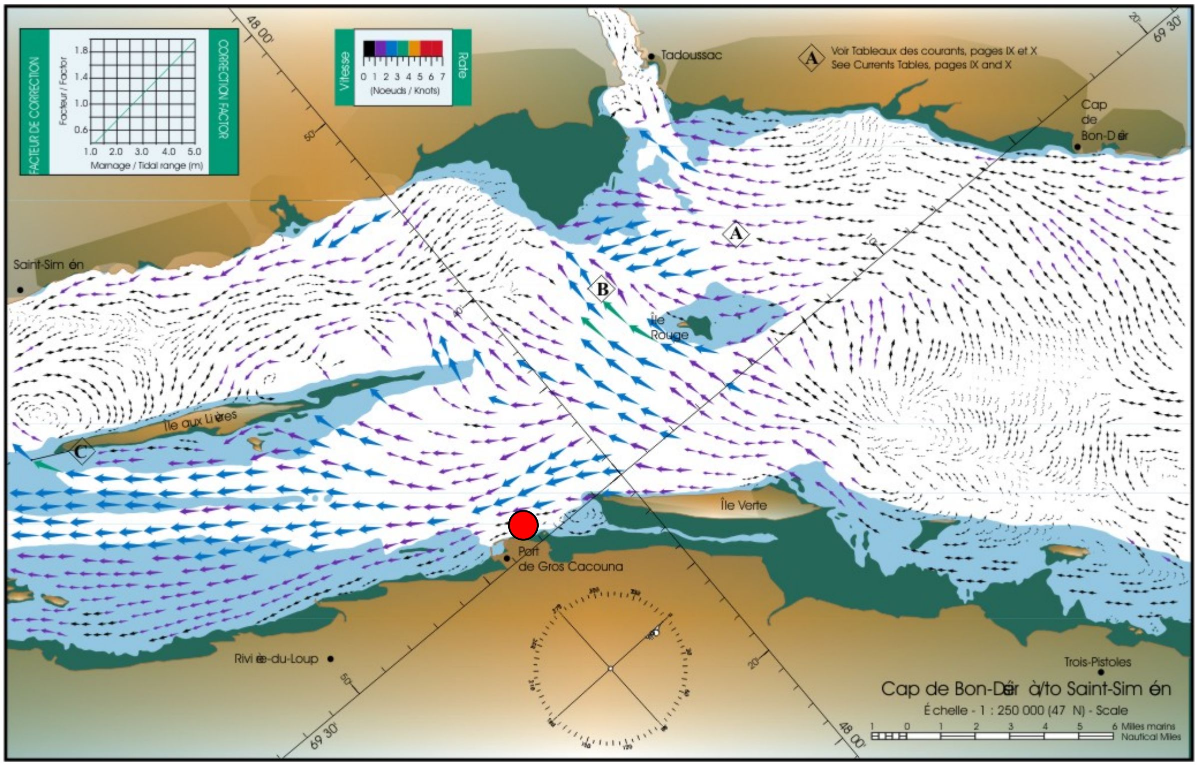


a) 0 to 1 hour after low water at Pointe-au-Père



b) 3 to 2 hours before high water at Pointe-au-Père

Figure 3.5 Tidal current patterns at Gros Cacouna and Ïle Verte



c) 1 to 0 hour before high water at Pointe-au-Père

Figure 3.5 - Tidal current patterns at Cacouna and Ïle Verte

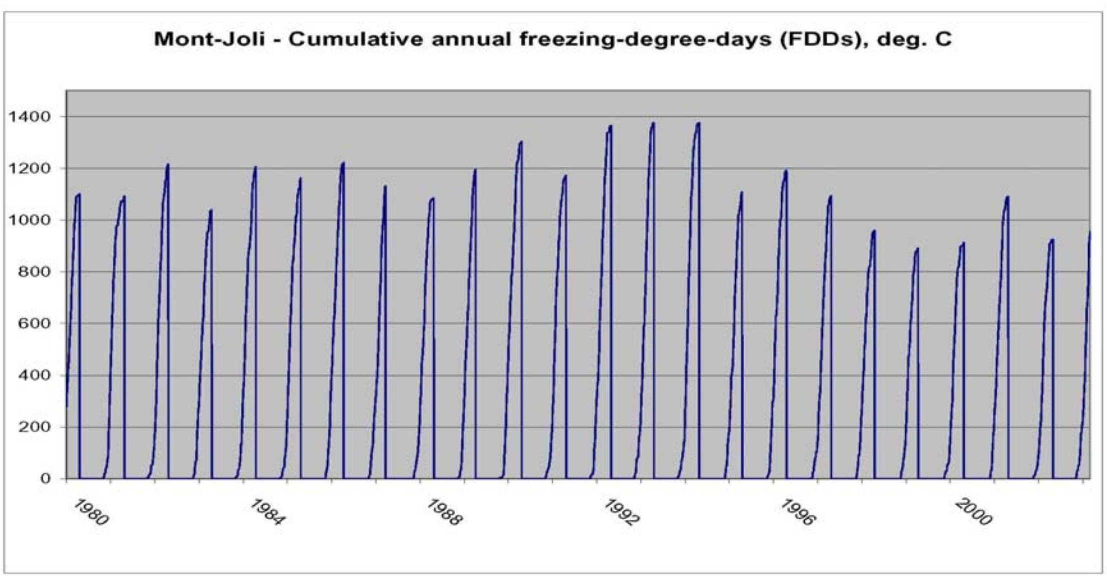
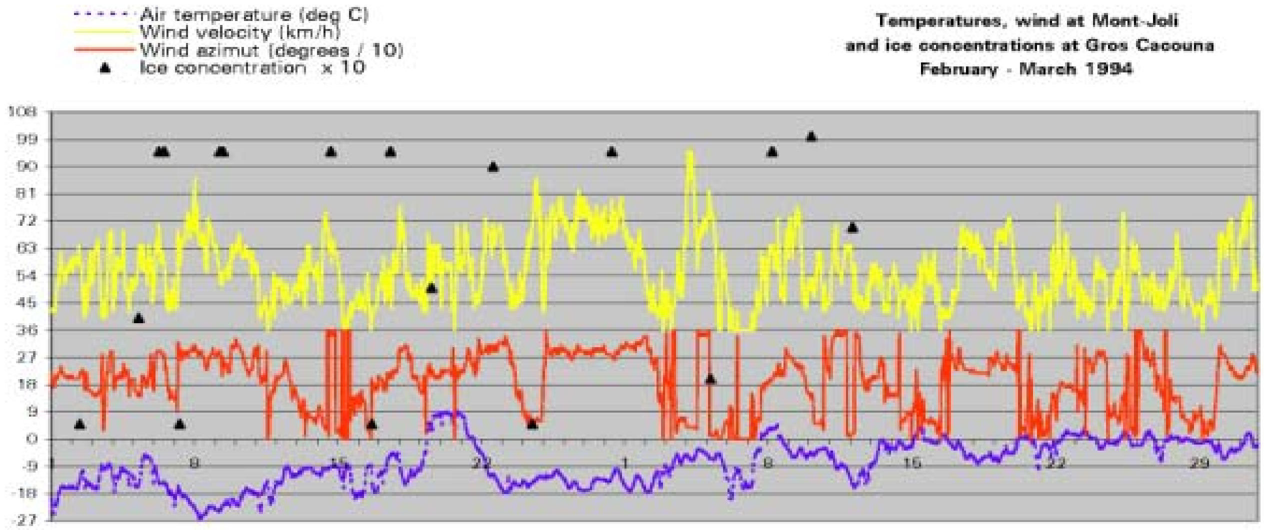
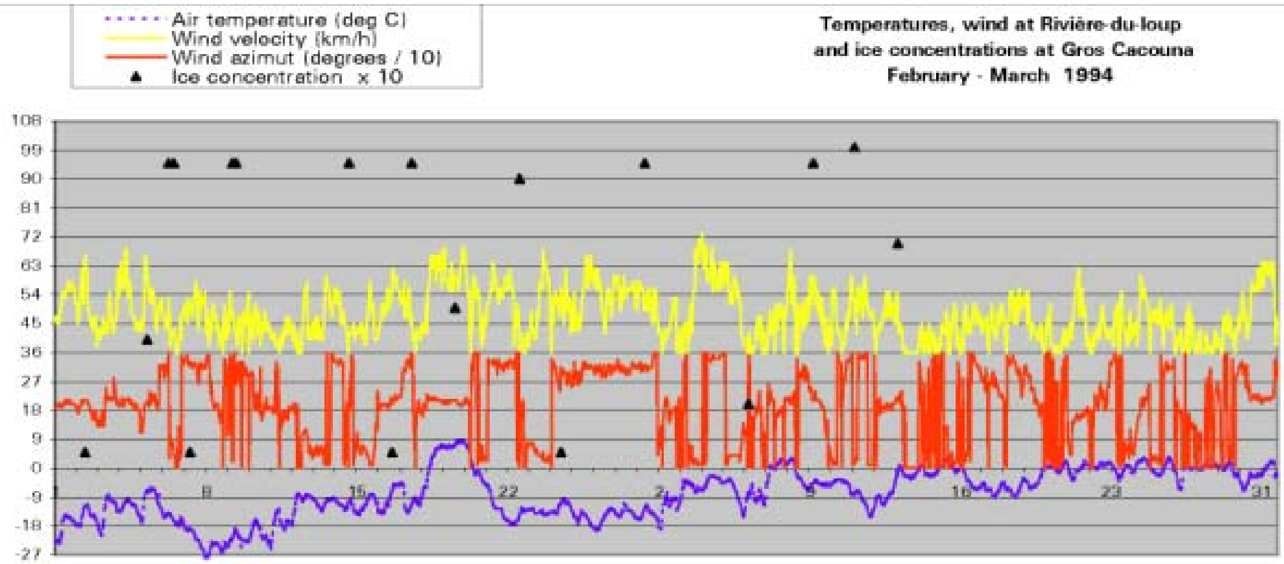


Figure 3.6 – Cumulative annual freezing-degree-days (FDDs), deg, C





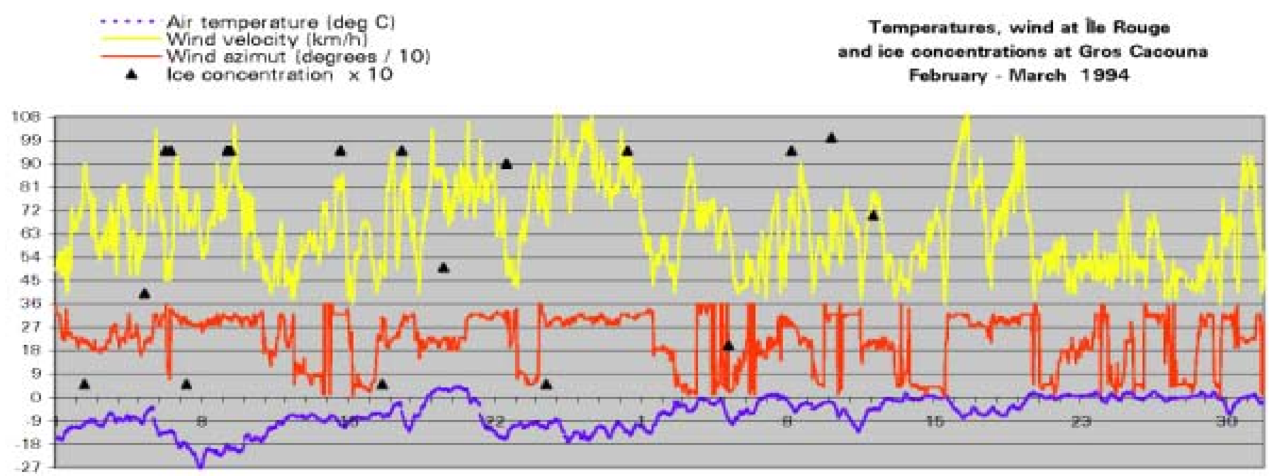


Figure 3.7 – Temperatures, wind and ice concentrations

4. VISIBILITY CONDITIONS

4.1 DEFINITIONS

This chapter presents an assessment of data describing visibility conditions as observed at 13 Environment Canada meteorological stations spreaded all along the maritime route to be followed by LNG carrier vessels, from their entry point in Canadian waters, in the Cabot Strait, up to Gros Cacouna and Lévis-Beaumont (see Figure 1.1). This data set consists of hourly visibility distances in kilometres given over the periods of time indicated in Table 1.1.

The main climatic elements likely to limit visibility are described on the Environment-Canada web site (http://www.climate.weatheroffice.ec.gc.ca/prods_servs/glossary_e.html). The following definitions are useful to understand the various climatic elements related to the visibility issue:

- visibility (km)

Visibility in kilometres (km) is the distance at which objects of suitable size can be seen and identified. Precipitation, fog, haze or other obstructions such as blowing snow or dust can reduce atmospheric visibility

- precipitation

Any and all forms of water, liquid or solid, that falls from clouds and reaches the ground. This includes drizzle, freezing drizzle, freezing rain, hail, ice crystals, ice pellets, rain, snow, snow pellets, and snow grains. Types of precipitation that originate aloft are classified under Liquid Precipitation, Freezing Precipitation and Frozen Precipitation. The measurement of precipitation is expressed in terms of vertical depth of water (or water equivalent in the case of solid forms) which reaches the ground during a stated period. The millimetre (mm) is the unit of measurement of liquid precipitation and the vertical depth of water or water equivalent is express to the nearest 0.2 mm. Less than 0.2 mm is called a "Trace". Snow depth is measured to the nearest 0.2 cm. Less than 0.2 cm is called a "Trace".

- fog

A visible aggregate of minute water droplets suspended in the air at or near the surface of the earth, reducing horizontal visibility to less than 1 km. It is created when the temperature and the dew point of the air have become the same, or nearly the same. It is rarely observed when the temperature and dew point differ by more than 2° C.

♦ ice fog

A type of fog composed of suspended particles of ice or ice crystals 20 to 100 microns resulting from the freezing of tiny supercooled water droplets. Ice fog occurs in clear, calm, stable air when temperatures are < -30° C

♦ blowing snow

Snow particles violently stirred up by wind to sufficient heights above the ground to reduce visibility to 10 km or less.

♦ smoke or haze

A suspension in the air of small particles produced by combustion. Viewed through smoke, the sun appears very red at sunrise and sunset. When high in the sky, smoke is tinged with orange. Smoke from nearby cities may be brown, dark gray or black. Smoke in extensive layers originating from forest fires give the sky a greenish-yellow hue. Evenly distributed smoke from distant sources is generally light gray or blue. In large quantities, smoke may be distinguished by its smell. Plumes of smoke of local origin are not reported as an atmospheric phenomenon

♦ drizzle

Fairly uniform precipitation composed of fine drops of water (diameter < 0.5 mm). Drizzle drops are too small to cause appreciable ripples on the surface of still water. The drops appear almost to float in the air, thus making visible even slight movements of air.

4.2 Visibility Conditions along the St. Lawrence

According to general practice in LNG terminals worldwide, a 1 nautical mile visibility distance (=1,8 km) represents a minimum limit below which berthing or unberthing manoeuvres are generally interrupted for safety reasons.

Table 4.1 gives, for each meteorological station considered and for each month of the year, the annual average number of hours with visibility distances less than 1.0 nautical mile. This same information is presented in a graphic form in Figure 4.1. As a (more or less) general trend, it can be noticed that December-January, March and July appear as three periods of the year during which limited visibility conditions occur more often than during other months. It can also be noticed that Gros Cacouna presents more frequent limited visibility conditions than Lévis-Beaumont in general.

Table 4.2 presents exceedance probabilities of limited visibility distances, less than 1,0 nautical mile, as calculated from each available data sets. Two series of data are presented: column (1) gives the results of the calculations based on all available data, whereas column (2) gives results established after excluding data with limited visibility combined with wind velocities exceeding 25 knots simultaneously, since the effect of these winds has already been considered in chapter 2.

As a general trend, it can be seen that the stations located in the Gulfe of Saint Lawrence show values somewhat higher than the stations located along the river. Gros Cacouna (Riviere-du-Loup station: 5.49%) shows conditions somewhat more restrictive than Lévis-Beaumont (Quebec station: 3.91%). Data from the Île Rouge station must be used cautiously considering the short period of time covered by these observations (2.4 years).

4.3 DURATIONS OF LIMITED VISIBILITY EPISODES

The durations of limited visibility episodes are assessed in Table 4.3. This Table gives exceedance probabilities for different durations, up to 35 hours for the Quebec City weather station and 26 hours for the Rivière-du-Loup (airport) station. In each case the cumulative probabilities of all durations combined add up to the probabilities given in Table 4.2. The mean durations in both cases are close to 5 or 6 hours.

Table 4.1 –Annual number of hours with visibility distances below 1.0 nautical mile, per month

No	Station	January	February	March	April	May	June	July	August	September	October	November	December
1	SYDNEY A, NS	49,1	59,0	66,5	81,0	81,4	52,0	41,7	29,7	23,6	22,0	42,3	41,5
2	PORT AUX BASQUES, NFLD	84,3	91,6	61,9	60,3	76,0	100,7	133,5	78,4	62,8	29,9	36,4	57,3
3	ILES DE LA MADELEINE A, QUE	43,6	38,8	30,9	28,6	21,5	18,1	12,3	4,9	3,1	5,7	9,9	30,7
4	PORT-MENIER, QUE	62,9	72,1	66,8	44,3	12,2	58,4	56,3	48,3	37,6	37,8	43,3	90,5
5	NATASHQUAN A, QUE	44,9	43,8	52,2	36,9	33,8	33,1	50,4	33,7	29,9	25,9	32,2	47,0
6	SEPT-ILES A, QUE	41,8	38,5	39,8	36,9	31,9	23,6	52,0	34,8	27,9	33,3	32,9	41,4
7	BAIE-COMEAU A, QUE	49,3	45,1	38,3	22,6	12,5	14,9	28,9	28,4	19,5	24,1	29,6	40,7
8	GASPE A, QUE	45,7	39,0	57,0	45,7	26,1	17,9	35,3	16,1	13,6	26,6	43,2	50,9
9	MONT-JOLI A, QUE	55,0	51,8	44,1	33,6	25,4	17,6	37,6	27,2	19,1	25,7	34,7	52,6
10	ILE ROUGE, QUE	37,3	46,7	58,3	21,0	26,7	64,7	109,5	47,5	67,0	51,5	17,0	35,0
11	RIVIERE-DU-LOUP, QUE	20,5	35,5	57,5	37,1	35,4	23,4	44,3	19,8	22,3	34,3	35,9	32,0
12	QUEBEC/JEAN LESAGE INTL A, QUE	57,1	52,3	46,9	24,4	7,6	8,0	8,3	7,3	10,8	17,8	42,6	59,5

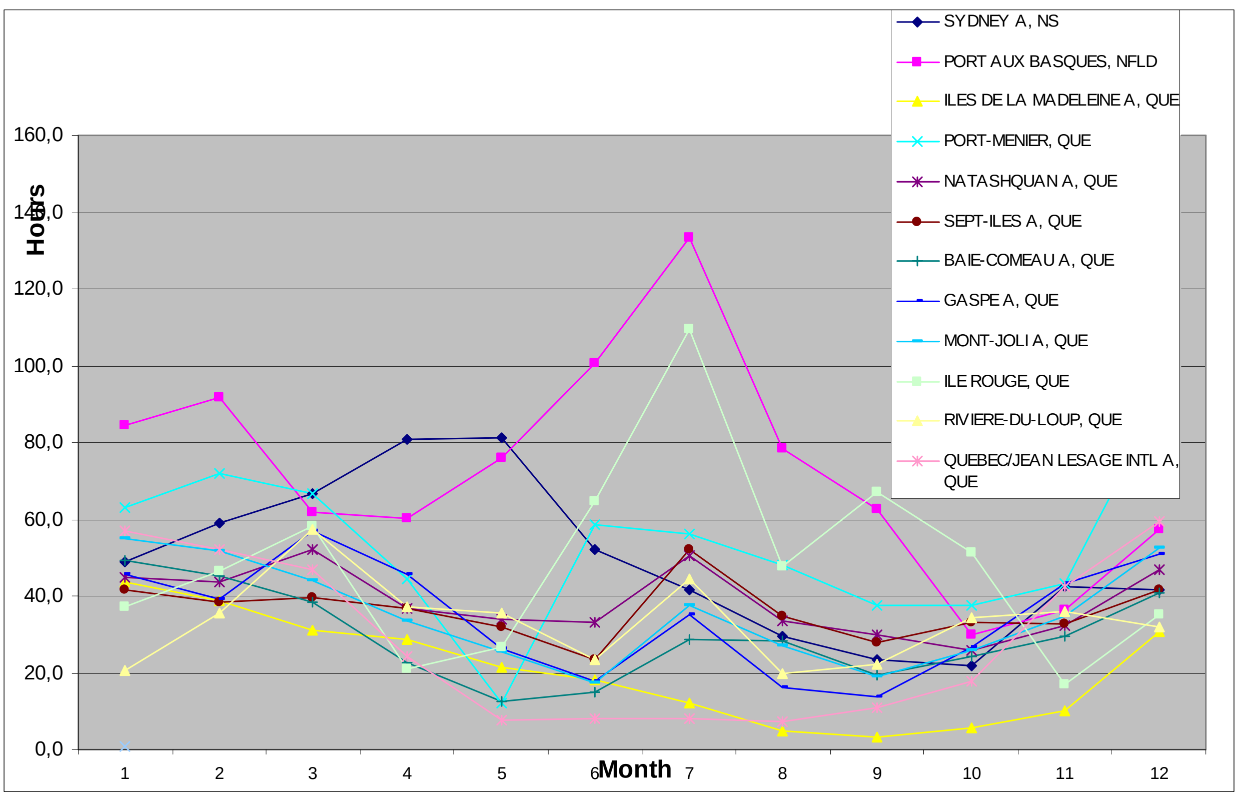


Figure 4.1 – Number of hours with visibility distances below 1.0 nautical mile, per month

Table 4.2 – Probability of visibility distances below 1,0 nautical mile at various meteorological stations

No	Weather Station	Observation Period		Duration	Probability of visibility distance below 1,0 nautical mile	
		From	**To**	**(years)**	**(1)**	**(2)**
1	SYDNEY A, NS	1989-01-01	2004-08-10	15,6	6,81%	6,70%
2	PORT AUX BASQUES, NFLD	1989-01-01	2004-08-11	15,6	13,03%	10,95%
3	ILES DE LA MADELEINE A, QUE	1989-01-01	2004-08-11	15,6	4,28%	3,41%
4	PORT-MENIER, QUE	1994-02-01	2002-08-13	8,5	9,69%	9,61%
5	NATASHQUAN A, QUE	1989-01-01	2004-08-12	15,6	6,47%	6,27%
6	SEPT-ILES A, QUE	1989-01-01	2004-08-23	15,7	5,08%	4,99%
7	BAIE-COMEAU A, QUE	1989-01-01	2004-08-11	15,6	4,06%	3,99%
8	GASPE A, QUE	1989-01-01	2004-08-23	15,7	4,77%	4,77%
9	MONT-JOLI A, QUE	1989-01-01	2004-08-10	15,6	4,85%	4,63%
11	ILE ROUGE, QUE	1994-02-01	1996-06-27	2,4	6,87%	6,30%
12	RIVIERE-DU-LOUP, QUE	1994-02-01	2001-09-25	7,7	5,49%	5,49%
13	QUEBEC/JEAN LESAGE INTL A, QUE	1989-01-01	2004-08-12	15,6	3,91%	3,86%

(1): considering all data

(2): excluding data with wind velocities > 25 knots simultaneously.

Table 4.3 – Duration of Limited Visibility Conditions

Duration (hrs)	Lévis-Beaumont (Quebec Airport Weather Station) Mean annual number of events	Lévis-Beaumont Exceedance probability (%)	Gros Cacouna (Rivière-du-Loup Airport Weather Station) Mean annual number of events	Gros Cacouna Exceedance probability (%)
1	44,4	3,810%	72,8	5,522%
2	20,9	3,303%	24,0	4,473%
3	11,4	2,826%	11,5	3,765%
4	8,6	2,437%	5,9	3,282%
5	5,8	2,046%	5,3	2,948%
6	2,9	1,717%	4,9	2,573%
7	3,6	1,516%	2,5	2,142%
8	2,0	1,226%	2,1	1,878%
9	2,0	1,044%	2,3	1,616%
10	0,8	0,838%	2,0	1,289%
11	1,4	0,746%	1,4	1,010%
12	0,8	0,565%	0,4	0,808%
13	0,6	0,462%	1,1	0,731%
14	0,5	0,379%	0,3	0,538%
15	0,3	0,299%	0,1	0,486%
16	0,3	0,256%	0,3	0,462%
17	0,1	0,210%	0,1	0,416%
18	0,1	0,186%	0,4	0,392%
19	0,1	0,161%	0,5	0,311%
20	0,1	0,133%	0,1	0,176%
21	0,0	0,105%	0,1	0,146%
22	0,0	0,105%	0,0	0,114%
23	0,0	0,105%	0,0	0,114%
24	0,0	0,105%	0,0	0,114%
25	0,0	0,105%	0,1	0,114%
26	0,1	0,105%	0,1	0,070%
27	0,0	0,068%		
28	0,1	0,068%		
29	0,0	0,048%		
30	0,0	0,048%		
31	0,0	0,048%		
32	0,1	0,048%		
33	0,0	0,025%		
34	0,0	0,025%		
35	0,1	0,025%		

5. CONCLUSION

5.1 VALIDATION OF SOURCES OF DATA

The first stage of this study (chapter 2) was comprised of a comparative assessment of different meteorological stations with the objective of demonstrating which ones could be considered the most suitable sources of data to establish wind conditions in the Levis-Beaumont and Gros Cacouna areas.

The Quebec City (airport), Lauzon and Île d'Orléans Environment Canada's weather stations were used in the first case. Data from the Île Rouge, Rivière-du-Loup (airport), Île Bicquette and Mont-Joli stations were analyzed in the second case. Moreover in this latter case, in addition to the Environment Canada's stations, some private data acquired at the Rivière-du-Loup wharf by the Rivière-du-Loup / St-Siméon ferry captain were also included in the comparison to complete the verification of the wind conditions.

Various types of comparisons were done on the wind data, such as mean velocities, occurrence frequencies by direction, simultaneous velocities, simultaneous directions.

The main conclusion of this analysis has been to confirm and justify the choices that had already been made in the pre-feasibility study carried out previously (Roche, February 2004). Statistical data issued from wind records at the Lauzon and Île Rouge weather stations are therefore included as Appendix B to this report; these are considered the most representative data sets for the two sites under study.

5.2 MARINE TERMINAL DOWN TIME

As a second stage, this study was comprised of a detailed description of the climatic and hydrodynamic conditions, i.e. wind, ice and visibility, likely to affect the marine operations of the future LNG receiving terminal.

The effect of each one of the climatic elements on the accessibility to the terminal is summarized as follows:

<u>Wind</u>

- Berthing or unberthing manoeuvres can be performed only with wind speeds below 25 kn (= 46 km/h);

- The comparative analysis of the two sites considered has shown that the Cacouna conditions are much more severe than the ones encountered in the Lévis-Beaumont area, in terms of occurrence frequencies as well as durations of wind episodes. For instance, the longest 25 knot annual wind episodes lasts less than 40 hours in Lévis-Beaumont whereas they can exceed 60 hours at Cacouna. The exceedance probabilities of the 25 knot winds are 1,16% in Lévis-Beaumont and 7,92% at Cacouna; if we neglect durations less than 6 hours which can be considered non significant for the marine operations, the above percentages are changed to 0,71% and 5,69% respectively;

- The maximum wind speed to allow LNG unloading operations is 35 knots. The current assessment has shown that this limit is rarely exceeded, either at Lévis-Beaumont or at Gros Cacouna, and therefore is considered negligible as an operational constraint;

Ice

- In Lévis-Beaumont, an analysis of historic data has shown that ice would have no significant impact on the navigation conditions, assuming that the already existing ice management system by Transport Canada would be maintained in the Port of Quebec area;

- The effect of ice at Cacouna is the object of a detailed presentation in Chapter 3. Unfavourable conditions likely to prevent berthing or unberthing manoeuvres are closely linked to NW winds since these winds can push floating ice floes towards the south shore of the river and create difficult navigation conditions. Sustained NW winds over a long fetch of river can create pressure in the ice cover. The accumulation of ice in the berthing area and the potential for ice under pressure, while unlikely to completely entrap the ship, can make an emergency departure significantly more difficult.

- Although it is hard to give accurate and reliable quantitative conclusions on the effect of ice on navigation in the Cacouna area, it has been estimated that between 10% and 30% of the winter LNG deliveries could be affected by delays with durations up to a few days;

Visibility

- A minimum visibility distance of 1 nautical mile is required to berth or to leave the terminal;

- Berthing / unberthing manoeuvres are feasible at night time as well as day time as long as appropriate visibility conditions are in place (lighting, fog,...);

- Based on an analysis of Environment Canada records, the exceedance frequency of poor visibility episodes (less than 1,0 nautical mile) of durations over 6 hours, on an annual basis, has been estimated to 1,72% in the Lévis-Beaumont area and 2,57% at Cacouna. The conditions are therefore similar at both sites on this aspect.

The general conclusion of this study is that Lévis-Beaumont is, in our opinion, a significantly more favourable site than Cacouna to implement a LNG receiving terminal. Although the latter should not be rejected as a potential site, it is clear that more important delays due to wind and ice are to be expected at that site. It is also important to mention that it is hard to give precise and reliable indications as to the behaviour of ice and its effect on the marine operations; there is a lack of experience on winter navigation in that area since there has never been intensive winter activities at the existing port of Gros Cacouna.

The ice issue is of particular importance since there is no already existing LNG terminal built or operated in ice conditions as severe as those found in the Saint Lawrence River. Therefore the operational risk associated to this site is to be evaluated carefully by the project proponent.