Marine Environment Component Study of Long Harbour, Placentia Bay and Vicinity:

Climate and Oceanography
Marine Ecology
Commercial Fisheries and Aquaculture
Bald Eagle
Marine Birds and Other Avifauna
River Otter

Prepared by

LGL LIMITED
environmental research associates

Prepared for

VOISEY'S BAY NICKEL COMPANY LIMITED

A subsidiary of Inco Limited

3 July 2007
SA889

Marine Environment Component Study of Long Harbour, Placentia Bay and Vicinity:

Climate and Oceanography
Marine Ecology
Commercial Fisheries and Aquaculture
Bald Eagle
Marine Birds and Other Avifauna
River Otter

Submitted by:

LGL Limited
environmental research associates
P.O. Box 13248, Stn. A
St. John's, NL A1B 4A5
709 754-1992 (phone)
709 754-7718 (fax)
www.lgl.com

Submitted to:

Voisey’s Bay Nickel Company Limited
Suite 700, Baine Johnston Centre
10 Fort William Place
St. John’s, NL A1C 1K4

3 July 2007
SA889

Suggested format for citation:

LGL Limited. 2007. Marine Environment Component Study of Long Harbour, Placentia Bay and Vicinity: Climate and Oceanography, Marine Ecology, Commercial Fisheries and Aquaculture, Bald Eagle, Marine Birds and Other Avifauna, River Otter. LGL Rep. SA889. Rep. by LGL Limited, St. John's, NL, for Voisey's Bay Nickel Company Limited, St. John's, NL.

Marine Environment Component Study

Executive Summary	Robert Buchanan, M.Sc.
Submitted by:	LGL Limited environmental research associates P.O. Box 13248, Stn. A St. John's, NL A1B 4A5 709 754-1992 (phone) 709 754-7718 (fax) rbuchanan@lgl.com www.lgl.com
Chapter 1.	Climate and Oceanography
Submitted by:	Oceans Ltd. 85 LeMarchant Road. St. John’s, NL A1C 2H1 Contact: Judith Bobbitt, President e-mail address: jbobbitt@oceans.nf.net oceans@oceans.nf.net
Chapter 2.	Marine Ecology
Submitted by:	John R. Christian, M.Sc. LGL Limited environmental research associates P.O. Box 13248, Stn. A St. John's, NL A1B 4A5 709 754-1992 (phone) 709 754-7718 (fax) jchristian@lgl.com www.lgl.com
Chapter 3.	Commercial Fisheries and Aquaculture
Submitted by:	Canning & Pitt Associates, Inc. P.O. Box 21461 St. John's, NL A1A 5G6 Tel: 709-738-0133 Fax 709-753-4471 www.canpitt.ca
Chapter 4.	Bald Eagle
Submitted by:	Ian Goudie, Ph.D. and Bruce Mactavish LGL Limited environmental research associates P.O. Box 13248, Stn. A St. John's, NL A1B 4A5 709 754-1992 (phone) 709 754-7718 (fax) igoudie@lgl.com; bmactavish@lgl.com

Chapter 5.	Marine Birds and Other Avifauna
Submitted by:	Ian Goudie, Ph.D. and Bruce Mactavish LGL Limited environmental research associates P.O. Box 13248, Stn. A St. John's, NL A1B 4A5 709 754-1992 (phone) 709 754-7718 (fax) igoudie@lgl.com; bmactavish@lgl.com
Chapter 6.	River Otter
Submitted by:	Ian Goudie, Ph.D. LGL Limited environmental research associates P.O. Box 13248, Stn. A St. John's, NL A1B 4A5 709 754-1992 (phone) 709 754-7718 (fax) igoudie@lgl.com

Table of Contents

Page

List of Figures

List of Tables

Executive Summary

This Marine Environment Component Study incorporates a variety of marine related topics. It is intended to satisfy the requirements for a Component Study on “the marine environment (including fish, fish habitat, and fisheries)” and to partially satisfy the requirement for information on avifauna as listed under the requirement for a terrestrial Component Study (as described in the EIS Guidelines issued by the provincial Department of Environment, 23 October 2006, hereafter referred to as the “EIS Guidelines”).

Voisey’s Bay Nickel Company Limited (VBNC) retained several St. John’s-based companies to conduct the following marine studies of Long Harbour and environs:

- Climate and Oceanography (Oceans Limited) — Chapter 1
- Marine Ecology (LGL Limited) — Chapter 2
- Commercial Fisheries and Aquaculture (Canning & Pitt) — Chapter 3
- Bald Eagles, Marine Birds, and Other Avifauna (LGL) — Chapters 4 and 5
- River Otter (LGL) — Chapter 6

These studies have been compiled under one cover as they are all directly related to the marine environment.

Climate and Oceanography

As reported in Chapter 1, VBNC contracted Oceans Ltd. of St. John’s to review existing climate and oceanographic data for Placentia Bay in general, and Long Harbour in particular. In addition, new weather data were collected at the old ERCO wharf in Long Harbour in order to support the collection of new current, temperature, and salinity data in Long Harbour. Previously, few current meter data were available for the area.

Data Sources

Wind and wave climate statistics in Placentia Bay were extracted from Environment Canada’s AES40 North Atlantic wind and wave climatology data set (50-year period from 1954 to 2004). In this study, Grid Point 5616 located at 46°52´N; 55°00´W was deemed to be most representative of conditions within Placentia Bay (see Figure 1).

Air temperature, sea surface temperature, precipitation types, and visibility statistics for Placentia Bay were compiled using data from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). A 30-year ICOADS subset of global marine surface observations from ships, drilling rigs, and buoys covering the period 1976 to 2005 was used in this report.

Other weather data included those from the Canadian Center for Marine Communications weather buoy in Placentia Bay at 46°59´N; 54°41´W as part of the SmartBay Demonstration Project, weather station installed on the old ERCO wharf in Long Harbour by Oceans Ltd., and a number of climate and weather stations maintained by Environment Canada around Placentia Bay (e.g., Arnold's Cove, Argentia, St. Lawrence, Placentia, Long Harbour, and Marticot Island) (see Figure 1).

Oceanographic data sources included current meter data from the Department of Physics and Physical Oceanography at Memorial University (MUN) (see Figure 2 for locations), the Bedford Institute of Oceanography (BIO), and Oceans Ltd. (see Figure 3 for locations). CTD data were analyzed from BIO archives and from VBNC data collected by Oceans Ltd.

Climate

Placentia Bay is subject to the weather systems that pass over the island of Newfoundland. Newfoundland experiences a maritime climate with the waters surrounding the island having a moderating effect on temperature. In general, maritime climates experience cooler summers and milder winters than continental climates, and have a much smaller annual temperature range. Furthermore, a maritime climate tends to be fairly humid, resulting in reduced visibilities, low cloud heights, and receives significant amounts of precipitation.

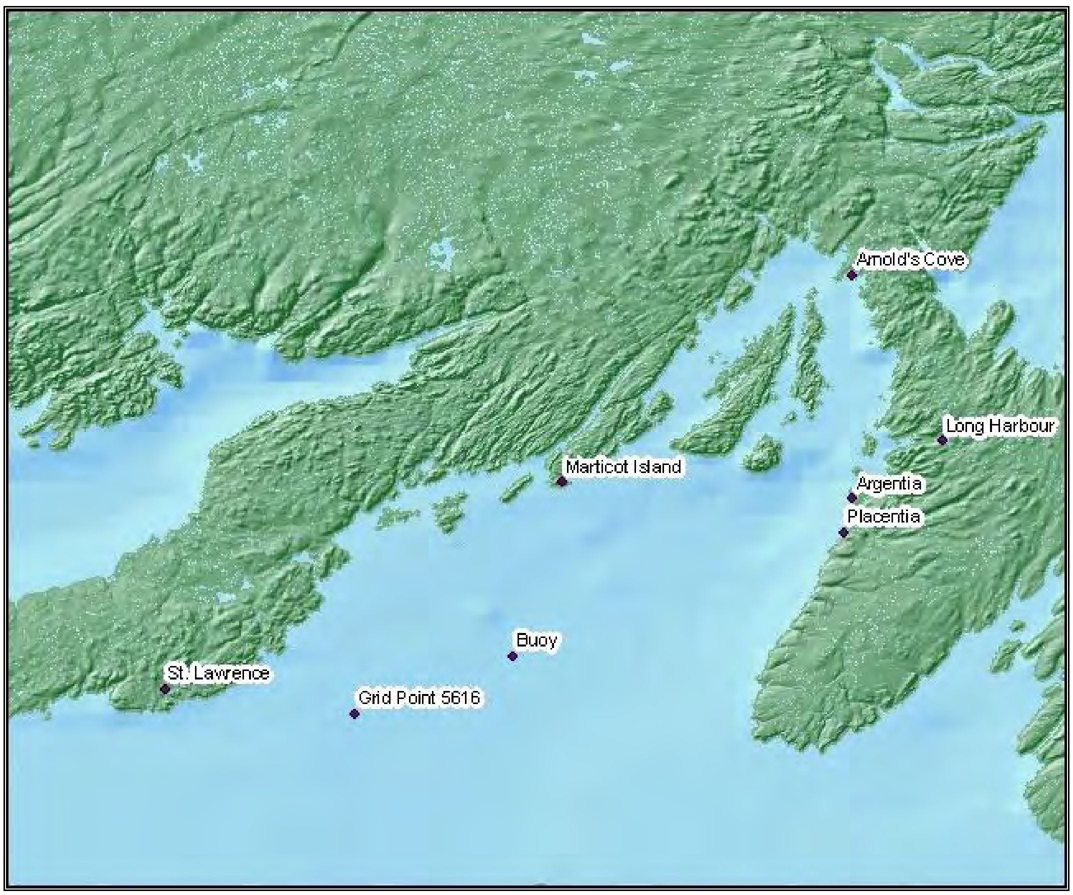


Figure 1. Locations of the Climate Data Sources.

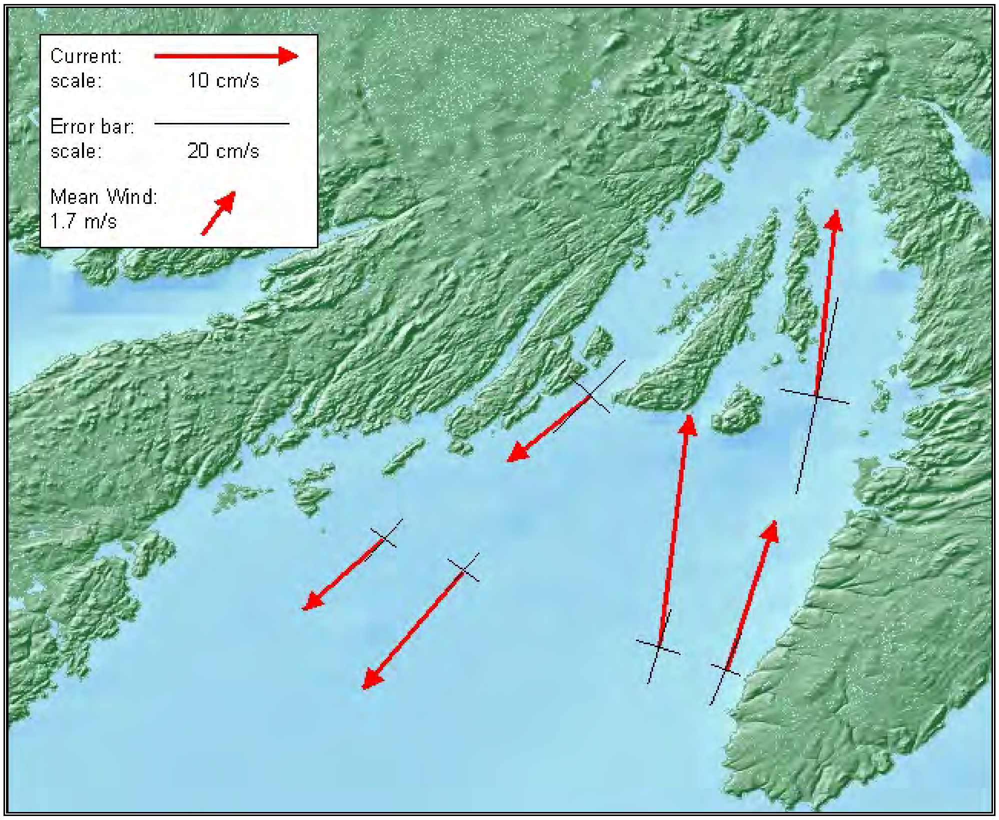


Figure 2. **Locations of MUN Current Meters and Mean Circulation in Placentia Bay at 20 m (from Schillinger et al. 2000 *in* Chapter 2).**

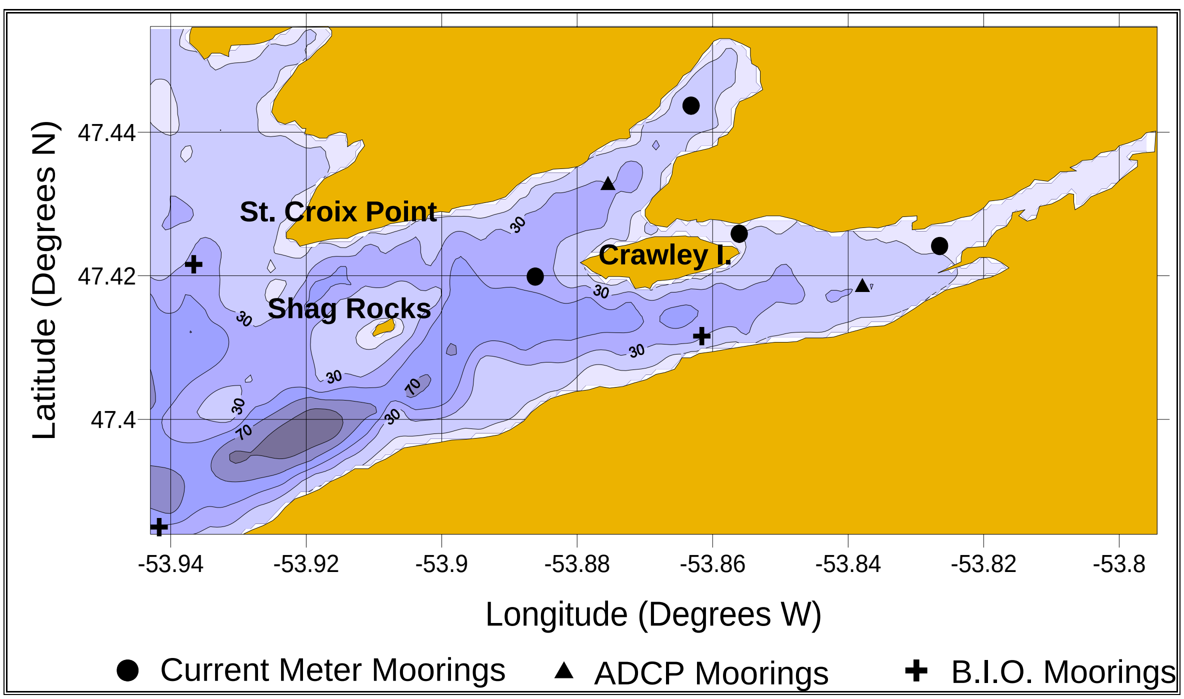


Figure 3. **Locations of BIO and Oceans' Current Meters in Long Harbour.**

Wind

Placentia Bay experiences predominately southwest to west flow throughout the year. Westerly winds prevalent during the winter months begin to shift counter clockwise during spring as the tropical-to-polar temperature gradient weakens, becoming generally southwesterly during the summer months. As autumn approaches, the tropical-to-polar temperature gradient strengthens and the winds shift slightly, becoming predominately westerly again by late fall and early winter.

Wind statistics (speed and direction, means and extremes) are presented by season and location in this section.

Air Temperature

Air temperature data (mean and extremes) are presented for the various stations around Placentia Bay. Mean seasonal air temperatures at Long Harbour ranged from -2.6ºC in winter to 13.9ºC in summer. Temperatures at Long Harbour have ranged from -25.0ºC to 30.6ºC.

Precipitation

Precipitation statistics are presented by precipitation type, amount, and location. In Placentia Bay, winter has the highest frequency of precipitation with frequencies between 26.4% and 29.2% for the land stations and 56.3% over the ocean. Snow accounts for the majority of precipitation during the winter months, occurring twice as often as rain at the land stations and 3.3 times more frequent than rain over the ocean. Summer has the lowest frequency of precipitation with the total frequency of occurrence ranging from 13.5% to 16.5%.

Icing

Statistics and information on freezing precipitation and icing are presented in this section.

Visibility

Observations from climate stations around Placentia Bay show that obstructions to visibility occur on a regular basis throughout the year, with good visibility (defined as visibility greater than 10 km) in the coastal communities of Argentia, Placentia, and St. Lawrence occurring, on average, less than 50% of the time. The incidence of fog at these stations is high during the summer months and peaks in the month of July with visibility less than one kilometre occurring as much as 27.2% of the time at St. Lawrence and 15.1% of the time at Placentia.

Visibilities in the bay are better than the land stations with good visibility occurring 71.2% of the time (ICOADS). The bay has a higher incidence of fog and lower incidence of mist (visibility of 1 km to less than 10 km) resulting in a higher incidence of good visibility than reported by the land stations. On average, the incidence of fog occurs 11.0% of the time throughout the year in Placentia Bay with the peak occurring in July at 20.7% of the time.

Oceanography

Bathymetry

The bathymetry of Placentia Bay is very irregular with many banks and troughs. The water depth at the mouth of the bay is approximately 200 m. There is a deep channel on the eastern side of Placentia Bay with water depths extending to approximately 300 m in some locations. A deep channel south of Merasheen Island with a maximum depth of 350 m is oriented in a northwest/southeast direction across the bay. White Sail Bank, Merasheen Bank, and Bennett Bank are located on the southern side of this channel. In general, the water is shallower on the western side of the Bay than on the eastern side with the exception of many deep troughs. North of Merasheen Island, the maximum water depth is approximately 200 m.

Currents

Current speeds and directions are described in detail based upon historical and new data for different locations and depths. In general, the near-surface currents in Placentia Bay have been observed to flow counter clockwise around the bay. This circulation pattern is not consistent at deeper levels. The flow in Placentia Bay is expected to be the result of tides, winds, and the Labrador Current. Since the variability due to tides account for approximately only 15% of the total variability, other factors are more important. Winds in the area are predominately from the southwest, and this likely contributes to a counter clockwise pattern in the near surface waters. The inshore branch of the Labrador Current follows the bathymetric contours around the Avalon Peninsula. North of Green Bank the direction of the bathymetric contours shift from an east/west direction to a north/south direction. The Labrador Current probably divides at this location with a portion of the Labrador Current contributing to the flow into Placentia Bay and becoming the major contributor to the overall current variability. A portion of the north-northeast flow following the bathymetric contours on the east side of Placentia Bay continues to follow the contours into Long Harbour, and be the major contributor to the overall current circulation in the harbour.

Current measurements in Long Harbour were made by BIO over a 29-day period at three locations during summer of 1969, and by Oceans Ltd. at five locations for VBNC during summer and fall, 2006 (Figure 3). These data demonstrate a complex current system that is not unusual for a coastal inlet with irregular bottom bathymetry. Analysis of this current data in conjunction with CTD data collected throughout the harbour showed that the circulation in Long Harbour was mainly driven by the circulation in Placentia Bay. Tidal measurements and analysis of tides from the current metre records showed that tides played a minor role. Winds played a modifying role, both directly and indirectly. The winds are strong enough on a daily basis in Long Harbour to play a direct role in the creation of wind driven currents in the top few meters. Since winds are predominantly from the southwest (into the bay), there is a tendency for the wind driven currents to push water against the shore. This will cause the currents to reverse direction at deeper levels. Reversals in currents were measured by the Acoustic Doppler Current Profiler (ADCP) current meter deployed in 32 m of water west of the wharf. Reversals in currents are also produced by internal waves whenever there are internal density boundaries, a source of energy such as the wind, and bathymetric features such as the mound which exists in the central region of the southern arm. The mean currents at the location of the ADCP were low varying with depth from 3.9 cm/s at a depth of 6 m to 2.7 cm/s at a depth of 26 m.

The current measurements indicate that in general the flow is directed into the harbour on the southern side, and out of the harbour on the northern side with an exchange between north and south taking place between Shag Rocks and Crawley Island.

Water Temperature and Salinity

Temperature-salinity (TS) diagrams of the water properties at the mouth of Placentia Bay, and for Labrador Current water northwest of Green Bank were constructed. The diagrams show that the water properties are almost identical which means that the water entering Placentia Bay is Labrador Current water.

Wave Climate

Wave data were analyzed for AES40 Grid Point 5616 and from the SmartBay Program. Significant wave heights in Placentia Bay are higher during the winter months with the mean monthly significant wave heights reaching 2.2 m in December and January. Since winds are predominately from the west and northwest during the winter months, wind waves are generally fetch-limited. As a result, mean significant wave heights in Placentia Bay during the winter are lower than would be expected in the open ocean. The lower significant wave heights occur in the summer with a mean monthly significant wave height of only 1.2 m. Mean significant wave height values from the SmartBay buoy recently deployed in Placentia Bay are similar to the AES40 data.

Sea Ice and Icebergs

Due to its location along the south coast of Newfoundland, Placentia Bay is a relatively ice-free bay in comparison to other bays surrounding Newfoundland. A weekly analysis of the Canadian Ice Service’s 30-Year Frequency of Presence of Ice in Placentia Bay reveals that ice is only present in Placentia Bay from mid February until late April. During the week of 12 February, there is a 4% chance that 67.4% of the bay will be covered and a 7% chance that 12.2% of the bay will be covered. During this period, when ice is present in the bay, the predominant type is either new (recently formed having a thickness of less than 10 cm), grey (young ice 10-15 cm thick) or grey-white (young ice 15-30 cm thick).

Marine Ecology

Chapter 2 of the Marine Environment Study presents the results of the October 2005 to October 2006 sampling program designed to collect baseline information on sea water, marine sediment, and marine biota quality (i.e., fish and fish habitat) in Long Harbour. The four sampling times during this period were October 2005, May 2006, July 2006 and September/October 2006. Sampling included sea water (surface and bottom), bottom temperatures (continuous recording thermographs), surficial sediments (Ponar grab), blue mussels (moorings containing cultured *Mytilus edulis*), winter flounder (*Pseudopleuronectes americanus*), and benthic habitat surveys with a Remotely Operated Vehicle

(ROV) (wharf and centre of bay). Local farm mussels were sampled in April 2007. Locations of sampling stations are shown in Figure 4. Analysis parameters are contained in Table 1.

While some maximum concentrations in both sea water and surficial sediment exceeded their respective guideline values, it occurred neither frequently nor consistently at any one station. Only Interim Sediment Quality Guidelines (ISQGs), and not Probable Effect Level (PELs), were exceeded in a few of the surficial sediment samples. The highest concentrations of some of the metals and hydrocarbons in sea water, surficial sediment, and biota were often observed at stations located in the inner part of Long Harbour. Concentrations typically were lower at stations towards the mouth of the harbour. Some possible explanations for the higher concentrations of some variables in samples from inner Long Harbour include spatial differences in geology, spatial and temporal differences in hydrology, and differences in anthropogenic influences.

Between five and six hours of underwater video were recorded with an ROV during benthic habitat surveys at various locations in Long Harbour. Both soft and hard bottom substrates and their respective ecologies were documented. Soft bottom habitat dominated the survey area in the vicinity of the candidate marine effluent outfall and hard bottom habitat dominated the survey areas in the vicinity of the former ERCO wharf.

Table 1. Analysis Parameters and Methods Performed by Analytic Laboratory.

Matrix	Parameter	Method
Sea Water	pH	pH Meter
	TSS[1]	Gravimetric
	BTEX/TPH[2]	Atlantic PIRI[4]
	Mercury	CVAA[5]
	Metal Scan	ICP-MS[6]
Marine Sediment	Particle Size	Sieve and Pipette
	Mercury	CVAA
	TIC/TOC[3]	Induction Furnace
	Extractable Hydrocarbons ($>C_{10}$-C_{32})	Atlantic PIRI
	Sulphate	COBAS[7]
	Available Metal Scan	ICP-MS
Blue Mussel	Metal Scan	ICP-MS
	Mercury	CVAA
	Extractable Hydrocarbons ($>C_{10}$-C_{32})	Atlantic PIRI
Winter Flounder	Metal Scan	ICP-MS
(muscle, liver, kidney)	Mercury	CVAA
	Extractable Hydrocarbons ($>C_{10}$-C_{32})	Atlantic PIRI

[1] Total suspended solids
[2] Benzene, toluene, ethylbenzene, xylene/total petrogenic hydrocarbons
[3] Total inorganic carbon/total organic carbon
[4] Atlantic Partnership in RBCA (Risk Based Corrective Action) Implementation
[5] Cold Vapour Atomic Absorption Spectrometer
[6] Inductively Coupled Plasma/Mass Spectrometer
[7] Automated Centrifugal Colorimetric Analysis

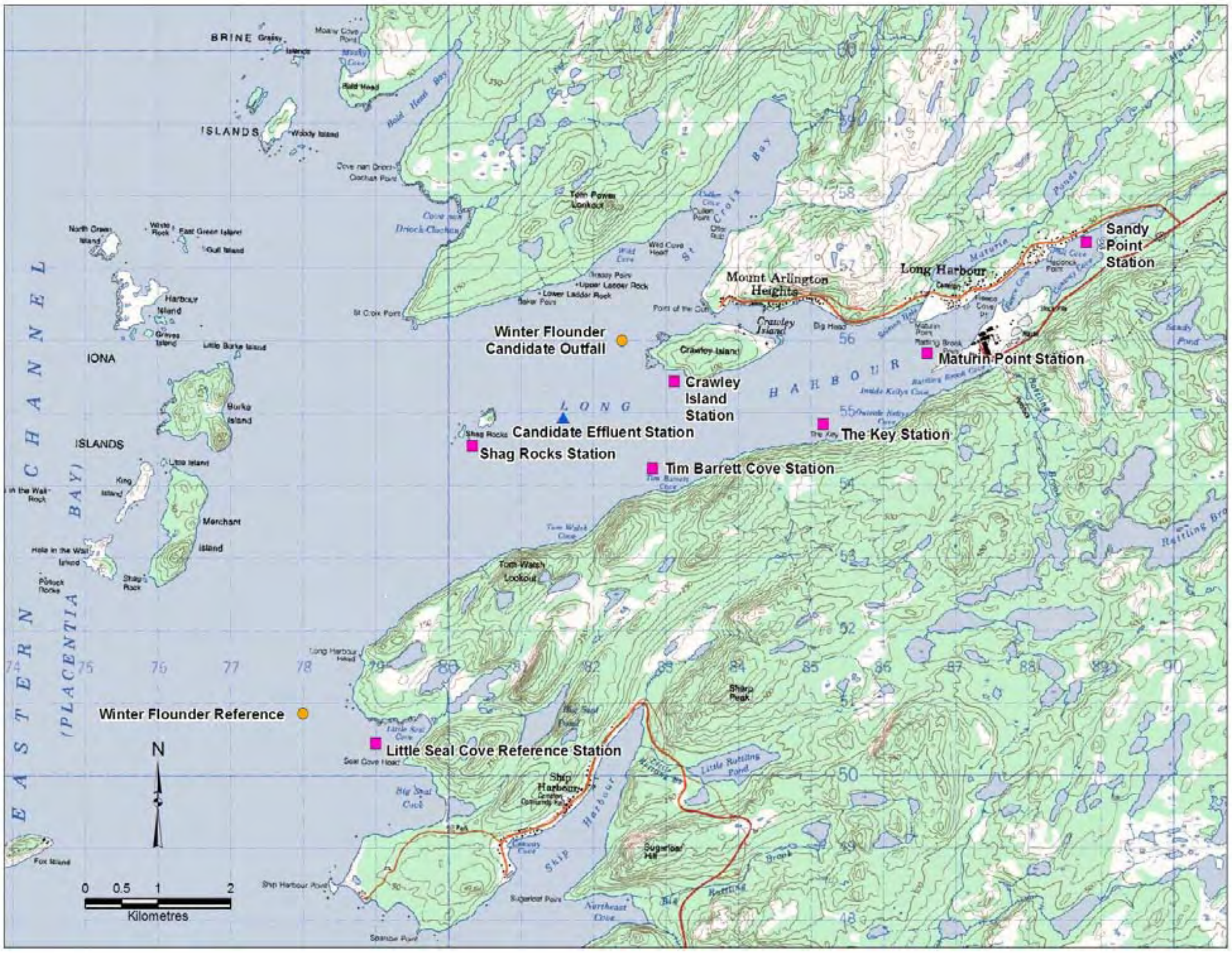


Figure 4. **Locations of Sampling Stations of the Long Harbour Marine Ecology Study.**

Commercial Fisheries

Chapter 3 presents a detailed review of the commercial environment in the Placentia Bay area (essentially Unit Area 3PSc). This includes the historical context, species harvested, the monthly distribution of fishing activities, fishing gears used, and geographic location of fishing activities. Information is also provided on aquaculture and fish processing operations. Sources of information included the federal Department of Fisheries and Oceans (DFO) Newfoundland and Maritime regions databases for Unit Area 3PSc, the provincial Department of Fisheries and Aquaculture (DFA), and Northwest Atlantic Fisheries Organization (NAFO) data. Consultations were conducted with DFO and DFA officials, the Canadian Coast Guard at Argentia, Long Harbour fishers, and fish processors based in Placentia Bay.

The focus for analysis of the domestic Canadian wild (i.e., non-aquaculture) harvest within and adjacent to Placentia Bay include the species harvested, typical harvesting locations, seasonality of the harvest, and harvesting methods used, as well as the landed quantities and value of the catch.

In recent years (2003-2005 data), the most important (in order of total mean landings) commercial species in 3PSc, the fisheries statistical area that includes much of Placentia Bay, included Atlantic cod, snow crab, herring, lumpfish (roe), scallops, and a few other species. Economically, cod, snow crab, lumpfish, and lobster account for 90% of fishers' incomes. American lobster accounts for less than one percent of the catch but almost seven percent of total value. Herring has indirect economic importance in the area as bait. Most of the fishing gear is fixed gear (i.e., gill nets, long lines, traps, and pots) although some purse seining is used to catch herring. Fishing in the immediate vicinity of Long Harbour is generally limited to lobster (15-20 pots), herring, and lumpfish.

The seasons, for management purposes, of harvesting for species in Placentia Bay in recent years are shown in Table 2. Locations recorded in the DFO geo-referenced dataset for all species (2005) are shown in Figure 5. However, this represents a small sub-set of the 3PSc harvest, and some years have fewer data than others (e.g., just 2% georeferenced data in 2005). Lobster fishing locations are not georeferenced in the datasets. However, lobster is harvested close to shore, typically close to the community where the fisher lives.

There are three blue mussel-farming sites within Long Harbour. Two of these are located on the north side of Crawley Island, and the other is situated within St. Croix Bay (Figure 6). All three sites are owned and operated by Baie Sea Farms, and have been under active development since the late 1980s.

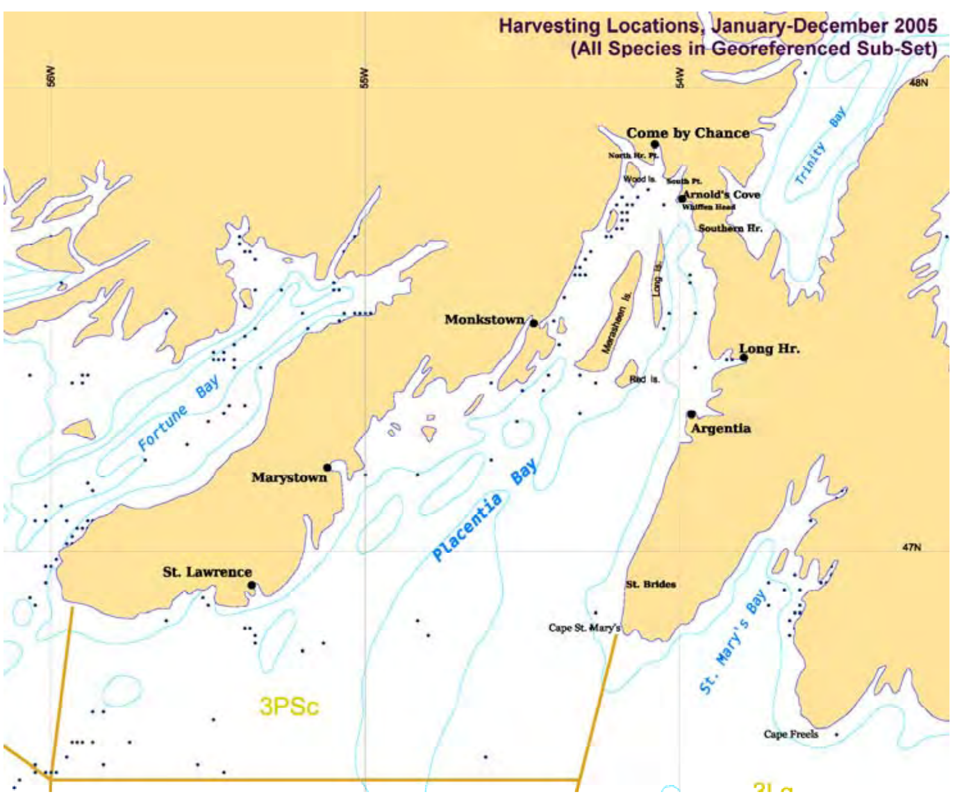


Figure 5. 2005 Georeferenced Harvesting Locations, All Species, All Months.

Table 2. Species Management Seasons.

Species	Season
Lobster	April 20 to June 30
Crab	April to September (or as per current year Management Plan)
Sea Urchins	October 1 to April 1
Lumpfish	May 1 to June 15 (opening/closing dates may vary).
Scallops	January 1 to December 31 (but usually closed during lobster season)
Herring (fixed gear)	1 March to 31 May and reopened September to December 31 (or until quota is reached)
Herring (mobile gear)	Same as above
Winter Flounder	Mid-May to December (for 2003)
Squid	June to December, depending on availability (but this species usually appears in the early to late fall)
Capelin	June to August, depending on the quota and market demand
Cod	Early May to end of February the following year. This fishery is closed during March and April (the spawning season for this species)

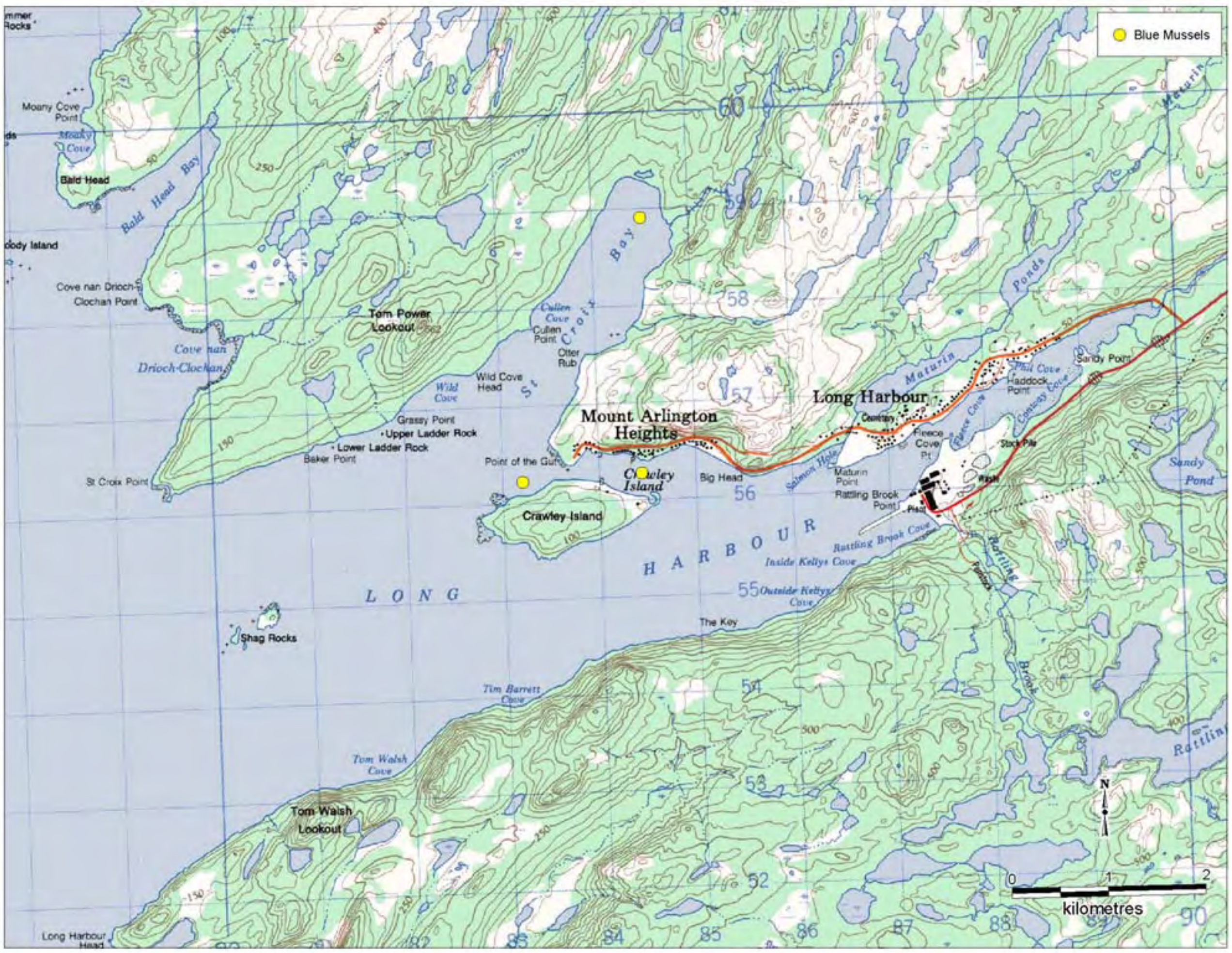


Figure 6. Aquaculture Operations in the Long Harbour Area.

Bald Eagle

Placentia Bay is known to contain aggregations of Bald Eagle (*Haliaeetus leucocephalus*), a key top-level predator in that marine environment. Chapter 4 on Bald Eagle is intended to partially fulfill the requirement for the avifauna subcomponent of the terrestrial component as listed in the EIS Guidelines. It is included within the marine environment portfolio because their lifestyle in the Placentia Bay area is primarily marine.

The provincial Wildlife Division conducts Bald Eagle nest surveys on their designated survey plots on Long Island, Merasheen Island, Ragged Island and a section of adjacent western Placentia Bay. However, they do not survey for eagles south or east of Come By Chance, and the VBNC/LGL aerial and ground surveys were intended to augment the Wildlife Division's database.

The aerial survey extended from Arnolds Cove in inner Placentia Bay and along the eastern shore to Northern Head, Cape St. Mary's on 7 June 2006 using a Bell Long Ranger. LGL personnel also undertook day-long reconnaissance level ground surveys of the Long Harbour area on 17 March, 13 April, 3 May, 21 July, and 25 October 2006. The spring dates coincided with herring spawning.

Long Harbour residents reported counts of up to 40 Bald Eagles in the upper reaches of Long Harbour during herring spawning season in May (A. Murphy, Long Harbour resident, pers. comm.). Reconnaissance visits by LGL on 17 March and 13 April 2006 resulted in day counts of over 30 Bald Eagles. On 13 April 2006, a Bald Eagle was observed flying with a medium size silver-coloured fish, presumably a herring, while being pursued by two other eagles. About half the eagles observed were adults (Table 3). Adult Bald Eagles should be attending nest sites from March to July. The origin of the adult Bald Eagles observed at Long Harbour is uncertain.

An active Bald Eagle nest was also found at Long Harbour Head on 17 May 2006 during marine water sampling by LGL (B. Mactavish, LGL, pers. comm.).

During the LGL aerial surveys, eight active nests, forty-four adults and eight subadult Bald Eagles were located (Figure 7). Two old inactive nests were noted and two recently-used nests including one located near Bald Head that had collapsed and was reported to have had young earlier in the year (A. Murphy, pers. comm.).

Table 3. Numbers and Maturity of Bald Eagles Observed during Day-long Ground-based Observations in Long Harbour, Placentia Bay in 2006.

Date	Total		
	Adult	Imm	Not Aged
17 Mar 06	8	5	0
13 Apr 06	14	14	6
3 May 06	0	0	0
21 July 06	0	0	0
25 Oct 06	0	0	0
Imm=immature			

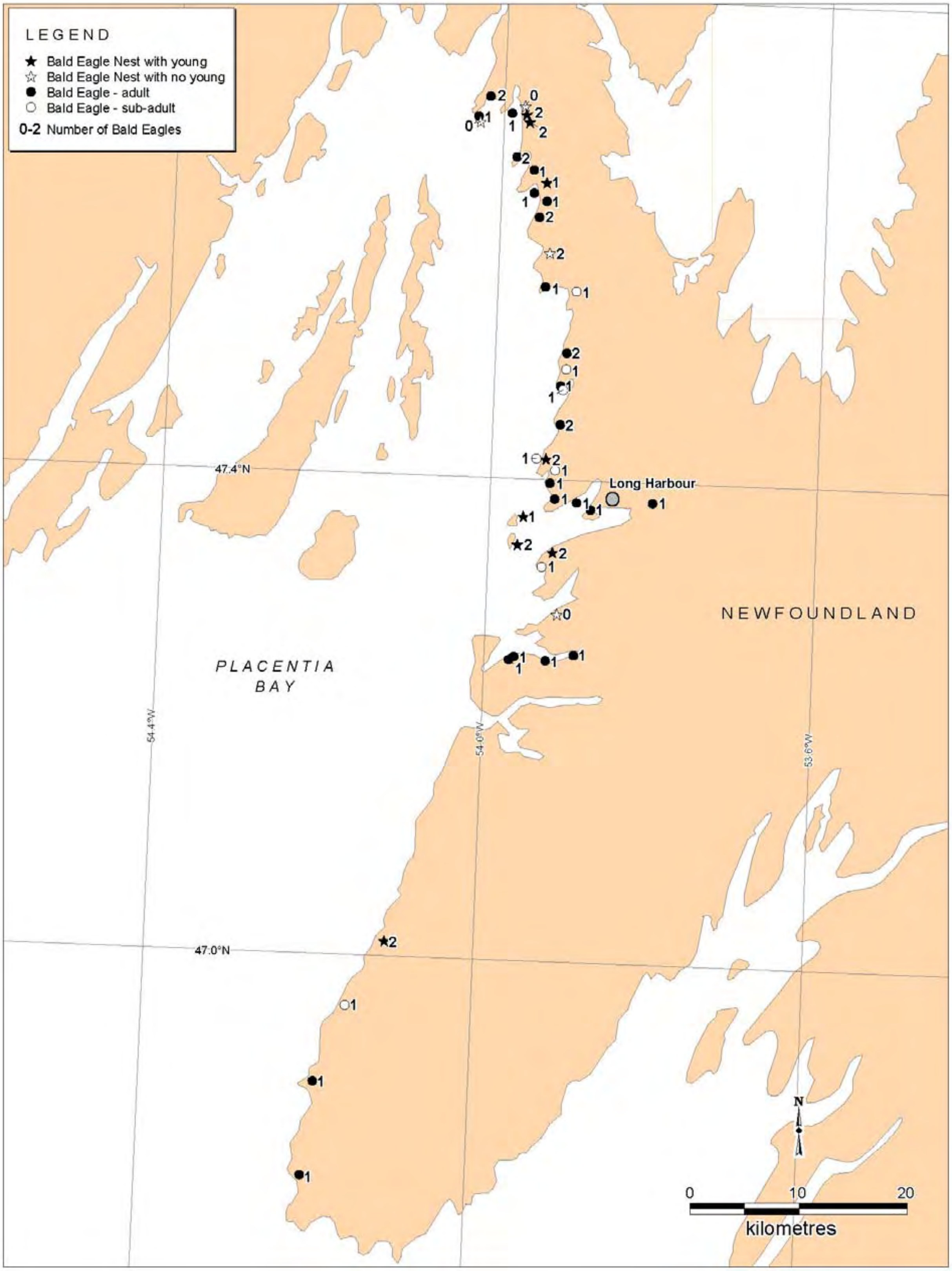


Figure 7. Aerial Survey for Nesting Bald Eagles, 7 June 2006.

Incidental observation recorded during the aerial survey included apparent colonies of Great Black-backed Gulls, Herring Gulls, Ring-billed Gulls, Black-legged Kittiwakes, terns (Common and Arctic), cormorants (Great and Double-crested), and a nest site of the Common Raven. During boat-based surveys on 13 June 2006, an adult Bald Eagle and a collapsed nest were observed at Drioch-Cloche, an adult Bald Eagle was observed at Burke Island (part of Iona Islands), and two Bald Eagles with two eaglets were observed at Merchant Island (part of Iona Islands). The latter site was recorded during the aerial survey. LGL personnel (I. Goudie) also recorded incidental observations of Bald Eagles during boat-based surveys for otter haul-out areas (see Chapter 6).

An Osprey was observed over the inner portion of Long Harbour on 21 July 2006 but no nest sites were detected. Other raptor species observed were limited to Merlin (*Falco columbarius*) at the inner narrows on 23 August 2006, and a Northern Harrier (*Circus cyaneus*) on the Long Harbour access Road on 21 July 2006. There were frequent observations of the Common Raven (*Corvus corax*) and American Crow (*Corvus brachyrhychos*).

Marine Birds

Areas of Placentia Bay are known to support waterfowl, shorebirds, and other avifauna associated with the coastal and marine environment. Because there is little published information on the avifauna in Placentia Bay, VBNC retained LGL to conduct a review of information and to provide baseline information for the inner bay area as part of the larger marine environmental study. The results of this research are detailed in Chapter 5 are intended to partially meet the requirement for the avifauna subcomponent as listed in the EIS Guidelines.

Placentia Bay is the richest bay in coastal Newfoundland for seabirds. The large colonies of Northern Gannets (*Sula bassanus*), Common Murres (*Uria aalge*) and Black-legged Kittiwakes (*Rissa tridactyla*) at Cape St. Mary's in summer are supported by the rich adjacent marine waters that also host huge numbers of Greater and Sooty Shearwaters (*Puffinus gravis*, *Puffinus griseus*) that breed in the Southern Hemisphere during the NW Atlantic winter. These seabirds are supplanted in winter by large aggregations of sea ducks, such as Common Eiders (*Somateria mollissima*), the most northerly wintering distribution of Black Scoters (*Melanitta nigra*), and the eastern Harlequin Duck (*Histrionicus histrionicus*) currently listed as a species of *special concern* by the Committee on Species of Endangered Wildlife in Canada (COSEWIC) and *vulnerable* under the *Endangered Species Act* of Newfoundland and Labrador. There are over 365 islands in Placentia Bay, many of which support small colonies of seabirds, such as gulls (*Larus* spp.), terns (*Sterna* spp.) and Black Guillemots (*Cepphus grylle*).

Surveys in the inner reaches of Placentia Bay have been ongoing for several years by the Newfoundland and Labrador Environmental Association (NLEA) (Stan Tobin) along the eastern side of Placentia Bay. In an effort to monitor populations of marine birds and other avifauna in Placentia Bay, VBNC has been supporting these marine bird surveys along the eastern shore of Placentia Bay which consist of weekly surveys at standardized observation points. More recently these surveys have been extended northward to include accessible locations at Fair Haven, Little Harbour East, and Southern Harbour.

LGL undertook additional ground-based (Figure 8) and boat-based (Figure 9) surveys on behalf of VBNC in order to increase the knowledge base in relation to key areas for marine-related avifauna and to supplement existing ongoing studies by the NLEA and government.

Modest numbers of marine birds, waterfowl, and shorebirds utilize Long Harbour and the adjacent offshore islands. Species that were documented as breeding included the Herring, Great Black-backed, and Ring-billed Gulls that are relatively ubiquitous to coastal Newfoundland. Smaller numbers of Common and Arctic Terns were detected, and these species are of greater conservation concern to management agencies because of displacement and competition from the larger gull species that have been expanding in numbers [Canadian Wildlife Service (CWS) Gull Management Plan]. In general, cormorants have been expanding in numbers over recent decades, and a healthy population was noted in the area. Waterfowl are very sparse and only incidental numbers of Black Ducks (*Anas rubripes*) were noted whereas a consistent presence of shorebirds on some of the intertidal sites in Long Harbour support the contention that these habitats, although limited in size and extent are important during the fall migration.

LGL observations suggest that the large Ring-billed Gull colony (~ 992 pairs) recorded at Crawley Island by CWS in 2005 had suffered considerable depredation by otters in spring and summer. The appearance of nesting Ring-billed Gulls and Common Terns at the Spit adjoining the slag heap at Fleece Cove is suspected to be a result of this displacement. It is estimated that there were much smaller numbers of breeding Ring-billed Gulls in the area in 2006 compared to those recorded by CWS in 2005.

The inner reaches of Placentia Bay sustain variable use by pelagic birds depending on food and weather conditions. Sooty Shearwaters and Northern Gannets were observed feeding in the presence of schooling capelin (*Mallotus villosus*). During heavy onshore storms, pelagic species including jaegers, shearwaters, and petrels may be relatively common in the inner Bay.

River Otter

Placentia Bay is known for its relatively large population of river otter (*Lutra canadensis*) and the species has been named as a valued ecosystem component (VEC) in the EIS Guidelines. Results of the VBNC/LGL surveys are presented in Chapter 6.

River otter is a large member of the family Mustelidae that includes the weasel, mink, and marten. River otter is a ubiquitous species ranging the temperate latitudes of North America, and inhabiting both marine and freshwater environments. In various areas of its range, this species lives a largely marine existence or may alternate between coastal and interior habitats. In Placentia Bay, some river otters have adopted a primarily marine lifestyle. The marine area offshore of, and adjacent to, Long Harbour in Placentia Bay is an archipelago and supports a population of marine otters. There is a documented presence of otters throughout most of the Placentia Bay archipelago, and they occur in the Long Harbour - Iona Islands and adjacent environs.

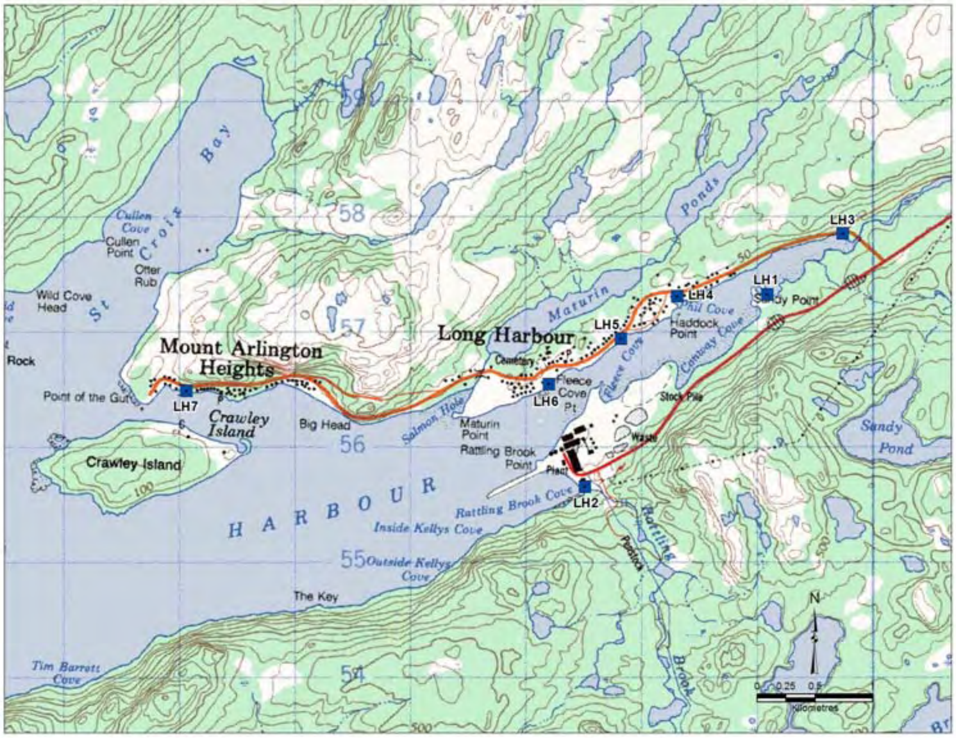


Figure 8. **Sites used by LGL for Standardized 20- to 30-Minute Ground-based Counts in the General Area of Long Harbour, Placentia Bay.**

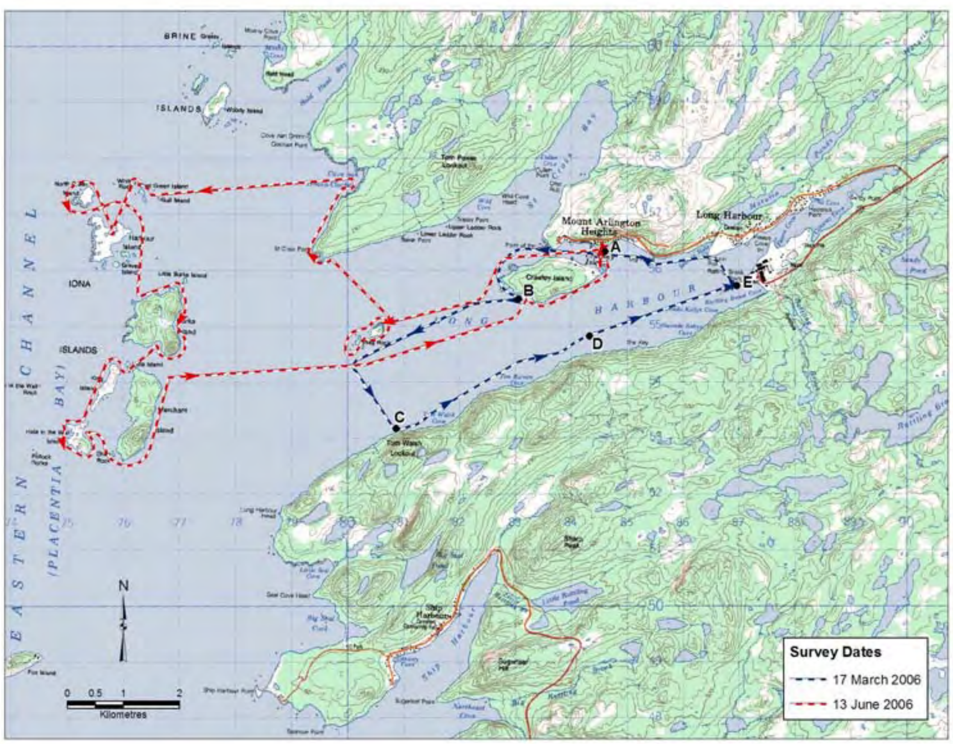


Figure 9. **Routes for Boat-based Surveys for Marine Birds in the Long Harbour Area on 17 March and 13 June 2006.**

Despite its historic presence, exploratory research commencing in the 1970s, local knowledge and traditional trapping activity, there remains very limited and only fragmented information on river otter in Placentia Bay. The objective of the present study was to gather preliminary information and baseline data on the presence of otters in the area of Long Harbour, the adjacent headlands and Iona Islands – Brine Islands area.

The coastal areas of Long Harbour, St. Croix Bay, and west to Bald Head, the intervening coastline and the adjacent headlands and the archipelago of Brine Islands-Iona Islands and the south shoreline of Long Harbour out to Long Harbour Head were surveyed in mid to late August 2006 using a boat skippered by an experienced local trapper (Mike Keating). All sites known to be used by otters as coastal haul-outs locations (rubs) as well as additional sites detected while in the field were visited. Sites were classed as used by otters if there was physical evidence of use, such as slides, scats, tracks, excavated turf, scent piles, fish remains, etc.

Sites having evidence of otter presence were ranked based on the freshness of the sign, for example, tracks, fresh scats, decaying fish parts versus only fully decomposed evidence, such as fish bones and scales. Ranks included:

1. actual sighting
2. very recent (within 1 week)
3. recent (>1 week but within 1 month)
4. fairly recent (>1 month but <3 months)
5. old (>3 months)

If sites had evidence of use by otters, latrine areas were cleared of scats (fresh material was collected). Sites were revisited at a later date and assessed for possible re-use. This provided some preliminary indication of the regularity of use of sites by otters. Twenty-one sites were identified in the Long Harbour area (Figure 10).

On 7 June 2006, LGL undertook an aerial survey for Bald Eagles along inner Placentia Bay, commencing at Arnolds Cove and extending along the eastern 'Cape Shore' to Northern Head, Cape St. Mary's (see Chapter 5, this report). Incidental observations of otter haul-out sites (rubs) along this route were recorded on GPS units by observers.

Results suggest that the river otter is ubiquitous in the Long Harbour area. The assessment of twenty-one areas (Figure 10) where otters were actively 'hauling-out' confirmed that many were currently being used, and the majority had evidence of recent use.

Little information is available on the biology of otters using Placentia Bay. It is likely that the population of otters using Placentia Bay is relatively contiguous given the large home range of this species and the results of studies of populations in other coastal areas (e.g., Cote et al. *in prep.*). In the 1970s, one juvenile otter captured and tagged in the Kings Island area of Merasheen archipelago, Placentia Bay was, later caught by a trapper in Come-by-Chance area, representing some 40-50 km of range (D. Slade, retired provincial Wildlife Division Technician, pers. comm.). These findings support a hypothesis that otters in the survey area might use most of the Placentia Bay archipelago. Placentia Bay otters could also conceivably interchange regularly with the Trinity Bay population and *vice versa*. The complexity of shoreline may be an important habitat component favouring the extensive use of the Placentia Bay archipelago by otters. New advances in genetic analyses using scat samples (and hair samples) have permitted biologists to estimate population size and home range of otters (refined in Prince William Sound, Alaska). Alaskan studies also have successfully used radio-tracer implants to track individuals. Such techniques hold promise for application in future studies of otters.

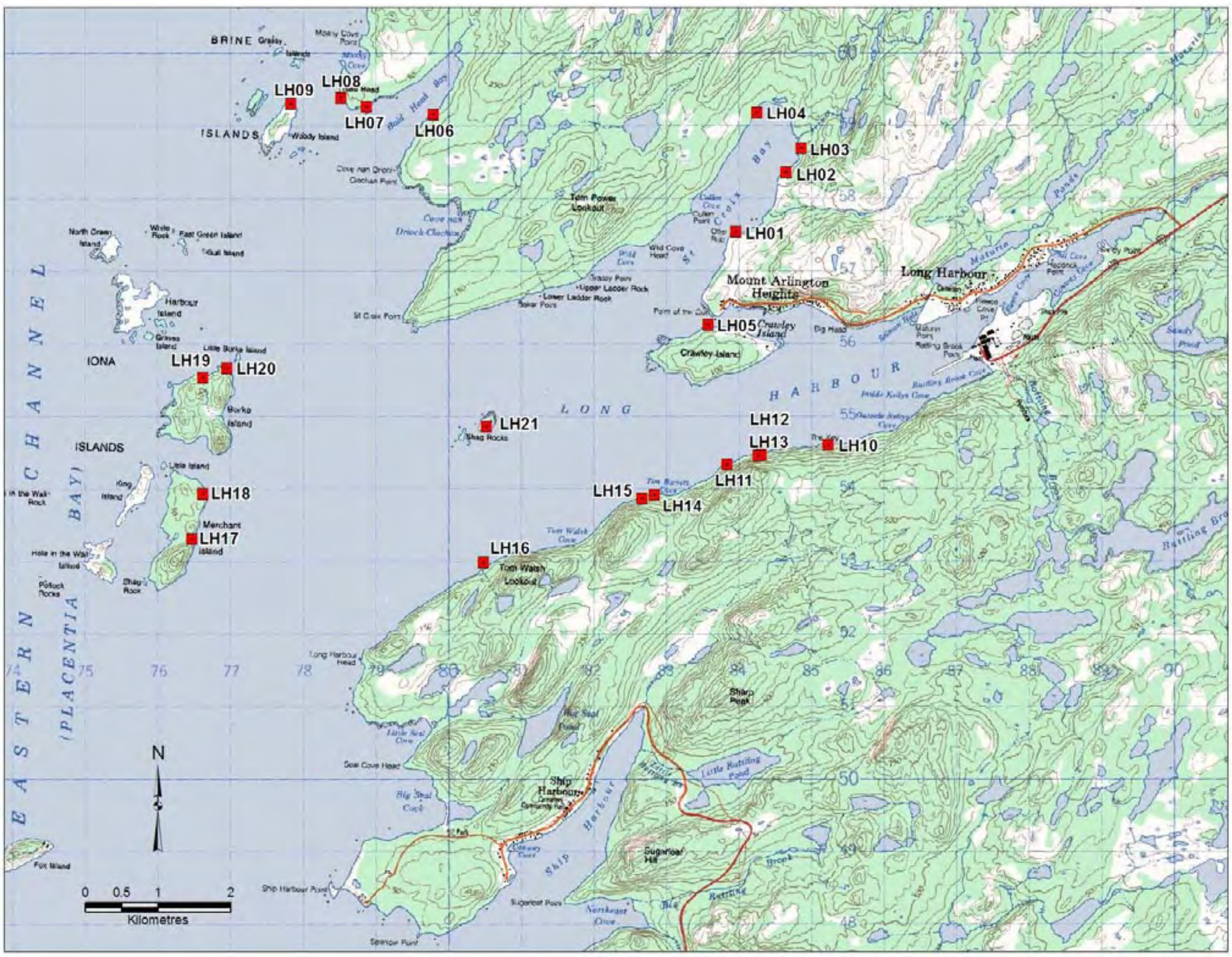


Figure 10. **Locations of Otter Haul-out Sites (rubs) Identified by LGL in the Long Harbour Study Area, Placentia Bay.**

Preface

This Marine Environment Component Study incorporates a variety of marine related topics. It is intended to satisfy the requirements for a Component Study on "the marine environment (including fish, fish habitat, and fisheries)" and to partially satisfy the requirement for information on avifauna as listed under the requirement for a terrestrial Component Study (as described in the EIS Guidelines issued by the provincial Department of Environment, 23 October 2006, hereafter referred to as the "EIS Guidelines").

Voisey's Bay Nickel Company Limited (VBNC) retained several St. John's-based companies to conduct the following marine studies of Long Harbour and environs:

- Climate and Oceanography (Oceans Limited) — Chapter 1
- Marine Ecology (LGL Limited) — Chapter 2
- Commercial Fisheries and Aquaculture (Canning & Pitt) — Chapter 3
- Bald Eagles, Marine Birds and Other Avifauna (LGL) — Chapters 4 and 5
- River Otter (LGL) — Chapter 6

These studies have been compiled under one cover as they are all directly related to the marine environment.

1.0 Climate and Oceanography

This chapter was prepared by Oceans Ltd. of St. John's.

Placentia Bay is subject to the weather systems that pass over Newfoundland. The island of Newfoundland experiences a maritime climate with the waters surrounding the island having a moderating effect on temperature. In general, maritime climates experience cooler summers and milder winters than continental climates and have a much smaller annual temperature range. Furthermore, a maritime climate tends to be fairly humid, resulting in reduced visibilities, low cloud heights, and receives significant amounts of precipitation. The Newfoundland climate is governed by the passage of high and low pressure circulation systems. These systems are embedded in, and steered by, the prevailing westerly flow that occurs in the upper levels of the atmosphere in the mid-latitude regions. This westerly flow is the consequence of the normal tropical-to-polar temperature gradient, the intensity of which determines the mean strength of the flow and the amount of energy available for the low pressure systems to draw upon. Therefore, during the winter months when the temperature gradient is strongest, low pressure systems are generally more intense and tend to move faster than in the summer months. [Meteorological convention defines seasons by quarters; e.g., winter is December, January, February, etc.]

Two main winter storm tracks; one from the Great Lakes Basin and the other from the Cape Hatteras - Cape Cod coastal area, direct low pressure systems toward Newfoundland and the Grand Banks (Bursey et al. 1977). The principal area of development of these low pressure systems extends from about Cape Hatteras to the waters around Newfoundland. The intensity of these systems ranges from relatively weak features to major winter storm systems with many producing gale to storm force winds by the time they reach Newfoundland.

Frequently, intense low pressure systems become 'captured' and slow down or stall as they move through the Newfoundland region. This may result in an extended period of little change in conditions that may range, depending on the position and overall intensity and size of the system, from the relatively benign to heavy weather conditions.

Rapidly deepening storms are a problem south of Newfoundland in the vicinity of the warm water of the Gulf Stream. The explosively deepening oceanic cyclone known as a "weather bomb" and defined as a storm that undergoes central pressure falls greater than 24 mb over 24 hours. Hurricane force winds near the center, the outbreak of convective clouds to the north and east of the center during the explosive stage, and the presence of a clear area near the center in its mature stage (Rogers and Bosart 1986) are typical of weather bombs. These systems after development will subsequently pass near Placentia Bay.

There is a general warming of the atmosphere during spring due to increasing heat from the sun. This spring warming is greater in the north than at the equator, resulting in a decrease in the north-south temperature gradient. Due to this weaker temperature gradient during the summer, storms tend to be weaker and not as frequent. Furthermore, the weaker tropical-to-polar temperature gradient in the summer results in the storm tracks moving further north, with most storm systems passing over the Gulf of St. Lawrence and Labrador. As a result, the incidences of gale or storm force winds are relatively infrequent over Newfoundland during the summer.

1.1. Study Team

The study team for the Long Harbour work consisted of the following personnel:

Data Collection

John Slade, an electronic technologist who is responsible for maintaining all the oceanographic equipment at Oceans Ltd. His work also involved building oceanographic moorings and deployment of equipment at sea. He deployed and recovered all oceanographic equipment at Long Harbour.

Andrew Cook, M.Eng. in electrical engineering with expertise in data communications and security; and the development of data acquisition and processing systems. He set up the weather station in Long Harbour.

Peter Chafe, a computer programmer/analyst, and hardware technologist. He maintains the computer network at Oceans Ltd. and assists with the deployment of oceanographic equipment. He assisted with the deployment and recovery of Oceanographic equipment at Long Harbour.

Oceanography Processing & Analysis

Judith Bobbitt, M.Sc., Principal, a Physical Oceanographer who has over 30 years of experience in oceanography data collection and analysis. She analyzed the majority of the Long Harbour oceanographic data, and prepared the report.

Ivan Victoria, a Physical Oceanographer with many years of experience in analyzing oceanographic data. He assisted with the analysis of the Long Harbour oceanographic data.

Ray Soper, a computer technologist trained in the management of information systems. He is responsible for processing and management of the oceanography data.

Climatology

Chris Lander, a meteorologist and weather forecaster. He was responsible for preparation of the Long Harbour climatology.

Malcolm Dewhurst, a meteorologist and weather forecaster. He assisted with the preparation of the Long Harbour climatology.

1.2. Data Sources

Wind and wave climate statistics in Placentia Bay were extracted from the AES40 North Atlantic wind and wave climatology data set compiled under contract to Environment Canada. The AES40 data set consists of continuous wind and wave hindcast data in 6-hour time steps for a 50-year period from 1954 to 2004, on a 0.625° latitude by 0.833° longitude grid. In this study, Grid Point 5616 located at 46°52´N; 55°00´W was deemed to be most representative of conditions within Placentia Bay (Figure 1.1).

Air temperature, sea surface temperature, wind speed and direction, precipitation types, and visibility statistics for Placentia Bay were compiled using data from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). A 30-year ICOADS subset of global marine surface observations from ships, drilling rigs, and buoys covering the period 1976 to 2005 was used in this report. The ICOADS data subset covered the area inside Placentia Bay bounded by a straight line across the mouth of Placentia Bay between 46°51´N; 55°48´W and 46°48´N; 54°08´W. The ICOADS data set has certain inherent limitations in that the observations are not spatially or temporally consistent. In addition, even though the data used in this report were subjected to standard quality control procedures, the data set is somewhat prone to observation and coding errors, resulting in some erroneous observations within the data set. The errors were minimized by using the enhanced filtering system using source exclusion flays, composite QC flags and an outlier trimming level of 4.5 standard deviations. The ICOADS data set is also suspected to contain a fair-weather bias, due to the fact that ships tend to avoid severe weather or simply do not transmit weather observations during storm situations.

The Canadian Center for Marine Communications deployed a weather buoy in Placentia Bay at 46°59´N; 54°41´W as part of its SmartBay Demonstration Project in August 2006. This buoy provides a continuous data set of average wind speed, wind direction, air temperature, sea temperature, relative humidity, and atmospheric pressure at 20-minute intervals.

A weather station installed on the wharf in Long Harbour by Oceans Ltd. has been in operation since May 2006. The weather station contains sensors to measure wind speed and direction, air temperature, and atmospheric pressure. The wind is recorded as 10-minute mean values and wind direction is recorded to a hundredth of a degree with respect to true north.

A number of climate and weather stations maintained by Environment Canada surround Placentia Bay. Cloud and visibility data are only available for stations that have had a manned observing station in the past. However, there are no weather stations situated around Placentia Bay that currently operate a manned observing program.

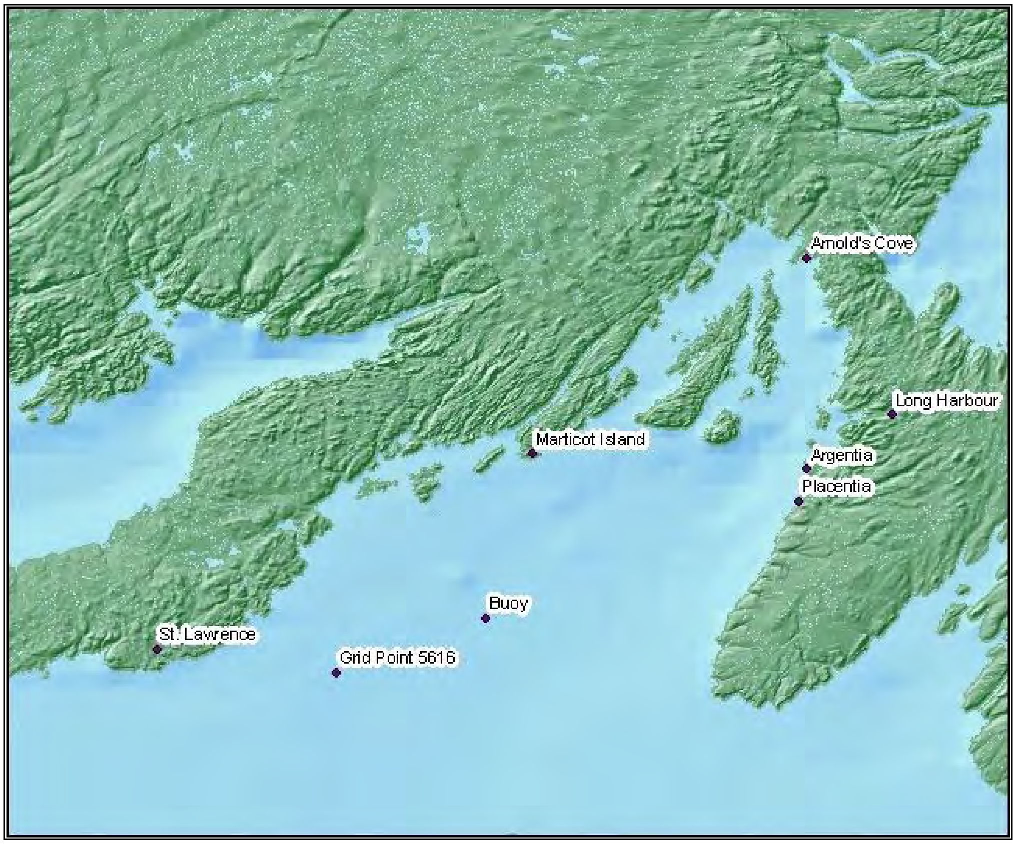


Figure 1.1. Locations of the Climate Data Sources.

The Arnold's Cove climate station recorded wind data at hourly intervals from July 1971 to June 1993. A manned observing station was operated at Argentia during the periods of January 1953 to May 1970 and May 1976 to October 1986, at St. Lawrence from February 1966 to February 1996 and at Placentia from November 1970 to December 1975. Wind data from Placentia are questionable because the station was sheltered. The Argentia and St. Lawrence stations were converted to automatic climate stations, recording only wind, temperature, relative humidity, and pressure data and are still in operation. The Long Harbour station operated for a 30-year period from November 1969 to November 1999. Temperature and precipitation data were recorded at this station for the entire period, and wind measurements were recorded until December 1983. A more recent climate station is located on Marticot Island and has been in operation since February 1994. Due to the difficulty in accessing this station, there is a lot of missing data within the data set, especially during the winter months when icing is prevalent. The locations where the data were collected are shown in Figure 1.1.

1.2.1. Wind Conditions

Placentia Bay experiences predominately southwest to west flow throughout the year. Westerly winds prevalent during the winter months begin to shift counter clockwise during spring as the tropical-to-polar temperature gradient weakens, becoming generally southwesterly during the summer months. As autumn approaches, the tropical-to-polar temperature gradient strengthens and the winds shift slightly, becoming predominately westerly again by late fall and into winter.

Low pressure systems crossing Newfoundland are more intense during the winter months. As a result, mean wind speeds tend to peak during this season. With the exception of the St. Lawrence weather station, mean wind speeds peak during the month of January (Table 1.1). The ICOADS data set recorded the highest January mean wind speed of 45 km/hr while Long Harbour recorded the lowest January mean wind speed of 19.1 km/hr. The winds from the ICOADS data set are not directly comparable to the measurements from the Environment Canada weather stations because the winds in the ICOADS data set were either estimated or measured by aneometers at various heights above sea level. The wind speed is dependent on height since the wind speed increases at increasing heights above sea level.

Table 1.1. Mean Wind Speed (km/hr) Statistics for Various Points in Placentia Bay.

Month	AES40	COADS	Argentia	Arnold's Cove	Long Harbour	Placentia	St. Lawrence	Marticot Island	Oceans Ltd*	SmartBay Buoy**
January	35.7	45.0	28.3	25.0	19.1	30.7	31.3	28.0	N/A	20.7
February	34.4	42.8	27.0	24.6	18.9	29.8	32.2	26.3	N/A	N/A
March	32.0	38.6	25.4	23.0	19.1	29.1	30.0	24.6	N/A	N/A
April	27.1	27.4	22.8	19.4	17.8	26.5	26.9	22.4	N/A	N/A
May	21.3	21.1	19.8	17.4	16.3	23.9	22.6	18.7	19.6	N/A
June	19.4	27.8	19.6	17.2	16.1	22.2	19.4	16.9	20.6	N/A
July	18.4	24.5	18.9	16.7	15.7	22.0	17.6	16.5	21.7	N/A
August	20.3	23.5	19.3	17.4	15.9	23.2	19.3	15.7	18.7	N/A
September	24.0	26.7	20.7	18.9	16.3	22.6	22.6	18.5	19.6	25.6
October	28.6	30.3	23.7	21.3	17.2	26.3	25.9	23.0	19.4	26.9
November	31.9	31.1	25.6	23.7	18.5	28.5	28.0	24.6	21.1	17.8
December	34.7	33.5	28.0	25.7	18.9	28.9	31.1	25.9	26.3	16.7

*Oceans Ltd. data coverage is from May18, 2006 to December 2006
**SmartBay data coverage is from September 28, 2006 to January 04, 2007

The wind data consist of 10-minute mean values with the exception of the Long Harbour and AES40 data sets which are 1-hour mean values. The adjustment factor to convert from 1-hour mean values to 10-minute mean values is usually taken as 1.06 (U.S. Biological Survey 1979).

Winds measured at the Long Harbour climate station are lower during the winter months than at the other land stations located around Placentia Bay. Much of this difference is due to local topography in the vicinity of each station; however other factors, including the length of each data set may also be a factor. The Oceans Ltd. weather station and the SmartBay buoy have the smallest data sets consisting of eight months and four months respectively, while the Argentia weather station has been in place since January 01, 1953.

A number of factors can contribute to the modification of winds by local topography. In Placentia Bay, coastal convergence (the convergence of land and sea winds resulting in stronger winds near the shore), is common when southwesterly winds occur along the eastern shore, and when northeasterly winds occur along the western shore of the bay. Also, the abundance of small river valleys along the coast, combined with the many large islands located throughout the bay result in channelling – the tendency of wind to follow the direction of a channel, and funnelling – an increase in wind speeds due to wind being forced through a narrow opening.

Since Long Harbour is located near Placentia and Argentia, one would expect similar wind conditions at Long Harbour as compared to these two stations. However, both Placentia and Argentia are subject to coastal convergence. Since the weather station at Long Harbour is situated at the head of the harbour, and thus further inland, coastal convergence has less of an effect. The effects of coastal convergence at Argentia can be readily seen when looking at the maximum wind speeds presented in Table 1.2.

Table 1.2. Maximum Wind Speeds (km/hr) for Various Points in Placentia Bay.

Month	AES40	COADS	Argentia	Arnold's Cove	Long Harbour	Placentia	St. Lawrence	Marticot Island	Oceans Ltd*	SmartBay Buoy**
January	90.5	103.7	109.1	92.0	72.0	89.1	145.0	95.0	N/A	33.0
February	95.3	107.4	110.9	90.0	79.1	84.1	145.0	102.0	N/A	N/A
March	99.8	113.0	87.0	80.0	72.0	77.0	115.9	115.0	N/A	N/A
April	74.6	96.3	93.0	79.1	53.0	89.1	95.9	98.0	N/A	N/A
May	75.4	57.4	84.1	69.1	64.1	68.0	93.0	93.0	57.8	N/A
June	68.0	55.6	74.1	68.0	55.0	64.1	84.1	67.0	49.3	N/A
July	63.9	61.1	78.0	65.9	53.0	68.0	84.1	74.1	55.2	N/A
August	61.2	64.8	80.0	84.1	55.9	68.0	80.9	80.0	43.5	N/A
September	85.1	59.3	89.1	65.9	63.0	64.1	89.1	107.0	64.1	44.6
October	102.4	100.0	103.0	82.0	70.9	72.0	113.0	100.0	58.7	62.2
November	86.4	87.0	100.9	84.1	72.0	80.0	100.0	93.0	59.1	42.8
December	89.5	77.8	108.0	93.0	74.1	84.1	107.0	98.0	63.9	39.1

*Oceans Ltd. data coverage is from May 18, 2006 to December 2006
**SmartBay data coverage is from September 28, 2006 to January 04, 2007

While the Long Harbour site is minimally affected by coastal convergence, local topography does have an influence at this station. Westerly winds entering the mouth of Long Harbour are channelled into a predominately southwest direction during the winter months. For this reason, southwest winds occur frequently at Long Harbour throughout the year. Similarly, local topography also dictates a secondary direction from the northeast in all seasons. Winds from this direction would not experience the funnelling effect that southwest winds experience. A wind rose of the annual wind speed from the Environment Canada data is presented in Figure 1.2 and a histogram of the wind speed frequency distribution in Figure 1.3. Monthly wind roses along with histograms of the frequency distributions of wind speeds from the Environment Canada Long Harbour climate station can be found in Oceans Ltd. (2007). These wind roses show the predominately southwesterly wind direction at Long Harbour, and its secondary northeasterly direction.

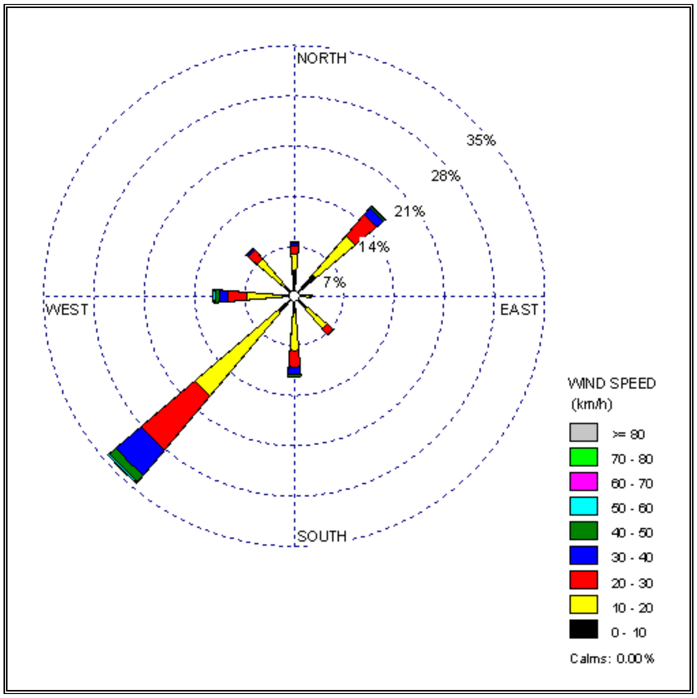


Figure 1.2. Annual Wind Rose from the Environment Canada Climate Station at Long Harbour.

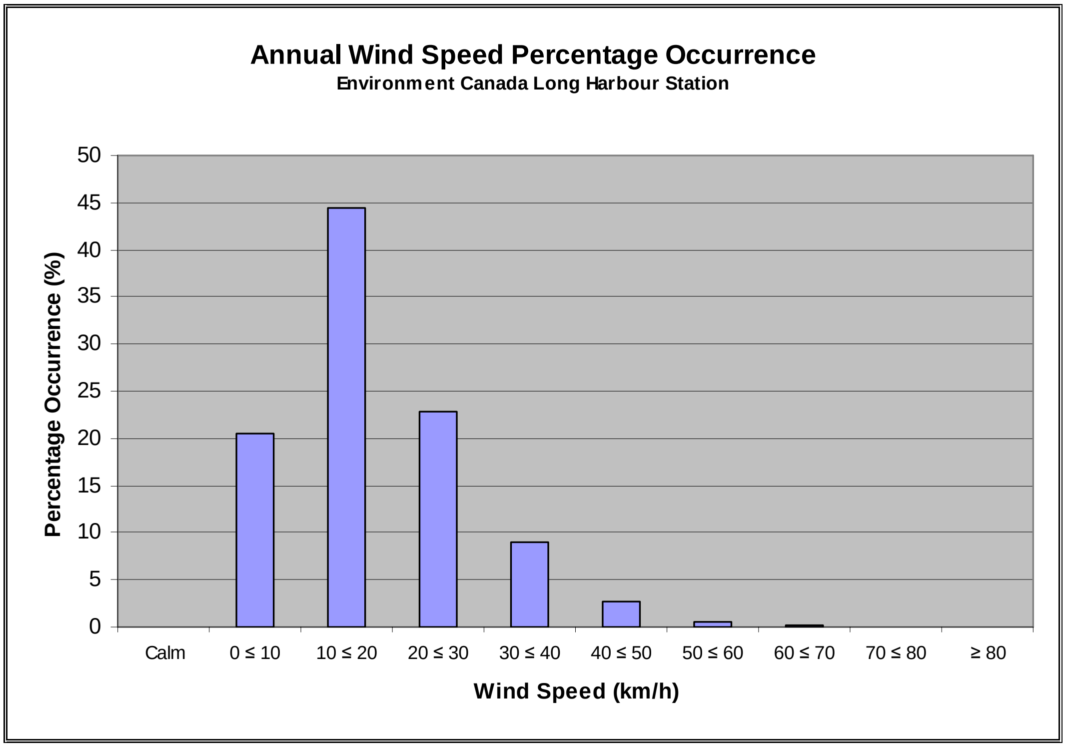


Figure 1.3. Annual Wind Speed Percentage of Occurrences from the Environment Canada Climate Station at Long Harbour.

A wind rose of the annual wind speed from the AES40 data set is presented in Figure 1.4 and the histogram of the frequency distribution of wind speeds in Figure 1.5. The monthly distributions are presented in Oceans Ltd. (2007). There is a marked increase in the occurrence of winds from the west to north in the winter months as opposed to the summer months, which is consistent with the wind climatology from weather stations in the area.

Wind measurements during the summer and fall of 2006 from Oceans Ltd.'s weather station show similar values of wind speed and direction as those measured from the Environment Canada weather and climate stations in the region. While wind speeds measured at Oceans Ltd.'s weather station are slightly higher than the Environment Canada climate station at Long Harbour, the values are similar to the data from other stations in the area. The higher wind speeds measured by Oceans Ltd. may be attributed to several factors, including, but not limited to the following.

- Oceans Ltd. data are present as 10-minute means, whereas the Environment Canada data are hourly means.
- The two weather stations are situated at different locations and are affected differently by local topography.
- The Environment Canada data set is over a 30-year period, whereas the Oceans Ltd. data set is over a period of eight months.

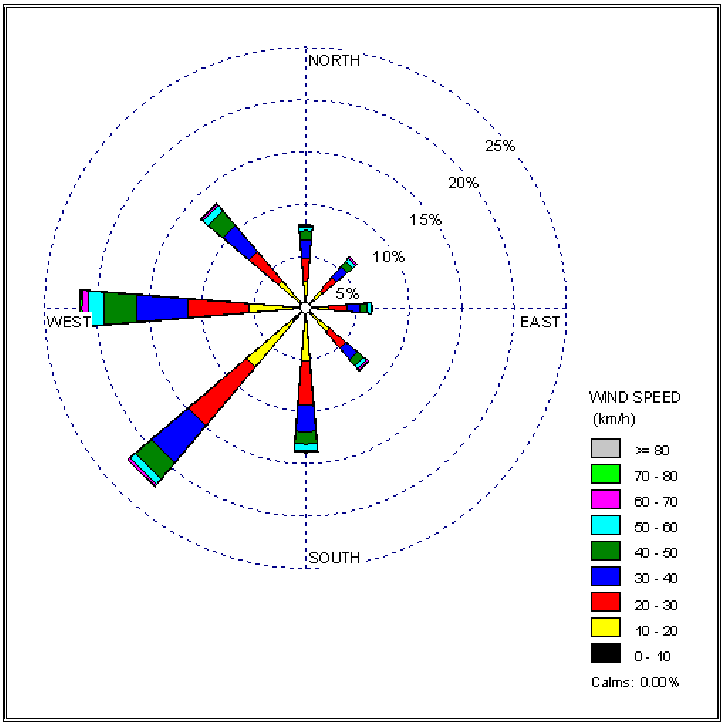


Figure 1.4. Annual Wind Rose from the AES40 Grid Point 5616.

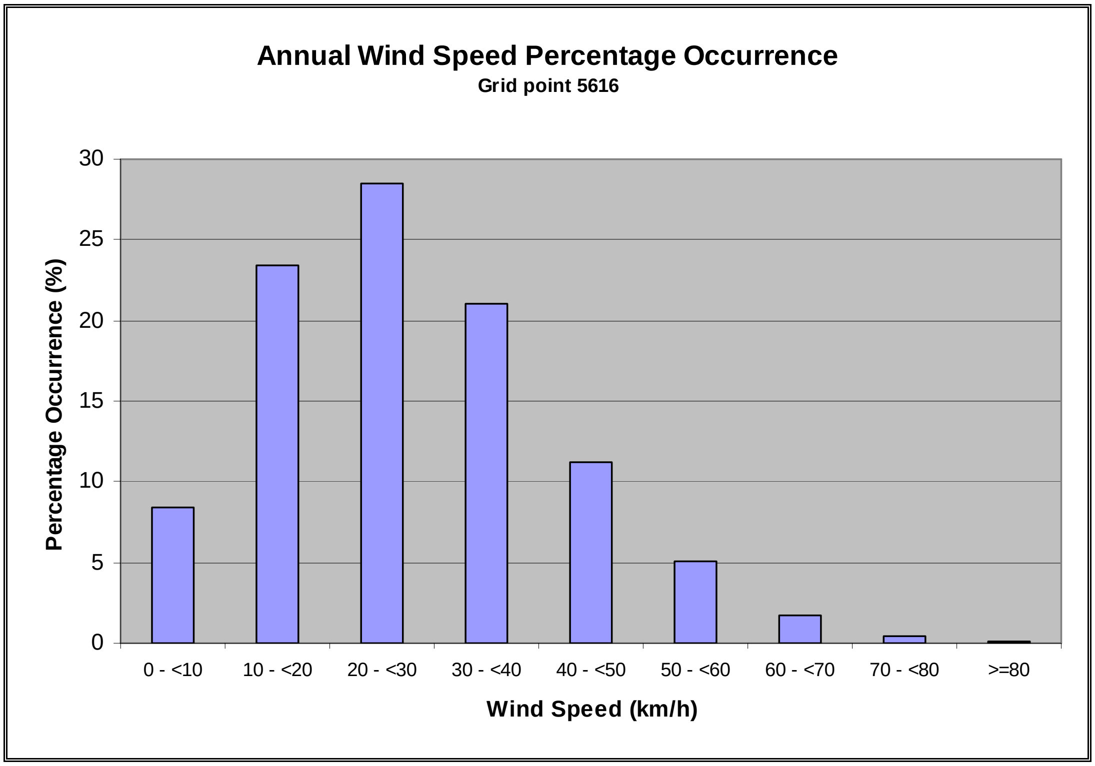


Figure 1.5. Annual Wind Speed Percentage of Occurrences from the AES40 Grid Point 5616.

Intense mid-latitude low pressure systems occur frequently from early autumn to late spring. In addition, remnants of tropical systems have passed near Newfoundland between spring and late fall. Therefore, while mean wind speeds tend to peak during the winter months, maximum wind speeds may occur at anytime during the year.

St. Lawrence recorded the highest winds speeds in Placentia Bay of 145 km/hr out of the west-southwest on February 22, 1967 and again on January 05, 1968. During the February 1967 storm, the AES40 wind speeds peaked at 89 km/hr out of the west and the Argentia wind speeds peaked at 90 km/hr from the west-southwest. In January 1968, the AES40 data had maximum wind speeds of 91 km/hr out of the southwest, and Argentia recorded maximum wind speeds of 84 km/hr from the southwest. The Long Harbour station was not in operation at the time of these storms. The higher wind speeds reported at the St. Lawrence weather station may be due to local topographic effects or due to its higher elevation. Both of these storms experienced the explosive deepening in the warm waters south of Newfoundland known commonly as a weather bomb. The February 1967 storm (Figure 1.6) experienced a central pressure drop from 986 mb at 18Z February 21, 1967 to 952 mb at 18Z February 22, 1967. Similarly, the January 1968 storm experienced a central pressure drop from 1003 mb at 18Z January 04, 1968 to 960 mb at 18Z January 05, 1968.

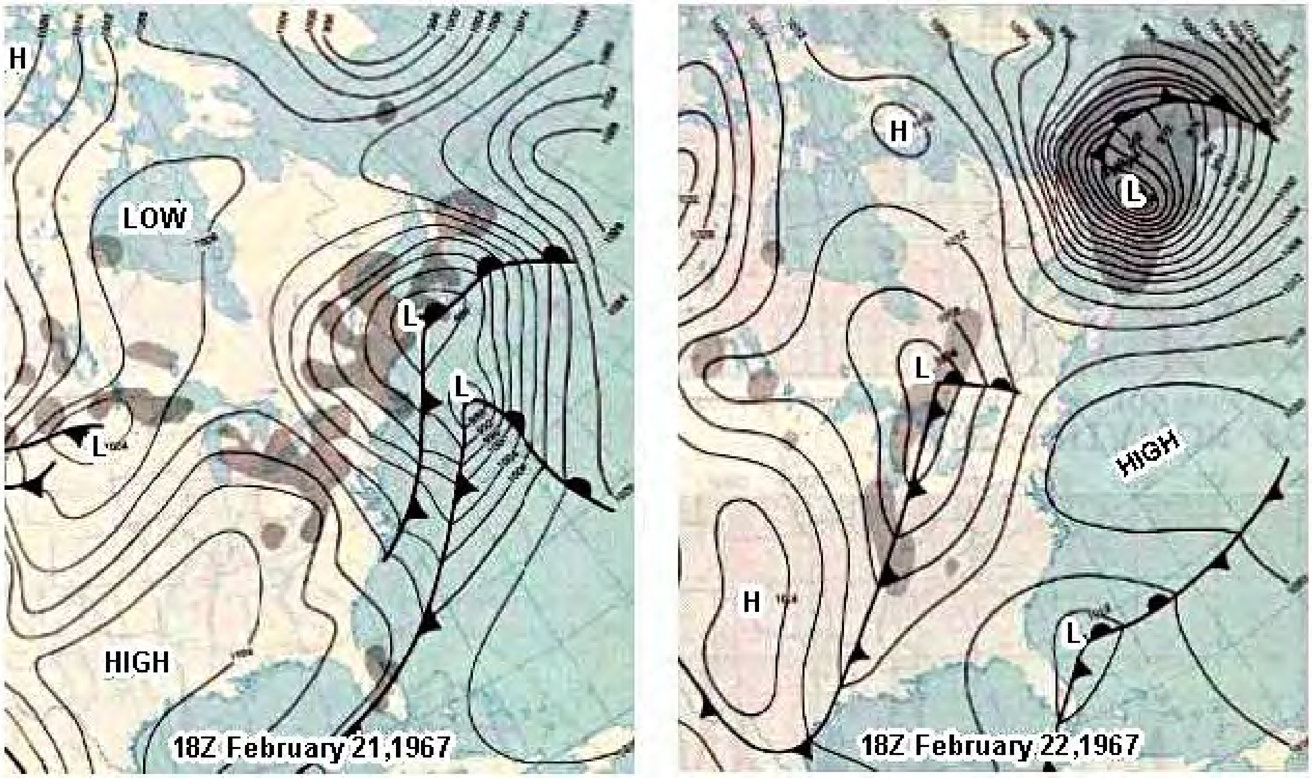


Figure 1.6. Explosive Deepening of a Mid-Latitude Low Pressure February 1967.

The highest hourly wind speed of 102 km/hr from the south obtained from the AES40 data set occurred on October 20, 2000 coinciding with the passing of Hurricane Michael west of the Burin Peninsula. On the same day, Marticot Island recorded wind speeds of 100 km/hr from the southwest and St. Lawrence recorded wind speeds of 96 km/hr from the west. No ICOADS reports are available in Placentia Bay as Hurricane Michael passed. No wind measurements are available from Long Harbour for this event, because the Long Harbour station was no longer in operation at the time of Hurricane Michael.

An extremal analysis was carried out for winds at the mouth of Placentia Bay using the AES40 data set for 50 years of data and Oceanweather's OMOSIS Software (Oceanweather Inc. 2001). Extreme value estimates for hourly winds using a Gumbel distribution on 158 storms were calculated for return periods of 1-year, 10-years, 25-years, 50-years and 100-years. The values were 80.6 km/hr, 92.5 km/hr, 96.8 km/hr, 100.1 km/hr, and 103.7 km/hr, respectively. The weather station data around Placentia Bay reported 10-minute mean wind speeds with the exception of Long Harbour which reported hourly mean data. For comparisons with the weather station data, the hourly extreme wind speeds previously quoted correspond to 10-minute winds speeds of approximately 85.3 km/hr, 97.9 km/hr, 102.6 km/hr, 106.2 km/hr and 109.8 km/hr, respectively using a conversion factor of 1.06 (U.S. Geological Survey 1979).

The highest winds are usually the result of tropical cyclones or their remnants. The highest winds in a tropical cyclone tend to be concentrated in a narrow band near its centre. Since the storm centre rarely passes over a reporting station, the highest winds are usually not measured. Tropical cyclones develop and strengthen over warm tropical waters, typically during the months of June to November. However, tropical cyclones have been known to develop as early as April and as late as January. These systems typically move east to west over the warm waters of the tropics. Systems that turn northwest maintain their strength from the warm waters of the Gulf Stream. As the tropical cyclone moves north, it moves over colder waters and begins to weaken. By the time these weakening cyclones reach Newfoundland, they are usually embedded into a mid-latitude low pressure system and their tropical characteristics are usually lost.

Since 1975, 26 tropical systems have passed within 278 km of Placentia Bay (Table 1.3; Figure 1.7). On occasion, tropical systems maintain their tropical characteristics as they approach Newfoundland. On October 19, 2000 Hurricane Michael made landfall along the south coast of Newfoundland, west of the Burin Peninsula, as a category one hurricane with a central pressure of 965 mb. Near the time Hurricane Michael made landfall, the St. Lawrence climate station reported north-northeast winds at 96 km/hr. Other stations in Placentia Bay were not reporting at the time.

Hurricane Luis passed over or close to Long Harbour on September 11, 1995. According to the NOAA Coastal Services Center Archive (NOAA 2006), Hurricane Luis had maximum sustained 1-minute mean, 10-metre wind speeds of 148 km/hr when it reached the Avalon Peninsula. This value converts to an hourly mean wind speed of approximately 121 km/hr. The maximum wind speeds reported from Argentia on September 11 measured 67 km/hr coming from the north or northwest. However, no winds were reported at Argentia at the time the hurricane passed through the region. Marticot Island reported winds peaking at 65 km/hr from the north-northeast as the system passed.

1.2.2. Air Temperature

The ocean takes longer than land to heat up during the summer and longer to cool down in the winter months. Therefore, the ocean has a moderating effect on air temperature along the Newfoundland coast, which is typical of a maritime climate. During the spring, sea surface temperatures take longer to warm up than the surrounding air temperatures. As a result, the water temperature tends to slow the warming of the air along the coast, resulting in cooler springs than would be experienced in a continental climate. In autumn, sea surface temperatures are generally warmer than the surrounding air, as air tends to cool faster than the ocean. This results in the sea surface temperatures typically being higher than air temperatures. The warm ocean reduces the rate at which the air temperature decreases resulting in generally warmer autumns than would be experienced in a continental climate.

The mean seasonal temperature statistics for the various data sources in Placentia Bay are shown in Table 1.4 through Table 1.6. On average, the temperature at Long Harbour was higher during summer than at any of the other stations, with a mean seasonal temperature of 13.9°C and a mean seasonal maximum temperature of 25.2°C recorded at the Environment Canada climate station. Long Harbour recorded an extreme maximum temperature of 30.6°C on August 13, 1972 (Table 1.7). The highest temperature of 31.3°C was measured at St. Lawrence on August 3, 1999. The Placentia weather station recorded the coldest mean seasonal air temperature of -3.1°C; the Long Harbour climate station had the coldest mean minimum temperature of -19.9°C. The coldest extreme minimum temperature of -25°C was recorded at Long Harbour on February 15, 1975.

Table 1.3. Storm Tracks of Tropical Systems Passing within 278 km of Placentia Bay, 1975 to 2006.

Record	Year	Month	Day	Storm Name	Wind Speed (km/h)	Pressure (mb)
1	1975	10	3	Gladys	157	960
2	1978	9	4	Ella	213	956
3	1982	6	20	SubTrop1	111	984
4	1982	9	18	Debby	185	960
5	1985	7	19	Ana	102	996
6	1989	8	8	Dean	120	978
7	1990	10	15	Lili	74	995
8	1995	6	9	Allison	74	995
9	1995	8	22	Felix	93	986
10	1995	9	11	Luis	148	965
11	1996	7	14	Bertha	93	995
12	1996	9	15	Hortense	111	982
13	1996	10	10	Josephine	83	985
14	1998	8	30	Bonnie	83	1000
15	1998	9	6	Earl	93	968
16	1999	9	18	Floyd	65	992
17	1999	9	23	Gert	111	964
18	2000	9	17	Florence	93	1000
19	2000	10	8	Leslie	74	1003
20	2000	10	19	Michael	157	965
21	2001	9	14	Erin	120	984
22	2002	7	17	Arthur	93	998
23	2004	9	1	Gaston	83	999
24	2005	7	30	Franklin	93	1001
25	2005	9	18	Ophelia	83	999
26	2005	10	26	Wilma	102	982
27	2006	6	16	Alberto	93	972
28	2006	7	18	NotNamed	56	1007
29	2006	7	22	Beryl	65	1003
30	2006	9	13	Florence	130	963
31	2006	10	2	Isaac	111	990

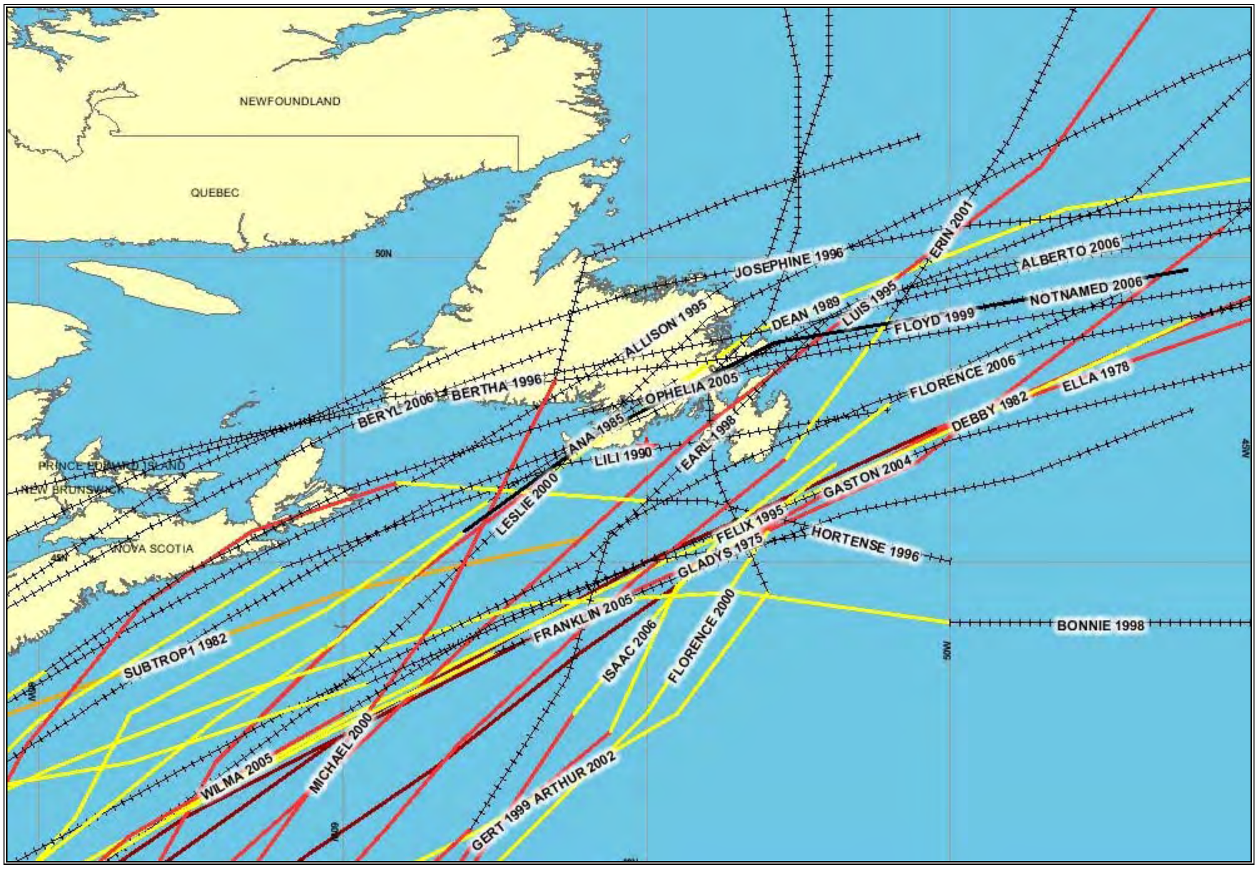


Figure 1.7. **Storm Tracks of Tropical Systems Passing within 278 km of Placentia Bay, 1975 to 2006.**

Table 1.4. **Mean Seasonal Air Temperature (°C) Statistics for Placentia Bay.**

	Winter	Spring	Summer	Autumn
ICOADS	-1.9	0.3	12.3	8.5
Argentia	-1.4	2.0	12.3	8.4
Long Harbour	-2.6	2.8	13.9	8.4
Placentia	-3.1	1.5	12.0	8.1
St. Lawrence	-2.4	1.9	12.4	7.7
Marticot Island	-1.7	2.0	12.5	8.9
Oceans Ltd*	2.3	8.2	14.9	10.3
SmartBay Buoy**	N/A	N/A	N/A	9.3

*Oceans Ltd. data coverage is from May 18, 2006 to December 19, 2006
**SmartBay data coverage is from September 28, 2006 to January 04, 2007

Table 1.5. Mean Seasonal Maximum Air Temperature (°C) Statistics for Placentia Bay.

	Winter	Spring	Summer	Autumn
ICOADS	4.6	6.6	16.7	15.0
Argentia	12.3	15.7	22.7	20.4
Long Harbour	13.5	17.6	25.2	22.4
Placentia	13.0	14.4	23.0	19.6
St. Lawrence	8.9	16.1	23.9	20.8
Marticot Island	7.0	14.0	19.9	20.5
Oceans Ltd*	13.5	13.6	24.5	21.1
SmartBay Buoy**	8.8	N/A	N/A	15.4

*Oceans Ltd. data coverage is from May 18, 2006 to December 19, 2006
**SmartBay data coverage is from September 28, 2006to January 04, 2007

Table 1.6. Mean Seasonal Minimum Air Temperature (°C) Statistics for Placentia Bay.

	Winter	Spring	Summer	Autumn
ICOADS	-7.4	-3.8	8.1	3.3
Argentia	-13.9	-10.4	2.1	-3.2
Long Harbour	-19.9	-14.4	0.7	-6.7
Placentia	-18.0	-11.4	2.0	-2.8
St. Lawrence	-16.7	-12.9	1.8	-6.1
Marticot Island	-13.4	-10.5	2.0	-4.8
Oceans Ltd*	-7.0	1.9	4.2	-4.8
SmartBay Buoy**	-6.5	N/A	N/A	-2.8

*Oceans Ltd. Data coverage is from May to December 2006
**SmartBay data coverage is from September 2006 to January 04, 2007

Table 1.7. Extreme Air Temperature Statistics for Placentia Bay.

	Maximum Temperature (°C)	Minimum Temperature (°C)
ICOADS	22.0	-17.4
Argentia	26.0	-21.0
Long Harbour	30.6	-25.0
Placentia	25.0	-20.0
St. Lawrence	31.3	-21.6
Marticot Island	24.2	-21.0

The mean air temperatures measured at Long Harbour by Oceans Ltd.'s weather station are slightly higher than the daily mean temperatures for the same months measured by Environment Canada. This may be attributed to the shorter duration period of the Oceans Ltd. data, or to the difference in location of the two weather stations.

The ICOADS data also show that mean air temperatures over the bay are similar in value to temperatures measured over the land, while mean seasonal maximum temperatures are much cooler and mean seasonal minimum temperatures are much warmer. The smaller temperature range of the ICOADS data gives an indication of the moderating effect that the ocean temperature has on the surrounding air temperature.

1.2.3. Precipitation

Precipitation can come in three forms: (1) liquid, (2) freezing, or (3) frozen. Included in the three classifications are

(1) Liquid Precipitation
  - Drizzle
  - Rain

(2) Freezing Precipitation
  - Freezing Drizzle
  - Freezing Rain

(3) Frozen Precipitation
  - Snow
  - Snow Pellets
  - Snow Grains
  - Ice Pellets
  - Hail
  - Ice Crystals

Precipitation was recorded at four of the Environment Canada climate stations in Placentia Bay: (1) Argentia, (2) Long Harbour, (3) Placentia, and (4) St. Lawrence as well as in the ICOADS data set. While all four of the land stations recorded both precipitation type and amounts, the ICOADS data set only contains precipitation type statistics.

1.2.3.1. Frequency of Precipitation Types

The frequency of precipitation type was calculated using hourly data at Argentia, Placentia, and St. Lawrence, with each occurrence counting as one event. Long Harbour, however, recorded the occurrence of precipitation type on a daily basis. Therefore, at Long Harbour, if precipitation was recorded for only one hour, it would count as one day with precipitation. Furthermore, since Long Harbour was an automatic weather station and sometimes cannot distinguish between precipitation types at or near 0°C, it is suspected that the occurrence of freezing rain at the site is recorded too low. Also, automatic stations have difficulty determining a mixture of rain and snow. As a result, the frequency of precipitation type at Long Harbour is presented separate from the other stations in this report.

The frequency distribution of precipitation in Placentia Bay from the ICOADS data and from the Argentia, Placentia, and St. Lawrence weather stations is shown in Table 1.8. These data show that winter has the highest frequency of precipitation with frequencies between 26.4% and 29.2% for the land stations and 56.3% over the ocean. Snow accounts for the majority of precipitation during the winter months, occurring twice as often as rain at the land stations and 3.3 times more frequent than rain over the ocean. Summer has the lowest frequency of precipitation with the total frequency of occurrence ranging from 13.5% to 16.5%.

The annual frequency distribution of precipitation in Placentia Bay is presented in Table 1.9. On average, precipitation occurs 20.0% to 21.8% of the time at the land stations and 34.6% of the time over the bay. The higher percentages over the bay are due to a higher frequency of occurrences of snow reported by ships.

Long Harbour experiences a high occurrence of days with precipitation, with a frequency of occurrence of 48.4% (Table 1.10). The highest occurrence is in October, with 59.7% of days reporting precipitation, most of which occurred in the form of rain. There was only one record of snow occurring in October. The lowest month for precipitation at Long Harbour was February, with 39.8% of days reporting precipitation. In February, rain and snow occurred at the same frequency with 21.4% of the days reporting snow and 21.4% of the days reporting rain. Note that there are incidences when both rain and snow were reported on the same day.

While rain occurs in all seasons, it is more frequent in autumn. The earliest observation of snow occurred in October; however, as stated earlier, only one observation was recorded in the 30-year record at Long Harbour. Snow occurs in all months between November and May, peaking in January with 24.2% of days reporting the occurrence of snow. A low frequency of freezing precipitation occurs from November to March. Freezing precipitation is discussed in more detail in a following section.

Table 1.8. Seasonal Frequency Distribution (%) of Precipitation in Placentia Bay.

		Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Total
ICOADS	**Winter**	11.9	3.2	1.1	39.7	0.4	56.3
	Spring	16.4	1.2	0.5	16.7	0.0	34.8
	Summer	14.3	0.0	0.0	0.0	0.0	14.3
	Autumn	26.7	0.0	0.0	1.3	0.0	27.9
Argentia	**Winter**	9.8	0.7	0.5	17.8	0.0	28.8
	Spring	13.9	0.4	0.5	8.6	0.0	23.4
	Summer	16.5	0.0	0.0	0.0	0.0	16.5
	Autumn	16.4	0.0	0.2	1.3	0.0	17.9
Placentia	**Winter**	8.0	0.8	0.3	17.4	0.0	26.4
	Spring	14.8	0.6	0.2	7.1	0.0	22.7
	Summer	18.8	0.0	0.0	0.0	0.0	18.8
	Autumn	17.1	0.0	0.1	1.7	0.0	19.0
St. Lawrence	**Winter**	8.0	0.9	0.1	20.2	0.0	29.2
	Spring	12.4	0.8	0.1	7.3	2.5	23.2
	Summer	13.4	0.0	0.0	0.0	0.0	13.5
	Autumn	14.7	0.0	0.1	1.6	0.0	16.5

Table 1.9. Annual Frequency Distribution (%) of Precipitation in Placentia Bay.

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Total
ICOADS	17.1	1.2	0.4	15.8	0.1	34.6
Argentia	14.1	0.3	0.3	7.0	0.0	21.7
Placentia	14.6	0.4	0.2	6.7	0.0	21.8
St. Lawrence	12.1	0.4	0.1	7.3	0.0	20.0

Table 1.10. Monthly Frequency Distribution (%) of Precipitation at Long Harbour.

	Rain / Drizzle	Freezing Rain / Drizzle	Snow	Total Precipitation
January	26.9	0.8	24.2	47.5
February	21.4	1.0	21.4	39.8
March	34.8	0.5	14.5	46.0
April	40.0	0.0	6.5	43.9
May	48.1	0.0	0.6	48.2
June	46.7	0.0	0.0	46.7
July	44.1	0.0	0.0	44.1
August	47.7	0.0	0.0	47.7
September	54.0	0.0	0.0	54.0
October	59.7	0.0	0.1	59.7
November	50.2	0.1	4.4	53.0
December	37.7	0.4	15.5	49.5
Total	42.7	0.2	7.2	48.4

1.2.3.2. Precipitation Amount

Daily precipitation amount values were recorded at all four stations, but not in the ICOADS data. Rainfall and total precipitation data were recorded in millimetres while snowfall data were reported in centimetres. To calculate total precipitation, snowfall amounts were converted to millimetres using the rule that one centimetre of snow is generally equal to one millimetre of water. Also, daily precipitation amounts recorded at these stations refer to the synoptic day, which begins at 0601 UTC and ends at 0600 UTC on the following day. As a result, a rain event occurring before 0230 NST would be recorded as occurring on the previous day.

Argentia, Long Harbour, and Placentia all report similar values of mean annual total precipitation (Table 1.11), with Placentia reporting the least amount (1,324 mm) and Argentia recording the highest (1,398 mm). This would be expected due to the proximity of the stations to each other. Values reported at St. Lawrence are much higher than the other stations with a mean annual total precipitation of 1,550 mm and maximum annual precipitation of 1,941 mm.

The majority of the total recorded precipitation was in the form of rain with each station recording total annual rain amounts (Table 1.12) between 85% and 90%. The maximum monthly rainfall amounts occurred in October at Argentia, Long Harbour, and Placentia, and in August at St. Lawrence. The maximum daily rainfall amounts of 85.7 mm and 119.0 mm were recorded on October 17, 1981 at Argentia and Long Harbour, respectively. No precipitation statistics are available on this date for the Placentia station because it was not in operation in 1981. The Placentia weather station reported a maximum daily rainfall amount of 93.2 mm on August 23, 1975. The St. Lawrence station reported a maximum rainfall amount of 116.0 mm on September 10, 1995 coinciding with the passage of Hurricane Luis in the early morning hours of September 11, 1995. As stated earlier, precipitation amounts recorded before 0230 NST on September 11, 1995 would have been entered in the previous day's climate record. There was no precipitation recorded on September 11, 1995 indicating that all precipitation had passed through the area ahead of the hurricane.

Snowfall has occurred in Placentia Bay in every season, including the summer season. Mean snowfall amounts (Table 1.13) show that on average, snow begins in October at the four stations with a mean snowfall ranging between 0.1 cm and 2.5 cm. While mean snowfall amounts are low for October, significant events can occur in October as evident from the maximum monthly snowfall of 20.3 cm reported by St. Lawrence. This monthly maximum is the result of a one-day event which occurred on October 31, 1975. Snowfall is recorded in all months between October and June, with the peak snowfall amounts occurring in January at each station. Snow in June does not occur every year resulting in a mean snowfall amount of 0.0 cm for Argentia and Long Harbour and 0.3 cm for Placentia. The maximum monthly snowfall of 176.8 cm was recorded at St. Lawrence during the month of February.

The highest maximum one-day snowfall of 71.3 cm occurred at St. Lawrence on September 14, 1987. This value is twice as high as other one-day maximum's reported in Placentia Bay. The other stations have reported maximum one-day snowfall events of 29.2 cm at Argentia, 35.6 cm at Long Harbour and 34.3 cm at Placentia.

Overall, St. Lawrence experiences the highest precipitation amounts and has the highest monthly mean and monthly maximum for rainfall and snowfall, as well as the highest one-day snowfall amount as compared with the other weather stations in the area.

Precipitation amounts were recorded at the Environment Canada Long Harbour climate station from November 1969 to November 1999. On average, 1,387.2 mm of precipitation falls on Long Harbour during a year with a maximum amount of 1,619.9 mm (Table 1.14). Included in these figures is a mean annual snowfall of 159.9 cm a year and a monthly maximum of 269.0 cm a year. The mean annual rainfall is 1,228.4 mm and the maximum annual rainfall is 1,499.9 mm.

Table 1.11. Precipitation Amount (mm) Statistics for the Environment Canada Climate Stations in Placentia Bay.

	Argentia		Long Harbour		Placentia		St. Lawrence	
	Mean	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**
January	126.4	170.8	127.4	202.1	106.1	183.7	132.8	203.4
February	84.4	155.7	111.6	207.7	86.7	185.4	124.7	234.0
March	113.0	228.1	110.0	218.4	105.3	138.1	122.4	210.8
April	79.2	143.9	101.9	240.9	103.3	177.5	113.7	233.1
May	94.9	143.1	92.7	157.2	81.8	129.7	118.1	228.6
June	124.0	193.7	112.8	249.2	96.6	148.9	127.8	341.3
July	107.9	196.8	92.3	223.4	81.1	110.4	106.8	200.8
August	112.9	176.0	110.5	343.6	157.4	200.4	118.2	399.2
September	139.3	185.6	124.5	222.7	100.4	158.8	148.6	248.0
October	136.9	280.5	148.0	311.2	172.1	249.2	145.9	265.9
November	110.5	177.0	125.9	208.4	141.1	227.9	147.4	248.6
December	129.5	227.8	118.5	168.2	102.7	163.8	134.9	263.2
Annual	1398.0	1704.8	1387.2	1619.9	1324.0	1488.7	1550.0	1940.8

Table 1.12. Total Rainfall Amount Statistics for the Environment Canada Climate Stations in Placentia Bay.

	Argentia		Long Harbour		Placentia		St. Lawrence	
	Mean	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**
January	85.6	120.6	83.3	156.0	50.8	81.3	70.7	139.1
February	46.8	148.0	71.2	183.8	61.9	156.4	64.3	150.6
March	80.6	193.9	83.4	202.4	79.2	115.7	81.6	189.1
April	63.4	106.2	92.3	215.9	93.3	168.6	99.7	226.3
May	93.9	142.9	91.1	157.2	75.2	129.7	115.2	228.6
June	124.0	193.7	112.8	249.2	96.3	148.9	127.6	341.3
July	107.9	196.8	92.3	223.4	81.1	110.4	106.8	200.8
August	112.9	176.0	110.5	343.6	157.4	200.4	118.2	399.2
September	139.3	185.6	124.5	222.7	100.4	158.8	148.6	248.0
October	136.6	280.5	147.7	311.2	168.6	249.2	144.6	245.6
November	103.4	177.0	118.4	208.4	126.6	204.4	136.2	224.6
December	107.2	194.5	87.5	150.8	68.4	119.6	96.1	242.1
Annual	1265.9	1578.1	1228.4	1499.9	1148.5	1313.6	1313.0	1766.8

Table 1.13. Total Snowfall Amount Statistics for the Environment Canada Climate Stations in Placentia Bay.

	Argentia		Long Harbour		Placentia		St. Lawrence	
	Mean	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**
January	40.7	90.9	43.4	122.0	61.3	103.3	64.7	127.8
February	38.2	71.7	39.9	92.4	30.3	42.4	61.4	176.8
March	34.2	74.3	26.6	60.9	28.4	60.4	41.8	113.6
April	15.9	61.2	9.3	33.0	12.2	44.3	13.9	54.4
May	1.0	9.2	1.6	36.1	5.7	24.3	2.2	24.4
June	0.0	0.3	0.0	0.0	0.3	1.3	0.2	6.4
July	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
September	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
October	0.1	1.0	0.3	10.2	2.5	6.4	1.3	20.3
November	7.2	27.3	7.3	39.5	14.4	23.6	10.9	38.7
December	25.7	86.6	28.3	80.0	37.0	63.0	39.5	83.2
Annual	140.3	208.7	159.9	269.0	193.4	224.8	243.9	430.1

Table 1.14. Precipitation Amount Statistics for the Environment Canada Climate Station at Long Harbour.

	Daily Mean Precip (mm)	**Daily Maximum Precip (mm)**	**Daily Standard Deviation (mm)**	**Monthly Mean (mm)**	**Monthly Maximum (mm)**	**Monthly Standard Deviation (mm)**
January	8.7	53.8	9.6	127.0	202.1	43.2
February	8.9	68.0	10.4	111.6	207.7	52.7
March	7.7	80.2	8.7	110.0	218.4	47.9
April	7.3	82.0	8.8	101.9	240.9	55.6
May	6.1	55.0	7.8	92.7	157.2	35.5
June	7.6	92.4	10.9	112.8	249.2	55.1
July	6.8	63.0	9.1	92.3	223.4	44.5
August	7.5	78.5	10.6	110.5	343.6	56.4
September	7.4	68.0	10.8	124.5	222.7	39.0
October	8.0	119.0	12.1	148.0	311.2	69.0
November	7.4	66.4	9.3	125.9	208.4	38.7
December	7.6	41.0	7.9	118.5	168.2	27.2
Year	7.6	119.0	9.8	1387.2	1619.9	181.5

The monthly maximum precipitation amount occurred in August (343.6 mm) but, on average, October gets the most precipitation with a mean value of 148.0 mm. The daily maximum precipitation occurred in the form of rain on October 17, 1981 with a value of 119.0 mm.

More snow falls in January than in any other month at the Long Harbour climate station (Table 1.15). The monthly maximum was 122.0 cm, and the monthly mean was 43.4 cm. However, the daily maximum amount of snow (35.6 cm) fell in March, with December as a close second (34.0 cm). Snow has been recorded to occur from October to May although only one snow event was recorded at Long Harbour in October over the 30-year period.

1.2.4. Icing

1.2.4.1. Freezing Precipitation

Freezing precipitation occurs when rain or drizzle aloft enters negative air temperatures near the surface and becomes super-cooled so that the droplets freeze upon impact with the surface. This situation typically arises ahead of a warm front extending from low pressure systems passing west of the area.

The percentage of occurrences of freezing precipitation (Table 1.16) was calculated using hourly data from the Environment Canada climate stations at Argentia, Placentia, and St. Lawrence as well as from the ICOADS data set. At all land stations, the frequency of freezing precipitation was slightly higher in the winter months than during the spring; however, all recorded freezing precipitation occurred less than one percent of the time at all land stations. The ICOADS data set (ship observations) had the highest occurrence of freezing precipitation with 3.2% in the winter and 1.2% in the spring. It is unclear whether these values are accurate, or whether the higher amounts were due to ice accretion from sea spray on the vessels. No freezing precipitation occurred during summer and autumn.

Table 1.15. Snowfall Amount Statistics for the Environment Canada Climate Station in Long Harbour.

	Daily Mean Snow (cm)	Daily Maximum Snow (cm)	Daily Standard Deviation (cm)	Monthly Mean (cm)	Monthly Maximum (cm)	Monthly Standard Deviation (cm)
January	6.0	30.5	5.7	43.4	122.0	27.6
February	5.9	30.0	6.1	39.9	92.4	27.0
March	5.9	35.6	5.6	26.6	60.9	17.6
April	4.6	24.0	4.6	9.3	33.0	10.1
May	8.9	31.0	11.2	1.6	36.1	6.5
June	0.0	0.0	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0	0.0
September	0.0	0.0	0.0	0.0	0.0	0.0
October	10.2	10.2	N/A	0.3	10.2	1.8
November	5.2	23.0	5.2	7.3	39.5	10.2
December	5.7	34.0	5.8	28.3	80.0	22.1
Year	5.8	35.6	5.8	159.9	269.0	66.1

Table 1.16. Percentage of Occurrences of Freezing Precipitation in Placentia Bay.

	Winter	Spring	Summer	Autumn
ICOADS	3.2	1.2	0.0	0.0
Argentia	0.7	0.4	0.0	0.0
Placentia	0.8	0.6	0.0	0.0
St. Lawrence	0.9	0.8	0.0	0.0

The Long Harbour station did not record freezing precipitation at hourly intervals, but instead recorded days with freezing rain. Since it is unclear from this data set how long a freezing rain event lasted, Long Harbour was not included with the other stations when calculating freezing precipitation statistics. At the Long Harbour station, there were only 25 days with freezing precipitation reported over a period of 30 years. These data are believed to be in error, because the manned observing stations in the area have reported a higher frequency of occurrence. In addition, automatic stations have not been reliable for reporting freezing precipitation. While Long Harbour recorded precipitation amounts, the freezing precipitation amount was included with rain/drizzle amounts. Therefore, a quantitative analysis of freezing precipitation was not possible for Long Harbour.

1.2.4.2. Sea Spray Vessel Icing

Spray icing can accumulate on vessels and shore structures when air temperatures are below the freezing temperature of water and there is potential for spray generation. In addition to air temperature, icing severity depends on water temperature, wave conditions, and wind speed influence the amount of spray and the cooling rate of droplets. A review of the spray icing hazard is provided by Minsk (1977). The frequency of potential icing conditions and its severity was estimated from the algorithm proposed by Overland et al. (1986) and subsequently updated by Overland (1990). The algorithm generates an icing predictor based on air temperature, wind speed, and sea surface temperature which was empirically related to observed icing rates of fishing vessels in the Gulf of Alaska. This method will provide conservative estimates of icing severity in the study region as winter sea surface temperatures are colder and wave conditions are lower in Placentia Bay compared to the Gulf of Alaska where the algorithm was calibrated (Makkonen et al. 1991). Potential icing rates were computed using wind speed and air sea surface temperature observations form the ICOADS data set. A total of 892 observations from vessels in Placentia Bay from January 1975 to December 2005 were used to calculate the percentage frequency of icing occurrence and severity in Placentia Bay. Monthly, seasonal, and annual summaries are presented in Table 1.17 and Figure 1.8.

Potential sea spray icing conditions start in Placentia Bay during the month of December with icing potential conditions estimated to occur 28.6% of the time. As temperatures cool throughout the winter months, the frequency of icing potential increases to a maximum of 49.2% of the time in February. February has a higher incidence of moderate, heavy, and extreme vessel icing and a lower incidence of light vessel icing than January or March. Extreme sea spray icing conditions were calculated to occur 3.0% of the time in Placentia Bay during February. Icing potential decreases rapidly after February in response to warming air and sea surface temperatures, and by April the frequency of icing conditions is less than 5%.

Table 1.17. Percentage Frequency of Potential Spray Icing Conditions for Placentia Bay, January 1975 to December 2005.

	None (0 cm/hr)	Light (<0.7 cm/hr)	Moderate (0.7- 2.0 cm/hr)	Heavy (2.0-4.0 cm/hr)	Extreme (>4.0 cm/hr)
January	57.9	31.6	7.9	2.6	0.0
February	50.8	29.9	8.6	7.6	3.0
March	53.8	35.5	5.4	4.3	1.1
April	96.4	3.6	0.0	0.0	0.0
May	100.0	0.0	0.0	0.0	0.0
June	100.0	0.0	0.0	0.0	0.0
July	100.0	0.0	0.0	0.0	0.0
August	100.0	0.0	0.0	0.0	0.0
September	100.0	0.0	0.0	0.0	0.0
October	100.0	0.0	0.0	0.0	0.0
November	100.0	0.0	0.0	0.0	0.0
December	71.4	20.0	8.6	0.0	0.0
Winter	60.0	27.2	8.4	3.4	1.0
Spring	83.4	13.0	1.8	1.4	0.4
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	85.9	10.1	2.5	1.2	0.3

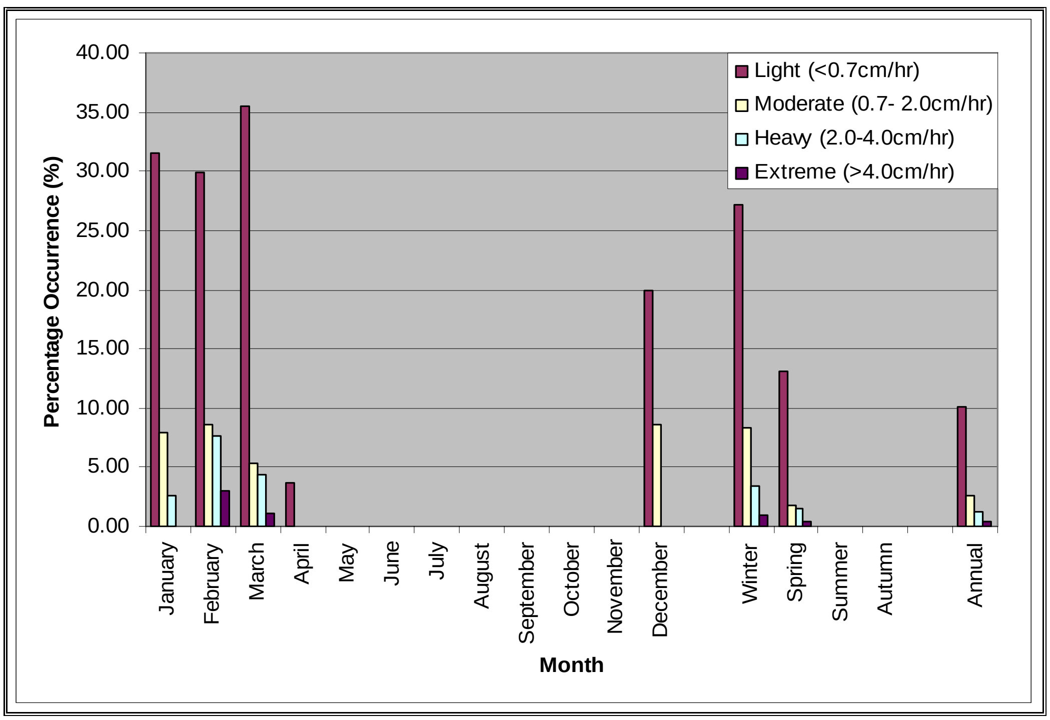


Figure 1.8. Percentage Frequency of Potential Spray Icing Conditions for Placentia Bay, January 1975 to December 2005.

1.2.5. Visibility

Visibility is defined as the greatest distance at which objects of suitable dimensions can be seen and identified. Horizontal visibility may be reduced by any of the following phenomena, either alone or in combination:

- Fog
- Mist
- Haze
- Smoke
- Liquid Precipitation (e.g., Drizzle)
- Freezing Precipitation (e.g., Freezing Rain)
- Frozen Precipitation (e.g., Snow)
- Blowing Snow

Sea surface temperatures south of Newfoundland are generally higher than those in Placentia Bay. During the summer months, southwesterly winds bring warm, moist air into the bay. When this moist air moves over the colder sea surface in the bay, the air cools. As it cools, its ability to hold moisture decreases and the moisture condenses to form fog. Therefore, fog in Placentia Bay is persistent throughout the day during summer as long as there are southerly winds. The ICOADS data show that the frequency of fog is greatest between the months of April and August. During the winter months, prevailing winds are generally from the west, off the continent, such that the air mass tends to be drier. Drier air, combined with sea-surface temperatures typically warmer than the air, result in a marked decrease in the amount of fog formation within the bay during the fall and winter months. During the winter months, snow and blowing snow account for the majority of poor visibility reported.

Observations from climate stations around Placentia Bay show that obstructions to visibility occur on a regular basis throughout the year, with good visibility (defined as visibility greater than 10 km) in the coastal communities of Argentia, Placentia, and St. Lawrence occurring, on average, less than 50% of the time. The incidence of fog at these stations is high during the summer months and peaks in the month of July with visibility less than one kilometre occurring as much as 27.2% of the time at St. Lawrence and 15.1% of the time at Placentia.

Visibilities in the bay are better than the land stations with good visibility occurring 71.2% of the time (ICOADS data). The bay has a higher incidence of fog and lower incidence of mist (visibility of 1 km to less than 10 km) resulting in a higher incidence of good visibility than reported by the land stations. On average, the incidence of fog occurs 11.0% of the time throughout the year in Placentia Bay with the peak occurring in July at 20.7% of the time. A graph of monthly frequency distribution of visibilities for Placentia Bay from the ICOADS data set is presented in Figure 1.9.

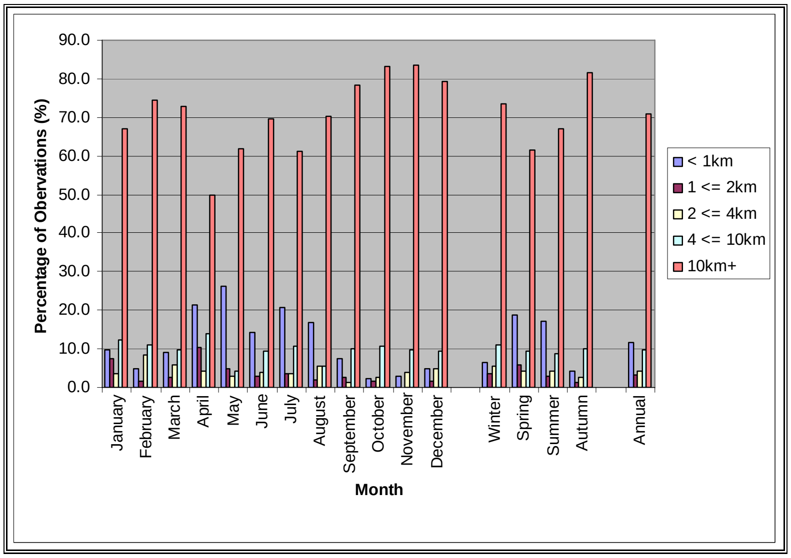


Figure 1.9. Frequency Distribution (%) of Visibility Recorded in the ICOADS Data Set.

As visibility statistics were not recorded at Long Harbour, Argentia (located 21 km southwest of Long Harbour) was deemed to be the most appropriate station to represent visibility at Long Harbour. At Argentia, good visibility occurs, on average, only 40.9% of the time (Figure 1.10). The incidence of fog is highest during the summer months and peaks in July with a visibility of less than one kilometre occurring 11.9% of the time. The predominant visibility at the Argentia station was between four to 10 km and occurs, on average, 49.8% of the time.

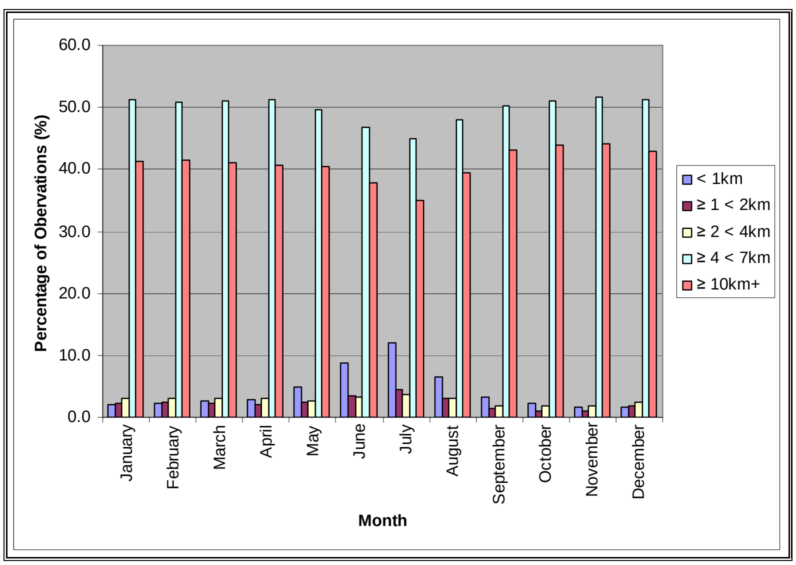


Figure 1.10. Frequency Distribution (%) of Visibility Recorded at Argentia.

1.2.6. Ceiling

A cloud ceiling is defined as the lesser of "the height above ground of the lowest cloud layer, at which the total cloud summation opacity is six tenths or more of the whole sky; or the vertical visibility in a surface-based layer that completely obscures the whole sky." In other words, it is the height at which an observer on the ground can no longer see six tenths of the whole sky. If the clouds present do not obscure six tenths or more of the whole sky it is deemed that the ceiling is unlimited. Furthermore, an obscuration to the sky must be opaque. A cloud layer that is not opaque would not be counted in the total cloud summation when determining a ceiling. The second part of the definition refers to conditions in which the sky obscuration touches the ground and generally refers to fog; however, during winter months the obscuration may also include snow and blowing snow.

Since ceiling heights were not recorded at Long Harbour, Argentia was deemed to be the most appropriate station to represent conditions at Long Harbour. An analysis of ceiling heights from the weather station at Argentia shows an increase in the frequency of cloud ceilings below 100 feet (30.5 m) from February to July (Figure 1.11). After July, the frequency of cloud ceilings below 100 feet begins to decrease. The increase in the percentage of ceiling heights below 100 feet from February to July and its subsequent decrease from August to December is directly proportional to the occurrence of fog observed at this station. The percentage of ceiling heights between 100 feet and 1,000 feet (304.8 m) also peak in July and may be attributed to cloud formation as moist southerly flow moves over land. As this moist air gets forced upward by topography, the moisture condenses to form clouds. This effect also occurs at Placentia, but not at St. Lawrence due to the relatively low terrain in the area.

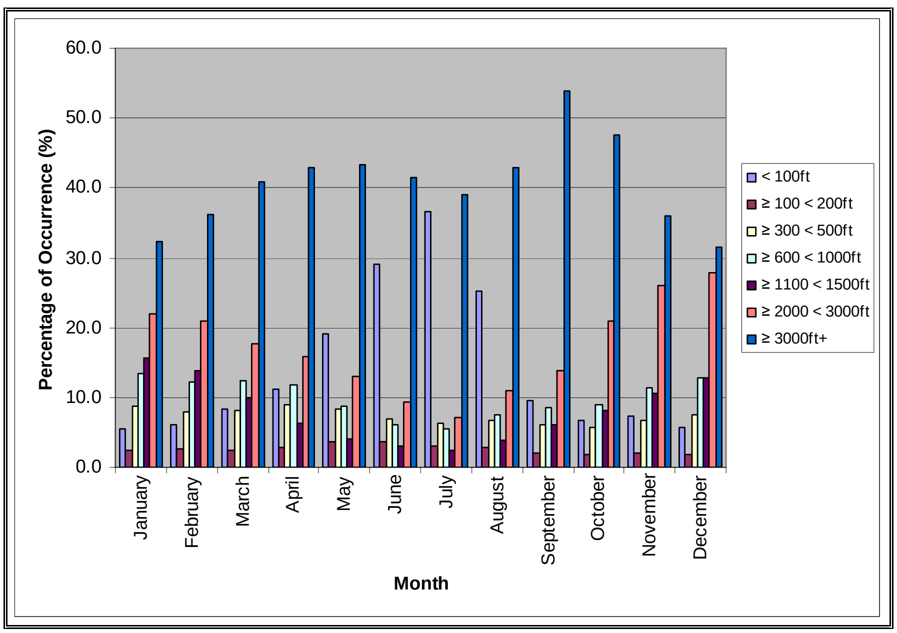


Figure 1.11. Percentage of Occurrence of Ceiling Heights Recorded at Argentia.

There is a decrease in the percentage of ceiling heights between 2,000 feet (609.6 m) and 3,000 feet (1,219.2 m) from January to July, and a subsequent increase from July to December. It is unclear whether this decrease can be attributed to an actual decrease in the amount of cloud at this level, or if the decrease is due solely to the increase in the amount of cloud at lower levels obscuring the 2,000–3,000 foot level.

August, September and October are the months with the highest frequency of ceilings above 3,000 feet, while December, January and February have the lowest incidence of ceilings above 3,000 feet with percentages ranging from 36.0% to 38.0%. This may be attributed to the effect of snow on the vertical visibility. In general, it is a lot harder to see cloud layers through snow and it is not unusual when measuring cloud heights for ceilings to appear lower.

1.3. Marine Physical Environment

The following sections detail the bathymetry, currents, temperature and salinity characteristics, waves and ice conditions of Placentia Bay in general and Long Harbour in particular.

1.3.1. Bathymetry

The Placentia Bay coastline is irregular with a large number of bays, inlets, and islands. Large islands; Merasheen Island, Long Island and Red Island are located in the middle of the inner section of the bay together with other smaller islands. The bathymetry of Placentia Bay is also very irregular with many banks and troughs (Figure 1.12). The water depth at the mouth of the bay is approximately 200 m. There is a deep channel on the eastern side of Placentia Bay with water depths extending to approximately 300 m in some locations. A deep channel south of Merasheen Island with a maximum depth of 350 m is oriented in a northwest/southeast direction across the bay. White Sail Bank, Merasheen Bank, and Bennett Bank are located on the southern side of this channel. In general, the water is shallower on the western side of the Bay than on the eastern side with the exception of many deep troughs. North of Merasheen Island, the maximum water depth is approximately 200 m.

Long Harbour is situated on the eastern side of the bay, east of Merasheen Island and Red Island. The water depth in the mouth of Long Harbour near the southern side is approximately 70 m, and the mean water depth is approximately 50 m. Shag Rocks is located near the mouth of the harbour. Between Shag Rocks and the northern shore there is a bathymetric ridge with a water depth of approximately 20 m. In the centre of the harbour between Shag Rocks and Crawley Island the water depths vary between 40 m and 70 m. At Crawley Island the harbour splits into two branches, St. Croix Bay to the north of Crawley Island, and a southern arm south of Crawley Island. The outer section of St. Croix Bay has a mean water depth of approximately 40 m, and the inner section has a mean depth of approximately 20 m. The southern arm has a mean depth of approximately 30 m with the exception of a bathymetrical mound in the middle of the area with a water depth varying between 13 m and 17 m.

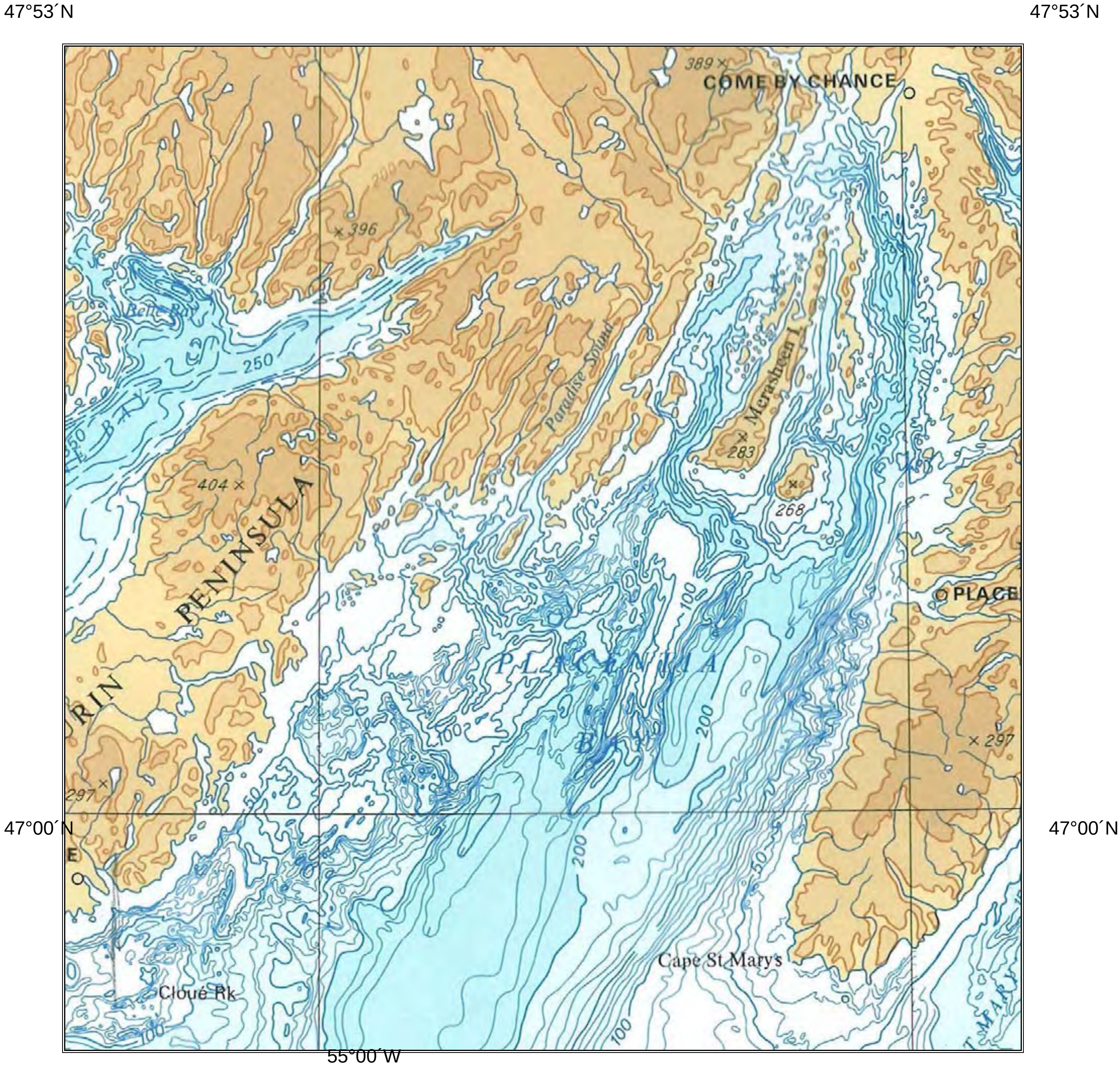


Figure 1.12. Bathymetric Structure of Placentia Bay.

1.3.2. Currents in Placentia Bay

Current data in Placentia Bay have been collected by the Department of Physics and Physical Oceanography at Memorial University (MUN) during the spring (April to June) of 1998 and 1999, and by the Bedford Institute of Oceanography (BIO) during winter 1988 (February 16 to March 29) and fall 1998 (September 27 to October 29). The MUN data are from two sites in 1998 and seven sites in 1999. In 1999, there were four moorings deployed in the outer section of the Bay with two instruments on each mooring, and three ADCPs (acoustic Doppler current profilers) deployed around the islands in the inner section of the Bay in the location shown in Figure 1.13. Two of the moorings in the outer section of the Bay in 1999 were in the same locations as the moorings in 1998. The BIO moorings consisted of three moorings (Figure 1.13) with two instruments on each mooring; one instrument moored near the surface between 15 m and 25 m and the other moored between 49 m and 63 m.

The published information on the circulation in Placentia Bay from the MUN data suggests the existence of a cyclonic (counter clockwise) circulation pattern in the bay (Bradbury et al. 2000; Hart et al. 1999; Schillinger et al. 2000). According to their description, the eastern side of the bay is dominated by currents flowing into the bay while at the western side the currents are usually flowing towards the mouth or out of the bay. Bradbury et al. (2000) reported the existence of a cross-bay current flow with currents flowing predominately toward the east on the eastern side of the Bay, and towards the west on the western side.

By summarizing the data into weekly mean magnitudes and directions, Schillinger et al. (2000) showed that the cyclonic circulation pattern around the bay was fairly stable in the near surface waters. The mean circulation for depths of 20 m and 44 to 45 m as presented by Schillinger et al. (2000) are shown in Figures 1.14 and 1.15. The axes at the base of the arrows in Figures 1.14 and 1.15 indicate the standard deviation of the current along the direction of maximum variance, and perpendicular to it.

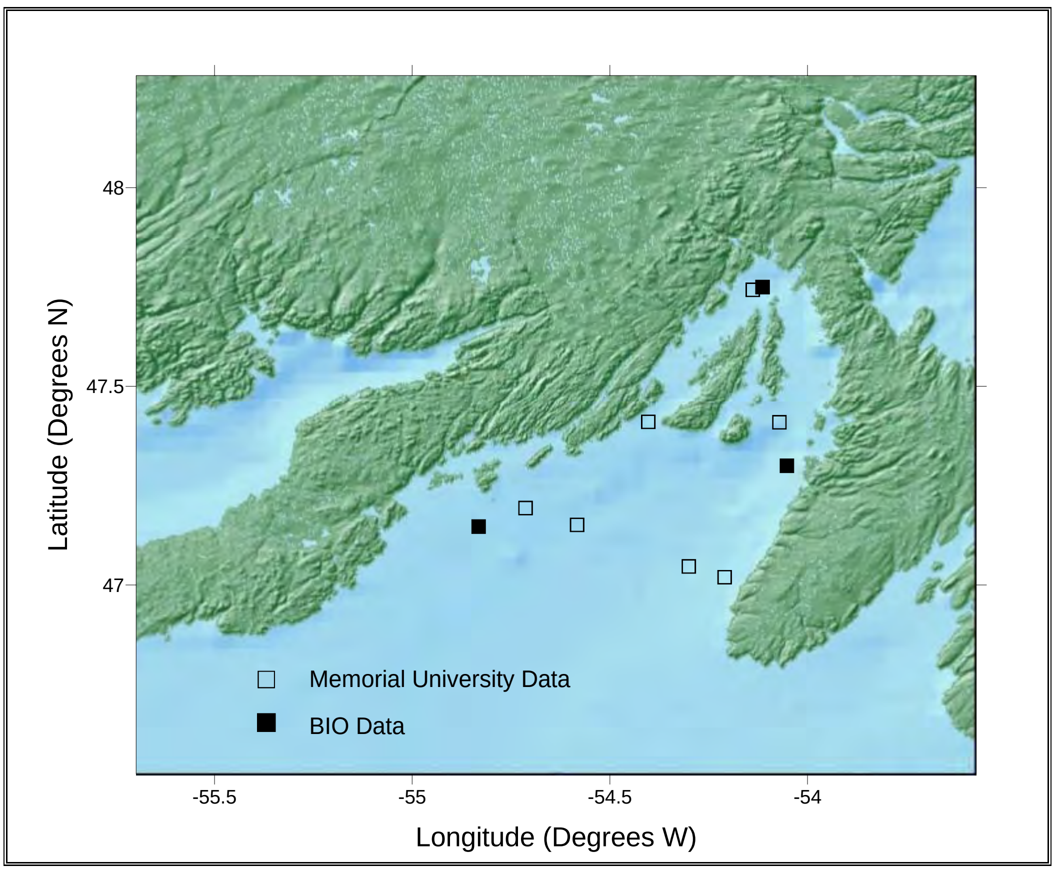


Figure 1.13. Location of BIO and MUN Current Meter Moorings in Placentia Bay.

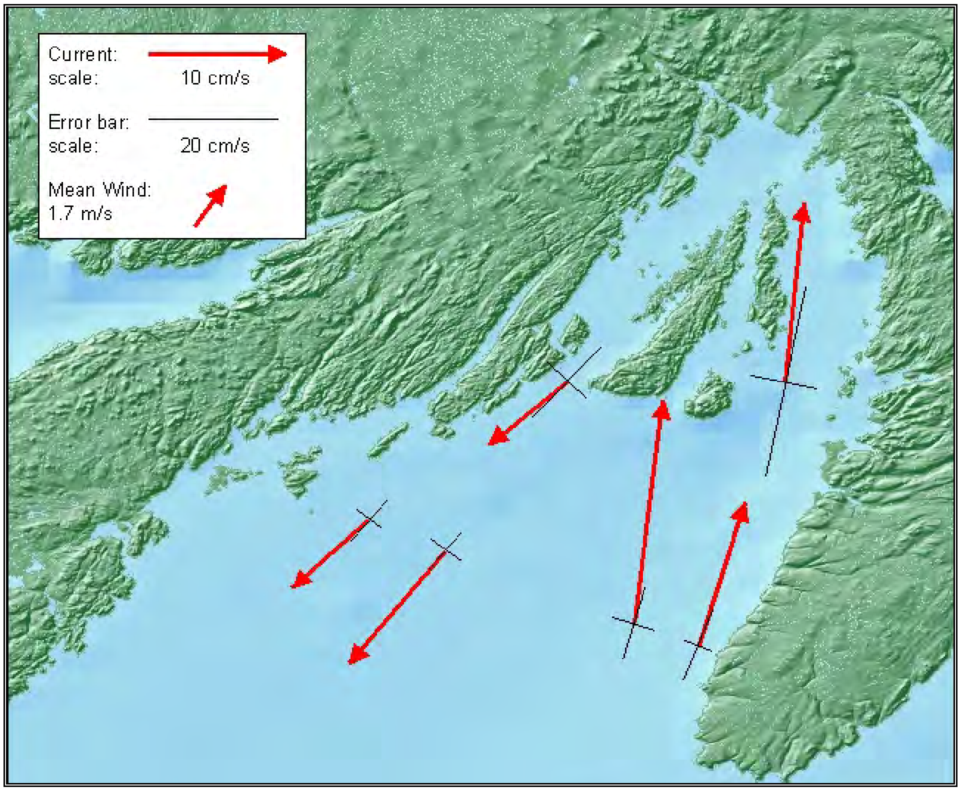


Figure 1.14. Mean Circulation in Placentia Bay at 20 m (from Schillinger et al. 2000).

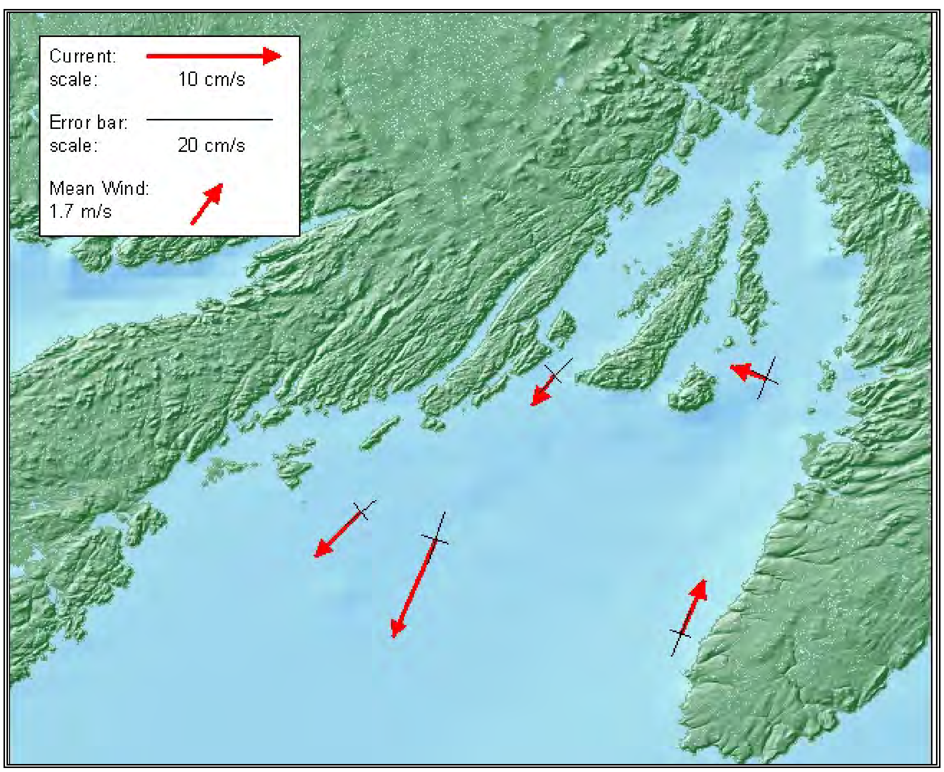


Figure 1.15. Mean Circulation in Placentia Bay at 45 - 55 m (from Schillinger et al. 2000).

The general pattern of currents in Placentia Bay from the MUN data is shown in Figures 1.16 to 1.18. Following the oceanographic convention, current directions in the rose plots refer to the direction in which the currents are flowing. Values of maximum speeds, mean speeds, and mean velocities are given in Table 1.18. The rose plots of currents in the near surface waters in Figure 1.16 from the 1999 data clearly show the persistent counter clockwise flow around the bay. On the eastern side of the bay, the currents had a residual flow of 17.6 cm/s near the mouth of the bay and 15.6 cm/s at the location outside Long Harbour. The maximum current speeds were 75 cm/s and 78.7 cm/s, respectively. At location M1 on the western side of the bay, the residual current was 7.1 cm/s, and the maximum speed was 49.7 cm/s. In 1998, the maximum current speed was 58.0 cm/s at a depth of 10 m on the eastern side of the bay and 61.6 cm/s on the western side.

At depths from 36 m to 55 m, the counter clockwise flow was still predominant as seen in Figure 1.17. At 100 m and below, the counter clockwise flow was no longer a dominant feature (Figure 1.18). In 1998, at a depth of 110 m on the eastern side of the bay, the flow was mainly in a northeast and east direction during March and April and then switched to east and southeast in May and June. At 180 m on the western side of the bay the flow remained in a predominantly southwest direction.

At a depth of 104 m at M6 (outside Long Harbour) the flow had two preferred directions, north and southwest. The flow was mainly towards the north in April, towards the southwest in May but with one occasion when the flow was towards the north for several days, and then oscillating between north and southwest in June.

At M5, west of the southern tip of Merasheen Island, the flow had similar characteristics. At 104 m, the current was predominantly towards the northeast in April, towards the southwest in May and early June, and then northeast until the end of the sampling record.

A harmonic analysis was carried out on the data to determine the contribution of tides to the overall flow. The magnitudes of the tidal constituents are shown in Table 1.19. The principal semidiurnal constituents are M_2 and S_2, and the principal diurnal constituents are O_1 and K_1. M_2 is the major constituent with values ranging between 3.5 cm/s and 6.1 cm/s in the near surface waters. In the deeper waters, the values ranged between 1.7 cm/s and 4.8 cm/s. The results of the harmonic analysis showed that the lower frequency components on the synoptic scale (order of days) contributed to the overall current flow. This contribution was particularly important in the surface water at M6 (outside Long Harbour) and at the locations on the eastern side of the bay.

Table 1.18. Current Speeds and Directions in Placentia Bay.

Year	Location	Depth (m)	Mean Velocity (cm/s)	Direction	Mean Speed (cm/s)	Maximum Speed (cm/s)
1998	Eastern side	10	11.6	North northeast	16.5	58.0
		110	1.4	East southeast	5.4	31.4
1998	Western side	10	12.8	Southwest	17.0	61.6
		180	1.7	Southwest	3.9	17.7
1999	M4 Eastern side	20	11.4	Northeast	14.4	58.9
		45	3.9	Northeast	7.5	43.8
1999	M3 Eastern side	20	17.6	North northeast	19.5	75.0
1999	M2 Western side	20	11.0	Southwest	13.1	47.4
		55	7.3	Southwest	10.4	41.8
1999	M1 Western side	20	7.1	Southwest	10.3	49.7
		55	4.8	Southwest	7.4	27.3
1999	M6 Eastern side of Island	16	15.6	North northeast	32.0	78.7
		36	2.8	Northeast	8.3	30.7
		72	1.7	West southwest	6.0	23.5
		104	1.7	West southwest	5.6	23.5
1999	M5 Western side of island	36	2.4	Southwest	7.9	36.5
		72	1.6	South	6.8	22.5
		104	1.2	Southeast	6.0	21.7

Table 1.19. Tidal Current Constituents in Placentia Bay.

Year	Location	Depth (m)	M_2 cm/s	S_2 cm/s	0_1 cm/s	K_1 cm/s
1998	Eastern side	10	3.8	1.5	1.0	1.1
		110	1.7	0.4	1.1	0.3
1998	Western side	10	6.1	1.4	0.6	1.4
		180	2.4	0.6	0.5	0.4
1999	M4 Eastern side	20	4.4	1.6	2.8	0.9
		45	3.7	1.0	1.1	0.7
1999	M3 Western side	20	4.4	1.7	1.0	0.7
1999	M2 Western side	20	3.5	0.6	0.8	1.1
		55	4.3	1.3	0.4	0.6
1999	M1 Western side	20	5.9	1.4	0.5	0.4
		55	5.4	1.2	1.1	0.4
1999	M6 Eastern side of island	16	6.0	3.7	1.6	2.1
		36	3.5	1.2	0.4	0.8
		72	3.4	1.1	0.2	0.4
		104	3.1	0.6	0.1	0.4
1999	M5 Western side of island	36	4.0	1.3	0.6	0.8
		72	4.3	1.4	0.3	0.2
		104	4.8	1.2	0.2	0.3

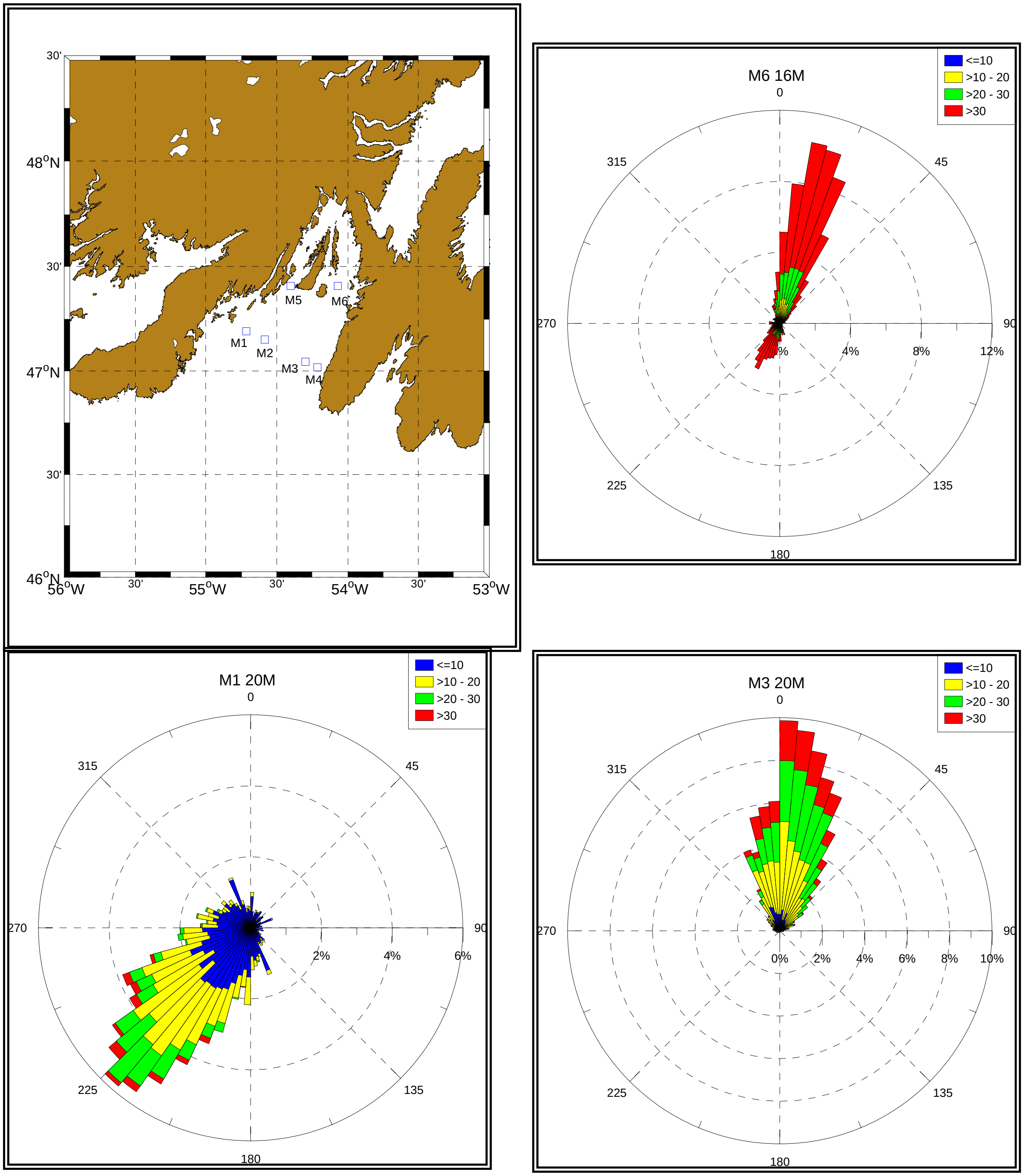


Figure 1.16. Rose Plots of the Near-Surface Current Speeds and Directions from MUN Data Set.

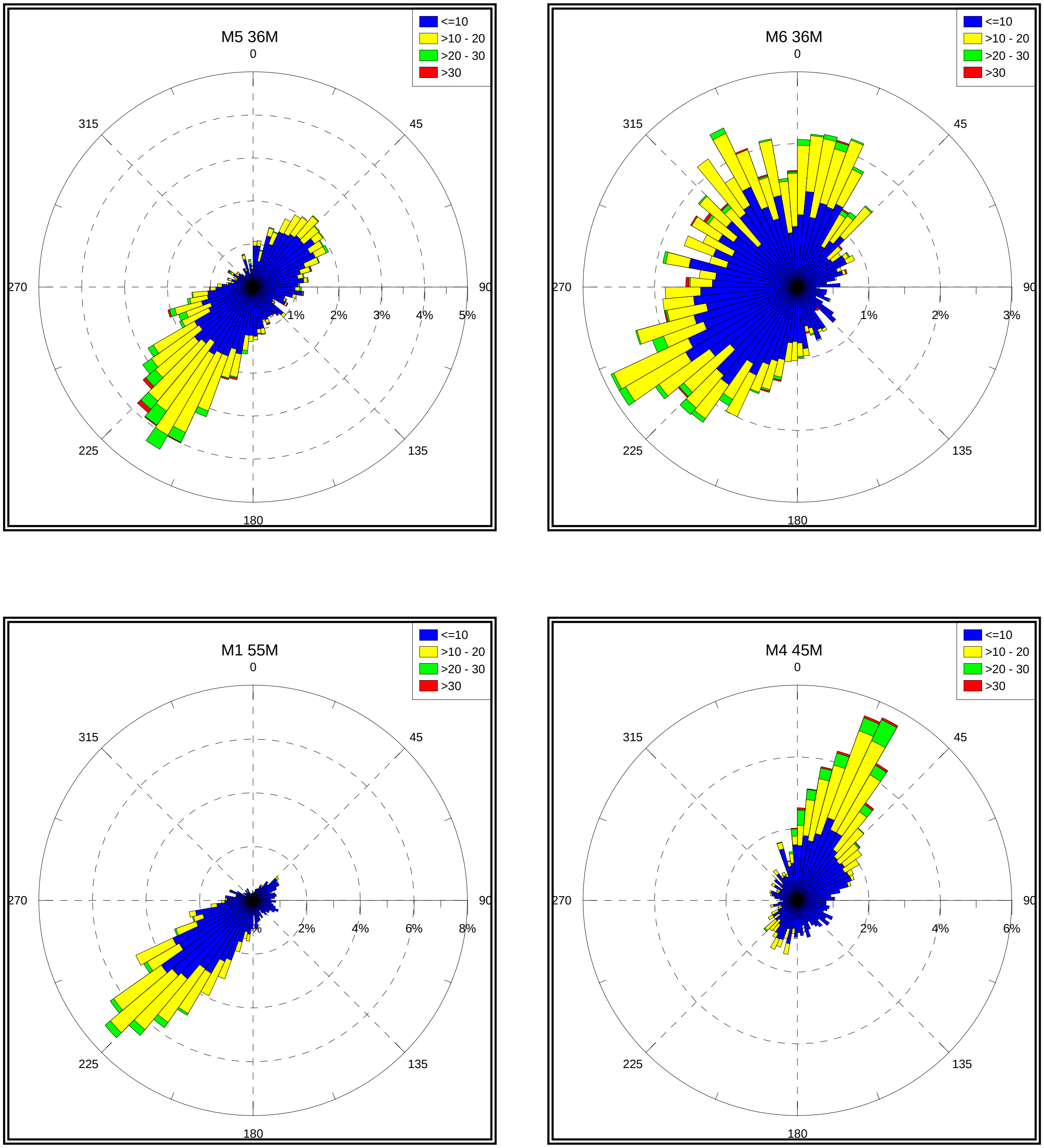


Figure 1.17. Rose Plots of Current Speeds and Directions between 36 m and 55 m from MUN Data Set.

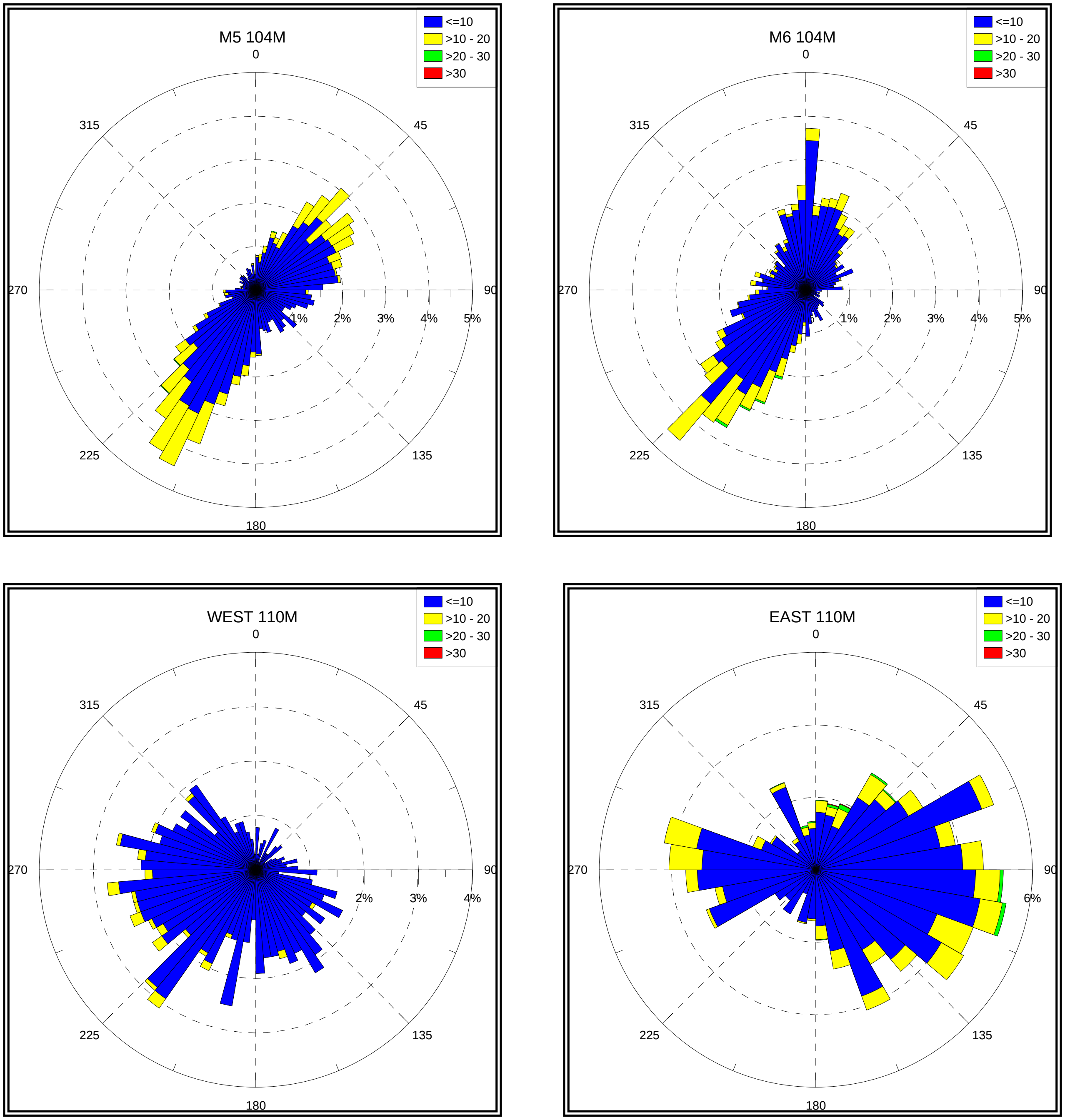


Figure 1.18. Rose Plots of Current Speeds and Directions in Deep Water from MUN Data Set.

An analysis of the BIO data collected during winter and fall 1988 also supports the existence of a counter clockwise flow in the near-surface waters of Placentia Bay. Rose plots in Figures 1.19 to 1.22 show the degree of persistence of different current directions combined with a histogram of current speeds at different intervals. Figure 1.19 and 1.21 show that the counter clockwise cyclonic flow persists during both seasons in the near surface waters. However, the BIO data do not support a persistent counter clockwise cyclonic flow at depths of 49 m and 56 m. The counter clockwise cyclonic flow was observed in the winter data (Figure 1.22) but not in the fall data (Figure 1.20). In fall, the flow was in the opposite direction with south southwest currents observed on the east side of the bay and east southeast currents at the head of the bay (Figure 1.20).

A statistical summary of the average and maximum speeds from the BIO data is presented in Table 1.20. The average current speeds range between 6.1 cm/s and 13.4 cm/s for the specific depths sampled. The maximum current speeds ranged between 17.9 cm/s and 74.8 cm/s, with a tendency for higher current speeds near the surface. The maximum current speed of 74.8 cm/s occurred on the east side of the bay at a depth of 22 m during the winter sampling period.

The BIO data sets were not long enough to completely resolve the tidal constituents. The overall contribution of the tidal currents to the total current variability was approximately 15%, with a minimum contribution of 8% near the surface on the east side of the bay and a maximum contribution of 33% at a depth of 49 m at the head of the bay.

Table 1.20. Statistical Summary of Current Speed from the BIO Data Set.

LOCATION	SEASON	DEPTH (M)	AVERAGE SPEED (CM/S)	MAXIMUM SPEED (CM/S)
East	**Fall**	23	13.4	57.0
		56	10.3	45.1
	Winter	22	12.1	74.8
		60	13.2	57.8
North	**Fall**	16	12.1	44.5
		49	8.8	52.0
	Winter	25	8.4	29.4
		63	6.1	17.9
West	**Fall**	21	9.1	37.3
		54	8.7	32.8
	Winter	15	11.5	43.4

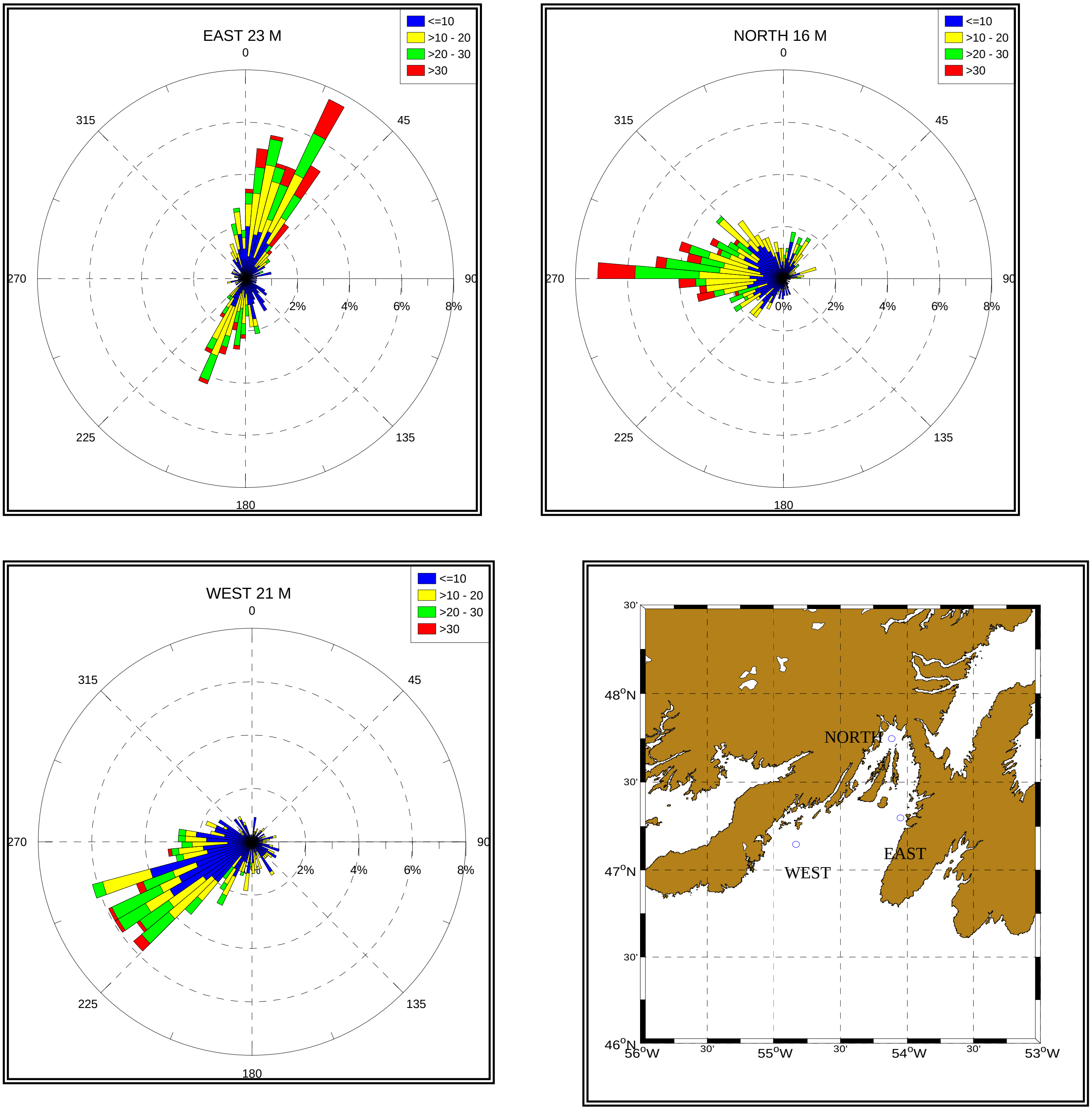


Figure 1.19. Rose Plots of Near-Surface Current Speeds and Directions from the BIO Fall Data Set.

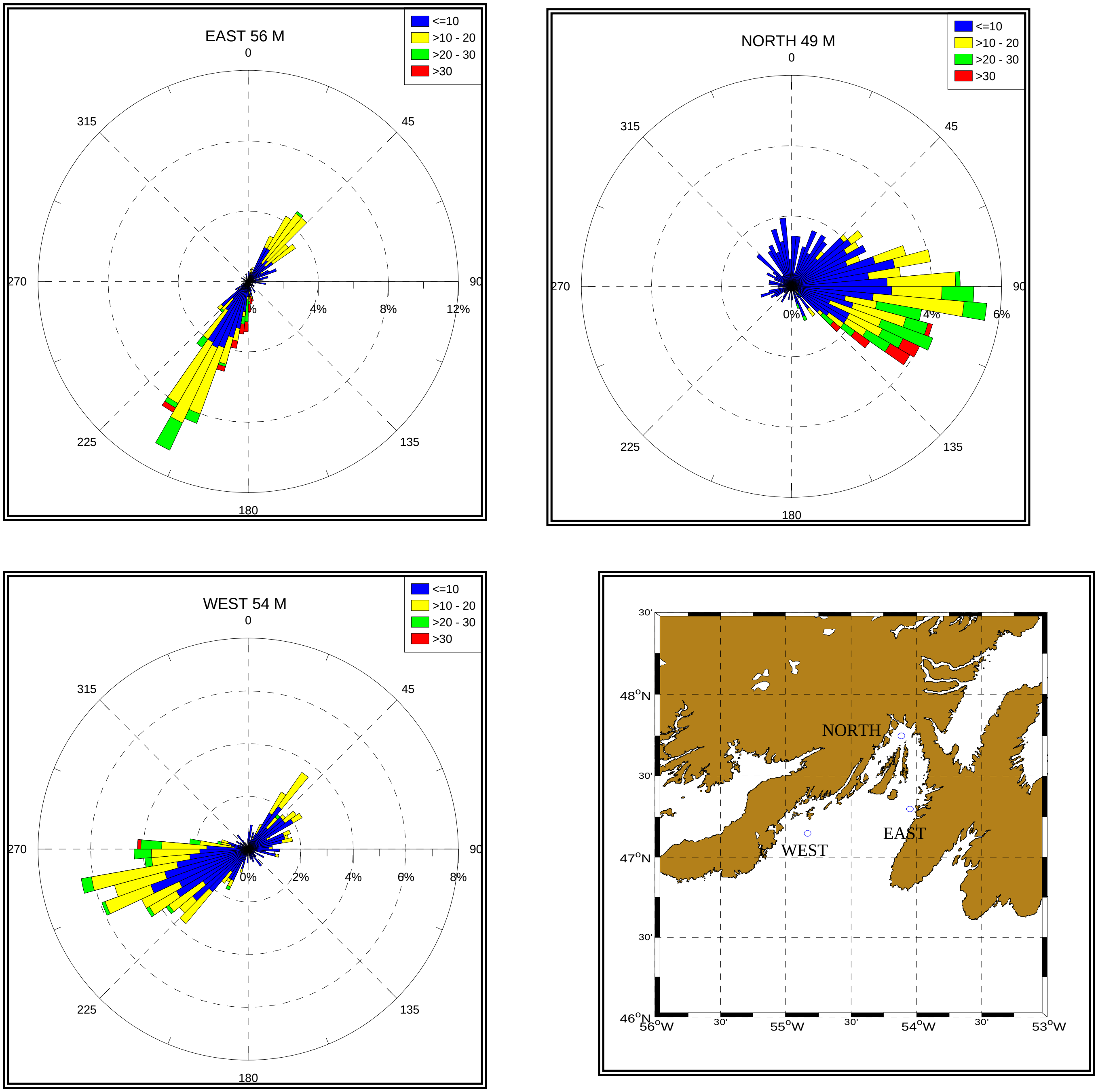


Figure 1.20. Rose Plots of the Deep Current Speeds and Directions from the BIO Fall Data Set.

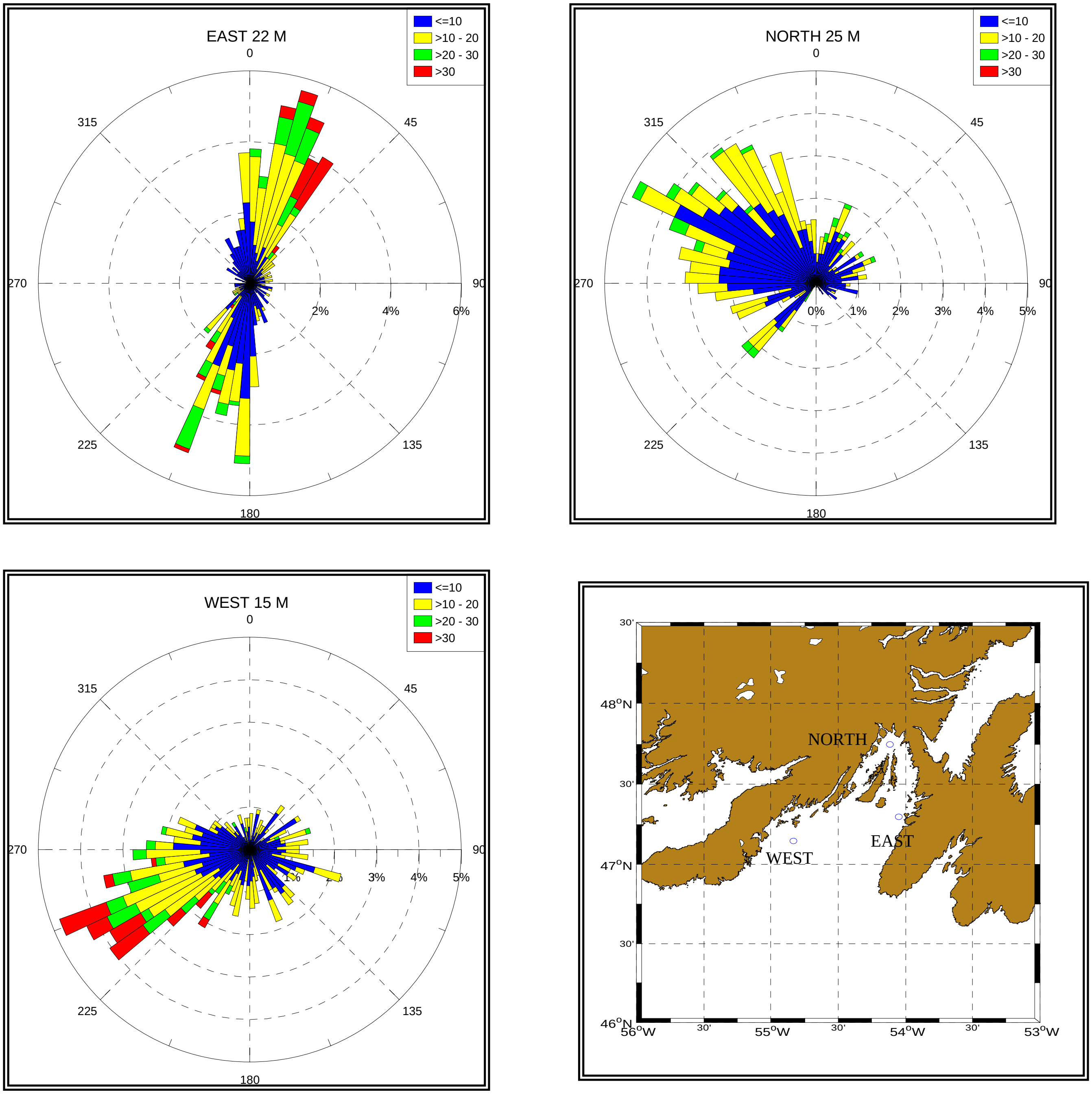
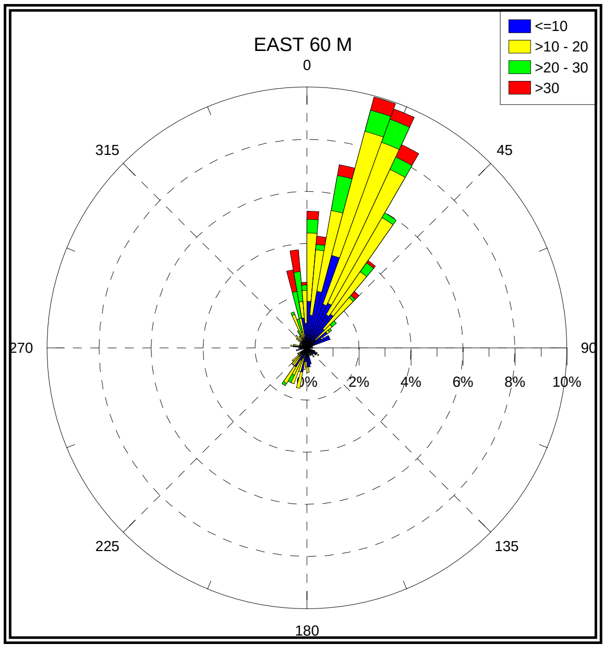
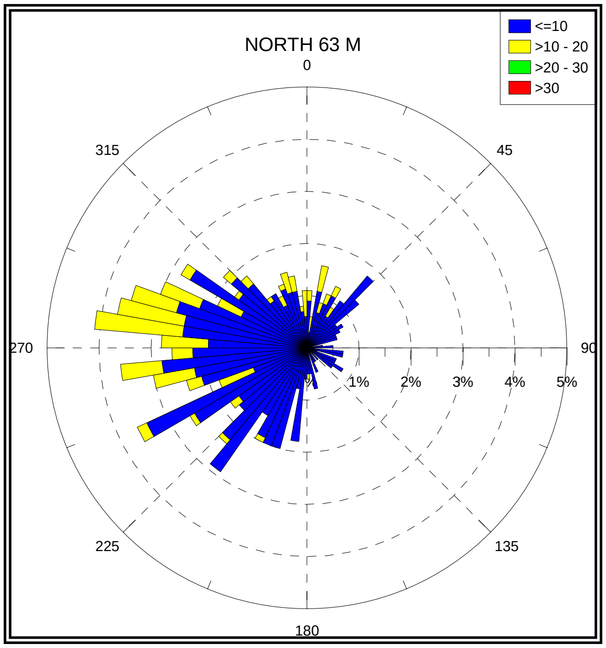


Figure 1.21. Rose Plots of Near-Surface Current Speeds and Directions from BIO Winter Data Set.





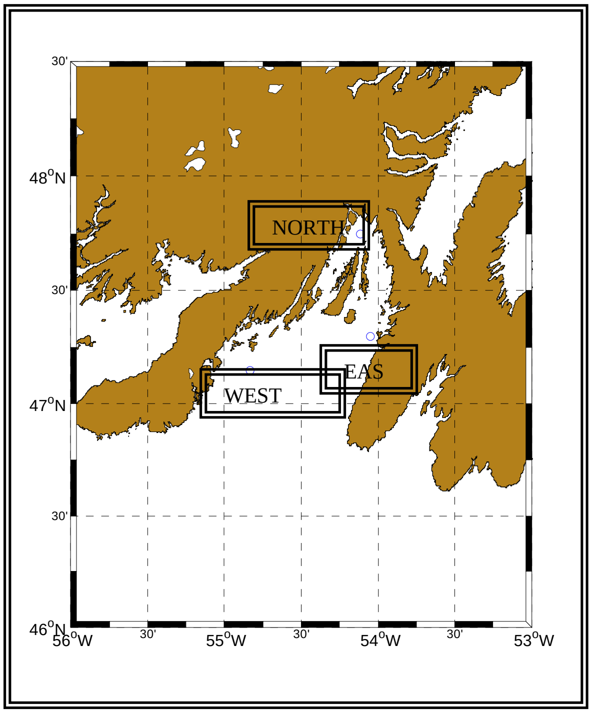


Figure 1.22. Rose Plots of the Deep Current Speeds and Directions from the BIO Winter Data Set.

1.3.3. Currents in Long Harbour

In general, the near-surface currents in Placentia Bay have been observed to flow counter clockwise around the bay. This circulation pattern is not consistent at deeper levels. The flow in Placentia Bay is expected to be the result of tides, winds, and the Labrador Current. Since the variability due to tides account for approximately only 15% of the total variability, other factors are more important. Winds in the area are predominately from the southwest during all seasons, and this would contribute to a counter clockwise pattern in the near surface waters. The inshore branch of the Labrador Current follows the bathymetric contours around the Avalon Peninsula. North of Green Bank the direction of the bathymetric contours shift from an east/west direction to a north/south direction. The Labrador Current probably divides at this location with a portion of the Labrador Current contributing to the flow into Placentia Bay and becoming the major contributor to the overall current variability. A portion of the north-northeast flow following the bathymetric contours on the east side of Placentia Bay would continue to follow the contours into Long Harbour, and be the major contributor to the overall current circulation in the harbour.

Current measurements in Long Harbour were made by BIO over a 29-day period at three locations during summer of 1969, and by Oceans Ltd. at five locations for VBNC during summer and fall, 2006. The locations of the current meter moorings are shown in Figure 1.23.

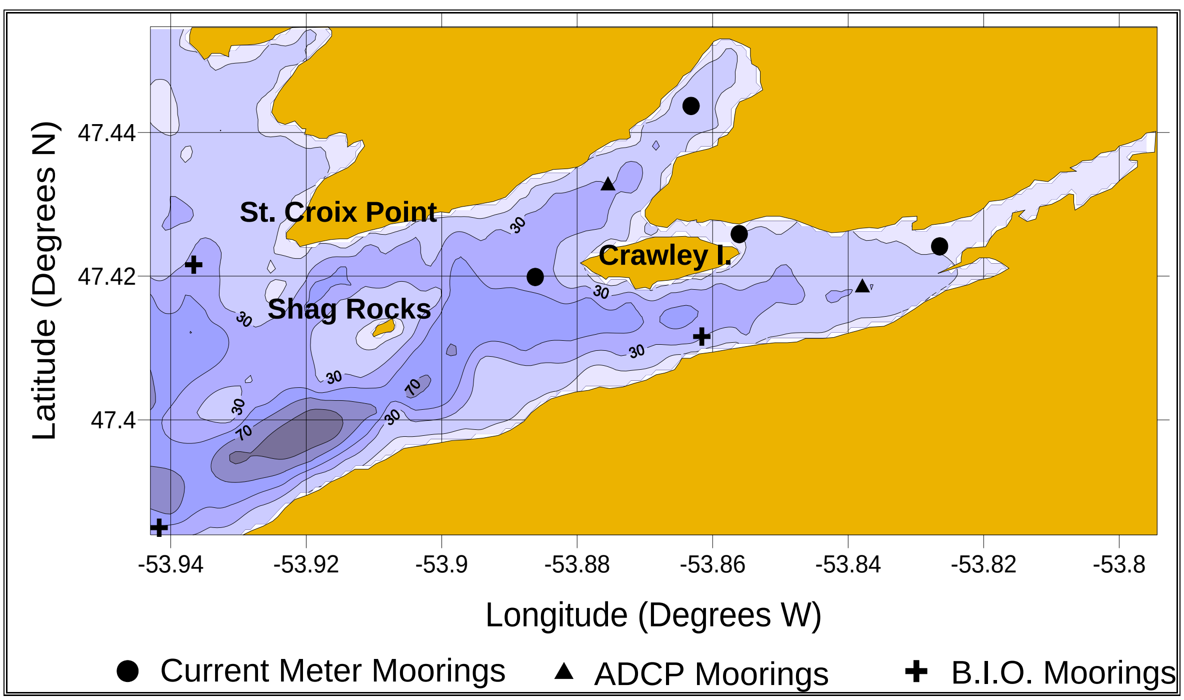


Figure 1.23. Location of Current Meter Moorings in Long Harbour.

The data demonstrate a complex current system, but this is not unusual for a coastal inlet with irregular bottom bathymetry (Figure 1.24). Analysis of the current data in conjunction with CTD data collected throughout the harbour showed that the circulation in Long Harbour was mainly driven by the circulation in Placentia Bay. Tidal measurements and analysis of tides from the current meter records showed that tides played a minor role. Winds played a modifying role, both directly and indirectly. The winds are strong enough on a daily basis in Long Harbour to play a direct role in the creation of wind driven currents in the top few metres. Since winds are predominantly from the southwest (into the bay), there is a tendency for the wind driven currents to push water against the shore. This will cause the currents to reverse direction at deeper levels. Reversals in currents were measured by the ADCP profiling current meter which was deployed in 32 m of water west of the wharf. Reversals in currents are also produced by internal waves whenever there are internal density boundaries, a source of energy such as the wind, and bathymetric features such as the mound which exists in the central region of the southern arm. The mean currents at the location of the ADCP were low varying with depth from 3.9 cm/s at a depth of 6 m to 2.7 cm/s at a depth of 26 m.

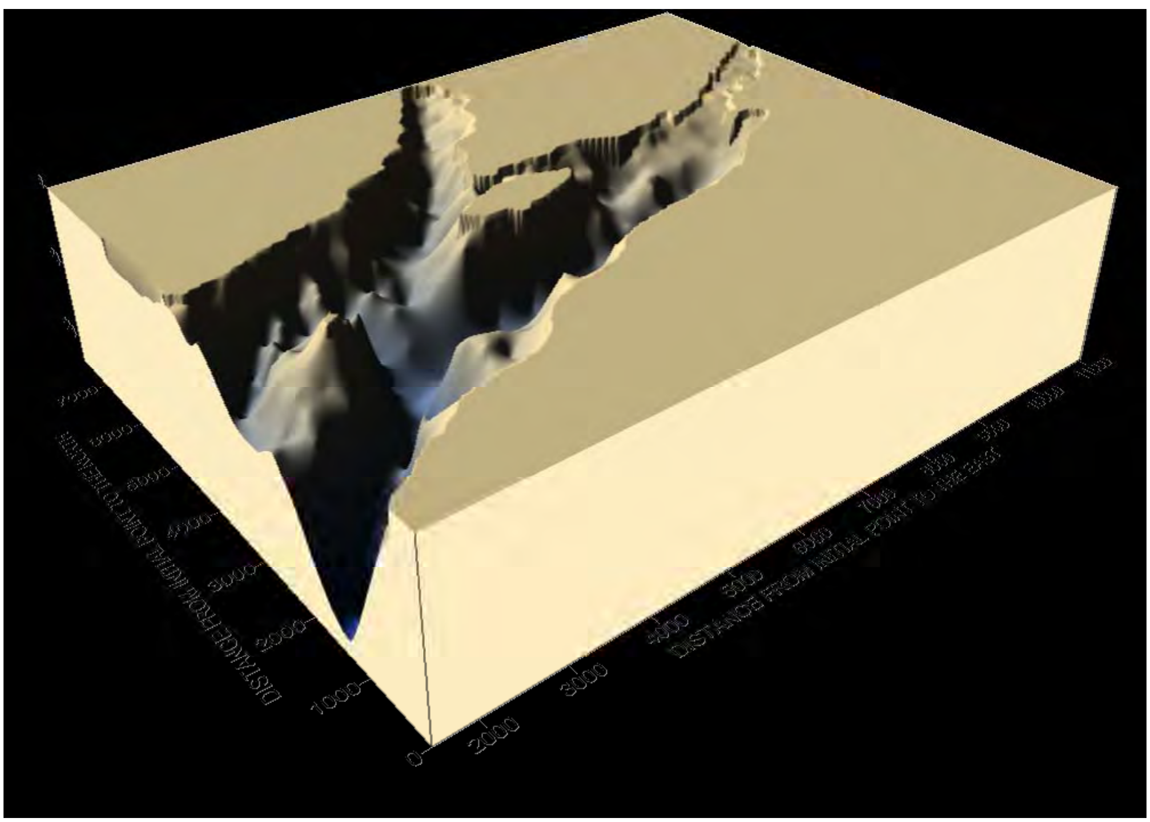


Figure 1.24. Bathymetry of Long Harbour.

Using surface drogues, drogued to a depth of six metres, Trites (1969) showed that wind direction influences the amount of Placentia Bay water entering Long Harbour. When the winds were from the northeast, directed out of the harbour, he reported a strong outflow of surface layer water on the north side of Long Harbour and a small inflow of surface water on the south side. When the winds were from the southwest (the dominant direction) he reported a strong inward flow on the south side of the harbour.

Current data collected at a depth of six to seven metres in the southern arm of the harbour are shown in Figure 1.25. South of Crawley Island, the current is flowing towards the east along the southern shore. West of the wharf, the current is flowing in all directions. East of Crawley Island, the flow is towards the southwest, following the bathymetric contours around the eastern side of Crawley Island.

Due to the predominantly southwest winds, the surface currents are toward the northeast in St. Croix Bay. The currents were measured at mid-depth in the inner part of the bay. At a depth of 13 m (Figure 1.26) the currents were directed towards the west and northwest for the majority of the measurement period with a mean speed of 4.0 cm/s and a maximum speed of 14.9 cm/s. At the entrance to St. Croix Bay, the flow had two preferred directions, northeast and southwest. The mean current speed was 3.3 cm/s and the maximum speed was 20.3 cm/s. This bimodal direction is partially attributed to tidal flow, northeast during the flood tide and southwest during the ebb tide. At depths below 13 m, the preferred direction is towards the southwest, but there is also a strong northeast flow (Figure 1.26).

The general circulation pattern in the outer section of Long Harbour is shown in Figure 1.27. The BIO data from 1969 measured at the southern entrance to the harbour at a depth of 72 m show that the current is flowing into the harbour on the southern side. The current measurements by Oceans Ltd. at a depth of 25 m west of Crawley Island show that the current is mainly towards the northeast with a mean speed of 5.7 cm/s and a maximum speed of 28.9 cm/s. At the northern entrance to the harbour, the BIO data measured at four metres had a mean speed of 8.8 cm/s and a maximum speed of 38.8 cm/s, directed towards the northwest, out of the harbour. The current measurements indicate that in general the flow is directed into the harbour on the southern side, and out of the harbour on the northern side with an exchange between north and south taking place between Shag Rocks and Crawley Island.

1.3.4. Water Properties

Temperatures and salinity data were collected by MUN during their two sampling periods from April to June of 1998 and 1999. In the upper 50 metres of the water column throughout the bay, temperature increased and salinity decreased from April to June (Hart et al. 1999). The increase in temperature was attributed to general atmospheric warming that occurs as the year progresses from spring to summer, and the decrease in salinity was due to local river runoff and increased precipitation during the spring. At depths greater than 55 m, this pattern was reversed. The temperatures decreased from April to June and the salinities increased. Hart et al. (1999) reported that the temperatures ranged from 0.1°C in April to 10.2°C in June for near-surface depths in 1998 and from 1.1°C to 11.7°C in 1999 for the same period. At deeper levels the temperatures ranged from 1.2°C to -0.4°C in 1998 and from 1.4°C to -0.5°C in 1999.

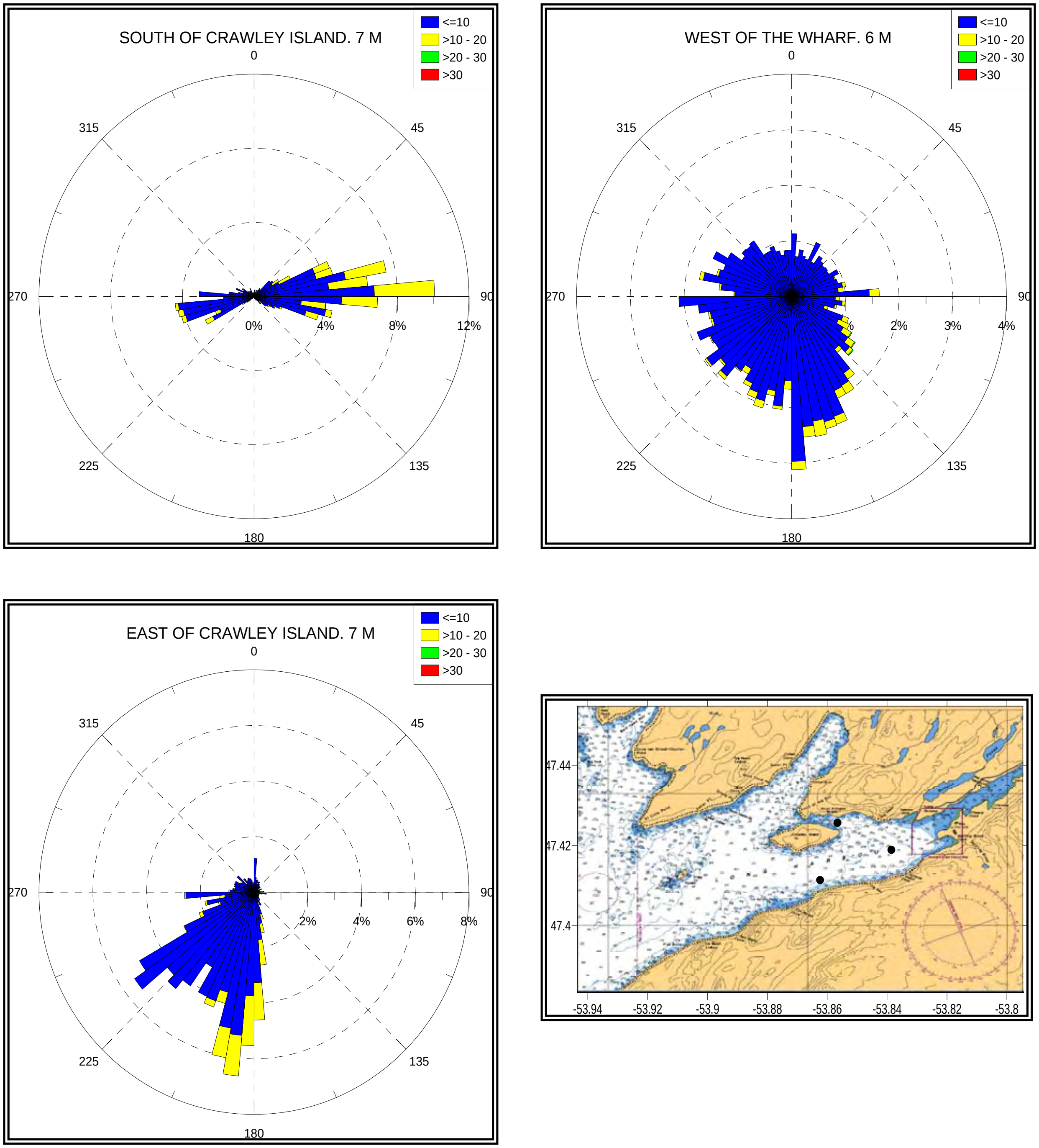


Figure 1.25. Rose Plots of Current Speeds and Directions in the Southern Arm of Long Harbour.

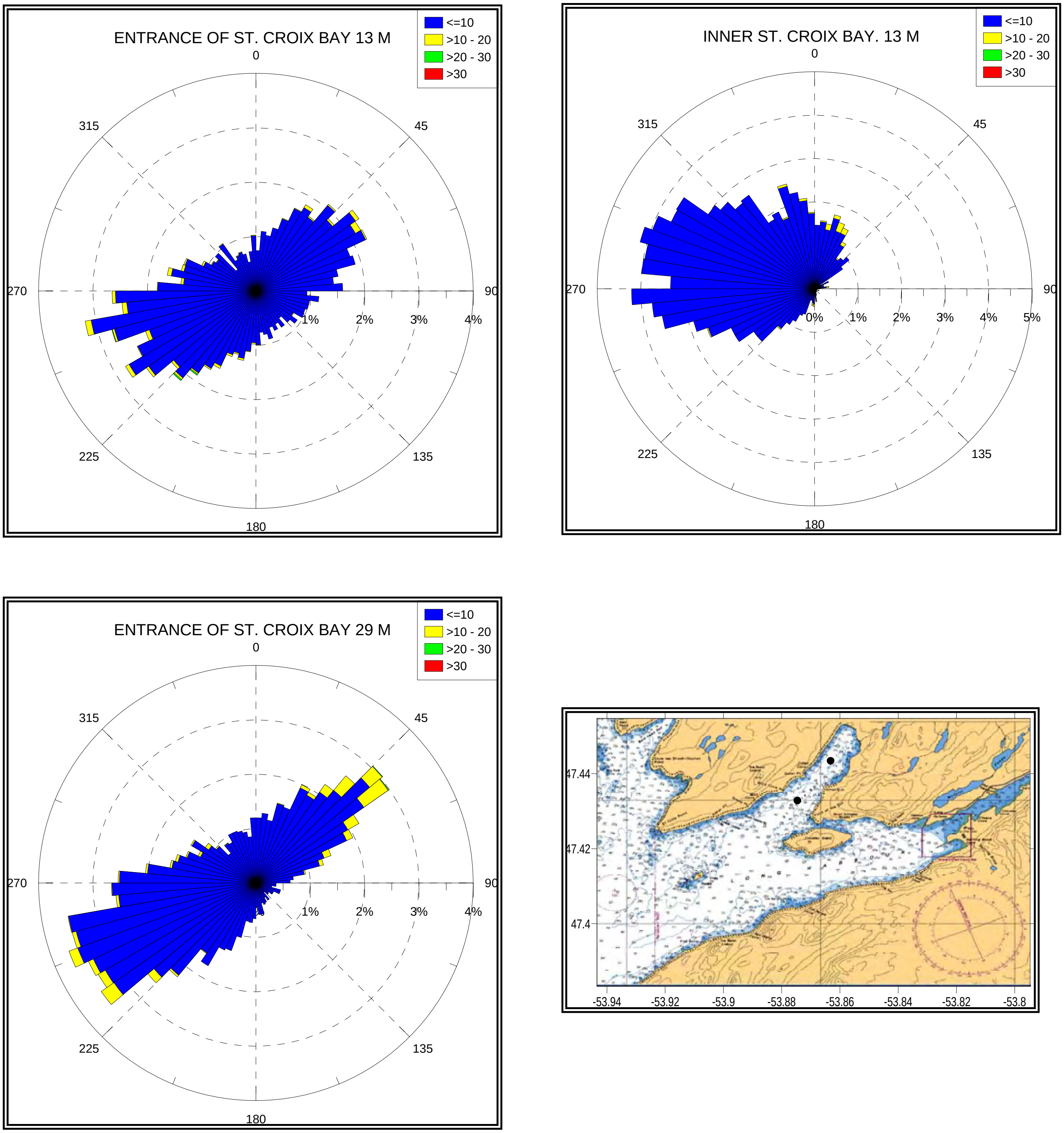


Figure 1.26. Rose Plots of Current Speeds and Directions in St. Croix Bay.

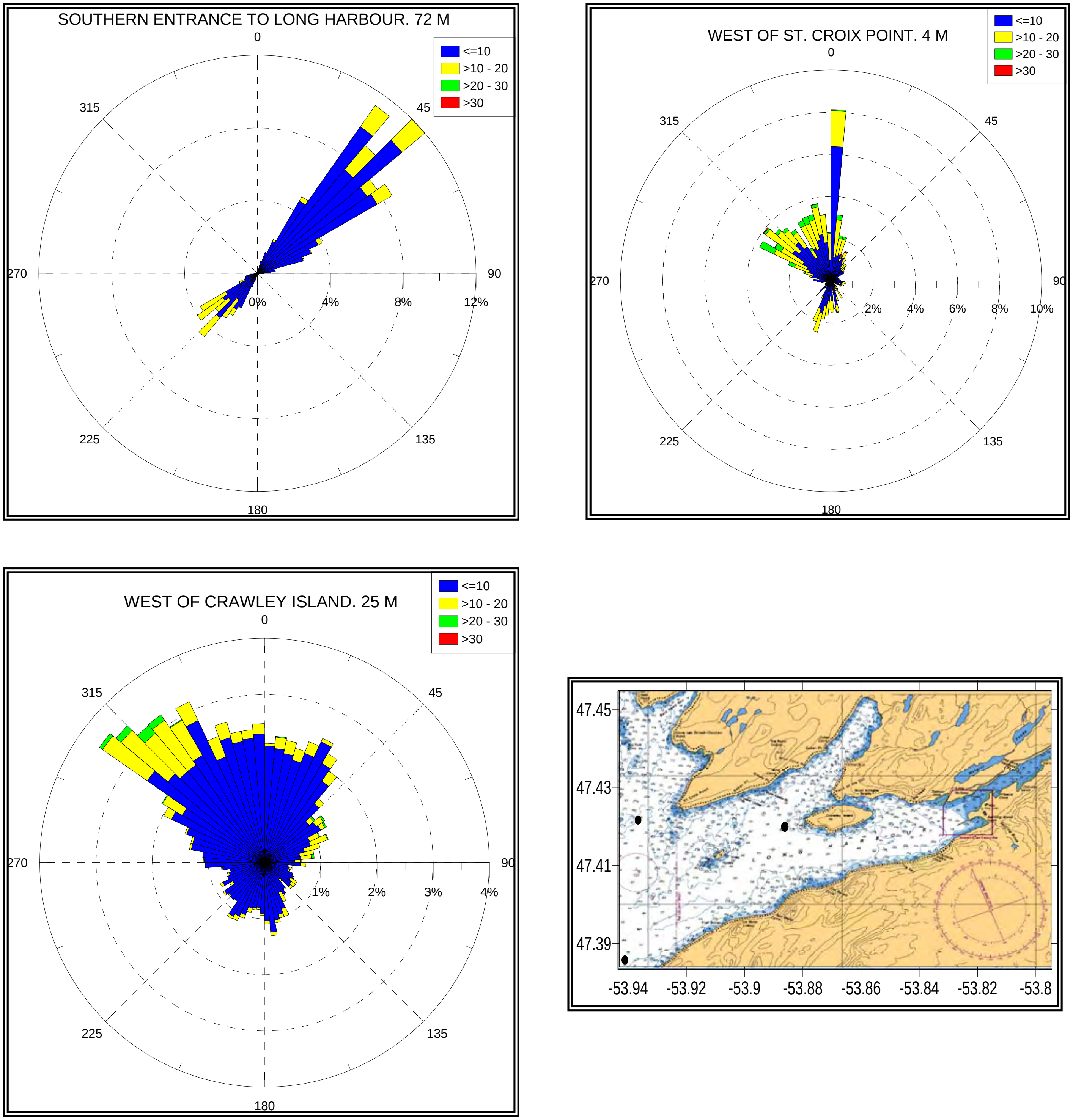


Figure 1.27. Rose Plots of Current Speeds and Directions in the Outer Section of Long Harbour.

For additional information on the spatial distribution of temperature and salinity in Placentia Bay, data were obtained from the BIO archive. The hydrographic conditions in late spring and late summer are shown in Figure 1.28 to 1.31. Figure 1.28 shows the warming trend that takes place during the summer season. In August, the surface temperatures varied between 13°C in the middle of the bay to 19°C at the head of the bay. Figure 1.29 shows the decrease in salinity as summer progresses and the lower salinity in June at the head of the bay and near the shore from river runoff.

At a depth of 100 m, temperature decreases and salinity increases between June and August (Figures 1.30 and 1.31). The coldest water of -1.3°C is present near the mouth of Placentia Bay.

A limited amount of CTD data is available for the winter months. In general, during winter the horizontal fields of temperature and salinity appear to display a great degree of homogeneity. At the surface during February, the temperature varied between -0.8°C near the mouth of Placentia Bay to 0°C near the head of Placentia Bay and along the western shore. On the eastern side of the bay the surface temperature varied between -0.4°C and -0.6°C. At deeper levels, similar characteristics were observed. The salinity was slightly higher at the mouth of the bay and along the eastern shore than elsewhere in the bay, corresponding to the lower water temperature.

Overall, the deep water near the mouth of Placentia Bay show temperatures and salinities which are consistent with values recorded by Colbourne (2000) who reported frequent occurrences of sub-zero temperatures and salinities in the range of 32 to 32.5 psu (practical salinity units) near the bottom in areas to the north of St. Pierre Bank, and attributed to the inshore branch of the Labrador Current. The temperature values are also consistent with those reported by Colbourne et al. (1994) for DFO Station 27 located east of St. John's in the inshore branch of the Labrador Current.

Temperature-salinity (TS) diagrams of the water properties at the mouth of Placentia Bay, and for Labrador Current water northwest of Green Bank are contained in Figure 1.32. The diagrams show that the water properties are almost identical which means that the water entering Placentia Bay is Labrador Current water.

CTD measurements were conducted by Oceans Ltd. in Long Harbour on May 17, July 11, and August 16, 2006. A description of the water properties at different locations in the harbour is contained in Oceans Ltd. (2007). The most significant feature is the presence of a deep mixed layer to a depth of approximately 25 m, below which exists a sharp pycnocline between 25 m and 30 m, and then a weak stratified water mass near the bottom. The local wind mixing in Long Harbour only extended to depths between four metres and eight metres. Figure 1.33 compares the water structure within Long Harbour to that in Placentia Bay. The depth profiles indicate that the 25 m mixed layer in Long Harbour is water transported into Long Harbour from Placentia Bay.

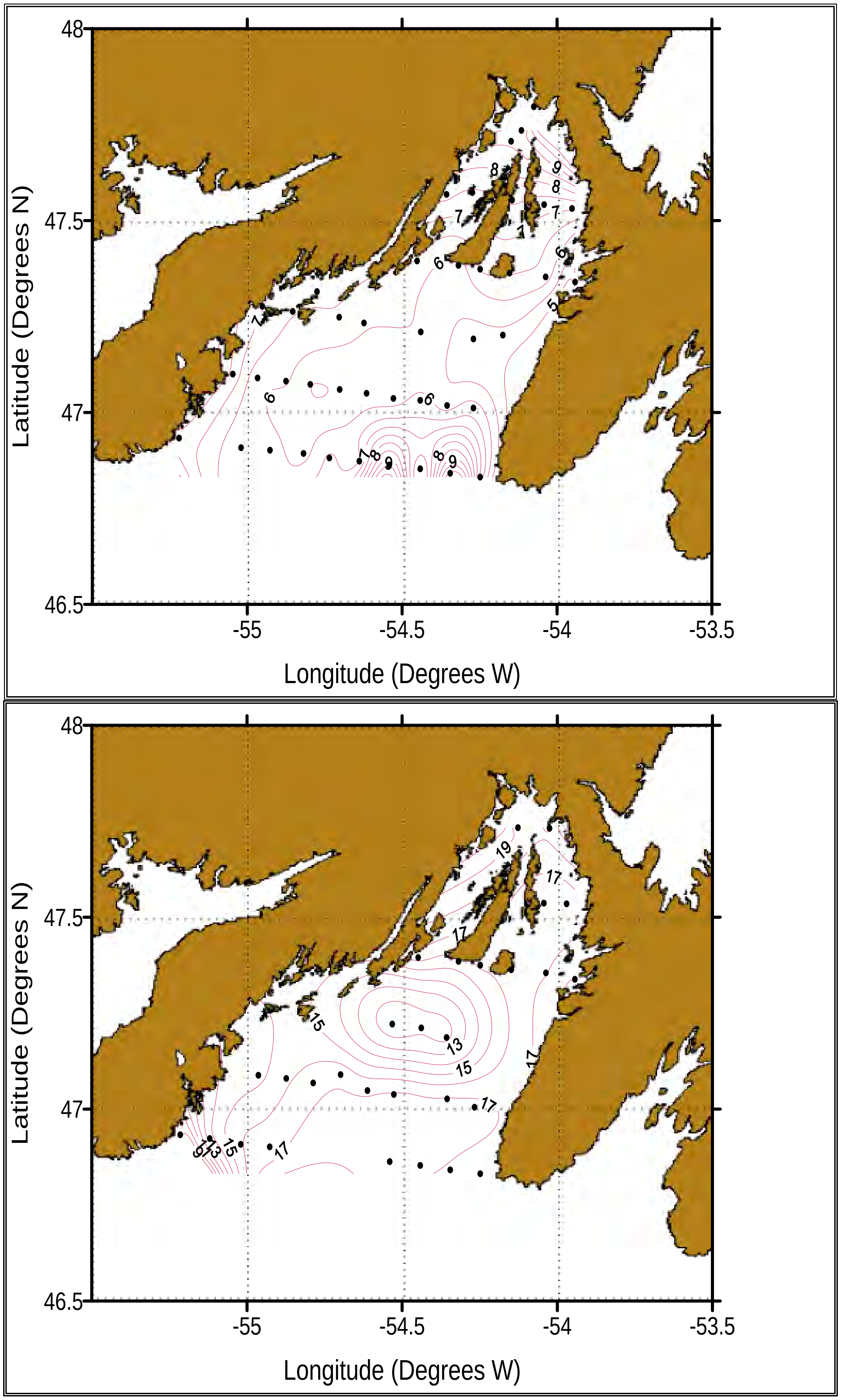


Figure 1.28. Temperature (°C) Distribution in June (above) and August (below), 1998.

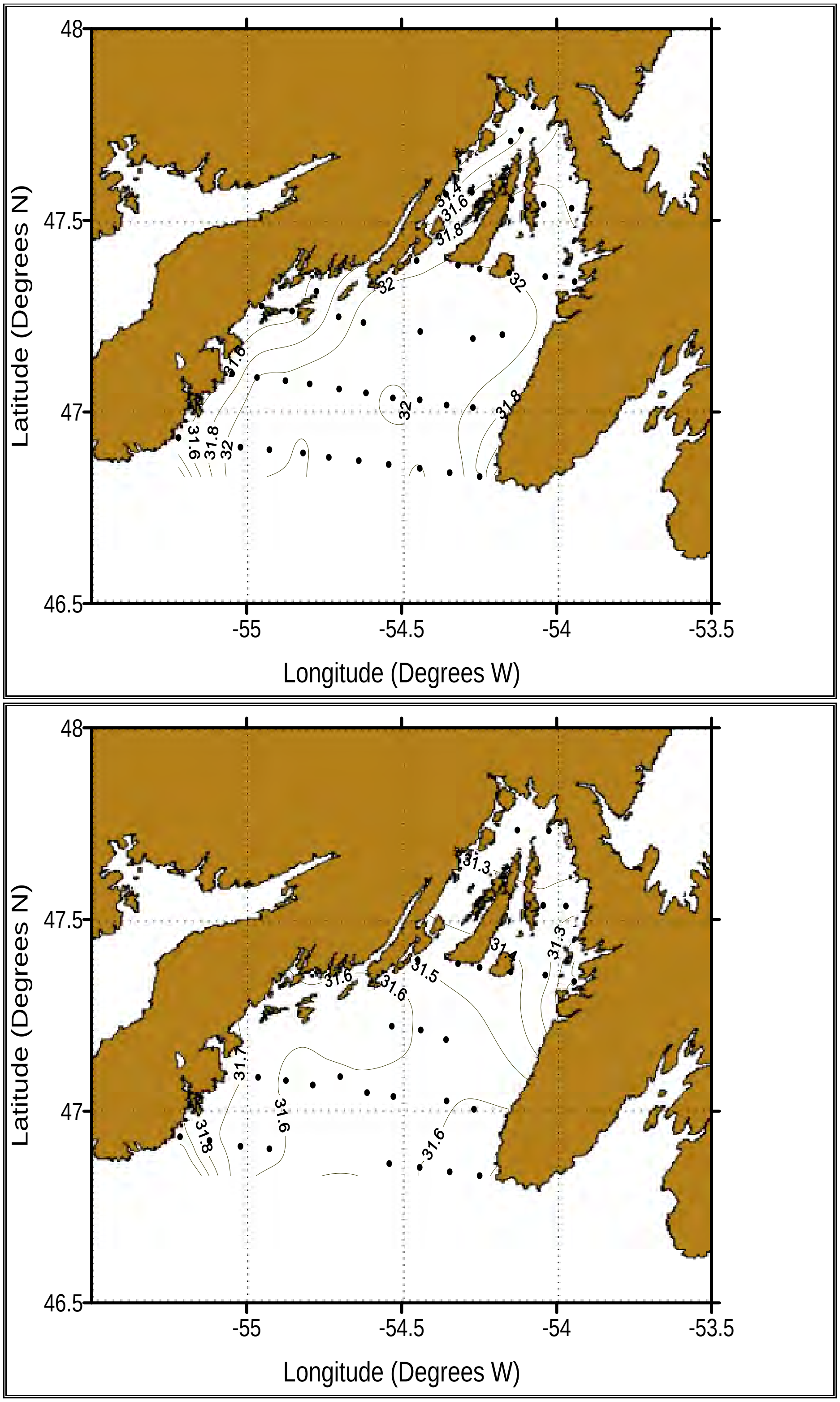


Figure 1.29. Surface Salinity (psu) Distribution in June (above) and August (below), 1998.

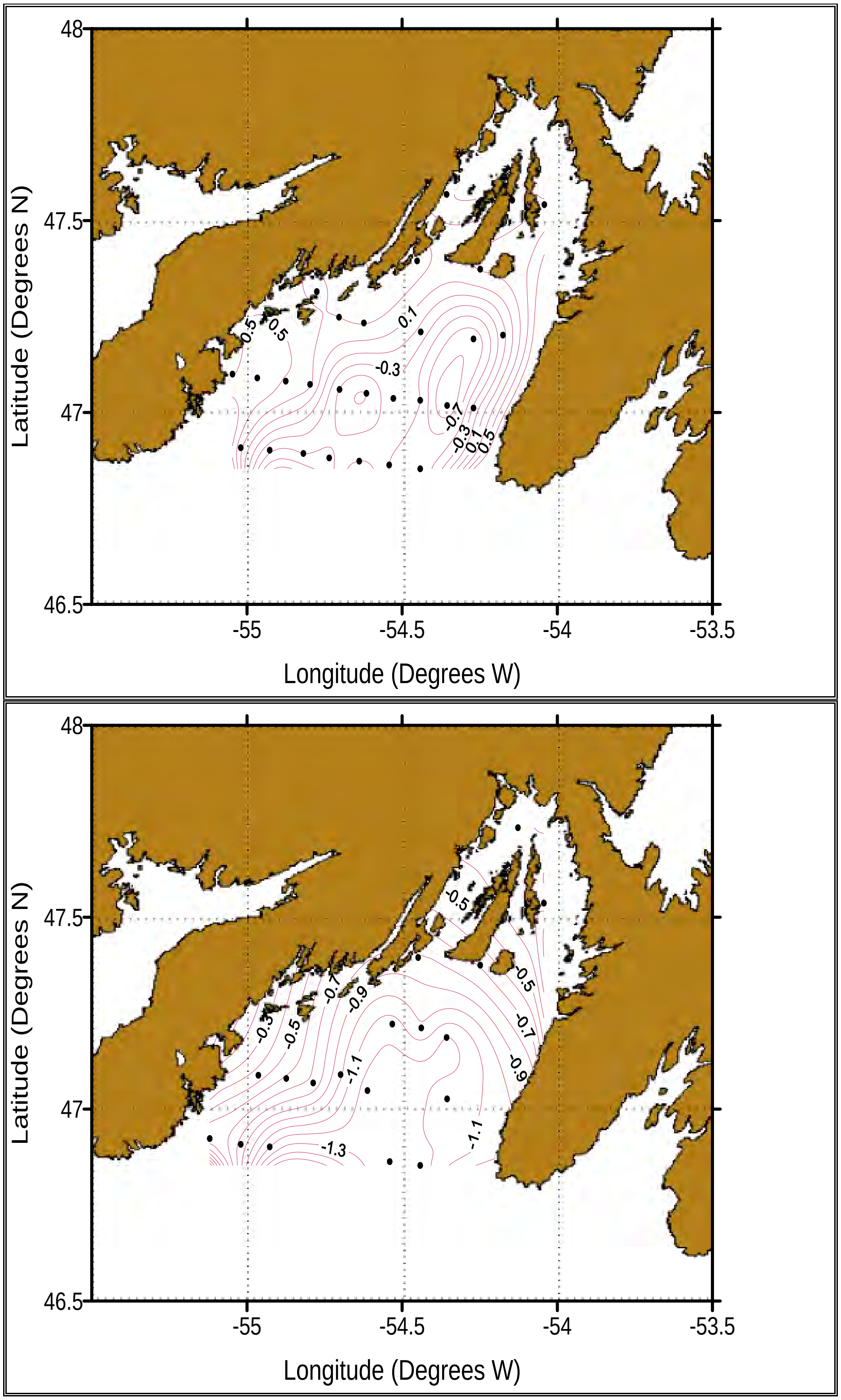


Figure 1.30. Temperature (°C) Distribution at 100 m in June (above) and August (below), 1998.

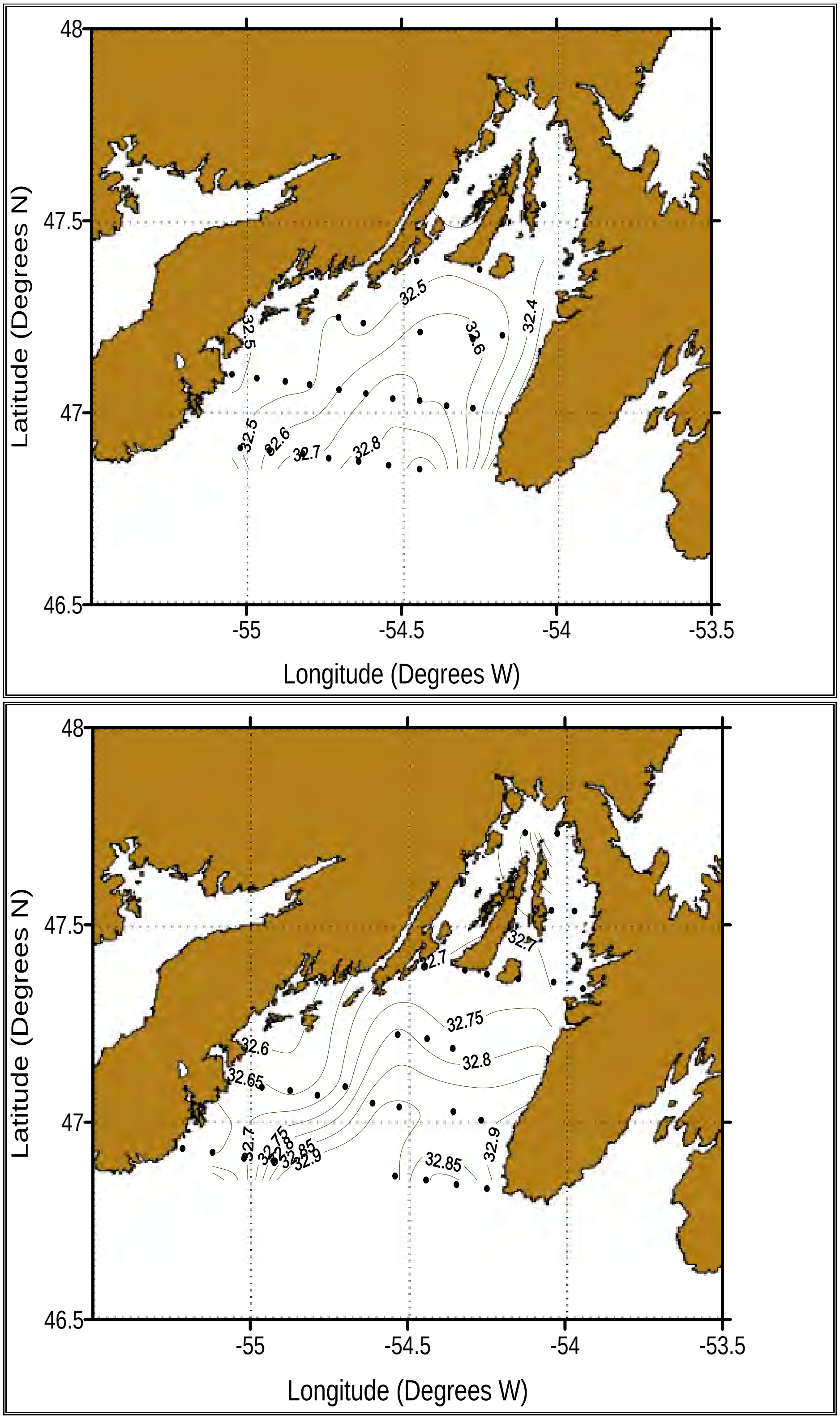
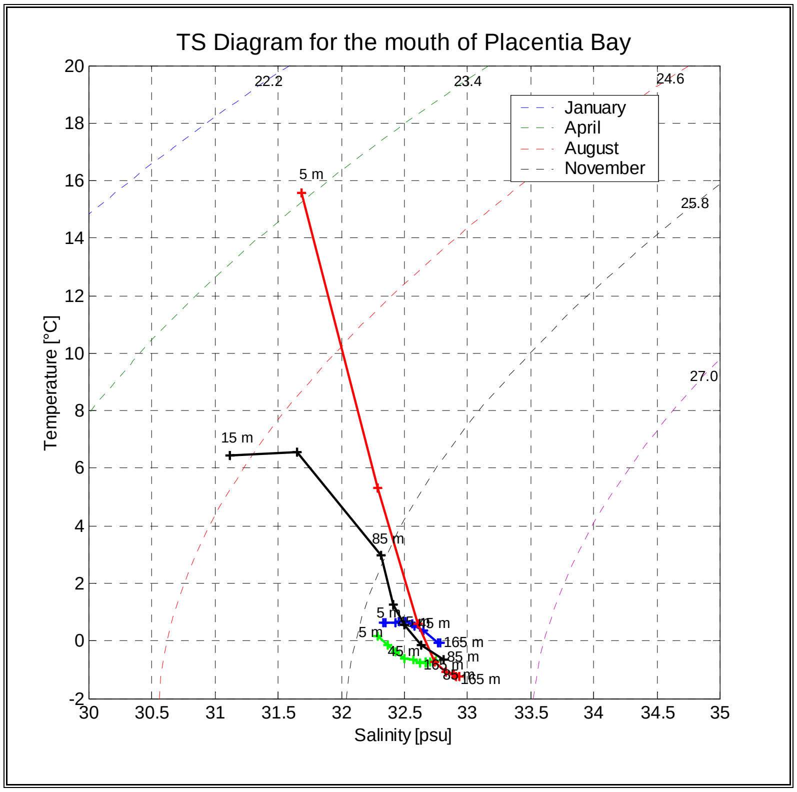


Figure 1.31. Salinity (psu) Distribution at 100 m in June (above) and August (below), 1998.



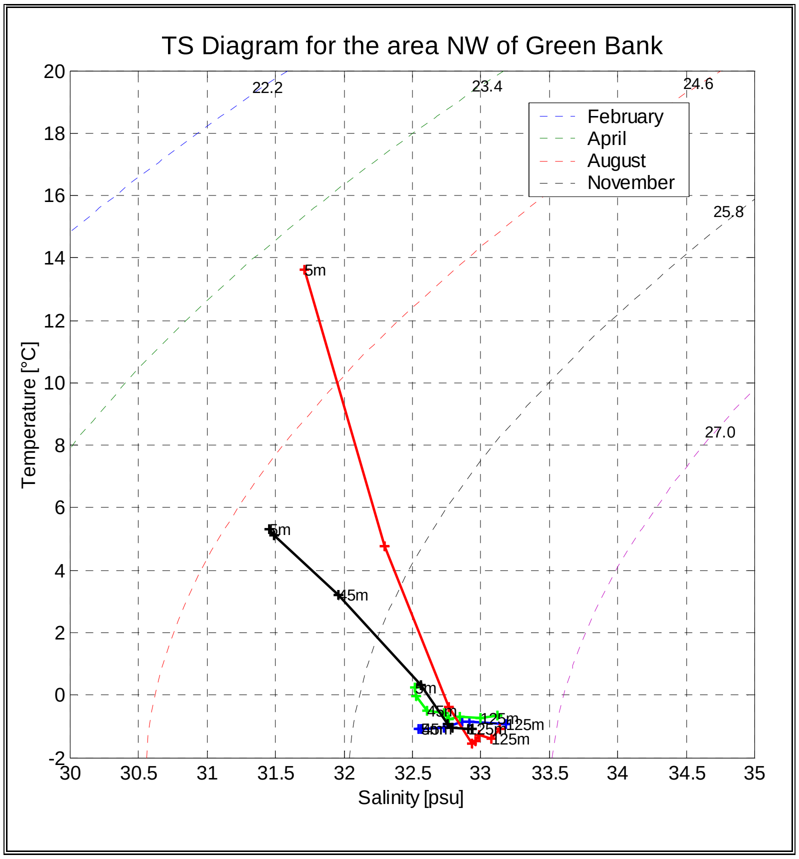


Figure 1.32. TS Diagrams of Water Properties.

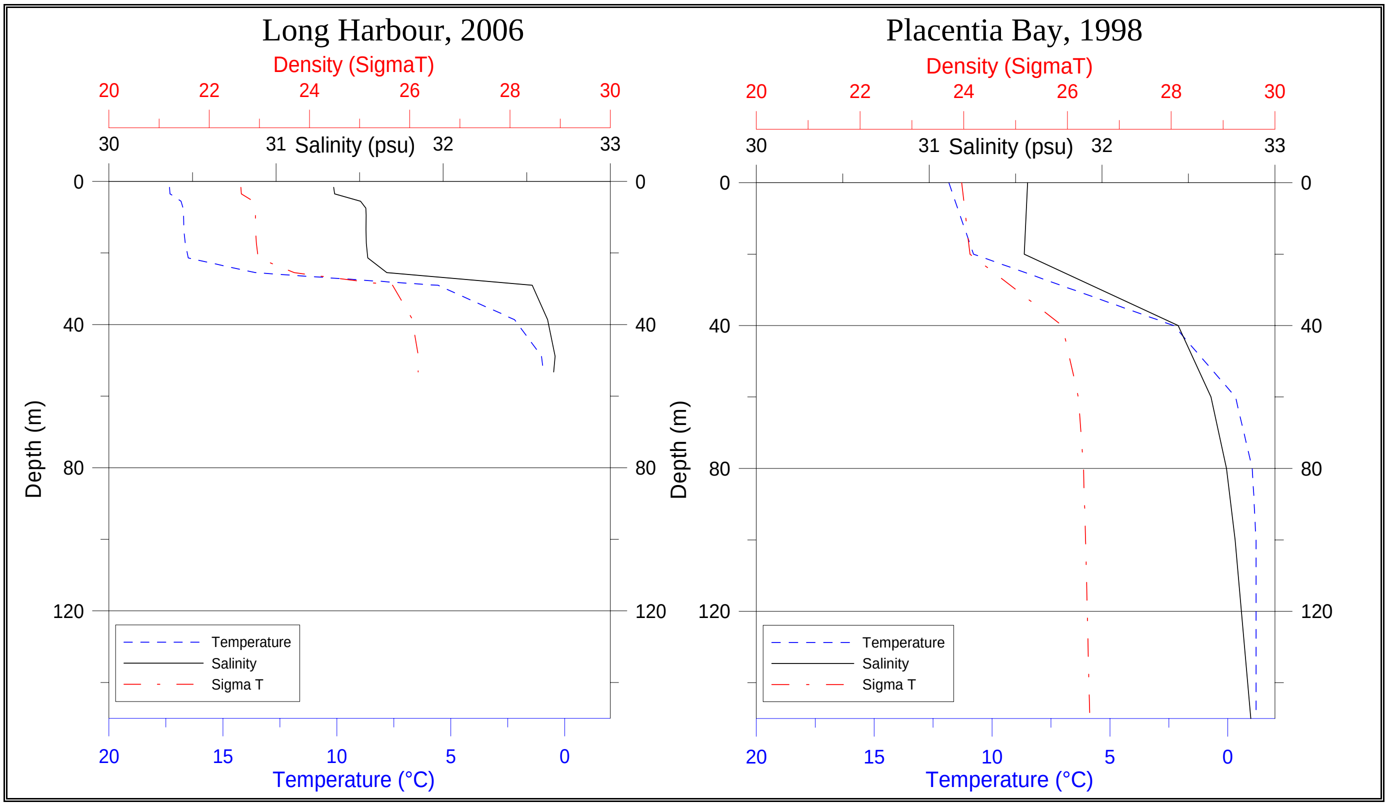


Figure 1.33. Water Structure in Long Harbour and Placentia Bay.

The mass transport from Placentia Bay to Long Harbour serves as an efficient flushing agent to replace the water in the outer section of the harbour in a relatively short time frame. By using the concentration of fresh water in the harbour as a tracer, and assuming that the time of transport through the harbour is equal to the time required for the fresh water to be replaced, the flushing time of the volume of water above 20 m was calculated to vary between 10 and 15 days during the summer season (Oceans Ltd. 2007).

1.3.5. Wave Climate

The main parameters for describing wave conditions are the significant wave height, the maximum wave height, the peak spectral period, and the characteristic period. The significant wave height is defined as the average height of the 1/3 highest waves, and its value roughly approximates the characteristic height observed visually. The maximum height is the greatest vertical distance between a wave crest and adjacent trough. The spectral peak period is the period of the waves with the largest energy levels, and the characteristic period is the period of the 1/3 highest waves. The characteristic period is the wave period reported in ship observations, and the spectral period is reported in the AES40 data set.

A sea state may be composed of the wind wave alone, swell alone, or the wind wave in combination with one or more swell groups. A swell is a wave system not produced by the local wind blowing at the time of observation. Swells are created at some distance away and propagate to the vicinity of the observation area. Swell waves travel out of a stormy or windy area and continue on in the direction of the winds that originally formed them as wind waves. The swell may travel for thousands of miles before dying away. As the swell advances, its crest becomes rounded and its surface smooth.

In the absence of long-term wave measurements for Placentia Bay, hindcasted wave data from the AES40 Grid Point 5616 were used for this wave climate analysis. The wave climate in Long Harbour .was modeled using wind data from Long Harbour and Argentia and described in Oceans Ltd. (2007). There may be slight low bias in the peak spectral periods of the hindcast waves since negative mean error of about 0.4 seconds in peak periods between hindcast and measured values was identified in a study carried out off the U.S. east coast (Cardone et al. 1995). The low bias is attributed to being a characteristic of third generation wave models (Cardone at al. 2000).

The majority of wave energy is from the south because Grid Point 5616 is located in the mouth of Placentia Bay where the waves are fetch-limited in a clockwise direction from west to east. The rose plot from the AES40 data (Figure 1.34) shows that the majority of wave directions are from the southwest to south with 36.2% of the wave energy coming form the south and 29.1% of the wave energy coming from the southwest.

Significant wave heights in Placentia Bay are higher during the winter months with the mean monthly significant wave heights reaching 2.2 m in December and January. Since winds are predominately from the west and northwest during the winter months, wind waves are generally fetch-limited. As a result, mean significant wave heights in Placentia Bay during the winter are lower than would be expected in the open ocean. The lower significant wave heights occur in the summer with a mean monthly significant wave height of only 1.2 m. Mean significant wave height values from the SmartBay buoy recently deployed in Placentia Bay are similar to the AES40 data as shown in Table 1.21.

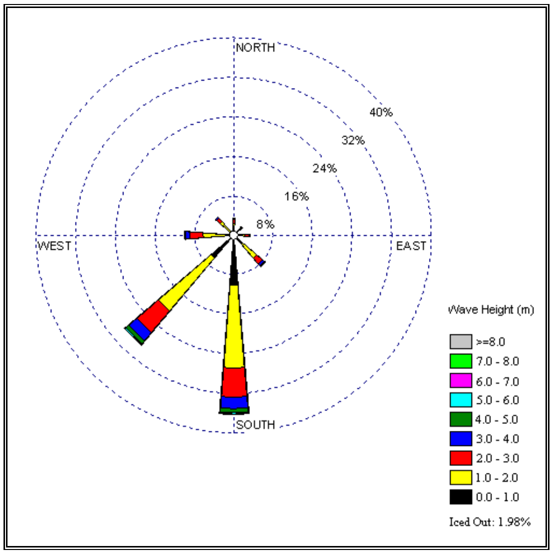


Figure 1.34. Annual Wave Rose from the AES40 Grid Point 5616.

Table 1.21. Mean Monthly and Maximum Significant Wave Heights in Placentia Bay.

	Significant Wave Height (m)		Maximum Significant Wave Height (m)	
Month	**AES40**	**SmartBay**	**AES40**	**SmartBay**
January	2.2	N/A	8.8	5.2
February	2.1	N/A	8.8	N/A
March	1.9	N/A	9.2	N/A
April	1.6	N/A	6.5	N/A
May	1.3	N/A	6.0	N/A
June	1.2	N/A	4.1	N/A
July	1.2	N/A	4.5	N/A
August	1.2	N/A	5.5	N/A
September	1.4	1.4	6.8	2.7
October	1.6	1.8	8.3	5.6
November	1.9	1.4	7.1	3.7
December	2.2	2.5	9.2	5.7
**SmartBay data is from September to January 04, 2007				

The highest significant wave height of 9.2 m from the AES40 data set occurred at 1800 UTC on December 20th, 1963 and again at 0600 UTC on March 18th, 1976 (Table 1.21). During the December 1963 event, a storm developed off Cape Cod at 0600 UTC on December 19th, and then rapidly deepened to 965 mb as it moved slowly northeast to lie over Sable Island at 1800 UTC. This situation generated south to southwest winds in Placentia Bay, and as a result, the wind wave reached 9.0 m with 1.5 m swells. The March 1976 storm, lying over Nova Scotia at 1200 UTC on March 17th, moved northeast and crossed Newfoundland early on March 18th. As it moved north, south to southwesterly winds over Placentia Bay again generated a 9.0 m wind wave and 1.7 m swells.

An annual histogram of the frequency distribution of significant wave heights is presented in Figure 1.35 and the percentage occurrence of significant wave height for each month is shown in Table 1.22 and Figure 1.36. Figure 1.36 shows that the majority of significant wave heights (47.0%) lie between 1.0 – 2.0 m. There is a significant decrease in frequency of wave heights above 2.0 m and only 9.8% of the wave heights exceed 3.0 m. Wave heights greater than 5.0 m are very rare and make up less than one percent of the data set.

The spectral peak period of waves vary with season with the most common period varying from seven seconds in the summer months to 11 seconds during winter. In February, 11 seconds is the most common peak spectral period, occurring 14.8% of the time. Annually, the most common peak spectral period is seven seconds, occurring 17.1% of the time. The peak spectral period reaches above 11 seconds 9.1% of the time. These longer spectral peak periods usually occur during the winter. The percentage occurrence of spectral peak periods for each month is shown in Table 1.23 and Figure 1.37.

A scatter diagram of the significant wave height versus spectral peak period is presented in Table 1.24 where it can be seen that the most common wave has a significant wave height of one metre with a peak spectral period of seven seconds. The second most common wave has a significant wave height of one metre and a peak spectral period of eight seconds. The nine metre significant wave heights typically coincide with peak spectral periods between 13 and 15 seconds; however, these heights occur very infrequently.

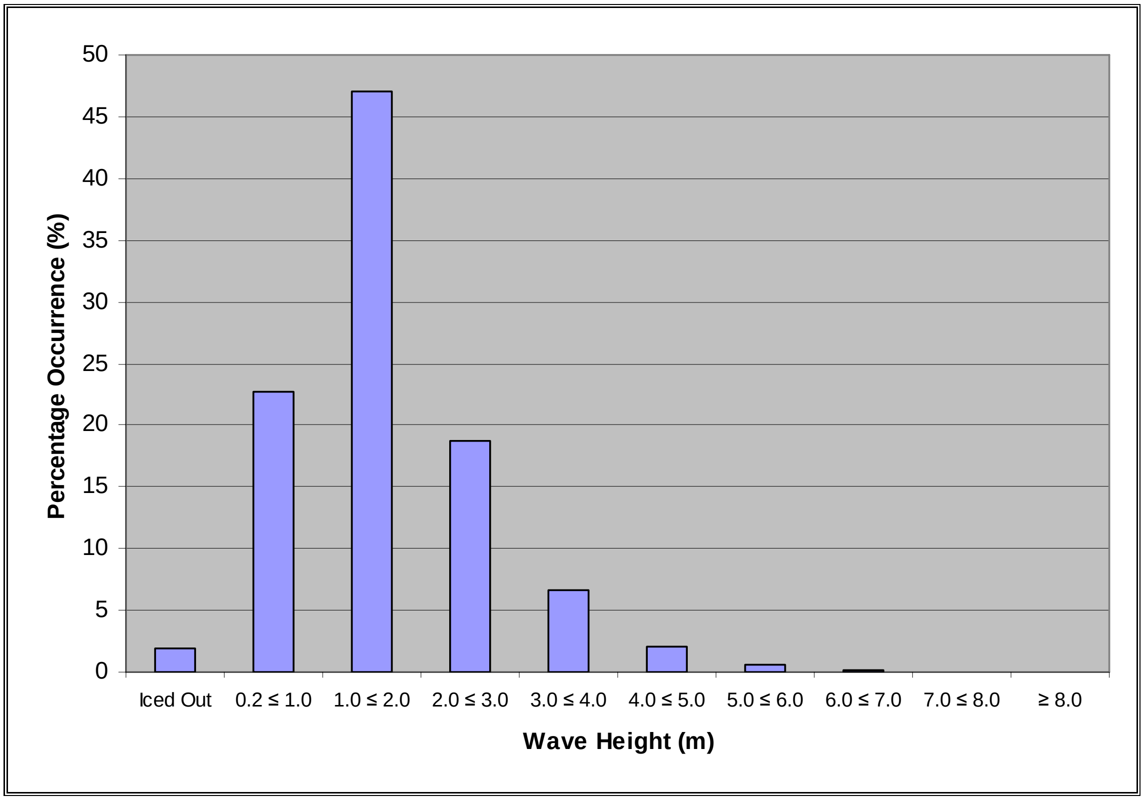


Figure 1.35. Frequency of Occurrence of Annual Significant Wave Heights at Grid Point 5616.

Table 1.22. Percentage Occurrence of Significant Wave Heights at Grid Point 5616.

Month	Significant Wave Height (metres)										Total
	0.0 - 0.9	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - 6.9	7.0 - 7.9	8.0 - 8.9	9.0 - 9.9	
January	7.71	37.90	31.45	14.62	5.28	2.20	0.62	0.13	0.08		100
February	9.45	40.51	29.39	13.78	4.59	1.62	0.45	0.17	0.04		100
March	15.29	42.45	27.18	10.72	3.12	1.08	0.12	0.02		0.02	100
April	22.34	48.45	22.03	6.12	0.96	0.09	0.02				100
May	39.84	47.99	9.91	1.94	0.26	0.03	0.02				100
June	43.32	48.94	6.85	0.85	0.03						100
July	42.50	52.23	4.71	0.44	0.13						100
August	43.55	50.08	5.76	0.55	0.05	0.02					100
September	32.85	52.32	12.20	1.90	0.60	0.08	0.05				100
October	22.29	52.76	18.98	4.73	0.87	0.19	0.13	0.03	0.02		100
November	15.13	46.90	25.65	8.27	2.83	0.93	0.27	0.02			100
December	10.29	40.24	29.52	12.90	4.82	1.63	0.44	0.11	0.03	0.02	100
Year	25.65	46.82	18.43	6.29	1.93	0.65	0.17	0.04	0.01		100

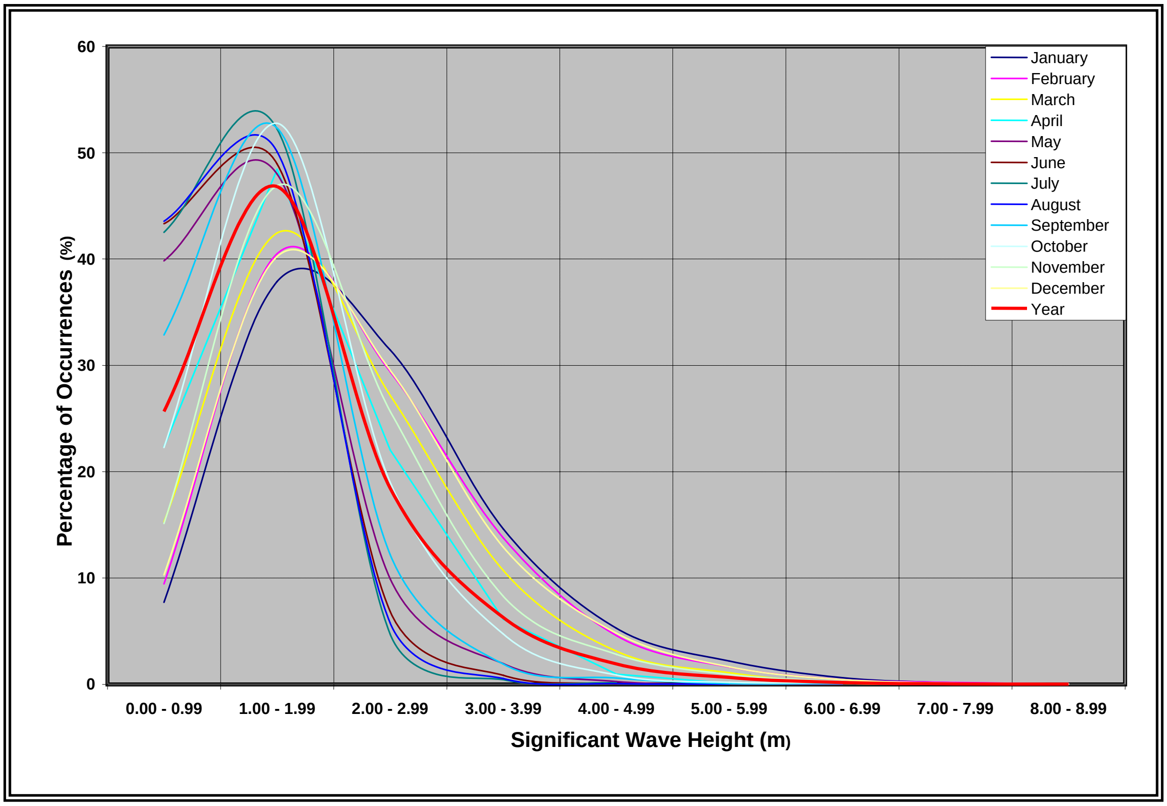


Figure 1.36. Percentage Occurrence of Significant Wave Height by Month at Grid Point 5616.

Table 1.23. Percentage Occurrence of Spectral Peak Periods at Grid Point 5616.

	Peak Spectral Period (seconds)															
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
January	0.0	0.0	0.1	2.9	8.6	11.8	11.9	7.9	10.1	**13.5**	**13.5**	11.6	5.9	1.7	0.5	0.0
February	0.0	0.0	0.2	3.4	9.7	13.0	10.9	7.8	9.1	14.1	**14.8**	9.4	5.1	2.3	0.2	0.1
March	0.0	0.0	0.4	5.5	11.3	11.4	10.8	8.4	10.5	**16.1**	12.2	7.4	4.1	1.5	0.3	0.1
April	0.0	0.0	0.2	5.3	10.0	10.9	11.3	12.8	**17.4**	16.1	10.2	4.1	1.3	0.4	0.1	0.0
May	0.0	0.0	0.4	6.4	10.9	10.7	18.4	**20.4**	17.6	8.2	3.4	1.7	0.6	0.6	0.2	0.4
June	0.0	0.0	0.3	4.1	9.5	12.6	**26.5**	21.8	13.8	5.6	1.8	1.3	1.3	1.0	0.4	0.1
July	0.0	0.0	0.1	2.5	8.0	14.5	**29.4**	22.2	13.2	5.2	1.6	1.2	0.7	0.4	0.3	0.5
August	0.0	0.0	0.2	4.4	11.6	16.1	**27.9**	16.5	9.8	4.6	3.9	2.3	1.5	0.9	0.2	0.1
September	0.0	0.0	0.2	6.8	12.3	12.6	**18.0**	13.1	12.3	8.1	6.1	4.4	3.6	1.5	0.5	0.4
October	0.0	0.0	0.3	6.3	15.3	14.0	**15.0**	14.7	13.3	9.6	5.7	3.6	1.4	0.4	0.1	0.2
November	0.0	0.0	0.4	5.4	11.7	13.4	13.2	10.2	**15.0**	14.3	9.2	4.2	1.9	1.1	0.1	0.0
December	0.0	0.0	0.1	3.9	9.6	12.1	11.5	8.8	11.7	**15.0**	12.8	8.9	4.3	1.3	0.1	0.0
Winter	0.0	0.0	0.1	3.4	9.3	12.3	11.4	8.2	10.3	**14.2**	13.7	10.0	5.1	1.7	0.3	0.0
Spring	0.0	0.0	0.3	5.7	10.7	11.0	13.5	13.8	**15.2**	13.5	8.6	4.4	2.0	0.8	0.2	0.2
Summer	0.0	0.0	0.2	3.7	9.7	14.4	**28.0**	20.2	12.3	5.1	2.4	1.6	1.2	0.8	0.3	0.2
Autumn	0.0	0.0	0.3	6.2	13.1	13.3	**15.4**	12.7	13.5	10.7	7.0	4.1	2.3	1.0	0.2	0.2
Annual	0.0	0.0	0.2	4.8	10.7	12.8	**17.1**	13.7	12.8	10.9	7.9	5.0	2.6	1.1	0.2	0.2

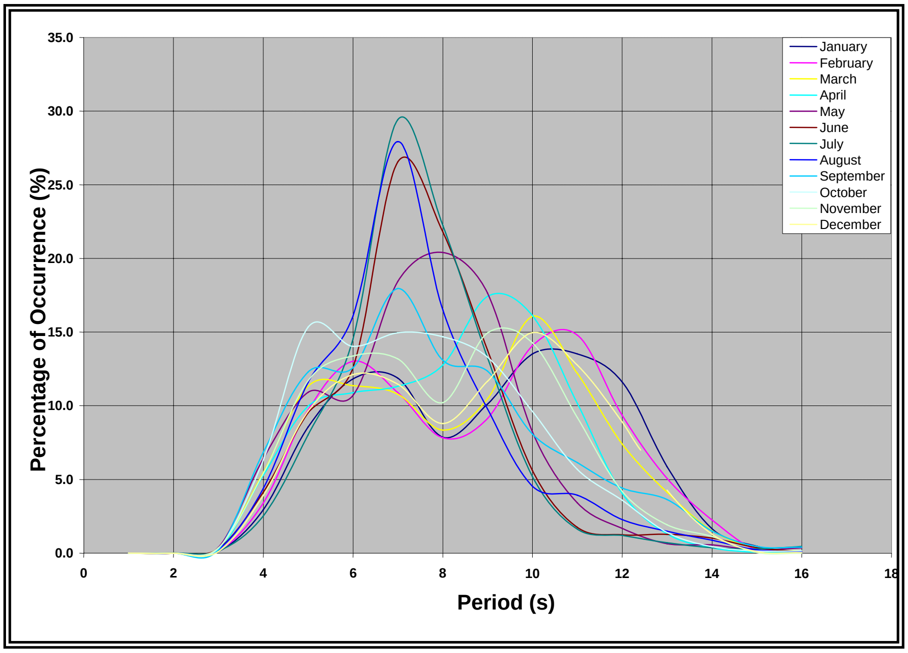


Figure 1.37. Percentage Occurrence of Spectral Wave Periods by Month at Grid Point 5616.

Table 1.24. The Frequency of Occurrence (%) of Significant Combined Wave Height and Peak Spectral Period at Grid Point 5616.

	Wave Height (m)													Total
Period (s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
0														0.00
1														0.00
2														0.00
3	0.16													0.16
4	4.30	0.11												4.41
5	8.51	1.92	0.01											10.44
6	4.41	7.75	0.14											12.31
7	9.04	4.89	2.46	0.04										16.42
8	8.48	2.40	1.87	0.51	0.01	0.00								13.28
9	6.89	3.51	1.14	0.62	0.09	0.00								12.26
10	3.82	4.37	1.28	0.51	0.22	0.03								10.23
11	2.02	3.10	1.65	0.46	0.19	0.05	0.01							7.50
12	1.14	1.32	1.40	0.58	0.21	0.08	0.02	0.00						4.75
13	0.67	0.48	0.54	0.51	0.17	0.10	0.03	0.01	0.00					2.52
14	0.31	0.16	0.18	0.15	0.13	0.05	0.02	0.01	0.01					1.02
15	0.12	0.03	0.02	0.03	0.02	0.01	0.00	0.00	0.00					0.23
16	0.11	0.02	0.01	0.01	0.00	0.00								0.15
17	0.04	0.00			0.00	0.00								0.05
18	0.00													0.00
19	0.00													0.00
20														0.00
	50.02	30.08	10.71	3.42	1.06	0.34	0.08	0.02	0.01	0.00	0.00	0.00	0.00	95.73

Source: AES grid point 5616. 46.875N 55.00W, 1954 to 2004.

1.3.5.1. Extremal Analysis

Extreme wave values were calculated for return periods of 1-year, 10-years, 25-years, 50-years, and 100-years using a Gumbel Distribution and the peak-over-threshold method. A sensitivity analysis was carried out to determine how many storms to use in the analysis, because the extreme values can vary depending on how well the data fits the distribution function. The sensitivity analysis showed that the Gumbel Distribution had a good fit using 158 storms, corresponding to a threshold significant wave height of 5.5 metres. The extreme value estimated for significant wave heights, maximum wave heights, and associated peak periods are presented in Table 1.25. The extreme significant wave heights for return periods of 1-year, 10-years, 25-years, 50-years, and 100-years are 6.6 m, 8.2 m, 8.8 m, 9.3 m, and 9.8 m, respectively.

Table 1.25. Extreme Wave Estimates for Placentia Bay.

Return Period (years)	Significant Wave Height (m)	Maximum Wave Height (m)	Associated Peak Period (s)
1	6.6	12.3	12.5
10	8.2	15.2	13.9
25	8.8	16.3	14.4
50	9.3	17.2	14.8
100	9.8	18.0	15.1

1.3.5.2. Joint Probability of Extreme Wave Heights and Spectral Peak Periods

In order to examine the period ranges of storm events, an environmental contour plot was produced showing the probability of the joint occurrence of significant wave heights and the spectral peak periods using the methodology of Winterstein et al. (1993). The environmental contour plot is presented in Figure 1.38. The wave heights were fitted to a Weibull Distribution and the peak periods to a lognormal distribution. The wave data were divided into bins of one metre for significant wave heights and one second for peak periods. Since the lower wave values were having too much of an impact on the wave extremes, the wave heights below two metres were modeled in a separate Weibull Distribution. The two Weibull curves were combined where they overlap, near 1.5 metres, the point where both functions generated the same wave and period values for the same probability.

Three-parameter Weibull Distributions were used with a scaling parameter α, shape parameter β, and location parameter γ. The three parameters were solved by using a least square method, the maximum log likelihood, and the method of moments. The following equation was minimized to get the coefficients

$$LS(\alpha,\beta,\gamma) := \sum_{i=0}^{N}\left[\ln\left(-\ln\left(1-CD_i\right)\right)-\beta\cdot\ln\left[\frac{\left(h_i-\gamma\right)}{\alpha}\right]\right]^2$$

where h_i is the endpoint of the height bin (1.0, 2.0, …) and CD_i is the cumulative probability of the height bin. Using a minimizing function, the three parameters α, β and γ were calculated.

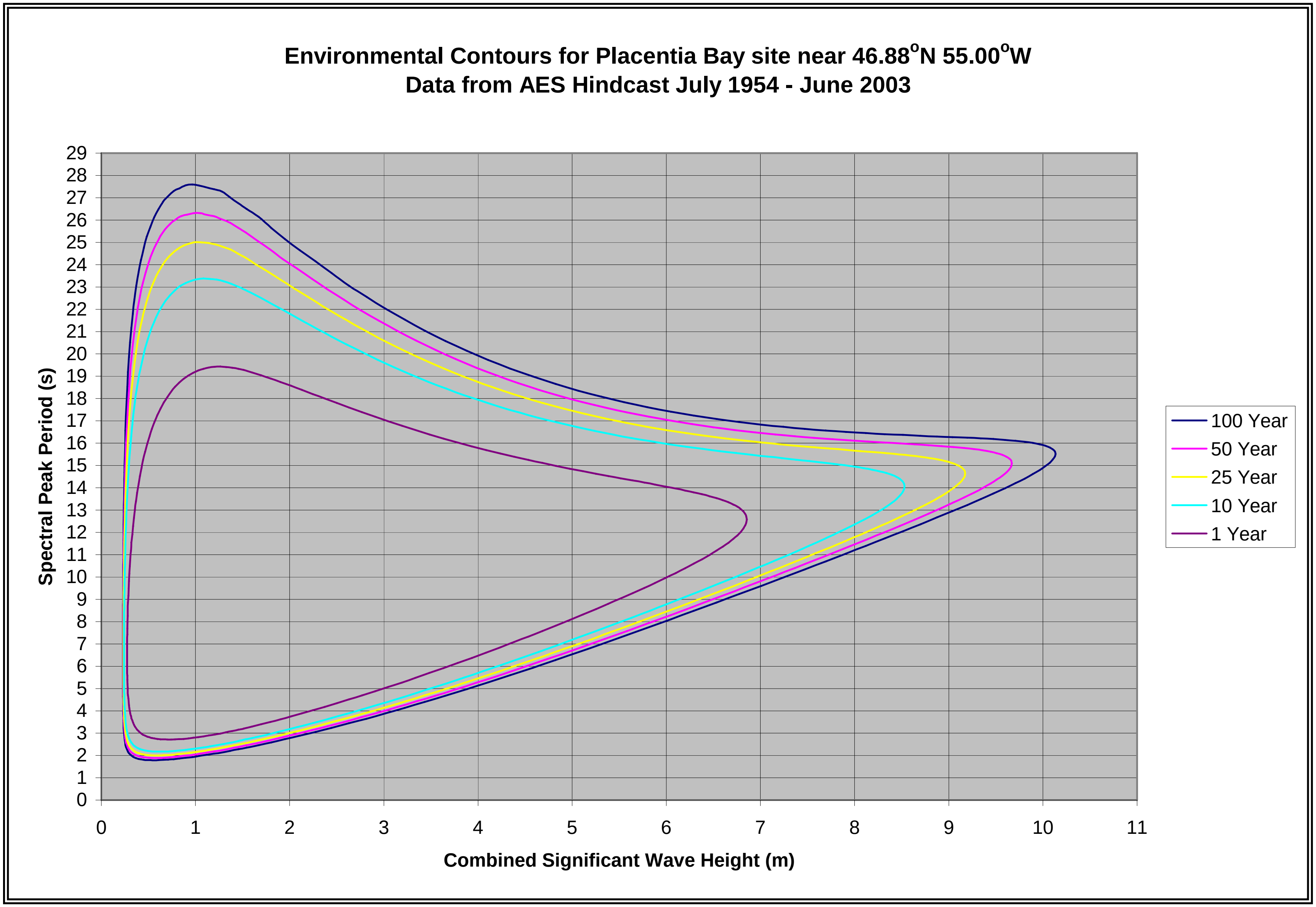


Figure 1.38. Environmental Contour Plot for Placentia Bay.

A lognormal distribution was fitted to the spectral peak periods in each wave height bin. The coefficient of the lognormal distribution was then calculated. Using the coefficients and the two distribution functions, the joint wave height and period combinations were calculated for the various return periods. The values were plotted and the contours produced are shown in Figure 1.38 for return periods of 1-year, 10-years, 25-years, 50-years, and 100-years. The values for the significant wave height estimates and the associated spectral peak periods are given in Table 1.26. The 100-year extreme wave height using the Weibull Distribution on the complete data set was 10.1 m as compared to 9.8 m using a Gumbel Distribution on a selected number of storms.

Table 1.26. Extreme Wave Estimates and Spectral Peak Periods for all Months Combined.

Return Period (years)	Significant Wave Height (m)	Spectral Peak Period(s) Median Value	Peak Period(s) Lower limit	Peak Periods (s) Upper Limit
1	6.9	12.6	9.7	16.3
10	8.5	14.1	11.7	17.0
25	9.2	14.6	12.4	17.3
50	9.7	15.1	13.0	17.6
100	10.1	15.5	13.5	17.8

1.3.6. Sea Ice and Icebergs

Heavy sea ice and icebergs are relatively rare in Placentia Bay. The following sections describe historical conditions.

1.3.6.1. Sea Ice

Due to its location along the south coast of Newfoundland, Placentia Bay is a relatively ice-free bay in comparison to other bays surrounding Newfoundland. A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Ice in Placentia Bay reveals that ice is only present in Placentia Bay from mid February until late April. A graph of the frequency of occurrence of ice in Placentia Bay is presented in Figure 1.39. In Figure 1.39, the shading of the bar gives the frequency of occurrence and the height of the bar gives the percentage coverage of ice in the bay. From the Placentia Bay graph it can be seen that the week of 12 February there is a 4% chance that 67.4% of the bay will be covered, and a 7% chance that 12.2% of the bay will be covered. During this period, when ice is present in the bay, the predominant type is either new (recently formed having a thickness of less than 10 cm), grey (young ice 10-15 cm thick) or grey-white (young ice 15-30 cm thick).

The likelihood of ice in Placentia Bay is highest during the week beginning 26 February. During this week, there is 4% chance that 11.5% of the bay will be covered, a 42.6% chance that 7% of the bay will be covered and a 45.7% chance that 10% of the bay will be covered. Of the types of ice present during this time, new ice is predominate; however, grey ice and grey-white ice is also present.

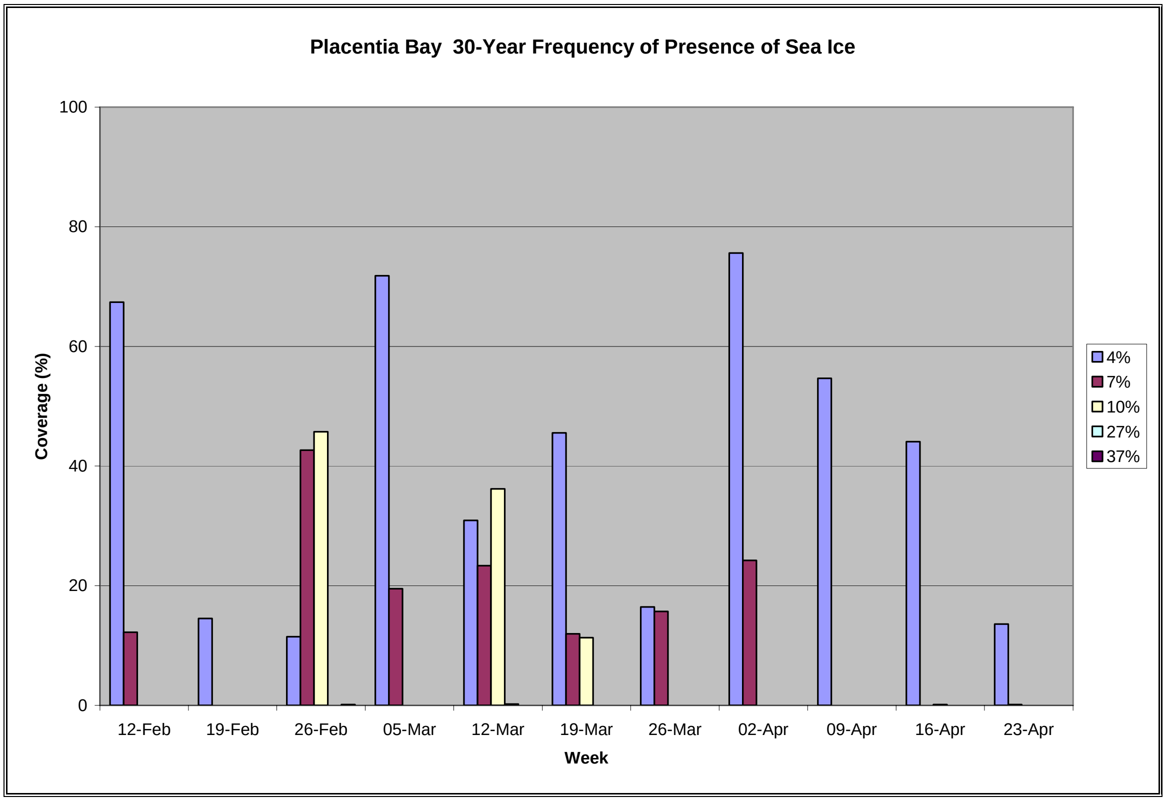


Figure 1.39. Frequency of Presence of Sea Ice in Placentia Bay (1971-2000).

During the month of March, first-year ice (young ice with a thickness of 0.3 to two metres) either forms within the bay or flows around the Avalon and enters the bay. By the week of 19 March, first-year ice is predominate and remains until the week of 23 April. The presence of sea ice within Placentia Bay begins to decrease during the week of 2 April and insignificant amounts remains after the week of 23 April (Figure 1.39).

In Long Harbour, there is a 4% chance of 33.8% coverage, a 7% chance of 62.6% coverage, and a 27% chance of 3.5% coverage during the week of 12 February (Figure 1.40). This ice appears to be absent during the week of 19 February, then reoccurs during the week of 26 February with a 10% chance of 100% coverage of grey-white ice. During the weeks of 12 March and 19 March, there is a 10% chance of 100% coverage and during the weeks of 26 March and 2 April there is a 7% chance of 100% coverage. The predominate ice type during the weeks of 26 March to 2 April is first year ice. After the week of 2 April, sea ice is no longer present in Long Harbour.

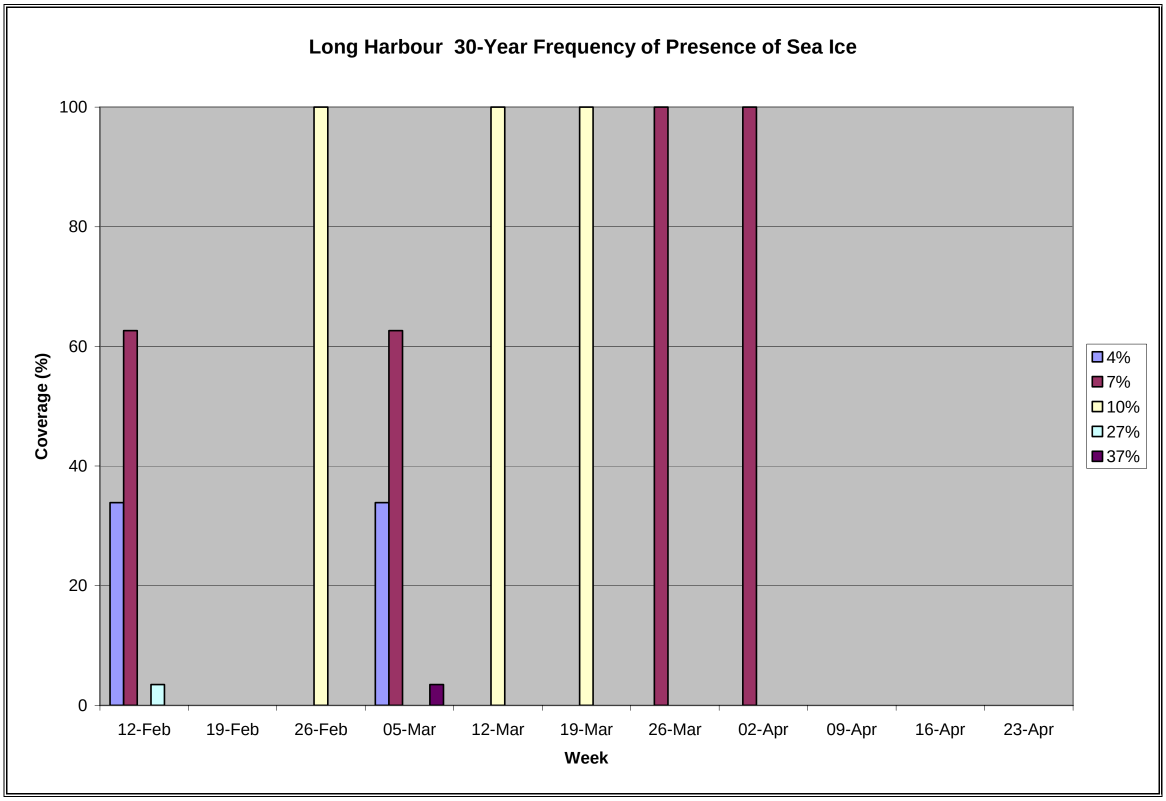


Figure 1.40. Frequency of Occurrence of Sea Ice at Long Harbour (1971-2000).

1.3.6.2. Icebergs

An analysis was performed to assist in determining the potential threat to shipping posed by icebergs in Placentia Bay. The International Ice Patrol (IIP) Iceberg Sightings Database from 1974-2003 was used as the primary data source in this analysis, (NSIDC 1995). Figure 1.41 shows the number of iceberg sightings below 48°N off the east coast of Newfoundland from 1974-2003. Overall there is a good distribution of iceberg sightings ranging from 2,202 in 1984 to 22 in 1999. Only iceberg sightings that occurred inside Placentia Bay above 46° 48´ N were considered in this analysis. Duplicate sightings of the same iceberg were also eliminated from the data set so that only the initial sighting was counted.

Figure 1.42 shows the positions of all icebergs within Placentia Bay from 1974-2003. Over the 30 years studied, only 30 icebergs have been sighted inside the bay. In terms of location, the iceberg sightings occurred more frequently on the eastern side of the bay. Since the icebergs are moving into the bay from south of the Avalon Peninsula this is not surprising. Environmental factors such as iceberg concentration, ocean currents, and wind determine if icebergs will move into the bay. There are not enough icebergs present to establish an iceberg drift pattern within the bay.

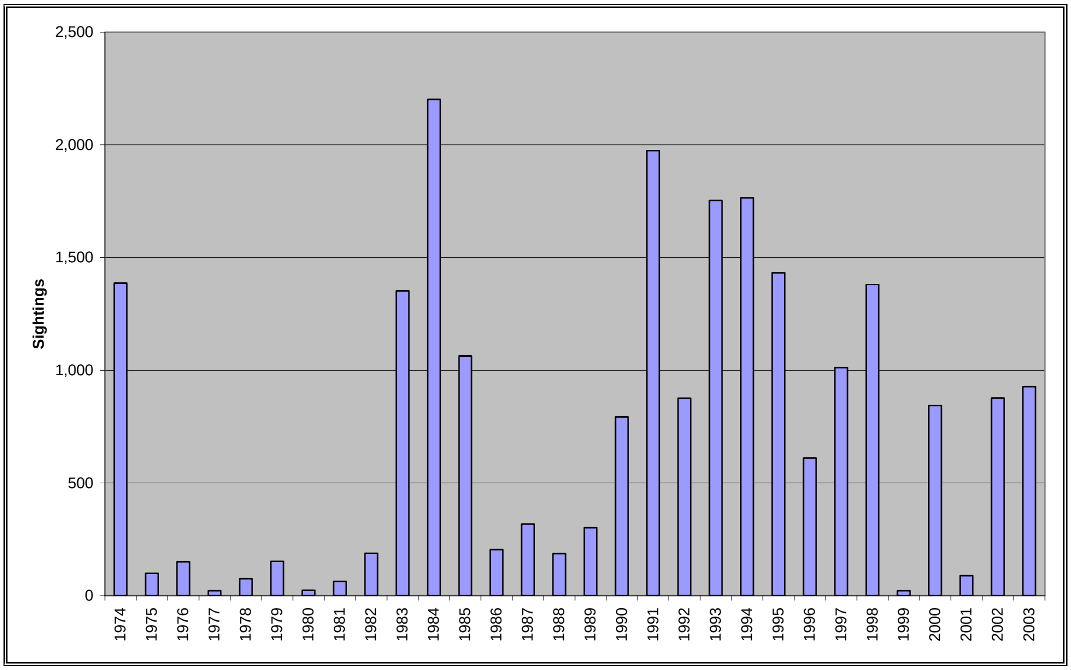
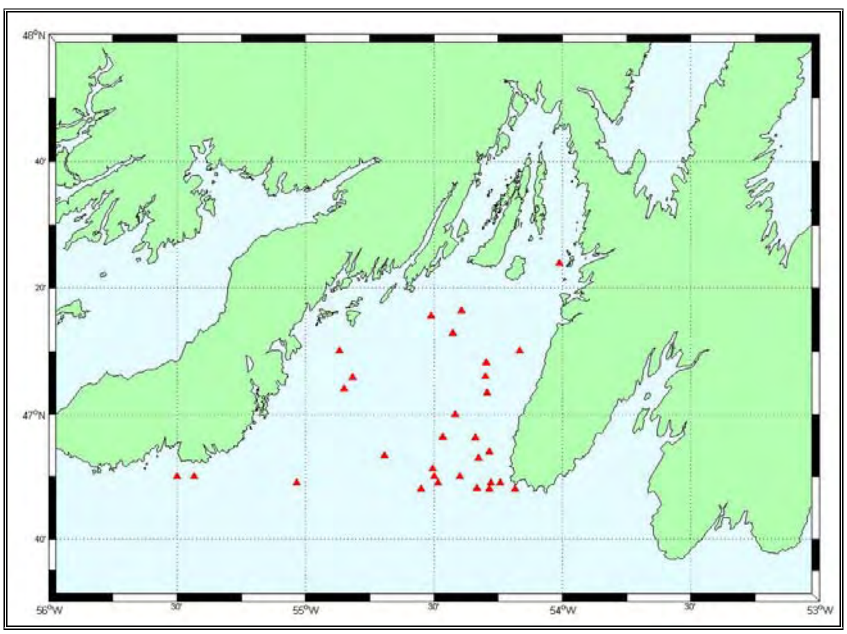


Figure 1.41. Iceberg Sightings below 48°N.



Source: IIP.

Figure 1.42. Iceberg sightings in Placentia Bay, 1974 – 2003.

It should also be noted that these sightings occurred over only seven of the 30 years. The bay was iceberg free for the remaining 23 years. Figure 1.43 shows the iceberg sightings in Placentia Bay by year.

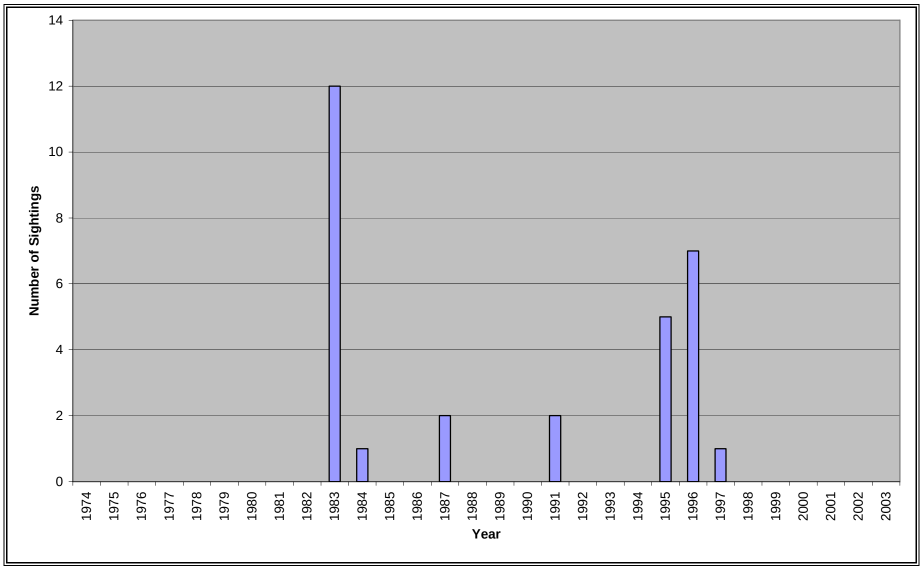


Figure 1.43. Iceberg Sightings in Placentia Bay by Year.

Iceberg sightings in Placentia Bay appear to be limited to years when there was a high concentration of icebergs below 48°N. However, a high iceberg concentration below 48°N does not necessarily indicate the presence of icebergs in Placentia Bay. There are a number of years when this occurred and no icebergs were sighted inside the bay. As well, iceberg sightings were limited to the months of March, April, May, and June as illustrated in Figure 1.44. This is similar to the monthly pattern of sightings on the Grand Banks.

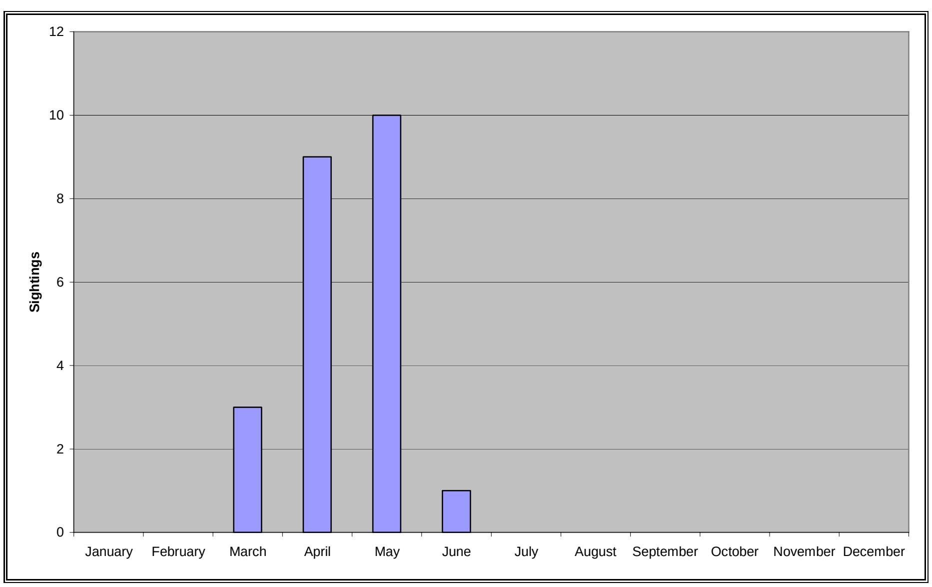


Figure 1.44. Placentia Bay Iceberg Sightings by Month.

1.3.7. Storm Surges

A storm surge is a pronounced increase in sea level associated with the passage of storm systems and defined as the difference between the observed water level and the predicted astronomical tide. This increase in sea level is typically the result of the combined forces of wind stress acting on the ocean and the inverted barometer effect due to the low atmospheric pressure associated with the storm.

Bernier and Thompson (2006) studied extreme storm surges in the NW Atlantic using a 40-year hindcast of storm surges. They showed a 40-year return period storm surge of 0.7 metres for the south coast of Newfoundland. Near the shoreline of Placentia Bay, the height of a storm surge could exceed 0.7 metres due to the shoaling and funneling effects of a movement of water into more shallow or restricted areas.

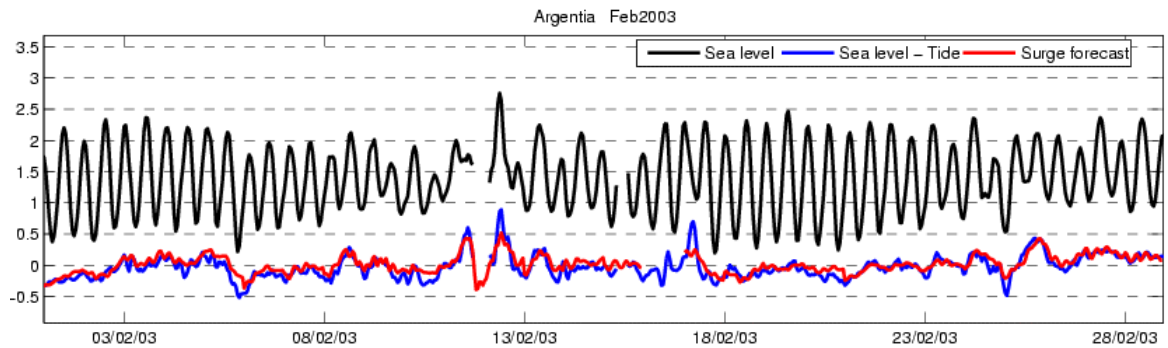
The Center for Marine Environmental Prediction at Dalhousie University maintains a Flooding Forecast Service for Atlantic Canada. Using their model results, storm surge warnings are issued by Environment Canada. The model results have been available since January 2003 for selected locations, one of which is Argentia in Placentia Bay. The web site shows a comparison between predicted and observed storm surge values. The observed storm surge values since January 2003 show that there has been many occasions, when the sea level exceeded the tidal level by more than 0.5 m and two occasions February 2003 and January 2004 when the sea level was approximately 0.9 m and 1.0 m, respectively, above the tidal height.

The tidal heights for various stations in Placentia Bay are presented in Table 1.27, taken from the Canadian Tide and Current Tables (DFO 2007). The tidal heights in Table 1.27 are in reference to chart datum.

Figure 1.45 and Figure 1.46 show the recorded sea level and storm surge heights along with output from the storm surge forecast model for February 2003 and January 2004, respectively.

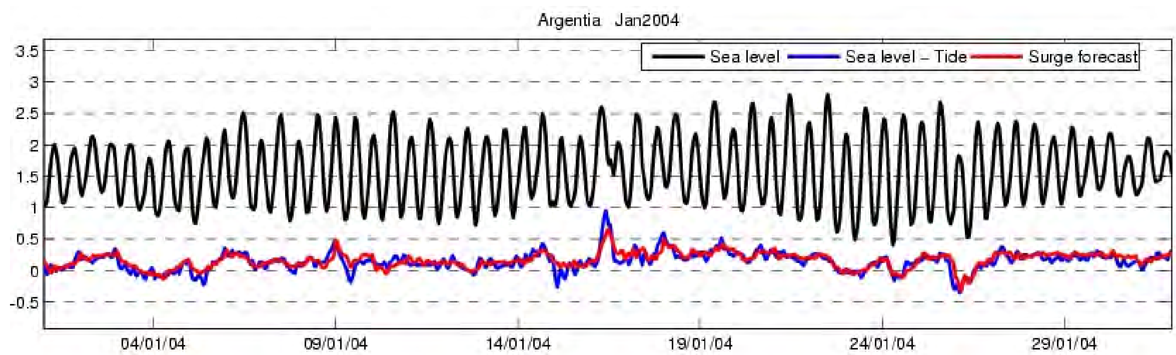
Table 1.27. Placentia Bay Tidal Data.

	Mean Water Level	Range (m)		High Water (m)		Low Water (m)		Recorded Extremes(m)	
Port		Mean Tide	Large Tide	Mean Tide	Large Tide	Mean Tide	Large Tide	Highest High Water	Lowest Low water
Argentia	1.3	1.6	2.5	2.2	2.6	0.6	0.1	3.1	-0.3
Burin		1.5	2.2	2.1	2.1	2.3	2.4		
South East Bight		1.3	2.1	2.0	1.8	2.4	2.2		
Tacks Beach	1.1	1.6	2.4	2.0	2.0	2.1	2.0		
Woody Island	1.2	1.6	2.5	2.1	2.1	2.2	2.1		
North Harbour	1.4	1.7	2.5	2.4	2.3	2.3	2.3		
Come By Chance	1.4	1.6	2.5	2.3	2.3	2.4	2.3		
Arnold's Cove	1.4	1.7	2.5	2.4	2.3	2.3	2.3		
Long Harbour	1.5	1.7	2.7	2.5	2.5	2.4	2.3		
St. Bride's	1.2	1.6	2.5	2.1	2.1	2.1	2.0		



Source: http://eero.ocean.dal.ca:8080/cmep_ca/

Figure 1.45. Plot of Observed Sea Level along with Forecasted and Actual Storm Surge for Argentia, Newfoundland in February 2003.

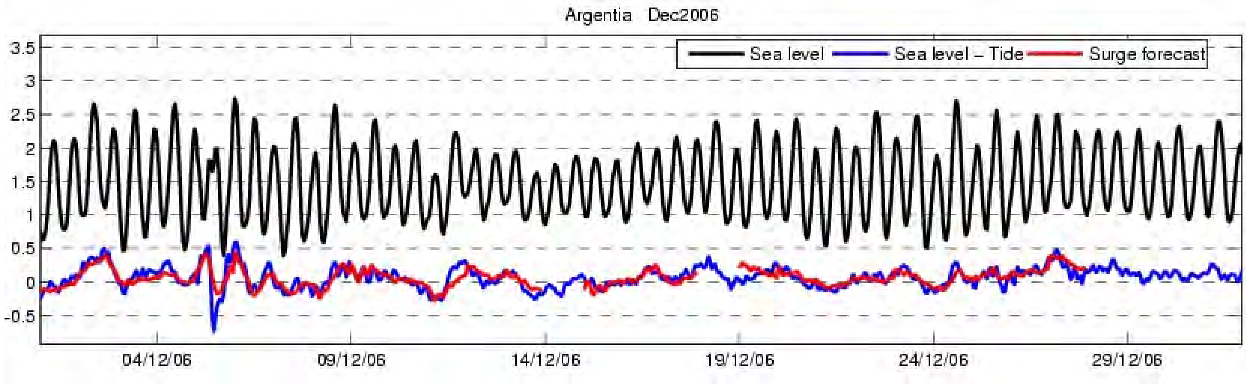


Source: http://eero.ocean.dal.ca:8080/cmep_ca/

Figure 1.46. Plot of Observed Sea Level along with Forecasted and Actual Storm Surge for Argentia, Newfoundland in January 2004.

During the event on January 16, 2004 a low pressure deepened to 951 mb along the south coast of Newfoundland, then moved inland to lie over central Newfoundland by afternoon. This low pressure became slow moving over Newfoundland resulting in a prolonged period of strong to gale force winds from the south to southwest over Placentia Bay. These winds created a storm surge within Placentia Bay near 1.0 m in height resulting in the sea level at Argentia rising to 2.6 m as a result of the combined tidal and storm surge heights.

Negative storm surges associated with offshore winds can result in a pronounced decrease in water level below the astronomical tide level. These events are usually not as pronounced as onshore storm surges, but may be of concern to mariners since they can create unusually shallow water if they occur near the low tide. In December 2006, a negative storm surge of -0.7 metres was recorded at Argentia (Figure 1.47). This negative surge was the result of an intense low pressure system passing west of Placentia Bay. As the system passed, strong to gale force northerly winds were generated over Placentia Bay resulting in offshore winds forcing water out of the bay.



Source: http://eero.ocean.dal.ca:8080/cmep_ca/

Figure 1.47. Plot of Observed Sea Level along with Forecasted and Actual Storm Surge for Argentia, Newfoundland in December 2006.

In the fall of 1999 and 2000, unusual events were observed in coastal areas of eastern Newfoundland, believed to be associated with the passage of tropical storms Jose in 1999 and Helene in 2000 as they moved across the Grand Banks. The waves had a period of tens of minutes and lasted between one and three hours, depending on location. The waves were large enough to cause local flooding and damage to docks and other structures. At Port Rexton in Trinity Bay the peak-to-trough displacement was two to three metres, destroying the local wharf (Mercer et al. 2002). Mercer et al. (2002) attributed the events to be a barotropic wake created by the tropical storms as they moved over the Grand Banks.

A numerical model was created which supported this theory. The model evolved and became part of the operational storm surge model for Atlantic Canada which includes Argentia in Placentia Bay.

1.4. Literature Cited

Bradbury, I.R., P.V.R. Snelgrove, and S. Fraser. 2000. Transport and development of eggs and larvae of Atlantic cod, *Gadus morhua*, in relation to spawning time and location in coastal Newfoundland. Canadian Journal of Fisheries and Aquatic Sciences 57:1761–1772.

Bernier N.B. and K.T. Thompson. 2006. Predicting the frequency of storm surges and extreme sea levels in the northwest Atlantic. Journal of Geophysical Research 111(C10):C10009.

Bursey, J.O., W.J. Sodden, A.D. Gates, and C.L. Blackwood. 1977. The Climate of the Labrador Sea, POAC77, Memorial University of Newfoundland.

Canada, Canadian Ice Service. 2002. Sea Ice Climatic Atlas: East Coast of Canada 1971-2000. Minister of Public Works and Government Services of Canada.

Cardone, V.J., A.T. Cox, and V.R. Sail. 2000. Specification of the Global Wave Climate: Is this the Final Answer? 6th International Workshop on Wave Hind casting and Forecasting, November 6-10, Monterey, California.

Cardone, V.J., H.C. Graber, R.E. Jensen, S. Wassermann, and M.J. Caruso. 1995. In search of the true surface wind field in SWADE IOP-1: Ocean wave modeling perspective. The Global Atmosphere and Ocean System 3:107-150

Colbourne, E. 2000. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average. Canadian Stock Assessment Secretariat. Research Document 2000/49.

Colbourne, E.B. and C. Fitzpatrick. 1994. Temperature, salinity and density at Station 27 from 1978 to 1993. Can. Tech. Rep. Hydrogr. Ocean Sci. 159, 117 p.

DFO. 2007. Canadian Tide and Current Tables, Volume 1 Atlantic Coast and Bay of Fundy, Department of Fisheries and Oceans, Ottawa, Ont.

Hart, D.J., B. de Young and J. Foley. 1999. Observations of Currents, Temperature and Salinity in Placentia Bay, Newfoundland 1998-9. Physics and Physical Oceanography data report; 1999-3. St. John's, NL: Department of Physics and Physical Oceanography, Memorial University of Newfoundland.

Makkonen, L., R.D. Brown, and P.T. Mitten. 1991. Comments on “Prediction of vessel icing for near-freezing sea temperatures”. Weather and Forecasting, 6, 565-567. Minsk, L.D., 1977: Ice Accumulation on Ocean Structures. U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report No. 77-17, 42 p.

Mercer, D., J. Sheng, R.J. Greatbach, and J. Bobanovic. 2002. Barotropic waves generated by storms moving rapidly over shallow water. Journal of Geophysical Research 107(C10):3152.

Minsk, L.D. 1977. Ice accumulation on ocean structures. CRREL Rep.77-17, Cold Regions Research and Engineering Laboratory, Hanover, N.H., 42 p.

National Snow and Ice Data Center (NSIDC). 1995. International Ice Patrol (IIP) iceberg sightings database. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

NOAA. 2006. Historical Hurricane Tracks. NOAA Coastal Services Center. National Oceanic & Atmospheric Administration. 01 August 2006. http://hurricane.csc.noaa.gov/hurricanes/index.htm

Oceans Ltd. 2007. Physical Oceanography Study of Long Harbour for the Commercial Processing Plant. Report prepared for Voisey’s Bay Nickel Company Limited, January 2007.

Oceanweather Inc. 2001. Oceanweather Software Meteorological Oceanographic Study Information System. Software Manual, Oceanweather Inc., 5 River Road, Cos. Cob., CT, 43p.

Overland, J.E. 1990. Prediction of vessel icing for near-freezing sea temperatures. Weather and Climate 5:62-77.

Overland, J.E., C.H. Pease, R.W. Preisendorfer, and A.L. Comiskey. 1986. Prediction of vessel icing. Journal of Climate and Applied Meteorology 25:1793-1806.

Rogers, E. and L.F. Bosart. 1986. An Investigation of Explosively Deepening Oceanic Cyclones. Monthly Weather Review 114:702-718.

Schillinger, D.J., P. Simmons and B. deYoung. 2000. Analysis of the mean circulation in Placentia Bay: spring and summer 1999. Physics and Physical Oceanography data report; 2000-1. St.

John's, NL. Department of Physics and Physical Oceanography, Memorial University of Newfoundland, 2000.

Trites, R.W. 1969. Capacity of Estuary to Accept Pollutants. P. 148-160 *In* Proc. Conf. Pollution, Chem. Inst. Canada, St. Mary's Univ., Halifax, N.S., Aug. 24-26, 1969.

U.S. Geological Survey. 1979. Operating Procedures for the OCS Platform Verification Program. Prepared by the U.S. Geological Survey Conservation Division Branch of Marine Oil and Gas Operations, October 1979.

Winterstein, S.R., T. Ude, C.A. Cornell, P. Jarager, and S. Haver. 1993. Environmental Parameters for Extreme Response: Inverse FORM with Omission Factors. ICOSSar-3, Paper No. 509/11/3, Innsbruck, 3-12 August 1993.