Environmental Assessment of WesternGeco's Southeastern Newfoundland Offshore Seismic Program, 2015–2024

Prepared by

LGL LIMITED
environmental research associates

For

WesternGeco Canada
(Division of Schlumberger Canada Limited)

May 2015
LGL Project No. FA0034

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1.0 Introduction

This document is an Environmental Assessment (EA) of WesternGeco Canada's (WesternGeco) proposed 2015–2024 2-Dimensional (2D), 3-Dimensional (3D), and/or 4-Dimensional (4D) seismic program in the Southeastern Newfoundland Offshore area. The EA is intended to enable the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) to fulfill its responsibilities under Section 138 (1)(b) of the *Canada-Newfoundland Atlantic Accord Implementation Act* and Section 134(1)(b) of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act* (Accord Acts). This EA has been guided by the Final Scoping Document (C-NLOPB 2015), as well as by advice and information received, and issues identified through various communications and consultations with other agencies, interest groups, stakeholders and beneficiaries.

The temporal scope of the Project is a 10-year period (2015 to 2024) with seismic operations potentially occurring between May and November in any given year. The Project Area identified in Figure 1.1 includes the Southern Grand Banks and an area beyond the shelf edge. WesternGeco will be the Operator and may conduct 2D, 3D, and/or 4D seismic surveys in one or more years within the 2015-2024 timeframe.

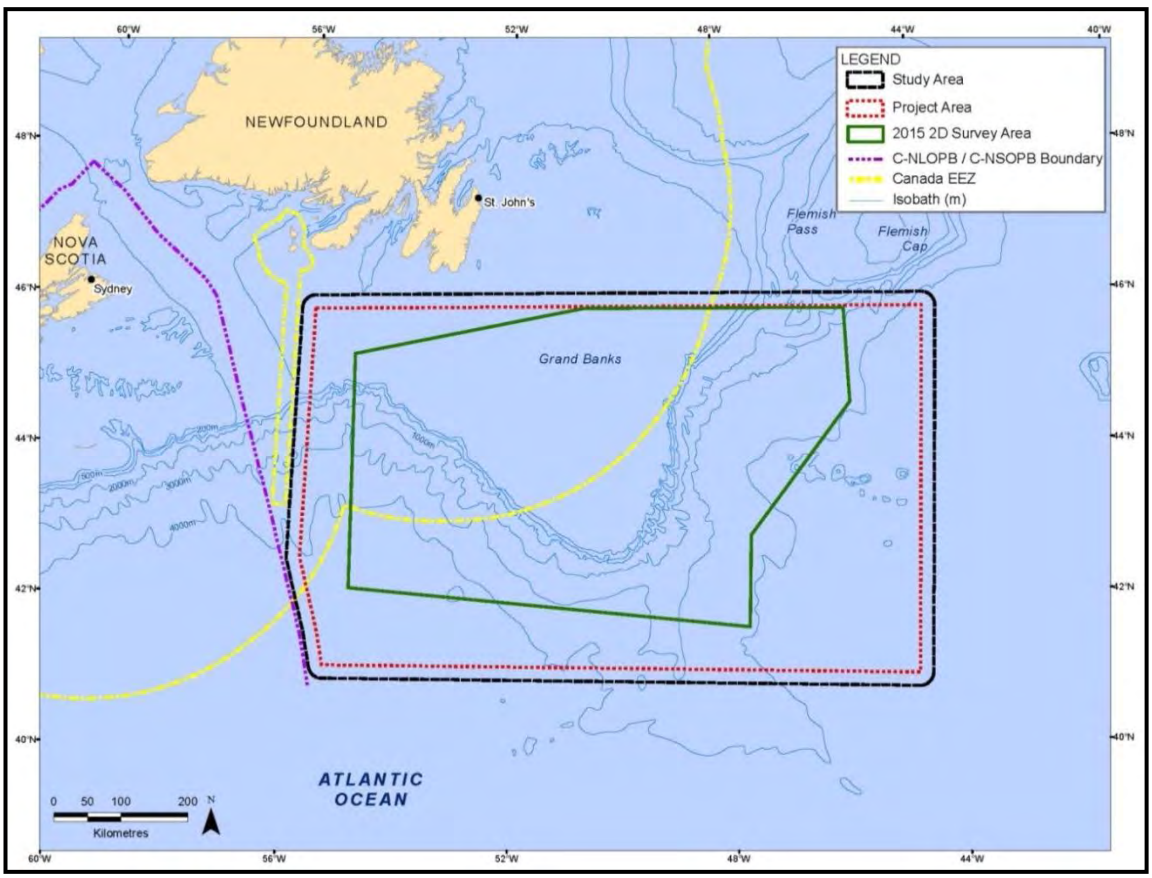

Figure 1.1 Locations of Project Area, Study Area and 2015 2D Survey Area for WesternGeco Canada's Proposed Southeastern Newfoundland Offshore Seismic Program, 2015-2024.

1.1 Relevant Legislation and Regulatory Approvals

An *Authorization to Conduct a Geophysical Program* will be required from the C-NLOPB. The C-NLOPB is mandated by the Accord Acts. Pursuant to the Accord Acts, the C-NLOPB is responsible for seeking to identify the federal departments or agencies that may have expertise required in the completion of the assessment. Because seismic survey activities have the potential to affect seabirds, marine mammals, sea turtles, and fish and fisheries, Fisheries and Oceans Canada (DFO) and Environment Canada (EC) are the agencies that have most involvement in the EA process. Legislation that is relevant to the environmental aspects of the Project includes:

- *Canada-Newfoundland Atlantic Accord Implementation Act*;
- *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*;
- *Oceans Act*;
- *Fisheries Act*;
- *Navigable Waters Act*;
- *Canada Shipping Act*;
- *Migratory Birds Convention Act*;
- *Species at Risk Act (SARA)*; and
- *Canadian Environmental Protection Act*.

WesternGeco will follow guidelines issued by the C-NLOPB, the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012), which include DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*. The Project will also follow other relevant advice received during the consultations for this Project.

1.2 The Operator

WesternGeco, the world's largest seismic company, provides advanced acquisition and data processing services. WesternGeco's parent company, Schlumberger, employs approximately 120,000 people, representing over 140 nationalities, working in more than 85 countries. WesternGeco Canada has offices in Calgary, Alberta and Halifax, Nova Scotia, as well as a Project Office in St. John's, Newfoundland and Labrador. WesternGeco Canada employs 60 permanent, full time Canadians in its regional offices, and many more on its vessels.

1.3 Canada-Newfoundland and Labrador Benefits

In full appreciation of the requirements of the Accord Acts, WesternGeco is committed to providing maximum benefits associated with East Coast operations to Canadians, and in particular, to Newfoundland and Labrador individuals and companies where they are commercially competitive in accordance with WesternGeco's requirements.

WesternGeco will manage the operations for these surveys from St. John's, Newfoundland and Labrador. WesternGeco supports the principle that first consideration be given to personnel, support and other services that can be provided within Newfoundland and Labrador, and to goods manufactured in Newfoundland and Labrador, where such goods and services can be delivered at a high standard of Health, Safety and Environmental competency, be of high quality and are competitive in terms of fair market price. Contractors and subcontractors working for WesternGeco in Newfoundland and Labrador must also apply these principles in their operations.

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2.0 Project Description

The official name of the Project is the Southeastern Newfoundland Offshore Seismic Program, 2015-2024. WesternGeco is proposing to conduct one or more 2D, 3D, and/or 4D seismic surveys within its proposed Project Area (see Figure 1.1) between 2015 and 2024, starting as early as July 2015. The timing of the surveys is subject to WesternGeco priorities and circumstances, weather conditions, contractor availability and regulatory approvals.

2.1 Spatial and Temporal Boundaries

The proposed Project Area includes space to account for ship turning and streamer deployment (see Figure 1.1). The areas of the Study and Project areas are 554,043 km^2 and 495,044 km^2, respectively. The Study Area does not overlap with either Nova Scotia waters or St. Pierre et Miquelon waters. More than half of the Study Area and Project Area is located outside of Canada's Exclusive Economic Zone (EEZ) (200 nm limit). Water depths in the Project Area range from <100 m to >5,000 m.

The "corner" coordinates (decimal degrees, WGS84 projection) of the extents of the Project Area are as follow:

- Northwest: 46.067°N, 55.809°W;
- West: 42.772°N, 55.827°W;
- Southwest: 41.287°N, 55.343°W;
- Southeast: 41.098°N, 44.667°W; and
- Northeast: 46.008°N, 44.112°W.

The 2D seismic survey area for 2015, with an area of 289, 914 km^2, is also shown in Figure 1.1.

The "corner" coordinates (decimal degrees, WGS84 projection) of the extents of the 2015 2D Survey Area are as follow:

- Northwest: 45.491°N, 55.003°W;
- Southwest: 42.340°N, 54.935°W;
- South: 41.849°N, 47.719°W;
- Southeast: 43.064°N, 47.573°W;
- East: 44.790°N, 45.611°W;
- Northeast: 46.051°N, 45.618°W; and
- North: 46.165°N, 50.626°W.

The temporal boundaries of the proposed Project Area are between 1 May and 30 November, from 2015-2024. The maximum duration of a seismic survey in any given year is 210 days. In 2015, the seismic survey is anticipated to require 120 to 150 days.

2.2 Project Overview

The proposed Project is a ship-borne geophysical program that includes approximately 21,000 km of 2D seismic survey lines for 2015. Data acquisition plans for 2D, 3D and/or 4D surveys during 2016-2024 are not yet determined.

For the proposed 2D survey in 2015, the seismic survey vessel would most likely be the MV *WG Tasman* (see Section 2.2.6 for more details) or a similar vessel. The seismic survey vessel(s) used during subsequent 2D/3D/4D surveys are unknown at present but will be approved for operation in Canadian waters and will be typical of the worldwide fleet. Details on airgun arrays and streamers are provided below.

The C-NLOPB's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012) will be used as the basis for the marine mammal monitoring and mitigation program for the seismic surveys. Dedicated Marine Mammal Observers (MMOs) will monitor for marine mammals and sea turtles and implement mitigation measures as appropriate. The airgun array will be ramped up, and ramp ups will be delayed if a marine mammal or sea turtle is detected within the appropriate safety zone (minimum of 500 m as noted in DFO's *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment*). The airgun array will be shut down any time an Endangered or Threatened (as listed on Schedule 1 of *SARA*) marine mammal or sea turtle is detected within the safety zone. These measures are designed to minimize disturbance to marine life, particularly marine mammals and species considered at risk under the *SARA*. In addition, the MMOs will conduct a monitoring and release program for seabirds which may strand on board Project vessels. A Fisheries Liaison Officer (FLO) provided by the Fish, Food and Allied Workers (FFAW) will be on board the seismic vessel to ensure implementation of communication procedures intended to minimize conflict with the commercial fishery.

2.2.1 Objectives and Rationale

The primary objective of the Project is to determine the presence and likely locations of geological structures that might contain hydrocarbon deposits. Existing seismic data in the area do not provide sufficient quality or coverage to serve the needs of the energy companies in their exploration, development and production activities. Acquisition of more 2D/3D/4D seismic data is required to provide images of higher resolution and quality that will reduce the possibility of unnecessary drilling activity.

2.2.2 Project Phases

The Project will have two phases. The actual timing of these activities within the temporal scope will be dependent on economic feasibility, vessel availability and results of data interpretation of survey work from preceding phases.

1. Phase 1 will include a 2D survey in 2015 in the Project Area (see Figure 1.1); and
2. Phase 2 may include 2D, 3D and/or 4D seismic surveys in the Project Area, depending on the results of analyses of existing and acquired data.

2.2.3 Project Scheduling

The seismic surveys will be conducted between 1 May and 30 November of any given year from 2015 to 2024. The estimated duration of the proposed 2015 survey is approximately 120 to 150 days.

2.2.4 Site Plans

In 2015, it is planned that approximately 21,000 km of 2D seismic data will be acquired. Most 2D seismic survey lines will be orientated in a grid pattern. Survey line lengths are anticipated to range in length from approximately 50 to 600 km.

2.2.5 Personnel

A typical seismic vessel can accommodate ~35-60 personnel. Personnel on a seismic vessel include ship's officers and marine crew as well as technical and scientific personnel. The seismic vessel will also have a FLO and MMOs on board. All project personnel will have all of the required certifications as specified by the relevant Canadian legislation and the C-NLOPB.

2.2.6 Seismic Vessel

In 2015, WesternGeco will likely use the MV *WG Tasman* or a similar vessel as the seismic vessel. The MV *WG Tasman* (Figure 2.1) was built in Dubai in 2010 and is registered in Cyprus. The vessel is 89.8 m long, 21 m wide and has a mean draft of 6.0 m. The vessel is equipped with six Wartsila engines and has a maximum cruising speed of 14.5 knots. It is also equipped with a helideck.

For seismic surveys in 2016-2024, vessel specifics will be provided once the vessel has been identified.

2.2.7 Seismic Energy Source Parameters

The proposed 2D survey sound source will consist of one or two airgun arrays, each 5,085 in^3 in total volume, which will operate at towed depths between 6 and 15 m. If two airgun arrays are used, they will not be operated simultaneously but in a "flip-flop" arrangement. The array will be operated with compressed air at pressures of 2000 psi, producing an approximate peak-to-peak pressure value that is between 104 and 141 bar-m, depending on which source filter is used by WesternGeco.

Detailed specifications of the airgun array will be provided once the project design is completed and parameters are selected.

Figure 2.1 MV *WG Tasman.*

2.2.8 Seismic Streamers

In 2015, the 2D seismic survey vessel will tow a single solid streamer that is 8,000-12,000 m in length at a depth of 10-45 m. In subsequent 2D, 3D and/or 4D seismic surveys (2016-2024), streamer equipment specifications will be provided when program design is complete. The solid streamers will be deployed at depths ranging from 10-45 m. As many as 16 streamers may be towed during a 3D or 4D seismic survey.

2.2.9 Logistics/Support

2.2.9.1 Vessels

Primary support and supply will be provided by chartered vessels. During the 2015 2D seismic survey, it is anticipated that one local picket vessel will accompany the seismic vessel. The guard vessel will be used to scout ahead of the seismic vessel for fishing vessels and gear, as well as for hazards such as ice and floating debris. A supply vessel will also regularly be present during the program.

2.2.9.2 Helicopters

The seismic vessel will be equipped with a helicopter deck. Helicopters are often used for crew changes and light re-supply. It is not known at this time whether helicopters or vessel-to-vessel transfers will be used for crew changes during seismic program(s) in 2016-2024. WesternGeco will not do port calls during the program.

2.2.9.3 Shore Base, Support and Staging

WesternGeco will have a shore representative based in St. John's for the duration of seismic programs. No new shore base facilities will be established as part of the Project.

2.2.10 Waste Management

Waste management will be consistent with industry best practices offshore Newfoundland and Labrador.

2.2.11 Air Emissions

Air emissions will be those associated with standard operations for marine vessels, including the seismic vessel and any potential picket and/or supply vessel.

2.2.12 Accidental Events

In the unlikely event of the accidental release of hydrocarbons during the Project, the measures outlined in WesternGeco's oil spill response plan will be implemented. The oil spill response plan will be filed with the C-NLOPB. In addition, WesternGeco will have an emergency response plan in place.

2.3 Mitigation and Monitoring

Project mitigations are detailed in this EA and follow the guidelines outlined in the *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*. Mitigation procedures will include ramp-ups, implementation of ramp-up delays and airgun array shutdowns for designated marine mammal and sea turtle species, use of dedicated MMOs and FLOs, and a fisheries compensation program. In addition, the MMOs will conduct a monitoring (systematic seabird counts based on protocols issued by the Canadian Wildlife Service [CWS]) and release program for seabirds which may strand on board Project vessels.

2.4 Project Site Information

Project location is in the southeastern Newfoundland offshore area (see Figure 1.1).

2.4.1 Environmental Features

The physical and biological environments of the general area have been described in the recently completed Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014), as well as an EA of the southern Grand Banks area prepared for Multi Klient Invest AS (MKI; LGL 2014a). Sections 3.0 and 4.0 of this EA provide a review of the physical and biological environments, respectively.

2.4.1.1 Physical Environment and Potential Effects on the Project

As indicated above, descriptions of the general physical environment of the Study Area are contained in the Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014) and an EA of the southern Grand Banks area prepared for MKI (LGL 2014a). The seismic surveys could be conducted in areas with water depth ranging from <100 m to >5,000 m. Extreme wind, wave and ice conditions can slow or even halt survey operations, and accidents are more likely to occur during extreme conditions than during calm conditions. The scheduling of 2D, 3D and/or 4D seismic surveys during a period (May to November) when NW Atlantic operating conditions are relatively good compared to the late fall/winter/early spring period, should lessen the risk of any potential effects of the environment on the Project.

A summary of the potential effects of the physical environment on the Project, based on information in the Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014), the MKI EA (LGL 2014a), and any new available information, is provided in Section 5.6.

2.4.1.2 Biological Environment

Considering the size of the Study Area for the proposed Project, the biological environment within it is varied and complex. The description of the biological environment is presented in Section 4.0 on the basis of Valued Environmental Components (VECs), which include the following:

- Fish and fish habitat;
- Fisheries;
- Marine-associated birds;
- Marine mammals and sea turtles;
- Species at risk; and
- Sensitive areas.

The potential effects of routine Project activities as well as accidental events (such as an unplanned hydrocarbon release) associated with Project activities are assessed in this EA. Cumulative effects on the VECs are also considered in this EA. Other marine users typically considered in the discussion on cumulative effects includes fishing, cargo and passenger vessels, other oil industry-related vessels, transport and military vessels, or other commercial work.

2.5 Consultations

During preparation of the EA, WesternGeco consulted with stakeholders with an interest in the Project. Those consulted and the results of those consultations are presented in Section 5.1.1 and Appendix 1.

In order to assist in scoping the effects assessment and mitigation plan, and to aid in addressing any issues of concern, WesternGeco consulted with the following stakeholders:

- Fisheries and Oceans Canada (DFO);
- Environment Canada (EC);
- Nature Newfoundland and Labrador (NNL) (and various member organizations);
- One Ocean;
- Fish, Food and Allied Workers Union (FFAW)/Unifor;
- Association of Seafood Producers (ASP);
- Ocean Choice International (OCI);
- Groundfish Enterprise Allocation Council (GEAC) Ottawa;
- Canadian Association of Prawn Producers;
- Clearwater Seafoods;
- Icewater Fisheries; and
- Newfound Resources Ltd. (NRL).

2.6 Effects of the Project on the Environment

The proposed Project will be well within the scope of other seismic programs routinely conducted offshore Newfoundland and elsewhere in eastern Canada, and is not expected to produce adverse significant environmental effects on the marine environment in or adjacent to the Project Area. Nonetheless, potential environmental effects are examined in detail with focus on the VECs listed above (Section 2.4.1.2) and the cumulative effects associated with other marine users.

2.7 Environmental Monitoring

MMOs will be on board the vessel(s) to monitor for and implement mitigation measures specific to marine mammals and sea turtles, and to collect opportunistic data on marine mammal behaviour and distribution with and without airguns operating. Information on marine-associated bird occurrence and distribution will also be collected during the seismic surveys.

3.0 Physical Environment

The Final Scoping Document (C-NLOPB 2015) required that the EA include a review of the meteorological and oceanographic characteristics of the Study Area, including extreme conditions, in order to provide a basis for assessing the effects of the environment on the Project. The physical environment of the Study Area has been described in the Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014). A review of the physical environment is provided below, with updated information from LGL (2014).

3.1 Bathymetry and Geology

The bathymetry within the Study Area ranges from just under 100 m to >5,000 m, and more than half of the Study Area is characterized by water depths exceeding 500 m. A substantial portion of the Study Area contains a grouping of banks including the Grand Bank, Whale Bank, Green Bank, and St. Pierre Bank, collectively known as the Grand Banks of Newfoundland. A large portion of the bank areas are found at depths up to 200 m. The majority of these areas are between 51 to 100 m depths, with the exception of portions of the St. Pierre Bank and the Southeast Shoal of the Grand Bank, which are <50 m. The continental slope waters in the southern and eastern regions of the Grand Banks reach depths > 1,000 m. The Grand Bank is deeply incised with submarine canyons along the southern and southeastern areas (e.g., Carson Canyon, Lilly Canyon). The submarine canyons run down off the continental slope into the Newfoundland Basin, which has depths of 2,000 to 4,000 m. The eastern region of the Study Area includes the Newfoundland Basin and Newfoundland Seamounts. The western region of the Study Area is bordered by the Laurentian Channel, but contains two smaller channels, Halibut Channel, situated between St. Pierre Bank and Green Bank, and Haddock Channel, situated between Green Bank and Whale Bank. The southern region of the Study Area includes the tail of the Grand Banks and the deep water to the south of the Banks.

The surficial geology of the Southern Grand Banks has been discussed in LGL (2009a,b) and subsequently summarized in the Southern Newfoundland SEA (C-NLOPB 2010). Unconsolidated Quaternary sediments deposited during and subsequent to the Wisconsinian glaciations lie above the Tertiary and older bedrock. Five surficial sedimentary formations are recognized within the SEA area: (1) Grand Banks Drift, (2) Downing Silt, (3) Adolphus Sand, (4) Placentia Clay, and (5) Grand Banks Sand and Gravel. See Section 4.2.1.2 for further details.

3.2 Climatology

Every marine seismic survey program is influenced by weather conditions both from routine operational and environmental safety perspectives. During routine activities, data quality can be affected by weather, particularly wind and wave conditions. This section provides a general overview of climatic conditions in the Study Area, including wind, waves, temperature, precipitation, visibility, and weather systems, with a more detailed description of extreme events.

The wind and wave climatology of the Study Area was prepared using the MSC50 hindcast wind and wave database for the North Atlantic (C-NLOPB 2014; LGL 2014a). The analyses were carried out using five grid points to represent the Study Area: grid point 05000 in the Laurentian Sub-Basin; grid point 08026 on the Southern Grand Banks; grid point 03889 on the Tail of the Banks; grid point 11154 in the Newfoundland Basin; and grid point 10537 in the deep water south of the Grand Banks (Table 3.1, Figure 3.1). The MSC50 data set was determined to be the most representative of the available data sets, as it provides a continuous 57-year period of hourly data for the Study Area. Continuous wind and wave hindcast data for grid points 05000 and 08026 are one-hour time steps from January 1954 to December 2010 (LGL 2014a). Hindcast data for grid point 03889 are one-hour time steps from January 1954 to December 2011 (C-NLOPB 2014). Hindcast data for grid points 11154 and 10537 are three-hour time steps from January 1954 to December 2010 (LGL 2014a).

Table 3.1 MSC50 Grid Point Locations.

Region	Grid Point	Latitude	Longitude
Laurentian Sub-Basin	05000	43.5°N	54.5°W
Southern Grand Banks	08026	45.0°N	50.0°W
Tail of the Banks	03889	43.0°N	50.0°W
Newfoundland Basin	11154	44.0°N	45.0°W
Deep Water South	10537	41.5°N	47.0°W

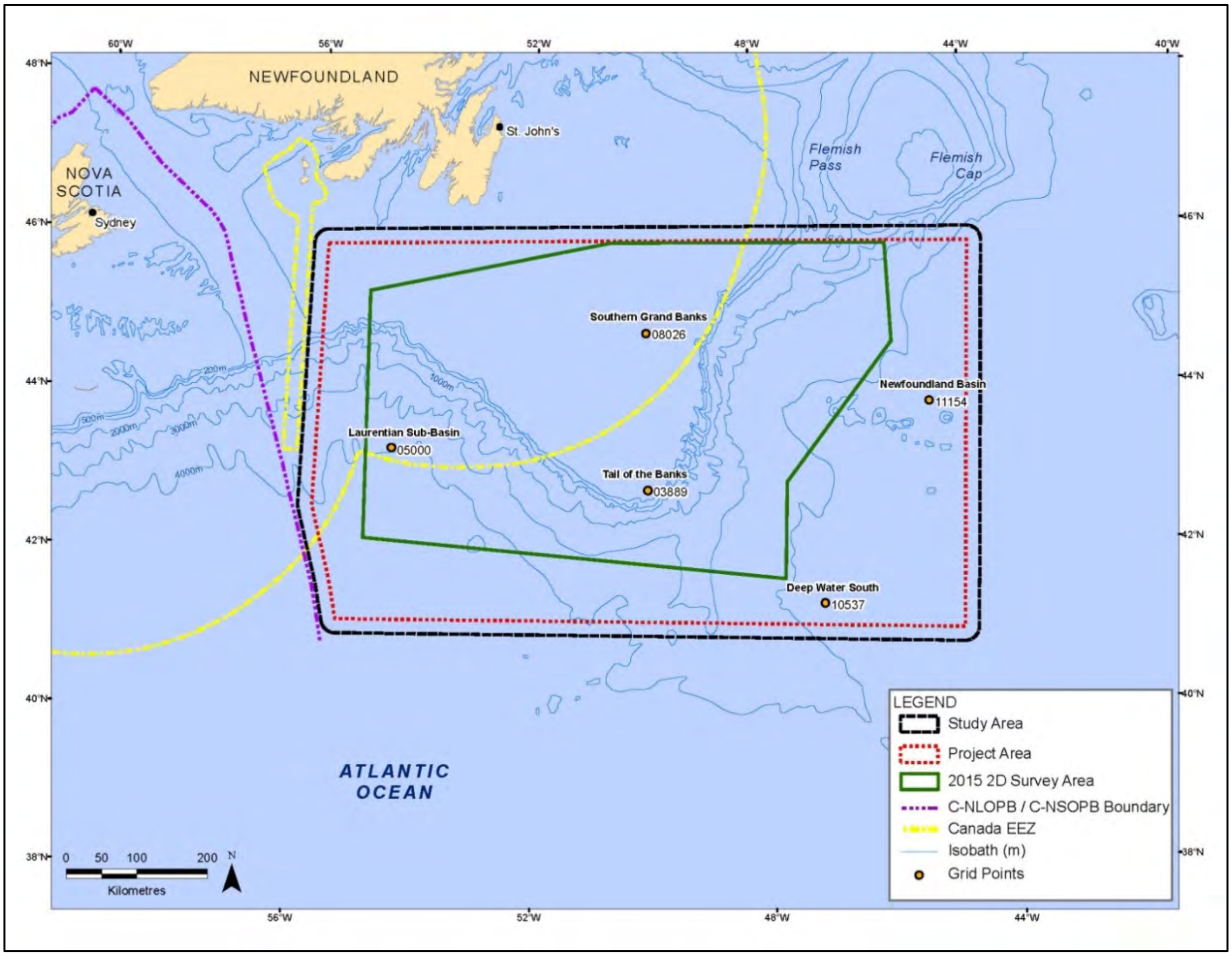
Data on air temperature, sea surface temperature, visibility, and precipitation was compiled using the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). A subset of global marine surface observations from ships, drilling rigs, and buoys in the Study Area, covering the period from January 1980 to September 2013 was used in the analyses for the Laurentian Sub-Basin, the Southern Grand Banks, the Newfoundland Basin, and the deep water south of the Grand Banks (LGL 2014a). A subset of observations covering the period from January 1950 to December 2012 was used in the analysis for the Tail of the Banks (C-NLOPB 2014).

3.2.1 Wind

Low pressure systems crossing south of Newfoundland are more intense during the winter months, and thus wind speeds tend to peak during this season. Mean hourly wind speeds for grid points within the Study Area are presented in Table 3.2. Mean wind speeds are highest during January/February in all regions. From May to November, the highest mean wind speeds occur during November and the lowest during July, ranging from 9.1 to 10.1 m/s and 5.8 to 6.3 m/s, respectively.

3.2.2 Waves

The wave climate south of Newfoundland is dominated by extratropical storms (discussed in Section 3.2.5), primarily during October through March. Tropical storms may occur during the early summer and early winter, but most often occur from late August through October. Hurricanes are generally reduced to tropical or post-tropical storms by the time they reach the Study Area, but may still produce gale force winds and high waves. The majority of wave energy in the Study Area comes from the southwest to south-southwest.



Sources: C-NLOPB 2014; LGL 2014a.

Figure 3.1 Location of MSC50 Grid Points and Regions used in the Physical Environment Analyses.

Wave conditions are described by significant wave height and maximum wave height (described below), as well as peak spectral period and characteristic period. Significant wave height is defined as the average height of one-third of the highest waves. Its value roughly approximates the characteristic height observed visually. Significant wave heights for grid points within the Study Area are presented in Table 3.3. From May to November, the highest waves occur during November and the lowest during July in all regions, ranging from 3.1 to 3.4 m and 1.6 to 1.7 m, respectively.

Maximum wave height is defined as the greatest vertical distance between a wave crest and adjacent trough. Maximum wave heights for grid points within the Study Area are presented in Table 3.4. From May to November, the most severe sea states occur during September in the Laurentian Sub-Basin (05000) and the Newfoundland Basin (11154) and November on the Southern Grand Banks (08026), on the Tail of the Banks (03889), and in the deep water south of the Grand Banks (10537).

Table 3.2 Mean Hourly Wind Speed Statistics for Offshore Southeastern Newfoundland.

Month	Mean Wind Speed (m/s)				
	Laurentian Sub-Basin (05000)	Southern Grand Banks (08026)	Tail of the Grand Banks (03889)	Newfoundland Basin (11154)	Deep Water South (10537)
January	11.2	10.4	10.3	10.8	11.2
February	11.2	10.3	10.3	10.8	11.2
March	10.3	9.3	9.4	10.0	10.2
April	9.0	8.0	8.3	8.9	9.0
May	7.5	6.6	6.9	7.4	7.6
June	6.8	6.2	6.2	6.8	7.0
July	6.3	5.8	5.7	6.1	6.2
August	6.7	6.1	5.9	6.3	6.5
September	7.9	7.1	7.1	7.3	7.6
October	9.1	8.3	8.2	8.4	8.9
November	10.1	9.1	9.1	9.5	9.7
December	11.2	10.1	10.1	10.5	10.9

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.3 Significant Wave Height Statistics for Offshore Southeastern Newfoundland.

Month	Significant Wave Height (m)				
	Laurentian Sub-Basin (05000)	Southern Grand Banks (08026)	Tail of the Grand Banks (03889)	Newfoundland Basin (11154)	Deep Water South (10537)
January	4.0	3.8	3.9	4.2	4.3
February	3.9	3.7	3.8	4.2	4.3
March	3.5	3.2	3.4	3.7	3.7
April	2.9	2.7	2.8	3.1	3.1
May	2.2	2.1	2.2	2.3	2.3
June	1.9	1.8	1.8	1.9	2.0
July	1.7	1.6	1.6	1.7	1.7
August	1.8	1.7	1.7	1.8	1.8
September	2.3	2.2	2.3	2.3	2.4
October	2.8	2.8	2.8	2.8	2.9
November	3.3	3.1	3.2	3.3	3.4
December	4.0	3.7	3.8	4.0	4.0

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.4 Maximum Wave Height Statistics for Offshore Southeastern Newfoundland.

Month	Maximum Wave Height (m)				
	Laurentian Sub-Basin (05000)	Southern Grand Banks (08026)	Tail of the Grand Banks (03889)	Newfoundland Basin (11154)	Deep Water South (10537)
January	14.1	14.1	12.0	13.1	15.4
February	13.3	12.8	13.3	12.6	14.1
March	12.6	12.3	12.6	13.2	13.1
April	11.2	10.7	11.5	11.3	10.2
May	10.2	7.9	8.5	9.5	9.2
June	9.7	8.2	8.7	8.0	7.7
July	6.7	7.0	5.9	8.3	7.1
August	10.1	9.4	9.7	9.7	7.9
September	13.0	11.0	10.9	12.5	11.3
October	12.7	10.8	11.9	9.7	12.0
November	11.8	11.1	12.1	11.8	12.0
December	12.6	12.6	13.3	13.7	12.9

Sources: C-NLOPB 2014; LGL 2014a.

3.2.3 Wind and Wave Extreme Value Analysis

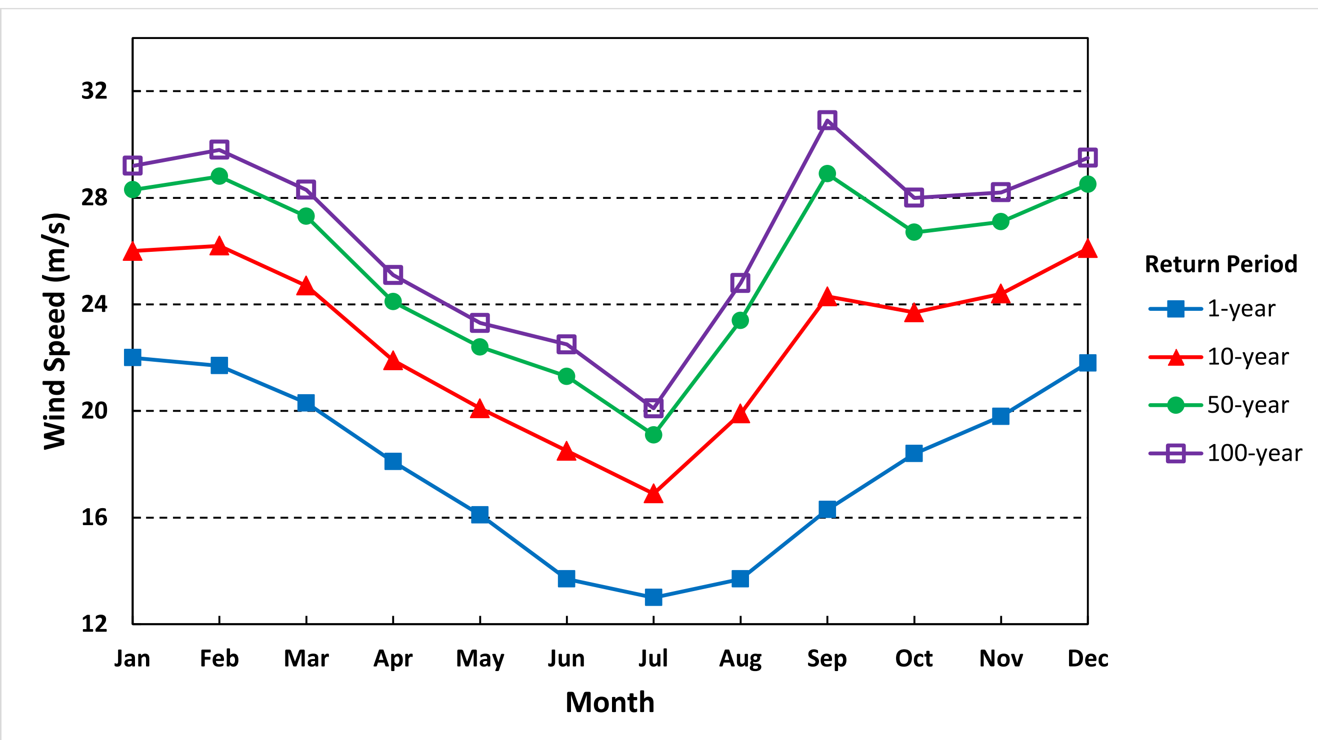
An analysis of extreme wind and waves was performed using five grid points already indicated to represent the Study Area (see Table 3.1, Figure 3.1). The extreme value analysis was based on the Gumbel distribution, to which data were fitted using the peak-over threshold method for grid points 05000, 08026, 11154, and 10537 (LGL 2014a) and the maximum likelihood method for grid point 03889 (C-NLOPB 2014).

3.2.3.1 Extreme Value Estimates for Winds from the Gumbel Distribution

The extreme value estimates for wind were calculated using Oceanweather's Osmosis software for return periods of 1-year, 10-years, 50-years, and 100-years. A storm with a return period of 100 years means that the calculated extreme wind speed will occur once every 100 years, averaged over a long period of time. The analysis used hourly mean wind speeds for a reference height of 10 m above sea level (C-NLOPB 2014, LGL 2014a). The calculated monthly extreme 1-hour wind speed estimates for grid points within the Study Area are presented in Figures 3.2 to 3.6. The calculated annual 100-year extreme 1-hour wind speed ranged from 30.8 to 34.0 m/s, and was determined to be 31.8 m/s for the Laurentian Sub-Basin (05000), 32.3 m/s for the Southern Grand Banks (08026), 34.0 m/s for the Tail of the Banks (03889), 30.8 m/s for the Newfoundland Basin (11154) and 31.0 m/s for the deep water south of the Grand Banks (10537). From May to November, the highest 100-year extreme 1-hour wind speeds occur during September in the Laurentian Sub-Basin (05000), on the Southern Grand Banks (08026), in the Newfoundland Basin (11154), and in the deep water south of the Grand Banks (10537), and during November on the Tail of the Banks (03889), while the lowest occur during June on the Southern Grand Banks (08026) and in the deep water south of the Grand Banks (10537) and during July in the Laurentian Sub-Basin (05000), on the Tail of the Banks (03889), and in the Newfoundland Basin (11154).

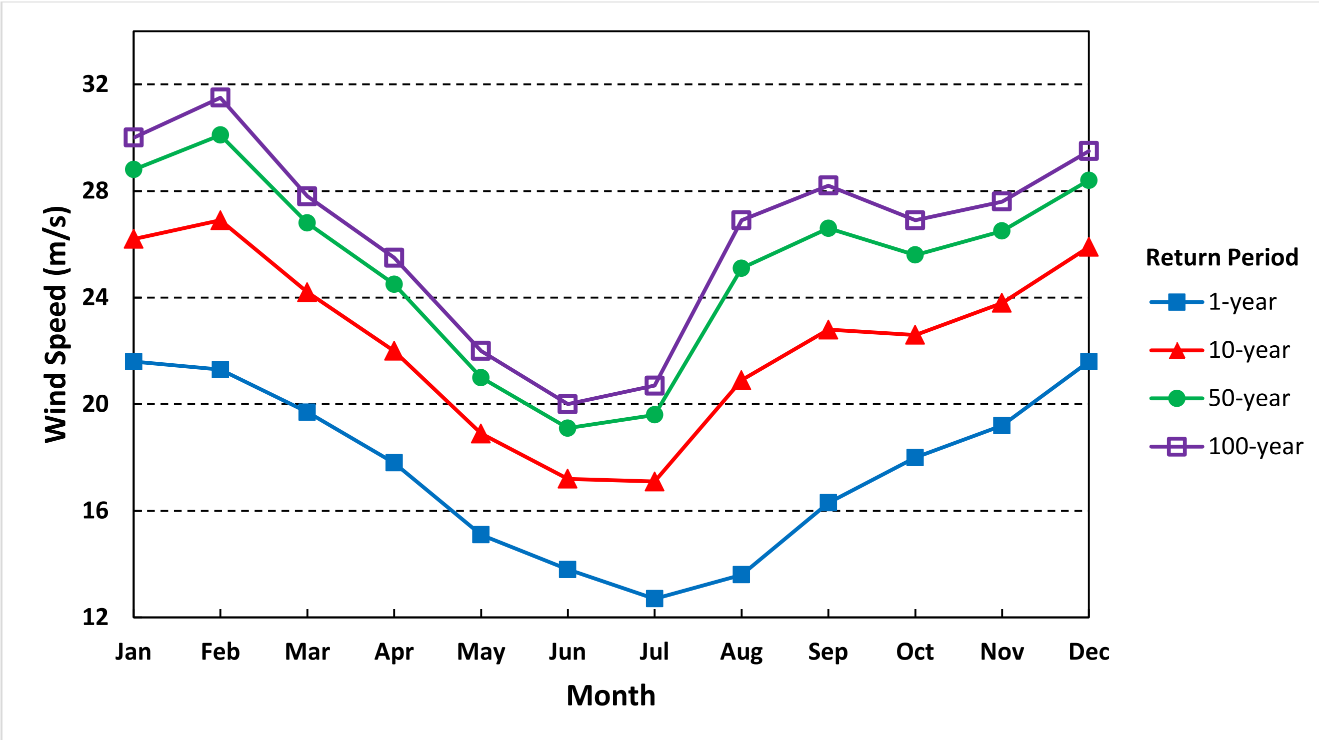
3.2.3.2 Extreme Value Estimates for Waves from a Gumbel Distribution

The monthly extreme value estimates for significant wave height for return periods of 1-year, 10-years, 50-years, and 100-years for grid points within the Study Area are presented in Figures 3.7 to 3.11. A storm with a return period of 100 years means that the calculated significant wave height will occur once every 100 years, averaged over a long period of time. The calculated annual 100-year extreme significant wave height ranged from 14.1 to 15.0 m, and was determined to be 14.6 m for the Laurentian Sub-Basin (05000), 14.1 m for the Southern Grand Banks (08026), 14.7 m for the Tail of the Banks (03889), 14.8 m for the Newfoundland Basin (11154), and 15.0 m for the deep water south of the Grand Banks (10537). From May to November, the highest extreme significant wave heights occur during November at all grid points, while the lowest extreme significant wave heights occur during July at all grid points.



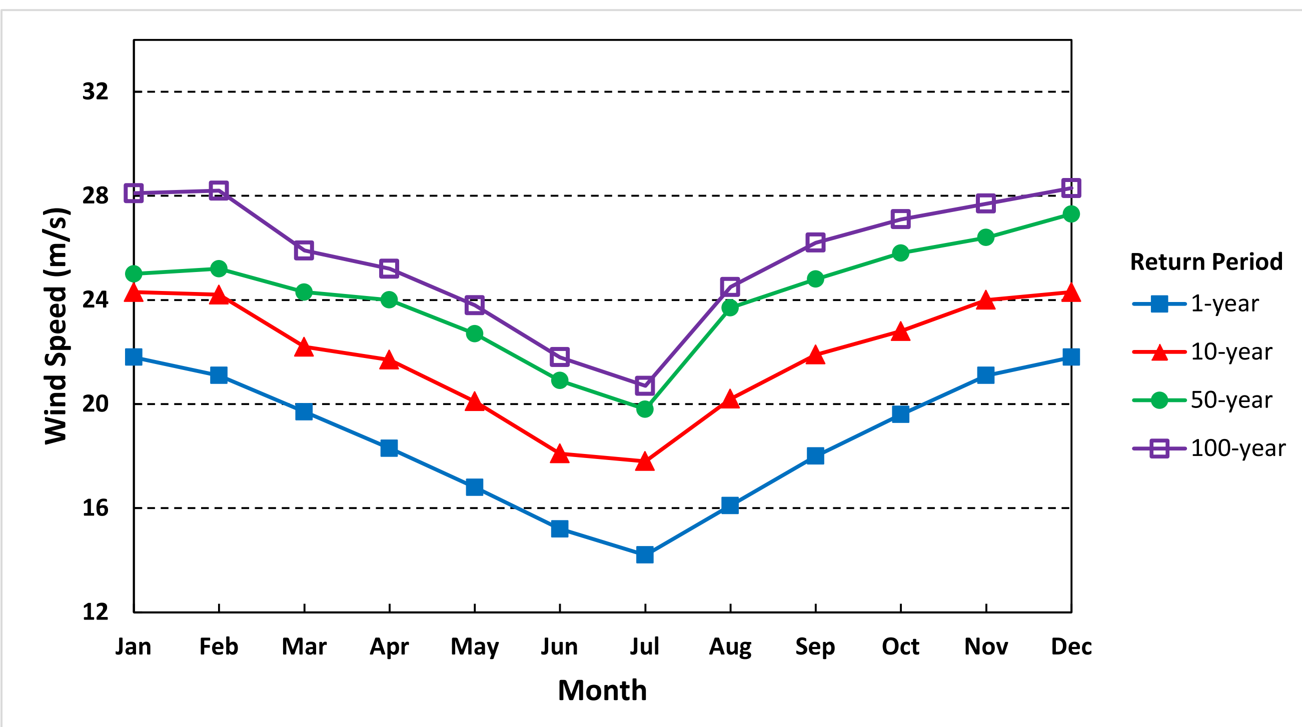
Sources: LGL 2014a.

Figure 3.2 Extreme 1-hour Wind Speed Estimates for the Laurentian Sub-Basin (05000).



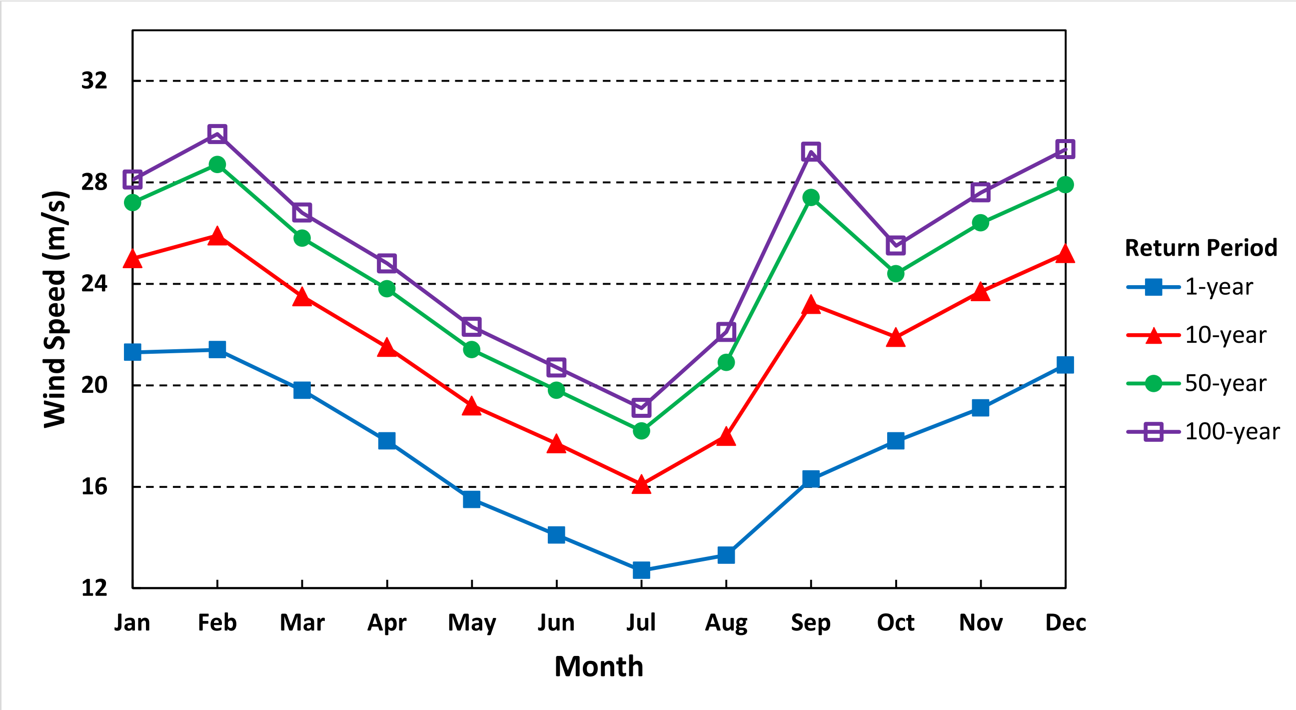
Sources: LGL 2014a.

Figure 3.3 Extreme 1-hour Wind Speed Estimates for the Southern Grand Banks (08026).



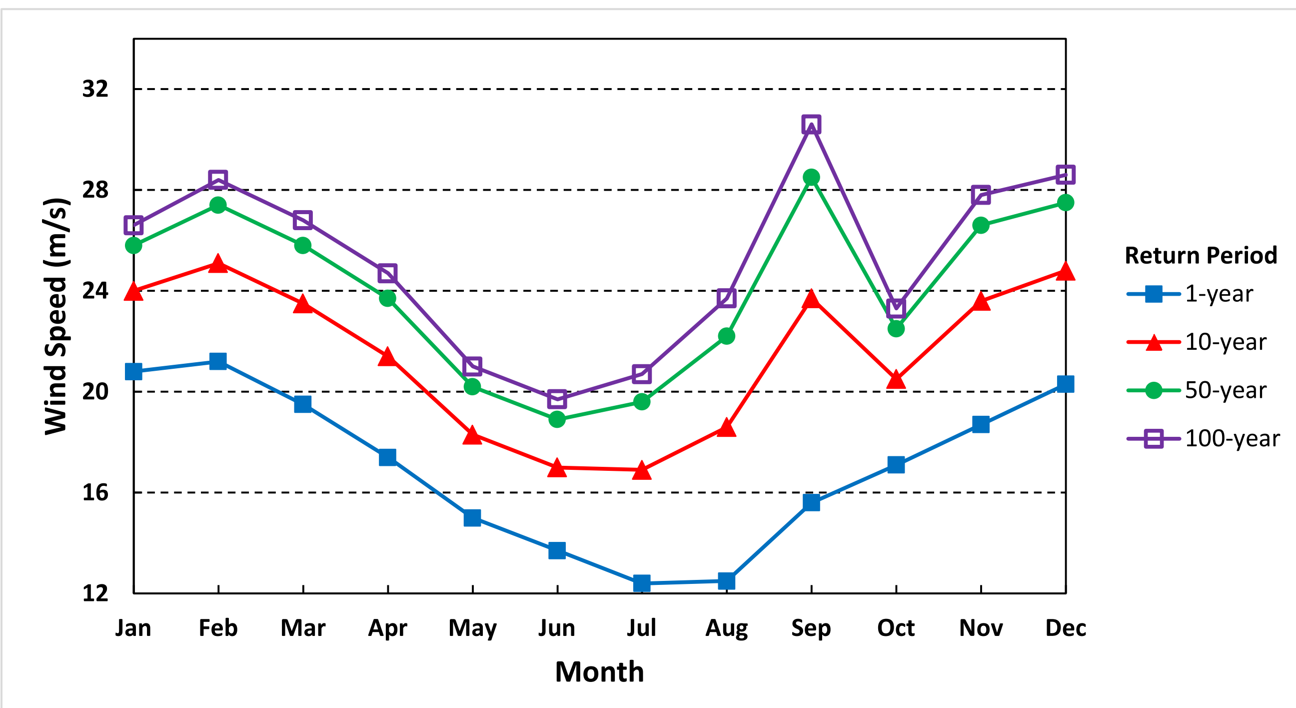
Sources: C-NLOPB 2014.

Figure 3.4 Extreme 1-hour Wind Speed Estimates for the Tail of the Banks (03889).



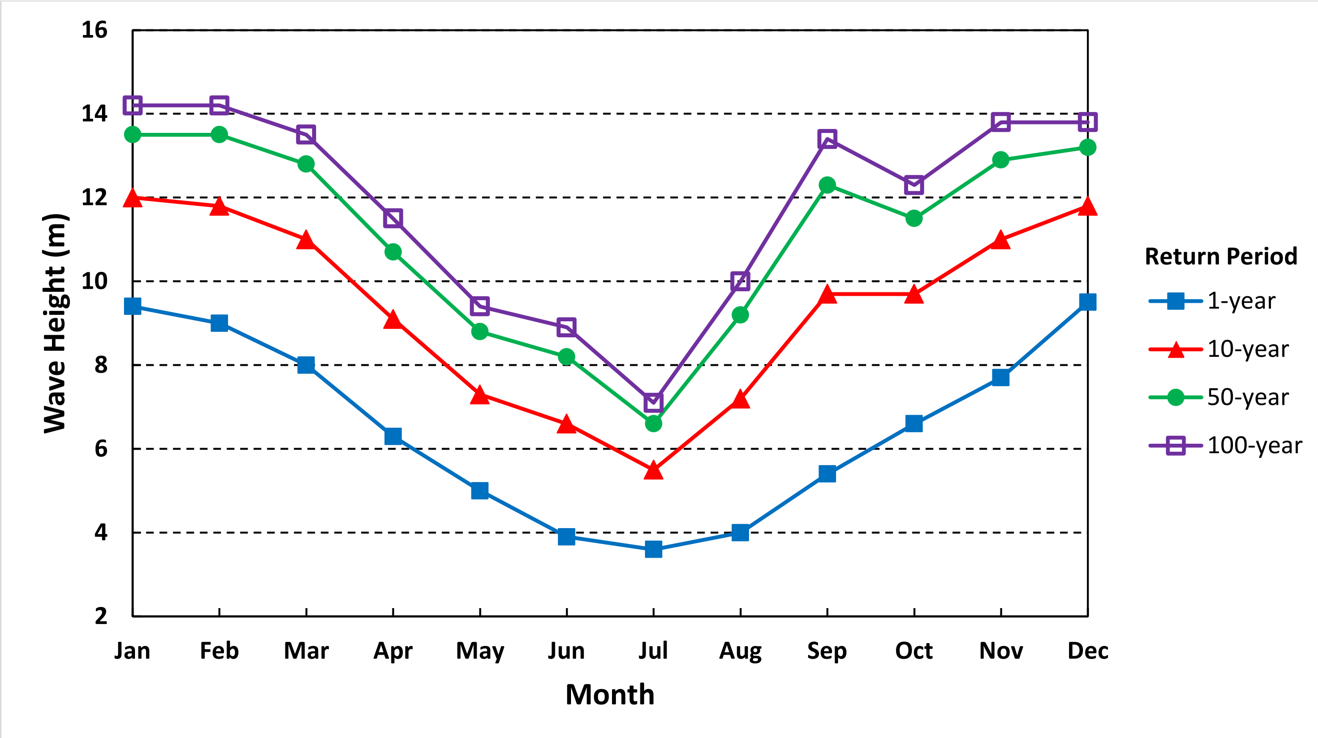
Sources: LGL 2014a.

Figure 3.5 Extreme 1-hour Wind Speed Estimates for the Newfoundland Basin (11154).



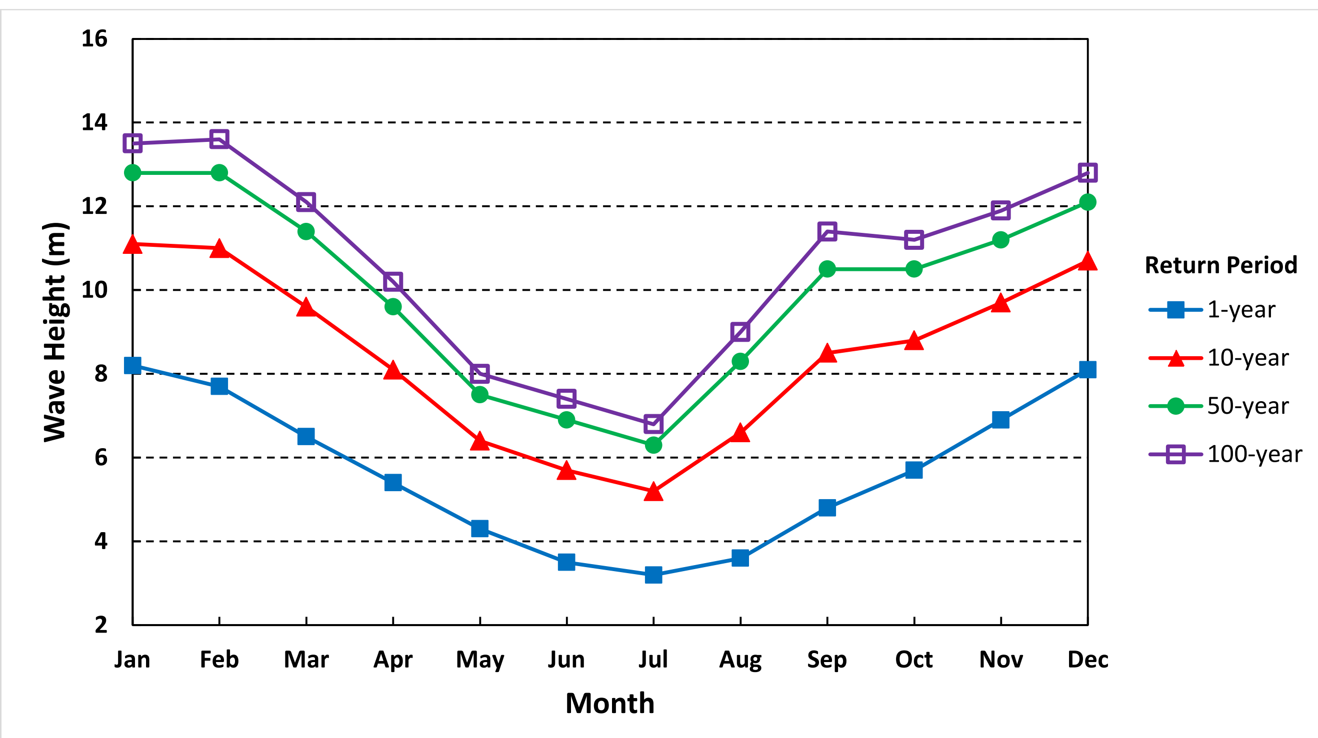
Sources: LGL 2014a.

Figure 3.6 Extreme 1-hour Wind Speed Estimates for the Deep Water South of the Grand Banks (10537).



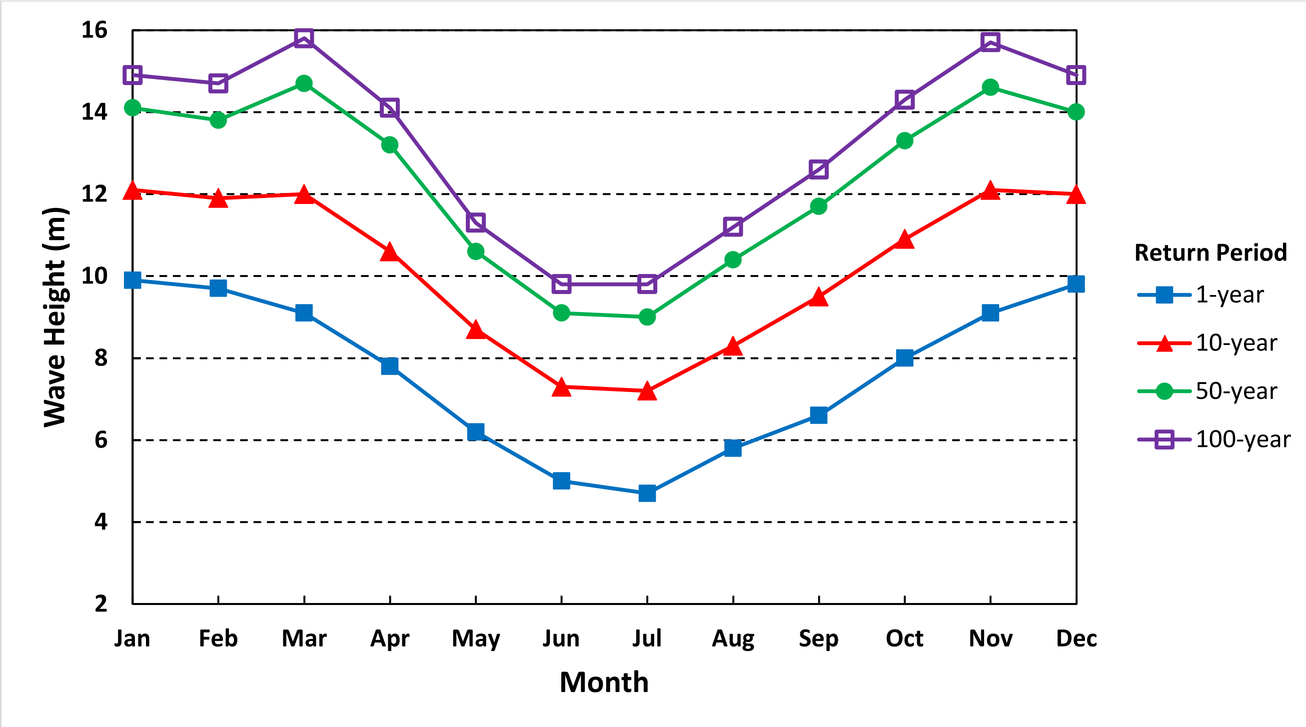
Sources: LGL 2014a.

Figure 3.7 Extreme Significant Wave Height Estimates for the Laurentian Sub-Basin (05000).



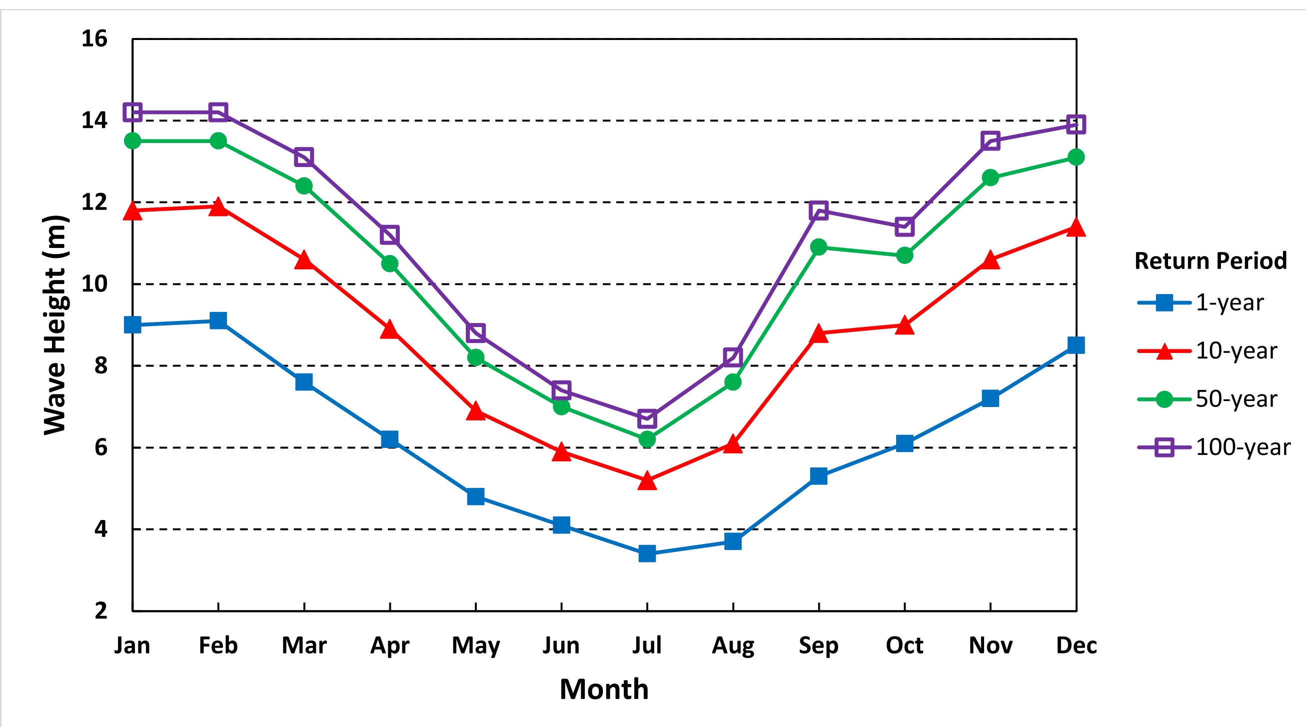
Sources: LGL 2014a.

Figure 3.8 Extreme Significant Wave Height Estimates for the Southern Grand Banks (08026).



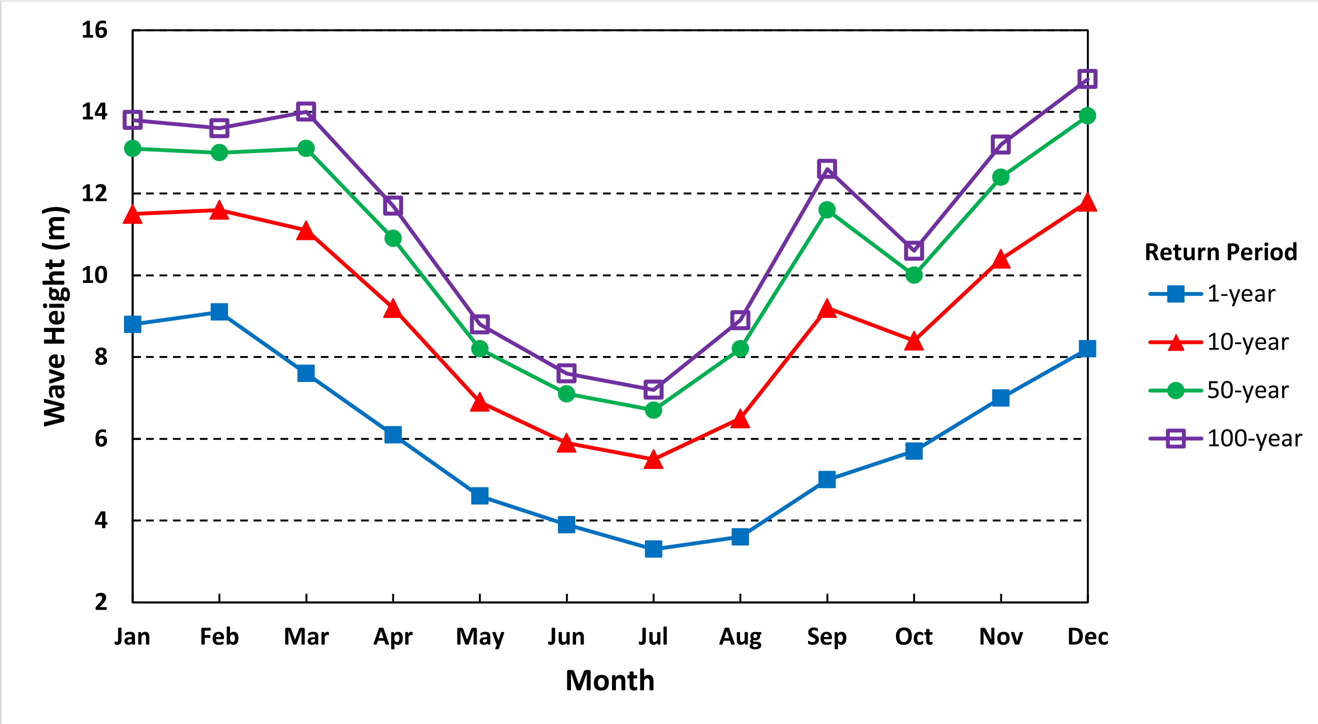
Sources: C-NLOPB 2014.

Figure 3.9 Extreme Significant Wave Height Estimates for the Tail of the Grand Banks (03889).



Sources: LGL 2014a.

Figure 3.10 Extreme Significant Wave Height Estimates for the Newfoundland Basin (11154).



Sources: LGL 2014a.

Figure 3.11 Extreme Significant Wave Height Estimates for the Deep Water South of the Grand Banks (10537).

3.2.4 Weather Variables

3.2.4.1 Temperature

The moderating influence of the ocean serves to limit both the diurnal and the annual temperature variation on the Grand Banks. Diurnal temperature variations due to the day/night cycles are very small. Short-term, random temperature changes are due mainly to a change of air mass following a warm or cold frontal passage. In general, air mass temperature contrasts across frontal zones are greater during the winter than during the summer months. Air and sea surface temperatures for each region (see Figure 3.1) were extracted from the ICOADS data set (C-NLOPB 2014, LGL 2014a). Mean monthly air temperatures and sea surface temperatures for the Study Area are presented in Tables 3.5 and 3.6, respectively, and are the mean of all recorded temperatures for a particular region during that month.

The temperature data indicate that the atmosphere is warmest during August and coldest during February in all regions. Sea surface temperature is warmest during August and coldest during February/March in all regions. Air and sea surface temperatures in the deep water south of the Grand Banks are warmer than the other four regions due to the location of the Gulf Stream.

Table 3.5 Mean Monthly Air Temperatures for Offshore Southeastern Newfoundland.

Month	Air Temperature (ºC)				
	Laurentian Sub-Basin	Southern Grand Banks	Tail of the Grand Banks	Newfoundland Basin	Deep Water South
January	1.9	2.3	5.3	6.4	9.6
February	0.8	1.3	4.7	6.0	9.2
March	1.4	2.0	5.5	6.8	9.7
April	4.0	3.9	7.2	9.6	11.4
May	6.9	6.2	9.5	11.1	14.0
June	10.6	9.9	12.3	13.6	17.0
July	16.0	15.4	16.7	17.6	21.2
August	18.3	17.7	18.9	18.7	22.1
September	16.2	15.6	16.8	17.1	20.1
October	12.3	12.5	13.4	14.0	17.1
November	8.6	8.0	10.4	11.2	13.7
December	4.8	5.1	7.5	8.5	11.0

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.6 Mean Monthly Sea Surface Temperatures for Offshore Southeastern Newfoundland.

Month	Sea Surface Temperature (ºC)				
	Laurentian Sub-Basin	Southern Grand Banks	Tail of the Grand Banks	Newfoundland Basin	Deep Water South
January	4.3	3.6	10.9	11.7	13.2
February	3.2	2.5	10.3	10.2	12.7
March	2.9	2.2	10.2	9.9	12.9
April	3.7	2.8	11.8	9.9	13.2
May	6.1	5.2	13.1	11.8	14.6
June	10.3	8.9	15.2	14.0	17.1
July	15.3	14.5	19.2	17.5	21.1
August	18.3	17.9	21.1	20.3	22.9
September	17.0	17.1	20.1	18.8	21.5
October	13.4	13.0	17.9	16.3	19.0
November	10.0	8.9	15.8	14.9	17.1
December	7.0	6.0	12.8	13.2	14.7

Sources: C-NLOPB 2014; LGL 2014a.

3.2.4.2 Precipitation

Precipitation may occur in three forms, classified as liquid, freezing, or frozen. Included in these classifications are:

- Liquid Precipitation
  - Drizzle
  - Rain
- Freezing Precipitation
  - Freezing Drizzle
  - Freezing Rain
- Frozen Precipitation
  - Snow
  - Snow Pellets
  - Snow Grains
  - Ice Pellets
  - Hail
  - Ice Crystals

The migratory high and low pressure systems transiting the middle latitudes of the Northern Hemisphere result in a variety of precipitation types. The frequency of occurrence of each precipitation type was calculated as a percentage of the total monthly and annual weather observations from the ICOADS data set, with each occurrence counting as one event. The frequencies of occurrence of precipitation types for regions within the Study Area are presented in Tables 3.7 to 3.11.

Most of the observed precipitation events are in the form of rain or snow. From May to November, the monthly occurrence of rain events is lowest during July and highest during October and November. The minimum frequency of snow events occurs from May to November, ranging from 0.1 to 4.1%, and is lowest during the summer months. Other types of precipitation, such as freezing rain/drizzle, mixed rain/snow, and hail, occur less frequently than rain or snow. Thunderstorms occur infrequently over the Study Area, although there is a year-round potential of occurrence. In general, thunderstorms are most frequent during the summer months.

Table 3.7 Frequency of Occurrence of Precipitation for the Laurentian Sub-Basin.

Month	Frequency of Occurrence (%)					
	Rain/Drizzle	Freezing Rain/Drizzle	Rain/Snow Mixed	Snow	Hail	Thunder Storm
January	10.9	0.4	1.8	25.2	0.2	0.2
February	9.8	0.7	2.2	23.8	0.1	0.1
March	11.5	0.5	1.0	14.4	0.2	0.2
April	14.0	0.1	0.5	4.7	0.1	0.1
May	11.4	0.0	0.0	0.8	0.0	0.2
June	14.4	0.0	0.0	0.4	0.1	0.3
July	9.5	0.0	0.0	0.3	0.1	0.4
August	13.4	0.0	0.1	0.2	0.1	0.7
September	15.6	0.0	0.1	0.5	0.1	0.3
October	19.7	0.0	0.2	0.7	0.1	0.2
November	20.0	0.0	1.1	4.1	0.6	0.2
December	15.1	0.1	1.8	13.0	0.4	0.3
Annual	13.7	0.2	0.7	6.7	0.2	0.3

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.8 Frequency of Occurrence of Precipitation for the Southern Grand Banks.

Month	Frequency of Occurrence (%)					
	Rain/Drizzle	Freezing Rain/Drizzle	Rain/Snow Mixed	Snow	Hail	Thunder Storm
January	12.5	0.2	1.4	12.3	0.0	0.2
February	11.6	0.4	1.5	15.4	0.4	0.4
March	12.4	0.4	0.9	10.9	0.2	0.2
April	12.8	0.1	0.4	4.0	0.0	0.1
May	13.5	0.0	0.2	0.9	0.0	0.0
June	11.1	0.0	0.0	0.4	0.0	0.1
July	8.6	0.0	0.0	0.1	0.0	0.3
August	11.9	0.0	0.1	0.4	0.1	0.5
September	16.4	0.0	0.0	0.3	0.0	0.3
October	17.5	0.0	0.1	0.6	0.1	0.4
November	15.7	0.0	0.7	2.5	0.3	0.4
December	16.8	0.0	0.8	8.6	0.2	0.1
Annual	13.3	0.1	0.5	4.3	0.1	0.3

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.9 Frequency of Occurrence of Precipitation for the Tail of the Banks.

Month	Frequency of Occurrence (%)					
	Rain/Drizzle	Freezing Rain/Drizzle	Rain/Snow Mixed	Snow	Hail	Thunder Storm
January	11.3	0.1	0.8	3.3	0.6	0.2
February	11.1	0.2	0.7	4.7	0.5	0.1
March	10.5	0.1	0.5	2.9	0.5	0.1
April	10.6	0.1	0.4	1.0	0.4	0.3
May	9.0	0.0	0.1	0.3	0.3	0.2
June	6.7	0.0	0.1	0.2	0.3	0.3
July	5.6	0.0	0.1	0.1	0.6	0.6
August	6.6	0.0	0.1	0.1	0.1	0.2
September	7.8	0.0	0.1	0.1	0.1	0.1
October	9.2	0.0	0.1	0.1	0.2	0.2
November	11.0	0.0	0.2	0.3	0.2	0.2
December	12.2	0.0	0.4	1.6	0.5	0.1
Annual	9.0	0.1	0.3	1.1	0.4	0.2

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.10 Frequency of Occurrence of Precipitation for the Newfoundland Basin.

Month	Frequency of Occurrence (%)					
	Rain/Drizzle	Freezing Rain/Drizzle	Rain/Snow Mixed	Snow	Hail	Thunder Storm
January	19.6	0.0	1.6	7.9	1.4	0.4
February	19.9	0.2	1.6	9.0	1.0	0.5
March	20.2	0.0	1.0	6.8	0.9	0.3
April	16.7	0.0	0.3	1.9	0.3	0.1
May	15.1	0.0	0.1	0.8	0.0	0.3
June	14.3	0.0	0.1	0.7	0.0	0.2
July	10.5	0.0	0.1	0.3	0.1	0.4
August	14.5	0.0	0.1	0.2	0.1	0.5
September	17.1	0.0	0.1	0.5	0.0	0.4
October	19.7	0.0	0.1	0.4	0.2	0.5
November	21.2	0.0	0.3	1.6	0.8	0.6
December	23.8	0.0	1.1	4.3	1.4	0.7
Annual	17.5	0.0	0.5	2.9	0.5	0.4

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.11 Frequency of Occurrence of Precipitation for the Deep Water South of the Grand Banks.

Month	Frequency of Occurrence (%)					
	Rain/Drizzle	Freezing Rain/Drizzle	Rain/Snow Mixed	Snow	Hail	Thunder Storm
January	26.7	0.0	0.7	2.6	0.5	1.0
February	24.5	0.0	0.9	3.5	0.5	1.0
March	22.8	0.0	0.5	2.4	0.6	1.1
April	21.4	0.0	0.4	1.3	0.2	1.1
May	17.0	0.0	0.2	0.7	0.1	0.6
June	16.0	0.0	0.1	0.9	0.0	0.7
July	12.7	0.0	0.1	0.7	0.1	1.3
August	15.5	0.0	0.1	0.5	0.1	2.3
September	14.9	0.0	0.1	0.7	0.2	1.2
October	19.6	0.0	0.1	0.5	0.1	0.9
November	23.4	0.0	0.2	0.9	0.5	0.9
December	26.4	0.0	0.3	1.8	0.7	0.9
Annual	19.6	0.0	0.3	1.3	1.1	0.3

Sources: C-NLOPB 2014; LGL 2014a.

3.2.4.3 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); and
- Blowing Snow.

The frequency distributions of visibility states from the ICOADS data set for each region within the Study Area are presented in Tables 3.12 to 3.16. The visibility states have been defined as very poor (less than 0.5 km for the Tail of the Banks (C-NLOPB 2014) and less than 1 km for all other regions), poor (0.5 to 2 km for the Tail of the Banks (C-NLOPB 2014) and 1 – 2 km for all other regions), fair

(2 to 10 km), and good (greater than 10 km). Annually, the Southern Grand Banks has the highest occurrence of reduced visibility, with poor to very poor visibility (less than 2 km) occurring 23.9% of the time, followed by the Laurentian Sub-Basin (18.5%), and the Tail of the Banks (16.4%). In these regions, visibility is poorest during July, with poor to very poor visibility occurring 47.7% of the time on the Southern Grand Banks, 36.1% in the Laurentian Sub-Basin, and 32.6% on the Tail of the Banks. There is less seasonal variation in visibility in both the Newfoundland Basin and the deep water south of the Grand Banks.

During the winter months, the main obstruction is snow, although mist and fog may also reduce visibility at times. As spring approaches, the reduction in visibility attributed to snow decreases. As air temperature increases, the occurrence of advection fog also increases. Advection fog which forms when warm moist air moves over cooler waters may persist for days or weeks. By April, the sea surface temperature south of Newfoundland is cooler than the surrounding air, and the presence of advection fog increases from April through July. The month of July has the highest percentage of obscuration to visibility, most of which is in the form of advection fog, although frontal fog may also contribute to the reduction in visibility. During August, the temperature difference between the air and the sea begins to narrow and by September, the air temperature begins to fall below the sea surface temperature and the occurrence of fog decreases. During the May to November period, October has the lowest occurrence of reduced visibility since the air temperature has, on average, decreased below the sea surface temperature, but it is not cold enough for snow. Reduction in visibility during autumn and winter is relatively low and is mainly attributed to the passage of low pressure systems. The influence of advection fog is mainly noticed in the Laurentian Sub-Basin and the Southern Grand Banks since the other regions experience a warmer climate.

Table 3.12 Frequency of Occurrence of Visibility States for the Laurentian Sub-Basin.

Month	Frequency of Occurrence (%)			
	Very Poor (<1 km)	Poor (1 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
January	6.5	3.3	19.3	70.9
February	9.5	3.9	21.1	65.4
March	11.1	3.2	15.6	70.1
April	21.2	4.1	14.7	60.0
May	28.5	3.8	11.3	56.3
June	30.6	3.6	12.1	53.7
July	33.0	3.1	13.2	50.8
August	16.6	2.4	13.6	67.3
September	7.3	1.6	11.7	79.4
October	5.4	1.5	11.3	81.7
November	7.9	2.0	14.0	76.0
December	5.6	2.2	16.1	76.0
Annual	15.6	2.9	14.3	67.2

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.13 Frequency of Occurrence of Visibility States for the Southern Grand Banks.

Month	Frequency of Occurrence (%)			
	Very Poor (<1 km)	Poor (1 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
January	9.0	2.4	17.3	71.3
February	13.0	3.4	18.5	85.1
March	14.2	3.3	14.9	67.6
April	25.7	4.0	14.3	56.0
May	32.6	4.3	13.2	49.8
June	37.4	3.0	12.3	47.3
July	44.4	3.3	13.1	39.2
August	22.2	3.0	12.9	61.9
September	13.6	2.3	12.8	71.3
October	8.5	2.0	11.2	78.3
November	11.4	2.8	12.0	73.8
December	9.1	2.9	16.5	71.5
Annual	20.8	3.1	14.0	62.2

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.14 Frequency of Occurrence of Visibility States for the Tail of the Banks.

Month	Frequency of Occurrence (%)			
	Very Poor (<0.5 km)	Poor (0.5 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
January	4.0	4.2	42.0	49.8
February	4.1	4.7	41.3	49.9
March	5.1	4.9	38.5	51.5
April	9.4	6.8	38.5	45.3
May	14.5	8.6	34.9	42.0
June	20.7	11.4	32.8	35.1
July	21.6	11.0	32.1	35.3
August	10.6	6.6	35.2	47.7
September	5.1	4.0	33.0	57.9
October	4.0	4.5	33.8	57.8
November	5.2	4.5	37.3	53.0
December	3.8	4.1	40.6	51.5
Annual	9.8	6.6	36.2	47.4

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.15 Frequency of Occurrence of Visibility States for the Newfoundland Basin.

Month	Frequency of Occurrence (%)			
	Very Poor (<1 km)	Poor (1 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
January	2.9	2.0	16.9	78.2
February	4.5	1.8	17.5	76.2
March	4.3	1.8	15.5	78.4
April	8.6	1.8	14.3	75.4
May	12.8	2.6	13.0	71.7
June	16.9	2.6	13.8	66.7
July	22.1	2.7	14.1	61.1
August	11.1	1.7	12.1	75.0
September	5.1	1.4	10.6	82.9
October	3.4	1.5	10.9	84.3
November	4.3	1.6	12.7	81.5
December	3.2	1.7	15.5	79.6
Annual	8.5	1.9	13.9	75.7

Sources: C-NLOPB 2014; LGL 2014a.

Table 3.16 Frequency of Occurrence of Visibility States for the Deep Water South of the Grand Banks.

Month	Frequency of Occurrence (%)			
	Very Poor (<1 km)	Poor (1 – 2 km)	Fair (2 – 10 km)	Good (>10 km)
January	1.6	1.0	14.9	82.4
February	1.8	1.3	15.3	81.6
March	2.3	1.2	14.1	82.5
April	4.8	1.5	13.6	80.0
May	5.3	1.4	11.6	81.7
June	5.3	1.3	13.6	79.7
July	5.1	1.2	12.0	81.8
August	1.7	0.6	7.7	89.9
September	1.3	0.6	7.5	90.5
October	1.3	0.6	8.5	89.6
November	1.5	1.0	9.4	88.2
December	1.5	0.9	12.8	84.8
Annual	3.1	1.1	11.8	84.0

Sources: C-NLOPB 2014; LGL 2014a.

3.2.5 Weather Systems

The area south of Newfoundland experiences weather conditions typical of a marine environment, with the surrounding waters having a moderating effect on temperature. In general, marine climates experience cooler summers and milder winters than continental climates and have a much smaller annual temperature range. Furthermore, a marine climate tends to be fairly humid, resulting in reduced visibilities, low cloud heights, and significant amounts of precipitation.

The climate south of Newfoundland is very dynamic, being largely governed by the passage of high and low pressure circulation systems. These circulation systems are embedded in and steered by the prevailing westerly flow that typifies the upper levels of the atmosphere in the mid-latitudes and arises because of the normal tropical to polar temperature gradient. The mean strength of the westerly flow is a function of the intensity of this gradient, and as a consequence is considerably stronger in the winter months than during the summer months, due to an increase in the south to north temperature gradient. [Meteorological convention defines seasons by quarters; e.g., winter is December, January, February, etc.]

During the winter months, an upper level trough tends to lie over central Canada and an upper ridge over the North Atlantic, resulting in three main storm tracks affecting the region: (1) one from the Great Lakes Basin; (2) one from Cape Hatteras, North Carolina; and (3) one from the Gulf of Mexico. These storm tracks, on average, bring eight low pressure systems per month over the area. The intensity of these systems ranges from relatively weak features to major winter storms. With increasing solar radiation during spring, there is a general warming of the atmosphere that is relatively greater at higher latitudes. This decreases the north-south temperature contrast, lowers the kinetic energy of the westerly flow aloft, and decreases the potential energy available for storm development. By summer, the main storm tracks have moved further north than in winter, and storms are less frequent and much weaker. During the summer months, with low pressure systems normally passing to the north of the region, in combination with the northwest sector of the sub-tropical high to the south, the prevailing wind direction across the Grand Banks is from the southwest to south. Wind speed is lower during the summer, and gale or storm force winds are relatively infrequent. There is also a corresponding decrease in significant wave heights.

Frequently, intense low pressure systems become ‘captured’ and slow down or stall off the coast of Newfoundland and Labrador. This may result in an extended period of little change in conditions that may range, depending on the position, overall intensity, and size of the system, from 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. Sometimes explosively deepening oceanic cyclones develop into a “weather bomb”; defined as a storm that undergoes central pressure decreases greater than 24 mb over 24 hours. Typical features of weather bombs include 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. After development, these systems will either move across Newfoundland or near the southeast coast producing gale to storm force winds from the southwest to south over the Study Area.

In addition to extratropical cyclones, tropical cyclones often retain their tropical characteristics as they enter the Study Area. Tropical cyclones account for the strongest sustained surface winds observed anywhere on earth. The hurricane season in the North Atlantic Basin normally extends from June through November, although tropical storm systems occasionally occur outside this period. Once formed, a tropical storm or hurricane will maintain its energy as long as a sufficient supply of warm, moist air is available. These systems typically move east to west over the warm water of the tropics; however, some of these systems turn northward, moving towards Newfoundland and the Orphan Basin. Since the capacity of the air to hold water vapour is dependent on temperature, as the hurricanes move northward over the colder ocean waters, they begin to lose their tropical characteristics. By the time these weakening cyclones reach Newfoundland, they are generally embedded into a mid-latitude low and are classified as post-tropical, either as an extratropical cyclone or a remnant low. Occasionally, conditions are favourable for tropical cyclones to retain their tropical characteristics long enough to reach the Orphan Basin.

A significant number of tropical cyclones that move into the mid-latitudes will undergo transition into extratropical cyclones. On average, 46% of tropical cyclones formed in the Atlantic transform into extratropical cyclones. During this transformation, the system loses tropical characteristics and becomes more extratropical in nature. These systems frequently produce large waves, gale to hurricane force winds, and intense rainfall. The likelihood that a tropical cyclone will undergo transition into an extratropical cyclone increases toward the second half of the tropical season, with October having the highest probability of transition. In the Atlantic, extratropical transition occurs at lower latitudes in the early and late hurricane season and at higher latitudes during the peak of the season.

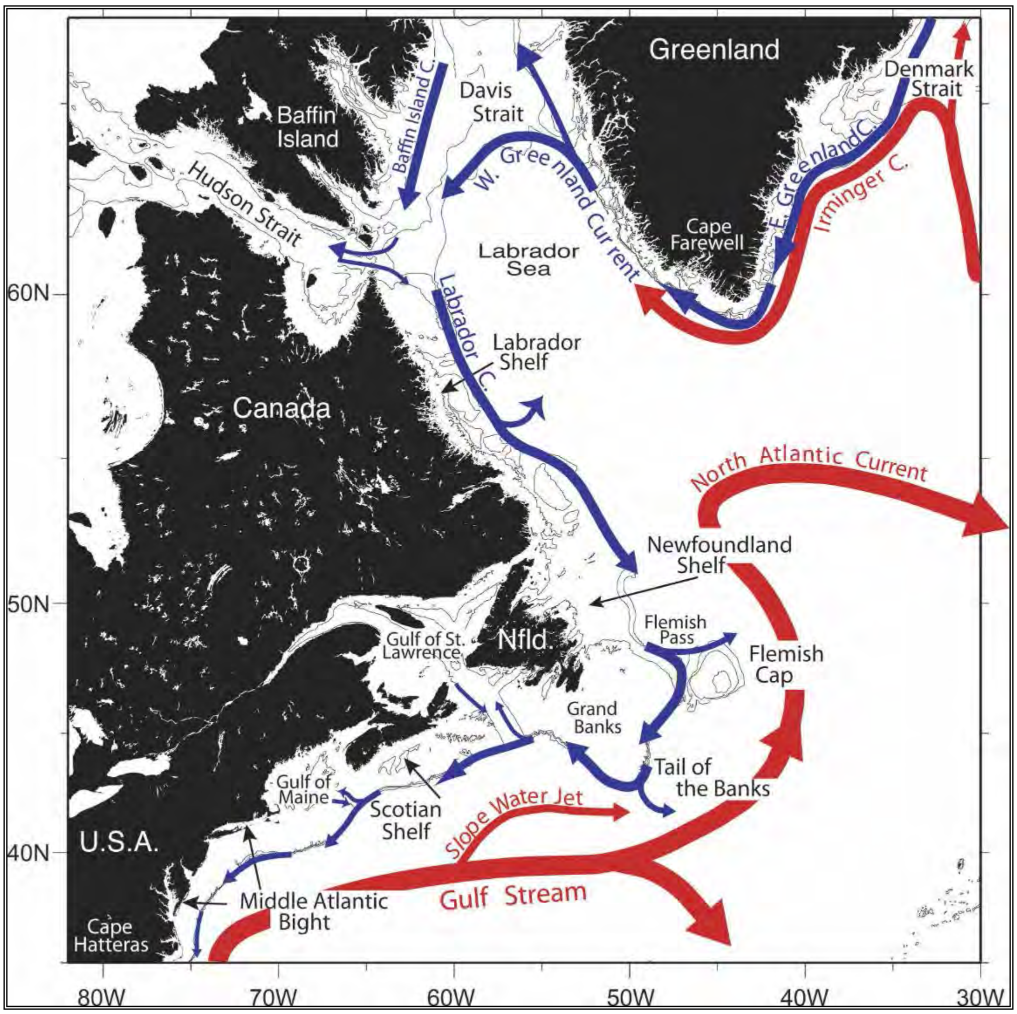
3.3 Physical Oceanography

A detailed review of the key physical oceanographic conditions and characteristics, including ocean currents, current velocities, and water mass properties (temperature, salinity, density), has been provided in the Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014). A summary of the major currents in the Study Area is provided below, with updated information from LGL (2014).

3.3.1 Major Currents in the Study Area

The Study Area primarily includes the Southern Grand Banks and its surrounding ocean waters, including the Laurentian Sub-Basin and Newfoundland Basin. The ocean circulation in this area is influenced by the Labrador Current, the Gulf Stream, the Slope Water, and the water exchange with the Gulf of St. Lawrence through the Laurentian Channel. The main current pattern is shown in Figure 3.12, with cold shelf break waters shown in blue and warm Gulf Stream waters shown in red.

The Labrador Current is the major current on the Grand Banks and is a continuation of the Baffin Island Current, which transports the cold and relatively low salinity water flowing out of Baffin Bay and a branch of the warmer and more saline waters of the West Greenland Current. The Labrador Current divides into two major branches on the northern Grand Banks. The inshore branch, which is approximately 100 km wide, is steered by the local underwater topography through the Avalon Channel, and then continues to follow the bathymetry around the Avalon Peninsula and southern Newfoundland. This branch then divides into two parts, one flowing west and around the north side of St. Pierre Bank and the other flowing south in Haddock Channel between Green Bank and Whale Bank.



Source: Fratantoni and Pickart 2007.

Figure 3.12 Major Ocean Currents and Features of Surface Circulation in the Northwest Atlantic.

The stronger offshore branch of the Labrador Current flows along the shelf break over the upper portion of the Continental Slope. This branch divides east of 48°W, resulting in part of the branch flowing to the east around Flemish Cap and the other part flowing south around the eastern edge of the Grand Banks and through Flemish Pass. Within Flemish Pass, the width of the Labrador Current is reduced to 50 km with speeds of about 30 cm/s. This flow transports cold, relatively low salinity Labrador Slope water into the region. To the southeast of the Flemish Cap, the North Atlantic Current transports warmer, high salinity water to the northeast along the southeast slope of the Grand Banks and the Flemish Cap. The southward flowing stream of the offshore branch of the Labrador Current splits into two parts south of the Grand Banks. One section continues eastward as a broad flow, part of which breaks off to return southward, while the other turns offshore at the Tail of the Grand Banks to flow northward along the edge of the North Atlantic Current.

The Gulf Stream and its associated eddies play an important role in the southern region of the Study Area. This extensive western boundary current plays a significant part in the poleward transfer of heat and salt and serves to warm the European subcontinent. While the Gulf Stream is usually located south of 40°N, one of the inherent features of this current system is its meandering path. These meanders may be formed both in northward and southward directions. Northward forming meanders, at certain stages of their development, separate from the main stream and generate rings or eddies, which begin moving independently from the Gulf Stream flow. Once eddies are formed, they drift in different directions and can be sustained for a considerable period of time. Their size may be of 100 to 300 km in diameter and may reach considerable depths. The trajectory of these warm water rings, once they depart from the Gulf Steam jet, together with their interaction with the bathymetry of the Continental Slope and with other current flows, influence the dynamic regime in the vicinity of the shelf break of the Grand Banks and the Scotian Shelf.

The structure of the Gulf Stream changes from a single, meandering front to multiple, branching fronts when it reaches the Grand Banks. Between 65°W and 50°W, the Gulf Stream flows eastward. Shortly after passing east of 50°W, the Gulf Stream splits into two currents. One branch, the North Atlantic Current, curves north along the continental slope, eventually turning east between 50° and 52°N. The other branch, the Azores Current, flows southeastward towards the Mid-Atlantic Ridge. The Gulf Stream transport also varies in time. According to GeoSat altimetry results, the current transports a maximum amount of water in the autumn and a minimum in the spring, in phase with the north-south shifts of its position.

There is a third major current between the eastward flowing Gulf Stream and the westward flowing Labrador Current, referred to as the Slope Water. This current is described as the northern bifurcation of the Gulf Stream that runs east-northeast along the continental slope south of Newfoundland. The Slope Water has been found to have distinct and unique properties because of mixing with coastal waters and underlying water masses. The Slope Water position varies laterally with the Gulf Stream at 55°W and its transport varies with the transport of the Labrador Current, as well as with changes in the deeper components of the slope water, at about 50°W.

The fourth influence on ocean circulation in the Study Area is the water exchange with the Gulf of St. Lawrence through the Laurentian Channel. In Laurentian Channel, the currents flow into the Gulf of St. Lawrence along the east side of the channel and out of the Gulf along the west side. The flow into the Gulf of St. Lawrence on the eastern side of Cabot Strait is mainly barotropic with a speed of 20 cm/s. The flow out of the Gulf of St. Lawrence on the western side of the Cabot Strait flows mainly along the western side of Laurentian Channel. A smaller portion flows along the inner Scotian Shelf and onto the Mid-shelf.

The interaction among these circulations is known to correlate with the behaviour of the North Atlantic Oscillation (NAO) index. The NAO index is the difference in winter sea level atmospheric pressures between the Azores and Iceland, and is a measure of the strength of the winter westerly winds over the northern North Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High which creates strong northwest winds, cold air and sea temperatures, and heavy ice in the Labrador Sea and Newfoundland Shelf regions. In low index years, the north wall of the Gulf Stream is displaced to the south and the southward transport associated with the Labrador Current is intensified. As a consequence of these north-south displacements of the shelf/slope front, the area is subject to thermal anomaly oscillations.

At all locations within the Study Area, the currents vary on different time scales related to tides, wind stress, atmospheric pressure changes from the passage of storm systems, volume transport of the Labrador Current, seasonal temperature changes, salinity variations, etc. The current variability in the Slope Region is influenced by the intermittent presence of Gulf Stream rings as well as by the relative position of the northern boundary of the Gulf Stream. On an inter-annual scale, the baroclinic transport component of the Labrador Current is negatively correlated with the NAO index. The relative strength of the two pressure systems control the strength and direction of westerly winds and the position of storm tracks in the North Atlantic, which in turn impacts the volume transport of the Labrador Current. Similarly, the current variability on a synoptic scale is directly linked to the passage of low pressure systems.

3.4 Ice Conditions

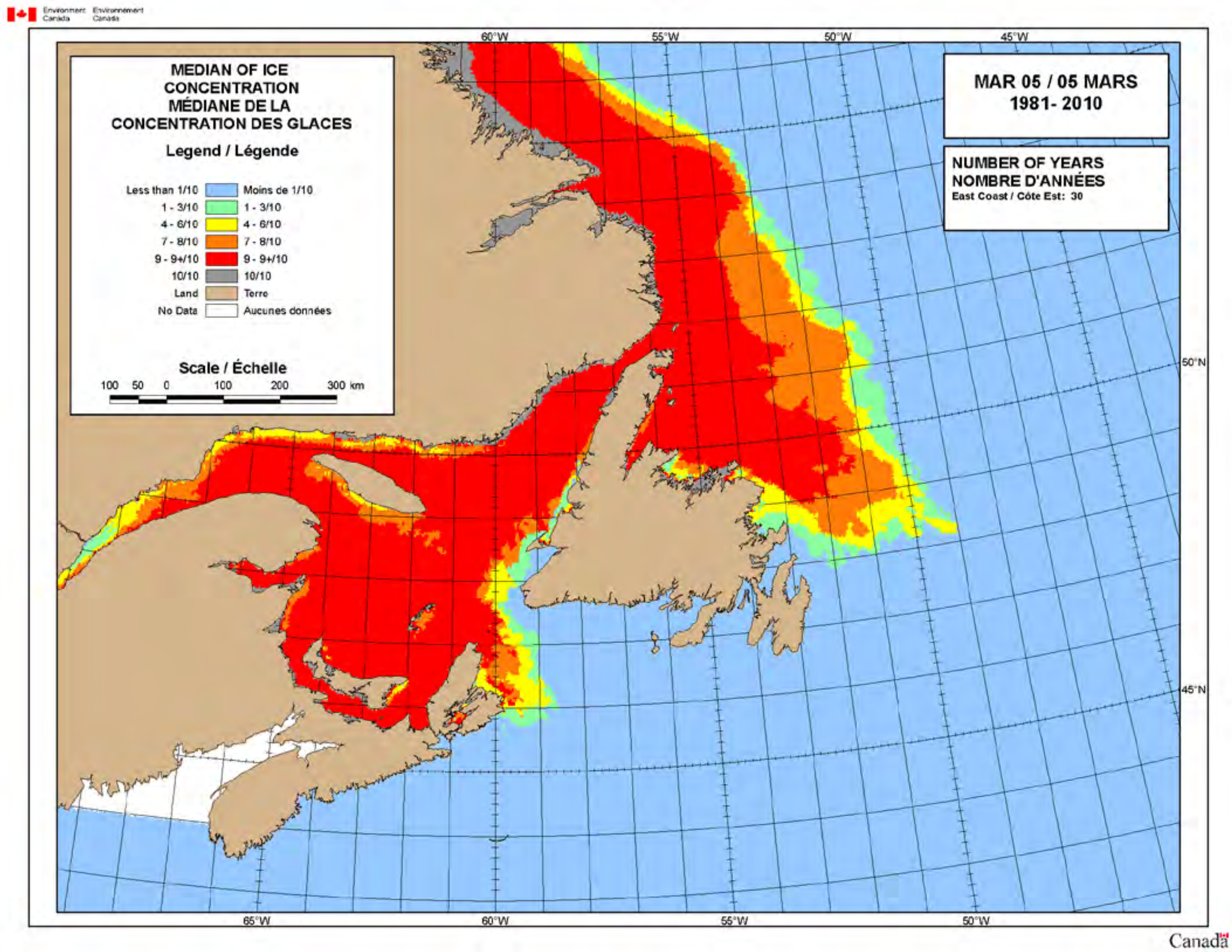
Ice conditions are an important component of the physical environment and often directly affect offshore activities along the coast of Newfoundland and Labrador. A review of ice conditions in the Study Area has been provided in the Southern and Eastern Newfoundland SEAs (C-NLOPB 2010, 2014). The classification of ice commonly found along Canada's eastern seaboard is based on internationally accepted terminology (CIS 2011).

3.4.1 Sea Ice

The 30-year median concentration of sea ice reaches its maximum during the week of 5 March. As depicted in Figure 3.13, the median of ice concentration does not extend into the Study Area. The maximum median sea ice extent reaches to approximately 48°N, 50°W.

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice indicates that the Study Area is first affected by sea ice beginning the week of 15 January and lasting until the week beginning 4 June. Figure 3.14 depicts the week of 12 March, the period when the frequency of presence of sea ice is the greatest over the Study Area. When sea ice is present, the predominant ice type within the area from 15 January to the week of 5 February is a mixture of grey and grey-white. By

12 February, thin first-year ice begins to form and is the predominant ice type from 19 February until 2 April, with a small amount of grey-white and new ice also present. Medium first-year ice begins to appear by the week of 5 March, and some thick first-year by the week of 26 March. Small amounts of old ice are present within the Study Area by the week of March 26.

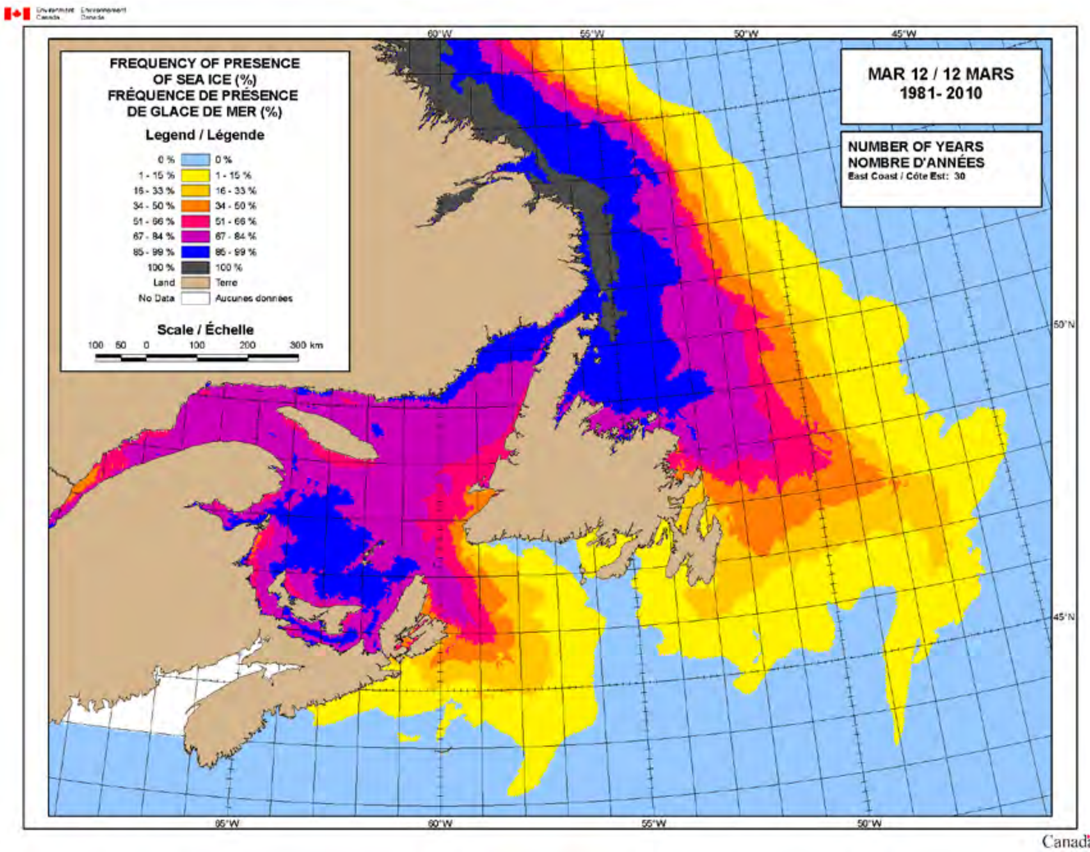


Source: Canadian Ice Service 30-Year Ice Atlas, accessed January 2015.

Figure 3.13 30-Year Median Concentration of Sea Ice, 1981 – 2010 (5 March).

3.4.2 Icebergs

Icebergs often cause concern with regard to navigation and offshore activities along the coast of Newfoundland and Labrador. The major source, contributing ~90% of icebergs in Canadian waters, is glaciers along the west coast of Greenland. Prevailing northwest winds and the strong Labrador Current move icebergs south along the coast of Labrador. The presence of easterly and northeasterly winds strongly influence the number of icebergs that move into the coast or remain offshore. In the Newfoundland offshore area, with the exception of the Flemish Pass, the highest numbers of icebergs are sighted along the northeast coast. Iceberg sightings generally decrease to the east and south.



Source: Canadian Ice Service 30-Year Ice Atlas, accessed January 2015.

Figure 3.14 30-Year Frequency of Presence of Sea Ice, 1981 – 2010 (12 March).

An analysis was performed to determine the threat posed by icebergs in the Study Area. The International Ice Patrol (IPP) Iceberg Sightings Database was used as the primary data source in this analysis (NSIDC 1995, updated annually). As shown in Table 3.17, during the period from 2001 – 2013, a total of 2,409 icebergs were observed in the Study Area (between approximately 41 to 46°N and 44 to 56°W). Only months with recorded iceberg sightings have been included (March to July). These observed sightings may not include all icebergs passing through the Study Area but indicate the relative abundance by month and year. Of the 2,409 icebergs sighted, 63.4% were observed during the proposed survey period from May to November. Most were sighted in May (49.4%), followed by June (11.8%), and July (2.2%). There were no icebergs observed from August to November. Additionally, there was a great deal of inter-annual variability in the numbers of iceberg sightings. For example, during May to November of 2003, there were 494 icebergs observed in the Study Area. During the same time period in 2004, there were 70 icebergs observed. During 2005, there were no icebergs observed in the Study Area for the entire season.

Iceberg size is typically characterized by waterline length, defined as the maximum dimension of the iceberg along the waterline, with a growler being defined as <5 m, a bergy bit as 5 – 14 m, small as 15 - 60 m, medium as 61 – 122 m, large as 123 – 213 m, and very large as >213 m. During the period from 2001 – 2013, 47.4% of the 1,459 icebergs recorded in the Study Area with a defined size classification were classified as medium, large, or very large sized.

Table 3.17 Annual and Monthly Iceberg Sightings within the Study Area, 2001 – 2013.

Year	Month					Total	% of Total
	March	April	May	June	July		
2001	0	24	6	10	1	41	1.7
2002	121	161	101	33	1	417	17.3
2003	21	238	403	87	4	753	31.3
2004	0	3	11	34	25	73	3.0
2005	0	0	0	0	0	0	0.0
2006	0	0	0	0	0	0	0.0
2007	0	29	3	27	17	76	3.2
2008	0	251	237	7	1	496	20.6
2009	1	14	53	82	3	153	6.3
2010	0	0	0	0	0	0	0.0
2011	0	0	0	0	0	0	0.0
2012	7	12	375	5	0	399	16.6
2013	0	0	1	0	0	1	0.0
Total	150	732	1190	285	52	2409	
% of Total	6.2	30.4	49.4	11.8	2.2		

Source: NSIDC 1995, IPP Iceberg Sightings Database, accessed January 2015.