# Environmental Assessment of Multiklient Invest Newfoundland and Labrador Offshore Seismic Program, 2017–2026

**Prepared by**

LGL LIMITED
environmental research associates

**Prepared for**

## Multiklient Invest AS

&

## TGS-NOPEC Geophysical Company ASA

**March 2017**
**LGL Report No. FA0106**

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**March 2017**
**LGL Report No. FA0106**

**Suggested Format for Citation:**

LGL Limited. 2017. Environmental Assessment of Multiklient Invest Newfoundland and Labrador Offshore Seismic Program, 2017–2026. LGL Rep. FA0106. Rep. by LGL Limited, St. John's, NL for Multiklient Invest AS, Oslo, Norway, and TGS-NOPEC Geophysical Company ASA, Houston, Texas, USA. 255 p. + Appendix.

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# 1.0 Introduction

Multiklient Invest AS (MKI), a wholly-owned subsidiary of Petroleum Geo-Services ASA (PGS), and TGS-NOPEC Geophysical Company ASA (TGS) are proposing to conduct two-dimensional (2D), three-dimensional (3D), and/or four-dimensional (4D) seismic surveys in offshore Newfoundland and Labrador (the Project). MKI will serve as the Operator. This document is the Environmental Assessment (EA) of the Project. The Project Area identified in Figure 1.1 includes Northern and Southern Grand Banks, the Flemish Cap and the shelf region off Northeast (NE) Newfoundland and Labrador, as well as offshore slope and deep water regions associated with the shelf (e.g., Flemish Pass, Orphan Basin, parts of the Labrador and Newfoundland basins). MKI and TGS are proposing to conduct seismic surveys, sometimes two or more operations, during one or more years within the 2017–2026 timeframe.

The EA is intended to enable the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) to fulfill its responsibilities under § 138 (1)(b) of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act* and § 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 C-NLOPB's Final Scoping Document (C-NLOPB 2017) posted on its website on 24 January 2017, as well as by advice and information received, and issues identified through various communications and consultations with other agencies, interest groups, stakeholders and beneficiaries.

## 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 fish and fish habitat, fisheries, marine mammals, sea turtles and marine-associated birds, Fisheries and Oceans Canada (DFO) and Environment Canada (EC) are the government agencies that have most involvement in the EA process. Legislation that is relevant to the environmental aspects of the Project includes:

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

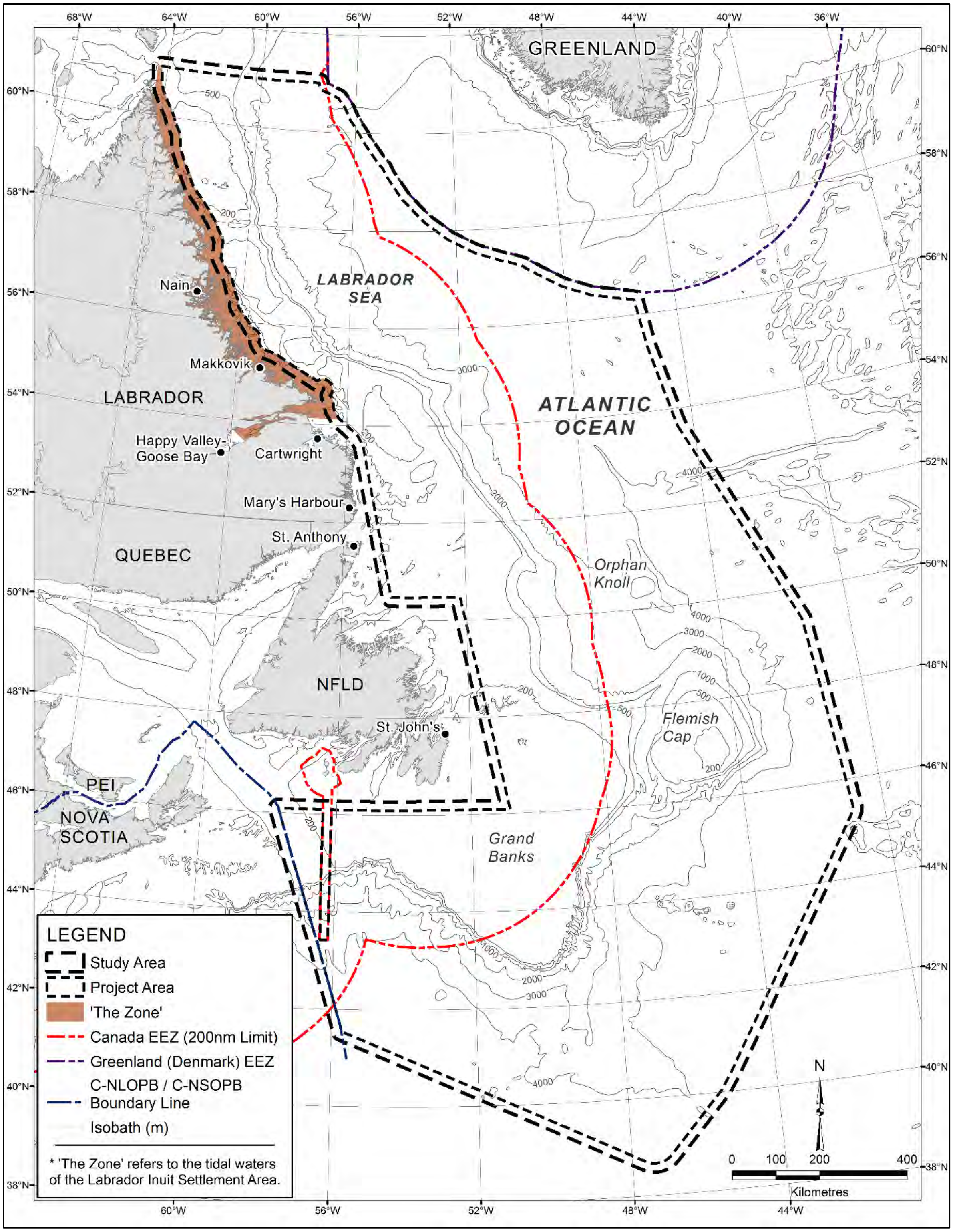


**Figure 1.1 Locations of Project Area and Study Area for MKI's Proposed Newfoundland and Labrador Offshore Seismic Program, 2017–2026.**

MKI will follow guidelines issued by the C-NLOPB, the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2016), which include DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*. The Project will also consider other relevant advice received during the consultations for this Project.

## 1.2 The Operator

The Operator, Multiklient Invest AS (MKI), is a wholly-owned subsidiary of Petroleum Geo-Services ASA (PGS). MKI has entered into a cooperative agreement with TGS-NOPEC Geophysical Company AS to conduct this work.

## 1.3 Canada-Newfoundland and Labrador Benefits

In full appreciation of the requirements of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act* and the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act*, MKI are committed to providing maximum benefits associated with East Coast operations to Canadians, and in particular, to individuals and companies from Newfoundland and Labrador that are commercially competitive in accordance with MKI's requirements.

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

## 1.4 Contacts

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# 2.0 Project Description

The official name of the Project is Multiklient Invest Newfoundland and Labrador Offshore Seismic Program, 2017–2026. MKI is proposing to conduct one or more 2D, 3D and/or 4D seismic surveys within its proposed Project Area (see Figure 1.1) between 2017 and 2026, starting as early as May 2017. There is the possibility that MKI will concurrently conduct two or more 2D, 3D and/or 4D surveys in any given year. The timing of the surveys is subject to MKI priorities and circumstances, weather conditions, contractor availability, and regulatory approvals.

## 2.1 Spatial and Temporal Boundaries

The Study Area includes the Project Area plus a 20 km buffer around the Project Area to account for the propagation of seismic survey sound that could potentially affect marine biota (see Figure 1.1). The proposed Project Area includes space to account for ship turning and streamer deployment. The areal extents of the Project Area and the Study Area are 1,898,806 $km^2$ and 2,053,781 $km^2$, respectively. As indicated in Figure 1.1, larger proportions of the Project Area and Study Area lie outside of Canada's Exclusive Economic Zone (EEZ) (~58%) than inside the EEZ (~42%). Water depths within the Project Area range from approximately 100 to 4,000 m (see Figure 1.1).

The Study Area and Project Area for this proposed Project are essentially amalgamates of the study areas and project areas, respectively, associated with the three currently active MKI projects: (1) Labrador Sea Seismic Program, 2014–2018 (C-NLOPB File No. 45006-020-003); (2) Northeast Newfoundland Slope Seismic Program, 2012–2017 (C-NLOPB File No. 45006-020-002); and (3) Southern Grand Banks Seismic Program, 2014–2018 (C-NLOPB File No. 45006-020-004). MKI has been conducting 2D and 3D seismic surveys in each of these three active project areas during recent years.

The coordinates that delineate the proposed Project Area (decimal degrees, WGS84 Datum) are as follow:

- 61.000°N, 64.253°W (western extreme);
- 61.003°N, 57.587°W (northern extreme);
- 60.700°N, 56.743°W;
- 57.818°N, 52.301°W;
- 56.307°N, 45.504°W;
- 53.644°N, 44.547°W;
- 49.374°N, 41.468°W;
- 45.417°N, 40.887°W (eastern extreme);
- 40.042°N, 45.501°W;

- 38.658°N, 47.365°W; (southern extreme);
- 41.546°N, 55.727°W;
- 46.093°N, 57.716°W;
- 46.099°N, 56.404°W; (Saint-Pierre et Miquelon (SPM) Exclusion)
- 43.418°N, 56.383°W; (SPM Exclusion)
- 43.411°N, 56.156°W; (SPM Exclusion)
- 46.100°N, 56.151°W; (SPM Exclusion)
- 46.091°N, 50.869°W;
- 50.473°N, 52.199°W;
- 50.481°N, 54.424°W;
- 53.601°N, 55.428°W;
- 54.601°N, 56.623°W;
- 55.614°N, 59.281°W;
- 57.254°N, 60.938°W; and
- 59.421°N, 63.041°W.

The coordinates that delineate the proposed Study Area (decimal degrees, WGS84 Datum) are as follow:

- 61.108°N, 64.546°W (western extreme);
- 61.128°N, 57.321°W (northern extreme);
- 60.835°N, 56.501°W;
- 57.970°N, 52.121°W;
- 56.426°N, 45.262°W;
- 53.703°N, 44.260°W;
- 49.415°N, 41.201°W;
- 45.395°N, 40.636°W (eastern extreme);
- 39.934°N, 45.315°W;
- 38.478°N, 47.410°W; (southern extreme);
- 41.445°N, 55.925°W;
- 46.205°N, 57.917°W;
- 46.274°N, 51.184°W;
- 50.294°N, 52.427°W;
- 50.345°N, 54.608°W;
- 53.681°N, 55.852°W;
- 54.543°N, 56.919°W;
- 55.584°N, 59.593°W;
- 57.220°N, 61.262°W; and
- 59.380°N, 63.382°W.

The temporal boundaries of the Project are 1 May–30 November during 2017–2026. The approximate durations of proposed 3D and 2D seismic surveys in 2017 are 90–150 days and 150 days, respectively.

## 2.2 Project Overview

The proposed Project is a ship-borne geophysical program that may include as much as 17,000 $km^2$ of 3D seismic survey and 22,000 km of 2D seismic survey lines in 2017. Specific data acquisition plans for 2D, 3D and/or 4D surveys during 2018–2026 are not yet determined.

For the proposed 3D survey(s) in 2017, the seismic survey vessel(s) would be the PGS vessel *Ramform Thethys* and/or a similar vessel. Depending on the final program plans for 2017, there is the possibility that a second seismic vessel will also be conducting 3D surveying. In 2017, the proposed 2D seismic survey will be acquired by either the PGS vessel *Atlantic Explorer* or a similar vessel. The seismic survey vessel(s) used during subsequent 2D/3D/4D surveys are currently unknown 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 in § 2.2.6 and § 2.2.7, respectively.

The C-NLOPB's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2016) will be used as the basis for the marine mammal monitoring and mitigation program for the seismic surveys. Qualified and experienced Marine Mammal Observers (MMOs) will monitor for marine mammals and sea turtles and implement mitigation measures as appropriate. Only visual monitoring is planned. The aspects of the monitoring and mitigation plan include the use of the ship's bridge for MMOs from which to conduct observations (i.e., good sight lines all around the vessel), and the use of reticle binoculars and other distance estimators to accurately estimate the location of the animal with respect to the safety zone. 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 a marine mammal or sea turtle with *endangered* or *threatened* status on Schedule 1 of the *SARA* is detected within the safety zone. These measures are designed to minimize disturbance to marine life, particularly marine mammals and other 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) 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 detail or coverage to serve the needs of the energy companies in their exploration, development and production activities. Acquisition of more 2D, 3D and/or 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 Scheduling

As already indicated in § 2.1, the seismic surveys will be conducted between 1 May and 30 November of any given year during 2017–2026.

### 2.2.3 Site Plans

In 2017, it is possible that there will be ~17,000 $km^2$ of 3D survey lines and ~22,000 km of 2D survey lines. The 2D seismic survey lines will be primarily orientated ESE-WNW or SSW-NNE with an approximate 3–50 km separation between adjacent lines. The 2D survey line lengths are estimated to vary between 50–250 km. In 2017, MKI expects to acquire 2D seismic data off southern Labrador, northeastern Newfoundland, southeastern Newfoundland and southern Newfoundland. The orientation and survey line lengths for 3D survey(s) are unknown at present. In 2017, MKI expects to acquire 3D seismic data off eastern Newfoundland and perhaps southeastern Newfoundland.

### 2.2.4 Personnel

A typical seismic vessel can accommodate ~55–60 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 MMOs and a FLO on board. All project personnel will have the required certifications as specified by the relevant Canadian legislation, the C-NLOPB, and MKI's Health, Safety, Environment, and Quality (HSEQ) agreement.

### 2.2.5 Seismic Vessel

In 2017, MKI will use either the MV *Ramform Thethys* or a similar vessel for the 3D seismic survey(s), and the MV *Atlantic Explorer* or a similar vessel for the 2D survey.

The MV *Ramform Thethys* was built in 2016 and is a Bahamian flagged vessel (Figure 2.1). It is 104.2 m long, with a beam of 70 m and a draft of 6.9 m. The *Ramform Thethys* has cruising and maximum speeds of ~28 km/h (15 knots) and ~ 30 km/h (16 knots), respectively, but will travel at a speed of ~9 km/h (5 knots) while conducting seismic surveying. The vessel is equipped with state of the art navigation, radar, communication and depth sounding equipment, bow and stern thrusters, and a Dynamic Positioning (DP) system. It has a fuel capacity of 5,800 $m^3$ of HFO and uses three diesel-electric engines. Three variable pitch propellers provide 1.8 Megawatts of power, which is more than sufficient to tow the very wide spread streamers. The *Ramform Thethys* operates two work boats that permit streamer maintenance while minimizing impairment to operations.

**Figure 2.1 MV *Ramform Thethys*.**

The *Ramform Thethys* belongs to the PGS Titan class and has 24 streamer reels; 16 abreast with a further 8 in a second row; and 22 tow points. The back deck layout is augmented by six independent airgun array handling booms. Together these enable faster deployment and recovery with increased flexibility and safety, making it possible to fully utilize the operational weather window. Steerable sources and streamers, combined with automated gear-handling systems increase flexibility and efficiency.

The MV *Atlantic Explorer*, which has been used to conduct 2D surveys in the NL offshore during 2014–2016, will again be used for 2D surveys in 2017.

For seismic surveys during 2018–2026, vessel specifics will be provided once the vessels have been identified.

### 2.2.6 Seismic Energy Source Parameters

The sound sources for the proposed 2D/3D/4D survey program will consist of one, two or three airgun arrays. For any sound source that consists of either two or three airgun arrays, the arrays will be discharged alternately (i.e., multiple airgun arrays will not be discharged simultaneously). The total volume of an airgun array will range from 3,000–6,000 $in^3$. The airgun array(s) will be deployed at depths ranging from 6–15 m, and the airguns will be operated with compressed air at pressures ranging from 2,000–2,500 psi. The peak-to-peak sound source level will be ~100–200 bar-m (~260–266 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$). Detailed specifications of the airgun array will be provided once the 2017 project design has been completed and parameters have been selected.

### 2.2.7 Seismic Streamers

In 2017, the 2D survey vessel will tow one solid streamer and the 3D vessel(s) will tow as many as 16 solid streamers (GeoStreamers). The maximum streamer length will be 12 km, and they will be towed at depths ranging from 9–25 m. Beyond 2017, it is possible that a 3D survey vessel may tow more than 16 streamers but this will be detailed in future EA updates.

### 2.2.8 Logistics/Support

#### 2.2.8.1 Vessels

MKI's primary support and supply will be provided by either the PGS vessel MV *Thor Magni* or a similar vessel. In addition, it is anticipated that at least one local escort vessel will accompany each operating seismic vessel. When necessary, escort vessels will be used to scout ahead of the seismic vessels for fishing vessels and gear, and hazards such as ice and floating debris.

#### 2.2.8.2 Crew Changes

Crew changes will be conducted by either ship-to-ship transfer or ship-to-shore transfer. Although the MV *Ramform Thethys* and the MV *Atlantic Explorer* are equipped with a helicopter deck, it is unlikely that crew changes will be conducted by helicopter. Helicopters will likely be used for emergencies only.

#### 2.2.8.3 Shore Base, Support and Staging

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

### 2.2.9 Waste Management

Waste management will be consistent with industry best practices in offshore Newfoundland and Labrador. Any garbage generated will be collected and separated into items that are either dischargeable to the sea, non-dischargeable to the sea or reusable according to MARPOL 73/78 Annex IV: Pollution by Sewage from Ships, and Annex V: Pollution by Garbage from Ships. Some waste will be incinerated at sea.

### 2.2.10 Air Emissions

Air emissions will be those associated with standard operations for marine vessels, including the seismic vessel, the support vessel and the escort vessel. MKI follows MARPOL 73/78 Annex VI: Regulations for the Prevention of Air Pollution from Ships.

### 2.2.11 Accidental Events

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

## 2.3 Mitigation and Monitoring

Project mitigation measures are detailed in the EA, some of which 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 qualified and dedicated MMOs and FLOs, and a fisheries compensation program. In addition, the MMOs will conduct a monitoring and release program for seabirds that may strand on Project vessels. Seabird monitoring will include systematic counts based on protocols issued by the Canadian Wildlife Service.

## 2.4 Project Site Information

The Project is located in the offshore areas east of Newfoundland and Labrador, and south of Newfoundland. It includes Northern and Southern Grand Banks, the Flemish Cap and the shelf region off NE Newfoundland and Labrador, as well as offshore slope and deep water regions associated with the shelf (e.g., Flemish Pass, Orphan Basin, parts of the Labrador and Newfoundland basins) (see Figure 1.1).

### 2.4.1 Environmental Features

The physical and biological environments of the general area have been described in the Labrador Shelf Strategic Environmental Assessment (C-NLOPB 2008)[1], the Eastern Newfoundland SEA (C-NLOPB 2014)[2], the Southern Newfoundland SEA (C-NLOPB 2010)[3] as well as in four project-specific EAs: (1) MKI's Labrador Sea Seismic Program, 2014–2018 (LGL 2014)[4]; (2) WesternGeco Canada's Eastern Newfoundland Offshore Seismic Program, 2015–2024 (LGL 2015a)[5]; (3) WesternGeco Canada's Southeastern Newfoundland Offshore Seismic Program, 2015–2024 (LGL 2015b)[6]; and (4) Seitel Canada Ltd.'s East Coast Offshore Seismic Program, 2016–2025 (LGL 2016)[7]. Reviews of the physical and biological environments, based on the three SEAs, the four project-specific EAs and newly available information, are provided in § 3.0 and § 4.0 of this EA, respectively.

Figure 2.2 shows the extent to which the proposed MKI Study Area overlaps the study areas associated with the three SEAs and the Seitel EA. The proposed Study Area lies almost entirely within the Seitel EA Study Area except for a small portion west of the French EEZ of St. Pierre et Miquelon.

#### 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 aforementioned SEAs (C-NLOPB 2008, 2010, 2014) and project-specific EAs (LGL 2014, 2015a,b, 2016). The proposed seismic surveys could be conducted in areas with water depths ranging from approximately 100 to 4,000 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 1 to November 30) when NW Atlantic operating conditions are

[1] Available at http://www.cnlopb.ca/sea/labrador.php
[2] Available at http://www.cnlopb.ca/sea/eastern.php
[3] Available at http://www.cnlopb.ca/sea/southern.php
[4] Available at http://www.cnlopb.ca/assessments/mkilabsseareport.php
[5] Available at http://www.cnlopb.ca/assessments/westgecoeast3.php
[6] Available at http://www.cnlopb.ca/assessments/westgecose3.php
[7] Available at http://www.cnlopb.ca/pdfs/seitel/eareport.pdf?lbisphpreq=1

relatively good compared to the late fall/winter/early spring period, should decrease the risk of 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 three SEAs (C-NLOPB 2008, 2010, 2014), the relevant project-specific EAs (LGL 2014, 2015a,b, 2016), and any new available information, is provided in § 5.6.

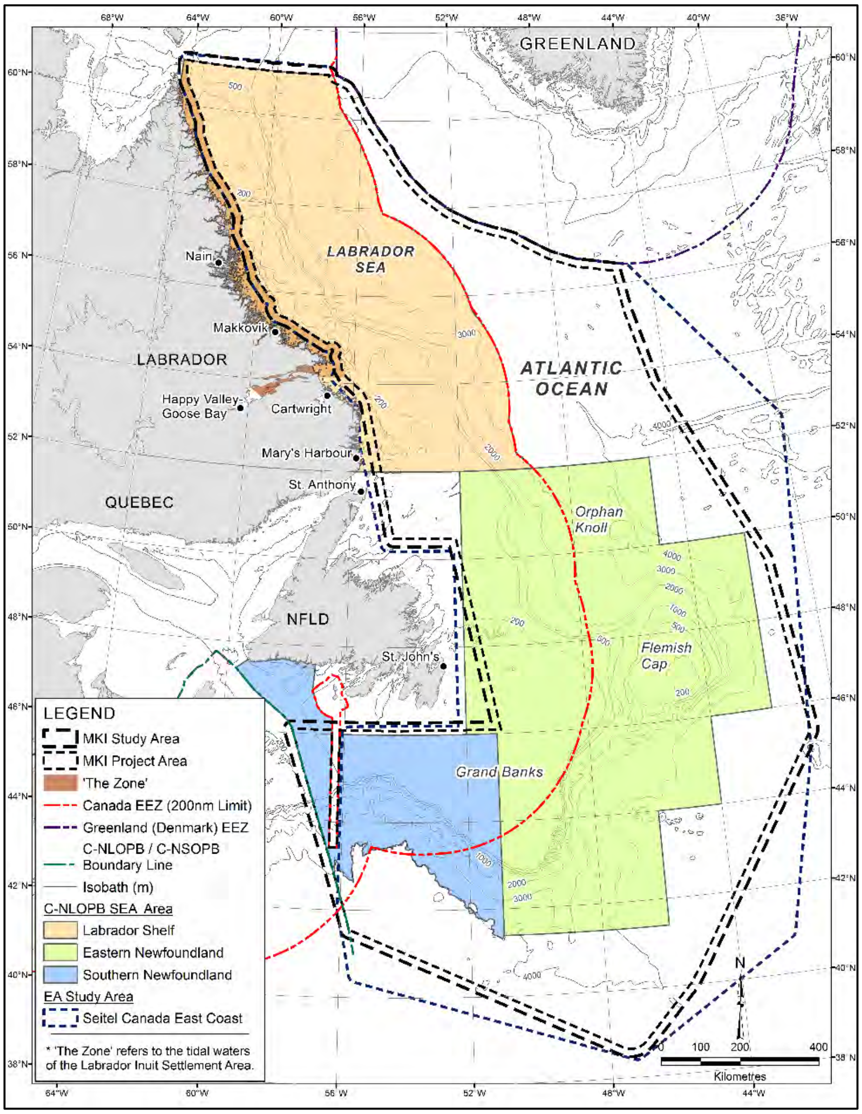



**Figure 2.2 Location of MKI's Study Area Relative to Study Areas Associated with Relevant SEAs and the Seitel EA.**

#### 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 § 4.0 on the basis of the following six Valued Environmental Components (VECs):

- 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 and accidental events (e.g., 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, MKI consulted with stakeholders in St. John's and in several communities in Labrador. A summary of the results of those consultations are presented in § 5.1.1 and a full report of consultations is provided Appendix 1.

MKI sent Project information emails to the following stakeholders based in St. John's in late January/early February 2017. The various consultees were invited to request a face-to-face meeting if deemed necessary. The five consultees that met with MKI in person are indicated below.

- Environment Canada - meeting on 31 January, 2017;
- Nature Newfoundland and Labrador (NNL) - meeting on 2 February, 2017;
- One Ocean - meeting on 2 February, 2017;
- Fish, Food and Allied Workers Union/Unifor - meeting on 31 January, 2017;
- Association of Seafood Producers (ASP);
- Ocean Choice International (OCI);
- Groundfish Enterprise Allocation Council (GEAC) Ottawa;
- Canadian Association of Prawn Producers;
- Clearwater Seafoods;
- Icewater Seafoods; and
- Newfound Resources Ltd. (NRL) - meeting on 2 February, 2017.

In January 2017, various stakeholders in Labrador were contacted and provided a link to the MKI Project Description posted on the C-NLOPB website. Those groups contacted are listed below. During 24–27 January, an MKI team conducted some consultations in Mary's Harbour and Happy Valley-Goose Bay (HV-GB). The groups consulted in late January are noted below. Remaining consultations in Labrador will be held in March 2017. Results of the remaining Labrador consultations will be included in the Addendum to the EA that is prepared to address EA reviewer comments.

- Labrador Fishermen's Union Shrimp Company Ltd. (LFUSCL) in Mary's Harbour – meeting on 24 January, 2017;
- Mayor of Mary's Harbour - meeting on 24 January, 2017;
- Public Information Session in Mary's Harbour - meeting on 24 January, 2017;
- Torngat Secretariat in HV-GB - meeting on 25 January, 2017;
- Torngat Fish Producers Co-op in HV-GB - meeting on 26 January, 2017;
- Public Information Session in HV-GB - meeting on 26 January, 2017;
- Innu Nation in HV-GB - meeting on 27 January, 2017;
- Cartwright Town Council;
- Town of Charlottetown;
- Labrador Choice Seafoods Inc., Charlottetown;
- Forteau Town Council;
- Town of Happy Valley-Goose Bay (HV-GB);
- NunatuKavut Community Council, HV-GB;
- Nunacor Development Corporation, HV-GB;
- Town of L'Anse au Loup;
- Nunatsiavut Government (Department of Lands and Natural Resources), Nain;
- Nain Inuit Community Government, Nain;
- Town of North West River;
- Community of Pinsent's Arm;
- Town of Port Hope Simpson; and
- Sheshatshiu First Nation Innu Band Council.

## 2.6 Effects of the Project on the Environment

The proposed Project is within the scope of other seismic programs routinely conducted offshore Newfoundland and Labrador and elsewhere in eastern Canada. Potential environmental effects are examined with focus on the VECs listed above in § 2.4.1.2 and the cumulative effects associated with other marine users. The assessment of the effects of the Project on the environment will also rely on information presented in the Labrador Shelf SEA (C-NLOPB 2008), the Eastern Newfoundland SEA (C-NLOPB 2014), the Southern Newfoundland SEA (C-NLOPB 2010), and the four relevant project-specific EAs (LGL 2014, 2015a,b, 2016).

## 2.7 Environmental Monitoring

MMOs will be on board the seismic vessel(s) to monitor for and implement mitigation measures specific to marine mammals and sea turtles, and to collect systematic data on marine mammal/sea turtle behaviour and distribution with and without airguns operating. Systematic seabird counts will also be conducted during the seismic surveys. As per LGL protocol, seabird observations will be conducted 10 to 15 times daily, each survey period lasting 10 minutes. The seabird observations are conducted by an experienced MMO, during which time a second experienced MMO is observing for marine mammals and sea turtles. Therefore, marine mammal and sea turtle observations are continuous throughout the daytime period.

Weekly reports from the seismic vessel to the C-NLOPB during operations will also include information related to commercial fishing (e.g., FLO reports of gear and/or fishing vessels encountered during the seismic survey).

# 3.0 Physical Environment

The Final Scoping Document (C-NLOPB 2017) requires 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 Labrador Shelf SEA (§ 3.0 of C-NLOPB 2008), the Eastern Newfoundland SEA (§ 4.1 of C-NLOPB 2014), the Southern Newfoundland SEA (§ 2.0 of C-NLOPB 2010), and four relevant EAs (§ 3.0 of LGL 2014, 2015a,b, 2016). An overview of the physical environment of the Study Area, based primarily on information in the aforementioned documents, is provided below. The overview also contains new and relevant information since publication of the SEAs and the site-specific EAs.

## 3.1 Bathymetry and Geology

The bathymetry and geology of the Study Area is highly variable as reflected in the list of primary areas that comprise the Study Area below.

1. Labrador Shelf (deep saddles (>200 m) separate several shallow offshore banks (<200 m), depths increase to >3,000 m in Labrador Basin beyond outer shelf);
2. Orphan Knoll (rising steeply from 3,000 to 1,800 m);
3. Orphan Basin proper (1,200 to 3,500 m);
4. Sackville Spur (≤1,000 m);
5. Flemish Pass (deep water >1,000 m confined between the Grand Banks and the Flemish Cap (~130 m));
6. Northeast Newfoundland Shelf (200 to 300 m);
7. Northeast Newfoundland Shelf Slope and Flemish Cap Shelf (>200 to 2,000 m);
8. Flemish Pass (deep water in excess of 1,000 m confined between the Grand Banks and the Flemish Cap (~130 m);
9. Jeanne d'Arc Basin (≤200 m);
10. Grand Banks of Newfoundland, including Grand Bank, Whale Bank, Green Bank, and the eastern portion of St. Pierre Bank (<200 m, and generally 50 to 100 m, with the exception of portions of St. Pierre Bank and the southeast shoal of Grand Bank, which are <50 m);
11. Halibut Channel, situated between St. Pierre Bank and Green Bank, and Haddock Channel, situated between Green Bank and Whale Bank (>300 to 2,000 m);
12. Lilly Canyon - Carson Canyon, along the 200 m isobaths of the southeast slope of Grand Bank (>200 m);
13. Laurentian Basin (500 to ~4,000 m);
14. Newfoundland Basin (2,000 to 5,000 m); and
15. Newfoundland Seamounts (peaks >2,500 m, with most >3,500 m).

The surficial geology of the Study Area ranges from fine (mud and clay) to extremely coarse (boulders and bedrock) (C-NLOPB 2008, 2010, 2014). Surficial sediments in the area are primarily hemi-pelagic, ice-rafted, and from glacial plume deposits (Toews and Piper 2002).

Ten surficial sedimentary formations are recognized within the Study Area (C-NLOPB 2008, 2010, 2014).

1) Grand Banks Drift – glacial till comprised of poorly sorted sand, silt, and clay;
2) Downing Silt – clayey and sandy silt, overlying and interbedded with Grand Banks Drift;
3) Adolphus Sand – fine to coarse-grained sand, containing some silt, clay-sized fractions, and gravel;
4) Placentia Clay – thin, homogeneous sandy to silty mud formation;
5) Grand Banks Sand and Gravel – basal transgressive sand and gravel deposit;
6) Qeovik Silt – proglacial and subglacial sediments;
7) Makkaq Clay – stratified clay and silt, with minor amounts of sand and gravel;
8) Sioraq Silt and Gravel– post glacial marine sediments;
9) Sioraq Sand – fine muddy sand to gravelly sand; and
10) Lower Till and Upper Till– clayey and sandy silt, with scattered shells and pebbles throughout.

## 3.2 Climatology

All marine seismic surveys are influenced by weather conditions, from both routine operational and environmental safety perspectives. During routine activities, data quality can be affected by weather, particularly by wind and wave conditions. This subsection, based on the Labrador Shelf, Southern Newfoundland, and Eastern Newfoundland SEAs (C-NLOPB 2008, 2010, 2014) and recent EAs (LGL 2014, 2015a,b), provides a general overview of climatic conditions in the Study Area, including wind, waves, temperature, precipitation, visibility, and weather systems. More detailed descriptions are provided for extreme events.

The wind and wave climatology of the Study Area was prepared using the Meterological Service of Canada 50 year (MSC50) hindcast wind and wave database for the North Atlantic. 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. The analyses were conducted using eight grid points to represent the Study Area: (1) grid point 14710 near Saglek Bank; (2) grid point 13643 in Hopedale Saddle; (3) grid point 17801 in Orphan Basin; (4) grid point 13451 on the Flemish Cap; (5) grid point 11595 on the Grand Banks; (6) grid point 05000 in the Laurentian Basin; (7) grid point 03889 on the Tail of the Banks; and (8) grid point 11154 in the Newfoundland Basin (Table 3.1, Figure 3.1).

**Table 3.1 MSC50 Grid Point Locations.**

| Region | Grid Point | Latitude | Longitude |
|---|---|---|---|
| Saglek Bank | 14710 | 59.0°N | 60.0°W |
| Hopedale Saddle | 13643 | 55.0°N | 55.0°W |
| Orphan Basin | 17801 | 51.0°N | 49.0°W |
| Flemish Cap | 13451 | 48.0°N | 44.0°W |
| Grand Banks | 11595 | 47.0°N | 50.0°W |
| Laurentian Basin | 05000 | 43.5°N | 54.5°W |
| Tail of the Banks | 03889 | 43.0°N | 50.0°W |
| Newfoundland Basin | 11154 | 44.0°N | 45.0°W |

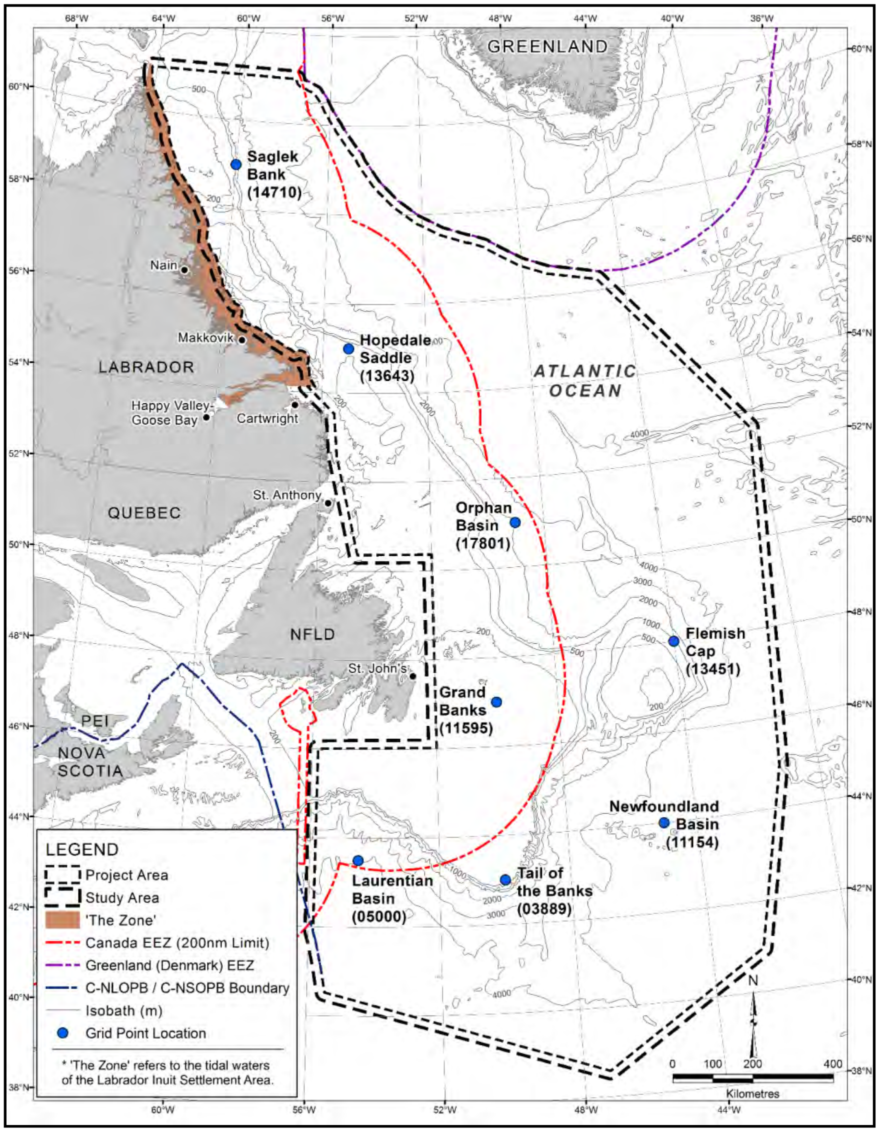



**Figure 3.1 Location of MSC50 Grid Points and Regions used in the Physical Environment Analyses.**

Continuous wind and wave hindcast data for grid points 14710 and 13643 are one-hour time steps from January 1954 to December 2005 (C-NLOPB 2008). Hindcast data for grid points 17801, 13451, 11595, and 03889 are one-hour time steps from January 1954 to December 2011 (C-NLOPB 2014). Hindcast data for grid point 05000 are one-hour time steps from January 1954 to December 2010 (Oceans 2014). Hindcast data for grid point 11154 are three-hour time steps from January 1954 to December 2010 (Oceans 2014).

### 3.2.1 Wind

Mean wind speeds are low during the summer and peak during the winter in all regions of the Study Area (Table 3.2). From May–November, the highest mean wind speeds occur during November and the lowest during July, ranging from 9.1 to 11.1 m/s and 4.8 to 6.7 m/s, respectively. While much of the Study Area experiences primarily southwest to west winds throughout the year, there is a strong annual cycle in wind directions. The Labrador Shelf most frequently experiences west to northwest winds. Similarly, west to northwest winds are prevalent during the winter months for Offshore Newfoundland. However they begin to shift counter-clockwise during March and April, resulting in mainly southwest winds during the summer months. During autumn, the tropical-to-polar gradient strengthens and the winds shift slightly, becoming predominately westerly by late autumn. Low pressure systems crossing south of Newfoundland are more intense during the winter months, thus wind speeds tend to peak during this season.

**Table 3.2 Mean Hourly Wind Speed Statistics for Offshore Newfoundland and Labrador.**

| Month | Mean Wind Speed (m/s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saglek Bank (14710) | Hopedale Saddle (13643) | Orphan Basin (17801) | Flemish Cap (13451) | Grand Banks (11595) | Laurentian Basin (05000) | Tail of the Banks (03889) | NF Basin (11154) |
| Jan | 9.7 | 10.3 | 12.4 | 12.5 | 11.0 | 11.2 | 10.3 | 11.2 |
| Feb | 8.5 | 9.4 | 12.0 | 12.2 | 10.8 | 11.2 | 10.3 | 11.2 |
| Mar | 8.2 | 8.9 | 11.0 | 11.0 | 9.8 | 10.3 | 9.4 | 10.2 |
| Apr | 7.3 | 7.7 | 9.6 | 9.3 | 8.4 | 9.0 | 8.3 | 9.0 |
| May | 6.1 | 6.2 | 8.1 | 8.1 | 7.1 | 7.5 | 6.9 | 7.6 |
| Jun | 5.4 | 5.5 | 7.1 | 7.4 | 6.6 | 6.8 | 6.2 | 7.0 |
| Jul | 4.8 | 4.8 | 6.6 | 6.7 | 6.2 | 6.3 | 5.7 | 6.2 |
| Aug | 5.4 | 5.4 | 7.0 | 7.1 | 6.6 | 6.7 | 5.9 | 6.5 |
| Sep | 7.0 | 7.1 | 8.6 | 8.6 | 7.7 | 7.9 | 7.1 | 7.6 |
| Oct | 8.6 | 8.6 | 10.0 | 10.1 | 8.9 | 9.1 | 8.2 | 8.9 |
| Nov | 9.6 | 9.6 | 11.1 | 10.8 | 9.7 | 10.1 | 9.1 | 9.7 |
| Dec | 10.3 | 10.5 | 12.0 | 11.9 | 10.6 | 11.2 | 10.1 | 10.9 |

Sources: C-NLOPB 2008, 2014; Oceans 2014.

### 3.2.2 Waves

Within the majority of the Study Area, the predominant direction of the combined significant wave heights is from the west during autumn and winter, primarily due to a high frequency of occurrence of wind waves during these seasons. During March and April, the wind waves remain primarily westerly while the swell begins to move southerly. During the summer, southwesterly wind waves and southwesterly swell contribute to produce combined significant wave heights in the southwest direction. During September and October, the wind waves deviate again to the west and become the predominant component of the combined significant wave heights. Extratropical storms can occur in the Study Area, predominantly during October through to March. 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. Tropical storms have the greatest possibility of occurring from late-August through October. Extratropical storms are discussed in more detail in § 3.2.5 of this EA.

Wave conditions are characterized 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 approximates the characteristic height observed visually. From May–November, the highest significant wave heights occur during November and the lowest during July in all regions, ranging from 2.7 to 3.8 m and 1.2 to 1.8 m, respectively (Table 3.3).

**Table 3.3 Combined Significant Wave Height Statistics for Offshore Newfoundland and Labrador.**

| Month | Significant Wave Height (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saglek Bank (14710) | Hopedale Saddle (13643) | Orphan Basin (17801) | Flemish Cap (13451) | Grand Banks (11595) | Laurentian Basin (05000) | Tail of the Banks (03889) | NF Basin (11154) |
| **Jan** | 2.8 | 3.2 | 4.3 | 4.9 | 3.7 | 4.0 | 3.9 | 4.3 |
| **Feb** | 2.2 | 3.1 | 3.6 | 4.6 | 3.3 | 3.9 | 3.8 | 4.3 |
| **Mar** | 2.1 | 2.7 | 3.3 | 4.0 | 2.8 | 3.5 | 3.4 | 3.7 |
| **Apr** | 1.9 | 2.4 | 2.9 | 3.2 | 2.5 | 2.9 | 2.8 | 3.1 |
| **May** | 1.5 | 1.7 | 2.3 | 2.5 | 2.2 | 2.2 | 2.2 | 2.3 |
| **Jun** | 1.4 | 1.5 | 1.9 | 2.1 | 1.9 | 1.9 | 1.8 | 2.0 |
| **Jul** | 1.2 | 1.3 | 1.7 | 1.8 | 1.7 | 1.7 | 1.6 | 1.7 |
| **Aug** | 1.3 | 1.4 | 1.8 | 2.0 | 1.8 | 1.8 | 1.7 | 1.8 |
| **Sep** | 1.8 | 2.0 | 2.6 | 2.7 | 2.3 | 2.3 | 2.3 | 2.4 |
| **Oct** | 2.3 | 2.6 | 3.2 | 3.4 | 2.9 | 2.8 | 2.8 | 2.9 |
| **Nov** | 2.7 | 3.0 | 3.7 | 3.8 | 3.2 | 3.3 | 3.2 | 3.4 |
| **Dec** | 2.9 | 3.4 | 4.3 | 4.5 | 3.8 | 4.0 | 3.8 | 4.0 |

Sources: C-NLOPB 2008, 2014; Oceans 2014.

Maximum wave height is defined as the greatest vertical distance between a wave crest and adjacent trough. From May–November, the most severe sea states occur from September through November based on maximum wave heights (Table 3.4).

**Table 3.4 Combined Maximum Wave Height Statistics for Offshore Newfoundland and Labrador.**

| Month | Maximum Wave Height (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saglek Bank (14710) | Hopedale Saddle (13643) | Orphan Basin (17801) | Flemish Cap (13451) | Grand Banks (11595) | Laurentian Basin (05000) | Tail of the Banks (03889) | NF Basin (11154) |
| Jan | 10.0 | 12.6 | 15.9 | 14.8 | 11.5 | 14.1 | 12.0 | 15.4 |
| Feb | 11.2 | 11.1 | 13.4 | 15.8 | 13.3 | 13.3 | 13.3 | 14.1 |
| Mar | 9.0 | 11.4 | 12.1 | 15.6 | 10.4 | 12.6 | 12.6 | 13.1 |
| Apr | 6.5 | 10.4 | 11.5 | 11.7 | 10.3 | 11.2 | 11.5 | 10.2 |
| May | 5.5 | 8.5 | 10.9 | 11.8 | 9.6 | 10.2 | 8.5 | 9.2 |
| Jun | 6.9 | 7.0 | 8.7 | 11.4 | 9.1 | 9.7 | 8.7 | 7.7 |
| Jul | 4.3 | 4.5 | 6.3 | 6.8 | 6.0 | 6.7 | 5.9 | 7.1 |
| Aug | 4.9 | 5.7 | 11.1 | 9.8 | 8.5 | 10.1 | 9.7 | 7.9 |
| Sep | 6.6 | 10.0 | 12.1 | 12.9 | 12.8 | 13.0 | 10.9 | 11.3 |
| Oct | 9.4 | 10.5 | 12.7 | 13.8 | 10.5 | 12.7 | 11.9 | 12.0 |
| Nov | 11.2 | 11.6 | 13.1 | 14.2 | 10.7 | 11.8 | 12.1 | 12.0 |
| Dec | 12.1 | 10.7 | 15.1 | 16.5 | 12.1 | 12.6 | 12.1 | 12.9 |

Sources: C-NLOPB 2008, 2014; Oceans 2014.

### 3.2.3 Wind and Wave Extreme Value Analysis

The occurrence of severe wind and waves associated with extreme storm events is of particular importance for the planning and execution of marine seismic surveys. An analysis of extreme wind and waves was performed using the eight grid points already indicated to represent the Study Area (see Table 3.1, Figure 3.1). Extreme value analyses were performed to determine the highest expected values for wind speed and significant wave height for each of the MSC50 grid points (C-NLOPB 2008, 2014; Oceans 2014).

#### 3.2.3.1 Extreme Value Estimates for Winds from the Gumbel Distribution

Extreme wind speed estimates were calculated using Oceanweather's Osmosis software for return periods of 1-year, 10-years, 50-years, and 100-years, using hourly mean wind speeds for a reference height of 10 m above sea level (C-NLOPB 2008, 2014; Oceans 2014). 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 calculated annual 100-year extreme 1-hour wind speed ranged from 29.9 to 35.8 m/s (Table 3.5). From May–November, the highest 100-year extreme 1-hour wind speeds occur from September–November, while the lowest occur during June and July (C-NLOPB 2014; Oceans 2014).

**Table 3.5 Extreme Wind Speed Estimates for Offshore Newfoundland and Labrador.**

| Return Period (years) | Wind Speed (m/s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saglek Bank (14710) | Hopedale Saddle (13643) | Orphan Basin (17801) | Flemish Cap (13451) | Grand Banks (11595) | Laurentian Basin (05000) | Tail of the Banks (03889) | NF Basin (11154) |
| **1** | nd | nd | 21.9 | 23.8 | 21.5 | 24.9 | 21.8 | 23.9 |
| **10** | 26.5 | 27.0 | 30.9 | 31.1 | 29.7 | 28.5 | 29.2 | 27.4 |
| **50** | 29.0 | 29.4 | 34.3 | 34.4 | 33.3 | 30.8 | 32.6 | 29.8 |
| **100** | 29.9 | 30.3 | 35.8 | 35.8 | 34.8 | 31.8 | 34.0 | 30.8 |

Sources: C-NLOPB 2008, 2014; Oceans 2014.

#### 3.2.3.2 Extreme Value Estimates for Waves from a Gumbel Distribution

Monthly extreme significant wave height estimates for return periods of 1-year, 10-years, 50-years, and 100-years for grid points within the Study Area are presented in Table 3.6. From May– November, the highest 100-year extreme significant wave heights occur during October and November, while the lowest extreme significant wave heights occur during July (C-NLOPB 2014; Oceans 2014).

**Table 3.6 Extreme Significant Wave Height Estimates for Offshore Newfoundland and Labrador.**

| Return Period (years) | Significant Wave Height (m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Saglek Bank (14710) | Hopedale Saddle (13643) | Orphan Basin (17801) | Flemish Cap (13451) | Grand Banks (11595) | Laurentian Basin (05000) | Tail of the Banks (03889) | NF Basin (11154) |
| **1** | ND | nd | 11.5 | 12.8 | 9.9 | 11.0 | 10.4 | 10.6 |
| **10** | 10.6 | 11.2 | 13.7 | 15.5 | 11.9 | 12.8 | 12.4 | 12.8 |
| **50** | 12.1 | 12.6 | 15.5 | 17.7 | 13.6 | 14.1 | 14.0 | 14.2 |
| **100** | 12.7 | 13.1 | 16.3 | 18.6 | 14.3 | 14.6 | 14.7 | 14.8 |

Sources: C-NLOPB 2008, 2014; Oceans 2014.

### 3.2.4 Weather Variables

For offshore Newfoundland, data related to air temperature, sea surface temperature, and visibility were 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 1950 to December 2012, was used in the analyses for the Orphan Basin, Flemish Cap, Grand Banks and Tail of the Banks (C-NLOPB 2014). A subset of observations covering the period from January 1980 to December 2013 was used in the analyses for the Laurentian Basin and the Newfoundland Basin (Oceans 2014).

For offshore Labrador, data related to air temperatures were compiled using the National Climate Data and Information Archive for two weather stations located along the Labrador coast, Nain and Cartwright, covering the period from 1981 to 2010 (EC 2015a). Data related to sea surface temperatures were compiled using the Bedford Institute of Oceanography (BIO) hydrographic database (BIO 2009). A subset of data from hydrographic bottles, CTD casts, Batfish tows, and bathythermographs, covering the period from 1910 to 2009, was used in the analysis for the Labrador Shelf (Husky 2010). Data related to visibility were extracted from over water observations of shipping weather in the Labrador Sea (McClintock and Davidson 1995 *in* Husky 2010).

#### 3.2.4.1 Temperature

The moderating influence of the ocean serves to limit both the diurnal and the annual temperature variation in the Study Area. 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. Mean monthly air temperatures and sea surface temperatures for the Study Area are presented in Tables 3.7 and 3.8, respectively, and are the mean of all recorded temperatures for a particular region during that month.

The temperature data indicate that from May–November, the air is warmest during August and coldest during May in all regions. Sea surface temperature is also warmest during August and coldest during May in all regions.

**Table 3.7 Mean Monthly Air Temperatures for Offshore Newfoundland and Labrador.**

| Month | Air Temperature (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nain | Cartwright | Orphan Basin | Flemish Cap | Grand Banks | Laurentian Basin | Tail of the Banks | NF Basin |
| **Jan** | -17.6 | -14.3 | -1.4 | 3.1 | 0.4 | 1.9 | 5.3 | 6.4 |
| **Feb** | -17.4 | -13.5 | -2.9 | 2.6 | -0.1 | 0.8 | 4.7 | 6.0 |
| **Mar** | -12.5 | -8.7 | -0.4 | 3.4 | 0.7 | 1.4 | 5.5 | 6.8 |
| **Apr** | -4.6 | -1.8 | 1.3 | 5.1 | 2.3 | 4.0 | 7.2 | 9.6 |
| **May** | 1.5 | 3.3 | 3.5 | 7.0 | 4.4 | 6.9 | 9.5 | 11.1 |
| **Jun** | 6.4 | 8.6 | 6.6 | 9.2 | 7.6 | 10.6 | 12.3 | 13.6 |
| **Jul** | 10.1 | 12.3 | 10.1 | 12.4 | 12.1 | 16.0 | 16.7 | 17.6 |
| **Aug** | 11.0 | 12.7 | 11.7 | 14.2 | 14.6 | 18.3 | 18.9 | 18.7 |
| **Sep** | 7.5 | 9.0 | 10.3 | 13.3 | 12.8 | 16.2 | 16.8 | 17.1 |
| **Oct** | 2.1 | 3.7 | 6.6 | 10.4 | 9.2 | 12.3 | 13.4 | 14.0 |
| **Nov** | -4.4 | -2.0 | 3.7 | 7.8 | 5.6 | 8.6 | 10.4 | 11.2 |
| **Dec** | -11.8 | -8.8 | 1.1 | 5.4 | 2.5 | 4.8 | 7.5 | 8.5 |

Sources: EC 2015a; C-NLOPB 2014; Oceans 2014.

**Table 3.8 Mean Monthly Sea Surface Temperatures for Offshore Newfoundland and Labrador.**

| Month | Sea Surface Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Labrador Shelf | Orphan Basin | Flemish Cap | Grand Banks | Laurentian Basin | Tail of the Banks | NF Basin |
| **Jan** | -0.6 | 0.9 | 4.8 | 0.9 | 4.3 | 10.9 | 11.7 |
| **Feb** | 0.7 | 0.4 | 3.8 | 0.0 | 3.2 | 10.3 | 10.2 |
| **Mar** | -0.4 | 0.7 | 4.1 | 0.1 | 2.9 | 10.2 | 9.9 |
| **Apr** | -1.4 | 1.2 | 4.8 | 0.7 | 3.7 | 11.8 | 9.9 |
| **May** | nd | 2.5 | 6.3 | 2.6 | 6.1 | 13.1 | 11.8 |
| **Jun** | 1.7 | 4.8 | 8.4 | 5.5 | 10.3 | 15.2 | 14.0 |
| **Jul** | 4.6 | 8.4 | 11.4 | 10.3 | 15.3 | 19.2 | 17.5 |
| **Aug** | 6.0 | 11.3 | 13.7 | 14.0 | 18.3 | 21.1 | 20.3 |
| **Sep** | 3.4 | 10.6 | 13.7 | 13.5 | 17.0 | 20.1 | 18.8 |
| **Oct** | 2.3 | 7.7 | 11.4 | 10.5 | 13.4 | 17.9 | 16.3 |
| **Nov** | 1.0 | 4.7 | 9.2 | 6.8 | 10.0 | 15.8 | 14.9 |
| **Dec** | -0.6 | 2.5 | 6.5 | 3.5 | 7.0 | 12.8 | 13.2 |

Sources: C-NLOPB 2014; Oceans 2014; Husky 2010; C-NLOPB 2010.

#### 3.2.4.2 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. Reduced visibility can affect crew changes and work boat operations as well as increase the risk of interactions of the seismic vessel and its towed gear with obstructions in the water. The ability of MMOs to effectively monitor the safety zone is also affected by reduced visibility.

The frequency distributions of visibility states from the ICOADS data set for each region within the Study Area are presented in Tables 3.9 to 3.15. The visibility states have been defined as very poor (less than 1 km for the Labrador Sea, Laurentian Basin, and Newfoundland Basin, and less than 0.5 km for all other regions), poor (1–2 km for the Labrador Sea, Laurentian Basin, and Newfoundland Basin, and 0.5–2 km for all other regions), fair (2–10 km), and good (>10 km).

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 decrease, and by September the air temperature begins to fall below the sea surface temperature and the occurrence of fog decreases.

Throughout the May–November period, September and October have the lowest occurrences of reduced visibility within the Study Area because the air temperature has, on average, decreased below the sea surface temperature but 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. There is less seasonal variation in visibility in the Labrador Sea, the Newfoundland Basin and south of the Grand Banks.

**Table 3.9 Frequency of Occurrence of Visibility States for the Labrador Sea.**

| Month | Frequency of Occurrence (%) | | | |
|---|---|---|---|---|
| | Very Poor (<1 km) | Poor (1–2 km) | Fair (2–10 km) | Good (>10 km) |
| January | 6 | 4 | 23 | 67 |
| February | 7 | 3 | 21 | 69 |
| March | 5 | 6 | 22 | 67 |
| April | 5 | 2 | 11 | 82 |
| May | 17 | 6 | 9 | 68 |
| June | 20 | 2 | 11 | 67 |
| July | 15 | 6 | 12 | 67 |
| August | 14 | 2 | 12 | 72 |
| September | 6 | 2 | 9 | 83 |
| October | 5 | 3 | 14 | 78 |
| November | 4 | 3 | 19 | 74 |
| December | 4 | 3 | 23 | 70 |

Source: Husky 2010.

**Table 3.10 Frequency of Occurrence of Visibility States for Orphan Basin.**

| Month | Frequency of Occurrence (%) | | | |
|---|---|---|---|---|
| | Very Poor (<0.5 km) | Poor (0.5–2 km) | Fair (2–10 km) | Good (>10 km) |
| January | 3.7 | 7.6 | 59.3 | 29.3 |
| February | 3.5 | 8.7 | 55.7 | 32.1 |
| March | 6.7 | 10.9 | 54.8 | 27.6 |
| April | 9.5 | 11.4 | 52.3 | 26.8 |
| May | 14.2 | 10.3 | 43.4 | 32.1 |
| June | 20.2 | 14.1 | 36.8 | 28.9 |
| July | 27.2 | 14.3 | 33.3 | 25.2 |
| August | 15.3 | 9.4 | 37.2 | 38.0 |
| September | 8.4 | 5.7 | 38.3 | 47.6 |
| October | 4.9 | 6.2 | 44.3 | 44.5 |
| November | 5.0 | 7.2 | 48.3 | 39.6 |
| December | 4.5 | 7.5 | 54.5 | 33.5 |
| Annual | 10.1 | 9.4 | 46.5 | 34.0 |

Source: C-NLOPB 2014.

## Table 3.11 Frequency of Occurrence of Visibility States for the Flemish Cap.

| Month | Frequency of Occurrence (%) | | | |
|---|---|---|---|---|
| | Very Poor (<0.5 km) | Poor (0.5–2 km) | Fair (2–10 km) | Good (>10 km) |
| **January** | 2.5 | 5.2 | 48.9 | 43.4 |
| **February** | 2.8 | 5.2 | 49.3 | 42.7 |
| **March** | 4.4 | 7.0 | 45.6 | 43.1 |
| **April** | 7.8 | 8.5 | 41.4 | 42.4 |
| **May** | 10.8 | 8.6 | 37.9 | 42.7 |
| **June** | 17.6 | 11.5 | 35.9 | 35.0 |
| **July** | 26.0 | 14.0 | 30.5 | 29.6 |
| **August** | 15.4 | 8.8 | 34.1 | 41.7 |
| **September** | 6.8 | 5.6 | 37.7 | 50.0 |
| **October** | 4.0 | 4.2 | 39.9 | 51.9 |
| **November** | 3.9 | 4.3 | 43.1 | 48.6 |
| **December** | 2.9 | 4.4 | 45.7 | 47.0 |
| **Annual** | 9.1 | 7.5 | 40.7 | 42.7 |

Source: C-NLOPB 2014.

## Table 3.12 Frequency of Occurrence of Visibility States for the Grand Banks.

| Month | Frequency of Occurrence (%) | | | |
|---|---|---|---|---|
| | Very Poor (<0.5 km) | Poor (0.5–2 km) | Fair (2–10 km) | Good (>10 km) |
| **January** | 6.0 | 5.9 | 45.3 | 42.9 |
| **February** | 7.7 | 7.3 | 45.6 | 39.3 |
| **March** | 9.2 | 8.4 | 43.5 | 38.9 |
| **April** | 16.6 | 9.3 | 39.2 | 34.9 |
| **May** | 21.5 | 10.9 | 34.6 | 33.1 |
| **June** | 29.3 | 11.6 | 31.8 | 27.3 |
| **July** | 40.3 | 11.5 | 25.4 | 22.9 |
| **August** | 21.5 | 7.9 | 32.7 | 37.9 |
| **September** | 10.1 | 5.0 | 33.5 | 51.3 |
| **October** | 7.3 | 4.6 | 36.8 | 51.4 |
| **November** | 8.3 | 5.6 | 38.6 | 47.5 |
| **December** | 6.5 | 5.5 | 42.6 | 45.4 |
| **Annual** | 15.8 | 7.9 | 37.2 | 39.1 |

Source: C-NLOPB 2014.

## Table 3.13 Frequency of Occurrence of Visibility States for the Laurentian 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 |

Source: Oceans 2014.

## 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 |

Source: C-NLOPB 2014.

**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 |

Source: Oceans 2014.

### 3.2.5 Weather Systems

The climate of the Study Area 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.

The passage of high and low pressure circulation systems yield a climate within the Study Area that can be highly variable. Conversely, intense low pressure systems also frequently slow down or stall off the coasts 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. Atmospheric circulation is predominantly from the northwest in the Labrador region, transporting cold Arctic air masses to the northerly portion of the Study Area (Prisenberg et al. 1996). Otherwise, prevailing winds are from the west in the Study Area, typical of such mid-latitudes due to the normal tropical to polar temperature gradient. The intensity of this gradient directly affects the mean strength of the westerly flow, resulting in a much stronger flow during the winter than the summer with the increase in the south-to-north temperature gradient.

Major storms travelling west-to-east across Canada generally pass through St. Lawrence and move seaward over the Grand Banks and Labrador Sea (CCG 2012). During the winter months, an upper level trough and upper ridge typically occur over central Canada and the North Atlantic, respectively, causing three primary storm tracks which affect the Study Area: (1) from the Great Lakes Basin; (2) from Cape Hatteras, North Carolina; and (3) from the Gulf of Mexico. These storm tracks bring an average of eight low pressure systems per month to the eastern Newfoundland and southern portions of the Study Area. The storms can range in intensity from relatively weak to major winter storms.

Low pressure systems that form in moisture-abundant southern latitudes are carried northward to Labrador by the jet stream, resulting in blizzard conditions with snow and strong winds during the winter months. As these low pressure systems move away, the wind shifts back to the northwest, resulting in extreme wind chills as the winds bring bitter Arctic air to the Labrador portion of the Study Area (Barney n.d.). Cold air temperatures result in freezing precipitation such as snow showers and squalls over open water in the Labrador Sea throughout the winter months, along with super-cooled fog which is most frequently reported between February and March (CCG 2012). Freezing precipitation generally occurs in the Labrador portion of the Study Area when the air temperature is -10ºC, the westerly wind speed is 30 knots, and wave heights are 4–5 m (CCG 2012). As solar radiation increases during the spring months, a general atmospheric warming occurs, that is relatively greater at higher latitudes. This results in a decreased north-south temperature contrast, thereby lowering the kinetic energy of the westerly flow and decreasing the potential energy available for storm development. In the Labrador portion of the Study Area, this often results in grey skies, frequent drizzle or freezing drizzle and temperatures around 0ºC (Barney n.d.). In the summer months, the primary storm tracks shift farther north than in the winter. Overall, storms occur less frequently and are much weaker in the Study Area, with decreased significant wave heights and wind speeds. The combination of the more northerly low pressure systems and the northwest sector of the sub-tropical high to the south results in a prevailing wind direction across the central and southern portions of the Study Area from the southwest to south. Southwesterlies are also common in the Labrador portion of the Study Area, with the northerly low pressure systems resulting in relatively frequent rainfall and coastal fog (Barney n.d.).

Problematic and quickly deepening storms are a concern south of Newfoundland, near the warm Gulf Stream waters. Rapidly deepening oceanic cyclones can develop into a “weather bomb”; defined as a storm that undergoes central pressure drops greater than 24 mb in 24 h. Weather bombs typically include hurricane-force winds near the storm’s center during the rapidly deepening stage and a clear area near the center during the storm’s mature stage. Post-development, these systems travel either across Newfoundland or near the southeast coast, producing gale- to storm-force winds from the southwest to south. These systems do not typically reach as far as the offshore Labrador portion of the Study Area.

In addition to extratropical cyclones, tropical cyclones often retain their tropical characteristics as they enter the Study Area, producing the strongest sustained surface winds observed 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. A tropical storm will maintain its energy until there is no longer a sufficient supply of warm, moist air available, and typically moves east to west over the warm waters in the southern tropics. If a tropical storm turns northwards and heads toward Newfoundland, it begins to lose some of its tropical characteristics while moving over the colder oceanic waters. Once these weakening storms reach Newfoundland, they are typically embedded into a mid-latitude low and are often down-classified to post-tropical, either as an extratropical cyclone or a remnant low. However, tropical cyclones occasionally encounter favourable conditions as they travel northwards, and retain their tropical characteristics long enough to reach the Orphan Basin. As with weather bombs, tropical storms do not typically extend into the Labrador portion of the Study Area, owing to the cold waters of the Labrador Sea.

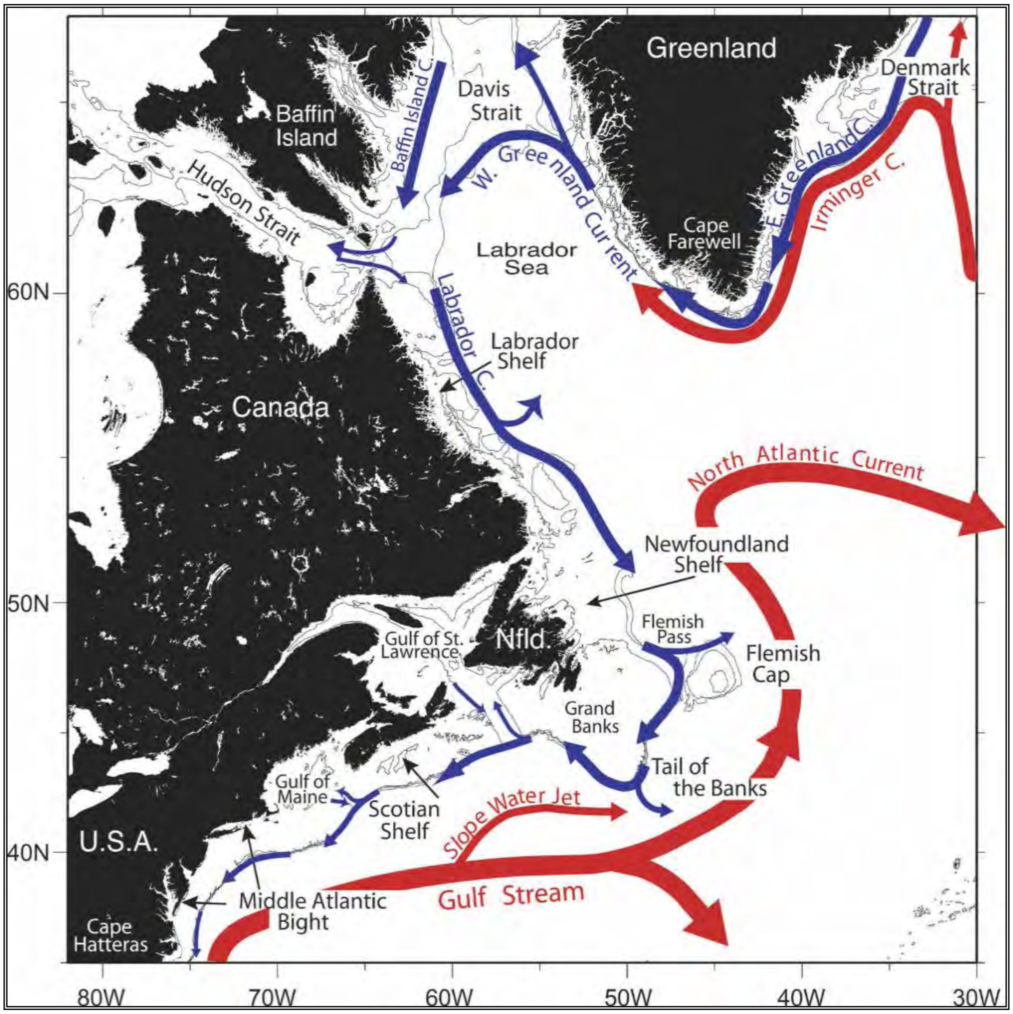
Approximately half of the tropical cyclones formed in the Atlantic that travel into the mid-latitude region transform into extratropical cyclones. During this transformation, the system loses its tropical characteristics but still produces large waves, gale- to hurricane-force winds and intense rainfall. The likelihood of the transformation of a tropical storm to an extratropical storm increases during the latter half of the hurricane season, with the highest probability of transition occurring in October. In the Atlantic, this transition occurs in the early and late hurricane season at lower latitudes, and during the peak of the season in higher latitudes.

## 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 Labrador Shelf, Southern Newfoundland, and Eastern Newfoundland SEAs (C-NLOPB 2008, 2010, 2014). A summary of the major currents in the Study Area is provided below, with additional information from project-specific EAs (LGL 2014, 2015a,b).

### 3.3.1 Major Currents in the Study Area

The large scale circulation off the coast of Newfoundland and Labrador is dominated by well-established currents that flow along the margins of the continental shelf. Three major current systems in the area are the Labrador Current, the North Atlantic Current, and the Gulf Stream. The main current pattern is shown in Figure 3.2, with cold shelf break waters shown in blue and warm Gulf Stream waters shown in red.




Source: Fratantoni and Pickart 2007.

**Figure 3.2 Major Ocean Currents and Surface Circulation Features in the Northwest Atlantic Ocean.**

The Labrador Current, originating in the Davis Strait, runs south along the Labrador Coast, with contributions from the warmer, more saline waters of the West Greenland Current, and the colder, less saline waters of the Baffin Island Current and Hudson Bay. 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.

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 the 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. At certain stages of their development, northward forming meanders 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, along 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 amount in the spring, in phase with the north-south shifts of its position.

There is another 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.

An additional influence on ocean circulation in the southern region of 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, the difference in winter sea level atmospheric pressures between the Azores and Iceland, 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 factors such as tides, wind stress, atmospheric pressure changes from the passage of storm systems, volume transport of the Labrador Current, seasonal temperature changes and salinity variations. 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 affects 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

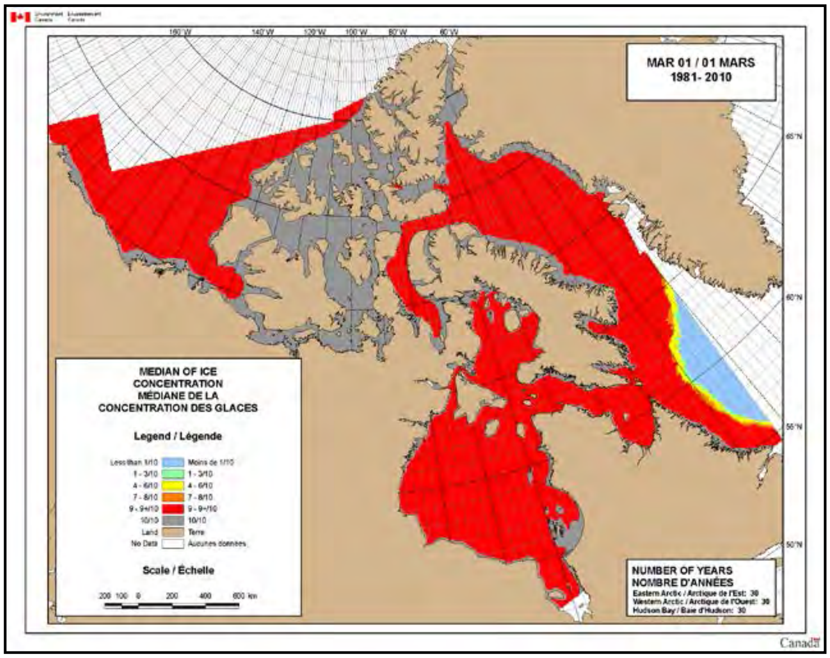
Ice conditions are an important component of the physical environment and often directly affect offshore activities, including seismic surveys, along the coast of Newfoundland and Labrador. A review of ice conditions in the Study Area has been provided in the Labrador Shelf, Southern Newfoundland, and Eastern Newfoundland SEAs (C-NLOPB 2008, 2010, 2014). A summary of ice conditions is provided below, with updated information on sea ice extent and iceberg sightings for offshore Newfoundland and Labrador. The classification of ice commonly found along Canada’s eastern seaboard is based on internationally accepted terminology (CIS 2011).

### 3.4.1 Sea Ice

Sea ice generally begins to form in mid-November to mid-December on the coast of southern Labrador (LGL 2014), spreading south to Newfoundland waters by early-January. The 30-year median concentration of sea ice reaches its maximum in the northern Labrador portion of the Study Area (north of 55ºN) during the week of 1 March (Figure 3.3), and in the southern Labrador (south of 55ºN extending to Newfoundland) and eastern Newfoundland (extending towards the Flemish Cap) portions of the Study Area during the week of 5 March (Figure 3.4). Thirty-year median concentrations of sea ice are not present in the southern (including the southern Grand Banks) portion of the Study Area.

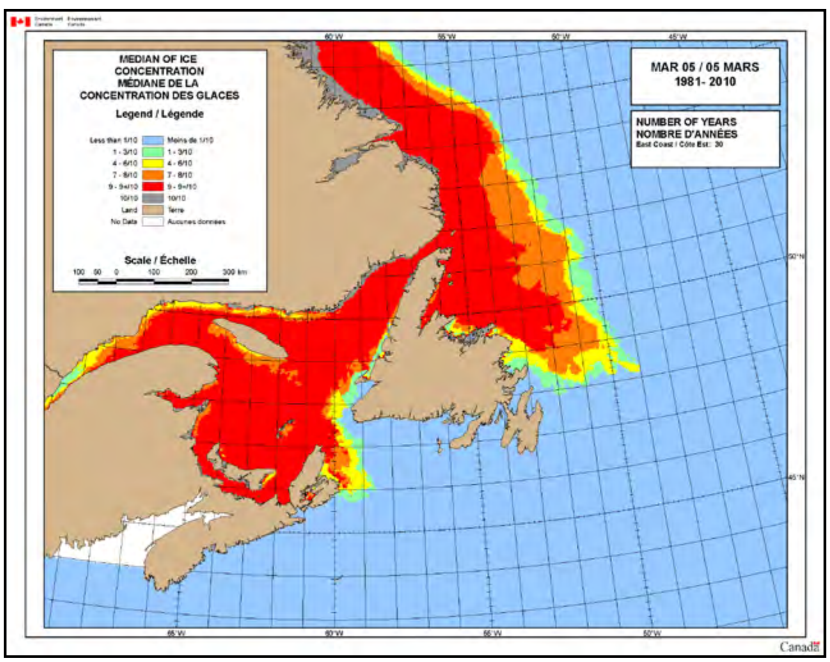
The maximum median sea ice extent reaches beyond the northernmost portion of the Study Area and to 56–59ºW in the northern Labrador portion of the Study Area, to ~51ºW in the southern Labrador portion and to ~48ºN, 49ºW in the eastern Newfoundland portion of the Study Area. Based on the 30-year median of data for 1981–2010, only the central and northern portions of the Study Area would have some ice cover (Figures 3.5 and 3.6). During extreme years, sea ice could occur throughout the northern and southern Labrador and eastern Newfoundland portions of the Study Area (Figures 3.5 and 3.6). Sea ice typically extends southwards to ~44ºN during extreme years in the southern portion of the Study Area (Figure 3.6); however, sea ice could occur as far south as ~43ºN (Figure 3.7). From mid-August until mid-November, the majority of the northern and southern Labrador portions of the Study Area will be free of sea ice. From mid-July to mid-December the eastern Newfoundland portion of the Study Area will be virtually or entirely ice-free. Lastly, from early-May until early-February the southern portion of the Study Area will generally be ice-free (CIS 2011).

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice indicates that the northern Labrador portion of the Study Area is first affected by sea ice beginning the week of 12 November, lasting until the week beginning 27 August (CIS 2011). Figure 3.8 depicts the week of 1 April, the period when the frequency of presence of sea ice is the greatest over the northern Labrador portion of the Study Area. The southern Labrador portion of the Study Area is first affected by sea ice during the week of 26 November, and is ice-free beginning between the weeks of 20 and 27 August. The eastern Newfoundland portion of the Study Area is initially affected by sea ice beginning the week of 18 December, with ice present until the week beginning 23 July. The southern portion of the Study Area is first affected by sea ice during the week of 5 February, lasting until the week beginning 14 May (CIS 2011). The frequency of presence of sea ice is greatest over the southern Labrador, eastern Newfoundland and southern portions of the study area during the week of 12 March (Figure 3.9).



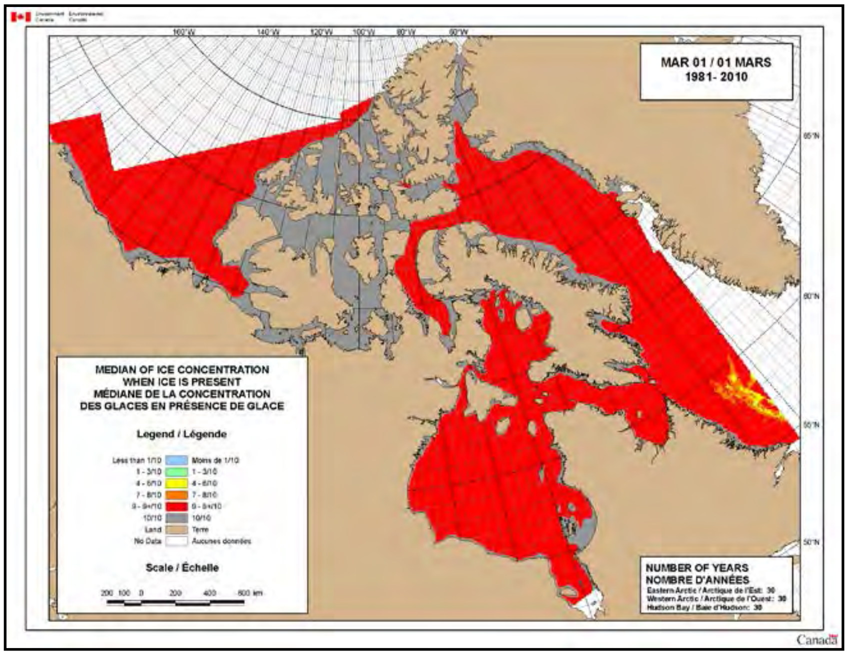

Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.3 30-Year Median Concentration of Sea Ice in Northern Canadian Waters, 1981–2010 (1 March).**



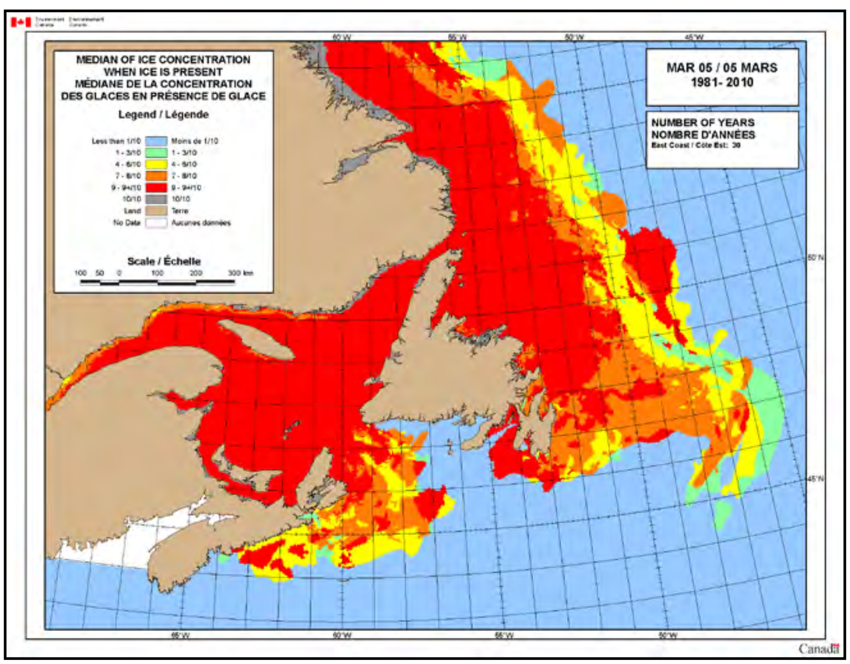

Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.4 30-Year Median Concentration of Sea Ice in East Coast Waters, 1981–2010 (5 March).**



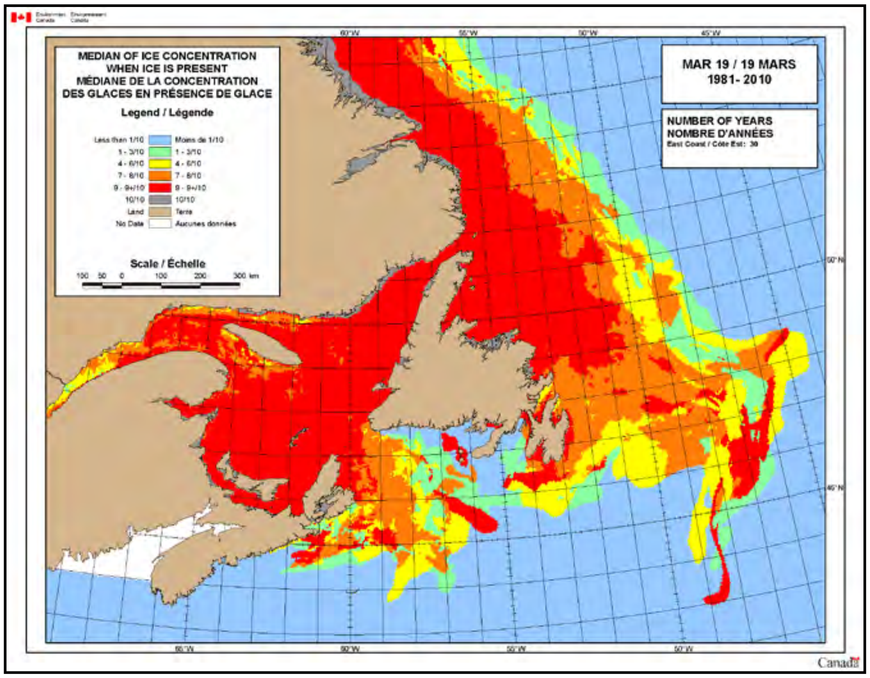

Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.5 30-Year Median Concentration of Sea Ice when Ice is Present in Northern Canadian Waters, 1981–2010 (1 March).**



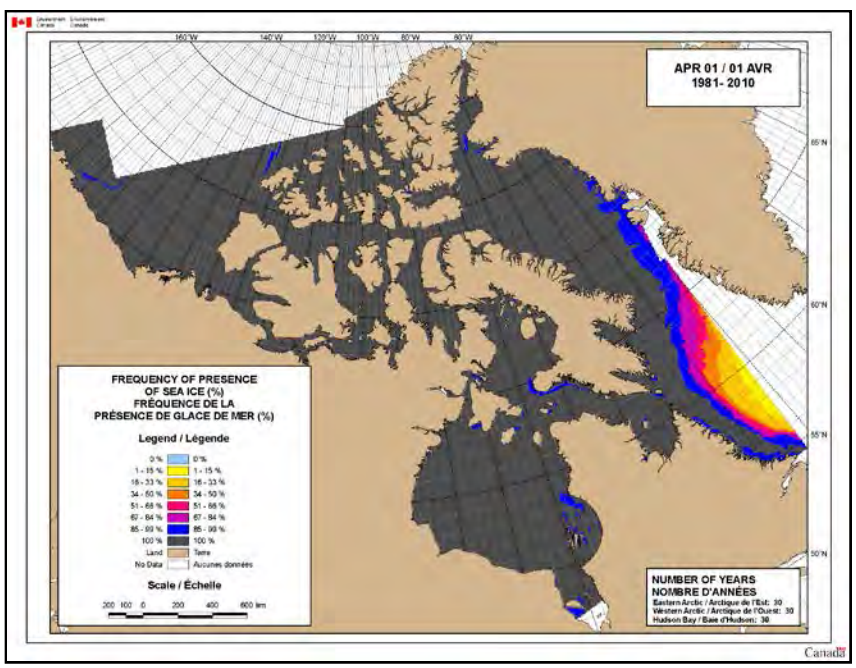

Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.6 30-Year Median Concentration of Sea Ice when Ice is Present in East Coast Waters, 1981–2010 (5 March).**



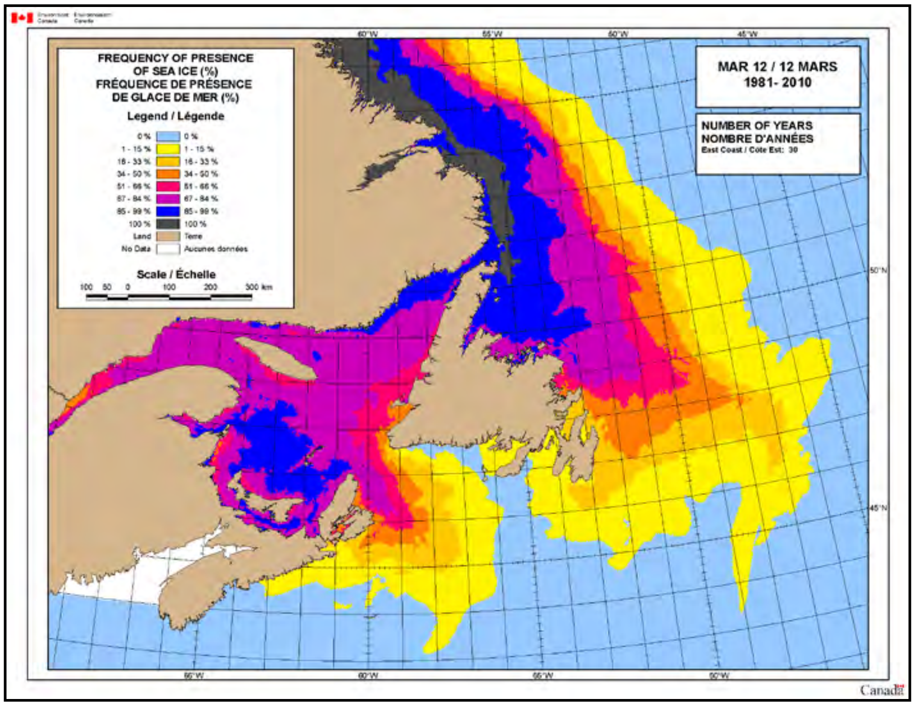

Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.7 30-Year Median Concentration of Sea Ice when Ice is Present in East Coast Waters, 1981–2010 (19 March).**




Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016.

**Figure 3.8 30-Year Frequency of Presence of Sea Ice in Northern Canadian Waters, 1981–2010 (1 April).**




Source: Canadian Ice Service 30-Year Ice Atlas.
(http://iceweb1.cis.ec.gc.ca/30Atlas/page1.xhtml?grp=Guest&lang=en), accessed November 2016

**Figure 3.9 30-Year Frequency of Presence of Sea Ice in Canadian East Coast Waters, 1981–2010 (12 March).**

When sea ice is present, the predominant ice type within the northern Labrador portion of the Study Area from 12 November until the week of 1 January is a mixture of new, grey and grey-white, with grey-white ice first appearing the week of 26 November. Some thin first-year ice near the Labrador coast is present as of the week of 1 January. Beginning the week of 1 February, thin first-year ice is present throughout this portion of the Study Area, with remnants of grey-white ice and some medium first-year ice until the week of 1 March. By the week of 1 April, thick first-year ice is present, and the grey-white ice has disappeared. Old ice begins to appear the week of 15 May, and is the predominant ice type by the week of 30 July (CIS 2011).

New ice begins to form near the coast in the week of 19 November within the southern Labrador portion of the Study Area, with grey and grey-white ice also present as of the weeks of 4 and 18 December, respectively. Thin first year-ice begins to form near the Labrador coast by the week of 1 January and extends eastwards over the next month, with medium first-year ice also present as of the week of 5 February. Thick first-year ice is observed by the week of 12 March, with some old ice present by the week of 4 June, and these two ice types consist of the majority of sea ice present by the week of 2 July, after which much of the ice begins to recede (CIS 2011).

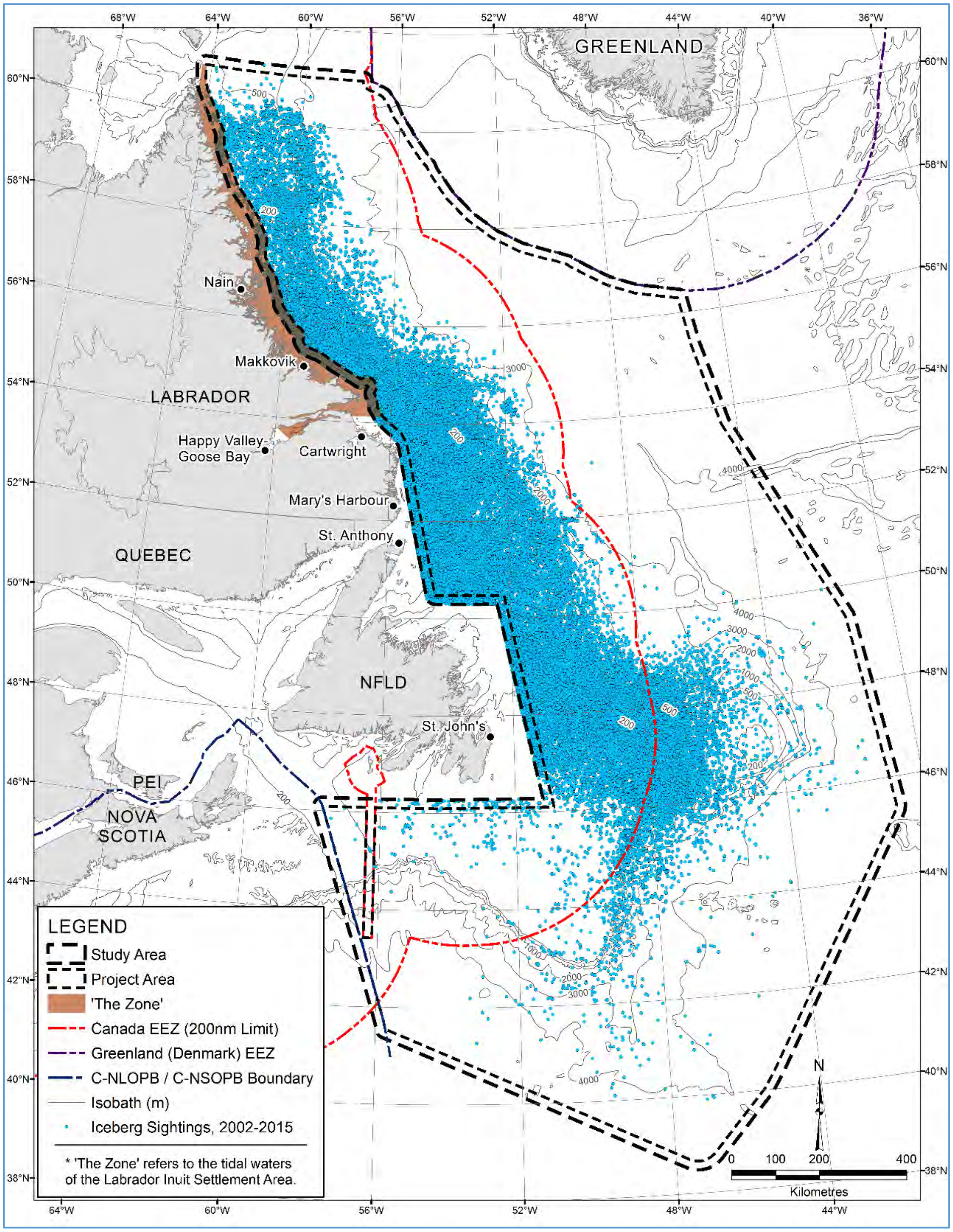
Grey-white ice begins to enter the southern portion of the Study Area by the week of 15 January, followed by a mixture of grey and grey-white ice by the week of 22 January. New ice also extends into the southern Study Area by the week of 5 February, with thin first-year ice appearing by the week of 12 February. Medium first-year ice is present by the week of 5 March and old ice by the week of 26 March (CIS 2011).

### 3.4.2 Icebergs

Icebergs often cause concern with regard to navigation and offshore activities (including seismic surveys) along the coast of Newfoundland and Labrador. The major sources, contributing ~90% of icebergs in Canadian waters, are 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 influences the number of icebergs that move into the coast or remain offshore. Major iceberg drift patterns flow southward along the western border of the Study Area from offshore Labrador to Newfoundland, branching eastward towards the Flemish Cap and extending towards the south-central portion of the Study Area. No iceberg sightings were recorded in the easternmost portion of the Study Area, and sightings decrease in the southwestern and southeastern portions of the Study Area (Figure 3.10).

An analysis was performed to determine the threat posed by icebergs in the Study Area. The International Ice Patrol (IIP) Iceberg Sightings Database was used as the primary data source in this analysis (NSIDC 1995, updated annually). As shown in Table 3.16, during the period from 2002–2015 a total of 70,087 icebergs were observed in the Study Area. It should be noted that in Labrador waters north of ~52ºN in the Study Area, there were no iceberg sightings data available for 2002 and 2004, and there were only five and seven sightings for 2003 and 2005, respectively. Sightings may not include all icebergs passing through the Study Area, but indicate the relative abundance by month. Of the 70,087 icebergs sighted, 57.1% were observed during the period of May–November. Most were sighted in April, May and June (25.8, 21.9 and 21.1%, respectively), followed by March (14.0%) and July (11.7%). All remaining months contributed <3% each to the total number of iceberg sightings. Additionally, there was a great deal of inter-annual variability in the numbers of iceberg sightings. For example, during May–November of 2009, there were 10,685 icebergs observed in the Study Area. During the same time period of 2010, there were only 1,843 icebergs observed.

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 2002–2015, 39.3% of the 70,087 icebergs with a defined sized classification recorded in the Study Area were classified as medium, large, or very large-sized.




Source: NSIDC 1995, IIP Iceberg Sightings Database, accessed November 2016.

**Figure 3.10 Iceberg Sightings in the Study Area, 2002–2015.**

**Table 3.16 Annual and Monthly Iceberg Sightings within the Study Area, 2002–2015.**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2002** | - | 67 | 786 | 1,270 | 768 | 614 | 100 | - | - | - | - | - | **3,605** |
| **2003** | - | 11 | 390 | 1,260 | 1,877 | 351 | 58 | - | - | - | - | - | **3,947** |
| **2004** | - | 1 | 74 | 971 | 1,305 | 175 | 39 | 6 | - | - | - | - | **2,571** |
| **2005** | - | 5 | 15 | 43 | 6 | 20 | - | - | - | - | - | 3 | **92** |
| **2006** | 6 | 133 | 113 | 638 | 498 | 2,087 | - | - | - | - | 3 | 6 | **3,484** |
| **2007** | 40 | 22 | 535 | 273 | 435 | 1,054 | 1,325 | 282 | 125 | - | 3 | 5 | **4,099** |
| **2008** | 34 | 139 | 635 | 2,451 | 603 | 591 | 300 | 19 | 16 | - | - | 2 | **4,790** |
| **2009** | 38 | 121 | 1,730 | 2,117 | 4,017 | 1,779 | 720 | 143 | 18 | - | - | 2 | **10,685** |
| **2010** | 2 | 37 | 127 | 1,015 | 160 | 339 | 119 | 38 | 5 | - | 1 | - | **1,843** |
| **2011** | 1 | 47 | 167 | 128 | 761 | 871 | 903 | 339 | 8 | 1 | - | - | **3,226** |
| **2012** | 12 | 128 | 293 | 951 | 1,155 | 530 | 347 | 71 | 52 | 18 | 15 | 2 | **3,574** |
| **2013** | 16 | 222 | 86 | 424 | 890 | 1,080 | 804 | 148 | 30 | 2 | 3 | 7 | **3,712** |
| **2014** | 117 | 684 | 3,070 | 3,887 | 1,034 | 3,212 | 992 | 206 | 10 | - | 4 | 11 | **13,227** |
| **2015** | 17 | 227 | 1,801 | 2,642 | 1,850 | 2,074 | 2,505 | 69 | 47 | - | - | - | **11,232** |
| **Total** | **283** | **1,844** | **9,822** | **18,070** | **15,359** | **14,777** | **8,212** | **1,321** | **311** | **21** | **29** | **38** | **70,087** |
| **% of Total** | 0.4 | 2.6 | 14.0 | 25.8 | 21.9 | 21.1 | 11.7 | 1.9 | 0.4 | 0.0 | 0.0 | 0.0 | - |

Source: NSIDC 1995, IIP Iceberg Sightings Database, accessed November 2016.