Environmental Assessment of MKI
Southern Grand Banks Seismic Program, 2014–2018

Prepared by

LGL LIMITED
environmental research associates

for

Multi Klient Invest AS

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TGS-NOPEC Geophysical Company ASA

March 2014
Project No. SA1250

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1.0 Introduction

This is an Environmental Assessment (EA) prepared by LGL Limited (LGL) for Multi Klient Invest AS (MKI) and TGS-NOPEC Geophysical Company ASA (TGS)'s proposed 2014–2018 2-Dimensional (2D) and/or 3-Dimensional (3D) marine seismic program in the Southern Grand Banks area, Newfoundland and Labrador. The EA is designed to apply to the Project conducted over the area of operations during a five-year period and 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 Scoping Document prepared by the C-NLOPB, 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 five-year period (2014 to 2018) with seismic operations potentially occurring between May and November in any given year. The present document focuses primarily on the proposed 2D seismic program which is anticipated to occur in 2014. It is currently uncertain if MKI and TGS will undertake seismic surveys in the Southern Grand Banks Project Area (Figure 1.1) during 2015–2018, as future surveys will depend on results of the initial survey and other factors. However, it is anticipated that there will be one seismic survey a year, with the possibility of 2D and 3D seismic surveys occurring in the same year.

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 *Canada-Newfoundland Atlantic Accord Implementation Act* and the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*. 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 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*.

MKI and TGS will follow guidelines issued by the C-NLOPB, the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (January 2012). These guidelines outline mitigation and monitoring requirements for marine mammals and sea turtles for the program. The Project will also follow DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* and other advice received during the consultations for this Project.

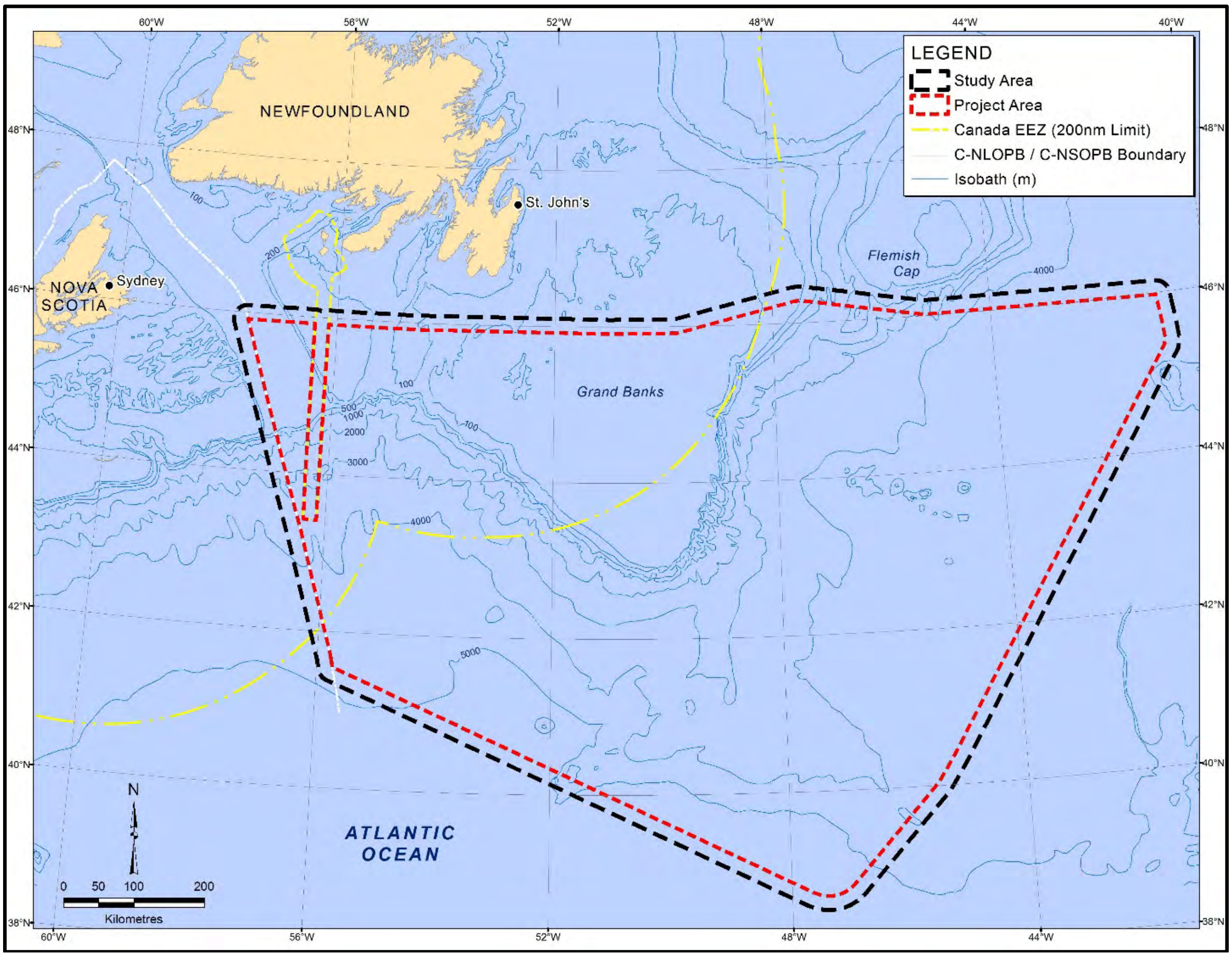

Figure 1.1 Locations of the Project Area and Study Area for Proposed Southern Grand Banks Seismic Program, 2014 to 2018.

1.2 The Proponents: MKI and TGS

The Operator, MKI, is a wholly owned subsidiary of Petroleum Geo-Services ASA (PGS), headquartered in Oslo, Norway. MKI has entered into a cooperation agreement with TGS, headquartered in Houston, Texas, to conduct this seismic program. PGS is a leading provider of seismic and electromagnetic survey services, data acquisition, processing, and reservoir analysis for the global oil and gas industry. PGS was founded in Norway in 1991 and currently has a presence in over 25 countries with regional centers in London, Houston, and Singapore.

TGS provides multi-client geoscience data to oil and gas exploration and production companies worldwide. In addition to extensive global geophysical and geological data libraries that include multi-client seismic data, magnetic and gravity data, digital well logs, production data and directional surveys, TGS also offers advanced processing and imaging services, interpretation products, permanent reservoir monitoring and data integration solutions

1.3 Canada-Newfoundland and Labrador Benefits

An important aspect of the C-NLOPB's mandate is the administration of provisions in the Accord Acts relating to industrial and employment benefits from the development of oil and gas resources in the Newfoundland and Labrador Offshore Area for Canada in general and for the Province of Newfoundland and Labrador in particular.

The Acts require that before any work or activity is authorized in the offshore area, a Canada-Newfoundland and Labrador Benefits Plan must be approved by the Board. In general terms, a benefits plan must describe a plan for the employment of Canadians and, in particular, members of the labour force of the province; and for providing manufacturers, consultants, contractors, and service companies in the province and other parts of Canada with a full and fair opportunity to participate on a competitive basis in the supply of goods and services. MKI will manage its east coast operations from St. John's, NL. MKI supports the principle that first consideration be given to personnel, support and other services that can be provided within NL, and to goods manufactured in NL, 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. All contractors and sub-contractors working for MKI in NL must comply with the approved MKI Canadian-Newfoundland and Labrador Benefits Plan.

1.4 Contacts

Relevant contacts at MKI and TGS for the proposed seismic program are provided below.

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2.0 Project Description

In 2014, MKI and TGS are proposing to conduct a 2D single streamer marine seismic survey in the Southern Grand Banks area (see Figure 1.1), potentially starting as early as 1 May and, depending on start date, concluding as late as 30 November. One or more 2D and 3D seismic programs are also anticipated to occur between 2015–2018, depending on the results of the initial survey in 2014 and/or the availability of seismic vessels.

The timing of the survey and/or individual survey lines is subject to regulatory approvals, and such factors as weather conditions, vessel availability, location of fishing activities, and regulatory approvals. Any subsequent seismic surveys conducted during 2015–2018 would also occur during the same temporal window of 1 May to 30 November.

2.1 Spatial and Temporal Boundaries

The spatial boundaries of the Project Area are shown in Figure 1.1. 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 areas of the Study Area and Project Area are 800,805 km^2 and 722,291 km^2, respectively. The Study Area extends slightly into both Nova Scotia waters and St. Pierre et Miquelon waters. Most of the Study Area and Project Area is located outside of Canada's Exclusive Economic Zone (EEZ) (200 nm limit).

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

- Northwest: 45.914°N, 57.631°W;
- Northeast: 45.979°N, 40.960°W;
- Southeast: 38.657°N, 47.274°W; and
- Southwest: 41.546°N, 55.727°W

The temporal boundaries of the proposed Project are between 1 May and 30 November during 2014-2018. The duration of a seismic survey is estimated at 60 to <120 days in a given year.

2.2 Project Overview

The proposed Project is a ship-borne geophysical program that could include as much as 19,000 km of 2D seismic survey lines in 2014 but the actual amount of data to be acquired in 2014 is yet to be determined. Data acquisition plans for 2D and 3D surveys during 2015-2018 are not yet determined. The proposed Project Area includes space to account for ship turning and streamer deployment.

The proposed 2014 2D program will use a conventional seismic ship (e.g., the M/V *Sanco Spirit* or a similar vessel; see Section 2.2.6) which will tow the sound source (airgun array) and a single streamer containing receiving hydrophones. The support vessel will be the M/V *Blain M.* (described below). The seismic survey and support vessels used during subsequent 2D or 3D surveys are unknown at present but will be approved for operation in Canadian waters by Transport Canada and C-NLOPB and will be typical of the worldwide fleet.

Proposed mitigation procedures for this survey (detailed in Section 5.6) are based on a variety of sources, including:

- Discussions and advice received during consultations for this Project;
- The C-NLOPB Scoping Document, and the Environmental Planning, Mitigation and Reporting guidance in Appendix 2 of the Board's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012);
- DFO's "Statement of Practice with respect to the Mitigation of Seismic Sound in the Marine Environment";
- National and international acts, regulations or conventions, such as the *Fisheries Act* and Regulations, *International Convention for the Prevention of Pollution from Ships* (MARPOL), and International Maritime Organization (IMO) standards;
- Other standards and guidance, such as the One Ocean Protocol for Seismic Survey Programs in Newfoundland and Labrador (2013), and the Joint Nature Conservation Committee (JNCC) guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys (2010);
- Stranded seabird handling and release protocols;
- Industry best practices; and
- Expert judgement / experience from past surveys.

These mitigations include such procedures as close communications with fish harvesting interests, avoidance of active fishing areas, the use of a Single Point of Contact to help communications between the survey and fishers, the establishment of a Fishing Gear Compensation Program, ramp-up (i.e., soft start) of the airgun arrays, the use of at least two dedicated Marine Mammal Observers (MMOs) to monitor for marine mammals and sea turtles, to record seabird and other wildlife data and to implement shut downs of the seismic sound source array when required, and the use of two Fisheries Liaison Officers (FLOs) to aid in coordination with fishing activities. One 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, and another Inuit FLO will be onboard the support vessel. An additional Inuit observer will also be onboard the seismic vessel to assist with marine mammal observations.

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 new 2D/3D 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 may 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 2014 in the Project Area (see Figure 1.1); and
2. Phase 2 will include 2D and/or 3D surveys in the Project Area (see Figure 1.1) that may be identified through analyses of existing and acquired data.

During Phase 2, it is anticipated that there will be one seismic survey a year, but there is a possibility of 2D and 3D seismic surveys occurring in the same year (i.e., two seismic vessels operating in the same season).

2.2.3 Project Scheduling

It is anticipated that annual seismic surveys will occur sometime within the period 1 May to 30 November from 2014 to 2018. The timing of the acquisition of specific lines within the Project Area in any year will depend on several factors, including commercial fish harvesting, the local weather, and sea state in specific locations. The estimated duration of the proposed 2014 survey is 60 to 120 days.

2.2.4 Site Plans

In 2014, it is planned that as much as 19,000 km of 2D seismic data could be acquired but the actual amount of data to be acquired is yet to be determined. Most 2D seismic survey lines will be orientated SW/NE or SE/NW, and line spacing will range from about 20-50 km. Survey line lengths are anticipated to range in length from approximately 100-800 km. Water depths in the Project Area range from about <100 m to >5,000 m (see Figure 1.1).

Most of the Southern Grand Banks seismic program will occur beyond Canada's Exclusive Economic Zone (EEZ).

2.2.5 Personnel

The *Sanco Spirit* can accommodate approximately 47 people. Personnel on seismic vessels typically include individuals from the Proponent (i.e., MKI), the vessel owner/operator (ship's officers and marine crew), and technical and scientific personnel from the main seismic contractor. The seismic vessels will also have FLOs and MMOs on board (see Section 5.6), as well as an MKI/TGS representative(s) who supervises Client Quality Control and Processing Quality Control. All project personnel will have all of the required certifications as specified by relevant Canadian legislation and the C-NLOPB. Regular personnel for the survey will include ship's officers and marine crew.

2.2.6 Project Ships

A single conventional seismic ship will be used for data acquisition. In 2014, the 86-m M/V *Sanco Spirit*[1] will serve as the survey vessel with support, as needed, planned to be from the 47-m *Blain M*. Ship re-supply, re-fuelling and transfers of personnel will take place in port during 2014, but in future years, may occur offshore using a support vessel for re-supply, crew changes and refuelling. Although the seismic vessel has a helideck, no helicopter or other support vessel use is planned for 2014.

2.2.6.1 Seismic Vessel

The M/V *Sanco Spirit* will tow the sound source (airgun) array and hydrophone streamer in 2014 (Figure 2.1). The specifications of the vessel are detailed below. The seismic ship will likely deploy a workboat to repair the streamer when necessary and will carry a Fast Rescue Craft. This Norwegian built (in 2009) vessel is 86 m long, 16 m wide, and is registered in Gibraltor. MKI will apply for a Coasting Trade Permit issued under the *Coasting Trade Act*. This vessel has a draft (loaded) of 5.8 m, cruises at 13 knots, and is equipped with a helideck. The *Sanco Spirit* has diesel-electric propulsion systems (main and thrusters) and operates on marine gas oil (MGO).

2.2.6.2 Support Vessel

In 2014, it is proposed that the seismic ship will be accompanied by a support vessel, the M/V *Blain M* (Figure 2.2). The support vessel will have responsibilities for communications with other vessels (primarily fishing vessels) that may be operating in the area and for scouting ahead to look for hazards. The *Blain M.* was built in Nova Scotia in 1981 and is registered in Ottawa. The vessel is 47.1 m long and about 11 m wide, with a draft of 2.5 m, and a cruising speed of 9 knots. The support vessel will be used as an additional method to obtain information on commercial fishing activity in the area and to warn other vessels in order to avoid gear losses for all parties involved. It would also be used to scout ahead of the seismic vessel for hazards such as floating debris. Re-supply, re-fuelling and transfers of personnel will be done in port during 2014, but may take place via the support vessel during subsequent years.

[1] Although this is the planned vessel, it is possible that a different ship may need to be used in some years, given the realities of contract finalization and other considerations. If another vessel is used as the seismic source ship, it will be equivalent in all respects related to environment and safety. This would not alter acquisition methods, mitigations or impact predictions.

Figure 2.1 Seismic Source Vessel MV Sanco Spirit.

***Sanco Spirit* Specifications**

Call sign: ZDJN 3
IMO number: 9429936
MMSI Number: 2365380000
Owner: Sanco Shipping AS
Classification: Research Vessel
Length overall: 86.5 m
Beam: 16.0 m
Draft Loaded: 5.8 m
Gross Tonnage: 4396 Tonnes
Net Tonnage: 1319 Tonnes
Cruising Speed: 13 knots
Accommodation: 47 persons

Figure 2.2 Support Vessel MV *Blain M.*

***Blain M.* Vessel Specifications**

IMO number: 7907099
Owner: McKeil Marine Limited
Classification: Fishery Science Vessel
Length overall: 47.1 m
Beam: 11.0 m
Draft: 4.3 m
Gross Tonnage: 925 Tonnes
Net Tonnage: 225 Tonnes
Cruising Speed: 9 knots
Endurance: 40 days
Accommodation: 34 persons

2.2.7 Seismic Energy Source Parameters

The proposed 2D or 3D survey sound source will consist of one or more airgun arrays with a total discharge volume of 3,000 to 6,000 in^3, operating at tow depth of 6 to 15 m. The airgun arrays are comprised of individual airguns ranging in size from 22 to 250 in^3 each. The airguns will be operated with compressed air at pressures of 2,000–2,500 psi and produce approximate peak-to-peak pressures of 100 to 200 bar-m. A typical airgun array used by PGS for 2D surveys consists of four sub-arrays with a total volume of 4,808 in^3, operated at a pressure of 2,000 psi. This array is generally towed at a depth of 9 m and produces peak-to-peak pressures of 179 bar-m. The airguns in the array are strategically arranged to direct most of the energy vertically downward rather than sideways. The shot interval will be one shot every 19 to 25 s, and the survey speed will be around 4.5 knots (8.3 km/h).

2.2.8 Seismic Streamers

For 2D surveys, the seismic ship will also tow a single seismic hydrophone cable (streamer) up to 10 km long, deployed near the ocean surface, at a depth of approximately 15–25 m. This is a passive listening device, which will receive the sound waves reflected from structures underneath the ocean floor and transfer the data to an on-board recording and processing system. The cable is a solid streamer, PGS GeoStreamer®. In subsequent 2D and 3D seismic surveys (2015–2018), streamer equipment specifications will be provided when program design is complete. Streamers will be solid with an expected length of 8,000 to 10,000 m, depending on survey design, and deployed at depths ranging from 15 to 25 m. As many as 16 streamers may be towed during a 3D seismic survey.

2.2.9 Other Equipment

The seismic vessel is equipped with a Furuno FE-700 echosounder. The downward-facing echosounder operates at a frequency of 50 kHz or 200 kHz and will be used to collect water depth information. For this Project, sound velocity profiles will also be acquired in the water column at various locations within the survey area. This is a routine practice during seismic programs. Sound velocity profiles allow for more accurate interpretation of the acoustic data (i.e., seismic pulses) recorded by the seismic streamer. These data are acquired with a small, passive device that will be deployed by the support vessel. The device measures pressure, temperature, and salinity, from which the speed of sound can be calculated.

2.2.10 Logistics and Support

As described above, the 2014 operations will consist of a single seismic ship, the MV *Sanco Spirit*, towing a sound source (airgun) array and a hydrophone streamer over widely spaced survey lines, working in ice-free marine areas. The project will also use a support ship, the MV *Blain M*. The survey will follow planned, pre-plotted seismic lines to the extent possible, given possible local ice conditions. In 2014, crew changes will occur every five weeks via port calls. The port will be St. John's or another port in Newfoundland and Labrador, depending on vessel location. It is not known at this time whether helicopters, vessel-to-vessel transfers, or port-calls will be used for crew changes during seismic program(s) in 2015–2018. If required, aircraft support would be provided by twin-engine helicopters. Helicopters may be used to ferry personnel and lightweight supplies to and from the seismic vessel. In addition, helicopter emergency response support will be available to the seismic vessel.

The seismic lines will be acquired in the most efficient manner practical. Typically the vessel will have a 6-km run-in to the start of a seismic line and a 4 to 5 km run-out at the end of a seismic line. The ship will travel at approximately 8–9 km/hr when in data acquisition mode. The vessel will aim to operate continuously, though typically about 60% of the time is spent in production with the remainder of the time for line changes, standby (e.g., for weather, marine mammal mitigation), maintenance and/or other technical operations.

MKI will have a shore representative based in St. John's for the duration of seismic. No new shorebase facilities will be required for the Project for the seismic surveys. Existing port infrastructure will be used for this Project.

2.2.11 Discharges

Vessel discharges will not exceed those of standard vessel operations and will adhere to all applicable regulations. The main discharges include grey water (wastewater from washing, bathing, laundry, and food preparation), black water (human wastes), bilge water, deck drainage and discharges from machinery spaces. All discharges will comply with requirements in the International Convention for the Prevention of Pollution of Ships, 1973, as modified by Protocol of 1978 (MARPOL 73/78) and its annexes. It is estimated that the seismic vessel will generate 0.25 m^3 of black and grey water per day and the support vessel will generate less. Ground galley food waste can be discharged when a vessel is more than 3 miles offshore. Non-ground galley food waste can be discharged when a vessel is more than 12 miles offshore.

2.2.12 Waste Management

Wastes produced from the seismic and support vessels, including hazardous and non-hazardous waste material, will be managed in accordance with MARPOL and with the vessel-specific waste management procedures. All solid wastes will be sorted by type, compacted where practicable, and stored on board before disposal to an appropriate certified reception facility. Non-toxic combustible material and waste oil from the vessels will be burned on-board in approved incinerators. The shipboard incinerators will have been examined and tested in accordance with the requirements of the shipboard incinerators IMO Res. MEPC 76(40) for disposing of ships-generated waste appended to the Guideline for the Implementation of Annex V of MARPOL 73/78. Sufficient and adequate facilities will be available on vessels to store solid wastes to the extent required. The MKI waste management procedures will be filed with the C-NLOPB. Only ports with licensed waste contractors will be used for any waste returned from offshore.

2.2.13 Atmospheric Emissions

The vessels will have an International Air Pollution Prevention Certificate issued under the provisions of the Protocol of 1997 as amended by resolution MEPC.176(58) in 2008, to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 related thereto (hereinafter referred to as the Convention). Atmospheric emissions will be those associated with standard operations for marine vessels in general, including the seismic vessel and support vessel. Vessels will only use diesel and gasoil with a sulphur content of no more than 1%

(weight) following the *International Convention for the Prevention of Pollution from Ships* (MARPOL) Annex VI, for the North American Emission Control Area, which was implemented in Canada in August 2012 (see http://www.tc.gc.ca/eng/marinesafety/bulletins-2013-06-eng.htm). It is expected that the ships will use ~1,000,000 L of fuel per survey within Canadian waters. There are no anticipated implications for the health and safety of workers on these vessels form atmospheric emissions.

2.2.14 Accidental Releases

In the unlikely event of the accidental release of hydrocarbons during the Project, MKI will implement the measures outlined in its oil spill response plan which will be filed with the C-NLOPB. In addition, MKI has an emergency response plan in place which bridges the emergency plans of all project entities and vessels to the local facilities and the Halifax Search and Rescue Region; this plan will be filed with the C-NLOPB. The MKI representative onboard will represent MKI in all offshore Quality, Health, Safety & Environment (QHSE) activities. The MKI Project Manager will represent MKI onshore from an office in St. John's.

2.3 Mitigation

Mitigation measures are referenced throughout the EA. The measures are described in detail in Section 5.6.

3.0 Physical Environment

The Scoping Document required that the EA include a review of the meteorological and oceanographic characteristics, including extreme conditions, in order to provide the basis for assessing the effects of the environment on the Project. A detailed description of met-ocean conditions in the Study and Project areas, and methodologies used, is contained in Oceans (2014). Summaries of the relevant sections of that report are provided below.

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 (see Figure 4.1). 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 under 50 m. The continental slope in the southern and eastern regions of the Grand Banks reach depths of over 1,000 m. The Grand Bank is deeply incised with submarine canyons along the southern and southeast areas (e.g., Carson Canyon, Lilly Canyon). The Study Area also includes the southern portions of the nose of the Grand Bank, the Flemish Pass, and the Flemish Cap. The most westerly 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 surficial geology of the Southern Grand Banks has been discussed in LGL (2003a) and LGL (2009a,b), and subsequently summarized in the Southern Newfoundland SEA (LGL 2010a). 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. These units consist of glacial tills, proglacial silts, sublittoral sands, recent mud, and basal transgressive sand and gravel. A detailed description of these sediment types is contained in Section 4.2.1.2.

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 and hence, survey time on site can be affected by weather, particularly wind and wave conditions. This section, based primarily on Oceans (2014), provides a general overview of climatic conditions in the Study Area with a more detailed description of extreme events. The reader is referred to Sections 2.0 and 3.0 of Oceans (2014) for further details.

3.2.1 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, which 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: one from the Great Lakes Basin, one from Cape Hatteras, North Carolina, and 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. 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 during the summer months 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 the relatively benign to heavy weather conditions.

Rapidly deepening storms are a problem south of Newfoundland in the vicinity of the warm water of the Gulf Stream. Sometimes these 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. Hurricane force winds near the center, the outbreak of convective clouds to the north and east of the center during the explosive stage, and the presence of a clear area near the center in its mature stage (Rogers and Bosart 1986 *in* Oceans 2014) are typical of weather bombs. 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 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 and make their way 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 usually embedded into a mid-latitude low and lose their tropical characteristics. 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 which 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 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 altitudes in the early and late hurricane season and at higher latitudes during the peak of the season (Hart and Evans 2001 *in* Oceans 2014).

3.2.2 Extreme Wind and Wave Analysis

The extreme value analysis was carried out using four grid points within the Study Area: grid point 05000 in the Laurentian Sub-Basin, grid point 08026 on the Southern Grand Banks, grid point 10537 in the Newfoundland Basin, and grid point 11154 in the deep water south of the Grand Banks (Table 3.1, Figure 3.1). An analysis of extreme wind and waves was performed by Oceans (2014) using the MSC50 data set. This 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 Project Area. The extreme values for wind speeds and waves were calculated using the peak-over-threshold method. After considering four different distributions, the Gumbel distribution was chosen to be the most representative as it provided the best fit to the data. Since extreme values can vary, depending on how well the data fits the distribution, a sensitivity analysis was carried out to determine how many storms to use in the analysis. The number of storms determined to provide the best fit annually and monthly for each of the four grid points used in the analyses are presented in Table 3.2.

Table 3.1 MSC50 Grid Point Locations.

Grid Point	Latitude	Longitude
05000	43.5°N	54.5°W
08026	45.0°N	50.0°W
10537	41.5°N	47.0°W
11154	44.0°N	45.0°W

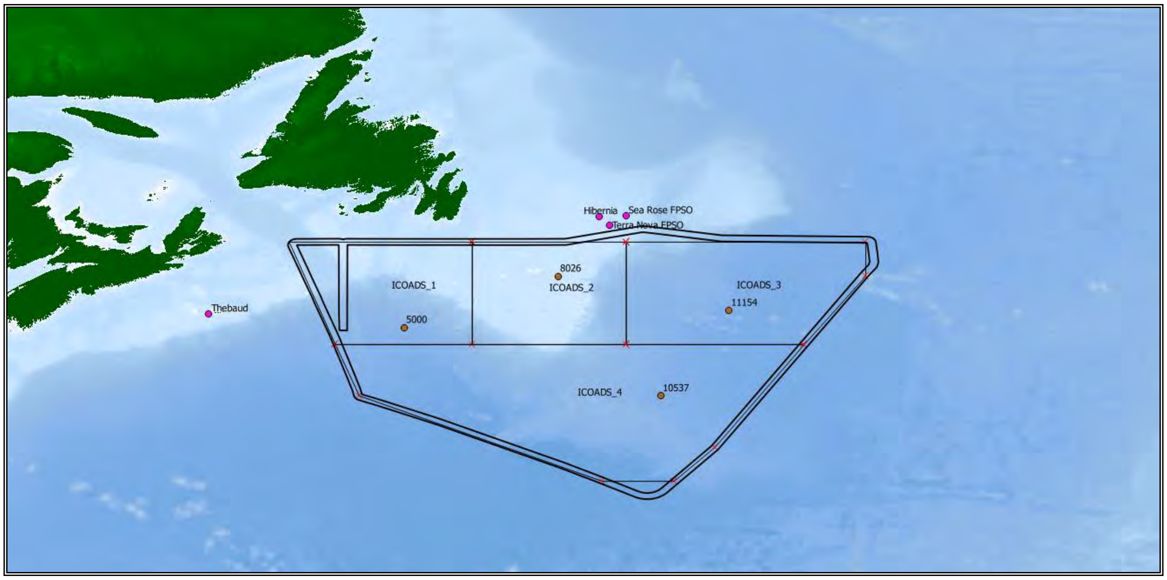


Figure 3.1 Location of the Grid Points and Regions used in the Physical Environment Analyses.

Table 3.2 Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves.

Grid Point	Parameter	Annually	Monthly
05000	Wind	228	75
	Wave	280	93
08026	Wind	191	80
	Wave	267	58
10537	Wind	279	88
	Wave	303	81
11154	Wind	396	95
	Wave	310	94

3.2.2.1 Extreme Value Estimates for Winds from the Gumbel Distribution

The extreme value estimates for wind were calculated by Oceans (2014) using Oceanweather's Osmosis software for the return periods of 1-year, 10-years, 25-years, 50-years and 100-years. The analysis used hourly mean wind values for the reference height of 10 m above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ratio of 1.06 and 1.22, respectively (U.S. Geological Survey 1979).

The calculated annual and monthly wind values for 1-hour, 10-minutes and 1-minute are presented in Tables 3.3 to 3.5. The annual 100-year extreme 1-hour wind speed was determined to be 31.8 m/s for grid point 05000, 32.3 m/s for grid point 08026, 31.0 m/s for grid point 10537, and 30.8 m/s for grid point 11154. Monthly, the highest 100-year extreme winds occurred during September at grid points 05000 and 10537 and during February at grid points 08026 and 11154. From May to November, the highest 100-year extreme 1-hour wind speeds occurred in September at all grid points, while the lowest occurred in June at grid points 08026 and 10537 and in July at grid points 05000 and 11154.

Table 3.3 1-hr Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50, and 100 Years.

	05000					08026				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	22.0	26.0	27.3	28.3	29.2	21.6	26.2	27.7	28.8	30.0
February	21.7	26.2	27.7	28.8	29.8	21.3	26.9	28.7	30.1	31.5
March	20.3	24.7	26.2	27.3	28.3	19.7	24.2	25.7	26.8	27.8
April	18.1	21.9	23.2	24.1	25.1	17.8	22.0	23.4	24.5	25.5
May	16.1	20.1	21.4	22.4	23.3	15.1	18.9	20.1	21.0	22.0
June	13.7	18.5	20.1	21.3	22.5	13.8	17.2	18.3	19.1	20.0
July	13.0	16.9	18.2	19.1	20.1	12.7	17.1	18.5	19.6	20.7
August	13.7	19.9	21.9	23.4	24.8	13.6	20.9	23.3	25.1	26.9
September	16.3	24.3	27.0	28.9	30.9	16.3	22.8	25.0	26.6	28.2
October	18.4	23.7	25.5	26.7	28.0	18.0	22.6	24.3	25.6	26.9
November	19.8	24.4	25.9	27.1	28.2	19.2	23.8	25.4	26.5	27.6
December	21.8	26.1	27.5	28.5	29.5	21.6	25.9	27.4	28.4	29.5
Annual	24.9	28.5	29.8	30.8	31.8	24.8	28.7	30.1	31.2	32.3

	10537					11154				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	20.8	24.0	25.0	25.8	26.6	21.3	25.0	26.2	27.2	28.1
February	21.2	25.1	26.4	27.4	28.4	21.4	25.9	27.5	28.7	29.9
March	19.5	23.5	24.8	25.8	26.8	19.8	23.5	24.8	25.8	26.8
April	17.4	21.4	22.7	23.7	24.7	17.8	21.5	22.8	23.8	24.8
May	15.0	18.3	19.4	20.2	21.0	15.5	19.2	20.4	21.4	22.3
June	13.7	17.0	18.1	18.9	19.7	14.1	17.7	18.9	19.8	20.7
July	12.4	16.9	18.4	19.6	20.7	12.7	16.1	17.3	18.2	19.1
August	12.5	18.6	20.7	22.2	23.7	13.3	18.0	19.7	20.9	22.1
September	15.6	23.7	26.5	28.5	30.6	16.3	23.2	25.6	27.4	29.2
October	17.1	20.5	21.6	22.5	23.3	17.8	21.9	23.3	24.4	25.5
November	18.7	23.6	25.3	26.6	27.8	19.1	23.7	25.3	26.4	27.6
December	20.3	24.8	26.4	27.5	28.6	20.8	25.2	26.7	27.9	29.3
Annual	23.7	27.5	28.9	30.0	31.0	23.9	27.4	28.8	29.8	30.8

Table 3.4 10-min Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50, and 100 Years.

	05000					08026				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	23.3	27.5	28.9	29.9	31.0	22.9	27.8	29.4	30.6	31.8
February	23.0	27.8	29.3	30.5	31.6	22.5	28.5	30.5	31.9	33.4
March	21.5	26.2	27.8	28.9	30.0	20.9	25.6	27.2	28.4	29.5
April	19.2	23.3	24.6	25.6	26.6	18.9	23.4	24.8	26.0	27.1
May	17.1	21.3	22.7	23.7	24.7	16.0	20.0	21.3	22.3	23.3
June	14.5	19.6	21.3	22.6	23.8	14.6	18.2	19.4	20.3	21.2
July	13.8	17.9	19.3	20.3	21.3	13.5	18.1	19.6	20.8	21.9
August	14.5	21.0	23.2	24.8	26.3	14.4	22.1	24.7	26.6	28.5
September	17.2	25.8	28.6	30.7	32.7	17.3	24.2	26.5	28.2	29.9
October	19.5	25.1	27.0	28.3	29.7	19.1	23.9	25.8	27.1	28.5
November	21.0	25.9	27.5	28.7	29.9	20.4	25.3	26.9	28.1	29.3
December	23.1	27.6	29.1	30.2	31.3	22.9	27.5	29.0	30.1	31.2
Annual	26.4	30.2	31.6	32.7	33.8	26.3	30.4	31.9	33.1	34.2

	10537					11154				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	22.0	25.4	26.5	27.4	28.2	22.6	26.5	27.8	28.8	29.8
February	22.5	26.6	28.0	29.0	30.1	22.7	27.5	29.2	30.4	31.7
March	20.6	24.9	26.3	27.4	28.4	20.9	24.9	26.3	27.3	28.4
April	18.5	22.7	24.1	25.2	26.2	18.8	22.8	24.2	25.2	26.3
May	15.9	19.4	20.5	21.4	22.3	16.5	20.3	21.7	22.7	23.7
June	14.5	18.0	19.1	20.0	20.9	15.0	18.7	20.0	21.0	21.9
July	13.1	17.9	19.5	20.7	21.9	13.4	17.1	18.3	19.3	20.2
August	13.3	19.7	21.9	23.5	25.2	14.1	19.1	20.8	22.1	23.4
September	16.6	25.2	28.1	30.3	32.4	17.3	24.6	27.2	29.1	31.0
October	18.2	21.7	22.9	23.8	24.7	18.8	23.2	24.7	25.9	27.0
November	19.8	25.1	26.8	28.2	29.5	20.3	25.1	26.8	28.0	29.3
December	21.5	26.3	27.9	29.2	30.4	22.1	26.7	28.3	29.5	31.0
Annual	25.2	29.1	30.6	31.7	32.9	25.4	29.1	30.5	31.6	32.7

Table 3.5 1-min Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50, and 100 Years.

	05000					08026				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	26.9	31.7	33.3	34.5	35.6	26.4	32.0	33.8	35.2	36.6
February	26.5	32.0	33.7	35.1	36.4	25.9	32.8	35.1	36.7	38.4
March	24.8	30.2	32.0	33.3	34.6	24.1	29.5	31.3	32.6	34.0
April	22.1	26.8	28.3	29.4	30.6	21.7	26.9	28.6	29.9	31.1
May	19.7	24.5	26.1	27.3	28.5	18.5	23.0	24.5	25.7	26.8
June	16.7	22.6	24.5	26.0	27.4	16.8	21.0	22.3	23.4	24.4
July	15.9	20.7	22.2	23.4	24.5	15.5	20.8	22.6	23.9	25.2
August	16.7	24.2	26.7	28.5	30.3	16.6	25.5	28.4	30.6	32.8
September	19.8	29.7	32.9	35.3	37.7	19.9	27.8	30.5	32.5	34.4
October	22.4	28.9	31.0	32.6	34.2	22.0	27.5	29.7	31.2	32.8
November	24.1	29.8	31.6	33.0	34.4	23.4	29.1	30.9	32.3	33.7
December	26.6	31.8	33.5	34.7	36.0	26.4	31.6	33.4	34.7	36.0
Annual	30.4	34.7	36.4	37.6	38.8	30.3	35.0	36.7	38.1	39.4

	10537					11154				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	25.4	29.2	30.5	31.5	32.5	26.0	30.5	32.0	33.1	34.3
February	25.9	30.6	32.2	33.4	34.6	26.1	31.6	33.6	35.0	36.4
March	23.8	28.6	30.3	31.5	32.7	24.1	28.7	30.3	31.5	32.6
April	21.2	26.1	27.7	29.0	30.2	21.7	26.3	27.9	29.0	30.2
May	18.3	22.3	23.6	24.6	25.6	19.0	23.4	24.9	26.1	27.2
June	16.7	20.7	22.0	23.0	24.0	17.3	21.5	23.0	24.1	25.3
July	15.1	20.6	22.4	23.9	25.2	15.4	19.6	21.1	22.2	23.3
August	15.3	22.7	25.2	27.1	29.0	16.3	22.0	24.0	25.5	26.9
September	19.1	29.0	32.3	34.8	37.3	19.9	28.3	31.3	33.5	35.6
October	20.9	25.0	26.4	27.4	28.4	21.7	26.7	28.5	29.8	31.1
November	22.8	28.8	30.9	32.4	33.9	23.4	28.9	30.8	32.2	33.7
December	24.8	30.3	32.1	33.6	34.9	25.4	30.7	32.6	34.0	35.7
Annual	29.0	33.5	35.2	36.5	37.8	29.2	33.5	35.1	36.3	37.6

3.2.2.2 Extreme Value Estimates for Waves from a Gumbel Distribution

The annual and monthly extreme value estimates for significant wave height for return periods of 1-year, 10-years, 25-years, 50-years and 100-years are given in Table 3.6. 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 annual 100-year extreme significant wave height was 14.6 m at grid point 05000, 14.1 m at grid point 08026, 15.0 m at grid point 10537, and 14.8 m at grid point 11154.

The maximum individual wave height estimates and extreme associated peak period estimates are presented in Table 3.7 and Table 3.8. From May to November, extreme maximum individual wave heights peak during the month of November at all grid points, and peak period estimates are greatest during September at grid points 05000 and 11154 and during November at grid points 08026 and 10537.

Table 3.6 Extreme Significant Wave Height Estimates for Return Periods of 1, 10, 25, 50, and 100 Years.

	05000					08026				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	9.4	12.0	12.9	13.5	14.2	8.2	11.1	12.1	12.8	13.5
February	9.0	11.8	12.8	13.5	14.2	7.7	11.0	12.0	12.8	13.6
March	8.0	11.0	12.0	12.8	13.5	6.5	9.6	10.6	11.4	12.1
April	6.3	9.1	10.0	10.7	11.5	5.4	8.1	8.9	9.6	10.2
May	5.0	7.3	8.1	8.8	9.4	4.3	6.4	7.0	7.5	8.0
June	3.9	6.6	7.5	8.2	8.9	3.5	5.7	6.4	6.9	7.4
July	3.6	5.5	6.2	6.6	7.1	3.2	5.2	5.8	6.3	6.8
August	4.0	7.2	8.3	9.2	10.0	3.6	6.6	7.5	8.3	9.0
September	5.4	9.7	11.2	12.3	13.4	4.8	8.5	9.6	10.5	11.4
October	6.6	9.7	10.8	11.5	12.3	5.7	8.8	9.8	10.5	11.2
November	7.7	11.0	12.1	12.9	13.8	6.9	9.7	10.6	11.2	11.9
December	9.5	11.8	12.6	13.2	13.8	8.1	10.7	11.5	12.1	12.8
Annual	11.0	12.8	13.5	14.1	14.6	9.9	12.0	12.8	13.5	14.1

	10537					11154				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	8.8	11.5	12.4	13.1	13.8	9.0	11.8	12.8	13.5	14.2
February	9.1	11.6	12.4	13.0	13.6	9.1	11.9	12.8	13.5	14.2
March	7.6	11.1	12.2	13.1	14.0	7.6	10.6	11.6	12.4	13.1
April	6.1	9.2	10.2	10.9	11.7	6.2	8.9	9.8	10.5	11.2
May	4.6	6.9	7.6	8.2	8.8	4.8	6.9	7.7	8.2	8.8
June	3.9	5.9	6.6	7.1	7.6	4.1	5.9	6.5	7.0	7.4
July	3.3	5.5	6.2	6.7	7.2	3.4	5.2	5.8	6.2	6.7
August	3.6	6.5	7.5	8.2	8.9	3.7	6.1	6.9	7.6	8.2
September	5.0	9.2	10.5	11.6	12.6	5.3	8.8	10.0	10.9	11.8
October	5.7	8.4	9.3	10.0	10.6	6.1	9.0	9.9	10.7	11.4
November	7.0	10.4	11.5	12.4	13.2	7.2	10.6	11.7	12.6	13.5
December	8.2	11.8	13.0	13.9	14.8	8.5	11.4	12.4	13.1	13.9
Annual	10.7	12.9	13.7	14.3	15.0	10.6	12.8	13.6	14.2	14.8

Table 3.7 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years.

	05000					08026				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	18.1	22.4	24.0	25.1	26.2	15.8	20.4	21.9	23.0	24.1
February	17.4	22.0	23.6	24.8	26.1	14.9	20.3	22.1	23.4	24.6
March	15.3	21.0	22.9	24.4	25.8	12.5	19.0	21.0	22.6	24.1
April	12.0	17.1	18.9	20.2	21.6	10.1	14.9	16.5	17.6	18.7
May	9.8	13.9	15.3	16.3	17.3	8.2	12.4	13.8	14.8	15.8
June	7.9	13.2	15.0	16.4	17.8	6.8	10.8	12.1	13.1	14.0
July	6.8	10.1	11.2	12.0	12.8	6.4	9.6	10.6	11.4	12.2
August	7.9	13.3	15.2	16.6	18.0	7.0	11.8	13.4	14.5	15.6
September	10.3	17.9	20.5	22.4	24.3	9.8	16.2	18.3	19.8	21.4
October	12.8	18.4	20.3	21.8	23.2	11.4	16.6	18.2	19.5	20.7
November	14.8	20.6	22.6	24.1	25.6	12.8	17.9	19.6	20.8	22.0
December	17.8	21.9	23.4	24.4	25.5	15.3	19.9	21.3	22.4	23.5
Annual	20.6	23.7	24.9	25.8	26.7	18.4	22.1	23.5	24.6	25.7

	10537					11154				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	16.4	21.4	23.1	24.3	25.5	17.2	22.3	24.1	25.4	26.8
February	17.0	21.7	23.3	24.5	25.6	17.8	22.4	24.0	25.2	26.3
March	14.9	20.9	22.9	24.4	25.9	15.4	20.4	22.2	23.5	24.8
April	12.3	18.5	20.5	22.0	23.5	12.5	17.3	18.9	20.2	21.4
May	9.1	13.7	15.3	16.4	17.5	9.3	13.6	15.1	16.2	17.3
June	8.0	11.3	12.4	13.2	14.0	7.9	11.4	12.6	13.5	14.4
July	6.8	10.4	11.7	12.6	13.5	6.7	10.0	11.2	12.0	12.9
August	7.1	12.4	14.1	15.5	16.8	7.5	11.8	13.3	14.5	15.6
September	10.5	17.0	19.1	20.7	22.3	10.3	16.1	18.1	19.6	21.1
October	11.1	15.9	17.5	18.7	19.9	11.6	17.2	19.1	20.5	21.9
November	14.7	20.5	22.5	23.9	25.4	14.0	20.7	23.0	24.7	26.4
December	15.5	21.8	24.0	25.6	27.1	16.3	21.3	23.0	24.3	25.5
Annual	20.2	23.9	25.3	26.3	27.4	20.2	24.0	25.5	26.6	27.7

Table 3.8 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years.

Month	05000					08026				
	1.0	10.0	25.0	50.0	100.0	1.0	10.0	25.0	50.0	100.0
January	12.9	14.5	15.1	15.4	15.8	12.6	14.4	14.9	15.3	15.6
February	12.8	14.3	14.8	15.1	15.4	12.0	13.9	14.5	14.9	15.3
March	12.4	13.8	14.2	14.5	14.8	11.4	13.5	14.0	14.4	14.8
April	11.3	12.7	13.2	13.5	13.8	10.5	12.1	12.6	12.9	13.2
May	10.0	12.0	12.6	13.1	13.5	9.7	11.4	11.9	12.2	12.6
June	9.1	11.5	12.2	12.6	13.1	8.6	10.8	11.4	11.8	12.2
July	8.8	10.9	11.6	12.1	12.5	8.4	10.2	10.7	11.1	11.4
August	9.6	12.5	13.4	14.0	14.5	9.2	11.7	12.4	12.9	13.3
September	10.7	13.4	14.2	14.7	15.2	10.1	12.8	13.5	13.9	14.4
October	11.5	13.0	13.5	13.8	14.1	10.9	12.9	13.5	13.9	14.2
November	12.2	13.8	14.3	14.6	14.9	11.7	13.4	13.8	14.2	14.5
December	12.9	14.2	14.7	15.0	15.3	12.5	14.0	14.4	14.7	15.0
Annual	13.9	15.0	15.4	15.7	16.0	13.5	14.6	15.0	15.2	15.5

Month	10537					11154				
	1.0	10.0	25.0	50.0	100.0	1.0	10.0	25.0	50.0	100.0
January	13.0	14.5	15.0	15.3	15.7	13.1	14.3	14.6	14.9	15.2
February	13.0	14.5	15.0	15.3	15.6	12.9	14.2	14.6	14.9	15.1
March	12.5	14.2	14.7	15.1	15.4	12.3	13.6	14.1	14.3	14.6
April	11.6	13.1	13.6	13.9	14.2	11.3	12.6	13.0	13.3	13.6
May	10.1	12.1	12.7	13.1	13.5	10.1	11.4	11.8	12.1	12.3
June	9.2	11.2	11.8	12.2	12.6	9.2	10.8	11.4	11.7	12.1
July	8.6	10.6	11.2	11.5	11.9	8.7	10.6	11.2	11.6	12.0
August	9.3	12.2	13.0	13.6	14.1	9.3	11.3	11.9	12.3	12.7
September	11.0	13.3	13.9	14.3	14.7	11.0	13.2	13.8	14.3	14.7
October	11.1	12.6	13.0	13.3	13.5	11.3	12.9	13.4	13.7	14.0
November	12.1	14.0	14.5	14.9	15.2	12.0	13.5	14.0	14.3	14.6
December	12.7	14.6	15.2	15.6	16.0	12.7	13.9	14.3	14.5	14.8
Annual	14.0	15.4	15.8	16.2	16.5	13.7	14.8	15.2	15.5	15.7

3.2.3 Weather Variables

3.2.3.1 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 (Oceans 2014). Mean monthly air and sea surface temperatures are presented in Table 3.9, and are the mean of all temperatures recorded at the site during that month.

Temperature statistics presented show that the atmosphere is warmest in August and coldest in February in all regions. Sea surface temperature is warmest in August in all regions and coldest March in all regions except Region 4, where sea surface temperature is coldest in February. Air and sea surface temperatures in Region 4 are warmer than the other three regions due to the location of the Gulf Stream.

Table 3.9 Mean Monthly Air and Sea Surface Temperatures.

Month	Air Temperature (ºC)				Sea Surface Temperature (ºC)			
	Region 1	Region 2	Region 3	Region 4	Region 1	Region 2	Region 3	Region 4
January	1.9	2.3	6.4	9.6	4.3	3.6	11.7	13.2
February	0.8	1.3	6.0	9.2	3.2	2.5	10.2	12.7
March	1.4	2.0	6.8	9.7	2.9	2.2	9.9	12.9
April	4.0	3.9	9.6	11.4	3.7	2.8	9.9	13.2
May	6.9	6.2	11.1	14.0	6.1	5.2	11.8	14.6
June	10.6	9.9	13.6	17.0	10.3	8.9	14.0	17.1
July	16.0	15.4	17.6	21.2	15.3	14.5	17.5	21.1
August	18.3	17.7	18.7	22.1	18.3	17.9	20.3	22.9
September	16.2	15.6	17.1	20.1	17.0	17.1	18.8	21.5
October	12.3	12.5	14.0	17.1	13.4	13.0	16.3	19.0
November	8.6	8.0	11.2	13.7	10.0	8.9	14.9	17.1
December	4.8	5.1	8.5	11.0	7.0	6.0	13.2	14.7

3.2.3.2 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)
- Blowing Snow

Plots of the frequency distribution of visibility from the ICOADS data set for each region are presented in Figures 2.33 to 2.36 in Oceans (2014). Region 2 had the highest occurrence of obstructions to vision with good visibility occurring only 62.2% of the time. There is little seasonal variation in visibility in Region 4. Seasonal variations are present in the other three regions.

During the winter months in Regions 1 and 2, the main obstruction is snow, although mist and fog may also reduce visibilities at times. As spring approaches, the visibility reduction attributed to snow decreases. As air temperature increases, the occurrence of advection fog also increases. Advection fog forms when warm moist air moves over cooler waters. 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 can also contribute to the reduction in visibility. In 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. 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. Regions 3 and 4 experience a warmer climate than Regions 1 and 2 and there is less of an influence from advection fog. As a result, reductions to visibilities in these regions can mainly be attributed to the passage of low pressure systems. Since the occurrence of snow in Region 4 is small, most of the obstructions to visibility are due to fog throughout the year.

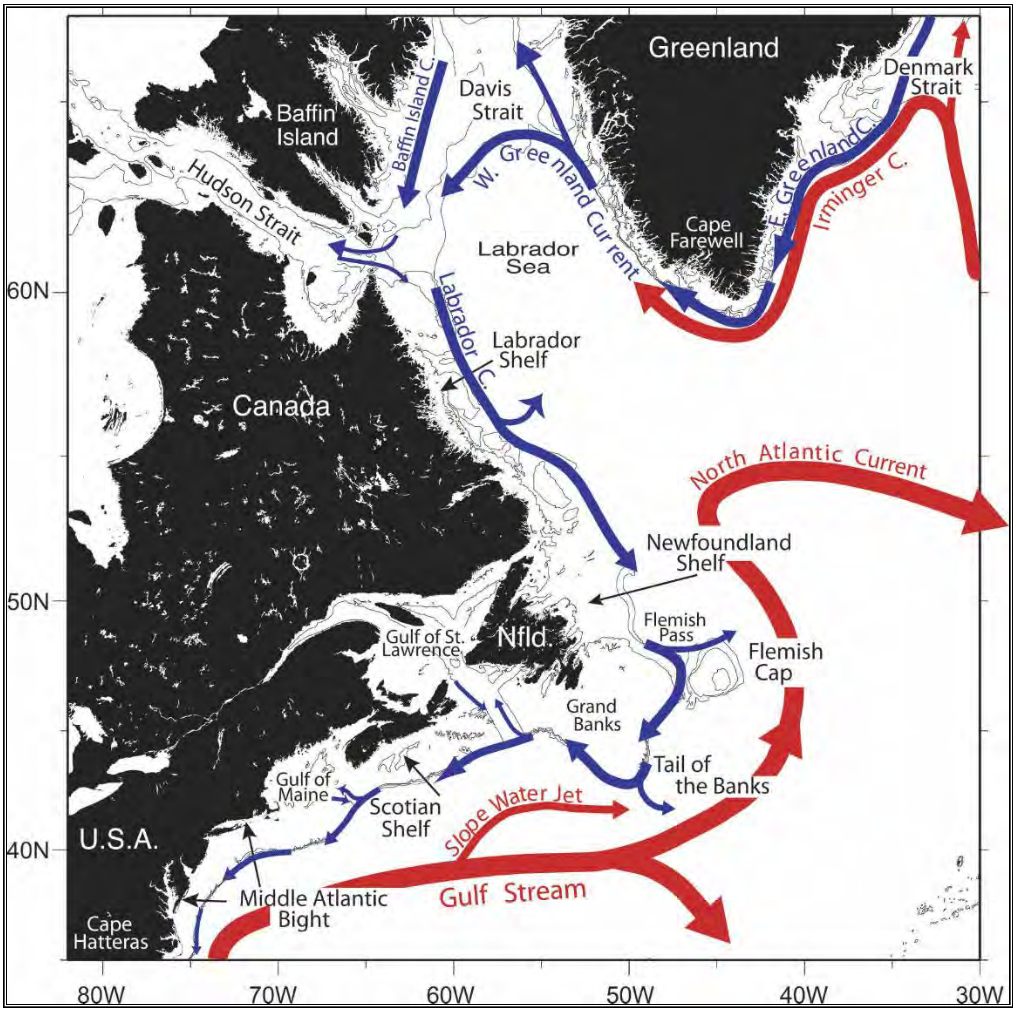
3.3 Physical Oceanography

A detailed review of current physical oceanographic information for the Study Area is contained in Oceans (2014). Current velocities and water mass properties (temperature and salinity) at various water depths for the southern Grand Banks, Laurentian Sub-Basin, and Newfoundland Basin are provided in Section 4.0 of Oceans (2014). A summary of the major currents in the Study Area is provided below.

3.3.1 Major Currents in the Study Area

The Study Area is the southern part of the 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 3.2.

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 (Stein 2007 *in* Oceans 2014), 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 (Figure 4.2 in Oceans 2014).



Source: Fratantoni and Pickart 2007.

Figure 3.2 Schematic Diagram of the Main Features of the Surface Circulation in the Western Atlantic Ocean (cold shelf break waters shown in blue; warm Gulf Stream waters shown in red).

The stronger offshore branch flows along the shelf break over the upper portion of the Continental Slope. This branch of the Labrador Current divides east of 48°W, resulting in part of the branch flowing to the east around Flemish Cap and the other 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 (Stein 2007 *in* Oceans 2014). 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 (see Figure 3.2). 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 part in the southern region of the Study Area. This extensive western boundary current plays a significant role in the poleward transfer of heat and salt and serves to warm the European subcontinent. 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: the North Atlantic Current and the Azores Current (Lazier 1994 *in* Oceans 2014). The Gulf Stream is usually located south of 40°N. However, 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 generates rings or eddies, which start 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 can 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 (Krauss 1986, Johns et al. 1995 *in* Oceans 2014). One branch curves north along the continental slope eventually turning east between 50° and 52°N. This branch is called the North Atlantic Current. The other branch flows southeastward towards the Mid-Atlantic Ridge and is called the Azores Current. The Gulf Stream transport also varies in time. According to GeoSat altimetry results, the current transports a maximum amount of water in the fall and a minimum in the spring, in phase with the north-south shifts of its position (Kelly 1991 *in* Ocean 2014).

There is a third major current between the eastward flowing Gulf Stream and the westward flowing Labrador Current, referred as the Slope Water (Fratantoni and Pickart 2007 *in* Oceans 2014). 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 (Pickart 1999, Haza 2004 in Oceans 2014).

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 (Han et al. 1999 *in* Oceans 2014). 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 (Han 2003 *in* Oceans 2014).

The interaction among these circulations is known to correlate with the behaviour of the North Atlantic Oscillation (NAO) index. The NAO index, as defined by Rogers (1984 *in* Oceans 2014) 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, cod 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 (Han 2006 *in* Oceans 2014). 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.

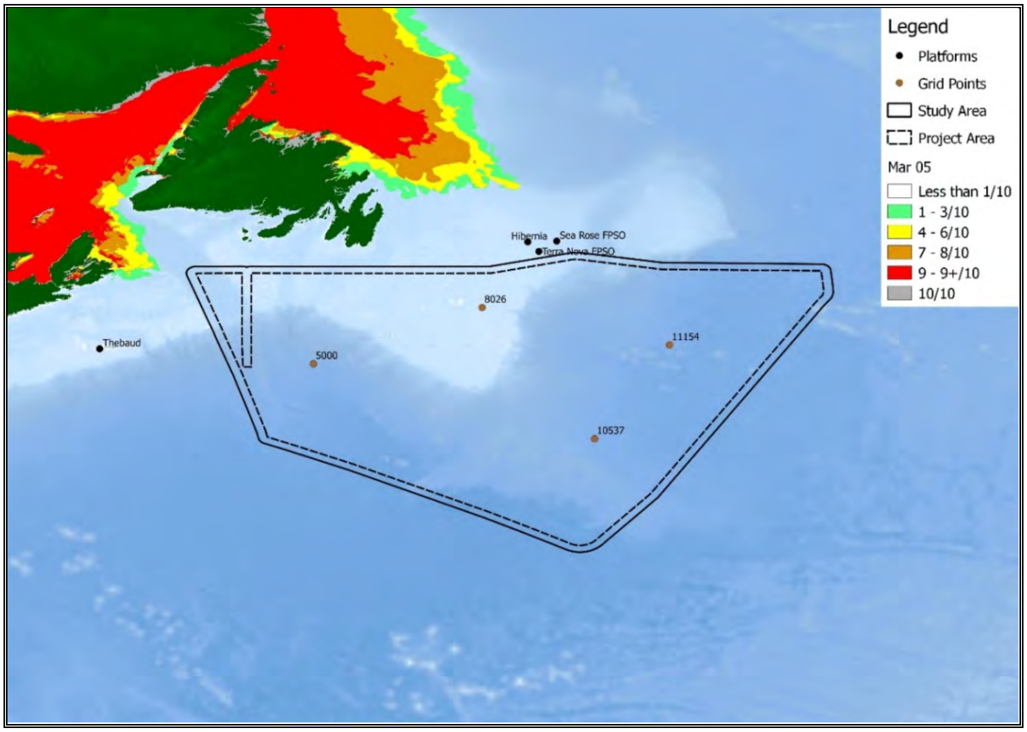
3.4 Sea Ice and Icebergs

A review of ice conditions in the Study Area is provided in Section 5 of Oceans (2014). Section 5.1 includes a classification of ice commonly found along Canada's eastern seaboard as well as definitions of the various ice types.

3.4.1 Sea Ice

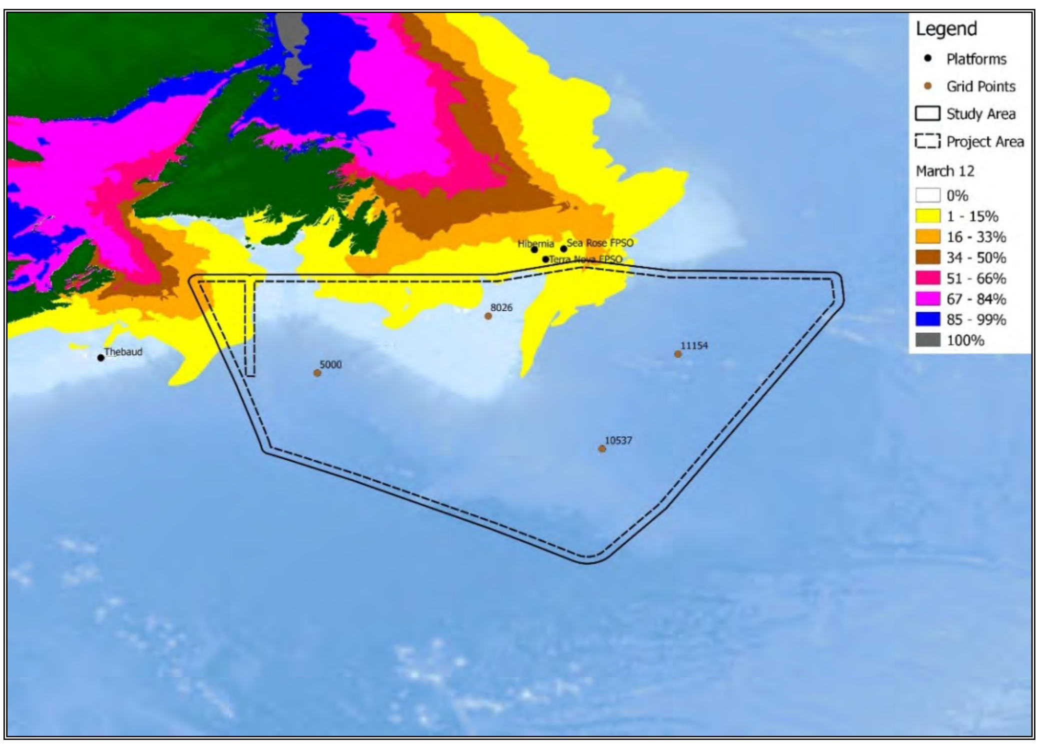
The 30-year median concentration of sea ice reaches its maximum during the week of 5 March. As can be seen in Figure 3.3, the median of ice concentration does not extend into the Study Area. The maximum median sea ice extent reaches to approximately 48°N, 49°W.

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice shows 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 3.4 shows the week of 12 March, the period when the frequency of presence of sea ice is the greatest over the Study Area. 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 2011.

Figure 3.3 30-Year Median Concentration of Sea Ice within the Study Area (5 March).



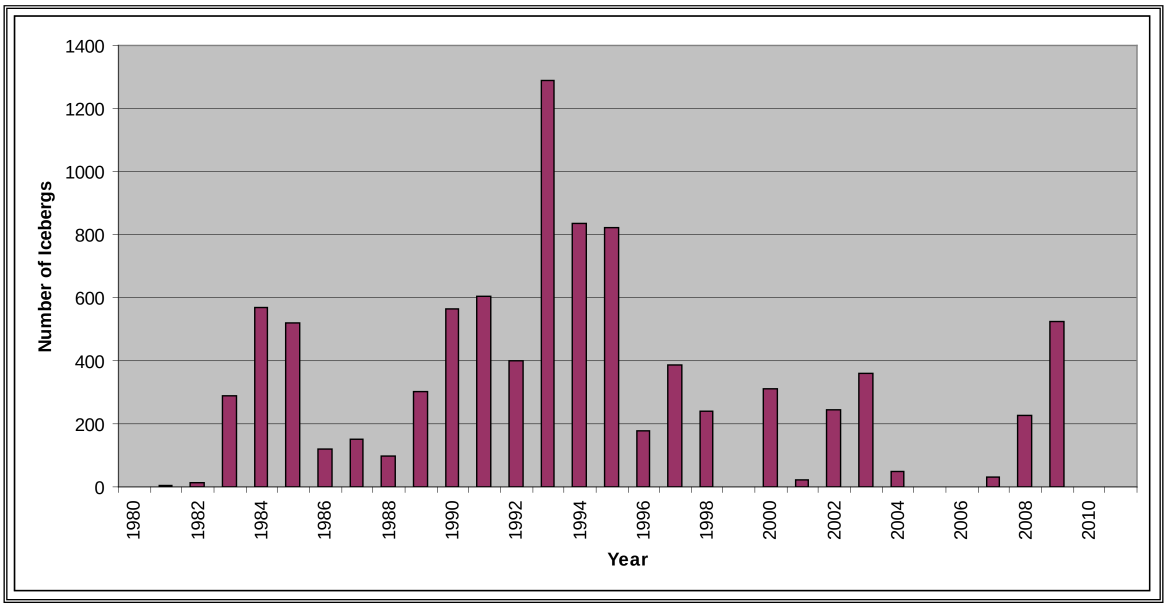
Source: Canadian Ice Service 2011.

Figure 3.4 30-Year Frequency of Presence of Sea Ice within the Study Area (12 March).

3.4.2 Icebergs

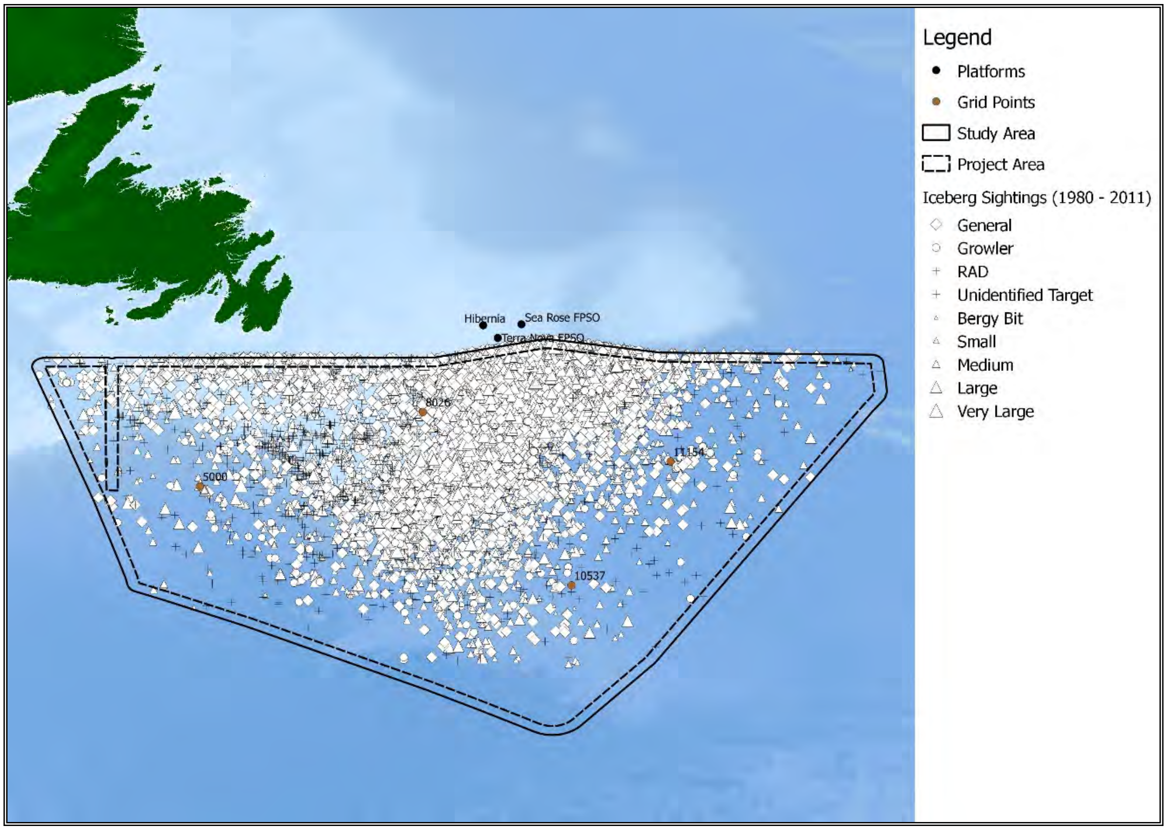
An analysis was performed to determine the threat posed by icebergs in the Study Area. The International Ice Patrol Iceberg Sightings Database from 1980-2011 was used as the primary data source in this analysis (NSIDC 1995, updated annually). Overall, there is a good distribution of iceberg sightings ranging from a total of 1,288 in 1993 to none in other years (Figure 3.5). Only iceberg sightings that occurred within the Study Area were considered in the analysis. Duplicate sightings of the same iceberg were also eliminated from the data set so that only the initial sighting was counted.

Figure 3.6 shows the positions of all icebergs within the study area from 1980-2011. Iceberg sightings were concentrated mostly towards the southern Grand Banks portion of the Study Area. Over the 31 years studied, 15,902 icebergs have been sighted within the Study Area. Environmental factors such as iceberg concentration, ocean currents, and wind determine how icebergs drift through the area.



Source: NSIDC 1995.

Figure 3.5 Iceberg Sightings within the Study Area (1980-2011).



Source: NSIDC 1995.

Figure 3.6 Iceberg Sightings within the Study Area (2008-2011).