offshore West Africa consists of long-period swell. These tables are not always conservative for certain applications to dynamically responding structures, therefore designers should also test against the appropriate dual-peaked cases such as those given in Table C.8.

Table C.6 — Percentage occurrence of total significant wave height *vs.* spectral peak period — Offshore Nigeria location

Significant wave height m	Peak period s													
	0 to 1,99	2 to 3,99	4 to 5,99	6 to 7,99	8 to 9,99	10 to 11,99	12 to 13,99	14 to 15,99	16 to 17,99	18 to 19,99	20 to 21,99	22 to 23,99	> 24	Total
0,00 to 0,49				0,02		0,03	0,02	0,03						0,10
0,50 to 0,99			0,50	5,37	2,55	3,48	3,14	2,46	0,64	0,13	0,05	0,02		18,34
1,00 to 1,49			0,34	11,01	16,65	9,40	11,01	8,76	2,74	0,88	0,24	0,04		61,07
1,50 to 1,99				0,08	5,85	4,67	2,76	2,95	1,19	0,33	0,09	0,03		17,95
2,00 to 2,49					0,17	0,79	0,58	0,41	0,19	0,07	0,03			2,24
2,50 to 2,99						0,06	0,08	0,04	0,05	0,02				0,25
> 3,00							0,02	0,03						0,05
Total			0,84	16,48	25,22	18,43	17,61	14,68	4,81	1,43	0,41	0,09	0	100,00

Table C.7 — Percentage occurrence of total significant wave height *vs.* spectral peak period — Offshore Angola location

Significant wave height m	Peak period s													
	0 to 1,99	2 to 3,99	4 to 5,99	6 to 7,99	8 to 9,99	10 to 11,99	12 to 13,99	14 to 15,99	16 to 17,99	18 to 19,99	20 to 21,99	22 to 23,99	> 24	Total
0,00 to 0,49				0,01	0,03	0,04	0,06	0,06						0,20
0,50 to 0,99		0,01	1,00	3,98	1,82	5,17	5,52	3,70	1,17	0,34	0,13	0,01	0,00	22,85
1,00 to 1,49			0,60	6,28	10,48	11,49	11,38	9,19	2,87	0,83	0,19	0,06	0,00	53,37
1,50 to 1,99			0,01	0,06	2,86	5,78	4,76	3,52	1,51	0,54	0,12	0,01		19,17
2,00 to 2,49					0,07	0,94	1,33	1,05	0,34	0,10	0,01			3,84
2,50 to 2,99					0,00	0,04	0,14	0,23	0,10	0,03				0,54
3,00 to 3,49								0,02	0,01					0,03
> 3,50								0,00						0,00
Total	0,00	0,01	1,61	10,33	15,26	23,46	23,19	17,77	6,00	1,84	0,45	0,08	0,00	100,00

Wind seas and swell conditions are considered as independent phenomena. In principle, any combination of wind seas and swell H_S—T_p classes is possible, and all permutations, with their joint frequency of occurrence, should be considered for engineering purposes.

Sea states offshore West Africa can be represented by the dual-peaked Ochi-Hubble spectra. Table C.8 provides an example of a scatter diagram for offshore Angola.

For the purposes of defining bimodal spectra representing combined swell and wind sea conditions, the total significant wave height H_S and the associated spectral peak period T_p should be divided into a swell part and a wind sea part. This can be achieved by inspection of a frequency table of the joint occurrences of H_S and T_p. The low wave heights associated with the wind sea component permit selection of relatively few significant wave height classes for wind seas. The frequency of occurrence of swell H_S with associated T_p should be calculated, conditional on the value of the wind sea H_S with its associated T_p, to determine the frequency of occurrence of each combined wind sea/swell bimodal sea state. The resolution of the swell H_s class will determine the number of combinations of wind sea and swell H_s and T_p available for engineering purposes.

The example in Table C.8 provides information on the joint frequency of occurrence of swell and wind sea conditions, giving the significant wave height, the peak period, the associated parameter γ and the direction of swell (θ_1) and wind sea (θ_2) for a site offshore Angola.

For the example data in Table C.8, the values from any row can be used to construct a bimodal Ochi-Hubble spectrum. Sea states should be assumed to be representative of a duration of 3 h. The values of percentage occurrence in Table C.8 can be used to define the fatigue wave climate.

Table C.8 — Example of wind sea states used for combined wind sea/swell bimodal sea states — Offshore Angola

No.	% occurrence	H_{s1} m	T_{p1} s	H_{s2} m	T_{p2} s	$\gamma1$	$\gamma2$	θ_1 (towards)	θ_2 (towards)
291	15,3	0,91	12	0,76	7,7	7,0	2,1	27	21
231	12,1	0,61	11	0,70	7,2	7,3	1,6	25	23
208	10,9	0,61	12	0,70	7,7	7,3	1,8	29	19
154	8,1	0,91	11	0,76	7,2	7,1	1,8	22	23
117	6,1	1,22	12	0,82	8,1	7,4	2,9	27	22
103	5,4	0,61	10	0,73	6,3	5,4	1,4	21	27
94	4,9	0,91	13	0,76	8,4	7,5	2,3	30	18
90	4,7	1,22	13	0,85	8,2	7,2	2,2	32	21
72	3,8	0,61	13	0,79	7,9	7,1	2,2	33	19
65	3,4	0,91	14	0,88	8,7	7,5	2,4	33	17
63	3,3	0,61	14	0,79	8,9	7,7	2,3	35	18
52	2,7	1,52	13	0,91	8,7	8,1	2,4	29	22
47	2,5	1,22	14	0,98	9,4	8,3	2,7	31	21
37	1,9	1,52	14	0,98	9,4	7,3	3,1	32	19
36	1,9	1,22	11	0,88	7,7	7,5	2,0	21	22
35	1,8	0,91	10	0,76	5,9	4,0	1,4	21	31
32	1,7	0,61	15	0,91	9,6	8,4	2,4	32	22
29	1,5	0,91	15	0,88	9,4	8,7	2,9	34	17
28	1,5	0,30	12	0,61	8,6	8,7	3,3	32	15
27	1,4	1,52	12	0,82	8,6	7,5	5,0	27	21
26	1,4	0,30	11	0,76	7,0	8,1	1,9	28	18
24	1,3	1,52	15	1,01	9,8	8,1	2,5	31	20
23	1,2	1,83	14	0,88	8,7	7,0	1,7	32	18
20	1,1	0,61	17	1,04	10,2	9,0	2,8	31	23

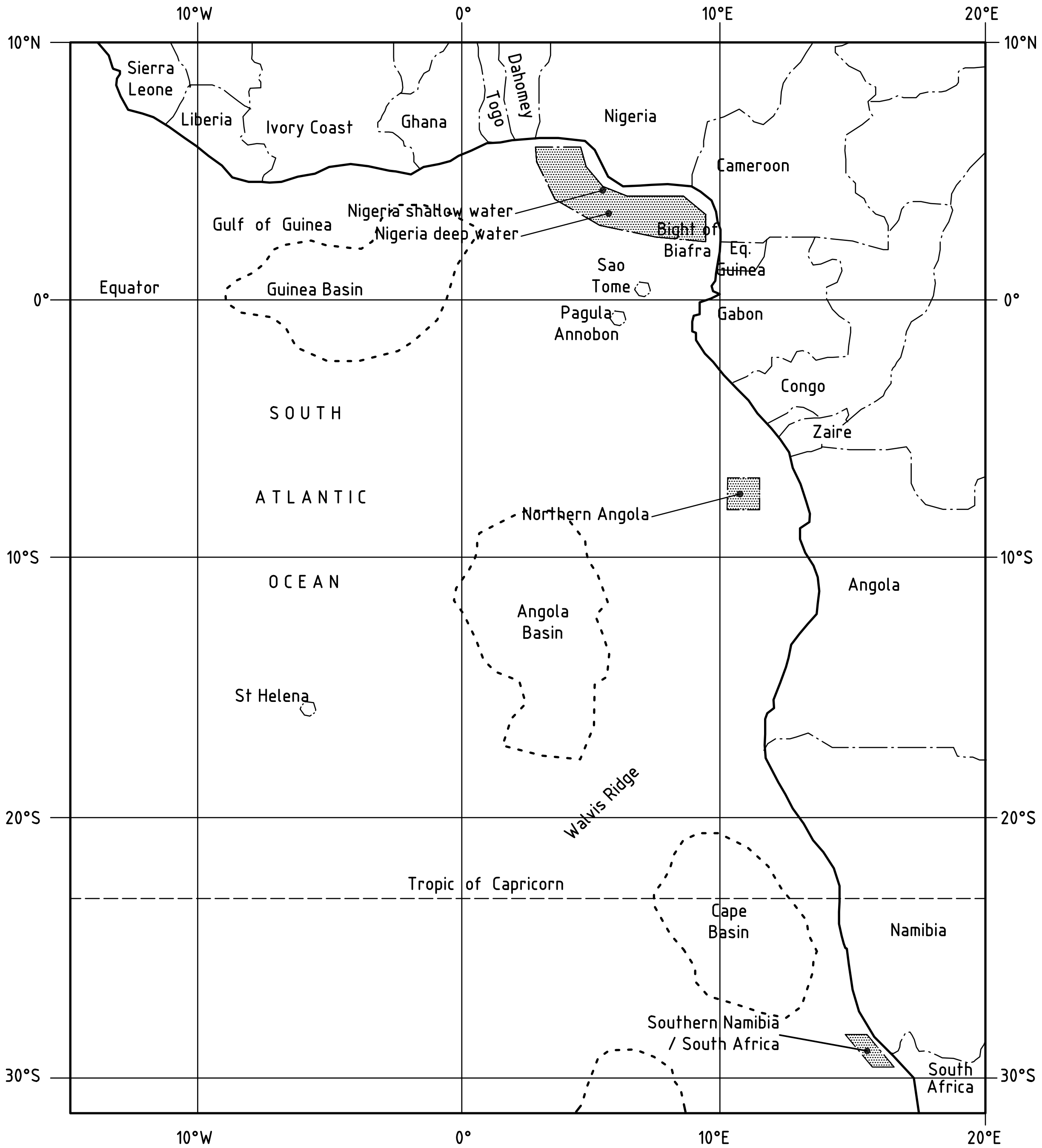

Figure C.1 — Map of west coast of Africa region — Locations of example metocean parameters

Annex D
(informative)

Offshore Canada

D.1 Description of region

D.1.1 General

The geographical scope of this annex includes current hydrocarbon-producing regions of offshore Canada: the Sable Island region offshore Nova Scotia and the Grand Banks of Newfoundland. Some areas with potential for future hydrocarbon development have also been included, such as East Coast Deepwater, the Beaufort Sea and the Gulf of St. Lawrence.

Future updates to this annex will include other areas of interest in the Canadian offshore such as:

— offshore Labrador;

— the Sverdrup Basin (Queen Elizabeth Islands),

— west coast of Canada (offshore British Columbia).

This annex provides an overview of metocean design and operating conditions for areas offshore Canada where hydrocarbon production exists, as well as for certain areas where significant industry interest exists. A range of values based on existing data sets is provided to give an indication of the degree of variability that can be expected for a particular region. The numbers provided are indicative only, and should be used in conjunction with site-specific or project-specific studies to develop environmental criteria to be used for design.

The current hydrocarbon production operations on the east coast of Canada are located offshore Newfoundland and Labrador on the Grand Banks, and offshore Nova Scotia on the Scotian Shelf near Sable Island, as shown in Figures D.1 and D.2.

Figure D.1 — Map of Canada

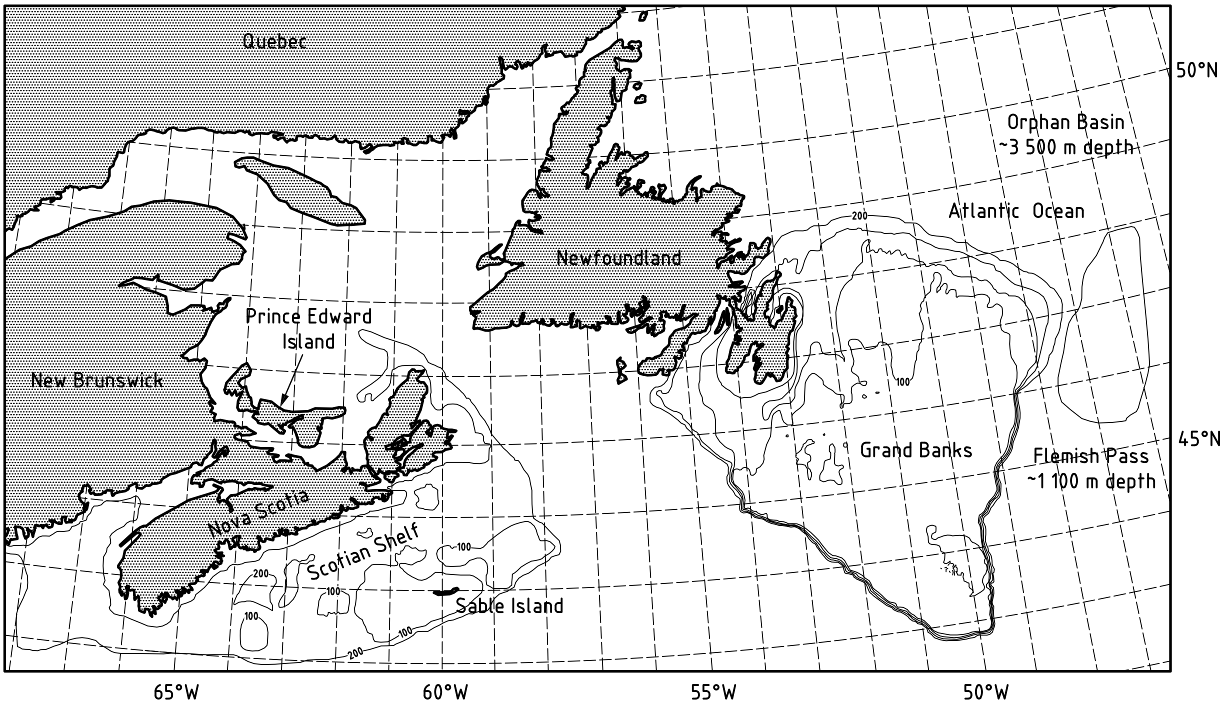

Figure D.2 — East Coast of Canada Current Regions of Oil and Gas Production Operations — Near Sable Island offshore Nova Scotia and on the Grand Banks offshore Newfoundland and Labrador

D.1.2 Grand Banks

The Grand Banks are one of the world's largest and richest resource areas, renowned for both its valuable fish stocks and petroleum reserves. Situated off the southeast coast of the island of Newfoundland, the Grand Banks are a series of raised submarine plateaus with a water depth ranging between approximately 40 m and 200 m. Grand Bank is the largest of several banks comprising the Grand Banks of Newfoundland, and lies to the east and southeast of the Avalon Peninsula. Grand Bank has a relatively flat surface that is generally less than 120 m deep. It is separated from the island of Newfoundland by the Avalon Channel which has water depths ranging up to 200 m deep.

D.1.3 Scotian Shelf

The Scotian Shelf comprises an area of approximately 120 000 km^2, is over 700 km long and ranges in width from 100 km to 250 km. The Scotian shelf physiography consists of three physiographic zones:

a) Inner Shelf

The Inner Shelf borders mainland Nova Scotia, extending roughly 25 km offshore, with water depths less than 100 m. It is characterized by rough topography.

b) Central Zone

This zone is about 80 km to 100 km in width and lies between the Inner Shelf and Outer Shelf. It is characterized by an inner trough running parallel to the coast, and isolated banks with intervening basins and valleys. Water depth varies from less than 100 m over the banks to about 180 m in the inner trough, with some basins up to 300 m in depth.

c) Outer Shelf

This zone is bounded by the eastern shelf break and is about 50 km to 70 km wide. This shelf is characterized by broad flat banks with little relief. Sable Island Bank is the largest and most extensive bank on the Scotian Shelf, with water depths less than 100 m. Sable Island is an arc-shaped sandbar more than 40 km long and about 1,3 km wide.

D.1.4 Deepwater

The Flemish Pass and Orphan Basin are two hydrocarbon fields located in deepwater. These fields are located beyond the Grand Banks, approximately 450 km offshore Newfoundland, as shown in Figure D.2. Water depth varies from 1 100 m to 3 500 m in the Flemish Pass and Orphan Basin, respectively.

D.1.5 Gulf of St. Lawrence

The Gulf of St. Lawrence is located at the mouth of the St. Lawrence River; it is the body of water enveloped by Quebec and the Atlantic Provinces, shown in Figure D.2. The Gulf contains channels with water depths up to 300 m.

D.1.6 Beaufort Sea

The Beaufort Sea is located along the Arctic Circle in northwestern Canada, as shown in Figure D.1. There are three main bathymetric features in the southeastern Beaufort Sea:

a) the continental shelf, which slopes gently from the coastline to water depths of approximately 100 m;

b) the continental slope, angling steeply from the edge of this shelf to depths of 1 000 m; and

c) the trench-like Mackenzie (or Herschel) Canyon, which transects a portion of the shelfNumber-1[173].

D.2 Data sources

Data regarding metocean conditions in the region are available from a variety of sources. These include regulatory bodies, such as the Canada-Newfoundland Offshore Petroleum Board and the Canada-Nova Scotia Offshore Petroleum Board, Operators, federal government agencies and published papers.

Another source of metocean related information is the MSC50 North Atlantic Wind and Wave hindcast model[187]. This model was developed for the Meteorological Service of Canada and is a 60-year (1954 to 2013) wind and wave hindcast model of the North Atlantic. The model is currently being updated to include the years 1998 to 2003. It allows the estimation of extreme wind and wave parameters for the Scotian shelf and the Grand Banks of Newfoundland as well as other locations in the North Atlantic. A separate hindcast has been carried out for the Canadian Beaufort Sea covering the period 1970-2013[231].

For the offshore Newfoundland and Labrador region, environmental impact statements as well as project-specific design environmental criteria were available from the Operators as well as other related information. With respect to the offshore Nova Scotia region, environmental impact statements and development plan applications were utilized such as Sable Offshore Energy Project (SOEP) (1996) [185], Deep Panuke (2002) [171] and Cohasset/Panuke (1990)[170].

A description of observed variability in ice patterns over a 30-year period (1981 to 2010) has been published in map format by the Canadian Ice Service and used here to describe normal conditions[166]. A second report of the Canadian Ice Service provides the thickness of un-deformed ice observed at land-fast ice stations around the Gulf[167]. The thicknesses are listed in Table D.1 along with observed ice drift statistics from satellite-tracked ice beacons deployed by Fisheries and Oceans Canada in the southern Gulf. Lastly, data for ice thickness of deformed mobile pack ice are listed that were collected with a helicopter-borne electromagnetic (EM) sensor over the southern Gulf. The southern Gulf is referred to as the shallow region southwest of the main shipping lane from Cabot Strait into the upper St. Lawrence Estuary. The deeper area of the Gulf, north of the shipping lane, is referred to as the northern Gulf.

Sea-ice data for the Flemish Pass has been extracted from the Provincial Airlines (PAL) (2001) report[183]. This report was conducted on behalf of Petro-Canada to evaluate sea ice and iceberg conditions surrounding the Bay du Nord exploration site (47,55° N, 46,20° W). PAL utilized the Canadian Ice Services (CIS) and the US National Ice Center (NIC) database for this purpose.

A comprehensive listing of additional related environmental and meteorological information sources is presented in D.13.

D.3 Overview of regional climatology

D.3.1 Atlantic Canada

D.3.1.1 General

Offshore Atlantic Canada has very complex and unpredictable weather. The variable climate of the Canadian east coast is influenced by the warm Gulf Stream and the cold water of the Labrador Current. It is also influenced by seasonal changes in air masses, exchanges in energy between the atmosphere and the ocean, seasonal variations in sun radiation, the rugged coastal topography as well as the variability of the Icelandic Low and the Bermuda High, which locally control the Jet Stream and thus storm tracks. They are described further below.

D.3.1.2 Icelandic Low

The Icelandic Low is a large low-pressure system normally located near Iceland and southern Greenland. In mid-summer, when it is at its weakest, it can lie as far west as the Hudson Strait. It exerts a major influence on the tracks of lows passing through Atlantic Canada, and fosters the strong cold northwesterly Arctic air flow across the region in winter and early spring.

D.3.1.3 Bermuda High

The Bermuda High is a semi-permanent high-pressure zone with its mean centre lying east of Bermuda and southwest of the Azores. It can play a major role in the climate of eastern Canada in spring and summer, when it is most persistent. It causes air of tropical origin to penetrate the southern United States and move northward to become entrained in westerly winds. In general, this air can bring in periods of warm humid air and heavy precipitation to Atlantic Canada.

D.3.1.4 Eastern Canada weather

High winds and storms are more common in eastern Canada during the winter months. Spring and summer months have fewer, less intense storms and moderate winds, and precipitation is usually in the form of fog, drizzle or rain showers. Hurricanes and tropical storms from the south can threaten the region in the autumn. Air quality in the region is generally good, both onshore and offshore.

Eastern Canada can experience very cold winters which result in the seasonal occurrence of ice. Under predominantly northwesterly winds and southward-moving Labrador Current branches, ice and icebergs travel southwards along the Labrador coast. Ice (pack ice and icebergs) is encountered seasonally offshore Newfoundland and Labrador in a variety of forms and concentrations. Icebergs of sufficient draft can make contact with the seafloor of the Grand Banks and create scours on the seabed. The maximum water depth at which scours would be expected to occur is approximately 200 m. Icebergs are rare offshore Nova Scotia, but pack ice can be encountered and should be considered in the design of offshore facilities.

The Grand Banks region offshore Newfoundland is considered to be a harsh environment due to the possibility of intense storms and the potential for ice (sea ice and icebergs). Superstructure icing can also occur between December and March because of the temperature and wind and wave conditions. Restricted visibility due to fog is also common, especially in the spring and summer months, when warm air masses overlie the cold ocean surface. The worst visibility conditions are experienced in July. During the winter months, restricted visibility can also be caused by snow in addition to fog and mist.

Major seasonal mean current patterns that influence the regional climatology, and the relative location of Greenland to the Canadian east coast, are shown in Figure D.3.

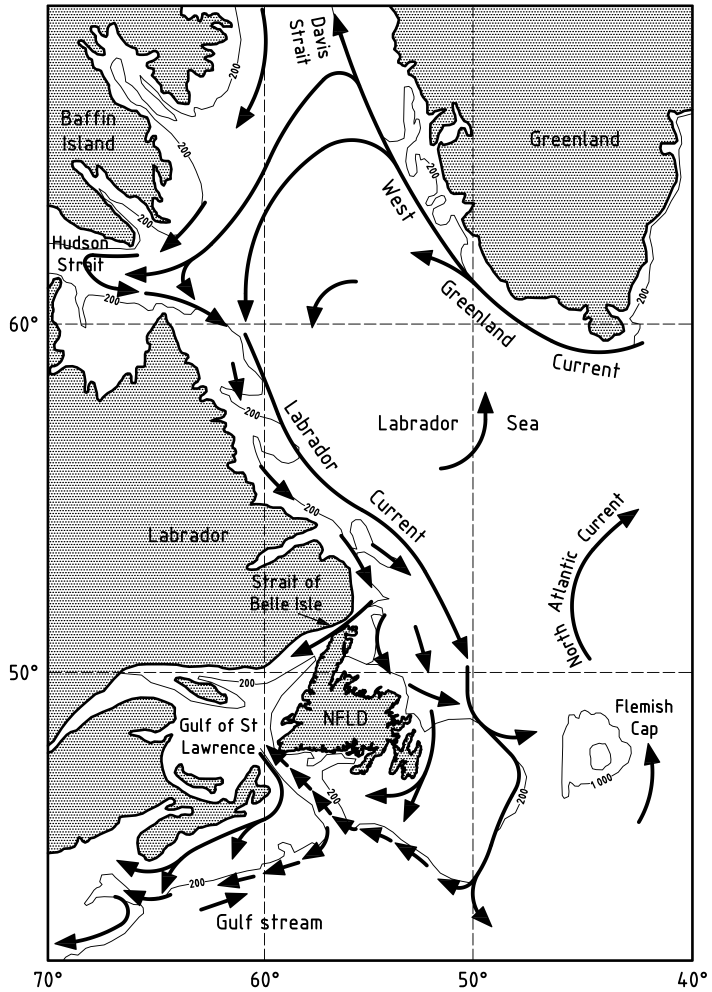

Figure D.3 — Canadian east coast ocean current regime

D.3.2 Beaufort Sea

Temperatures in the Beaufort Sea typically range up to +20°C in the summer and typically down to below −35 °C in the winter. There are, on average, approximately 4 500 freezing-degree days in this region each year. Winds in the Beaufort Sea are influenced by the sharp thermal contrast between the land and water, and the high coastal lands[232]. The dominant wind direction ranges from northeast to southeast during any month of the year. Southerly winds are rare during the summer months. From July to September, westerly to northwesterly winds in excess of 36 km/h become persistent. Fifty percent of all strong winds with speeds exceeding 50 km/h are from the west or northwest. These winds are responsible for the multi-year ice-pack ice intrusions into the coastal waters. The average rainfall is about 150 mm per year, and the average snowfall is 750 mm each year. Poor visibility of less than 8 km occurs about 20 % of the time due to snow, fog, etc.

NOTE: Due to the complexity of the heat exchange between ice, water and air and their measurement, readily available air temperature measurements are often used to quantify the effect of freezing and melting conditions. More specifically, when the mean air temperature for a day is below the freezing point temperature of water, the numerical value can be expressed as the number of Freezing Degree-Days (FDD) and, when above the freezing point temperature, expressed as the number of Melting Degree-Days (MDD). The freezing point temperature of typical marine waters is −1,8° Celsius.

D.4 Water depths

The water depths on the Grand Banks are generally less than 200 m, as shown in Figure D.2.

The water depths in the offshore Nova Scotia area addressed in this annex range from 20 m to 80 m, whereas the waters of the Grand Banks current installations are on the order of 80 m to 130 m.

There are also deepwater locations offshore eastern Canada, such as the Flemish Pass and the Orphan Basin, which have depths of 1 100 m and 3 500 m, respectively. There are other potential deepwater hydrocarbon-producing areas offshore Newfoundland and off the Scotian Shelf.

The main characteristic of the water depths in the Gulf of St. Lawrence is the presence of channels of 300 m depth that run into the Gulf from Cabot Strait, as shown on Figure D.4. One branch runs towards the west up to the Saguenay River entrance, and others run east and north towards the strait of Belle-Isle and around Anticosti Island. The next largest feature is the southern Gulf, surrounding Prince Edward Island and the Magdalen islands, with water depths less than 100 m.

Water depth is highly variable in the Beaufort Sea. The continental shelf here has a depth of approximately 100 m. This shelf slopes down from its edge to depths of 1 000 m. The trench-like Mackenzie (or Herschel) Canyon transects a portion of the shelf.

D.5 Winds

Extreme surface winds are mainly associated with the passage of extra-tropical cyclones and their associated frontal structures. Given the large gradients in sea-surface temperature in the region and the closeness of cold and warm continental air mass source zones, the boundary layer wind shear, and hence the strength of surface winds relative to the pressure-gradient-driven free atmosphere flow, tends to be strongly modulated by the stability of the boundary layer, as evidenced by the air-sea temperature difference. The strongest surface winds tend to occur in unstable sectors of storms (air colder than the sea). Extreme winds, on the order of 25 m/s (1-h average at 10 m elevation), tend to be associated with smaller (than cyclone) scale features, such as the “surface wind jet streaks” which propagate rapidly within the broader air flows about each cyclone, within narrow frontal zones and near the cores of nascent explosively developing cyclones. At even smaller scales, convectively produced squalls can occur during seasons and in regions where cold air overlays relatively warm waters. Extreme winds in tropical cyclones are comparable to those in extra-tropical cyclones because larger-scale considerations limit the maximum intensity of tropical cyclones to a Saffir-Simpson scale intensity 2 at most (on a scale of 1 to 5). The winds vary considerably in the different regions as indicated in Table D.5.

D.6 Waves

The wind fields associated with extra-tropical and tropical cyclones excite a wide range of sea states depending on storm size, radius of curvature of the wind field, peak wind speeds, storm propagation speeds, intensity and speed of propagation of surface wind jet streaks, and proximity of land which will limit fetch for appropriate wind directions. Of course water depth is important in the shallower development areas of the Scotian Shelf for basically all return periods of interest. Indeed, on the Grand Banks, marginally shallow water can affect seas states in the most intense systems. Even relatively small-scale features, such as the small area of high winds in the right quadrant of a propagating tropical cyclone or cyclone undergoing transformation to extra-tropical stage, or a jet-stream propagating through a larger air stream, can generate enormous sea states if the propagation speed of the wind feature and its peak wind speed allow optimum resonance coupling between the wind field and the surface waves. Extreme wave heights, with maximum individual waves up to 30 m, have been recorded in the region during previous severe storms (e.g. Hurricane Luis in 1995).

D.7 Currents

The Labrador Current is perhaps the most dominant in the Atlantic Canada region. It plays a major role in the transport of colder water to the region, and the resultant regional current pattern is a function not only of this large current, but also of tides, encounters with ocean currents (such as the warmer eddies and meanders of the Gulf Stream) and storm winds.

The Labrador Current is also responsible for the transport of icebergs from northern areas to offshore Newfoundland. Figure D.3 shows how the Labrador Current divides into an inshore branch and an offshore branch. The offshore branch of the Labrador Current is mainly responsible for the transport of icebergs to the hydrocarbon-producing region of the Grand Banks.

The main feature in the Gulf of St. Lawrence is the Gaspé current that flows out of the St. Lawrence Estuary along the Gaspé Peninsula towards the Gulf, loosely following the 50-m isobath as shown in Figure D.4. It is driven by the freshwater outflow of the St. Lawrence River and is intensified by winds. In addition, strong tidal currents are present in the Jacques Cartier Passage, north of Anticosti Island, and at the mouth of the Saguenay River.

The mean circulation pattern in the Beaufort Sea is shown in Figure D.5 [173]. Offshore in the Beaufort, the surface flow is dominated by the clockwise circulation of the Beaufort Gyre. Estimates by Newton (1973) [180] indicate that flow speeds reach 5 cm/s to 10 cm/s at the southern rim of the Gyre over the western Beaufort Sea. Figure D.6 shows the pattern of the currents in the nearshore region for both northwest winds and east winds. During the summer season, measurements of currents made at the Kopanoar location indicate values of 0,3 m/s to 0,4 m/s at 5 m depth, and decreasing to 0,1 m/s to 0,2 m/s at 12 m depth [174].

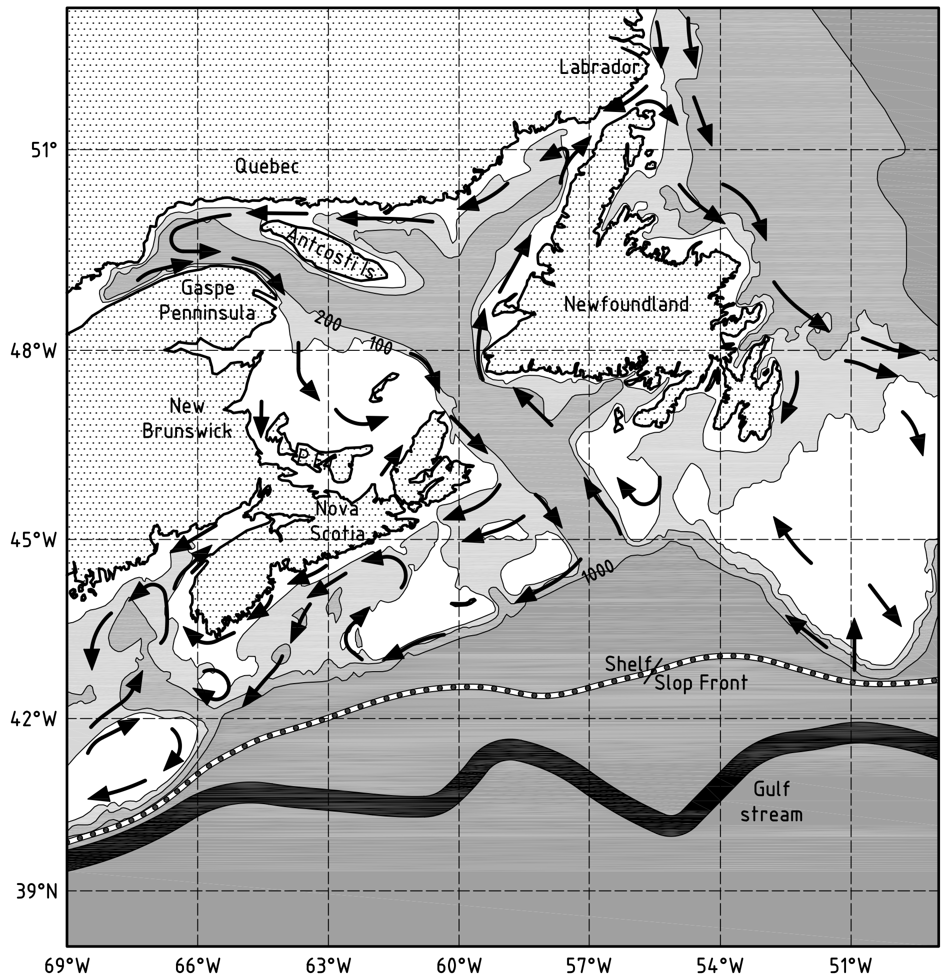

Figure D.4 — Map of the Gulf of St. Lawrence showing the general circulation pattern