Port au Port Bay
Exploration Drilling Program
Environmental Assessment Addendum

Prepared by

LGL LIMITED
environmental research associates

Prepared for

PDI PRODUCTION INC.

28 November 2007
SA930

Port au Port Bay
Exploration Drilling Program
Environmental Assessment Addendum

Prepared by

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

in association with

CALIXTE
Environmental
Management

Prepared for

PDI Production Inc.
Suite 201
Baine Johnston Centre
10 Fort William Place
St John's, NL A1C 1K4

28 November 2007
SA930

Table of Contents

Page

Introduction

This is an Addendum to the environmental assessment (EA) for the Port-au-Port Bay exploration drilling program to be undertaken by Shoal Point Energy Ltd (SPEL) and partners PDI Production Inc. (PDIP) and Canadian Imperial Venture Corporation (CIVC). It has been prepared in response to comments provided to PDIP by the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). The Addendum is organized as closely as possible to the order of the comments as they were received which generally follow the section numbering of the original EA (LGL 2007). Comments related to the physical environment are addressed in the appended report by Oceans Ltd. (Oceans 2007).

Reviewer comments are in italics and responses are in normal font.

General Comment

The ***Scoping Document*** *(Section 5.4 Cumulative Effects) requests that a description of other projects or activities that have been or will be carried out (i.e., other seismic activities, fishing activities, including Aboriginal fisheries, other oil and gas activities, marine transportation) be included. This does not appear to be the case and the EA should be revised accordingly.*

Response:

Cumulative effects of other projects and activities were assessed in the EA (see sections 6.6.5, 7.2.1.3, 7.2.2.3, 7.2.3, 7.2.4.7, 7.2.5.4, 7.2.6.4, 7.2.7.4, and 7.2.8.6) and summarized in Section 9.2.

Projects and activities considered in the cumulative effects assessment included:

- Within-project cumulative impacts. For the most part, and unless otherwise indicated, within-project cumulative effects are fully integrated within this assessment;
- Other present or future oil exploration activity under applications or approvals for the area [The public registry on the C-NLOPB website on 25 September 2007 listed three projects for the west coast of Newfoundland: (1) Ptarmigan Resources marine 2D/3D seismic surveys in EL 1069, to the north of Port au Port Peninsula, (2) Tekoil 3D nearshore/onshore marine seismic for western Port au Port Peninsula, and (3) Tekoil “Little Port” onshore to offshore drilling in EL 1069 under “farm-in” from Ptarmigan Resources. Little Port is over 18 km to the northeast of the northeastern tip of the peninsula.];
- Commercial fisheries and aquaculture;
- Marine transportation (tankers, cargo ships, supply vessels, naval vessels, fishing vessel transits, etc.);
- Hunting activities (marine birds and seals, terrestrial birds and mammals);
- Recreational fishing activities (freshwater/estuarine); and
- Other land uses (e.g., wood harvesting).

Marine exploration, commercial fishery activity and marine transportation all have the potential to interact with marine macro-invertebrate/fish habitat to a greater degree than the routine activities associated with the proposed onshore to offshore exploration drilling project. Various aspects of marine exploration (e.g., drilling disruption of bottom substrate, drill cuttings, seismic and other activity related noise), commercial fisheries (disruption of bottom substrate, noise, releases of waste materials and hydrocarbons), and marine transportation (noise, releases of waste materials and hydrocarbons) are the likely primary causes of the existing cumulative effects on this VEC. As the proposed Project's routine activities will have no or negligible effect on this VEC, there will be no cumulative effect caused by the Project.

Marine exploration, commercial fishery activity, marine transportation and recreational fisheries all have the potential to interact with marine macro-invertebrates and fish to a greater degree than the routine activities associated with the proposed onshore to offshore exploration drilling Project. Various aspects of marine exploration (e.g., drilling disruption of bottom substrate, drill cuttings, seismic and other activity-related noise), commercial fisheries (harvesting of animals, disruption of bottom substrate, noise, releases of waste materials and hydrocarbons), marine transportation (noise, releases of waste materials and hydrocarbons), and recreational fisheries (harvesting of animals, noise, releases of waste materials and hydrocarbons) are the likely primary causes of the cumulative effects on this VEC. The routine activities of the Project will create no cumulative effect on this VEC because of the extremely localized nature of the effect, even if it occurs.

Any effects in combination with other activities (mostly fishing) are also expected to result in no significant cumulative effect on fishing gear, fishing grounds available or overall catchability of commercial and bait species.

Marine and terrestrial exploration, commercial fishery activity, marine transportation, recreational fisheries and hunting all have the potential to interact with marine-associated birds to a greater degree than the routine activities associated with the proposed onshore to offshore exploration drilling Project. Various aspects of marine and terrestrial exploration (e.g., seismic and other activity-related noise, physical disturbance to shorebirds, releases of waste materials and hydrocarbons), commercial fisheries (noise, releases of waste materials and hydrocarbons), marine transportation (noise, releases of waste materials and hydrocarbons), and recreational fisheries (noise, releases of waste materials and hydrocarbons, physical disturbance of shorebirds) and hunting (harvesting of animals, noise, releases of waste materials and hydrocarbons) are the likely primary causes of the cumulative effects on this VEC. The Project will create essentially no cumulative effects on the marine environment because of the extremely *low* magnitude and geographic extent of any potential effects from routine activities on land.

Seismic and other activity-related noise from marine exploration, commercial fishery activity, marine transportation and recreational fisheries all have the potential to interact with marine mammals and sea turtles to a greater extent than the routine activities associated with the proposed onshore to offshore exploration drilling. Various aspects of marine exploration (e.g., seismic and other activity-related noise, releases of waste materials and hydrocarbons), commercial fisheries (noise, releases of waste materials and hydrocarbons), marine transportation (noise, releases of waste materials and hydrocarbons), and recreational fisheries and hunting (noise, releases of waste materials and hydrocarbons) are the likely primary causes of the cumulative effects on this VEC. This land-based Project will create essentially no cumulative effects on marine mammals and sea turtles.

Terrestrial exploration, recreational fisheries, hunting and wood cutting all have the potential to interact with freshwater fish and fish habitat to a greater degree than the routine activities associated with the proposed onshore to offshore exploration drilling Project. Various aspects of terrestrial exploration (e.g., seismic and other activity-related noise, line cutting), recreational fisheries (physical presence and atmospheric emissions of ATVs and other vehicles, harvesting of animals, release of waste materials and hydrocarbons, noise), hunting (physical presence and atmospheric emissions of ATVs and other vehicles, noise), and wood cutting (physical presence and atmospheric emissions of ATVs, other vehicles and associated equipment, noise, waste wood products entering freshwater systems) are the likely primary causes of the cumulative effects on this VEC. The potential for cumulative effects from the Project is very limited due to the limited magnitude and geographic scale of any potential effects.

All other projects/activities listed in Table 7.9 of the EA have the potential to interact with at least some of the indicated species at risk to a greater degree than the routine activities associated with the proposed onshore to offshore exploration drilling Project. Various aspects of terrestrial exploration (e.g., seismic and other activity-related noise, line cutting), recreational fisheries (atmospheric emissions of ATVs, outboard motors and other vehicles, harvesting of animals, release of waste materials and hydrocarbons, noise), hunting (harvesting of animals, physical presence and atmospheric emissions of ATVs, outboard motors, and other vehicles, noise), and wood cutting (physical presence and atmospheric emissions of ATVs, other vehicles and associated equipment, noise) are the likely primary causes of the cumulative effects on the species at risk VEC. Because of the no to negligible effect to low magnitude and limited geographic extent of any potential effects, there will be essentially no cumulative effects on the species at risk VEC due to the Project.

Projects and activities considered in the cumulative effects assessment included:

- Onshore to offshore exploration drilling within-project cumulative impacts. For the most part, and unless otherwise indicated, within-project cumulative effects are fully integrated within this assessment;
- Other marine exploration activity (seismic surveys and exploratory drilling);
- Commercial fisheries;
- Marine transportation (tankers, cargo ships, supply vessels, naval vessels, fishing vessel transits, etc.);
- Terrestrial exploration activities (seismic surveys, exploratory drilling);
- Recreational fisheries (marine and freshwater species); and
- Hunting activities (marine birds and seals, terrestrial birds and mammals).

Any cumulative effects on the Gulf of St. Lawrence ecosystem from drilling outside the proposed drilling area will probably not overlap in time and space and thus, will be additive but not multiplicative.

This level of activity will not change the effects predictions when viewed on a cumulative basis unless significant oil spills or blowouts occur.

All cumulative effects from project activities are predicted to be *not significant* with the potential exception of effects from a blowout that results in a large marine spill. There could be significant cumulative effects with other projects if there were simultaneous blowouts on the west coast that spilled into the marine environment, a scenario that is unrealistic given the very low probability of a blowout (much less two), the unlikelihood of significant amounts of oil entering the marine environment from a land based drill rig, and the good potential for effective countermeasures.

The predicted cumulative effects of the proposed 5-year onshore to offshore exploration drilling program on the VECs are predicted to be *not significant*.

Specific Comments

Request:

Section 4.0, Page 19, Physical Environment*: The scoping document for this EA specified the requirements for the description of the physical environment: "For the Study Area, provide a summary description of the meteorological and oceanographic characteristics, including extreme conditions, and any change to the Project that may be caused by the environment". The information on winds and waves presented in the EA is fairly general and brief. It is based on the description of winds and waves in the Strategic Environmental Assessment for western Newfoundland offshore areas (C-NLOPB 2005). Data for that SEA were obtained from the deep water AES40 hindcast of modeled winds and waves (Swail et al 2000). However, there should be some additional analysis of both winds and waves specific to the project area. It would also be advisable to consider potential effects of storm surge and sea-ice.*

Response:

Additional analysis is provided in a separate report (Oceans 2007) contained in the Appendix.

Request:

Section 4.2.2, Page 27, Waves*: Although the rig would be on land, it would be located at low elevations close to the shore. Figure 3.1 shows the drill hole on Shoal Point at an elevation of 1.21 m, about 45 m from the highwater mark. Other equipment on the drill site would be closer. Section 3.5.3 Site Plans mentions a berm to contain potential spills but no height was specified. The EA should consider the possibility of high waves breaking on shore in extreme storms. Thus shallow water wave modelling of the transformation of high, long period, deep water waves is important. There is no discussion of this, or any mention of future plans to do this analysis. This would be relevant for waves from the north, entering Port au Port Bay and breaking on Shoal Point. In addition, the western shore of Long Point is fully exposed to waves in the Gulf of St. Lawrence. There should be some discussion in section 6.8 of the potential effects of waves reaching the drill site. A related issue is the effect of icing from freezing spray on the structure. This was not mentioned yet may be important.*

Response:

Shallow water wave modelling has been carried out and included in the appended report (Oceans 2007).

Request:

Storm Surge - *There should be some discussion of storm surge for the project area and its effects on the project. It seems that there is potential for flooding of low lying parts of Shoal Point or Long Point during an extreme event combining high storm surge, high waves, and high tide. As noted, the centre of the project site on Shoal Point is only 1.21 m above sea level and close to the water's edge. The estimate by Bernier and Thompson (2006) of 40-year return period storm surge height along the western coast of Newfoundland is 0.7 m. However, that value may be larger within the bay due to wave set-up with north* *to northeast winds. Section 4.3.2 Tides gives the tidal amplitude as up to 0.53 m. What would be the combined effect on a drill rig or storage tanks of waves carried onshore by storm surge arriving at high tide?*

Response:

Included in the appended report (Oceans 2007).

Request:

Section 4.3.1, Page 29, Currents*: The figure presented gives a typical summer surface circulation pattern. This information is not applicable to 2007 drilling activities, as the project is scheduled to take place in fall and winter. Circulation patterns appropriate for the project timeline should be presented instead.*

Response:

Addressed in the appended report (Oceans 2007).

Request:

Section 5.1.1, Page 40, Marine Ecosystem: *The descriptions of the marine ecosystem provided focus mainly on commercially important fish and invertebrate species, and are based on landings data (which would not give the location of capture) and on stock assessment information, much of which is outside of the Port au Port Bay area. This represents a data/knowledge gap for the area in terms of allowing an adequate assessment of the potential impacts of accidental release of hydrocarbons. At the very least, these data gaps should be identified in a separate section of the report and the resultant limitations of the effects assessment acknowledged.*

Response:

It is acknowledged that information relating to both commercial and the less conspicuous non-commercial fish and invertebrate species within the Project Area is lacking and that additional data would be beneficial to the assessment. As the reviewer notes, most of the distributional information provided for the Study Area in the assessment was based on commercial landings data and stock assessment data, and much of this was relevant to areas outside of Port au Port Bay. This lack of biological information constitutes a data/knowledge gap. Some traditional ecological knowledge is available through the Community-based Coastal Resource Inventory (CCRI) but these data are also somewhat limited because they are qualitative. In order to address this data gap, PDIP conducted consultations in the Port au Port area in order to glean additional local knowledge and to identify any local issues associated with the proposed drilling program, marine ecosystem-related or otherwise. The level of confidence associated with any significance rating of residual environmental effect is always correlated to the amount and quality of supporting information. While residual effects of accidental events on various components of the Port au Port Bay ecosystem were determined to be *not significant*, the level of confidence would be higher if more information on the marine ecosystem was available but the determination of *not significant* would be unlikely to change.

Request:

Section 5.1.1.4, Page 79, Nesting Populations and Breeding Biology, 3rd paragraph:
The statement "Shorebird species (plovers and sandpipers) nesting along the west coast of insular Newfoundland include the nationally endangered Piping Plover. Nesting has not been recorded in the Study Area…". This statement contradicts the statement made on page 84 under Bird Species at Risk "Piping Plover is designated endangered in Schedule 1 under the federal Species at Risk Act (SARA) and the Endangered Species Act of Newfoundland and Labrador. This species has nested at a number of coastal sites within the Study Area discussed above."

Response:

The reviewer is correct. Nesting has not been recorded in the Study Area (see Figure 1.1 in the EA). The nearest recorded nesting of Piping Plover is Stephenville Crossing.

Request:

Section 5.1.3.1, Page 110, SARA: *The statement: "Currently, there are no recovery strategies, action plans, or management plans in place for species under Schedule 1 and known to occur in the Study Area" is incorrect. Wolffish (spotted and northern) occur in the area, are on Schedule 1 of SARA and have recovery plans as stated on page 116. A recovery strategy for Leatherback Turtles (Atlantic population) is also on the SAR Public Registry, as is a management plan for striped wolffish. The proponent should refer to these recovery strategies/plans to ensure that proposed mitigation is consistent with these documents.*

Response:

A proposed recovery strategy for the northern wolffish (*Anarhichas denticulatus*) and spotted wolffish (*Anarhichas minor*) as well as a management plan for Atlantic wolffish (*Anarchichas lupus*) in Canada (Kulka et al. 2007) was recently reviewed and accepted by Fisheries and Oceans Canada as the Recovery Strategy and Management Plan for these species as required by the *Species at Risk Act* (*SARA*). The Recovery Strategy and Management Plan identifies the paucity of existing information on the population dynamics, ecology, abundance, distribution, habitat utilization, behaviour, interaction with fishing gear and environment of these wolffish species. The document emphasizes the immediate need for additional research to allow for the formulation of recovery approaches. The Recovery Strategy and Management Plan document discusses the potential interactions between oil and gas exploration and production activities and wolffishes. It points out the lack of information on the potential impact of seismic surveying and drilling activities on wolffishes and associated habitats, the need for further research in this area and on general mitigation measures.

The Leatherback Turtle Recovery Strategy (ALTRT 2006) identifies numerous data gaps concerning leatherbacks, including the lack of general knowledge about "appropriate measures to mitigate any negative human-induced effects". The document does note that a marine animal disentanglement and stranding program is in place in Newfoundland and that it can mitigate impacts of inshore fisheries on leatherbacks. Additional mitigation measures have not been identified in the recovery strategy given that the threats to leatherback turtles are not fully understood.

The Operator will continue to monitor *SARA* status and any relevant recovery and management plans and will ensure that proposed mitigation measures for its drilling program are consistent with them.

Request:

Section 5.1.3.4, Page 110, *Profiles of Species Listed as Endangered, Threatened or Special Concern on Schedule 1 of SARA: There does not appear to be a description of the "Sowerby's beaked whale" in the report. If relevant to the project area, it should be included.*

Response:

Sowerby's beaked whales are considered rare in the Study Area given that this species typically occurs in deep waters, including continental shelf edges and slopes. There are no records of sightings or strandings in Quebec, Prince Edward Island or along the Gulf of St. Lawrence coastlines of Newfoundland (including the Study Area) or Nova Scotia (COSEWIC 2006). Therefore, this species was not included in the EA.

Request:

Table 5.15, Page 111: *While Atlantic cod in general is listed on Schedule 3 of SARA, the Newfoundland and Labrador population is not on any SARA schedule and currently has no status under SARA. The species was considered a single unit and assigned a status of Special Concern in April 1998. However, the species was split into separate populations for consideration in May 2003. Please refer to the species profile on the SARA Registry for further explanation.*

Response:

The general reference to Atlantic cod (*Gadus morhua*) in Table 5.15 should be removed from the table. As indicated in Table 5.15, the Laurentian North population of Atlantic cod (*Gadus morhua*) is currently listed as *threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) but has no status under *SARA*. This Atlantic cod population was last assessed by COSEWIC in May 2003.

Request:

Section 5.2, Page 119, Notable Areas: *There is no reference in the report to the Community-based Coastal Resource Inventory (CCRI). This database is an important source of qualitative biological*

information for many coastal marine areas, including Port au Port Bay. The proponent should access the CCRI database at the following website and reference relevant information to Port au Port Bay in the EA.
http://public.geoportal-geoportail.gc.ca/publicGeoBrowser/public/GeoPortalBrowser.jsp

Response:

The CCRI database was accessed through the DFO GeoPortal website. The entire resource database was examined and the following flora and fauna were indicated as occurring within the Study Area. Distribution is categorized as 'within Port au Port Bay', 'outside Port au Port Bay', and both areas.

Within and Outside of Port au Port Bay

American plaice
Atlantic cod
Capelin
Dolphins/porpoises
Flounder
Eelgrass
Giant scallop
Atlantic herring
Kelp
Lobster
Mackerel
Mussels
Rock crab
Rock weed
Sea urchin
Seals
Toad crab
Whelk
Whales

Within Port au Port Bay

Clams
Irish moss
Periwinkles

Outside Port au Port Bay

Haddock
Atlantic halibut

Lumpfish
Snails
Squid
Snow crab
Witch flounder

Many of these resources identified by the CCRI were discussed in the EA. As indicated in Section 5.1.1.1 of the EA, the Western Newfoundland and Labrador Strategic Environmental Assessment (C-NLOPB 2005) discussed a variety of coastal algal communities that include flora and various invertebrates such as periwinkles and mussels.

Request:

DFO recently released a report on ecologically and biologically significant areas (EBSA) in the Estuary and Gulf of St. Lawrence: Identification and characterization. DFO Can. Sci. Advis. Sec., Sci. Adv. Rep. 2007/016. One of these areas is adjacent to the study area and should be noted in the document and in the potential impacts assessment.
http://www.dfo-mpo.gc.ca/csas/Csas/status/2007/SAR-AS2007_016_E.pdf

Response:

The West Coast of Newfoundland Ecologically and Biologically Significant Area (EBSA) (10) identified in the Canadian Science Advisory Secretariat Science Advisory Report entitled "Ecologically and Biologically Significant Areas (EBSA) in the Estuary and Gulf of St. Lawrence: Identification and Characterization" (DFO 2006) does overlap with the western portions of both the Study Area and Project Area. This area of overlap occurs outside of Port au Port Bay on the west side of Port au Port Peninsula. The approximate range of water depths in the overlap area is 50 to 200 m. This EBSA includes main concentration areas for juvenile cod, redfish, American plaice and Atlantic wolffish in the Estuary and Gulf of St. Lawrence. The overlap area may also represent important migration corridors for particular species including Atlantic cod and redfish. Many pelagic species (e.g., Atlantic herring, capelin, ribbon barracudina, spiny dogfish, silver hake and pollock) concurrently use the channel in the vicinity of the strait offshore from Port au Port as a summer feeding area. Within and proximate to the area of overlap between EBSA 10 and the Study/Project Area are areas known for cod spawning, and an abundance of capelin and Atlantic herring larvae. The southern part of EBSA 10 has been identified as important for marine mammals, especially around St. George's Bay, a potentially important feeding area for many species of marine mammals (e.g., blue whale, divers, krill eaters).

Request:

Section 6.8, Page 136, Effects of the Environment on the Project*: The effect of seaice on the project was not discussed in section 6.8. What is the potential for damage caused by ice ride-up (ice carried onshore by wind stress, ice pressure, or storm surge)? During the extreme storm of January 20-22, 2000, the high storm surge caused ice to ride-up along the shores of PEI and southeastern NB, which caused significant damage to coastal infrastructure (McCulloch et al. 2006; also see Parlee 2006).*

Response:

Addressed in the appended report (Oceans 2007).

Request:

Section 8.2.3, Page 172, Releases from the Crude Oil Holding Tank: *The likelihood that hydrocarbon released from failure of diesel fuel tank storage reaching the environment was provided. The same should be provided for the crude oil holding tank.*

Response:

Crude oil holding tanks on site will be surrounded by a berm capable of holding, as a minimum, the contents of the largest tank plus 10% of its volume. Alternatively, road tankers may be used and filled with crude oil directly, eliminating the need for static tanks. As a result, it is considered highly unlikely that any crude would be released to sea as a result of crude oil holding tank leaks.

Request:

Section 8.2.5, Page 173, Release of Contaminated Drilling Fluids*: Drilling fluid used in the offshore typically has a hydrocarbon content of 80%, yet the assumptions used in the analysis is for 50% hydrocarbon content. Please clarify.*

Response:

The Operator has confirmed that the hydrocarbon content of the mud will be zero.

Request:

Section 8.4.2.3, Page 178, Oil Spill Trajectory Modeling-General Model Results*: It is concluded that the likelihood of accidentally released hydrocarbons moving beyond the northern boundary of the study area is negligible. There are potentially other factors besides the prevailing winds that could influence surface currents and the movement of oil beyond the study area. Some of these are described earlier in the report (section 4.3, Physical Oceanography). It is recommended that these factors be considered or addressed in the modeling carried out in relation to this aspect.*

Response:

In relation to the driving forces of the spread and evolution of an oil spill at sea, it is important to note that marine currents are a potentially important factor to consider. However, its role is only important in areas where the strength of the current flows is significant.

The Study Area lacks direct observations of marine currents which would allow a comprehensive assessment of the currents regime in the area. However, several studies are available showing model-generated current fields, which cover the Study Area. For example, Chasse (2001) shows that residual currents, including wind forcing, off the Port Au Port Bay are in the order of 10 cm/s or less, while inside the bay the currents reach between 0 cm/s and 5 cm/s.

If we consider the scenario of a constant southerly wind episode lasting more than five days combined with constant north-westward currents of 10 cm/s, then part of the oil slick could go outside the limits of the Study Area, however, the probability of such scenario is negligible.

In addition, such a current field would greatly overestimate the currents inside the bay and would contain no tidal oscillations, which would diminish the chances of the oil spreading beyond the Study Area, since tidal oscillations would amount to periodic departures from the direction of maximum spread. Furthermore, the 10 cm/s currents reported by Chasse (2001) already contain the effect of the wind, therefore the wind would be considered twice in this case (once inherently by the current vector itself and twice by the wind vector as an input to the model), resulting in an exaggeration of effect.

The simulation study shows that after some time (usually less than 5 to 6 days), while the oil is still inside the Study Area, there is no further change in the amount of oil evaporated or coming ashore, an indication that the oil remaining in the media has left the sea surface.

Almost 100% of the sustained southerly winds will have duration of less than 50 hours, which is not enough time for the oil, even with strong north-westward currents, to go outside the boundaries of the Study Area (see Figure A below).

Chassé, J., 2001. Physical Oceanography of Southern Gulf of St. Lawrence and Sydney Bight Areas of Coastal Cape Breton. CSAS Research Document 2001/113, Fisheries and Oceans, Canada, 200p

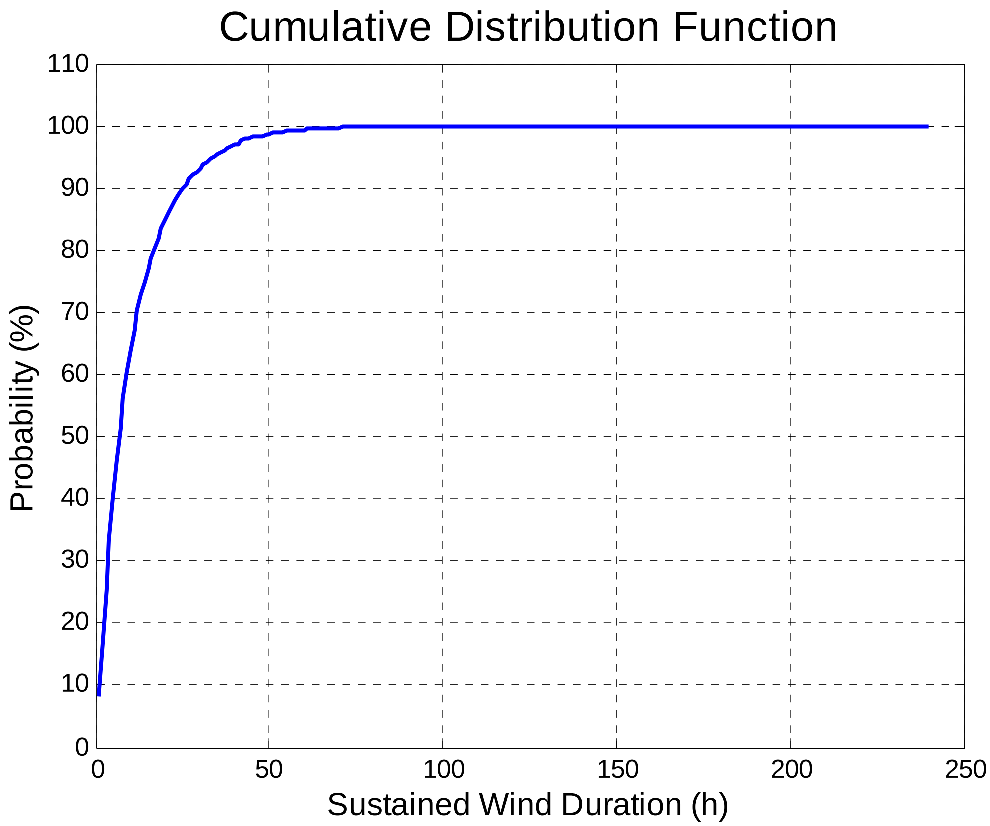


Figure A. Cumulative probability of the duration of sustained southerly winds for node 14462 of the MSC50 dataset

Request:

Section 8.7, Page 180, Alternatives to Containment and Recovery: *Use of dispersants and In situ burning are not approved mitigations. Approval must be obtained before use.*

Response:

Use of dispersants and *in situ* burning is not the primary method for oil containment and recovery. Approvals will be obtained before dispersants or *in situ* burning would be used as a mitigation.

Request:

Section 8.8.1, Page 181, Proposed Mitigations for Port au Port Drilling Project: *The mitigations listed are primarily to prevent terrestrial-related impacts. Mitigation measures for the marine environment should be included. In particular, the oil spill response plan should include contingency measures for hydrocarbons and/or chemicals that reach the marine environment. Clarification regarding the types of mitigations proposed for the marine environment, under the OSRP, should be provided.*

Response:

The majority of the mitigation measures listed in Section 8.8.1 are aimed at preventing the release of hydrocarbons to the environment, in order to minimize the possibility of negative impact on either the terrestrial or marine environment. Should oil or other pollutants enter the marine environment, flotation containment booms will be deployed in order to contain the spill in a fixed location. In addition, if for any reason, it is believed that equipment available on-site may not be adequate to contain the spill, the Operator will immediately request the assistance of the Eastern Canada Response Corporation (ECRC), a professional emergency response organization with access to additional resources and personnel trained in oil spill management and response. ECRC has suitable equipment available in Western Newfoundland that will be mobilized to Shoal Point should SPE request it, and they will provide assistance in mitigation and containment, recovery and clean-up, if required.

An Arctic Pack Container will be provided on site, which will include:

- 1000' of 36" Flat Containment Boom
- 8 x Hi-B8-10 Absorbent Boom, 4 x 8" x 10' absorbent boom per bundle, complete with connecting hardware
- 12 x Hi-AL-P100, 15" x 19" heavy weight Absorbent Pads, 100/bundle
- 2 x Towing paravanes (for containment boom)
- 6 x 22 lb Danforth Style Anchors
- 9 x 12" Marker Buoys
- 12 x 3/8" Shackles
- 9 x Boom Joiners
- 1 Coil of 5/8" rope (approx. 1200')
- 1 Box or Rags
- 1 x 1000 Gallon Flex Tank
- 30 x 44 liter bags of Oclansorb
- 10 Boxes of 4" x 4' Sorb-Sox, 15/box

In addition, ECRC equipment will be available, which includes:

- Transport trailer, containing:
  - Flotation boom.
  - Anchors.
  - Anchor marker buoys.
  - Anchor mooring and marker ropes.
  - Rope reel stands.
  - Spare parts box.
- Boston Whaler, 21 ft fibreglass work boat.
- Trailer for Boson Whaler.
- VHF hand held radios.
- Battery charging units for VHF radios.

- Oil skimmer and power pack.
- Portable tank.
- Consumables, including:
  - Spare batteries for VHF radios.
  - Bundles of sorbent pads.
  - Sorbent boom.
  - Rolls of sorbent blanket fabric.
  - Polypropylene rope.
- Rental equipment, including:
  - Locally chartered, trailer mounted, work boat.
  - Oil spill tracker buoys.
  - Pager.
  - Cellular telephone.
  - 4-wheel drive vehicle with ball hitch to tow and launch Boston Whaler.
  - Highway tractor to tow ECRC transport trailer.

Recovery methods employed, if required, will depend on the size of the spill, water state and weather conditions. Options for recovery include:

- Dispersants.
- Skimmers and recovery tank.
- Absorbents (for small spills only).

Further details on measures to be taken in the event of a spill are provided in the Shoal Point Contingency Plan for Event of a Spill of Oil or Other Pollutant.

Request:

Section 8.8.5.1, Page 189, Effects of Exposure to Hydrocarbons*: The name Oldsquaw has been changed to Long-tailed Duck.*

Response:

So noted. Please change all such references to Long-tailed Duck.

Request:

Section 8.8.9, Page 195, Species at Risk: *For clarity, a reference to Table 5.15 should be included after the first sentence.*

Response:

So noted. Please reference to Table 5.15.

Information for Project Planning Purposes

The following comments are offered for consideration in the design and planning of drilling activities.

These guidance comments have been forwarded to the Operator.

Request:

Section 4.2.1, Page 24, Wind: *The AES40 winds used in the EA are representative of one-hour mean winds at 10-m. Estimates of extreme winds of shorter averaging periods such as a one-minute mean and a 3-second gust are generally used by industry for design one-hour mean winds to maximum winds at shorter averaging intervals or to gust values. Wind climate data from nearby stations, including hourly reports from Stephenville, available online from Environment Canada, should be assessed for the severity and frequency of extreme wind events. Any known local effects should be described. The importance of this information is clear from Section 6.8, which states that given the high winds anticipated at Shoal Point, the rig's derrick will be stabilized using high strength guy wires.*

Response:

The reviewer is referred to additional detail on extremal analyses provided in the separate report by Oceans (2007) (see Appendix). The derrick will be stabilized with high-strength guy wires with anchors into the ground. Anchoring design will be such that it will withstand any winds likely to be encountered during the drilling program.

Request:

Section 4.2.2, Page 27, Waves*: The wave information provided in the EA is based on the AES40 hindcast for the deep water to the west of the project area. The MSC50 hindcast dataset is now available and should be examined also, as it improves upon the AES40 in a number of ways including finer grid spacing and time step, and the inclusion of shallow water wave physics (Swail et al 2006). The EA gives the maximum value for the significant wave height (Hs) during the 5 decades of the AES40 hindcast as Hs 9.43 m. Typical winter peak wave periods in winter were given as 6 to 7 seconds. Normally the peak wave period associated with the highest waves is given, rather than the typical peak wave periods. The MSC50 Wind and Wave Climatology Atlas [at http://www.oceanweather.net/msc50waveatlas/] shows a 50-yr return period extremal analysis of Hs 8 to 9m and Tp of 12 s for western Newfoundland. Waves with Tp of 12 s would be in transitional depth water for depths of less than 58 m (WMO 1998), which is the condition for nearly all of the project area.*

Response:

The reviewer is referred to additional detail on extremal analyses provided in Oceans (2007).

Request:

Section 7.0 Routine Project Activities

Use of Concrete in the Aquatic Environment Section 7.1.4.2 *indicates that cement will be used in drilling operations. The proponent should be aware of the following best practices relating to cement or concrete production near water:*

- *If concrete is to be produced on-site, the location and design of the concrete production area and yard should be described with provisions for environmental protection.*

- *Drainage from a concrete production area and yard, and wash water from the cleaning of batch plant mixers, mixer trucks, conveyors and pipe delivery systems, are very alkaline and may be harmful to fish. Drainage and wash water also contain sediment, and concrete additives and agents, which may be harmful to fish. Therefore, appropriate mitigation should be employed to ensure such drainage does not enter receiving waters. All drainage from the concrete production area and yard, including wash water, should be directed to a settling pond for control and treatment, as appropriate.*

- *Aggregate used in the production of concrete may be stored and processed on site. Sediment-laden drainage from an aggregate storage area, and any wash water from the processing of aggregate may be harmful to fish. All drainage from an aggregate storage area should be directed to a drainage control device such as a settling pond.*

  Effluent should be treated as appropriate before release to receiving waters, or alternatively, effluent should be recycled for reuse after treatment. Solids that accumulate in a settling pond should be removed on a regular basis to ensure the settling pond remains effective.

Response:

The Operator will dispose of all concrete waste and wastewater off-site at an approved disposal location. The Operator will not discharge any effluent or solids from the cementing process into waterbodies.

Request:

Section 8.5, Page 179, Spill Response*: It should be noted that any spills in waters frequented by fish or likely to enter waters frequented by fish must be reported immediately to the Canadian Coast Guard 24 Hour Spill Line at 1 800 563-9089.*

Response:

So noted. The Operator will specify in contingency plans and drilling program documents that any and all spills will be reported immediately to the Canadian Coast Guard 24-hour spell line at 1-800-563-9089.

Comments Related to Issues outside the Scope of the EA

The environmental assessment included information and discussion on a number of issues that were outside the scope of the assessment.

So noted.

References Cited

A.L.T.R.T. 2006. Recovery strategy for the leatherback turtle (*Dermochelys coriacea*) in Atlantic Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. vi + 45 p.

COSEWIC. 2006. COSEWIC assessment and update status report on the Sowerby's beaked whale *Mesoplodon bidens* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 20 p.

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2005. Western Newfoundland and Labrador Strategic Environmental Assessment. Rep by LGL Limited, St. John's, NL, Oceans Limited, St. John's NL, Canning and Pitt Associates Inc., St. John's, NL, and PAL Environmental Services, St. John's, NL for the Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 335 p + appendices.

DFO (Department of Fisheries and Oceans). 2006. Ecologically and Biologically Significant Areas (EBSA) in the Estuary and Gulf of St. Lawrence: Identification and Characterization. DFO Can. Sci. Advis. Sec. Sci. Adv. Rep. 2007/016.

Kulka, D., C. Hood, and J. Huntington. 2007. Recovery Strategy for Northern Wolffish (*Anarichas denticulatus*) and Spotted Wolffish (*Anarhichas minor*), and Management Plan for Atlantic Wolffish (*Anarhichas lupus*) in Canada [Proposed]. Fisheries and Oceans Canada: Newfoundland and Labrador Region. St. John's, NL. x + 103 pp.

LGL 2007. Port au Port Bay Exploration Drilling Program Environmental Assessment. Prepared by LGL Limited in association with Calixte and Oceans for PDI Production Inc., St. John's. LGL Report No. SA930.

Oceans 2007. Physical environment Port-au-Port Bay. Port-au-Port Bay Exploration Drilling Program Environmental Assessment. Prepared by Oceans Ltd. for PDI Production Inc., St. John's.

Appendix: Physical Environmental Report by Oceans Ltd.

Physical Environment
Port-au-Port Bay

Exploration Drilling Program
Environmental Assessment

Prepared for: PDI Production Inc.
Suite 201 Baine Johnson Centre
10 Fort William Place
St. John's, NL A1C 1K4

Prepared by: Oceans Ltd.
85 LeMarchant Road
St. John's, NL A1C 2H1

October 2007

Table of Contents

Table of Figures

Table of Tables

1.0 Introduction

This report has been prepared in response to comments from C-NLOPB on the Physical Environment Section of the Environmental Assessment prepared for PDI Production Inc. by LGL Limited. The description of the physical environment in the Environmental Assessment was brief and extracted from a previous description of winds, waves and currents in the Strategic Environmental Assessment for Western Newfoundland areas (C-NLOPB, 2005). The present report has been produced to provide additional information on winds (Section 2) and waves (Section 3) specific to the project area, and to provide information to address comments made by Environment Canada on waves, storm surges, currents and sea ice.

The drill site is located on Shoal Point at an elevation of 1.21 m, about 45 m from the high water mark. The possibility of high waves breaking on shore in extreme storms was considered using a shallow water wave model. The results are presented in Section 4. The potential for waves reaching the drill site and the possibility of icing from freezing spray reaching the drilling structure was also considered.

This report contains a discussion of storm surges, and the potential for flooding on low elevation areas. Bernier and Thompson (2006) in Section 5 estimated a 40-year return period storm surge height of 0.7 m along the west coast of Newfoundland. The height is expected to increase if the storm surge occurs during high tide.

There is little information available on the physical oceanography of the project area. There are no current measurements available from moored meters at any location in the project or study areas shown in Figure 1.1. Geostrophic currents have been calculated by El-Sabh (1976) and Trites (1972) for the Gulf of St. Lawrence as a whole from hydrographic data. These circulation patterns are presented in this report in Section 6 together with other information from the literature. Overall, current information for the area is sparse.

The frequency and coverage of sea ice in the study area and in Port-au-Port Bay is presented in Section 7. During the extreme storm of January 20-22, 2000, a storm surge caused ice to ride up along the shores of PEI and New Brunswick which caused significant damage to coastal infrastructure. The potential of whether such an event could occur in Port-au-Port Bay was evaluated and discussed.

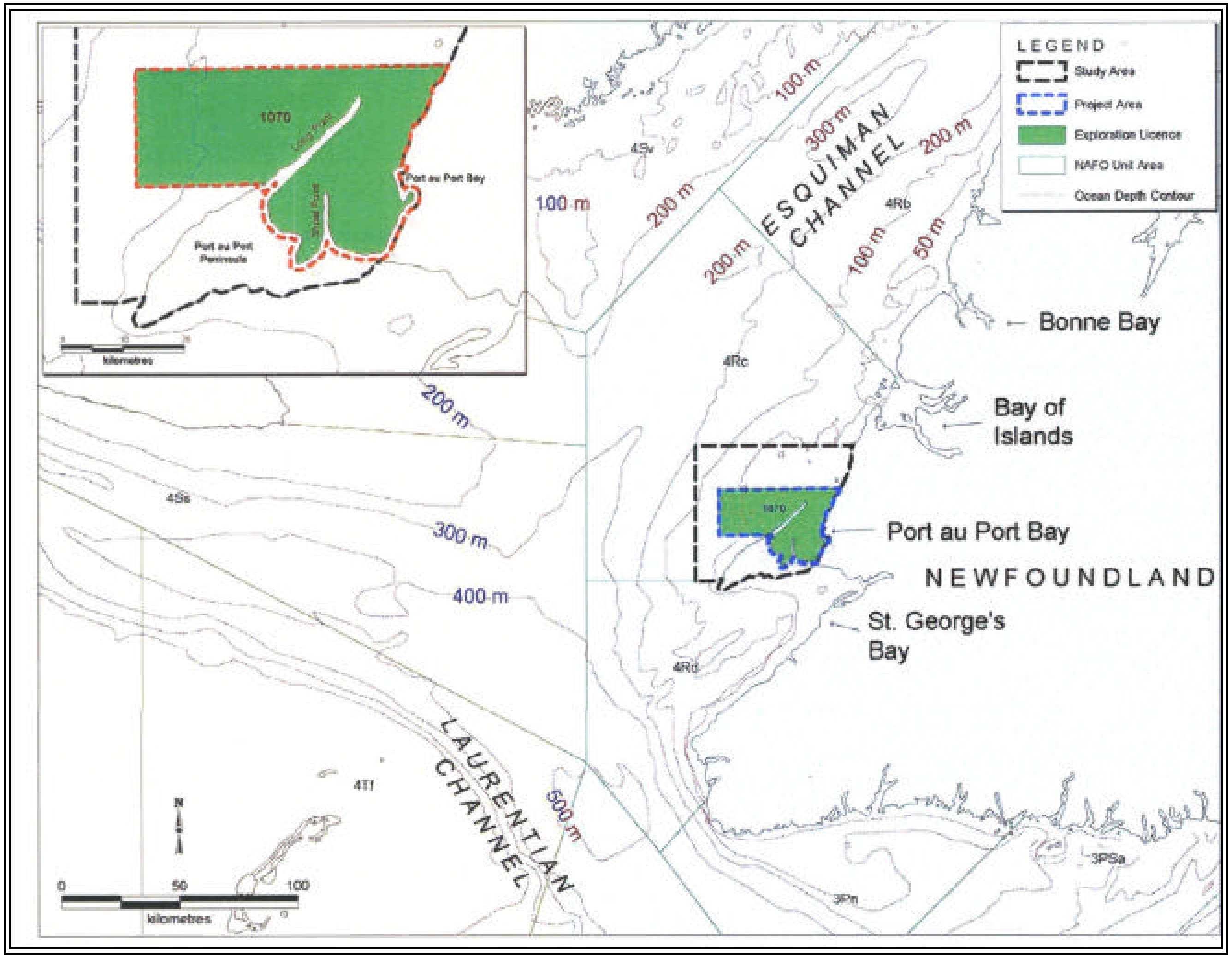


Figure 1.1 Locations of Project Area and Study Area
Source: C-NLOPB, 2005

2.0 Climate

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

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

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

During the winter months, the Port-au-Port Peninsula is subject to the cold arctic air flowing from the Quebec North Shore. As the arctic air moves across the warm waters of the Gulf of St. Lawrence, the cold air acquires heat and moisture from the ocean resulting in the formation of streamers of snow showers which, during periods of prolonged northwesterlies, reach the west coast of Newfoundland.

South of Newfoundland in the vicinity of the warm water of the Gulf Stream rapidly deepening storms are a problem. The explosively deepening oceanic cyclone is known as a “weather bomb” and defined as a storm that undergoes central pressure falls greater than 24 mb over 24 hours. Hurricane force winds near the center, the outbreak of convective clouds to the north and east of the center during the explosive stage, and the presence of a clear area near the center in its mature stage (Rogers and Bosart, 1986) are typical of weather bombs. After development these systems will either move across Newfoundland, or along the southeast coast, resulting in gale to storm force northerly winds over the area.

There is a general warming of the atmosphere during spring due to increasing heat from the sun. This spring warming results in a decrease in the north-south temperature gradient. Due to this weaker temperature gradient during the summer, storms tend to be weaker and not as frequent. Furthermore, the weaker tropical-to-polar temperature gradient in the summer results in the storm tracks moving further north. With the low pressure systems passing to the north of the region, the prevailing wind direction during the summer months is from the southwest to south. As a result, the incidences of gale or storm force winds are relatively infrequent over Newfoundland during the summer.

2.1. Data Sources

Wind and wave climate statistics for Port-au-Port Bay were extracted from the MSC50 North Atlantic wind and wave climatology data set compiled by Oceanweather Inc. under contract to Environment Canada. The MSC50 data set consists of continuous wind and wave hindcast data in 1-hour time steps from January 1954 to December 2005, on a 0.1° latitude by 0.1° longitude grid. Winds in the MSC50 data set are 1-hour averages of the effective neutral wind at a height of 10 m (Harris, 2007). In this study, Grid Point 14620 located at 48.8°N;59.0°W was chosen for the analysis and deemed to be most representative of conditions near Port-au-Port Bay (Figure 2.1).

Air temperature, sea surface temperature, wind speed and direction, precipitation types, cloud, visibility, and wave statistics for Port-au-Port were compiled using data from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). A subset of global marine surface observations from ships, drilling rigs, and buoys covering the period from January 1954 to May 2007 was used. Wind speeds from the ICOADS data set are 10-minute averages. The ICOADS data subset covered the area within the study area. This area begins at 49°00’N; 58°30’W and goes west to 49°00’N; 59°30’W. Then it goes south to 48°30’N; 59°30’W after which it goes east along latitude 48°30’N until it reaches the coast. The area then follows the coast back to 49°00’N; 58°30’W (Figure 1.1). The ICOADS data set has certain inherent limitations in that the observations are not spatially or temporally consistent. In addition, even though the data used in this report were subjected to standard quality control procedures, the data set is somewhat prone to observation and coding errors, resulting in some erroneous observations within the data set. The errors were minimized by using the enhanced filtering system using source exclusion flags, composite QC flags and an outlier trimming level of 4.5 standard deviations. The ICOADS data set is also suspected to contain a fair-weather bias, due to the fact that ships tend to avoid severe weather or simply do not transmit weather observations during storm situations.

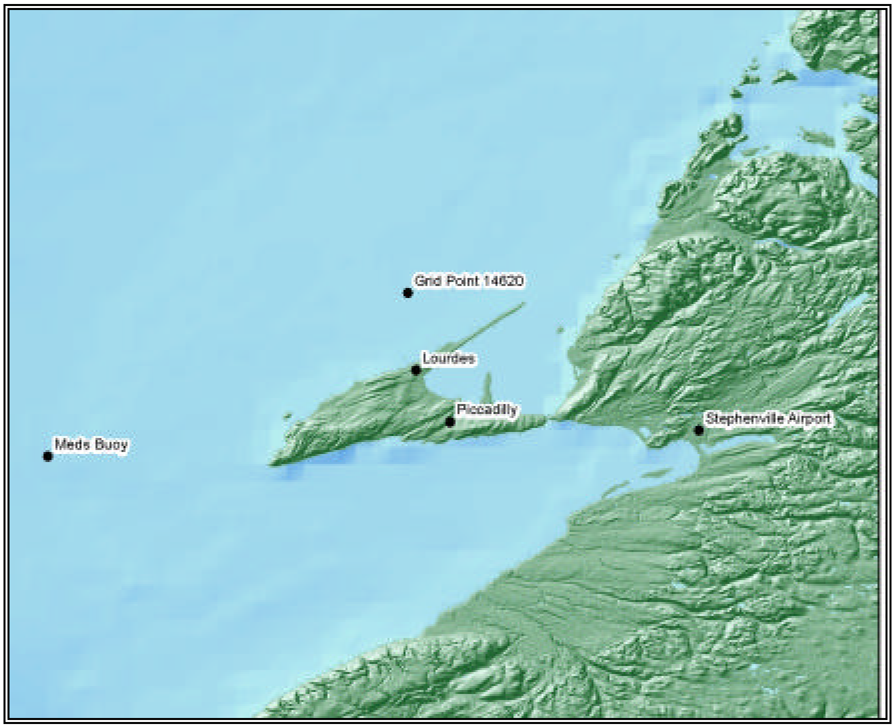


Figure 2.1 Locations of the Climate Data Sources

A number of climate and weather stations maintained by Environment Canada are located in the vicinity of Port-au-Port Bay. Climate stations at Lourdes (September 1990-Present) and Piccadilly (October 1980–June 1989) recorded temperature and precipitation while a manned weather station at Stephenville Airport (February 1942–Present) recorded wind, temperature, relative humidity, clouds, visibility and pressure statistics. Wind speeds from Stephenville Airport are 2-minute average speeds. Statistics for Stephenville Airport were compiled using a subset of the data from January 01, 1953–October 07, 2007. The locations where the climate data were collected are shown in Figure 2.1.

2.2. Wind Conditions

Port-au-Port experiences predominately southwest to west flow throughout the year. West to northwest winds which are prevalent during the winter months begin to shift clockwise during March and April resulting in winds becoming slightly predominant from the northwest to northeast in spring. Southwesterly winds prevail during the summer months. As autumn approaches, the tropical-to-polar temperature gradient strengthens and the winds shift slightly, becoming predominately westerly again by late fall and during winter.

Low pressure systems crossing Newfoundland are more intense during the winter months. As a result, mean wind speeds tend to peak during this season. With the exception of the MSC50 data set which has the highest mean wind speed in December of 36.2 km/h, mean wind speeds peak during the month of January (Table 1.1). The ICOADS data set recorded the highest January mean wind speed of 39.7 km/hr while Stephenville recorded the highest January maximum mean wind speed of 22.0 km/hr. The winds from the ICOADS data set are not directly comparable to the measurements from the Stephenville Airport weather station because the winds in the ICOADS data set were either estimated or measured by anemometers at various heights above sea level. Wind speed is dependent on height and increases at increasing heights above sea level.

Winds speeds from each of the data sources have different averaging periods. The MSC50 winds are 1-hour averages, the ICOADS winds are 10-minute averages and winds from Stephenville Airport are 2-minute averages. The adjustment factor to convert from 1-hour mean values to 10-minute mean values is usually taken as 1.06 (U.S. Geological Survey, 1979).

Winds measured at the Stephenville Airport weather station are generally lower than the winds from other data sources used in this study. This difference may be attributed to local topography in the area or such factors as the length of each data set. Due to funneling effects from Pine Tree Ridge to the north and Indian Head to the south, Stephenville Airport has two prevailing wind directions; one from the west-southwest to west and the other from the east-northeast to east. These directions dominate throughout the year and little difference is observed seasonally. Winds from the east are also subject to funneling through the ridges.

Table 2.1 Mean Wind Speed (km/hr) Statistics for Port-au-Port

Month	MSC50	ICOADS	Stephenville
January	35.4	39.7	22.0
February	28.3	33.4	20.4
March	27.4	32.0	19.0
April	25.6	30.9	17.9
May	21.0	23.2	15.6
June	19.3	24.0	13.7
July	19.1	23.6	12.8
August	21.5	24.7	14.1
September	26.4	29.6	15.4
October	30.5	31.6	17.1
November	33.7	37.7	18.7
December	36.2	37.8	21.0

A number of factors can contribute to the modification of winds by local topography. In Port-au-Port Bay at Shoal Point, corner effects (the small scale effects convergence of land and sea winds resulting in stronger winds off prominent headlands) are common. Also, violent northerly winds have been reported south of the Port-au-Port as northerly winds entering the Port-au-Port Bay funnel across the narrow isthmus that connects the Port-au-Port Peninsula with the Island of Newfoundland. These winds are known as 'Gap Winds' (Environment Canada, 1995).

A wind rose of the annual wind speed from Stephenville Airport is presented in Figure 2.2 and a histogram of the wind speed frequency distribution in Figure 2.3. The wind rose shows the predominate west-southwest to west wind directions at Stephenville, and its secondary east to east-northeasterly directions.

Table 2.2 Maximum Wind Speeds (km/hr) Statistics for Port-au-Port

Month	MSC50	ICOADS	Stephenville
January	91.6	101.9	93.0
February	80.4	111.2	89.0
March	80.7	96.5	91.0
April	78.8	101.9	83.0
May	70.4	64.8	83.0
June	61.1	74.2	65.0
July	74.2	70.2	54.0
August	85.8	70.2	83.0
September	81.2	83.2	72.0
October	87.6	87.1	89.0
November	86.9	101.9	83.0
December	91.4	101.9	93.0

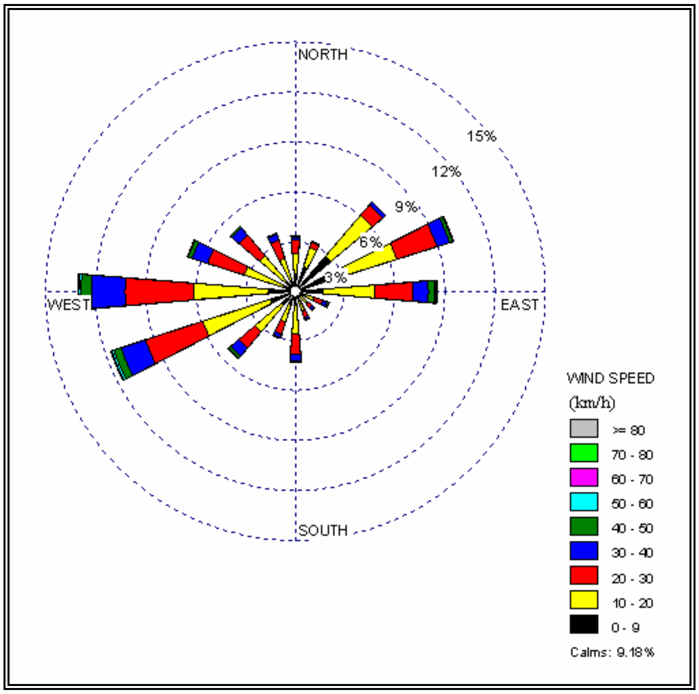


Figure 2.2 Annual Wind Rose from the Environment Canada Climate Station at Stephenville Airport

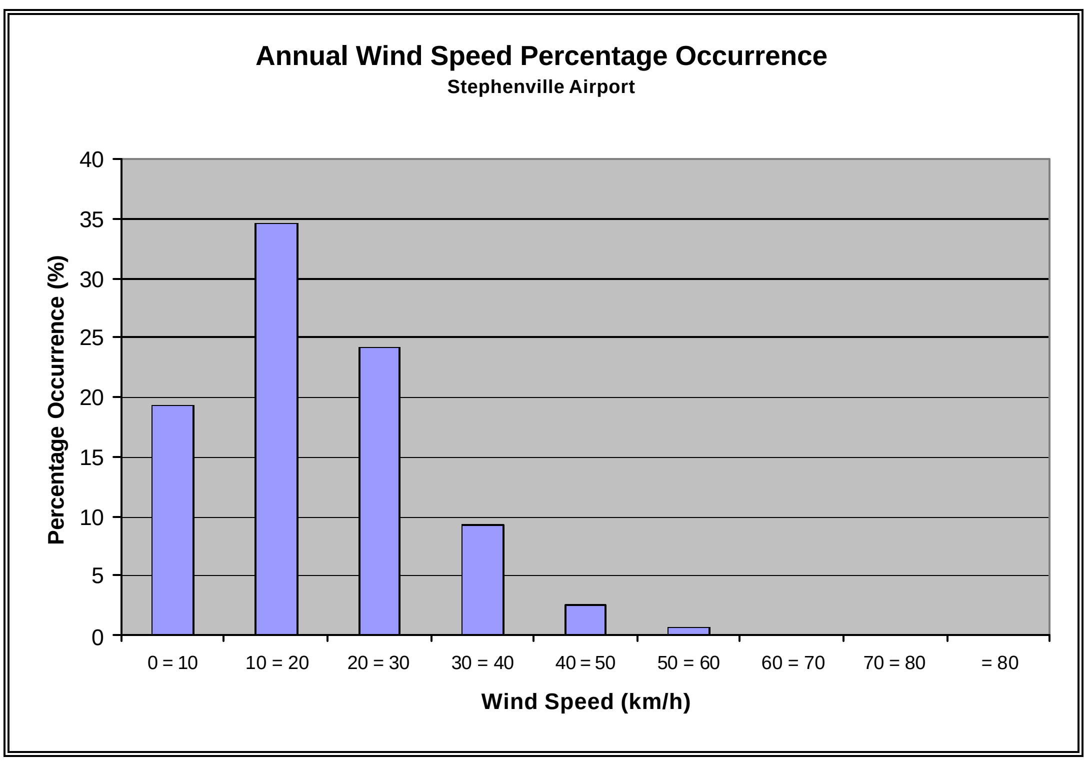


Figure 2.3 Annual Wind Speed Percentage of Occurrences from the Environment Canada Climate Station at Stephenville Airport

A wind rose of the annual wind speed from the MSC50 data set is presented in Figure 2.4 and the histogram of the frequency distribution of wind speeds in Figure 2.5. The monthly distributions are presented in Appendix 1. The monthly distributions show that there is a marked increase in the occurrence of winds from the west to northwest in the winter months as opposed to the summer months. The percentage exceedance of wind speeds at grid point 14620 is shown in Figure 2.6. Plots for individual months are presented in Appendix 2

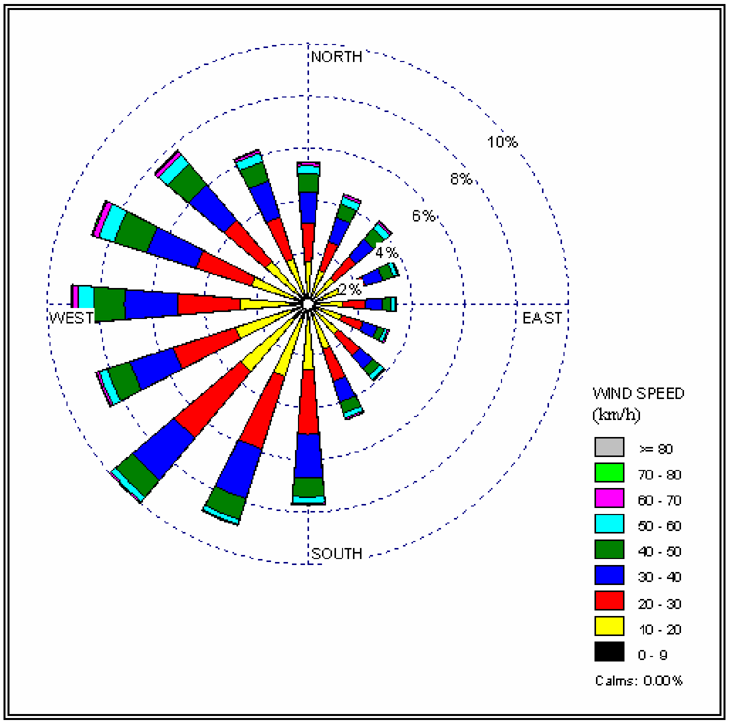


Figure 2.4 Annual Wind Rose from the MSC50 Grid Point 14620

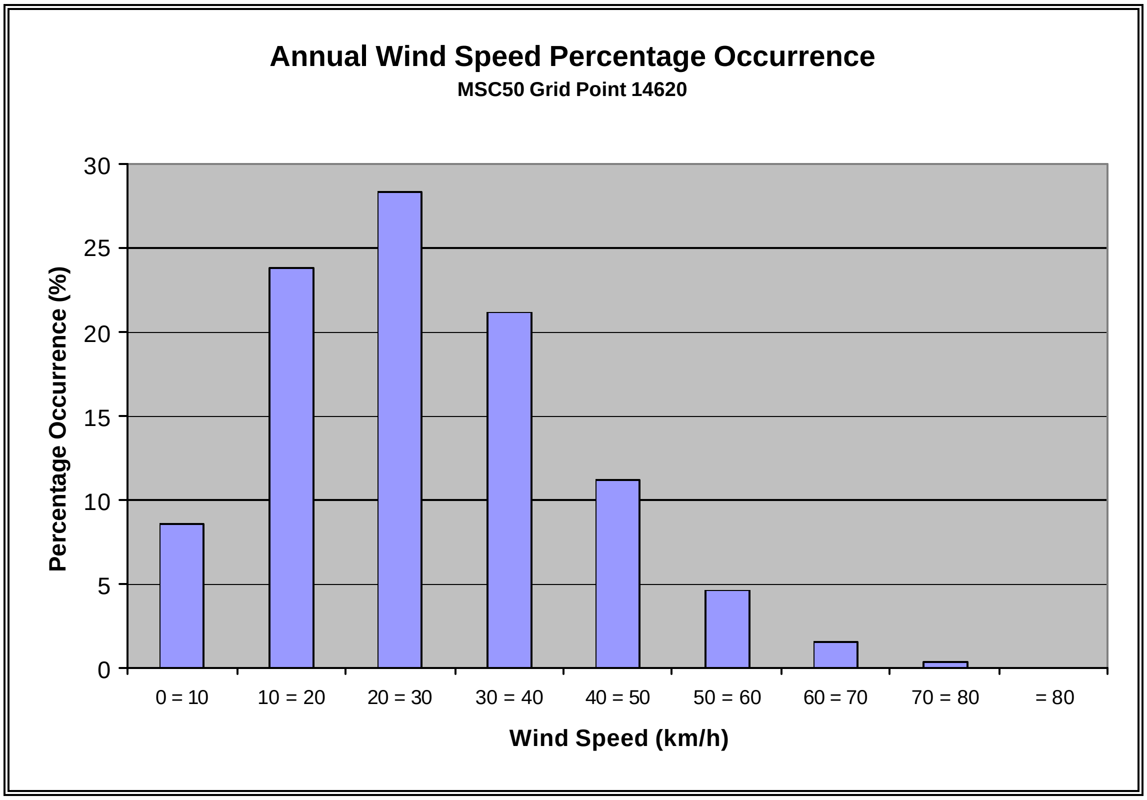


Figure 2.5 Annual Wind Speed Percentage of Occurrences from the MSC50 Grid Point 14620

.

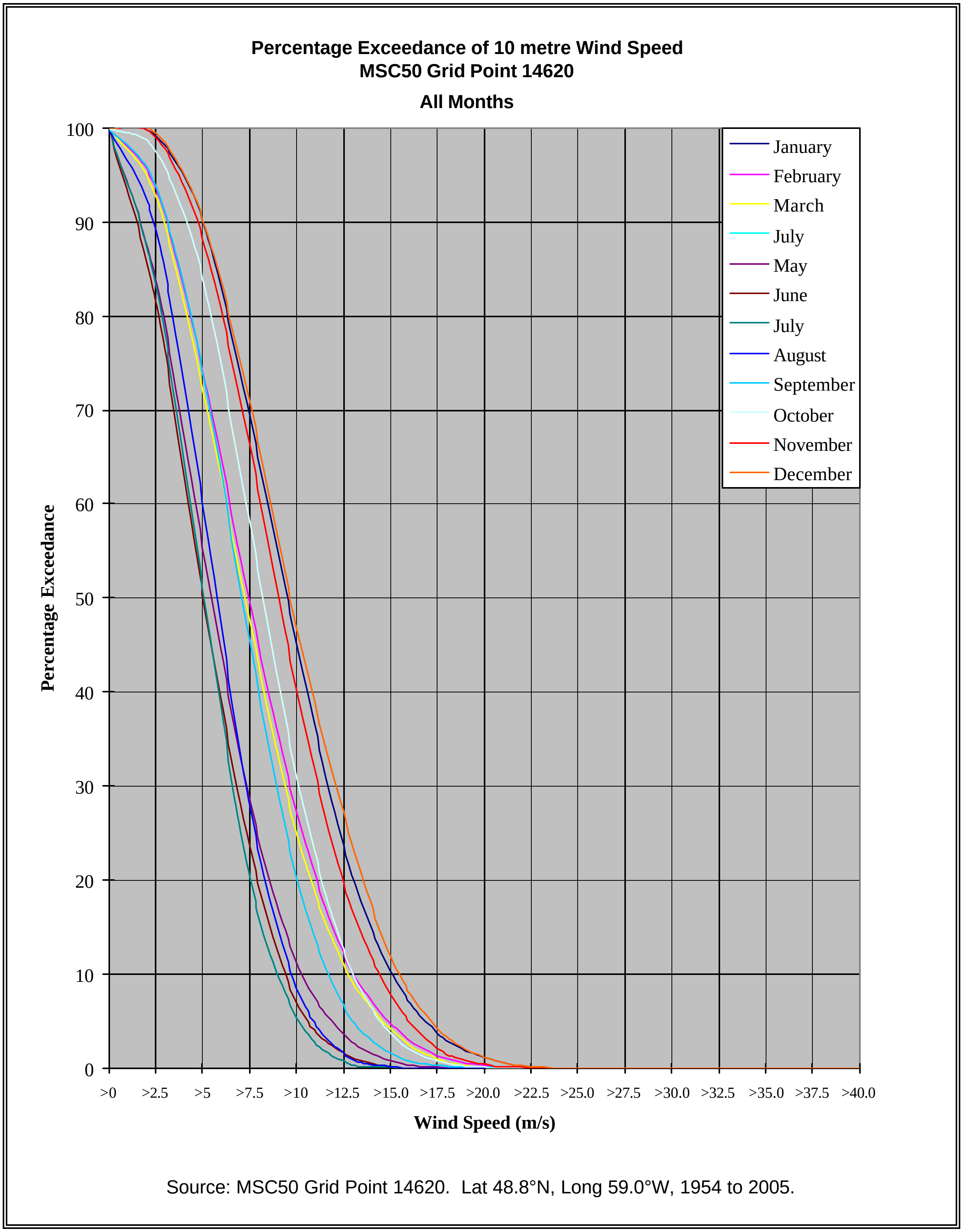


Figure 2.6 Percentage Exceedance of 10-metre wind speed at MSC50 Grid Point 14620

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

For example, a 985 mb low pressure system over James Bay on January 30, 1974 deepened as it moved east across Labrador, to lie over the Labrador Sea on February 02. The highest measured mean wind speeds near Port-au-Port of 111 km/hr out of the west-northwest were recorded in the ICOADS data set on February 03, 1974 as a result of this storm system. A day earlier, on February 02, the MSC50 wind speeds peaked at 75 km/h from the west and hourly observations at Stephenville airport reported winds speeds peaking at 80 km/h.

While this storm produced strong-gale to storm force winds over the area, more intense storm systems have affected the region. On February 21, 1967 a low pressure system south of Newfoundland experienced the explosive deepening in the warm waters south of Newfoundland known commonly as a weather bomb. This storm system (Figure 2.7) experienced a central pressure drop from 986 mb at 18Z February 21, 1967 to 952 mb as it moved across the island of Newfoundland at 18Z February 22, 1967. Wind speeds of 56 km/h were recorded from the north at Stephenville airport as the system passed. These wind speeds would have been reduced significantly at the airport as compared to other locations due to the Table Mountains to the north. The MSC50 data set have winds peaking near 72 km/h from the northwest on February 22, 1967. No observations were recorded in the ICOADS data set during this particular storm.

Similarly, another storm moving north from the warm waters south of Newfoundland experienced a central pressure drop from 1003 mb at 18Z January 04, 1968 to 960 mb as it passed over the Port-au-Port Peninsula at 18Z January 05, 1968. As this low pressure receded to the north on January 5, the Stephenville airport recorded wind speeds of 63 km/h from the north. Like the February 1967 storm, these winds would have also been reduced by the Table Mountains to the north. At the same time, MSC50 winds peak near 89 km/h from the northwest and similar to the February 1967 storm, no observations were recorded in the ICOADS data set during this storm.

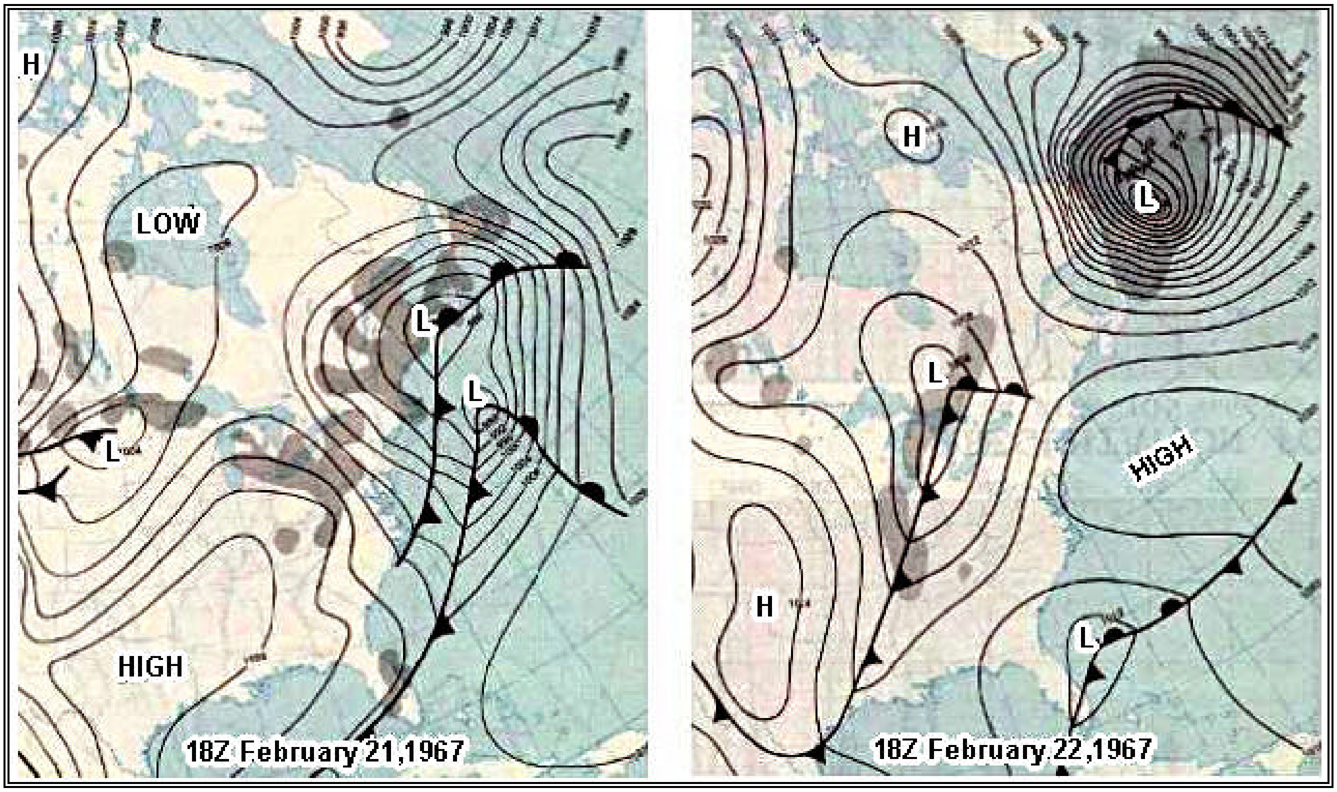


Figure 2.7 Explosive Deepening of a Mid-Latitude Low Pressure February 1967

2.3. Air and Sea Temperature

The ocean takes longer than land to heat up during the summer and longer to cool down in the winter months. Therefore, the ocean has a moderating effect on air temperature along the Newfoundland coast, which is typical of a maritime climate. During the spring, sea surface temperatures take longer to warm up than the surrounding air temperatures. As a result, the water temperature tends to slow the warming of the air along the coast, resulting in cooler springs than would be experienced in a continental climate. In autumn, sea surface temperatures are generally warmer than the surrounding air, as air tends to cool faster than the ocean. This results in the sea surface temperatures typically being higher than air temperatures. The warm ocean reduces the rate at which the air temperature decreases resulting in generally warmer autumns than would be experienced in a continental climate. Seasonal sea surface temperatures (SST) statistics near the Port-au-Port Peninsula were compiled from the ICOADS dataset and are presented in Table 2.3 and a monthly plot of air temperature versus sea surface temperature is presented in Figure 2.8.

Table 2.3 Seasonal Sea Surface Temperatures Statistics near the Port-au-Port Peninsula

	Winter	Spring	Summer	Autumn
Seasonal Mean (°C)	0.3	1.0	12.4	8.4
Seasonal Mean Maximum (°C)	3.5	4.1	16.5	14.7
Seasonal Mean Minimum (°C)	-0.6	-0.7	7.1	4.4

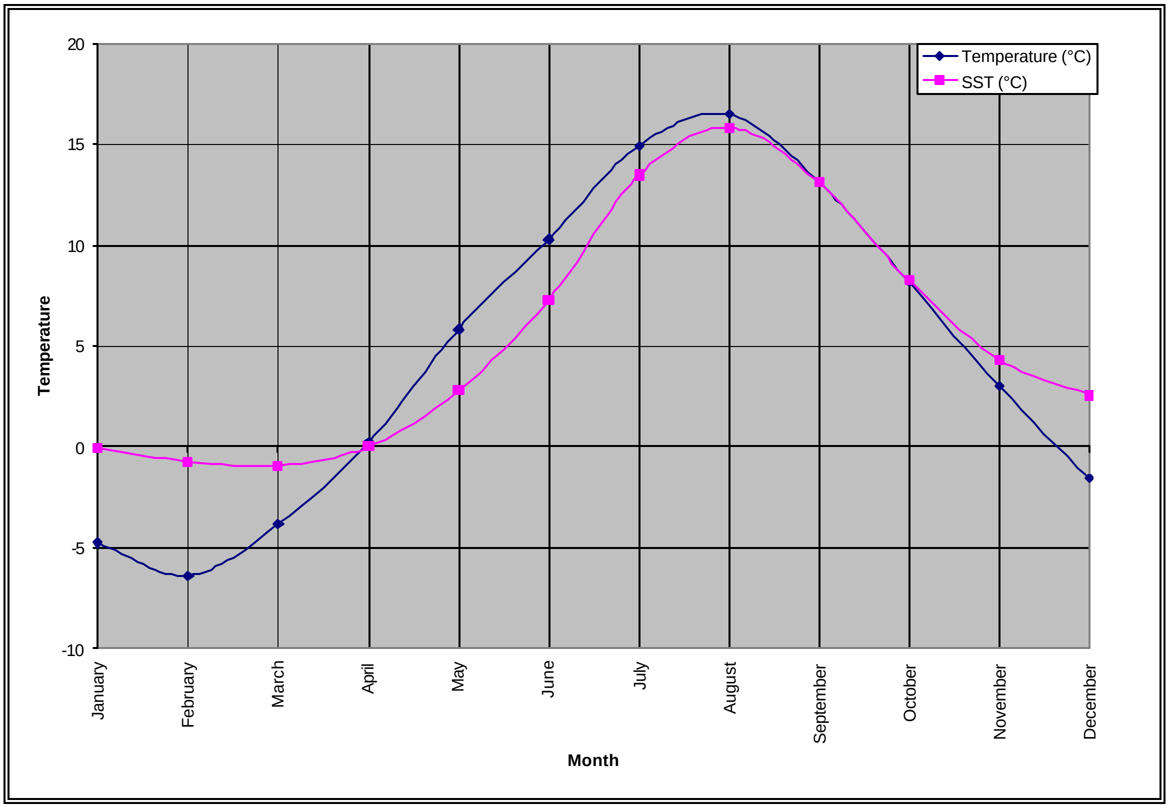


Figure 2.8 Monthly Mean Air Temperature and Monthly Mean Sea Surface Temperature from the ICOADS Data Set

The mean seasonal temperature statistics for the various data sources near the Port-au-Port Peninsula are shown in Table 2.4 through Table 2.6. Little difference is observed in the temperatures between each of these data sources, with mean summer temperatures ranging from 14.3°C in Piccadilly to 14.8°C in Lourdes and Stephenville Airport. Mean winter temperatures range from -4.4°C in the ICOADS data set to -5.1°C in Lourdes and Stephenville Airport. The similar temperatures observed between the land stations and the ICOADS data set give an indication of the moderating influence the ocean has upon temperatures in coastal areas.

Table 2.4 Mean Seasonal Air Temperature (°C) Statistics for the Port-au-Port Peninsula

	Winter	Spring	Summer	Autumn
ICOADS	-4.4	0.3	14.6	8.1
Lourdes	-5.1	1.4	14.8	7.5
Piccadilly	-4.7	2.2	14.3	6.9
Stephenville Airport	-5.1	2.5	14.8	7.1

Table 2.5 Mean Seasonal Maximum Air Temperature (°C) Statistics for the Port-au-Port Peninsula

	Winter	Spring	Summer	Autumn
ICOADS	4.4	8.4	19.8	16.0
Lourdes	-1.5	5.1	19.0	10.8
Piccadilly	-1.2	6.4	18.5	10.4
Stephenville Airport	-1.6	6.6	18.7	10.5

Table 2.6 Mean Seasonal Minimum Air Temperature (°C) Statistics for the Port-au-Port Peninsula

	Winter	Spring	Summer	Autumn
ICOADS	-10.6	-6.7	8.4	0.0
Lourdes	-8.7	-2.2	10.5	4.0
Piccadilly	-8.5	0.0	10.0	3.3
Stephenville Airport	-8.5	-1.7	14.8	3.7

Table 2.7 Extreme Air Temperature Statistics for the Port-au-Port Peninsula

	Maximum	Minimum
ICOADS	25.0	-22.0
Lourdes	30.5	-29.0
Piccadilly	28.0	-25.0
Stephenville Airport	29.9	-29.5

2.4. Precipitation

Precipitation can come in three forms: liquid, freezing, or frozen. Included in the three classifications are:

(1) Liquid Precipitation
- Drizzle
- Rain

(2) Freezing Precipitation
- Freezing Drizzle
- Freezing Rain

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

Precipitation was recorded at all three of the Environment Canada stations on the Port-au-Port Peninsula as well as in the ICOADS data set. While all three of the Environment Canada stations recorded precipitation amounts, only the Stephenville Airport data set contained precipitation type. The ICOADS data set contains precipitation type, and does not include amounts due to being ship observations.

2.4.1. Frequency of Precipitation Types

The frequency of precipitation type (Table 2.8) was calculated using hourly data from Stephenville Airport and the ICOADS data set, with each occurrence counting as one event. These observations show that winter has the highest frequency of precipitation with frequencies between 50.5% for the ICOADS data and 48.4% for Stephenville Airport. Snow accounts for the majority of precipitation during the winter months, accounting for 88-89% of the precipitation. Summer has the lowest occurrence of precipitation with the total frequency of occurrence ranging from 13.8% in the ICOADS data to 12.8% at Stephenville Airport.

The annual frequency distribution of precipitation is presented in Table 2.9. Precipitation occurs 26% of the time at Stephenville Airport and 33.0% of the time over the ocean.

Table 2.8 Seasonal Frequency Distribution (%) of Precipitation for the Port-au-Port Peninsula

		Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Total
ICOADS	Winter	4.4	0.3	0.9	44.8	0.1	50.5
	Spring	10.8	0.7	0.4	20.9	0.2	33.1
	Summer	13.8	0.0	0.0	0.0	0.0	13.8
	Autumn	20.2	0.0	0.9	8.1	0.0	29.2
Stephenville Airport	Winter	4.9	0.6	0.3	42.6	0.0	48.4
	Spring	9.1	0.3	0.4	12.6	0.0	22.4
	Summer	12.7	0.0	0.0	0.0	0.0	12.8
	Autumn	15.2	0.0	0.4	5.3	0.0	20.9

Table 2.9 Annual Frequency Distribution (%) of Precipitation for the Port-au-Port Peninsula

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Total
ICOADS	11.8	0.3	0.6	20.2	0.1	33.0
Stephenville Airport	10.5	0.2	0.3	15.0	0.0	26.0

2.4.2. Precipitation Amount

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

Mean annual precipitation amounts range from 1228.9 mm at Lourdes to 1408.6 mm in Piccadilly. The majority of the total recorded precipitation was in the form of rain with each station recording total annual rain amounts (Table 2.12) between 72% and 78%. The maximum monthly rainfall amounts occurred in August at Stephenville Airport, September at Lourdes and in February at Piccadilly with Stephenville Airport recording the highest monthly maximum of the three stations. A maximum one-day precipitation amount of 96.0 mm was recorded on August 5, 1989 at Stephenville Airport as a warm frontal trough associated with a low pressure over the Maritimes was slow moving over the area. Neither the Lourdes nor the Piccadilly climate stations were in operation in August 1989. The Lourdes climate station recorded a maximum one-day precipitation amount of 67.0 mm on August 30, 1997 and the Piccadilly station recorded a maximum one-day precipitation amount of 57.0 mm on November 5, 1980. Stephenville Airport reported 42.2 mm of precipitation on August 30, 1997 and 57.6 mm of precipitation on November 5, 1980.

Table 2.10 Precipitation Amount (mm) Statistics for the Environment Canada Climate Stations on the Port-au-Port Peninsula

	Stephenville Airport			Lourdes			Piccadilly		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
January	140.4	93.0	209.2	120.3	39.5	215.2	142.4	62.6	210.0
February	109.1	40.3	229.9	101.2	30.2	185.8	112.6	23.6	245.0
March	75.0	35.2	131.3	81.5	32.2	108.8	68.5	28.4	94.0
April	77.3	26.7	136.0	71.7	32.2	180.6	98.8	26.2	165.2
May	84.4	49.5	115.4	98.8	41.8	172.0	80.5	43.8	137.0
June	129.2	69.6	171.3	82.1	46.6	155.8	141.5	76.2	226.0
July	108.3	42.2	172.8	93.8	30.2	180.8	102.6	36.8	137.2
August	148.2	78.3	345.6	99.5	38.2	171.4	130.8	70.0	197.0
September	125.3	83.4	176.8	135.6	85.2	225.6	120.1	80.8	149.4
October	115.3	49.2	183.2	126.8	61.2	204.0	112.1	46.2	176.8
November	124.5	76.5	161.4	121.4	78.3	201.7	146.3	107.6	176.0
December	128.6	69.3	193.1	126.8	72.8	206.4	137.7	75.0	191.0
Annual	1346.8	1202.8	1660.5	1228.9	999.3	1370.0	1408.6	1186.8	1785.0

Table 2.11 Total Rainfall Amount Statistics for the Environment Canada Climate Stations on the Port-au-Port Peninsula

	Stephenville Airport			Lourdes			Piccadilly		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
January	29.5	2.3	87.3	39.6	0.0	100.4	41.2	2.0	101.0
February	29.8	0.4	101.9	24.8	Trace	135.8	32.3	2.0	111.0
March	24.0	8.3	53.6	34.4	Trace	73.2	36.7	6.4	59.0
April	63.0	16.4	108.5	53.7	16.2	177.0	93.7	24.6	158.2
May	81.8	49.2	115.4	97.1	32.2	172.0	80.0	43.8	137.0
June	129.2	69.6	171.3	82.1	46.6	155.8	141.5	76.2	226.0
July	108.3	42.2	172.8	93.8	30.2	180.8	102.6	36.8	137.2
August	148.2	78.3	345.6	99.5	38.2	171.4	130.8	70.0	197.0
September	125.0	83.4	176.5	135.6	85.2	225.6	120.1	80.8	149.4

October	112.9	45.8	183.2	126.4	61.2	204.0	112.1	46.2	176.8
November	95.7	45.2	131.7	100.4	47.2	156.6	126.6	72.0	170.0
December	40.3	1.3	97.2	64.7	17.2	153.1	68.9	22.2	154.0
Annual	977.2	762.9	1208.7	935.6	707.2	1144.4	1098.1	823.0	1408.9

Snowfall has occurred on the Port-au-Port Peninsula in every season, including the summer season. Mean snowfall amounts (Table 2.13) show that on average, snow begins in October at the four stations with a mean snowfall ranging from trace amounts in Piccadilly to 2.4 cm at the Stephenville Airport. While mean snowfall amounts are low for October, significant events can occur in October as evident from the maximum monthly snowfall of 9.8 cm reported at the Stephenville Airport. Snowfall is recorded in all months between October and June, with the mean snowfall amounts peaking during the month of January. The mean maximum monthly snowfall of 264.0 cm was recorded at the Stephenville Airport during the month of January.

The highest maximum one-day snowfall of 39.2 cm occurred at the Stephenville Airport on January 15, 1982. The other stations have reported maximum one-day snowfall events of 29.8 cm at Lourdes and 30.6 cm at Piccadilly.

Overall, Piccadilly experiences the highest precipitation amounts and has the highest monthly mean and monthly maximum for rainfall and total precipitation. However, Stephenville Airport has the highest snowfall amounts.

Table 2.12 Total Snowfall Amount Statistics for the Environment Canada Climate Stations on the Port-au-Port Peninsula

	Stephenville Airport			**Lourdes**			**Piccadilly**		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
January	129.4	80.5	264.0	77.6	39.5	139.6	101.2	50.2	183.4
February	88.8	26.8	223.3	74.7	Trace	142.2	80.3	10.4	216.0
March	55.8	20.5	100.2	47.1	21.2	93.4	31.8	7.0	55.8
April	14.8	1.1	43.4	17.9	Trace	66.6	5.1	0.0	19.8
May	2.7	0.0	22.3	1.7	0.0	11.4	0.5	0.0	4.8
June	Trace	0.0	Trace	0.0	0.0	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
September	0.3	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
October	2.4	Trace	9.8	0.4	0.0	3.0	Trace	0.0	Trace
November	29.6	12.5	45.3	21.0	4.4	45.1	19.7	6.0	35.6
December	100.5	66.6	219.5	62.1	39.8	118.5	68.8	20.2	118.3
Annual	415.9	299.4	698.6	301.5	213.1	367.1	310.5	126.2	506.9

2.5. Icing

2.5.1. Freezing Precipitation

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

The percentage of occurrences of freezing precipitation (Table 2.13) was calculated using hourly data from the Stephenville Airport weather station as well as from the ICOADS data set. The frequency of freezing precipitation was slightly higher in the winter months than during the spring at Stephenville, while within the ICOADS data set, spring had the highest amount of freezing precipitation. Both data sets had freezing precipitation occurring less than 1% of the time. The ICOADS data set had a slightly higher occurrence of freezing precipitation with 0.3% in the winter and 0.7% in the spring. No freezing precipitation occurred during summer and autumn.

Table 2.13 Percentage of Occurrences of Freezing Precipitation on the Port-au-Port Peninsula

	Winter	Spring	Summer	Autumn
ICOADS	0.3	0.7	0.0	0.0
Stephenville Airport	0.6	0.3	0.0	0.0

2.5.2. Sea Spray Vessel Icing

Spray icing can accumulate on vessels and shore structures when air temperatures are below the freezing temperature of water and there is potential for spray generation. In addition to air temperature, icing severity depends on water temperature, wave conditions, and wind speed influence the amount of spray and the cooling rate of droplets. A review of the spray icing hazard is provided by Minsk (1977). The frequency of potential icing conditions and its severity was estimated from the algorithm proposed by Overland et al. (1986) and subsequently updated by Overland (1990). The algorithm generates an icing predictor based on air temperature, wind speed, and sea surface temperature which was empirically related to observed icing rates of fishing vessels in the Gulf of Alaska. This method will provide conservative estimates of icing severity in the study region as winter sea surface temperatures are colder and wave conditions are lower in the study area compared to the Gulf of Alaska where the algorithm was calibrated (Makkonen et al., 1991). Potential icing rates were computed using wind speed and air sea surface temperature observations from the ICOADS data set. A total of 2517 observations from vessels within the study area from January 1954 to

May 2007 were used to calculate the percentage frequency of icing occurrence and severity for the Port-au-Port area. Monthly, seasonal, and annual summaries are presented in Table 2.14 and Figure 2.9.

Potential sea spray icing conditions start in the Port-au-Port region during the month of October with a frequency of icing potential of just 0.4%. As temperatures cool throughout the winter, the frequency of icing potential reaches a maximum of 69.0% of the time in February. Extreme sea spray icing conditions were calculated to occur 13.4% of the time in the Port-au-Port area during February. Icing potential decreases rapidly after February in response to warming air and sea surface temperatures, and by May the frequency of icing conditions is 0%.

Table 2.14 Percentage Frequency of Potential Spray Icing Conditions in the Port-au-Port area from January 1954 to May 2007

	None (0cm/hr)	Light (<0.7cm/hr)	Moderate (0.7-2.0cm/hr)	Heavy (2.0-4.0cm/hr)	Extreme (>4.0cm/hr)
January	28.1	33.7	17.4	8.5	12.2
February	31.0	31.0	17.6	7.0	13.4
March	45.3	20.8	21.7	6.6	5.7
April	75.4	16.6	3.7	2.7	1.6
May	100.0	0.0	0.0	0.0	0.0
June	100.0	0.0	0.0	0.0	0.0
July	100.0	0.0	0.0	0.0	0.0
August	100.0	0.0	0.0	0.0	0.0
September	100.0	0.0	0.0	0.0	0.0
October	99.6	0.4	0.0	0.0	0.0
November	89.7	9.9	0.4	0.0	0.0
December	62.6	34.1	3.3	0.0	0.0
Winter	40.6	32.9	12.8	5.2	8.5
Spring	73.6	12.4	8.5	3.1	2.4
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	96.4	3.4	0.1	0.0	0.0
Annual	77.6	12.2	5.3	2.1	2.7

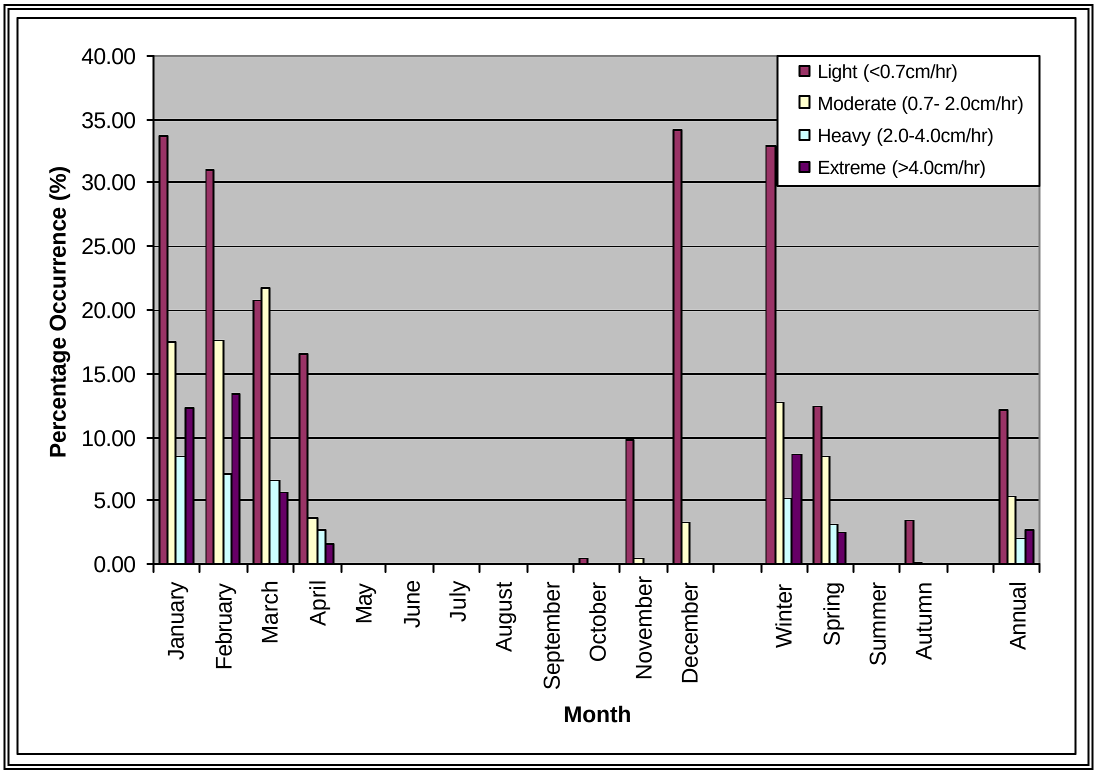


Figure 2.9 Percentage Frequency of Potential Spray Icing Conditions for Port-au-Port from January 1975 to December 2005

2.6. 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

A plot of the frequency distribution of visibility from the ICOADS data set is presented in Figure 2.10. Figure 2.10 show that obstructions to vision can occur in any month. Annually, 23.3% of the observations recorded had reduced visibilities. January month has the highest percentage (39.7%) of obscurations, and September has the least (11.8%).

During the winter months snow is the predominate obstruction; however mist and fog may reduce visibilities as well. As spring approaches, the amount of visibility reduction attributed to snow decreases as the air temperature increases. Advection fog becomes the main source of reduced visibility. Advection fog forms when warm moist air moves over the cooler waters of the Gulf of St. Lawrence. By May month, according to Figure 2.8 the sea surface temperature in the Gulf is cooler than the surrounding air. As warm moist air moves over the colder sea surface in the Gulf, the air cools and its ability to hold moisture decreases. The air will continue to cool until it becomes saturated and the moisture condenses to form fog.

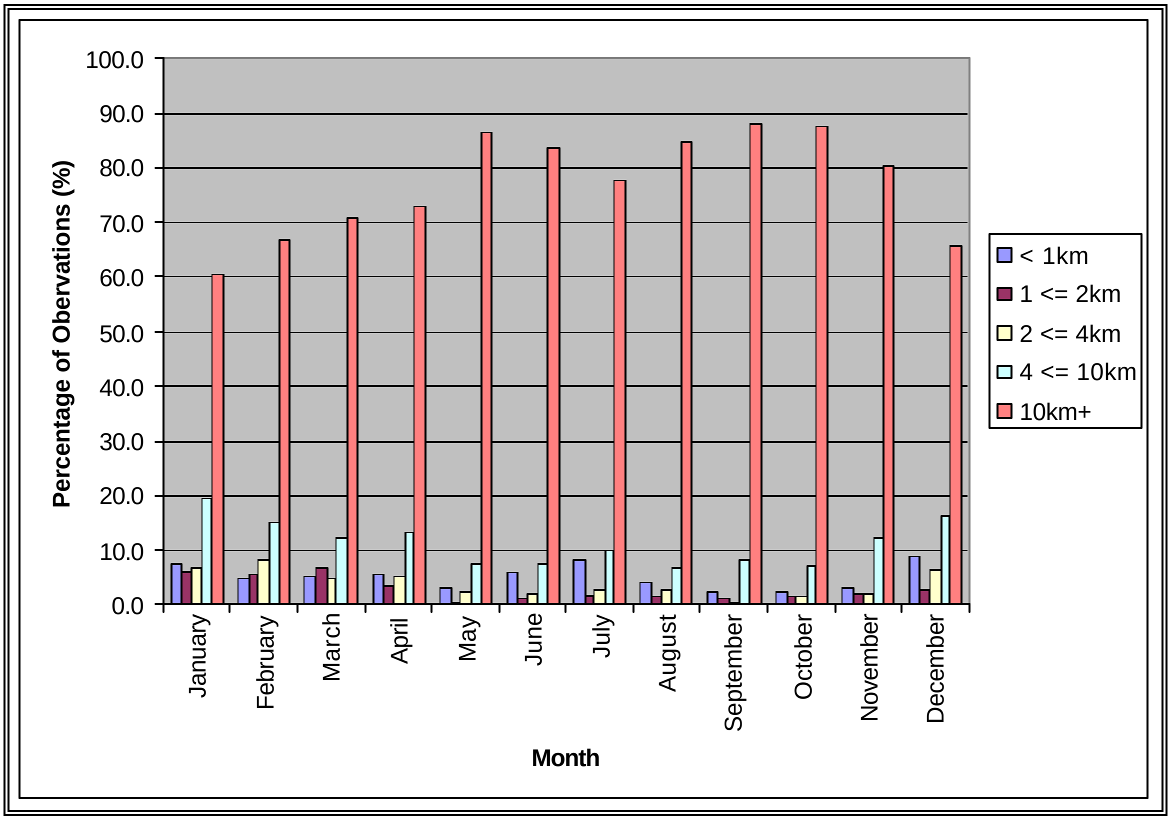


Figure 2.10 Frequency Distribution (%) of Visibility Recorded in the ICOADS Data Set from January 1954 to May 2007

2.7. Tropical Systems

While the strongest winds typically occur during the winter months and are associated with mid-latitude low pressure systems, storm force winds may occur at any time of the year as tropical systems move north, often passing over Newfoundland. Tropical cyclones develop and strengthen over warm tropical waters in southern latitudes. Typically during the months of June to November, tropical cyclones have been known to develop as early as April, and as late as December. These systems move east to west over the warm water of the tropics. Some of these systems turn northward and make their way towards Newfoundland. As the tropical cyclone moves north, it moves over colder waters and begins to weaken. By the time these weakening cyclones reach Newfoundland, they are usually embedded into a mid-latitude low and their tropical characteristics are usually lost.

Since 1956, 23 tropical systems have passed within 278 km of the Port-au-Port Peninsula. The names are given in Table 2.15 and the tracks over Newfoundland are shown in Figure 2.11. On occasion, these systems still maintain their tropical characteristics when they reach Newfoundland. On August 02, 1990, Hurricane Bertha, still a Category 1 Hurricane with 129 km/h winds and a central pressure of 973 mb as it moved north across Sable Island at 00Z, weakened to a post-tropical storm by the time it crossed the Port-au-Port Peninsula at 12Z. As this system moved north of the area, Stephenville Airport recorded a wind speed of 83 km/h. Peak winds of 86 km/h were reported in the Environment Canada data set as this storm system passed. Once again, no winds were recorded in the ICOADS data set during this time period.

On October 19, 2000 Hurricane Michael made landfall along the south coast of Newfoundland, west of the Burin Peninsula, as a Category 1 hurricane with a central pressure of 965 mb. Near the time Hurricane Michael made landfall, the Stephenville Airport reported northeast winds of 41 km/h. The next morning, as the remnants of this system moved north, 52 km/h west-northwest winds were recorded at Stephenville. During this event, the MSC50 data set has winds peaking at 73 km/h from the northwest as the system receded.

Table 2.15 Storm Tracks of Tropical Systems Passing within 278 km of the Port-au-Port Peninsula, 1956 to 2006

Year	Month	Day	Hour (Z)	Name	Wind (Kts)	Pressure (mb)	Category
1958	09	29	18	Helene	65	968	E
1959	07	12	12	Cindy	35	N/A	E
1964	09	15	18	Dora	55	N/A	E
1966	07	22	0	Celia	25	N/A	E
1971	08	17	6	Beth	50	998	E
1973	07	06	18	Alice	50	N/A	TS
1977	10	15	18	Evelyn	70	999	H1
1979	09	07	18	David	55	986	E
1979	10	25	6	**SubTropical** 1	50	982	SS
1988	08	08	12	Alberto	30	1008	E
1988	08	30	12	Chris	25	1008	TD
1990	08	02	6	Bertha	60	978	E

1991	08	21	0	Bob	40	1008	E
1995	06	09	6	Allison	40	996	E
1995	07	10	0	Barry	45	990	TS
1996	07	15	0	Bertha	50	995	E
1996	09	15	12	Hortense	60	982	TS
1996	10	10	6	Josephine	45	985	E
1999	09	18	18	Floyd	35	992	E
2000	10	20	0	Michael	75	966	E
2002	09	12	12	Gustav	60	965	E
2005	09	18	18	Ophelia	45	999	E
2006	07	22	6	Beryl	35	1003	E

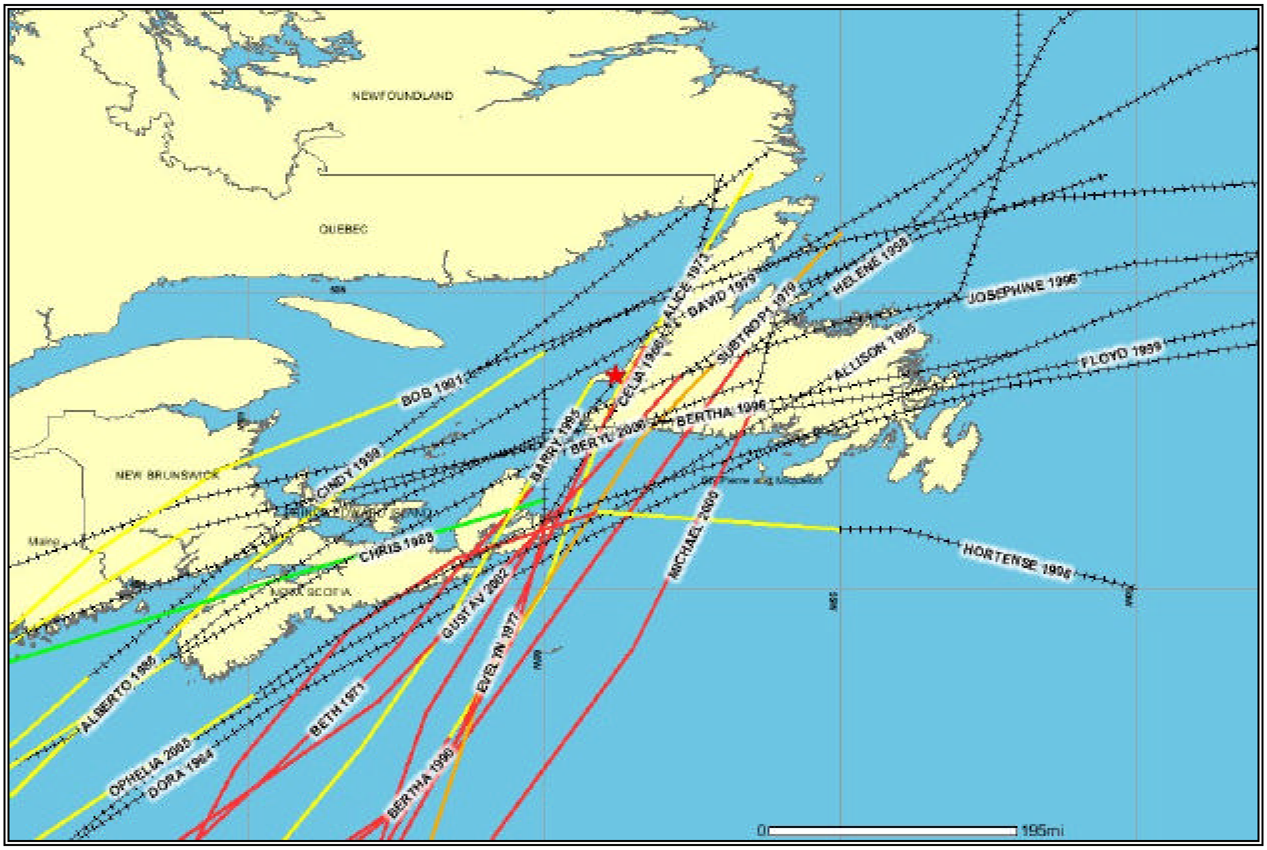


Figure 2.11 Storm Tracks of Tropical Systems Passing within 278 km of the Port-au-Port Peninsula, 1956 to 2006

2.8. Extreme Winds

An analysis of extreme winds was performed using the MSC50 data set. This data set was determined to be the most representative of the available datasets, as it provides a continuous 52-year period of 6 hourly data for the study area. The extreme values for winds were calculated using the peak-over-threshold method; and 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.

Grid Point 14620 located at 48°48'N; 59°00'W was deemed to be the most representative of this study area. A sensitivity analysis was performed which determined that 642 storms provided the best statistical fit for the annual data and 123 storms for the monthly data.

2.8.1. Extreme Value Estimates for Winds from the Gumbel Distribution

The extreme value estimates for wind were calculated using Oceanweather's software programs for the return periods of 1-year, 10-years, 25-years, 50-years and 100-years. The annual and monthly calculated values for 1-hour, 10-minutes and 1 –minute are presented in Table 2.15 to Table 2.17. The analysis used hourly wind values for the reference height of 10-meters above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ration of 1.06 and 1.22 respectively (U.S. Geological Survey 1979). The annual 100-year extreme 1-hour wind speed was determined to be 26.8 m/s. Monthly, the highest extreme winds occur during January, having 1-hour extreme wind estimates of 26.1 m/s.

Table 2.15 1-hr Extreme Wind Speed Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Wind Speed 1-hr (m/s)				
Month	**1.00**	**10.00**	**25.00**	**50.00**	**100.00**
January	19.84	23.40	24.50	25.31	26.12
February	17.54	21.35	22.51	23.39	24.25
March	17.09	20.65	21.75	22.57	23.38
April	15.75	19.76	21.06	22.02	22.98
May	13.90	17.61	18.75	19.60	20.44
June	12.78	15.57	16.43	17.07	17.70
July	11.88	15.75	16.94	17.82	18.70
August	12.36	16.75	18.10	19.11	20.11
September	15.08	19.74	21.17	22.24	23.30
October	16.85	20.34	21.41	22.21	23.00

November	18.10	21.93	23.10	23.98	24.85
December	19.93	23.21	24.23	24.98	25.73
Annual	21.69	24.31	25.32	26.08	26.84

Table 2.16 10-min Extreme Wind Speed Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Wind Speed 10-min (m/s)				
Month	**1.00**	**10.00**	**25.00**	**50.00**	**100.00**
January	21.03	24.80	25.97	26.83	27.69
February	18.59	22.63	23.86	24.79	25.71
March	18.12	21.89	23.06	23.92	24.78
April	16.70	20.95	22.32	23.34	24.36
May	14.73	18.67	19.88	20.78	21.67
June	13.55	16.50	17.42	18.09	18.76
July	12.59	16.70	17.96	18.89	19.82
August	13.10	17.76	19.19	20.26	21.32
September	15.98	20.92	22.44	23.57	24.70
October	17.86	21.56	22.69	23.54	24.38
November	19.19	23.25	24.49	25.42	26.34
December	21.13	24.60	25.68	26.48	27.27
Annual	22.99	25.77	26.84	27.64	28.45

Table 2.17 1-min Extreme Wind Speed Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Wind Speed 1-min (m/s)				
Month	**1.00**	**10.00**	**25.00**	**50.00**	**100.00**
January	24.20	28.55	29.89	30.88	31.87
February	21.40	26.05	27.46	28.54	29.59
March	20.85	25.19	26.54	27.54	28.52
April	19.22	24.11	25.69	26.86	28.04
May	16.96	21.48	22.88	23.91	24.94
June	15.59	19.00	20.04	20.83	21.59
July	14.49	19.22	20.67	21.74	22.81
August	15.08	20.44	22.08	23.31	24.53
September	18.40	24.08	25.83	27.13	28.43
October	20.56	24.81	26.12	27.10	28.06
November	22.08	26.75	28.18	29.26	30.32
December	24.31	28.32	29.56	30.48	31.39
Annual	26.46	29.66	30.89	31.82	32.74

3.0 Wave Climate

The main parameters for describing wave conditions are significant wave height, maximum wave height, peak spectral period, and characteristic period. The significant wave height is defined as the average height of the 1/3 highest waves, and its value roughly approximates the characteristic height observed visually. The maximum height is the greatest vertical distance between a wave crest and adjacent trough. The spectral peak period is the period of the waves with the largest energy levels, and the characteristic period is the period of the 1/3 highest waves. The characteristic period is the wave period reported in ship observations, and the spectral period is reported in the MSC50 data set.

A sea state may be composed of the wind wave alone, swell alone, or the wind wave in combination with one or more swell groups. A swell is a wave system not produced by the local wind blowing at the time of observation and may have been generated within the local weather system, or from within distant weather systems. The former situation typically arises when a front, trough, or ridge crosses the point of concern, resulting in a marked shift in wind direction. Swells generated in this manner usually have a long period.

Swells generated by distant weather systems may propagate in the direction of the winds that originally formed to the vicinity of the observation area. These swells may travel for thousands of miles before dying away. As the swell advances, its crest becomes rounded and its surface smooth. As a result of the latter process, swell energy may propagate through a point from more than one direction at a particular time.

The Marine Environmental Data Services operated a wave buoy at 48°29'N;58°42'W measuring wave heights and periods near Stephenville from October 1974 to November 1975. Due to its location in St. Georges Bay, this dataset is fetch-limited from all directions except from directions between 210° and 270°. As a result, wave heights and periods remain low throughout the dataset.

Mean monthly ice statistics were used when calculating the wave heights in the MSC50 data. As a result, if the mean monthly ice coverage for a particular grid point is greater than 50% for a particular month, the whole month (from the 1st to the 31st) gets "iced out"; meaning that no forecast wave data has been generated for that month. This sometimes results in gaps in the wave data. According to the Environment Canada Sea Ice Climatic Atlas, the 30-year Frequency of Presence of Sea Ice in Port-au-Port Bay is greater than 50% for the weeks of February 12 to April 02. When ice is present in the bay, it is generally new (recently formed having a thickness of less than 10 cm), grey (young ice 10-15 cm thick) and grey-white (young ice 15-30 cm thick) during the month of January. As March approaches, first-year ice (young ice with a thickness of 30 cm to 2 m) either forms along the coast of Newfoundland or comes down through the Strait of Belle Isle. When first year ice is present it typically remains in the Gulf until mid-May.

Located in the Gulf of St. Lawrence, waves at Grid Point 14620 are fetch limited from all directions. Due to its position just east of Long Point, the fetch limiting is more noticeable from the east to south-southwest. As a result, the majority of wave energy arrives from the southwest to the west-northwest. The annual wave rose from the MSC50 data (Figure 3.1) shows that the majority of wave heights are from the west-southwest with 19.8% of the wave energy. The second most prominent direction is from the west with 14.7% of the wave energy. Waves were "iced out" for 12.7% of the time over the 50-year record, however this value may be somewhat high since monthly ice files were used when generating the waves.

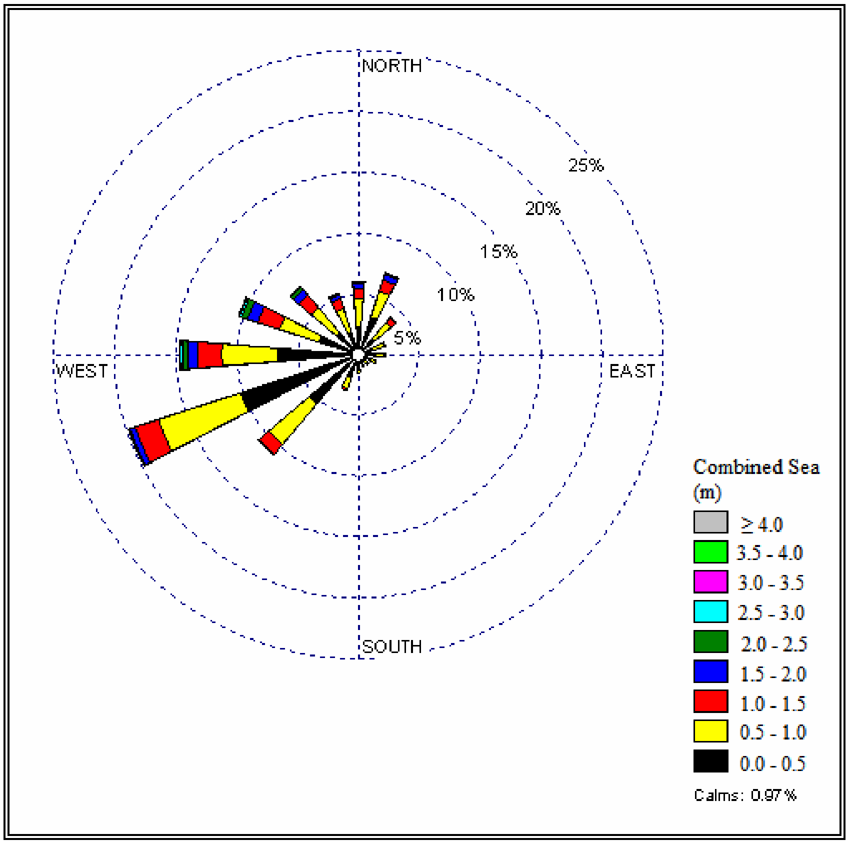


Figure 3.1 Annual Wave Rose from the MSC50 Grid Point 14620

Most of the wave energy in the study area is from wind waves. Since the location is fetch limited from most directions, very little swell energy propagates into the area. Of the swell energy that does reach the Port-au-Port Peninsula, 89.7% of the swell waves have a significant wave height of less than 0.5 m. Only 0.1% of the total swell waves reaching the Peninsula have a significant wave height above 1.0 m.

Significant wave heights near Port-au-Port peak during the winter months with the MSC50 mean monthly significant wave heights reaching 2.0 m in December. The lowest significant wave heights occur in the summer with May, June and July months having a mean monthly significant wave height of only 0.8 m. Since winds are predominately southwest to south during the summer months, waves are generally fetch limited.

Mean significant wave height values from the MEDS buoy are lower than the MSC50 data, especially during the winter months, and show little variation throughout the year. These lower heights can be attributed to significant sheltering from the northwesterly winds which prevail during the winter. The results from both data sets are presented in Table 3.1.

A direct comparison of the MSC50 data with the MEDS buoy data for period of October 07, 1974 to November 26, 1975 is presented in Table 3.2. The data highlights the effect that sheltering had on the MEDS data in St. George's Bay.

Table 3.1 Mean Monthly Combined Significant Wave Heights near Port-au-Port

	Mean (m) SWH*		Maximum (m) SWH*	
Month	**MSC50**	**MEDS**	**MSC50**	**MEDS**
January	1.6	0.7	8.4	2.2
February	0.7	N/A	5.4	N/A
March	0.5	N/A	5.2	N/A
April	0.7	N/A	5.8	N/A
May	0.8	0.2	6.0	0.5
June	0.8	0.4	4.2	1.2
July	0.8	0.7	4.1	2.5
August	0.9	0.5	5.5	2.4
September	1.2	0.7	6.9	2.4
October	1.5	0.9	7.5	4.9
November	1.8	1.0	8.0	2.4
December	2.0	0.7	8.5	2.0

** SWH = Significant Wave Height*

Table 3.2 Comparison of Monthly Wave Heights for the MEDS Buoy and the MSC50 Data Set from October 07, 1974 to November 26, 1975

	AES40		MEDS Buoy	
	Mean (m)	**Maximum (m)**	**Mean (m)**	**Maximum (m)**
January	1.92	5.29	0.5	1.7
February	0.24	2.56	0.5	1.8
March	0.00	0.00	N/A	N/A
April	0.12	2.02	0.5	1.1
May	0.89	4.72	0.5	1.7
June	0.71	2.34	0.4	1.1
July	0.87	2.36	0.4	0.8
August	0.78	3.23	0.3	0.7
September	1.12	3.23	0.4	1.1
October	1.80	4.97	0.4	1.5
November	1.88	4.99	0.4	1.7
December	1.60	4.65	0.5	1.8

The highest significant wave height of 8.53 m from the MSC50 Grid Point 14620 near the Port-au-Port Peninsula occurred at 16Z December 02, 1972. A low pressure over the Gulf of Maine on December 01, 1972 moved northeast across western Newfoundland on December 02. Winds increased to storm force west southwest winds behind this low pressure resulting in a wind wave of 8.4 m and a swell of 1.2 m from the west-northwest.

An annual histogram of the frequency distribution of significant wave heights is presented in Figure 3.2 and the monthly distributions presented in Appendix 3. This histogram shows that the majority of significant wave heights (45.4%) lie between 0.0-0.5 m near the Port-au-Port Peninsula. There is a gradual decrease in frequency of wave heights above 0.5 m and only 2.6% of the wave heights exceed 2.0 m. Wave heights greater than 2.5 m are rare and make up less than 1% of the dataset.

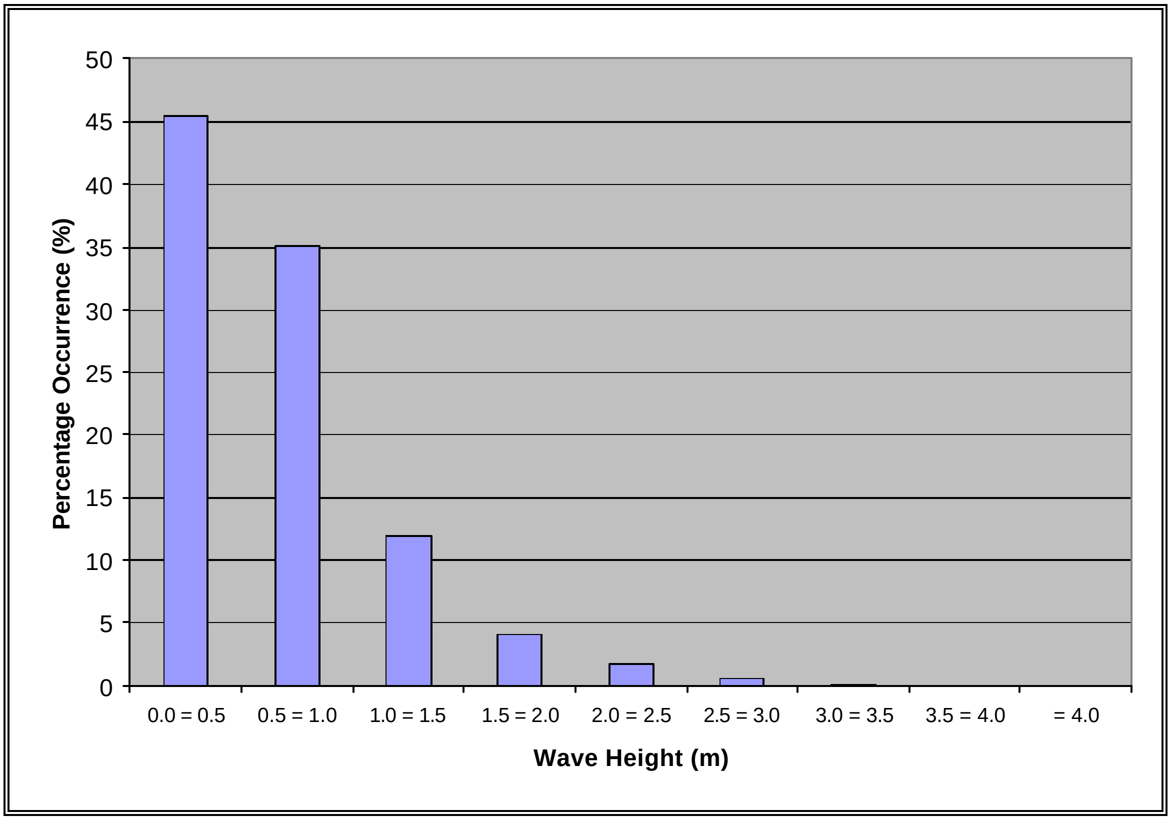


Figure 3.2 Annual Wave Height Percentage Occurrence for MSC50 Grid Point 14620

The spectral peak period of waves vary with season, with the most common period varying from 4 seconds in spring to 7 seconds in December and January. Annually, the most common peak spectral period is 5 seconds, occurring 24.1% of the time. The peak spectral period reaches above 10 seconds. Periods above 10 seconds occur more frequently during the winter months; though they may occur during the summer as well. The percentage occurrence of spectral peak period for each month is shown in Table 3.3 and Figure 3.3.

A scatter diagram of the significant wave height versus spectral peak period is presented in Table 3.4. From this table it can be seen that the most common wave has a significant wave height of 1 m with a peak spectral period of 5 seconds, and the second most common wave has the same height and a peak spectral period of 4 seconds. Note that wave heights in Table 3.4 have been rounded to the nearest whole number. Therefore, the 1 metre wave bin would include all waves from 0.51 m to 1.49 m. The percentage exceedance of significant wave height at the grid point is shown in Figure 3.4. Plots for individual months are presented in Appendix 4.

Table 3.3 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 14620

	Peak Spectral Period (seconds)															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
January	0.1	0.3	2.8	13.5	19.5	20.3	**20.6**	12.2	6.4	3.1	1.0	0.2	0.0	0.0	0.0	0.0
February	3.3	3.3	9.6	**24.0**	23.1	17.8	10.5	5.1	1.7	1.3	0.0	0.2	0.1	0.0	0.0	0.0
March	3.5	4.0	10.4	**26.7**	22.3	15.4	10.0	5.3	1.4	0.8	0.0	0.1	0.0	0.0	0.0	0.0
April	3.2	3.7	10.6	**28.1**	22.9	14.8	9.2	5.1	1.0	1.2	0.1	0.1	0.0	0.0	0.0	0.0
May	1.2	4.4	8.3	**28.1**	25.0	16.9	7.8	6.2	0.5	1.5	0.1	0.1	0.0	0.0	0.0	0.0
June	0.4	4.3	8.0	26.7	**27.9**	19.5	7.0	4.8	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0
July	0.3	3.9	7.2	28.4	**30.4**	19.3	6.3	3.1	0.1	0.9	0.0	0.0	0.0	0.0	0.0	0.1
August	0.1	2.7	6.2	25.6	**31.1**	21.1	8.8	3.1	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0
September	0.1	1.2	4.3	20.2	**26.1**	23.5	14.2	7.2	1.9	1.0	0.1	0.1	0.0	0.0	0.0	0.0
October	0.0	0.4	2.9	14.6	23.2	**24.2**	19.2	9.9	3.9	1.3	0.2	0.0	0.0	0.0	0.0	0.0
November	0.0	0.1	2.0	12.5	20.5	**21.5**	20.8	12.2	6.5	3.3	0.7	0.1	0.0	0.0	0.0	0.0
December	0.0	0.1	1.6	9.8	17.6	19.8	**22.1**	14.3	8.3	4.4	1.7	0.3	0.1	0.0	0.0	0.0
Winter	1.1	1.3	4.7	15.8	**20.1**	19.3	17.7	10.5	5.5	2.9	0.9	0.2	0.1	0.0	0.0	0.0
Spring	2.6	4.0	9.8	**27.7**	23.4	15.7	9.0	5.5	1.0	1.2	0.1	0.1	0.0	0.0	0.0	0.0
Summer	0.3	3.6	7.1	26.9	**29.8**	20.0	7.4	3.7	0.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Autumn	0.0	0.6	3.1	15.8	**23.3**	23.1	18.1	9.8	4.1	1.9	0.3	0.1	0.0	0.0	0.0	0.0
Annual	1.0	2.4	6.2	21.5	**24.1**	19.5	13.0	7.4	2.7	1.7	0.3	0.1	0.0	0.0	0.0	0.0

Source: MSC50 grid point 14620. 46°48'N 59°00W, 1954 to 2005.

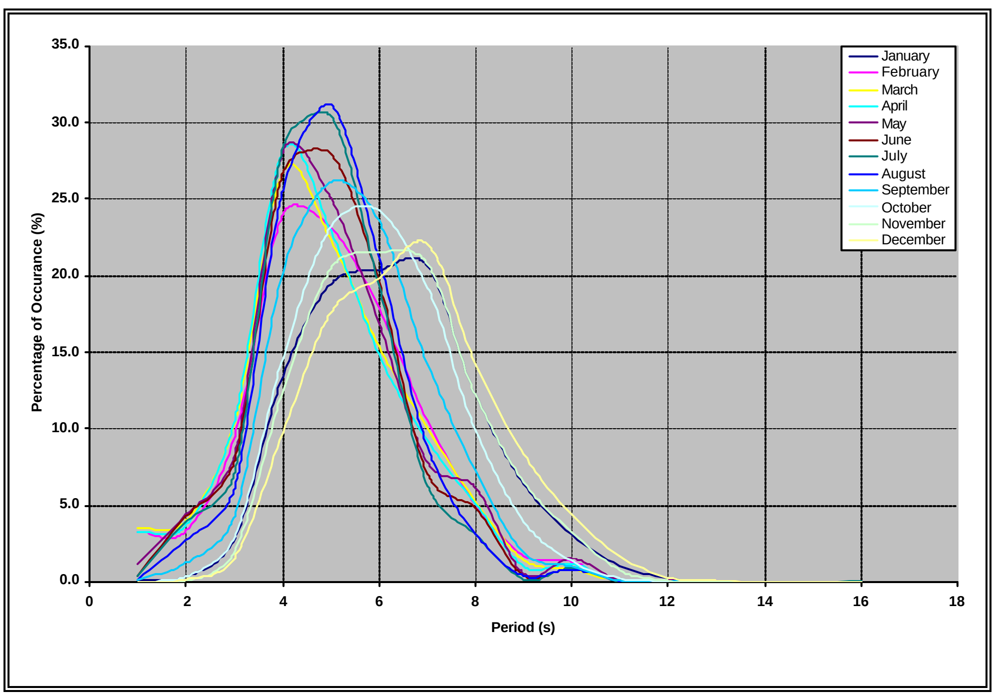


Figure 3.3 Percentage of Occurrence of Peak Wave Period at Grid Point 14620

Table 3.4 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 14620

		Wave Height (m)													Total
		<1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Period (s)	**0**	12.84	0.00												12.84
	1	0.52													0.52
	2	1.94													1.94
	3	3.54	1.41												4.95
	4	6.81	11.54	0.01											18.36
	5	2.31	17.52	1.47	0.00										21.30
	6	0.17	10.96	6.18	0.10										17.41
	7	0.25	1.94	7.81	1.62	0.01									11.63
	8	1.08	0.13	1.67	3.25	0.48	0.00								6.61
	9	0.01	0.00	0.13	0.82	1.34	0.16	0.00							2.46
	10	0.51	0.03	0.02	0.07	0.32	0.50	0.09	0.01						1.54
	11	0.00	0.00		0.00	0.02	0.11	0.11	0.07	0.00					0.31
	12	0.04	0.01					0.00	0.02	0.01					0.08
	13	0.00								0.01	0.00				0.01
	14	0.00													0.00
	15	0.00													0.00
	16	0.01													0.01
	17														0.00
	18														0.00
	19														0.00
	20														0.00
		30.03	43.54	17.30	5.87	2.16	0.78	0.20	0.09	0.02	0.00	0.00	0.00	0.00	100.00

Source: MSC50 grid point 14620. 46°48’N 59°00W, 1954 to 2005.

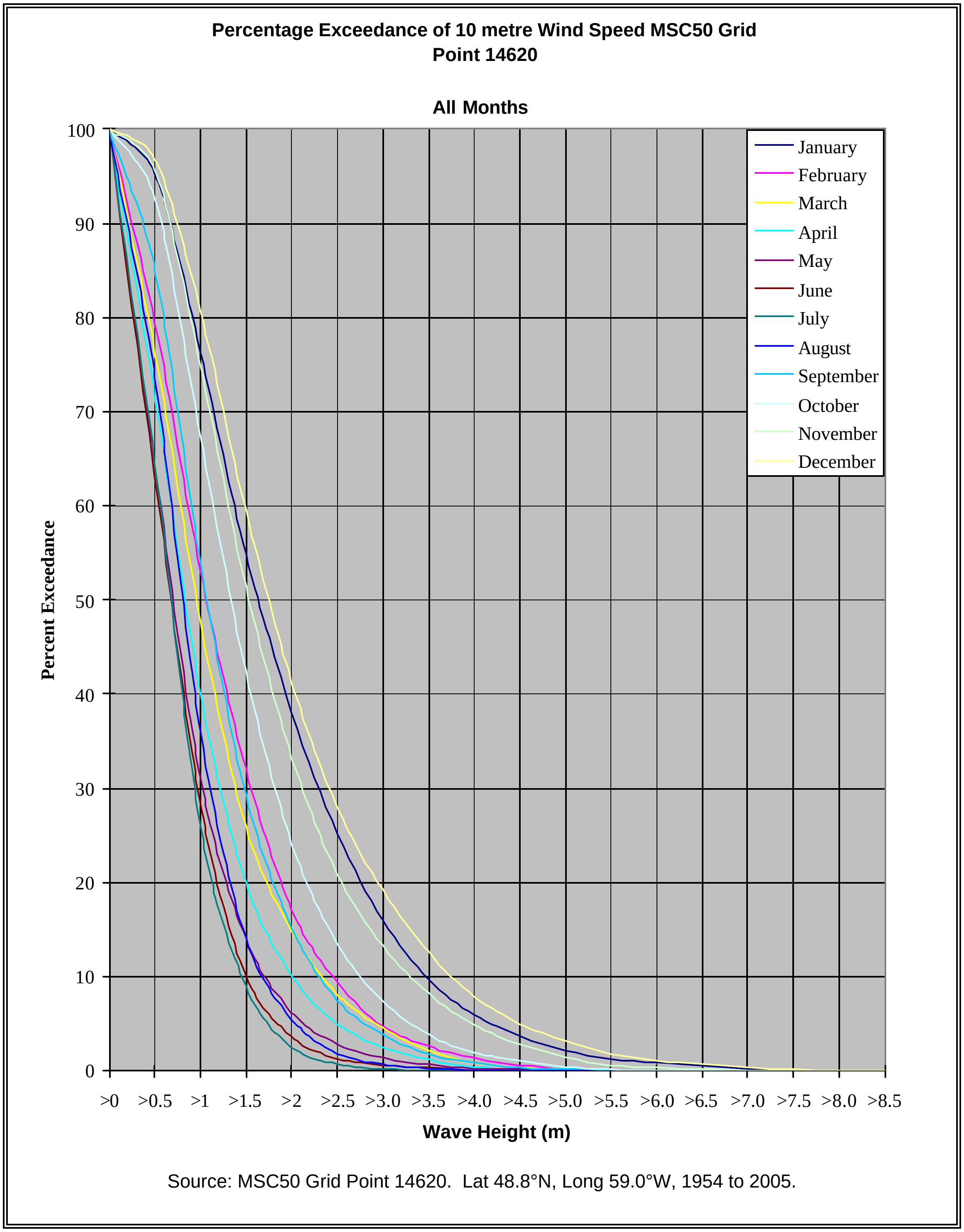


Figure 3.4 Percentage Exceedance of Significant Wave Height at MSC50 Grid Point 14620

3.1. Extreme Waves

The extremal analysis for waves was carried out from the MSC50 data set for grid point 14620. The extreme values were calculated using the Gumbel Distribution and peak-over-threshold method. A sensitivity analysis on the data showed that the best statistically fit was achieved using 272 storms for the annual data and 57 for the monthly data.

3.1.1. 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 3.5. The annual 100-year extreme significant wave height for Grid Point 14620, located just east of Long Point on the Port au Port Peninsula, is 9.4 m. Monthly, the highest extreme significant wave height occurred during December with an extreme height of 9.1 m. The highest significant wave height of 8.5 m in the MSC50 data set occurred in on December 02, 1972. This corresponds with the December 50-year extreme significant wave height of 8.6 m.

Table 3.5 Extreme Significant Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Significant Wave Height (m)				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	4.7	7.1	7.8	8.3	8.8
February	3.2	4.8	5.4	5.8	6.2
March	2.7	4.6	5.1	5.5	5.9
April	2.7	4.5	5.0	5.4	5.8
May	2.4	4.5	5.2	5.6	6.1
June	2.2	3.7	4.1	4.4	4.7
July	2.0	3.2	3.6	3.9	4.1
August	2.4	3.9	4.4	4.7	5.1
September	3.3	5.2	5.8	6.2	6.6
October	3.9	5.8	6.3	6.7	7.1
November	4.6	6.8	7.4	7.9	8.3
December	5.5	7.6	8.2	8.6	9.1
Annual	6.3	7.9	8.5	8.9	9.4

The maximum individual wave heights were calculated within Oceanweather's OSMOSIS software by evaluating the Borgman integral (Borgman 1973), which was derived from a Raleigh distribution function. The variant of this equation used in the software has the following form (Forristall 1978):

$$\Pr\{H > h\} = \exp\left[-1.08311\left(\frac{h^2}{8M_0}\right)^{1.063}\right]; \quad T = \frac{M_0}{M_1}$$

where h is the significant wave height, T is the wave period, M_0 and M_1 are the first and second spectral moments of the total spectrum. The associated peak periods are calculated by plotting the peak periods of the chosen storm peak values versus the corresponding significant wave heights. This plot is fitted to a power function ($y = ax^b$), and the resulting equation is used to calculate the peak periods associated with the extreme values of significant wave height. The maximum wave heights, and associated peak periods are presented in Table 3.6 and Table 3.7.

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

	Maximum Wave Height (m)				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	8.8	13.2	14.5	15.5	16.4
February	6.0	9.4	10.5	11.3	12.2
March	5.5	8.8	9.8	10.5	11.3
April	5.1	8.5	9.5	10.3	11.0
May	4.7	8.5	9.6	10.5	11.3
June	4.1	7.3	8.2	8.9	9.5
July	3.9	6.1	6.7	7.2	7.6
August	4.5	7.3	8.1	8.7	9.3
September	6.3	9.9	10.9	11.7	12.5
October	7.4	10.7	11.6	12.3	13.0
November	8.8	12.6	13.7	14.5	15.3
December	10.3	14.1	15.2	16.0	16.8
Annual	11.8	14.6	15.7	16.6	17.4

Table 3.7 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Associated Peak Period (sec)				
Month	**1.0**	**10.0**	**25.0**	**50.0**	**100.0**
January	12.5	15.1	15.7	16.2	16.6
February	10.4	12.7	13.4	13.9	14.4

March	9.7	11.7	12.2	12.5	12.9
April	9.7	12.0	12.6	13.0	13.4
May	9.5	11.9	12.5	13.0	13.3
June	8.9	10.9	11.3	11.7	12.0
July	8.6	9.9	10.2	10.4	10.6
August	9.3	11.2	11.7	12.0	12.3
September	10.8	13.1	13.6	14.0	14.4
October	11.8	13.8	14.4	14.8	15.1
November	12.3	14.1	14.5	14.9	15.2
December	13.8	16.1	16.7	17.1	17.5
Annual	13.7	14.9	15.4	15.7	16.0

4.0 The Impact of Waves from Extreme Storms

This section addresses the characteristics of waves at the project site, on the end of Shoal Point in Port-au-Port Bay, Newfoundland, during extreme storms. Shoal Point is generally sheltered from seas propagating from the adjacent Gulf of St. Lawrence by the geography of the land surrounding Port-au-Port Bay. The Port-au-Port Peninsula and the Long Point bar ("The Bar") separate most of the bay from the Gulf of St. Lawrence. Direct exposure to northerly seas from the gulf is along the 9 km entrance on the north end of Port-au-Port Bay, between Long Point and the west coast of Newfoundland.

For the project site, the analysis in this section examines:

- the effect of waves generated locally from extreme winds in Port-au-Port Bay
- the transformation and impact of extreme seas propagating through entrance of Port-au-Port Bay
- the effectiveness of the Long Point bar in sheltering from extreme seas
- the possibility of freezing spray from waves

4.1. Methodology and Modelling

Investigating the exposure of the project site to waves generated under extreme storm conditions, including the possibility of icing on structures at the drill site from associated freezing spray, required modelling the transformation of deep-water waves to breakers, with respect to the constrains of the local bathymetry and topography. For completeness, the study examined both deep-water waves propagating into Port-au-Port Bay from the Gulf of St. Lawrence, and those generated locally in Port-au-Port Bay.

Given the complex bathymetry, the bay is subject to refraction, diffraction, and reflection of waves. As the purpose of the study is determining maximum wave heights under extreme conditions, and since these effects generally diminish wave heights, the modelling did not include these effects. The Canadian Hydrographic Service 1:350,000 digital navigation chart, centred on Port-au-Port Bay and surrounding waters, provided the bathymetry for the project.

4.1.1. Breaking Waves

The height of a wave is the vertical distance between crest and trough, while the wavelength is the horizontal distance between successive crests. As deep-water waves initially enter shallow water, wavelength will decrease, as will height. As the waves propagate further into shallower water, wavelength continues decreasing, but wave height increases up to a critical height, finally collapsing or breaking the waves. If the slope of the sea floor is significantly less than about 1:100 (U.S. Army Coastal Engr. Res. Centre, 1973), the height of breakers H_b depends only on water depth d_b (WMO, 1998):

$$d_b = 1.28 H_b$$

As a wave breaks, the water plunges forward a certain distance. This plunge distance Xp depends on breaker height and the near shore slope m of the sea bottom (U.S. Army Coastal Engr. Res. Centre, 1973):

$$Xp = (4.0 - 9.25m) H_b$$

Waves must break close enough to shore, and be high enough, in order that the plunge distance is sufficient to carry water anywhere near the project site. The drill site on Shoal Point is at an elevation of 1.21 m, about 45 m from the high water mark. The criteria for wave impact at the site considered the distance offshore of 1 metre breakers compared to their plunge distance. That is, if waves higher than the site break farther offshore than their plunge distance, waves and freezing spray will not reach the level of the site. In addition, the 1 metre threshold for breaker height was also the lowest value reasonable, given the resolution of the available bathymetry.

4.1.2. Extreme Waves and Wind

The MSC50 wind and wave reanalysis database (Swail et. al., 2006) provided a historical time series of winds and waves for the extreme condition analysis. Simulation of incoming deep-water waves, as well as local winds for modelling waves in Port-au-Port Bay, was at a point 17 km west of the tip of Long Point, at 48.8° N, 59.0° W, in waters near 40 m deep. Tables 4.1 and 4.2 are the absolute maximum wave heights (metres) and wind speeds (metres per second) in the record, by month and direction from which the winds and waves are coming.

Table 4.1 Maximum Wave Height (m) off Long Point by Month and Direction

MONTH	SW	W	NW	N	NE	E	SE	S
January	5.5	8.4	7.2	7.2	5.6	3.0	2.7	3.2
February	4.7	5.1	5.3	5.4	4.2	2.8	2.4	2.9
March	3.1	5.2	4.5	5.0	4.3	3.0	1.8	2.5
April	4.0	5.8	5.0	5.1	4.9	2.2	2.2	2.1
May	4.1	6.0	4.7	4.6	4.0	1.8	1.7	2.0
June	3.2	3.9	4.0	4.2	3.8	1.6	1.5	1.8
July	3.6	4.1	3.2	4.0	2.9	1.8	2.2	2.4
August	3.3	5.5	4.4	4.6	3.6	1.7	2.8	3.3
September	4.7	5.6	6.9	5.9	3.9	1.8	1.8	2.5
October	4.3	7.5	5.8	5.2	5.6	2.5	2.2	2.7
November	5.1	8.0	7.4	6.1	4.8	2.4	2.4	3.1
December	6.9	8.5	7.5	7.3	5.2	2.6	2.6	3.3

Table 4.2 Maximum Wind Speed (m/s) off Long Point by Month and Direction

MONTH	SW	W	NW	N	NE	E	SE	S
January	23	24	23	23	22	23	25	25
February	22	22	21	22	22	21	22	22
March	22	22	22	20	20	21	20	20
April	21	19	19	18	18	18	20	22
May	19	16	17	17	19	20	17	17
June	16	13	15	16	14	15	16	17
July	14	15	21	17	17	15	15	16
August	16	17	24	17	15	18	15	18
September	17	22	17	23	19	23	22	21
October	24	18	20	19	19	22	21	20
November	20	20	21	21	21	24	24	21
December	23	21	21	22	25	25	24	23

4.1.3. Waves Generated Locally in Port-au-Port Bay

For fetch-limited wave growth in the deeper waters of Port-au-Port Bay, the following expression determined wave height and period (Bretschneider, 1969):

$$H = 0.238 \frac{U^2}{g} \tanh\left(0.0125 \left(\frac{gF}{U^2} \right)^{0.42} \right)$$

$$T = 7.54 \frac{U}{g} \tanh\left(0.077 \left(\frac{gF}{U^2} \right)^{0.25} \right)$$

Where H is the wave height in metres, P is the period in seconds, U is the wind speed in metres per second, F is the fetch in metres, and g is the acceleration of gravity.

The wave height in the transitional zone between deep and shallow water is somewhat less than H, but since the focus is on maximum wave heights in extreme conditions, this is inconsequential. The analysis marked the transition to shallow water, and subsequent increase in wave heights beyond H, where the ratio of water depth (d) to wavelength (L), or the relative depth was according to (Sorensen, 2006):

$$\frac{d}{L} \geq 0.1$$

The expressions for deep and shallow water wavelengths are:

$$L = \frac{gT^2}{2p} \text{ (Deep water)}$$

$$L = T\sqrt{gd} \text{ (Shallow water)}$$

In general, the fetch (or distance) and duration of wind blowing over the water constrain the growth of deep-water waves. As the distance from Shoal Point to any adjacent shore in Port-au-Port Bay is relatively short, the growth of any significant local waves is fetch limited. The maximum height of these waves depends only on the speed of the local wind, and they build to their full height in about an hour.

Table 4.3 shows local waves heights and periods generated by extreme winds (see Tables 4.1 and 4.2), along with fetch distance to Shoal Point, according to wind direction. The directions in the tables are the directions from which winds and waves are coming with respect to the project site, the maximum fetch of wave development, the maximum local wind speed, and the locally generated wave heights and periods. Since the table presents locally generated waves, the Gulf of St. Lawrence swell component from the northeast is not included.

Table 4.3 Waves generated by Extreme Local Winds in Port-au-Port Bay Propagating towards Shoal Point

Direction	Fetch [km]	Wind Speed [m/s]	Wave Height [m]	Wave Period [s]
Southwest	7.8	25	1.4	5
West	8.9	25	1.5	5
Northwest	7.0	25	1.4	5
North	9.0	25	1.5	5
Northeast	23.0	23	2.0 (1)	6 (1)
East	12.4	24	1.7	5
Southeast	12.9	25	1.8	5

1. *The wave height and period are from locally generated winds, and do not include swells from the Gulf of St. Lawrence.*

4.2. Analysis and Results

There are three possible source mechanisms for extreme waves propagating towards the project site on Shoal Point:

- seas entering the mouth of Port-au-Port Bay from the Gulf of St. Lawrence
- local wind waves generated within Port-au-Port Bay
- waves potentially breaking over the Long Point bar

The following sections discuss each of these mechanisms, and their impact on the project site.

4.2.1. Transformation of Extreme Seas from the Gulf of St. Lawrence to Shoal Point

The configuration of land encompassing Port-au-Port Bay effectively shelters Shoal Point from direct propagation of waves from all directions except a relatively narrow band to the north-northeast, centred around 020° true. Waves entering from the Gulf of St. Lawrence marginally east of this band are fetch limited by the west coast of Newfoundland, and lose energy through refraction over coastal waters as well. Waves entering slightly west of this band are sheltered, and lose energy through diffraction, by the Long Point bar.

In the path of any incoming waves directly propagating toward Shoal Point from the gulf are two areas of relatively shallow water. The first is a set of ridges, about 13 km from the mouth of Port-au-Port Bay, extending south-southwest and east-southeast from Long Ledge. The depth here ranges from 0 to 9 m, with an average depth of about 7 m. The second area of shallows extends from Fox Island roughly west-northwest across most of mouth to Long Point. The water here is 2 to 5 m deep, with an average depth of about 3 to 4 m.

As the waves from the gulf travel past the shallow water, near the mouth of Port-au-Port Bay, the water deepens to a maximum of about 22 m, with an average of about 16 m. At approximately 5 km from Shoal Point, the bottom begins a gradual rise, reaching the 4-m depth at about 3 km offshore, and a depth of 1 m near a km offshore.

At the Long Ledge shallows, the modelling indicated that any waves over 5 to 6 m will break, while waves higher than 1 to 3 m break in the shallow water near Fox Island. Therefore, swells entering Port-au-Port Bay after Fox Island are at the very most 3 m high, even in the most extreme conditions.

As the swells continue to propagate across the deeper water of Port-au-Port Bay towards Shoal Point, local wind conditions will add a maximum of one-half metre to the wave height, in extreme conditions. These waves begin to break in the gently sloping shallow water leading to Shoal Point at approximately 3.5 km offshore. Once the depth reaches about 2 m, about 1.5 km offshore, waves over 1.4 m will break. Finally, waves 1 m and higher break no closer than a kilometre offshore.

Table 4.4 summarizes the transformation of waves generated under extreme conditions from the open gulf to Shoal Point. At each significant location along the maximum wave height propagation band, the table shows the main factors limiting the growth of waves, average water depth, estimated average sea bed slope, highest possible wave height, and plunge distance of the highest breakers. For the shallow areas indicated, the slope is the rise in the direction of wave propagation.

Table 4.4 Transformation of Extreme Waves from the Gulf of St. Lawrence to Shoal Point

Vicinity	Sea Height Limiting Factor	Water Depth [m]	Bottom Slope	Extreme Sea Height [m]	Plunge Distance [m]
Gulf of St. Lawrence	fetch/duration	54	0.000	7.3	0
Long Ledge Shallows	breaking	7	0.002	5.7	23
Long Ledge to Fox Is.	fetch	14	0.000	6.0	0
Fox Is. Shallows	breaking	4	0.001	2.9	11
Fox Is. to Shoal Pt.	fetch	16	0.000	3.5	0
3.5 km from Shoal Pt. (1)	breaking	4	0.005	3.5	13
1.5 km from Shoal Pt.	breaking	2	0.001	1.4	6
1.0 km from Shoal Pt.	breaking	1	0.001	1.0	4

(*1) The highest waves propagating across Port-au-Port Bay will break 3 km from Shoal Point*.

4.2.2. Waves Generated by Extreme Local Winds

In addition to seas from the open Gulf of St. Lawrence, fetch-limited waves generated by local winds in Port-au-Port Bay propagate toward the project site on Shoal Point. Table 4.5 shows the maximum height of waves produced by extreme winds (Table 4.3), propagating from each direction relative to site. The table indicates the distance offshore of breakers, and their plunge distance, from waves of maximum height down to 1 m. The height of waves from the northeast includes the maximum swell from the Gulf of Lawrence in addition to the local wind wave.

Table 4.5 Offshore Breaking and Plunge Distance of Extreme and One Metre Waves by Direction from Shoal Point

Direction Relative to Project Site	Extreme Waves			1 Metre Waves	
	Maximum Height [m]	Offshore Breaker Distance [m]	Breaker Plunge Distance [m]	Offshore Breaker Distance [m]	Breaker Plunge Distance [m]
Southwest	1.4	500	5.6	350	4.0
West	1.5	400	6.0	280	4.0
Northwest	1.4	550	5.4	380	4.0
North	1.5	2000	6.0	1400	4.0
Northeast (1)	3.5	3500	14.0	1000	4.0
East	1.7	450	6.5	280	4.0
Southeast	1.8	1400	7.0	800	4.0

1. *This direction includes swell propagating in from the Gulf of St. Lawrence*

4.2.3. Potential for Waves Breaking over the Long Point Bar

The Long Point bar is a narrow strip of land separating Port-au-Port Bay from the Gulf of St. Lawrence from west to northwest. The southern part extending about 8 km from Lourdes to the community of Black Duck Brook is 1 to 2 km wide with an average elevation of around 20 m. Given the width and elevation, this part of Long Point protects Shoal Point from extreme seas generated in the Gulf of St. Lawrence.

The northern part of the Long Point bar, extending about another 14 km is a quarter to a half kilometre wide on average, with an elevation well below 20 m. Given the narrowness and low elevation, the study investigated the potential for waves overrunning this section and reaching the project site on Shoal Point. In particular, there is a portion extending 5 km southwest of Beach Point averaging about 400 m wide, on the exposed western side, which steeply drops to a 3 to 4 m depth. Given the depth and steepness of the drop-off, higher waves break directly on this section of shore. In Table 6, the coordinates 48° 45.12' N; 058° 49.05' W represent the middle of this section.

The investigation examined the distance offshore of breakers compared to their plunge distance for extreme (8.5 metre), 3 m, and 1 m As shown in Table 6, the analysis considered seven representative locations along the narrow part of the Long Point bar. The table also displays the width of the bar at each location.

Table 4.6 Offshore Breaking and Plunge Distance of Extreme and One Metre Waves by Direction at the Long Point Bar

North Latitude [degrees] [minutes]	West Longitude [degrees] [minutes]	Bar Width [m]	8.5 Metre Waves		3 Metre Waves		1 Metre Waves	
			Offshore Breaker Distance [m]	Breaker Plunge Distance [m]	Offshore Breaker Distance [m]	Breaker Plunge Distance [m]	Offshore Breaker Distance [m]	Breaker Plunge Distance [m]
48 42.39	058 53.41	460	2100	34	500	11	182	4
48 42.96	058 52.63	580	1300	34	500	11	63	4
48 43.87	058 51.03	380	690	34	400	11	182	4
48 45.12	058 49.05	400	1200	34	0 (1)	0 (1)	— (1)	— (1)
48 46.24	058 47.36	300	700	34	300	11	112	4
48 46.50	058 46.91	300	1000	34	300	11	56	4
48 47.19	058 46.02	<200 (2)	700	34	350	11	112	4

(1) Three metre waves break on shore here.
(2) Width of the bar is less than 200 m here.

4.3. Summary of Potential Effects of Waves on the Drill Site

From Table 4.4, the shallow waters near Long Ledge, Fox Island, and those leading to Shoal Point effectively block any extreme waves propagating from the Gulf of St. Lawrence. Under extreme conditions, the highest seas approaching Shoal Point from the mouth of Port-au-Port Bay, produced by combining local wind waves with the open gulf swell, are 3.5 m. These waves, with a plunge distance of 14 m, break approximately 3.5 km offshore, well away from the site.

For any significant effect at the project site, waves higher than, or at least near, the site elevation (1.42 m) must break on or close to shore. Table 4.4 shows that any waves propagating from the mouth of Port-au-Port Bay, greater than a metre in height, break no closer than 1 km from shore. With a plunge distance of 4 m, these waves do not reach the site.

The impact on the project site from local waves produced in Port-au-Port Bay is in Table 4.5. Aside from northeast waves (which include swell from the Gulf of St. Lawrence), the highest local waves generated from extreme winds (see Table 4.3) range from 1.4 to 1.8 m. These break from 400 m to 2 km offshore, plunging from 5 to 7 m. The local o1 m waves break from 280 m to 1.4 km offshore, so that with only a 4-m plunge distance, these waves do not reach the project site.

Table 4.6 summarizes the results of the Long Point bar wave analysis. The highest waves of 8.5 m (see Table 4.1) from the Gulf of St. Lawrence break from 690 m to 2 km offshore. These waves plunge 34 m, far short of the shore. In general, 3 m waves break from 300 to 500 m offshore, and plunge 11 m. However, over a section extending 5 km southwest of Beach Point, with a steep 3 to 4 m drop-off on the gulf side (represented by 48° 45.12' N; 058° 49.05' W in Table 4.6), waves up to 3 m high break onshore. As the average width of the bar is 400 m here, these breakers will not overrun the bar to reach the project site.

As shown in Table 4.6 any waves over a metre break at least 56 to 182 m from the shore, plunging 4 m at this distance. Therefore, even in extreme conditions no waves from the Gulf of St. Lawrence can reach the project site on Shoal Point over the Long Point bar.

Overall, the exposure of the project site and in particular the drill hole on Shoal Point to waves generated under extreme storm conditions is negligible. Furthermore, since the height (under 1 m) and plunge distance (under 4 m) of waves breaking on, or near, the shore could not generate sufficient spray to reach the site, icing on structures at the drill site (about 45 m for the high water mark) from freezing spray would be negligible.

5.0 Storm Surges

A storm surge is a pronounced increase in water level usually associated with the passage of storm systems and is defined at the coast as the difference between the observed water level and the predicted astronomical tide. This increase in water level is typically the result of two forces acting together on the ocean. These forces are the wind stress acting on the sea and the inverted barometer effect under the low pressure area near the center of the storm. There is, however, another process by which the surge may become more exaggerated than would be anticipated by these two effects alone. As the storm depression travels over the water surface, a long surface wave travels along with it. If the storm path is such as to direct this wave up onto shore, the wave may steepen and grow as a result of shoaling and funneling (Forrester, 1983).

Located in the Gulf of St. Lawrence, on the west coast of Newfoundland, the Port-au-Port Peninsula has experienced numerous storm surges caused by the passage of storm systems. On January 21 and 22, 2000 a powerful storm passed over the coastal waters of Eastern Canada, generating a 1.4 m storm surge in the southern part of the Gulf of St. Lawrence. This surge resulted in severe flooding around Prince Edward Island and along the eastern shore of New Brunswick (Bobanovic, 2006). Bernier and Thompson (2006) did a study of extreme storm surges in the Northwest Atlantic using 40 year hindcast of storm surges. In their study, they showed a 40 year return period storm surge of greater than 1.3 m for the affected region. In the same study, they showed a 40 year return period of 0.7 m near the Port-au-Port Peninsula. Local effects within Port-au-Port Bay may enhance sea levels resulting in higher storm surges affecting Shoal Point.

In the absence of water level data for the Fox Island tidal station, an analysis of storm surge was done using data from the Lark Harbour station located in the Bay of Islands to the northeast of the Port-au-Port Peninsula. Water levels at Lark Harbour are available from September 02, 1963 to April 21, 1988. A storm surge analysis was performed on a subset of the Lark Harbour data from January 01, 1984 to April 21, 1988. Tidal predictions for the station were extracted from a tidal model developed by G. Godin. These predictions were then subtracted from measured waters levels to determine what portion of the measured height may be attributed to storm surge. Figure 5.1 shows the resulting calculated storm surge for Lark Harbour.

A maximum value of 1.4 m was calculated for Lark Harbour on January 02, 1985. This value appears to be due to bad data as an area of high pressure lay over the area with light winds from the north to northeast at this time. A second maximum of 0.87 m occurred at 18NST January 14, 1986 resulting in a combined sea level rise of 1.92 m. During this event, a 979 mb low pressure over Sable Island at 12Z, moved north passing over the west coast of Newfoundland and resulting in gale force northwest to west winds over the

Gulf. This value is higher than the 40 year return period storm surge of 0.7 m. This higher value may be the result of enhancement by local topography.

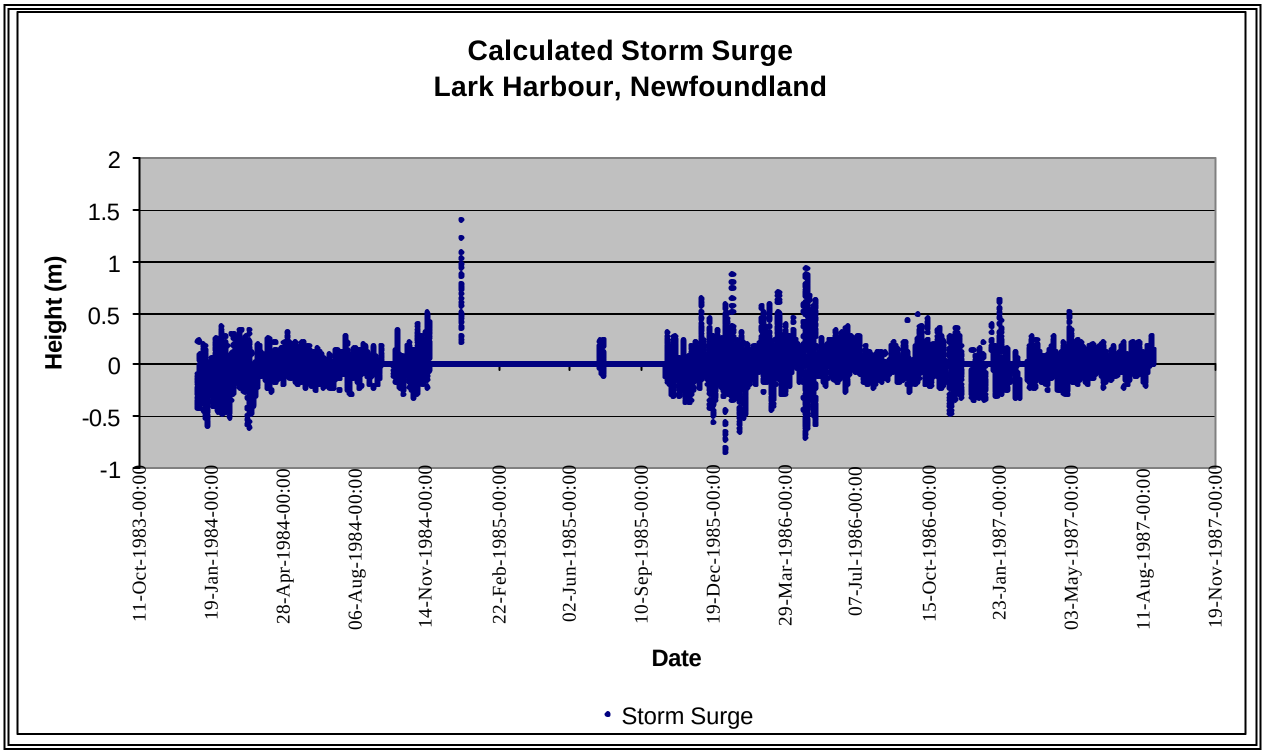


Figure 5.1 Calculated Storm Surge for Western Newfoundland

If this storm surge occurred at 12NST January 01, 1987, combined with a tidal height of 2.23 m, sea levels would have rose to 3.1 m at Lark Harbour. At Fox Island, the maximum tidal height from the tidal model is 1.77 m at 12NST November 25, 2003. If the 40 year return wave of 0.7 m occurred at this time, Fox Island would see a sea level rise of 2.47 m. Assuming that the maximum recorded storm surge at Lark Harbour could be applied to a point within Port-au-Port Bay, a sea level rise as high as 2.64 m could be expected within the bay if the storm surge were to occur at high tide. This value may be larger depending on the wave setup.

Negative storm surges, typically associated with offshore winds and traveling high pressure systems, result in a pronounced decrease in water level below the astronomical tide level. These events are usually not as pronounced as storm surges; however they may be of concern to mariners since they can create unusually shallow water if they occur near the low tide. On January 05 1986 a negative storm surge of -0.83 m was recorded at Lark Harbour. This negative surge was the result of a 972 mb low pressure system passing west of the Port-au-Port Peninsula.

A storm surge model developed at Dalhousie University is currently being used operationally by Environment Canada to help predict high waters levels for Atlantic Canada. The storm surge predictions are added to tidal predictions to help determine areas of potentially dangerous flood levels.

6.0 Currents

The Gulf of St. Lawrence is a highly stratified semi-enclosed sea connected to the North Atlantic Ocean through Cabot Strait to the southeast and through the Strait of Belle Isle to the northeast. It exchanges salt water with the North Atlantic Ocean and receives a considerable amount of fresh water from the St. Lawrence River and other smaller rivers located around the Gulf. As a consequence, the circulation in the Gulf of St. Lawrence resembles a large estuary where the Coriolis effect and baroclinic processes are important factors. However, practically nothing is known about the hydrodynamics of this system, compare to other semi-enclosed seas in the world (Koutitonsky and Bugden, 1991).

The current circulation in the Gulf of St. Lawrence is produced by such factors as 1) buoyancy forces, 2) tides, 3) wind stress, 4) large-small meteorological forcing over the Gulf and 5) exchange with the Atlantic Ocean through Cabot Strait and the Strait of Belle Isle.

In general, the overall circulation has a cyclonic pattern in the central region of the Gulf, an anticyclonic cell in the Northwastern Gulf, and a cyclonic cell in the Estuary (Koutitonsky and Bugden, 1991). Summer surface geostropic currents have been calculated from monthly averaged density fields by El-Sabh (1976) and by Trites (1972). The summer surface circulation pattern presented by Trites (1972) is shown in Figure 6.1 and the surface geostrophic currents for the month of November presented by El-Sabh (1976) in Figure 6.2.

Figure 6.1 and Figure 6.2 both show an inflow of water through Cabot Strait on the Newfoundland side and an outflow on the Cape Breton side. In the Strait of Belle Isle there is an inflow of the Labrador Current on the Quebec/Labrador side and an outflow of Gulf Water on the Newfoundland side. It is the exchange of water through these two Straits combined with the freshwater contribution from the St. Lawrence River that maintains the cyclonic circulation in the Gulf.

Temperatures and salinity data for the Bonne Bay transect (Figure 6.3) was downloaded from the Atlantic Zone Monitoring Program on the Marine Environmental Data Service (MEDS) website, and used to produce density contours across the northeastern section of the Gulf. The density contours are presented in Figures 6.4 and 6.5 for the months of June and November, respectively. The slopes of the contours in both figures show a northeastern flow along the west coast of Newfoundland. This geostrophic flow is more pronounced in November than in June, indicated a stronger geostrophic current during fall than during summer. The currents in the project area which is located south of the Bonne Bay transect would be in the same direction.

Tidal currents are oscillatory in nature and do not contribute to the mean flow, but can contribute significantly to the current speed. Chasse (2001) calculated a depth-averaged current amplitude of 15 cm/sec for the M_2 tidal component and 10 cm/sec for the K_1 tidal component offshore Cape Ray. Using the cotidal chart (Figure 6.6) for the Gulf of St. Lawrence produced by Godin (1980) would indicate that the tidal currents are in excess of 20 cm/sec in the study area. Taking the phases of M_2 and K_1 into consideration would mean that the magnitude of the tidal current would add to the geostrophic current in the area. Also, the current speeds would be further enhanced by contributions from wind stress and other meteorological forcing parameters. Unfortunately, there are no historical current measurements for the study area from which to extract the mean and maximum values of current speeds or to understand the extent of the current variability.

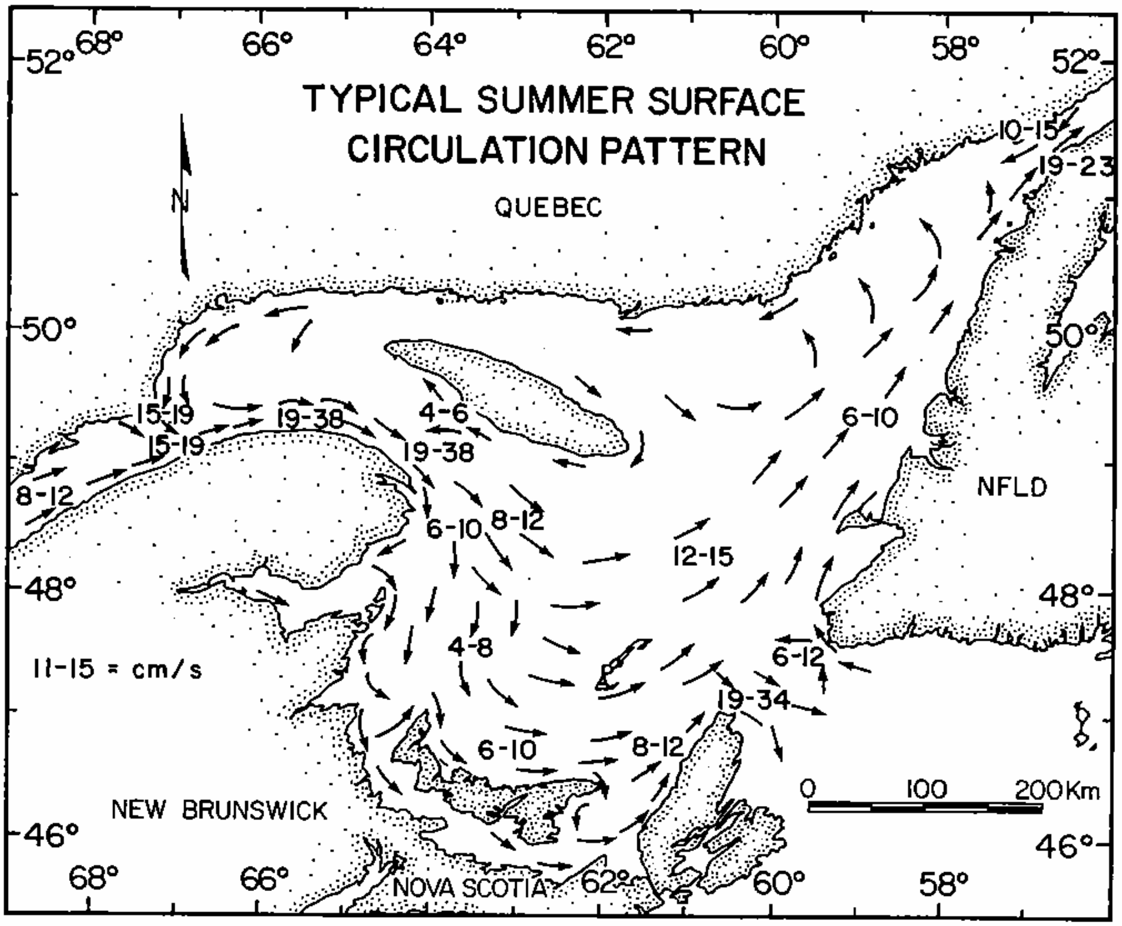


Figure 6.1 Summer surface circulation pattern for the Gulf of St. Lawrence
Source: Trites; 1972 (speed ranges are in cm/sec).

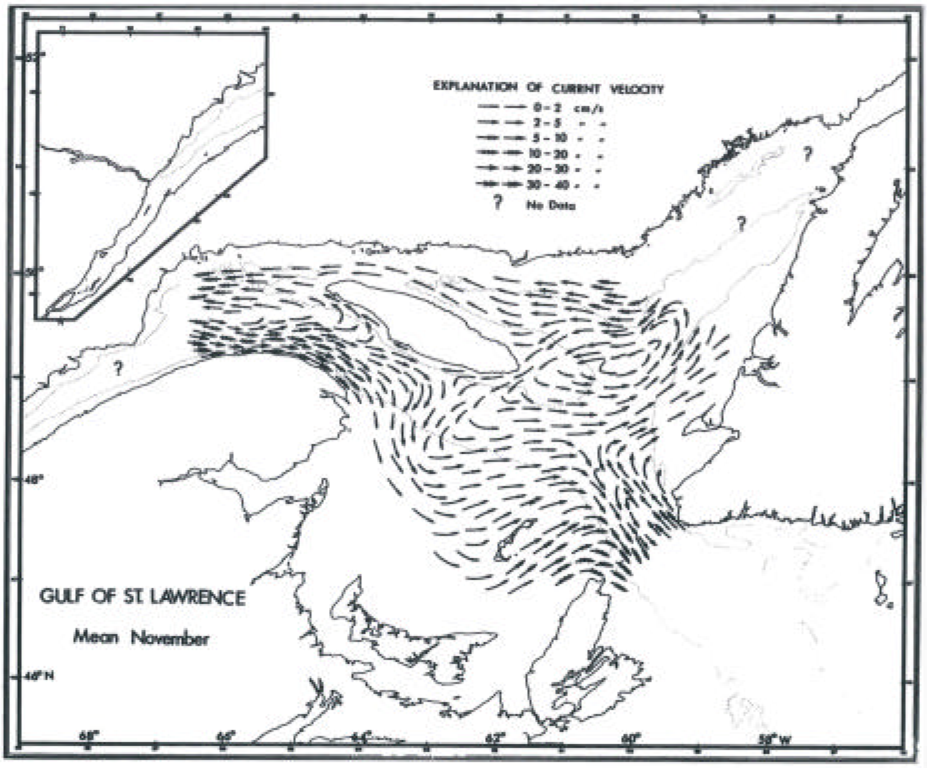


Figure 6.2 November surface circulation pattern for the Gulf of St. Lawrence
Source: El-Sabh (1976)

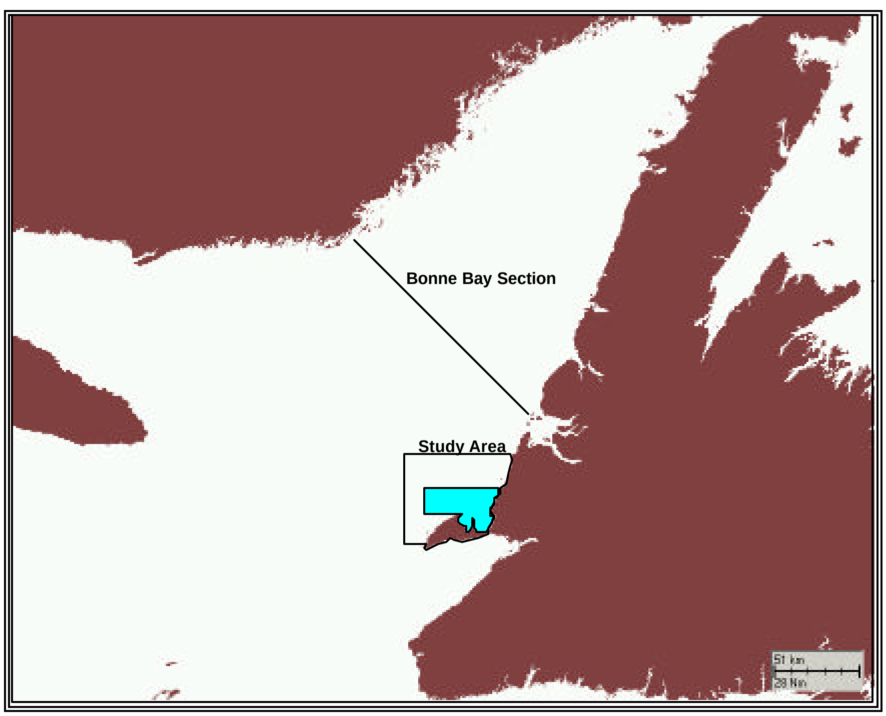


Figure 6.3 Location of the Bonne Bay hydrographic Transect

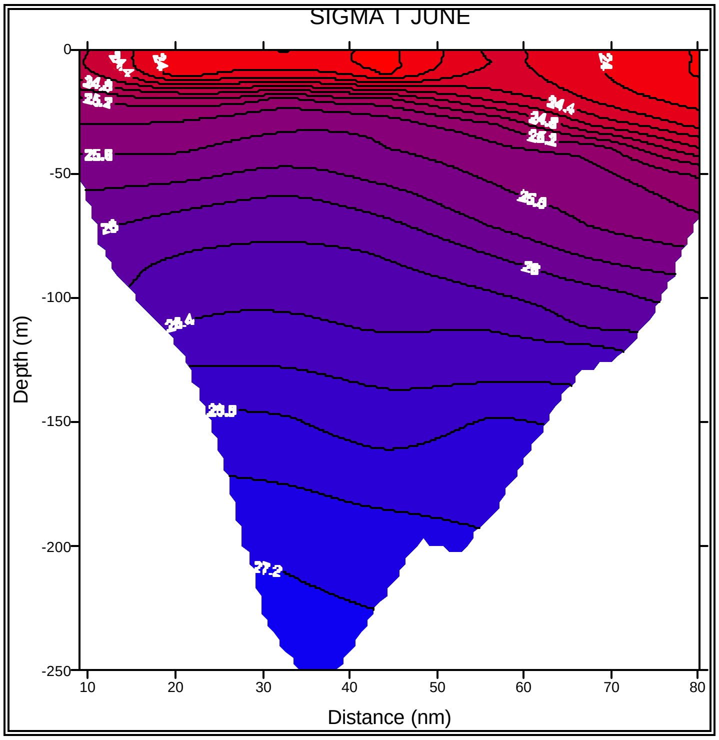


Figure 6.4 Density contours in June along the Bonne Bay transect

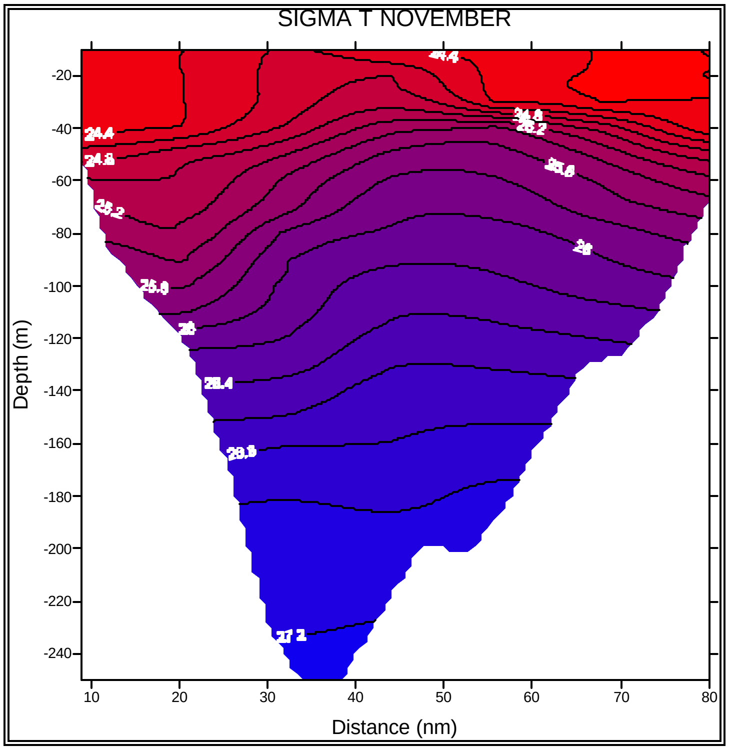


Figure 6.5 Density contours in November along the Bonne Bay transect

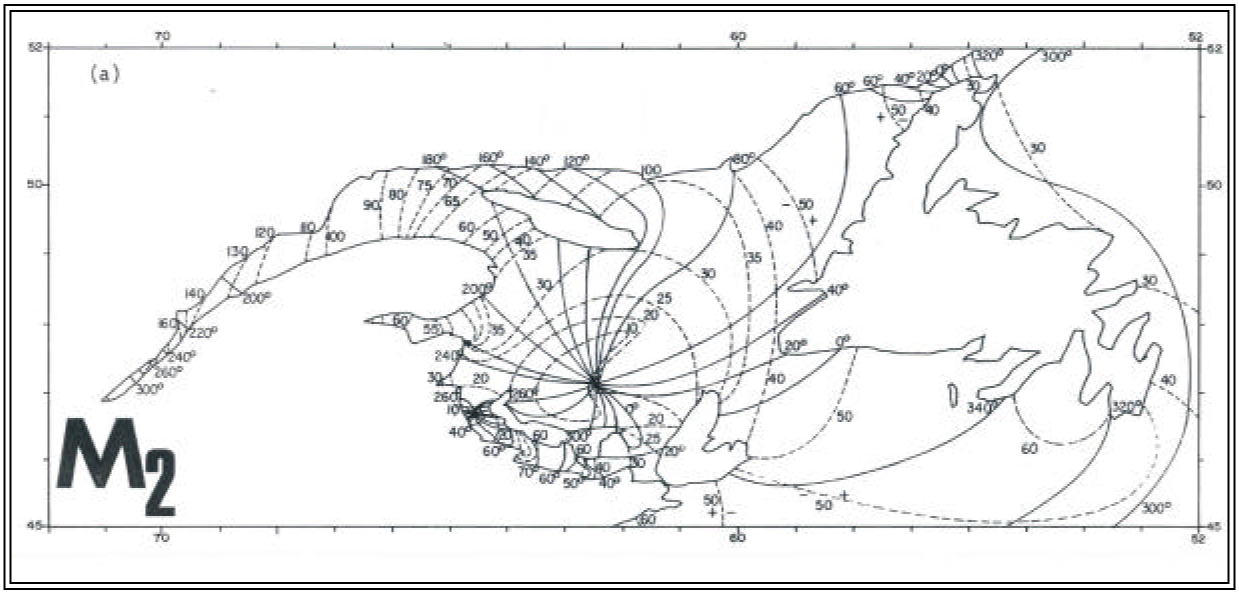


Figure 6.6 Cotidal charts of M_2 for the Gulf of St. Lawrence
Source: Godin (1980)

7.0 Sea Ice

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Ice reveals that ice is present within the study area from late December until early May, and for the same time period within Port-au-Port Bay. A graph of the presence of sea ice in the study area is presented in Figure 7.1 and for the Port-au-Port Bay in Figure 7.2. These graphs show the probability of ice covering a portion of the area at some time during the month. For example, during the month of December, Figure 7.1 shows that there is a 10% chance of at least 27.7% coverage some time during the month. This figure also shows that the greatest ice coverage occurs during the month of March with an 80% chance that 46.9% of the bay will be covered with ice, and a 90% chance that 19.8% of the bay would be covered at some point during that month. Within Port-au-Port Bay, the data set shows that ice coverage is greatest in the month of February with a 90% chance that at some time during the month, 80.3% of the Bay would be covered in ice.

When ice is present in the study area, the dominate ice type for the month of December and most of January is new (recently formed having a thickness of less than 10 cm) and grey (young ice 10-15 cm think). By the last week of January, grey-white white ice (young ice 15-30 cm thick) begins to form and fast ice (sea ice which forms and remains fast along the coast) begins to develop within the bay. By mid-February, first year ice (not more than one winter's growth, developing from young ice; thickness 30 cm to 2 m) is present and becomes the dominate ice type outside of the bay. Fast ice is the predominate type within the bay. First year ice will remain in the area until it recedes around mid-May.

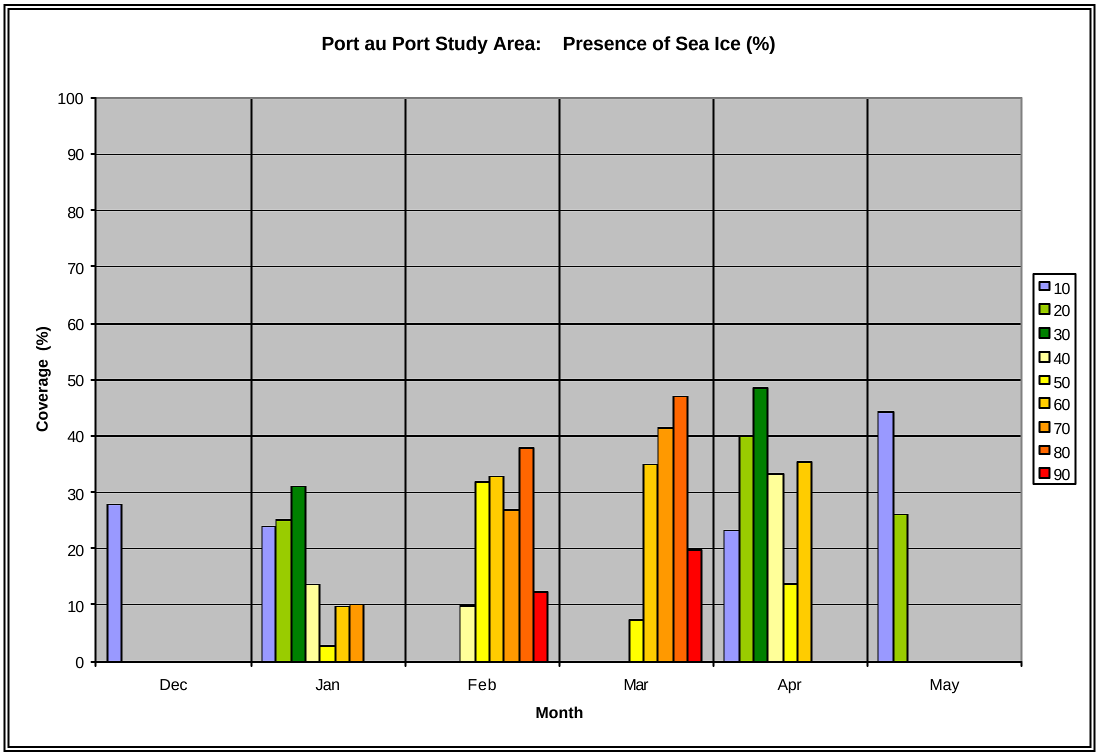


Figure 7.1 Presence of Sea Ice in the Study Area (1971 - 2000)

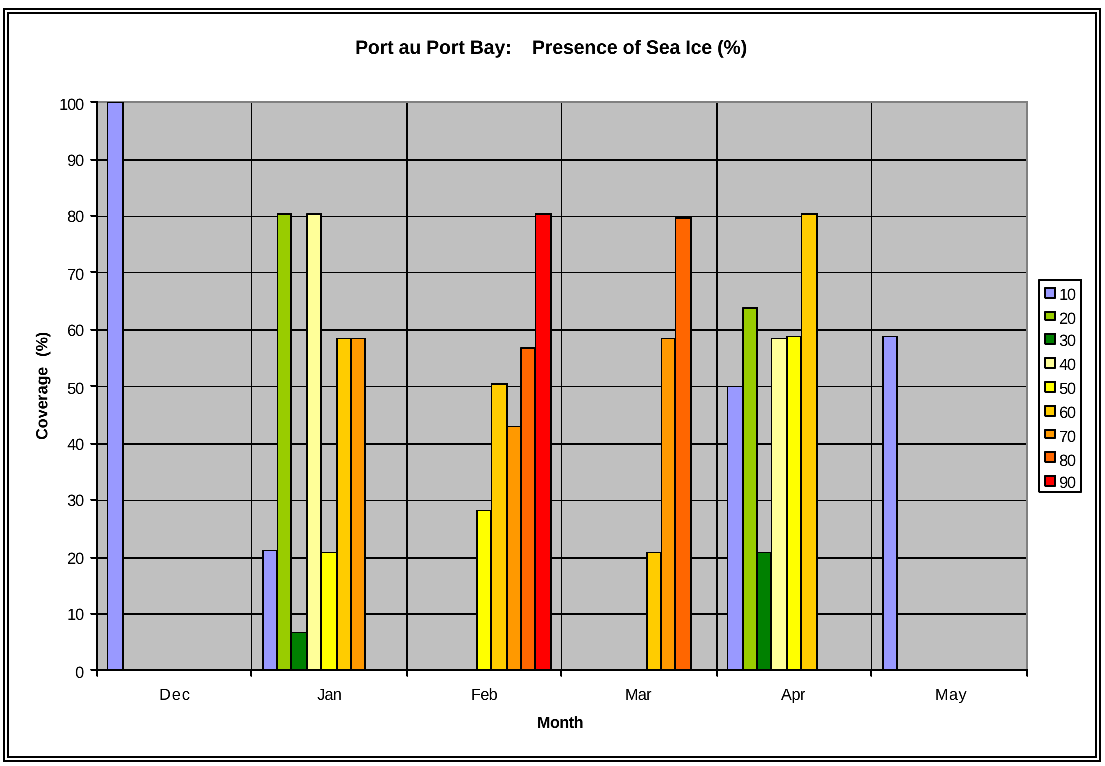


Figure 7.2 Presence of Sea Ice in the Port-au-Port Bay (1971 - 2000)

Figure 7.3 and 7.4 gives the median ice concentration for the study area and Port-au-Port Bay respectively. Ice concentrations are determined by the color of the bars. These graphs show that by the week beginning February 19 the whole study area is 100% covered in ice with Port-au-Port Bay being completely covered in 10/10ths concentration of ice. While the study area is consider to have 100% coverage, 29.5% of the area has 10/10ths concentration, 62.4% of the area has 9/10ths concentration, and 8.1% of the area has only 7/10ths concentration. By March 05, 85.1% of the study area has 10/10ths ice coverage. Ice begins to recede from the area the week beginning March 26 with only 91% of the Bay covered and only 71% of the study area covered.

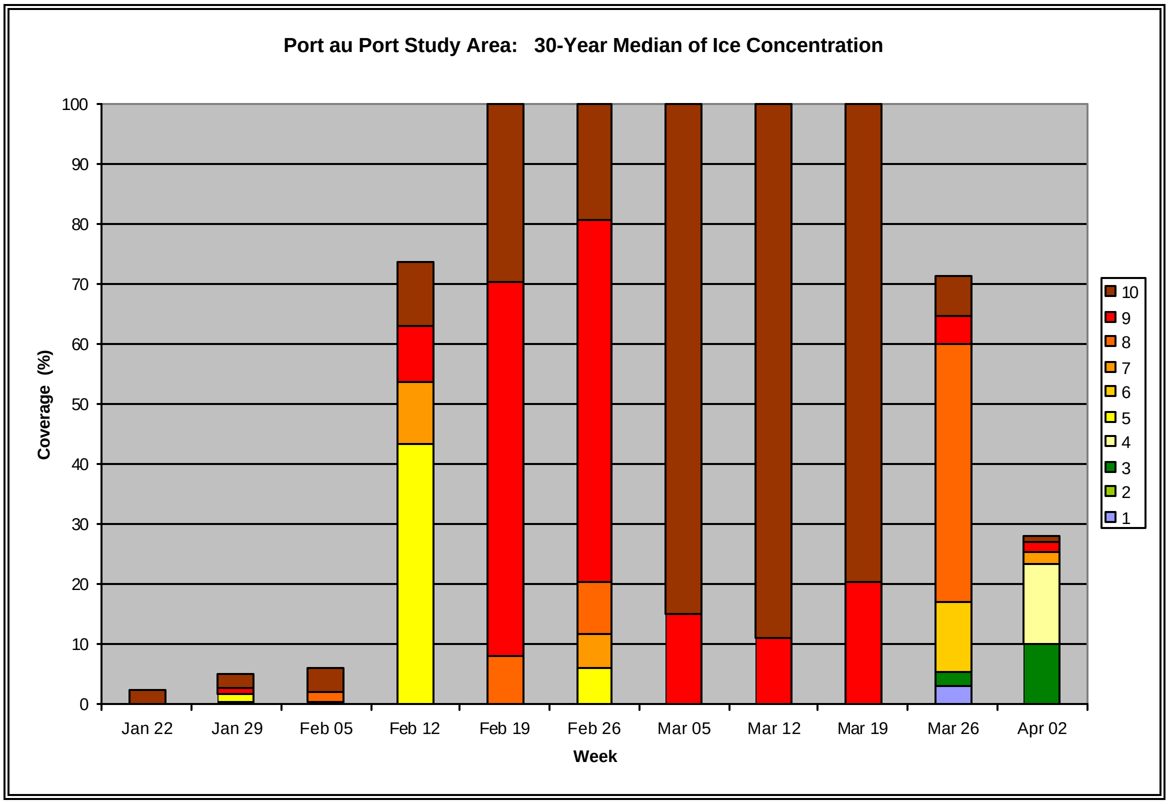


Figure 7.3 30-Year Median of Ice Concentration in the study area

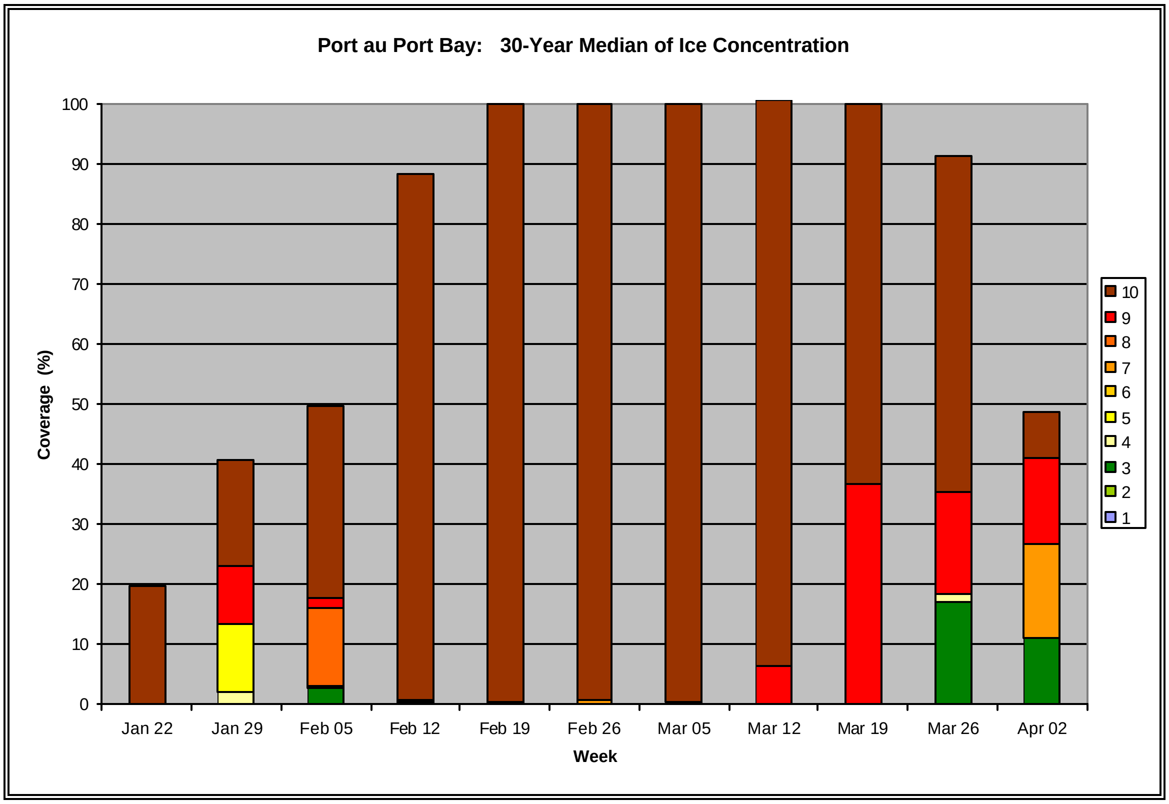


Figure 7.4 30-Year Median of Ice Concentration in Port-au-Port Bay

7.1.1. Ice Ride-up and Pile-Up

A low pressure forming off Cape Hatteras on the morning of Thursday, January 20 2000 moved northeast and rapidly deepened throughout the day to become an intense 954 mb storm lying south of Nova Scotia by Friday afternoon. Light winds over the Gulf of St. Lawrence on Friday morning quickly increased as the low pressure approached to become strong northeast to east by afternoon. The storm then moved over the eastern shore of Prince Edward Island by evening as it weakened slightly to 956 mb.

During this storm, an extreme storm surge of 2.0 m combined with an unusually high tide resulted in a record water level of 4.22 m above chart datum at Charlottetown, Prince Edward Island (Figure 7.5). Ice ride-up, pile-up and flooding resulting from the storm surge caused extensive damage, estimated at nearly a million insurable dollars, to the area (McCulloch, 2002).

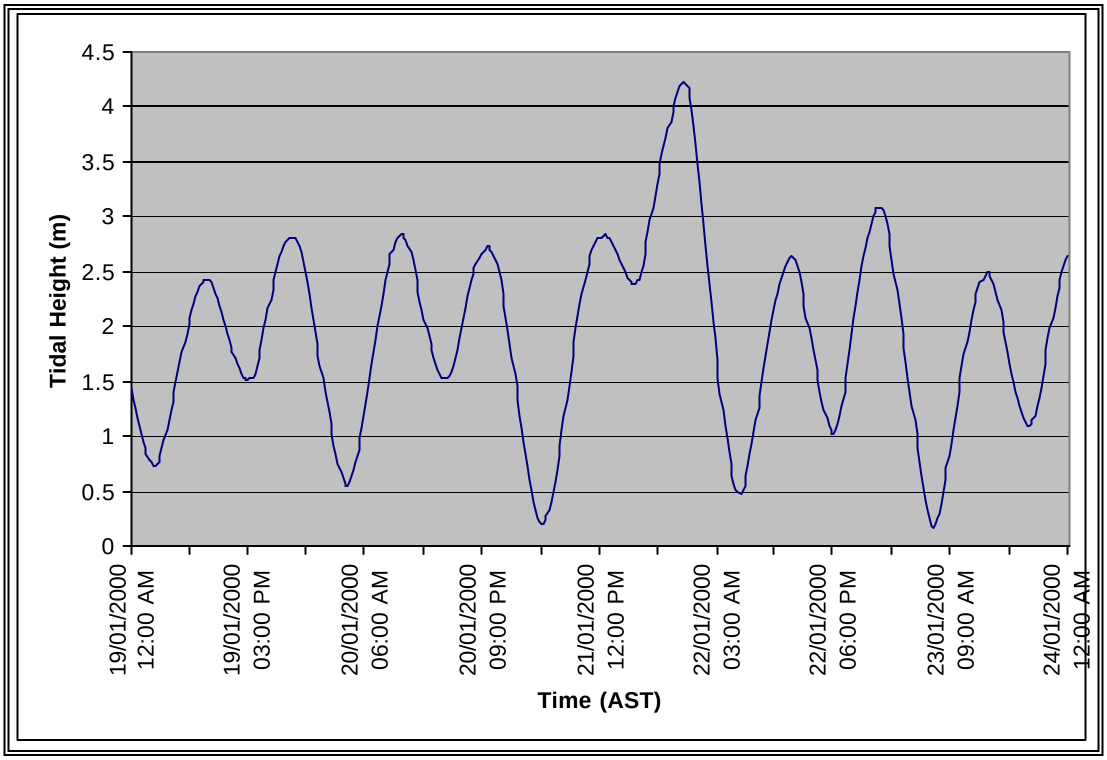


Figure 7.5 Time-Series plot of height of water level at Charlottetown, PEI January 19 - 24, 2000

A plot of the 30-year median ice concentration (Figure 7.6) shows that the median ice concentration for the region is greater than 9/10ths for the week starting January 22 and consists of mainly grey and grey-white ice. A daily ice chart for January 22, 2000 (Figure 7.7) shows ice conditions in the Gulf were well below average and consisted of grey and grey-white ice near the coast of New Brunswick and Prince Edward Island. This reduced ice coverage would have resulted in greater wind stress on the sea as the storm system passed than would normally have been experienced. Northeasterly winds blowing over this large fetch would have resulted in a build up of water along the coast of New Brunswick. This build up of water would have been amplified as it tried to flow through the relatively narrow Northumberland Strait creating a storm surge at Charlottetown. Furthermore, with the low lying directly over Prince Edward Island on Friday evening and winds still blowing from the northeast over the Gulf, the storm surge would have been amplified due to the inverse barometer effect. Assuming a standard atmosphere of 1013 mb, a 956 mb low pressure would result in a storm surge of 0.57 m due only to the inverse barometer effect.

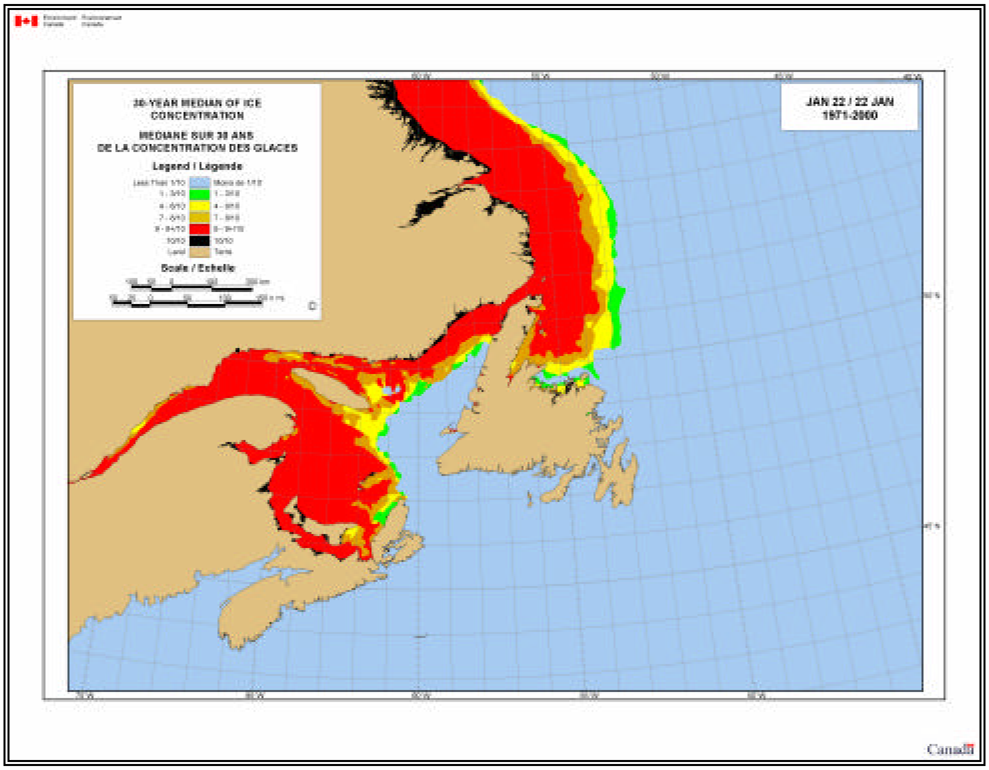


Figure 7.6 30-Year Median Ice Concentration for the week of January 22, 1971-2000

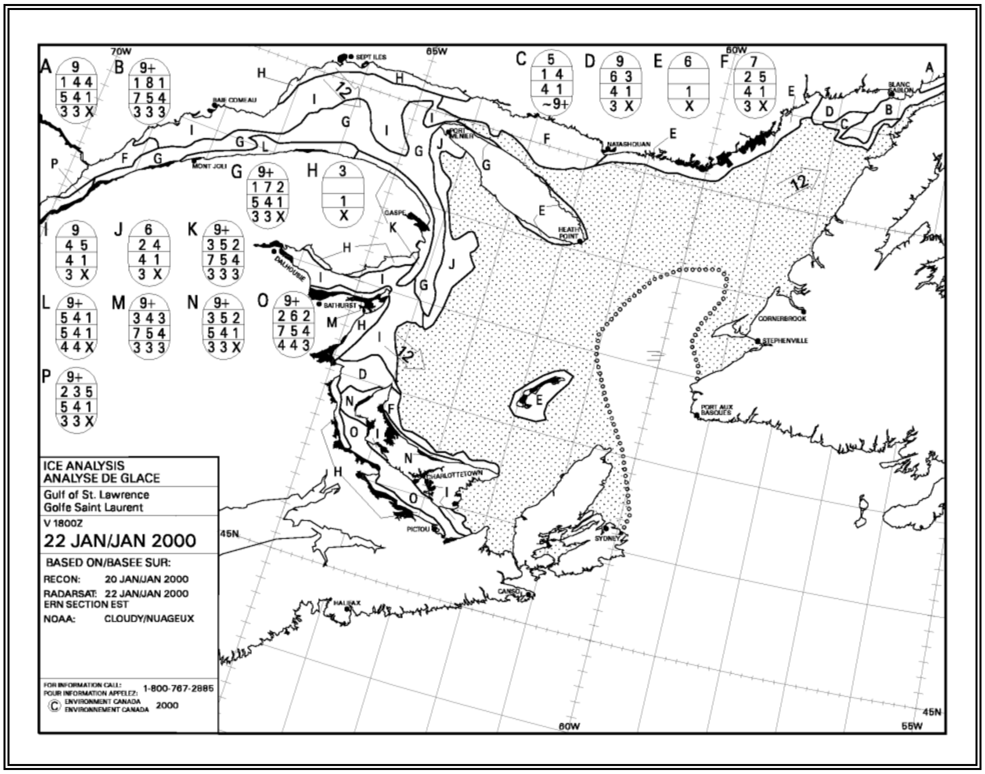


Figure 7.7 Daily Ice Analysis Chart for the Gulf of St. Lawrence, January 22, 2000.

In the extreme event at Charlottetown, several factors combined resulting in the record storm surge and ice pile-up. Due to it's location in the Gulf of St. Lawrence, Storm surge resulting in ice ride-up within Port-au-Port Bay would not be as significant as that which occurred near Charlottetown. However, ice pile-up could still occur at Shoal Point due to the low elevation of the site. GIS data for Port-au-Port Bay provided by the Canadian Ice Service shows a 0.9% reduction in land mass for the week beginning January 29, a 0.6% decrease for the week beginning February 05 and a 1.9% decrease for the week beginning March 12. This reduction in land mass occurred in the data set on Shoal Point and may be attributed to ice ride-up along the shores.

Bernier and Thompson (2006) estimated a 40-year return period storm height along the west coast of Newfoundland of 0.7 m. Amplification of storm surge within Port-au-Port Bay could result in an even higher storm surge at Shoal Point resulting in the possibility of ice-ride up and pile-up if this storm surge were to coincide with high tide.

References

Bernier, N.B., K.R. Thompson, 2006. Predicting the Frequency of Storm Surges and Extreme Sea Levels in the Northwest Atlantic. Journal of Geophysical Research, Vol. 111. C10009, doi:10.1029/2005JC003168, 2006.

Bobanovic, J., K. Thompson, S Desjardins, and H. Ritchie, 2006. Forecasting Storm Surges along the East Coast of Canada and the Northeastern United States: The Storm of 21 January 2000. Atmosphere-Ocean, p.151-161.

Borgman, L. E. 1973. Probabilities for the highest wave in a hurricane. J. Waterways, Harbors and Coastal Engineering Div., ASCE, 185-207

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

Bretschneider, C.L., 1969. "Wave Forecasting," Chapter 11 in *Handbook of Ocean and Underwater Engineering*. J. J. Myers et al., eds., McGraw-Hill Book Co., New York.

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

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

Cardone, V.J., A.T. Cox and V.R. Swail, 2000. “Specification of the Global Wave Climate: Is this the Final Answer?’ 6th International Workshop on Wave Hindcasting and Forecasting November 6-10, Monterey, California.

Chase, J., 2001. Physical Oceanography of Southern Gulf of St. Lawrence and Sydney Bight area of Coastal Cape Breton. CSAS Res. Doc. 2001/113, Canadian Science Advisory Secretariat, Fisheries and Oceans, Canada, 20p.

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board), 2005. Western Newfoundland and Labrador Offshore Area Strategic Environmental Assessment. LGL Rep. SA8858. Rep. by LGL Limited, St. John’s, NL, Oceans Ltd., St. John’s, NL, Canning & Pitt Associated, Inc., St. John’s, NL, and PAL Environmental Services, St. John’s, NL, for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John’s, NL. 335 p + appendices.

Daily Weather Maps Home Page. NOAA Central Library. U.S. Daily Weather Maps Project. 09 January 2007 http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html

El-Sabh, M.I., 1976. Surface circulation Pattern in the Gulf of St. Lawrence. J. Fish. Res. Bd. Can., vol. 33, No. 1, p.124-138

Environment Canada, 2006. Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick.

Environment Canada, 1995. Where the Wind Blows. Ottawa: Minister of Public Works and Government Services of Canada, 1995.

Forrester, W.D. 1983. Canadian Tidal Manual. Department of Fisheries and Oceans, Ottawa, 138pp.

Forristall, G.Z., 1978. On the statistical distribution of wave heights in a storm. J. Geophys. Res. V.83, P.2353-2358.

Godin, G. Cotidal Charts for Canada. Manuscript Report Series No. 55. Marine Sciences and Information Directorate, Dept. Fisheries and Oceans, Canada.

Harris, Erin. Personal Correspondence. Oceanweather, October 15, 2007

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

Koutitonsky, V.G. and G.L. Bugden, 1991. The Physical Oceanography of the Gulf of St. Lawrence: a Review with Emphasis on the Synoptic Variability of the Motion. Can. Spec. Publ. Fish. Aquat. Sci. No. 113, p. 57-90.

Makkonen, L., R.D. Brown, and P.T. Mitten, 1991: Comments on “Prediction of Vessel Icing for Near-Freezing Sea Temperatures”./Wea. Forecasting/, *6*, 565–567.

Minsk, L.D., 1977: Ice Accumulation on Ocean Structures. CRREL Rep. 77-17, COld Regions Research and Engineering Laboratory, Hanover, N.H., 42pp.

McCulloch, Martha M., et al. 2002. Coastal Impacts of Climate Change and Sea-Level Rise on Prince Edward Island. Executive Summary. Geological Survey of Canada.

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

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

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

Sorensen, R.M., 2006. *Basic Coastal Engineering*, Spring Science+Business Media, Inc., New York.

Swail, V.R., V.J. Cardone, M. Ferguson, D.J. Gummer, E.L. Harris, E.A. Orelup, and A.T. Cox, 2006. "The MSC50 Wind and Wave Reanalysis", 9th International Workshop On Wave Hindcasting and Forecasting, Victoria, B.C. Canada.

Trites, R.W., 1972. The Gulf of St. Lawrence from a pollution point of view. In M. Ruino (ed), Marine Pollution and Sea Life, FAO, Fishing News Books, London, p.59-72.

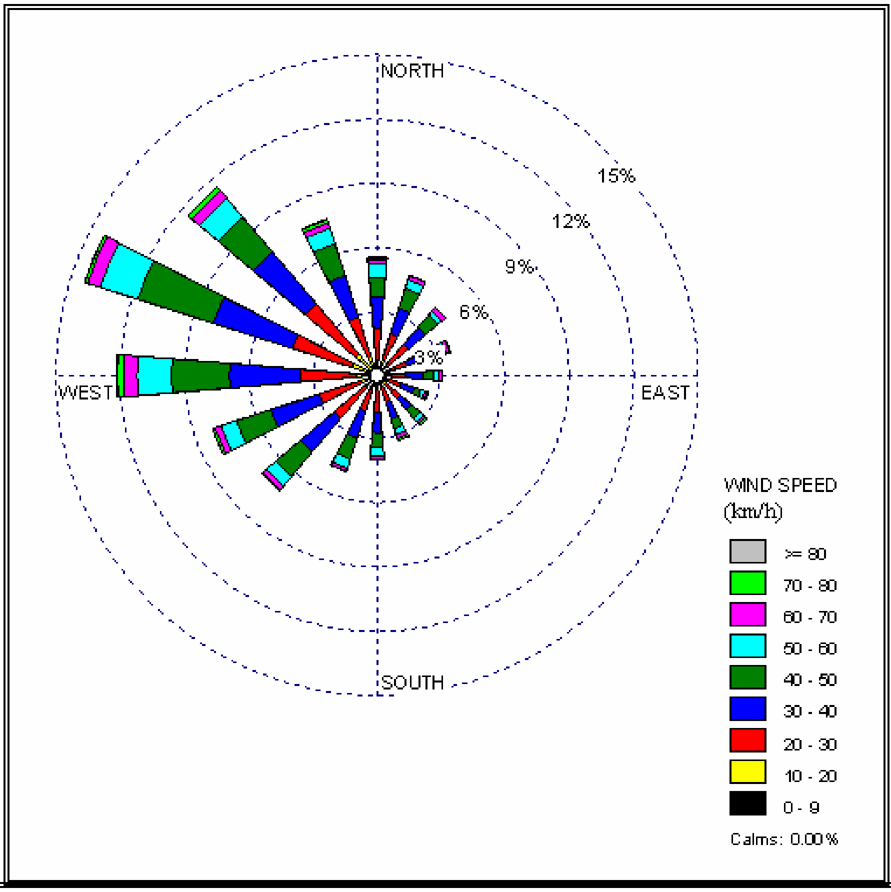
U.S. Army Coastal Engineering Research Center, 1973. *Shore Protection Manual*, U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey, 1979. OSC Platform Verification Program, United States Geological Survey, Conservation Division, Reston, Virginia.

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

WMO, 1998. Guide to Wave Analysis and Forecasting. Secretariat of the World Meteorological Organization. WMO, Geneva, Switzerland, 159p.

Appendix 1
Wind Rose and Frequency Distributions for MSC50 GridPoint 14620



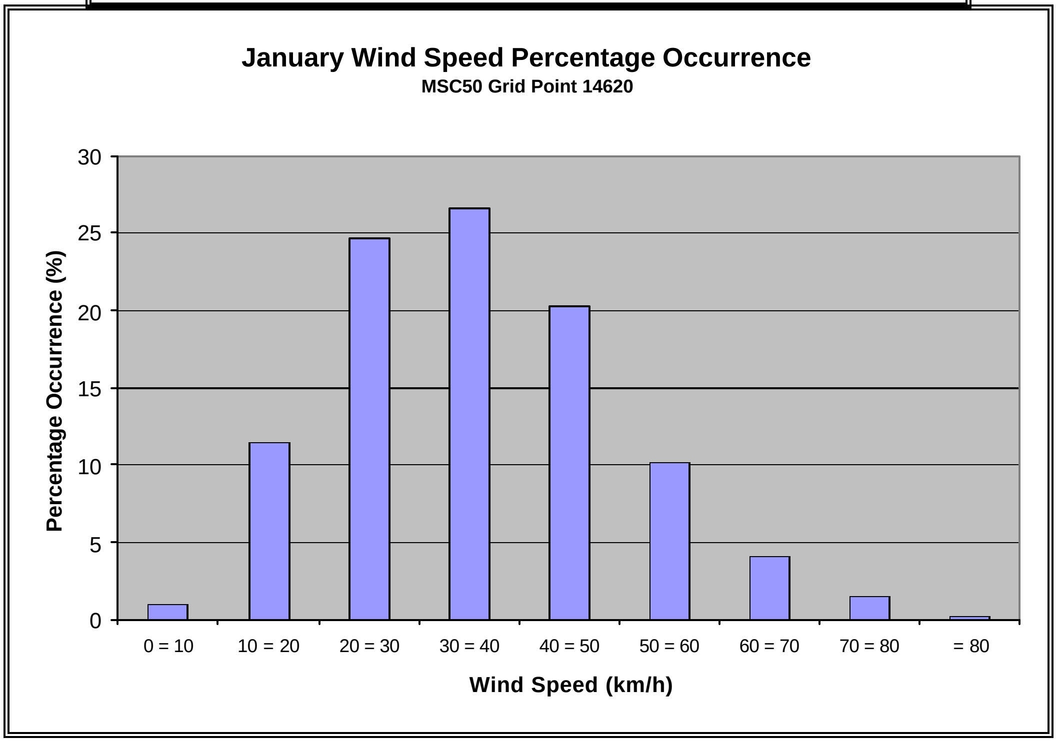


Figure A.1 January Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620

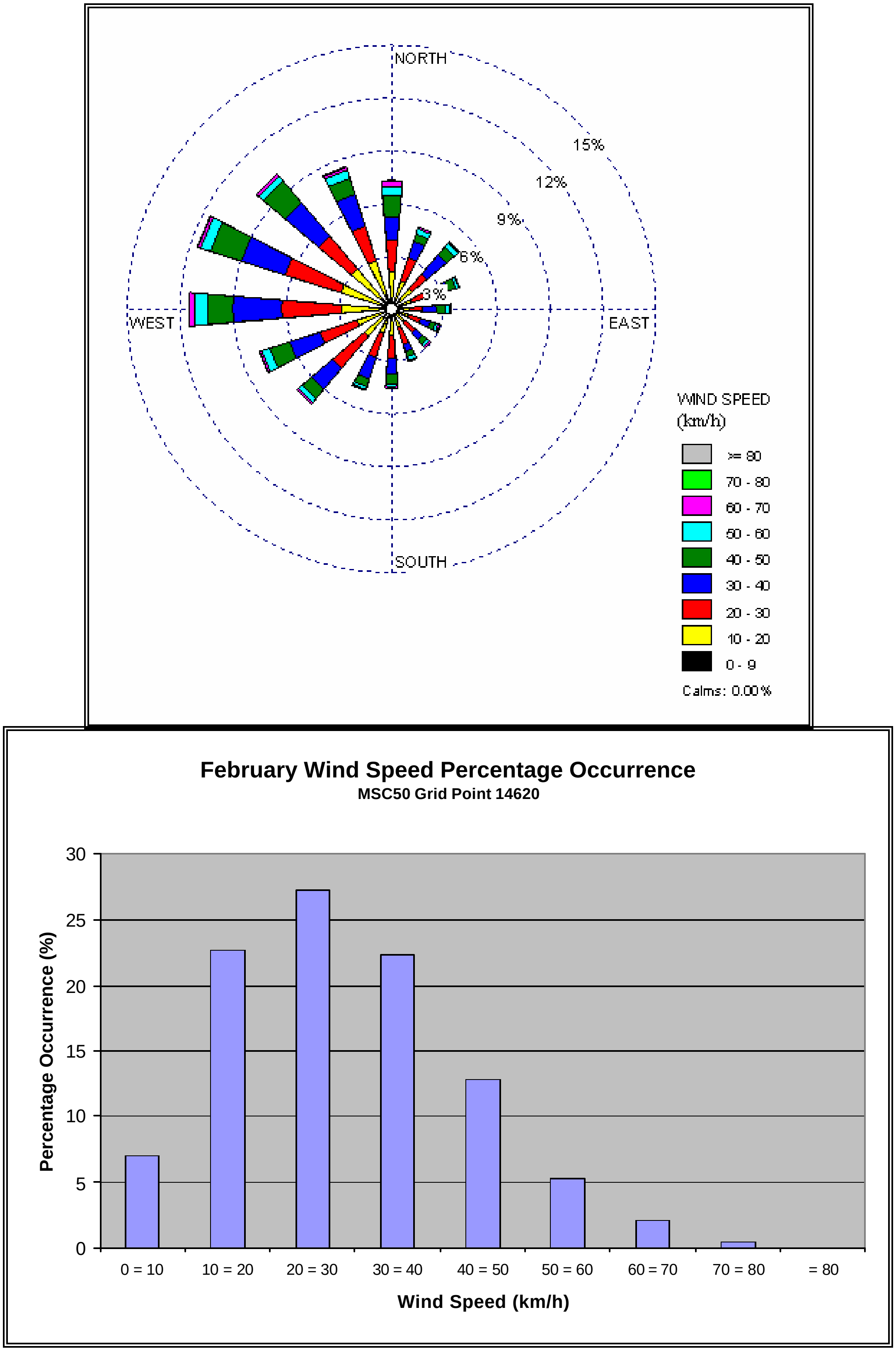
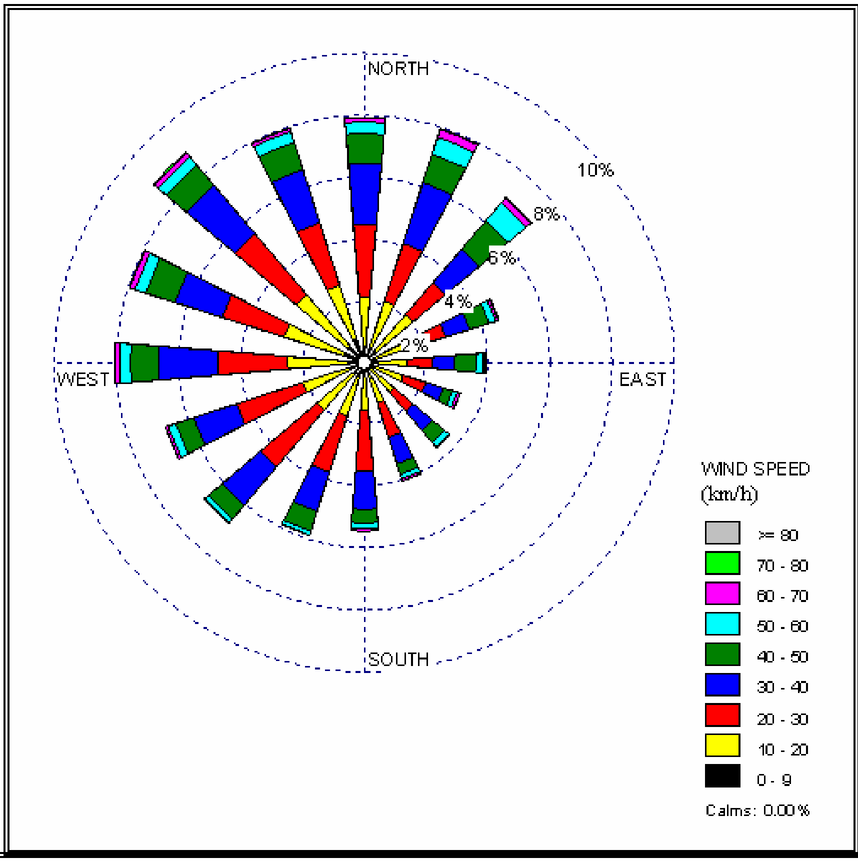


Figure A.2 February Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



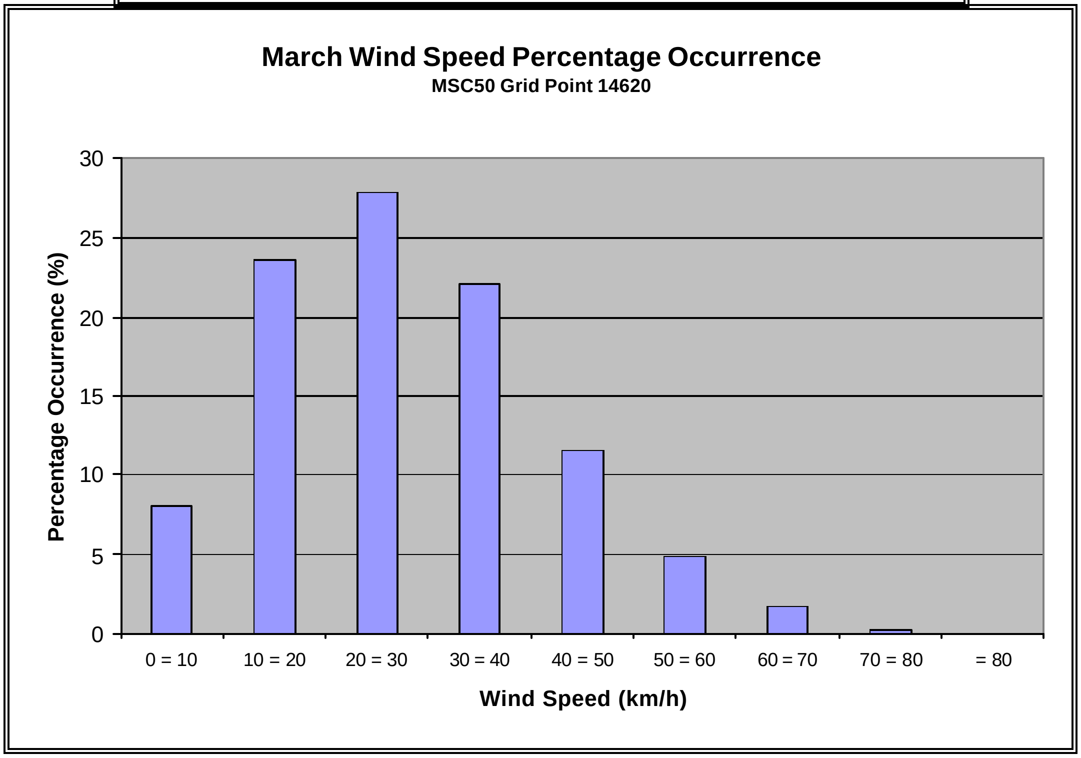
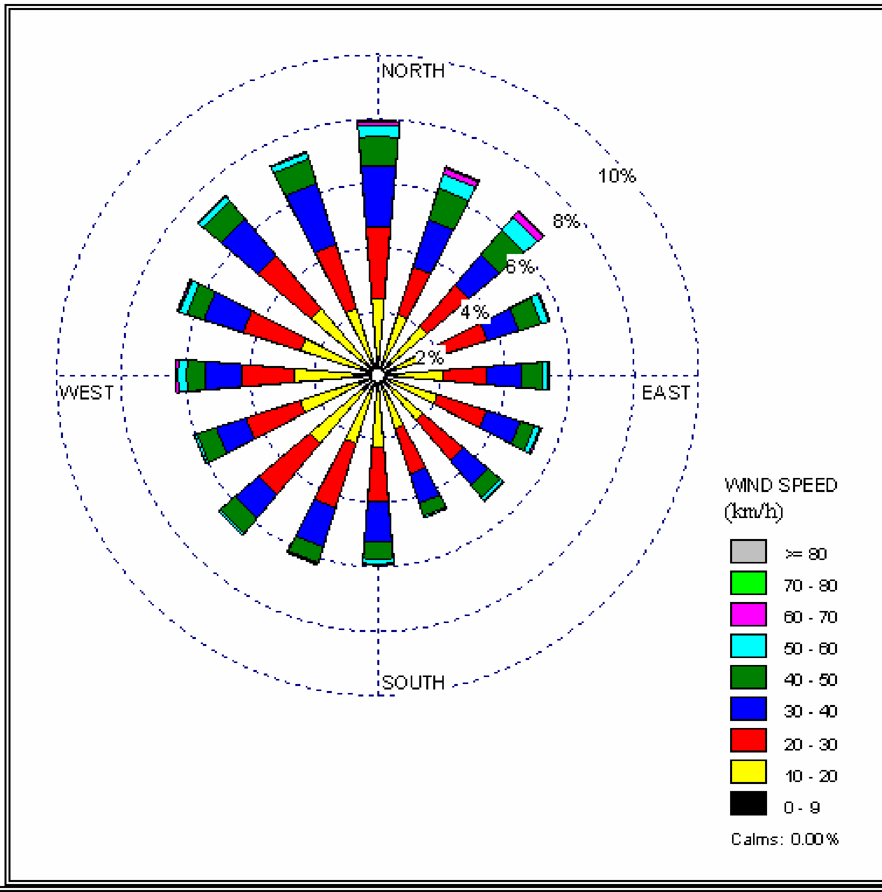


Figure A.3 March Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



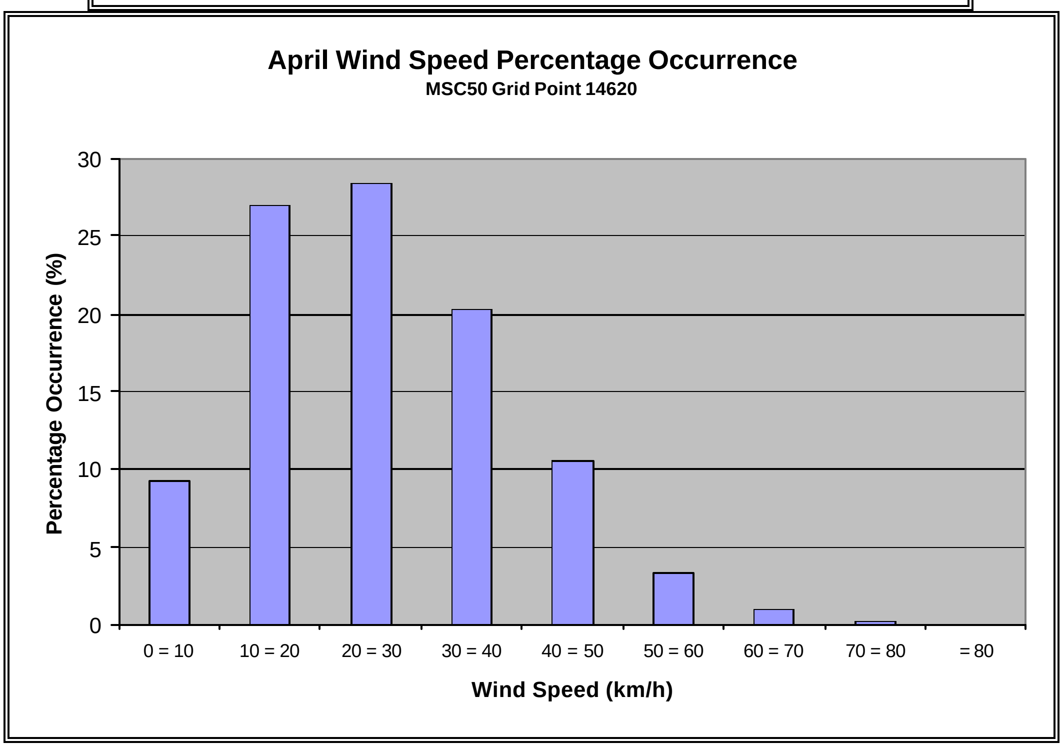
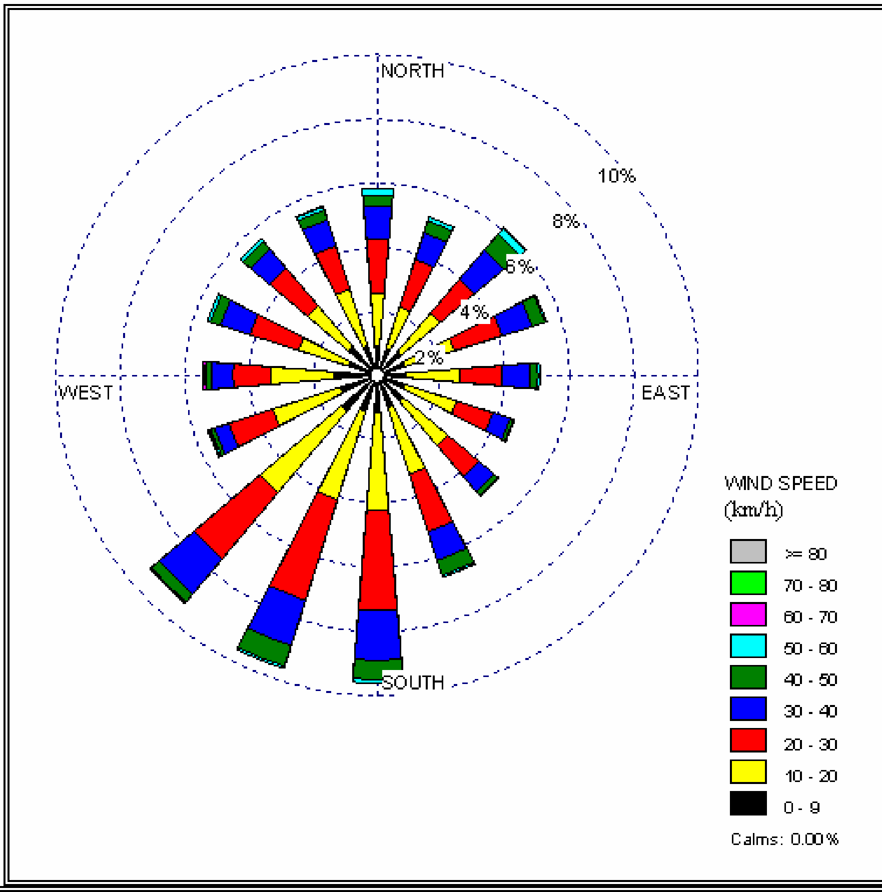


Figure A.4 April Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



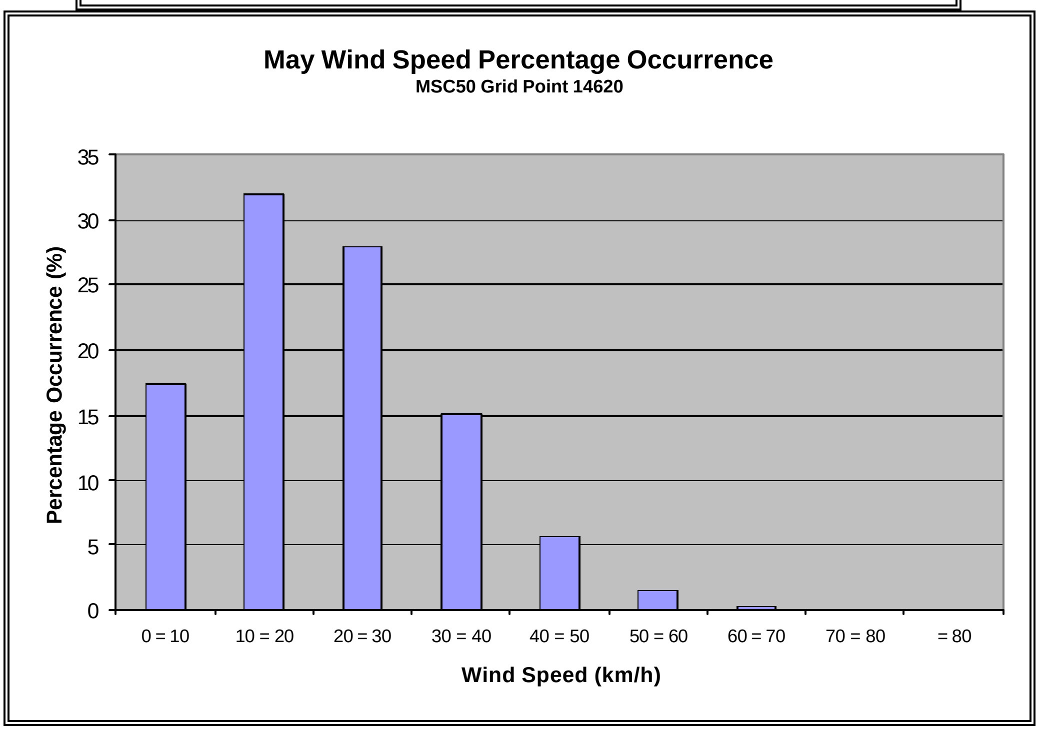
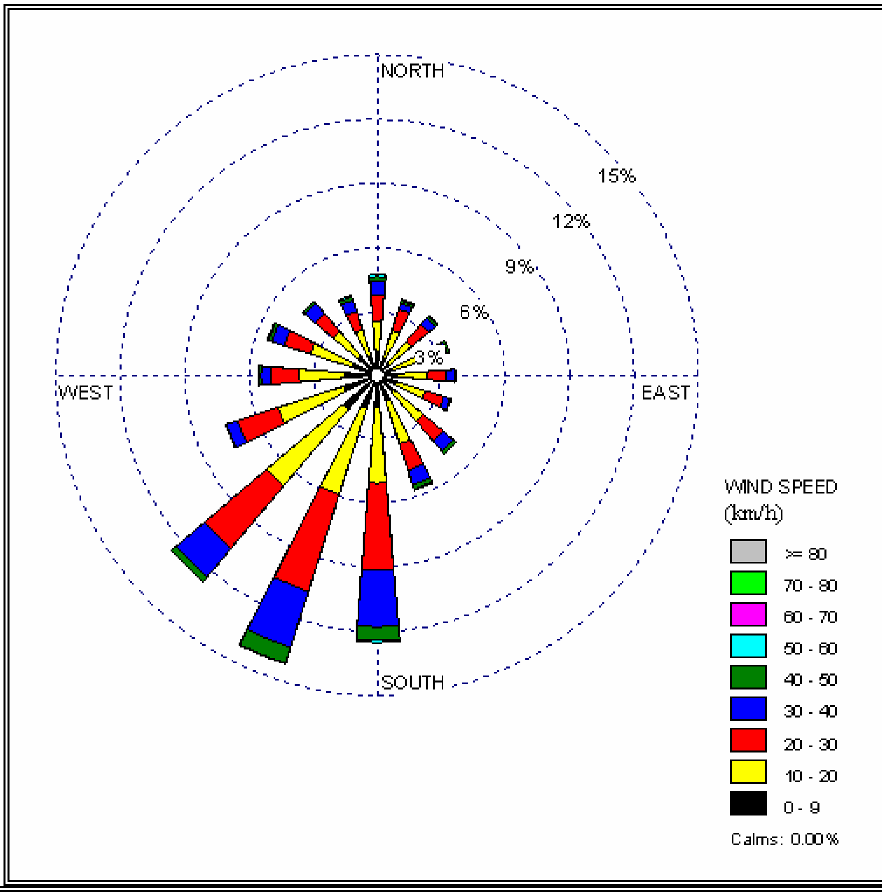


Figure A.5 May Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



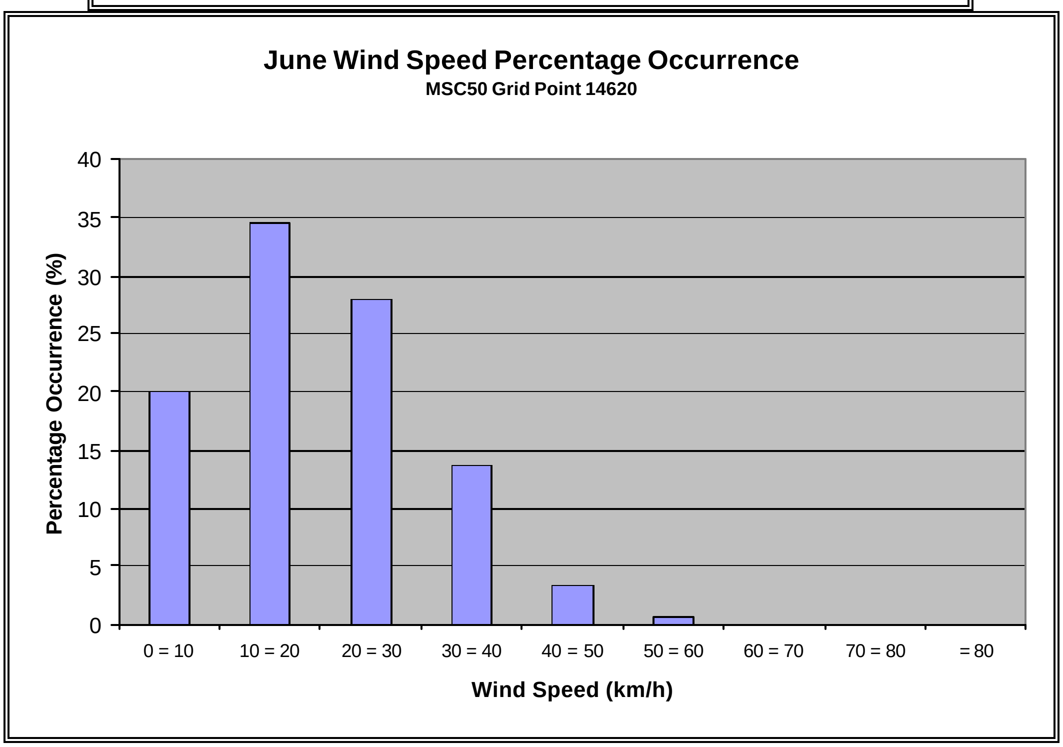
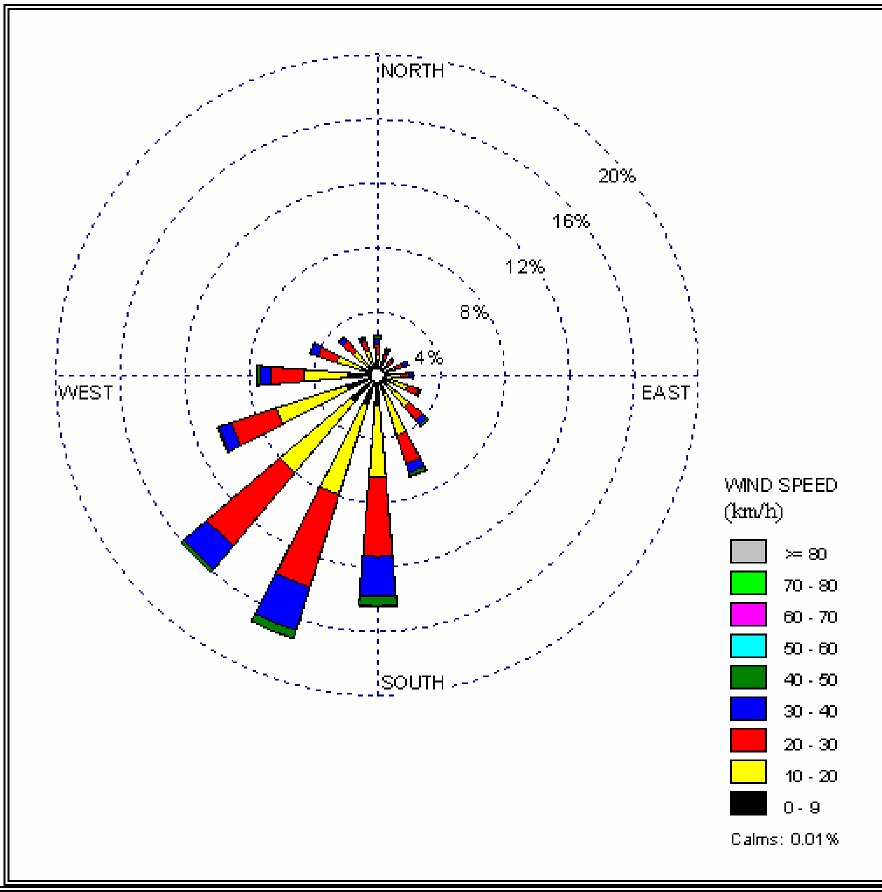


Figure A.6 June Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



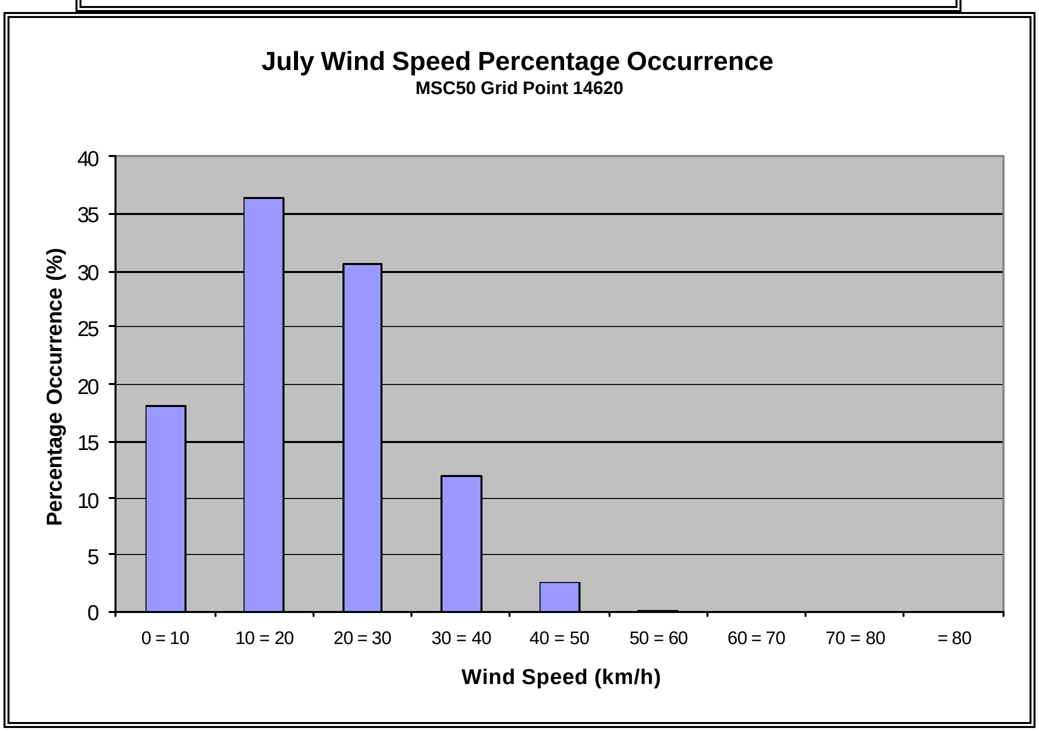
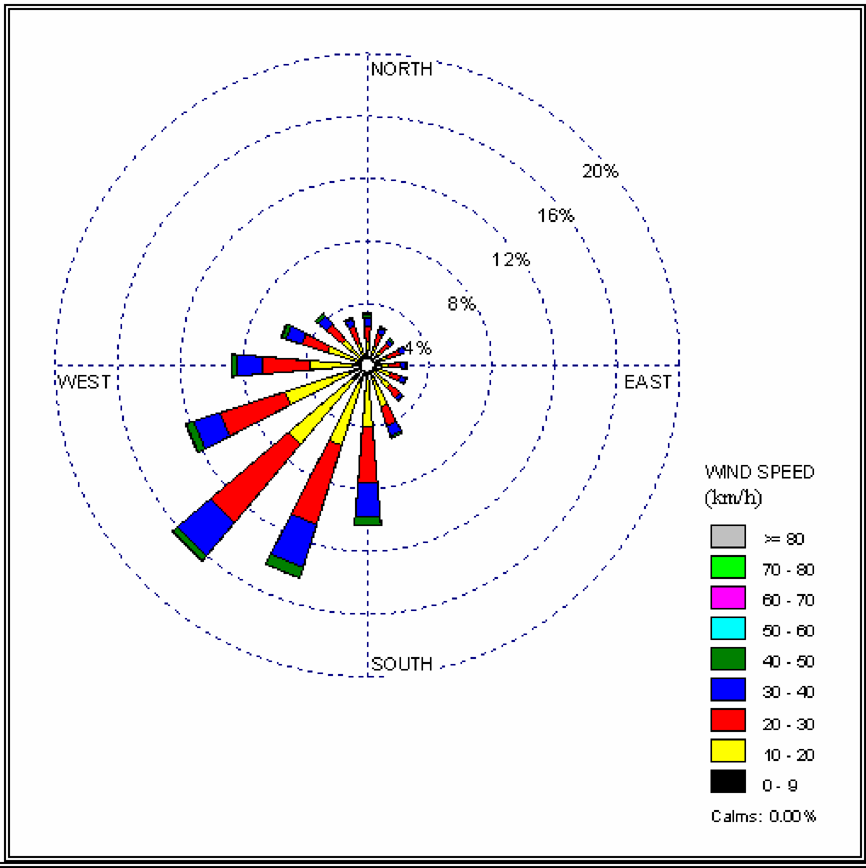


Figure A.7 July Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



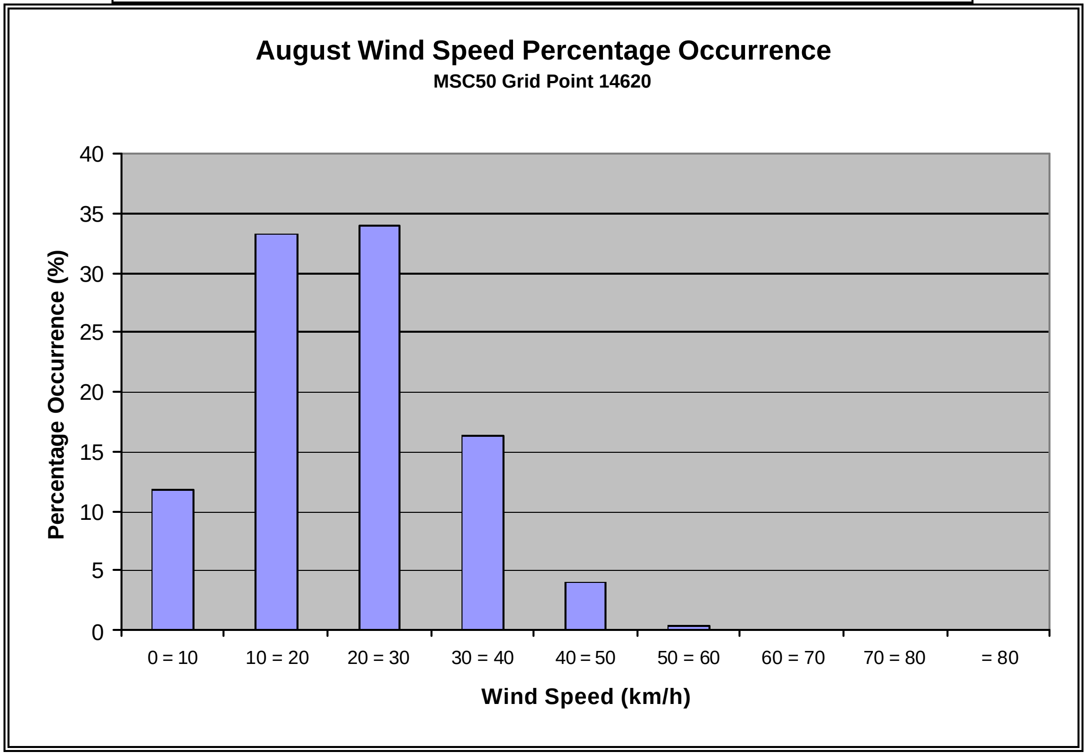
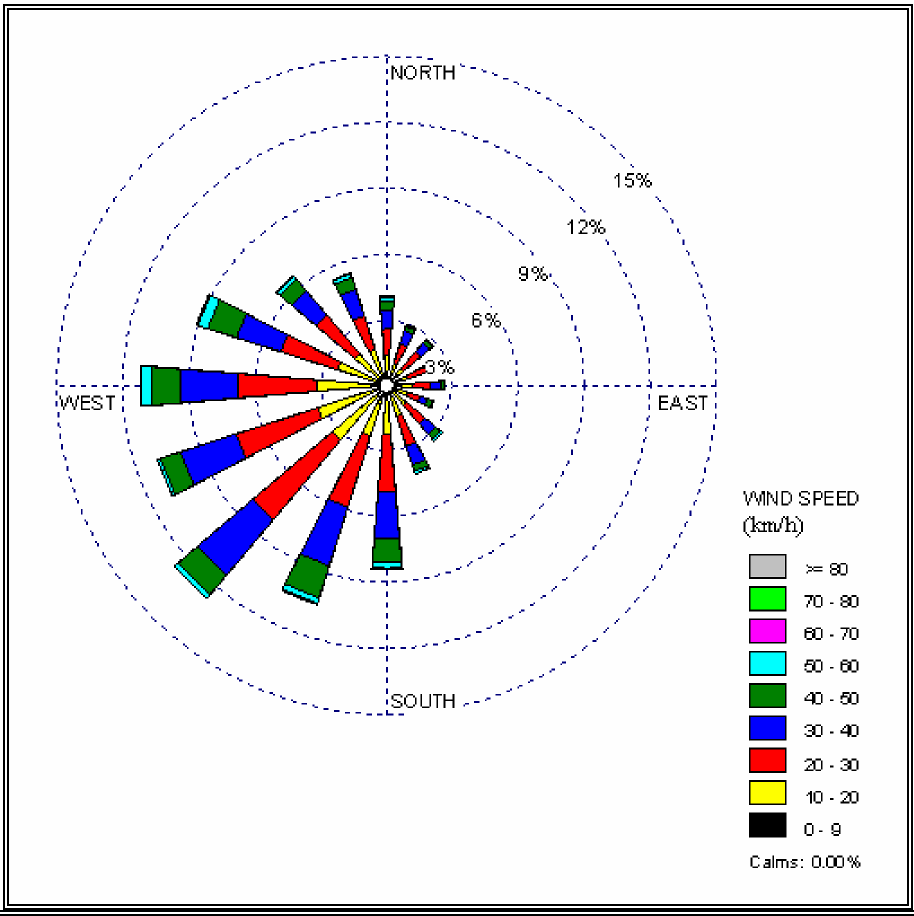


Figure A.8 August Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



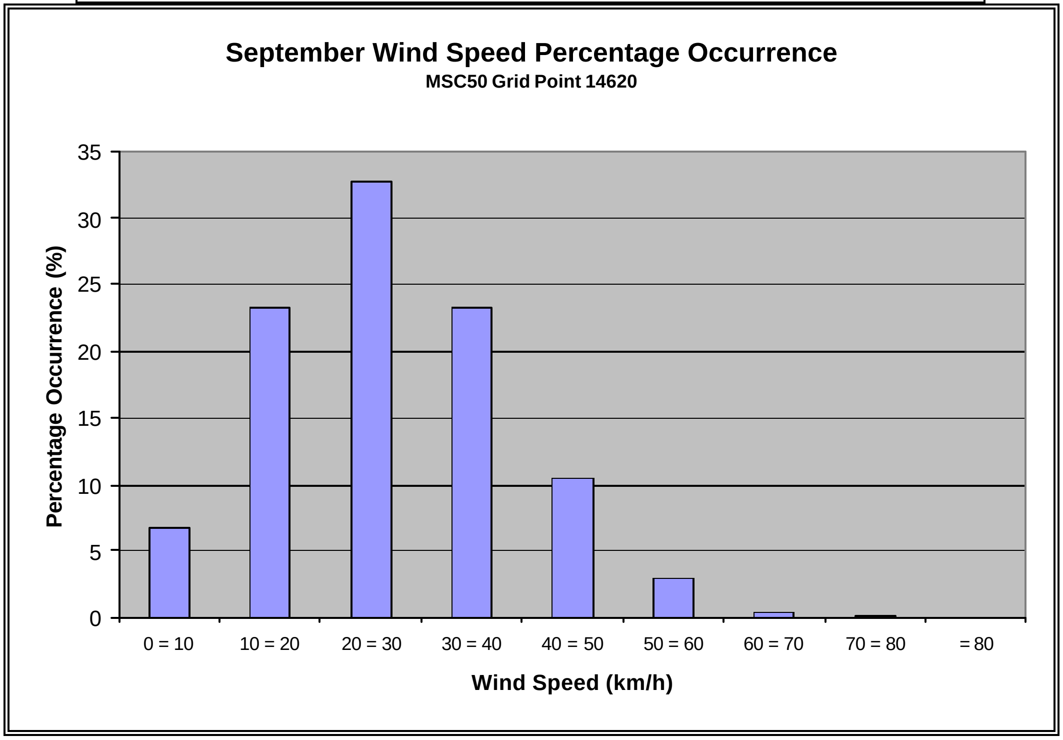
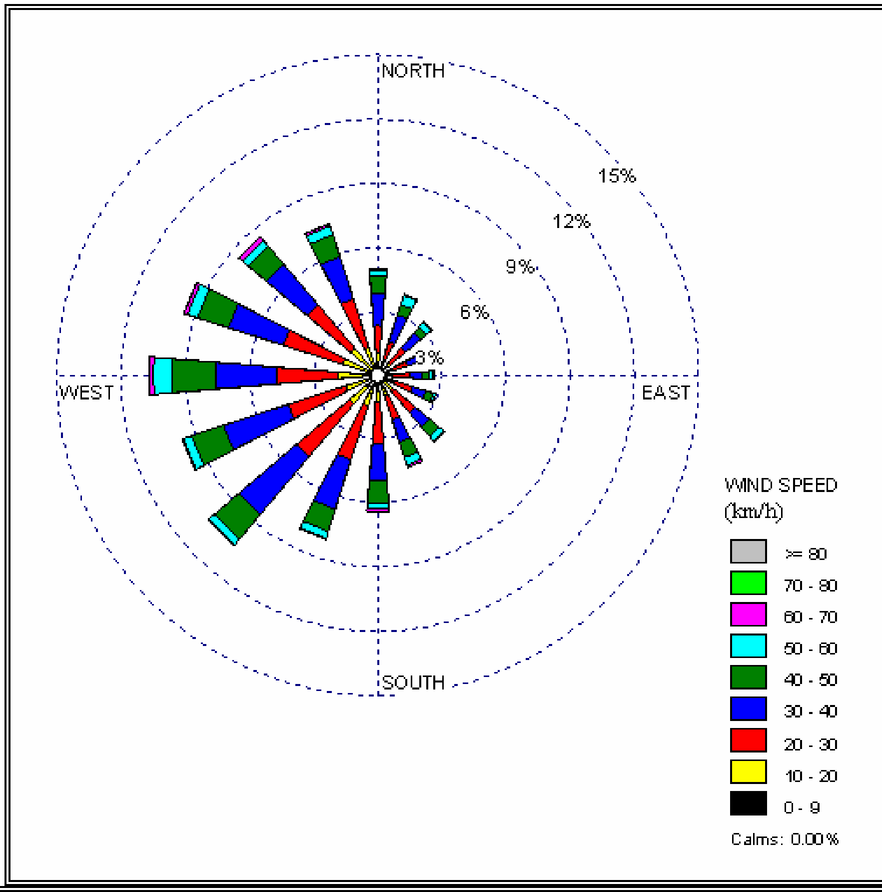


Figure A.9 September Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



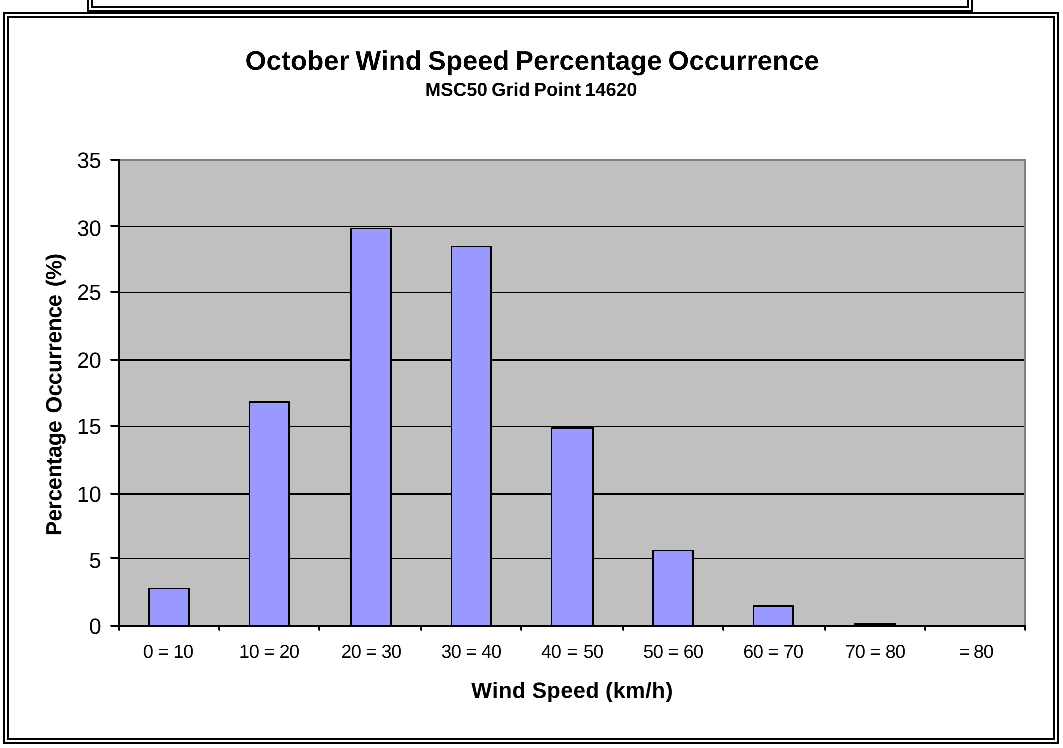
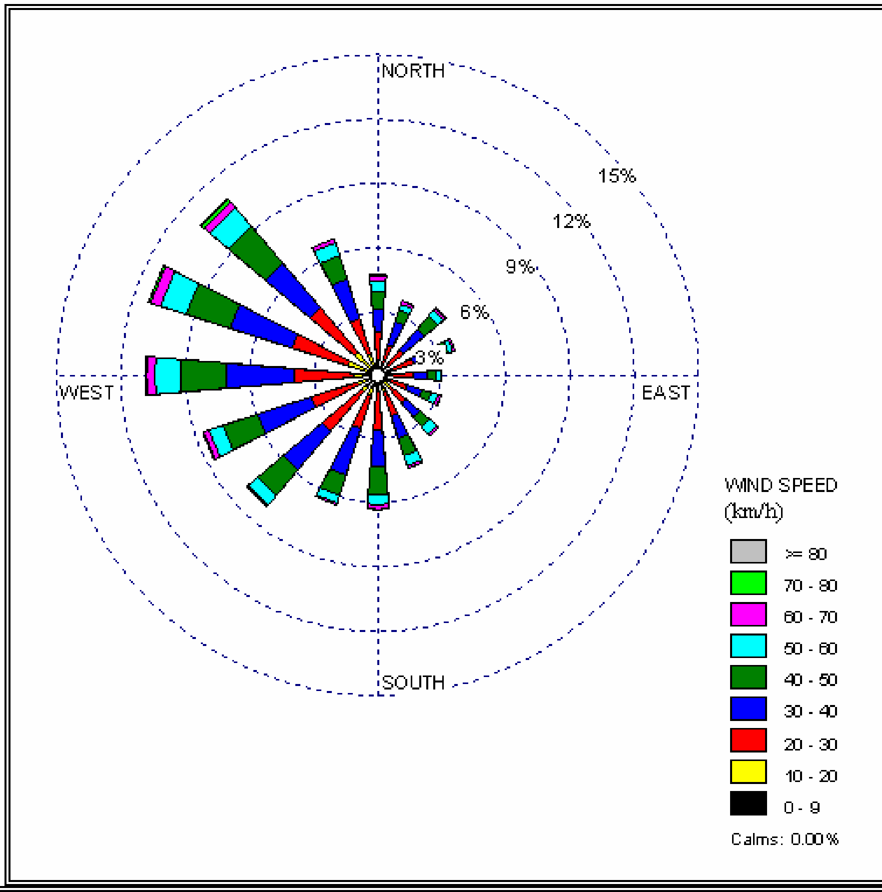


Figure A.10 October Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



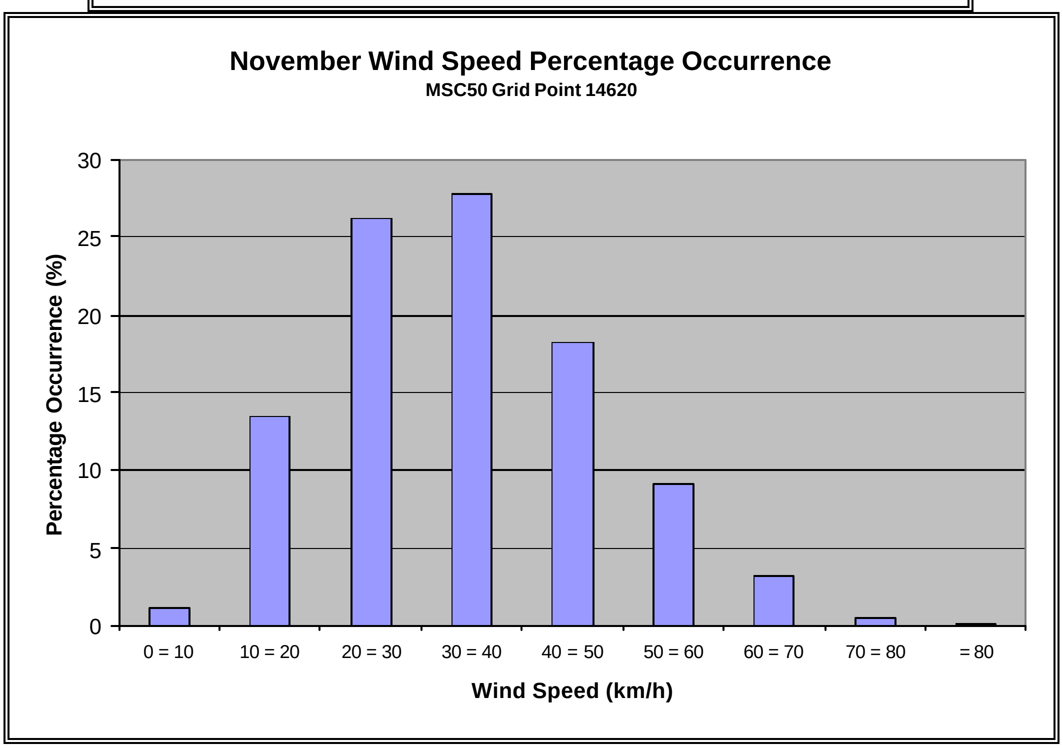
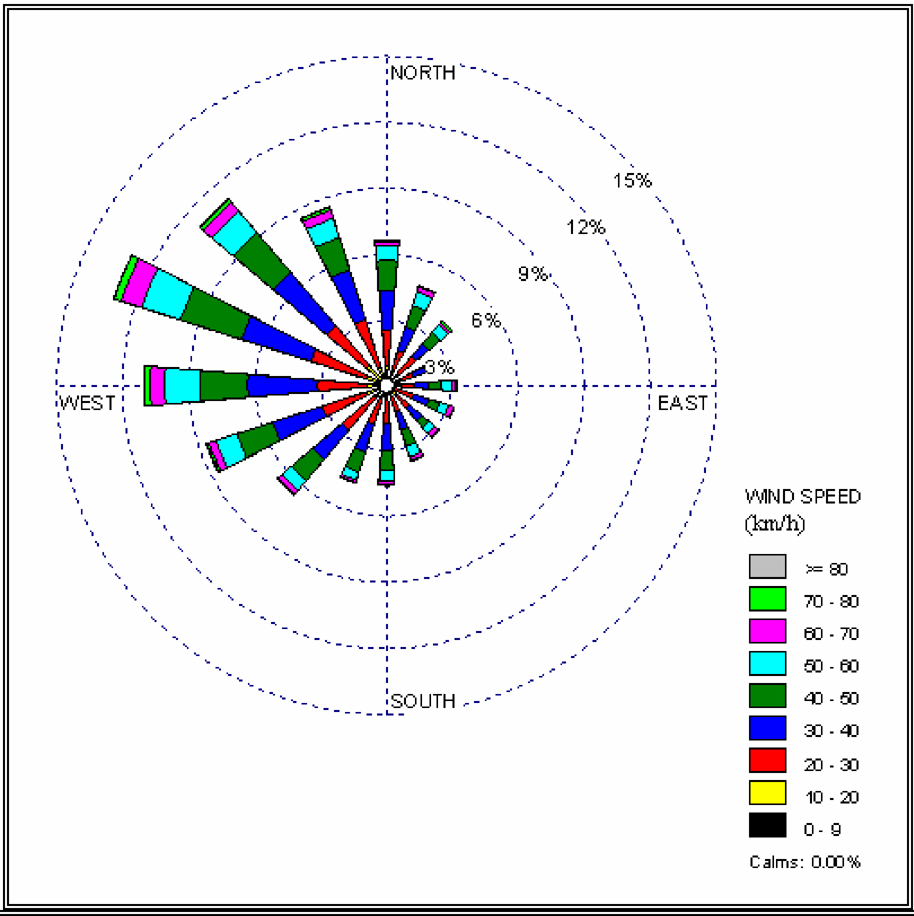


Figure A.11 November Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



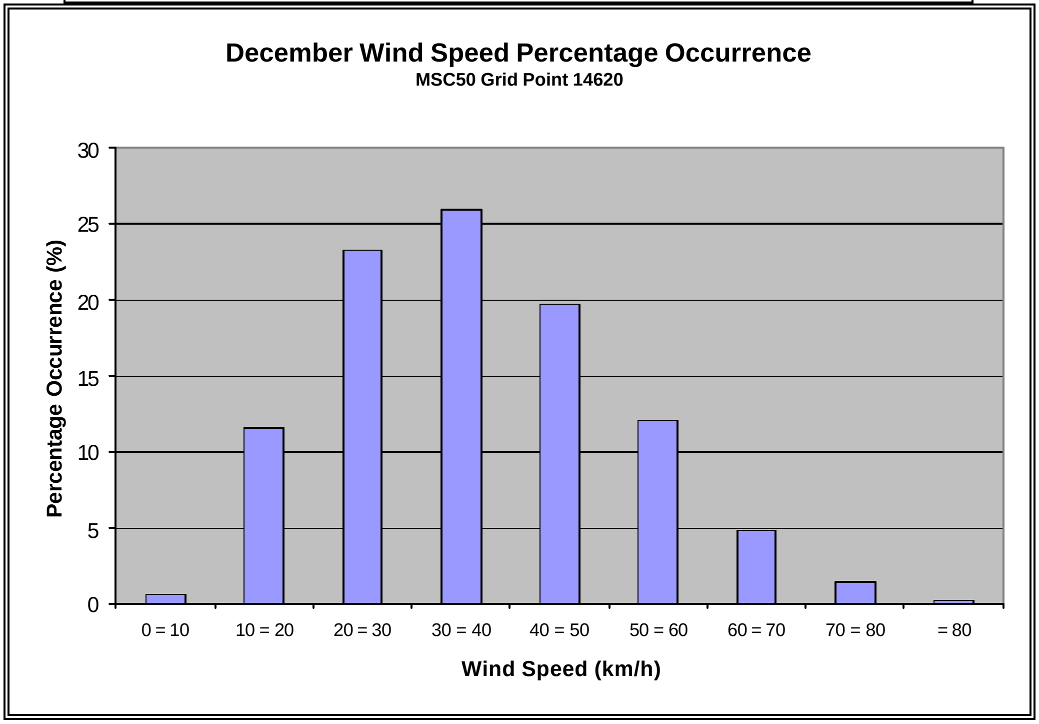


Figure A.12 December Wind Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620

Appendix 2
Percentage Exceedance of Wind Speeds for MSC50 GridPoint 14620

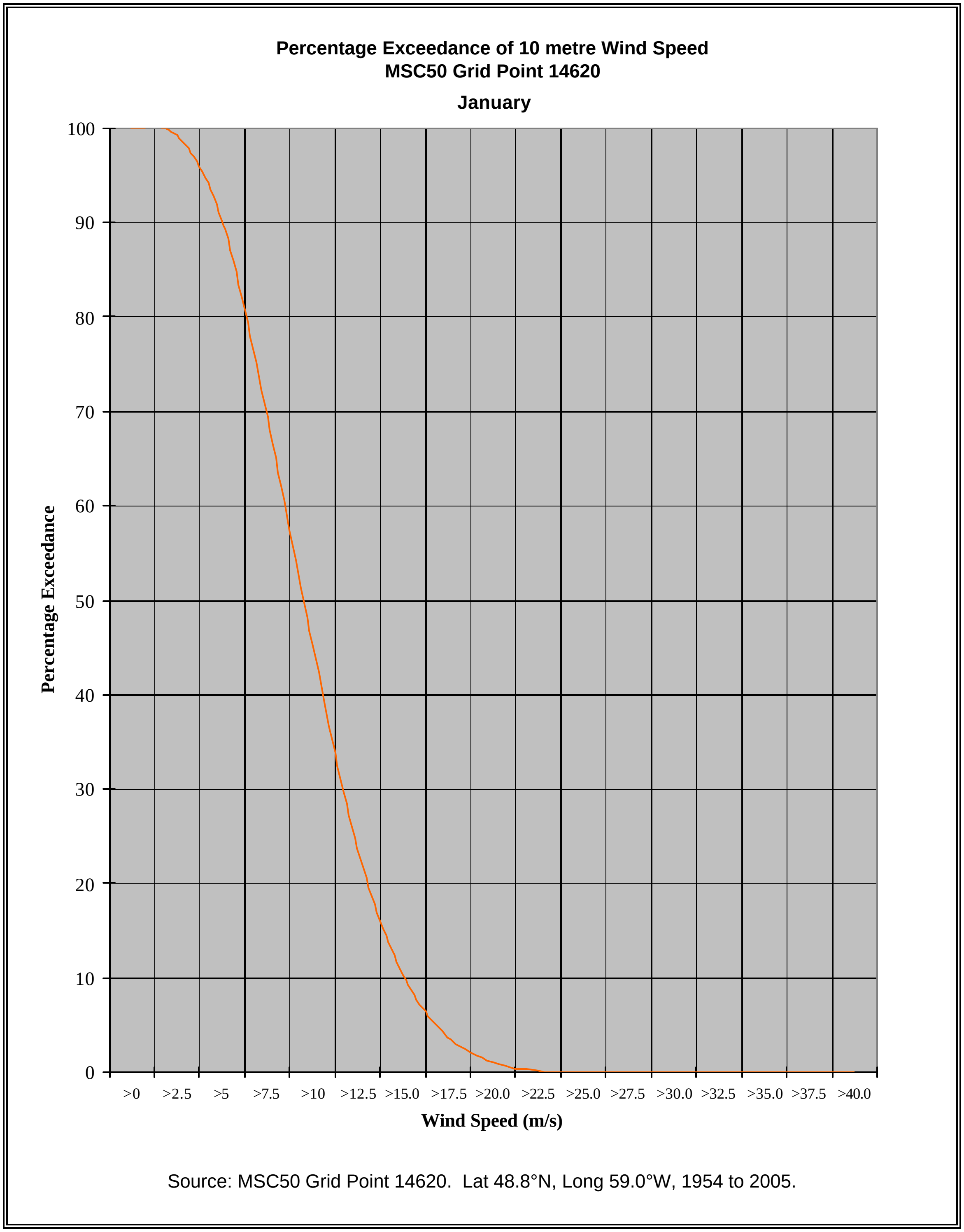


Figure B.1 January Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

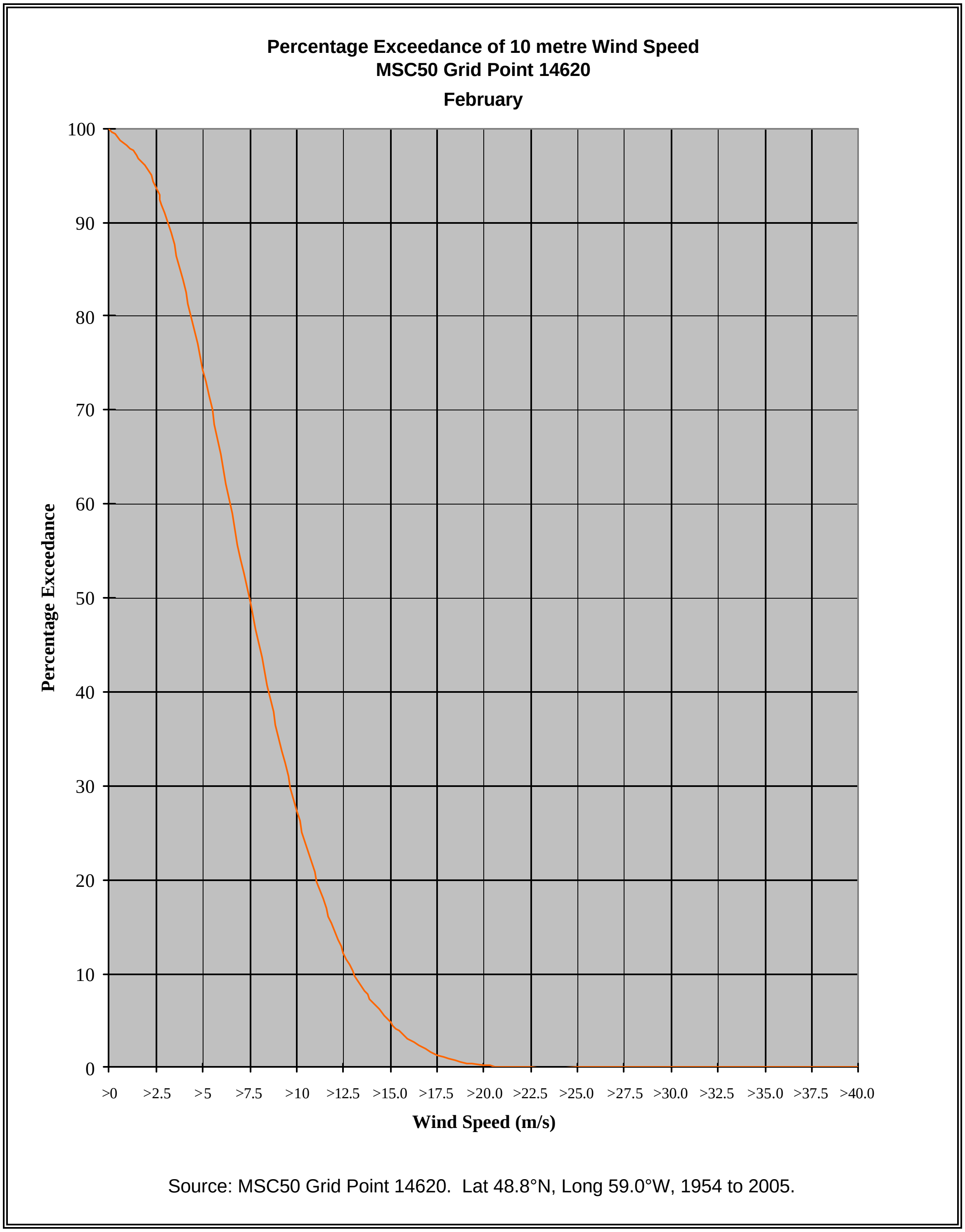


Figure B.2 February Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

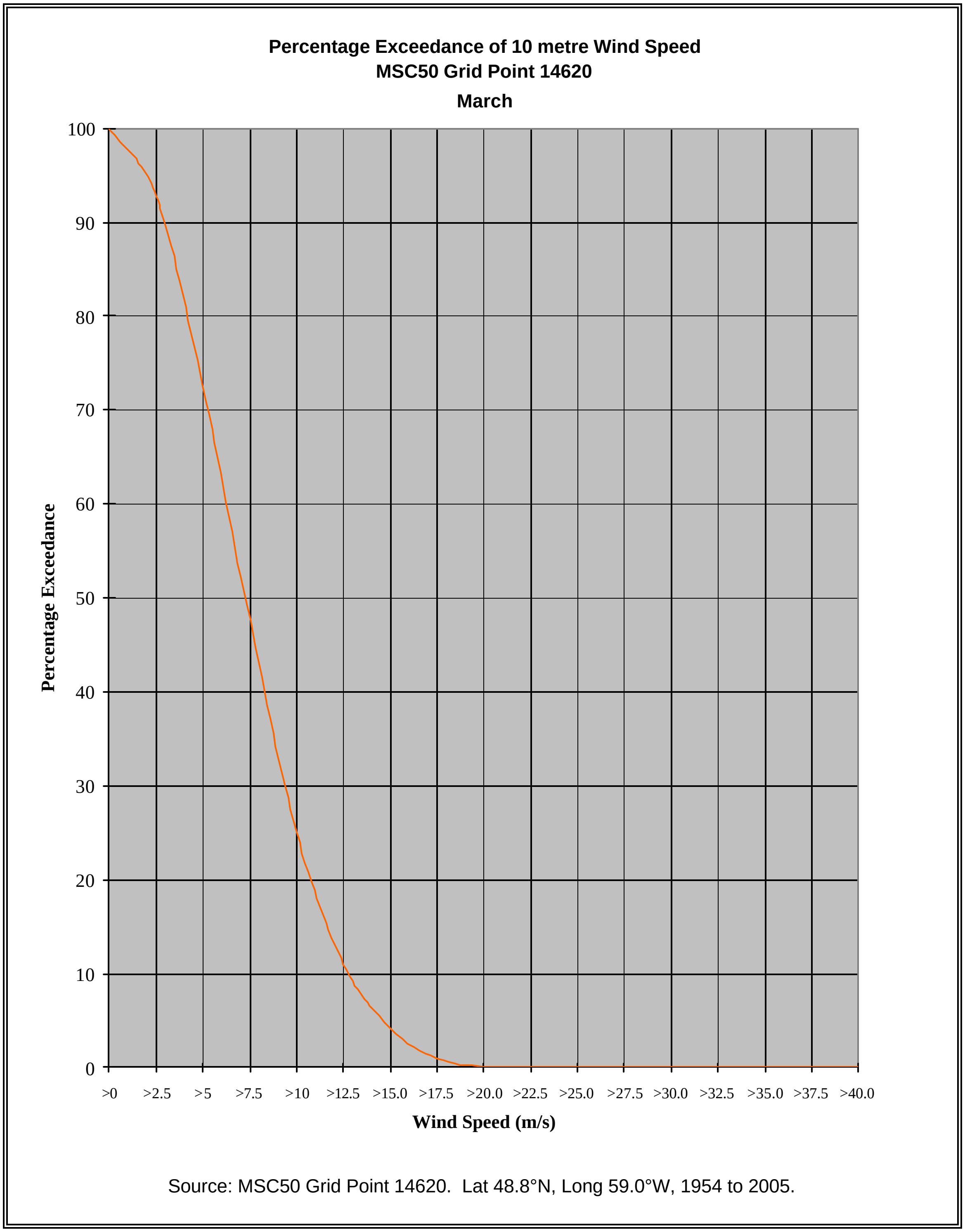
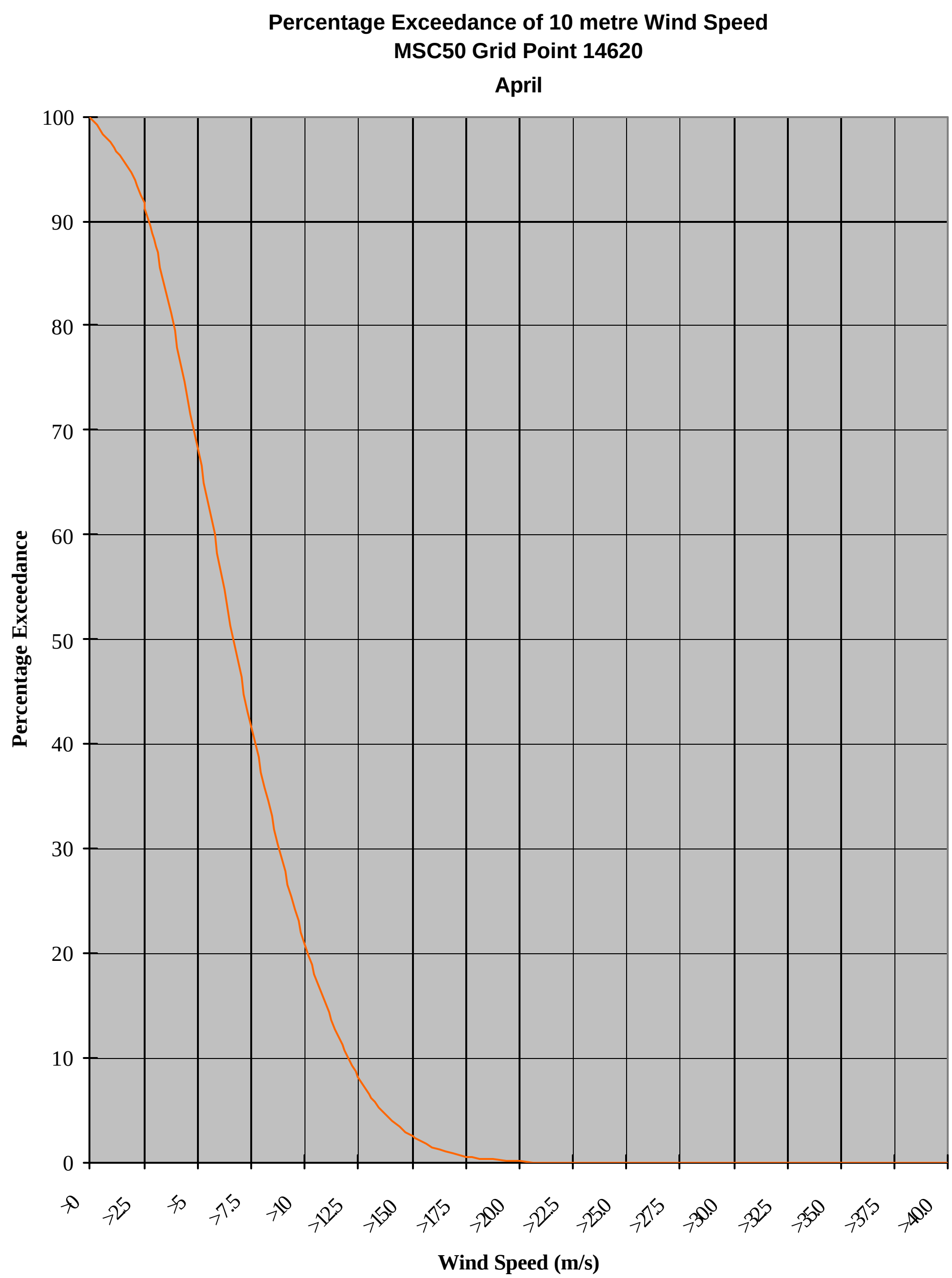


Figure B.3 March Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620



Source: MSC50 Grid Point 14620. Lat 48.8°N, Long 59.0°W, 1954 to 2005.

Figure B.4 April Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

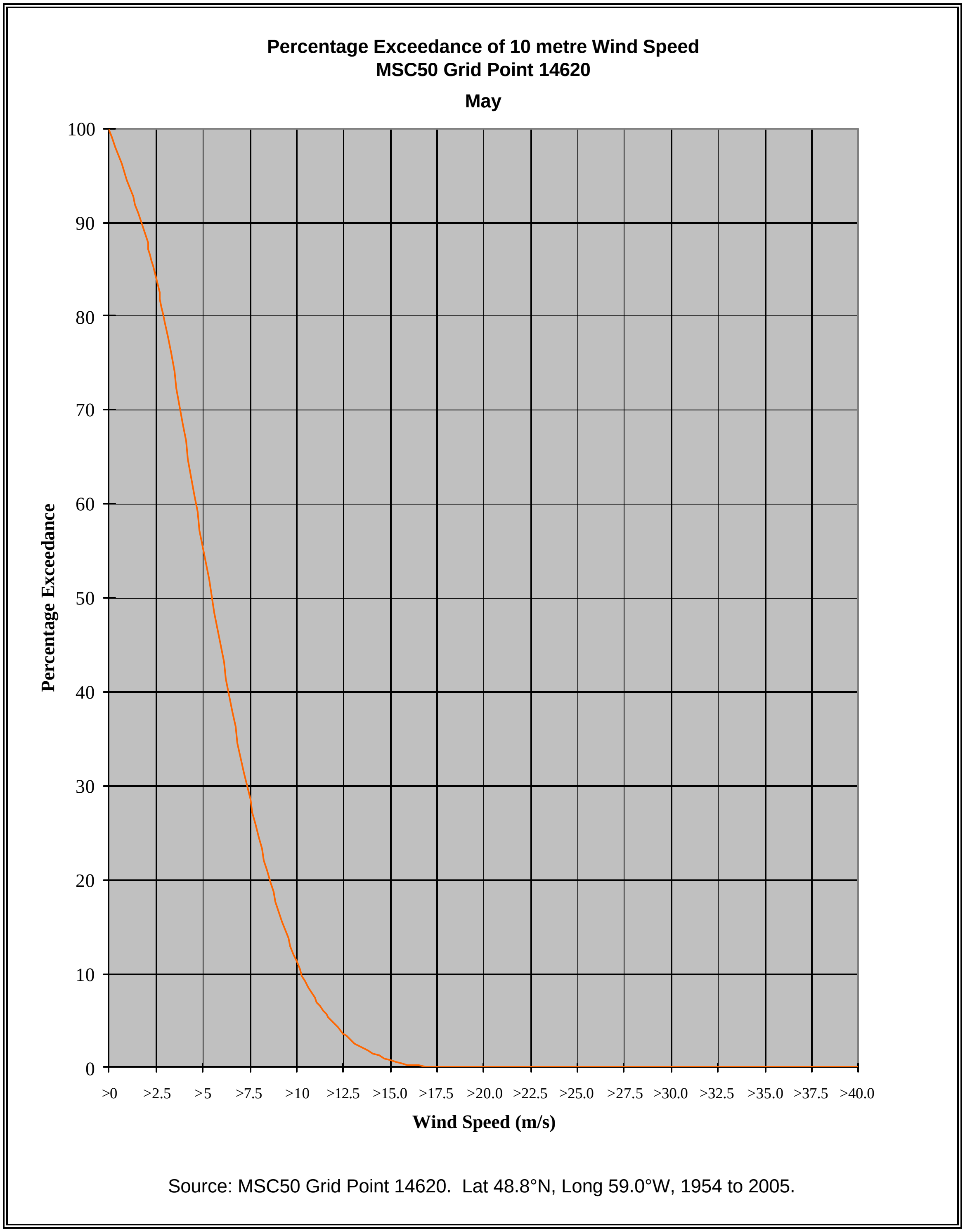


Figure B.5 May Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

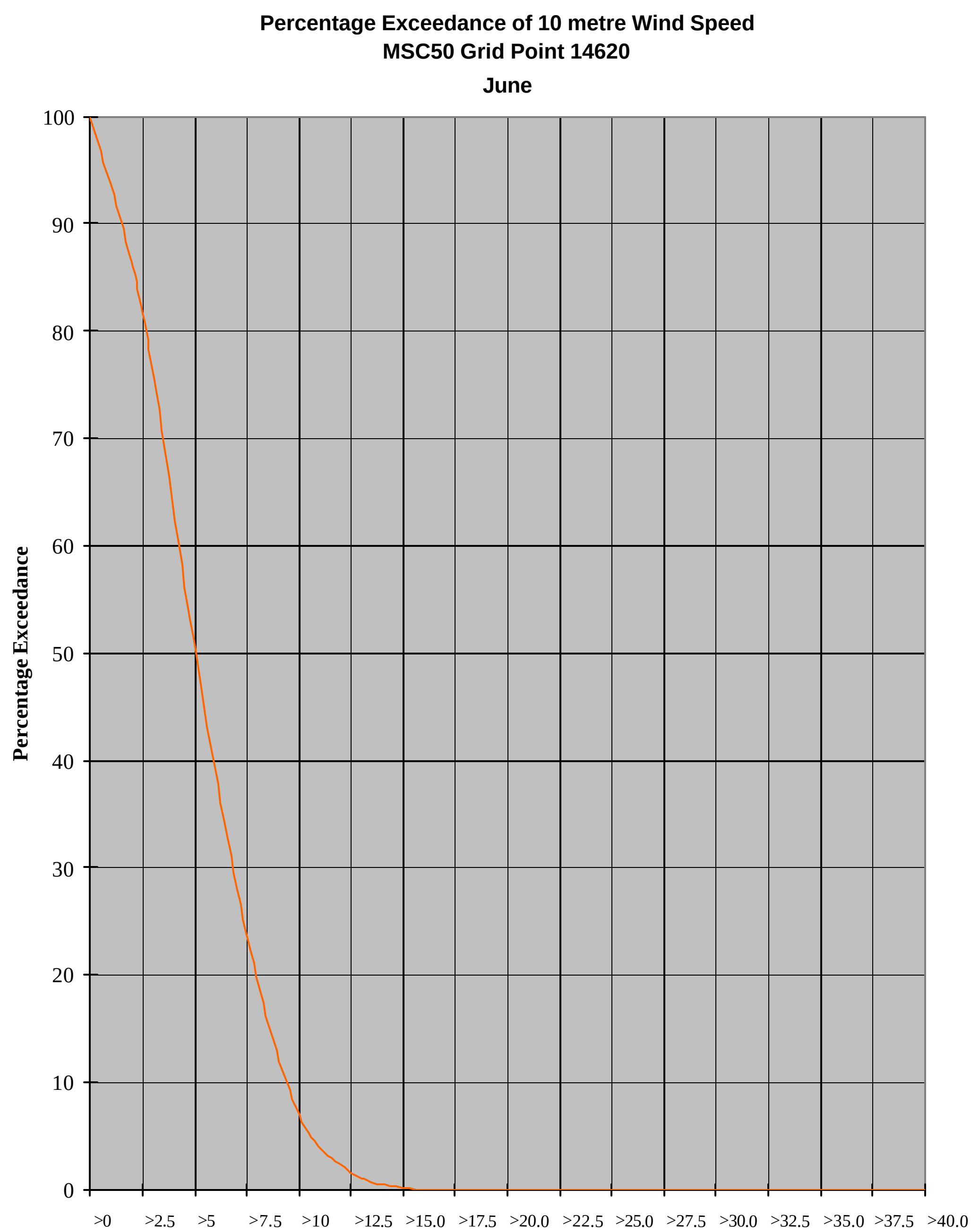


Figure B.6 June Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

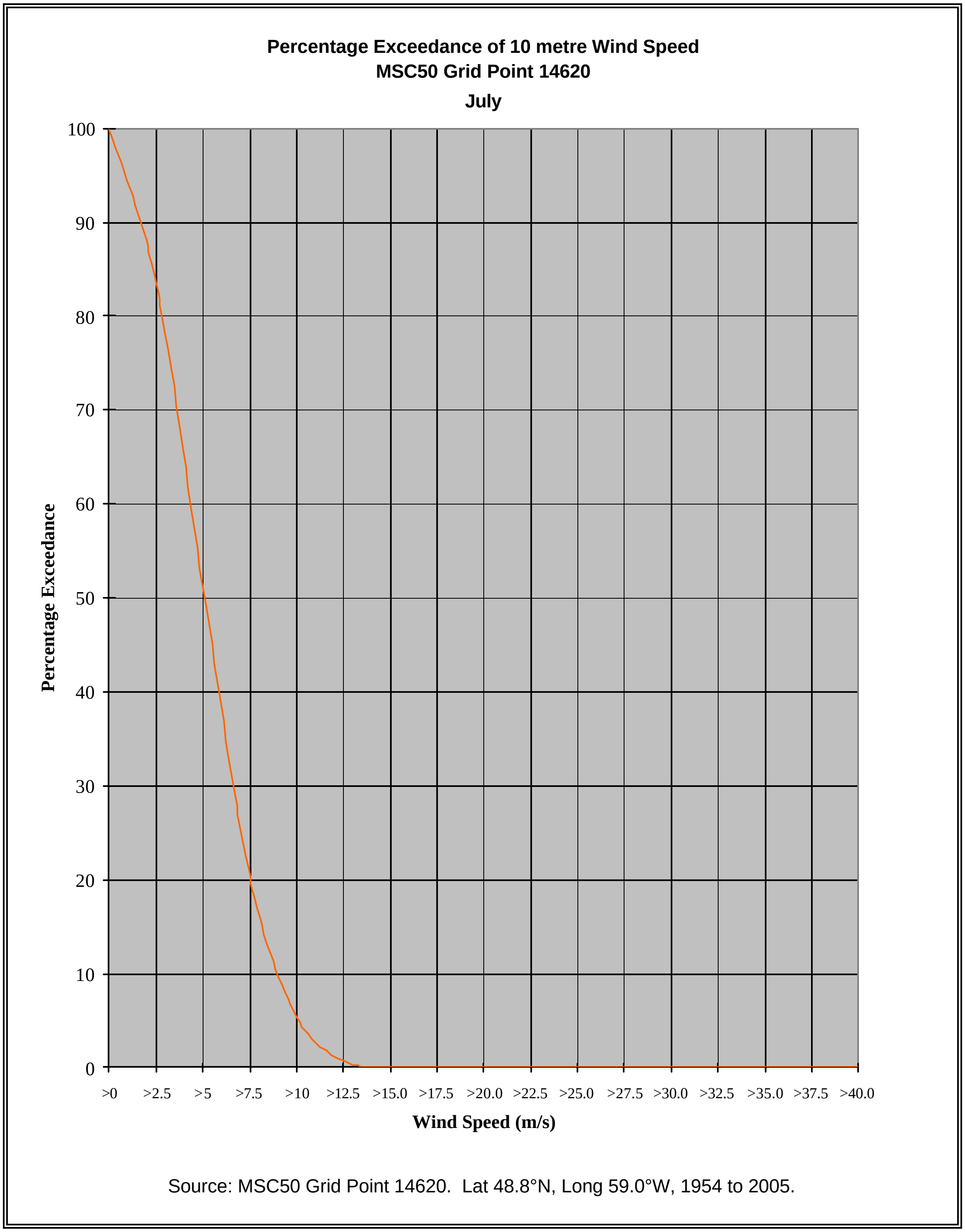


Figure B.7 July Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

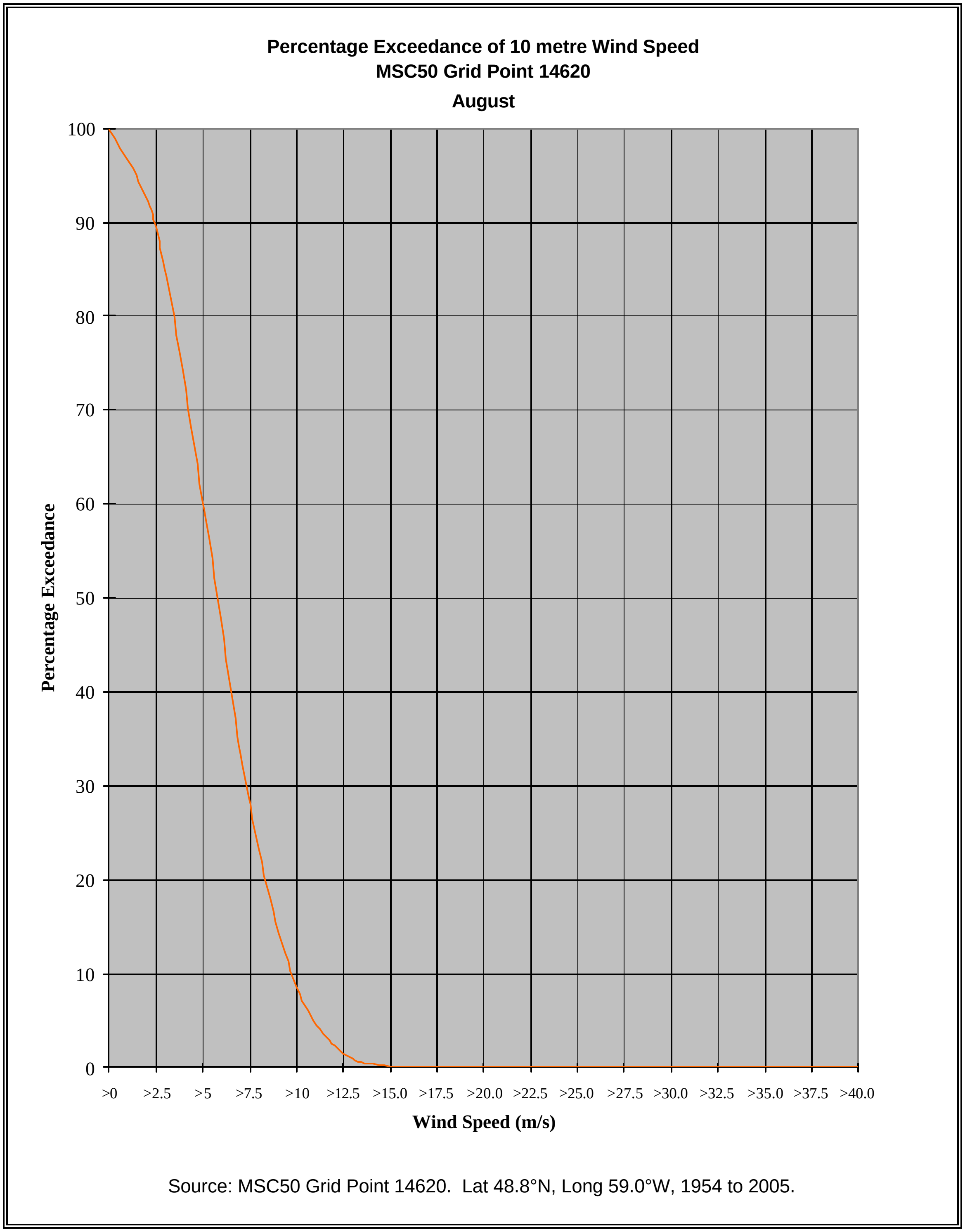


Figure B.8 August Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

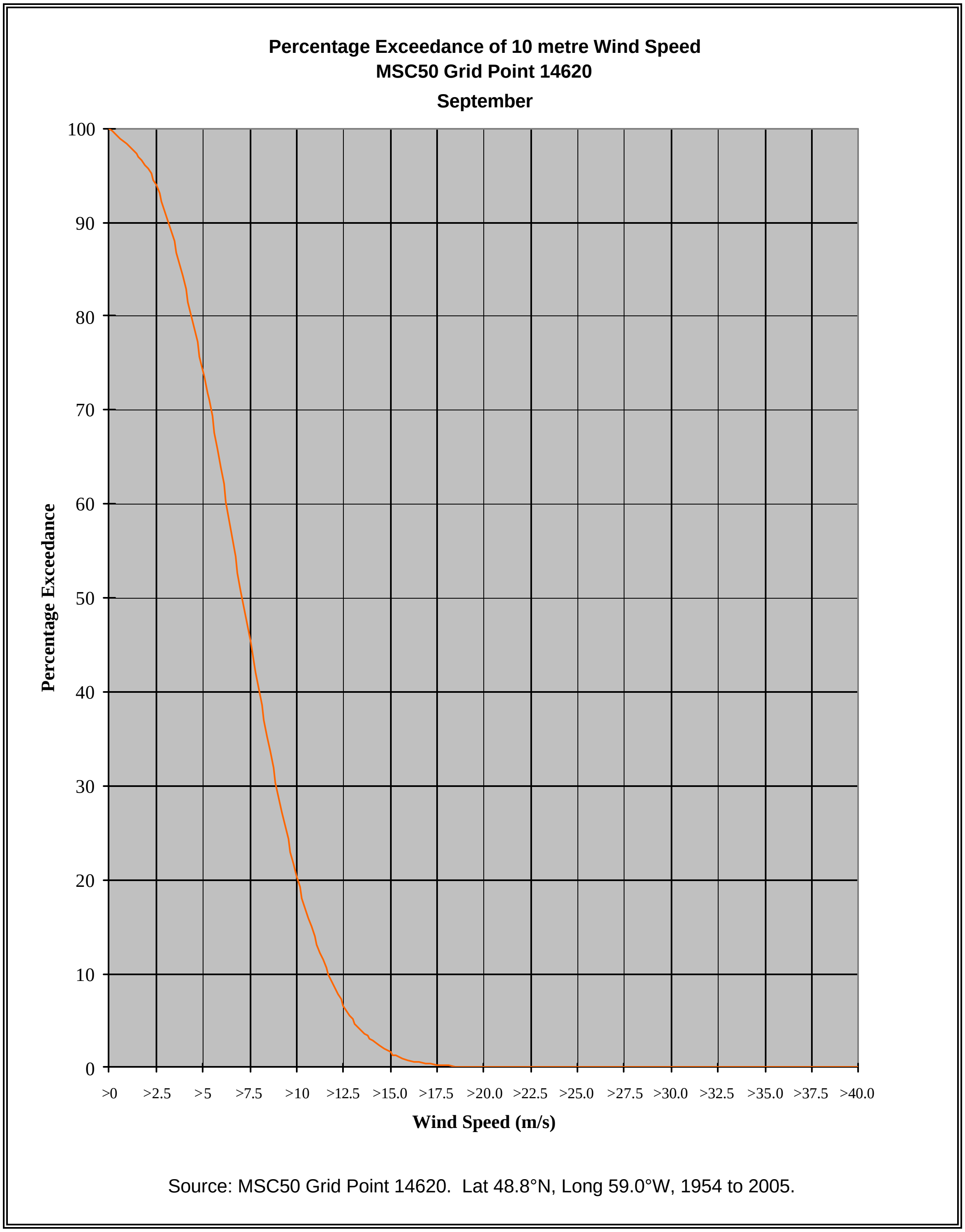
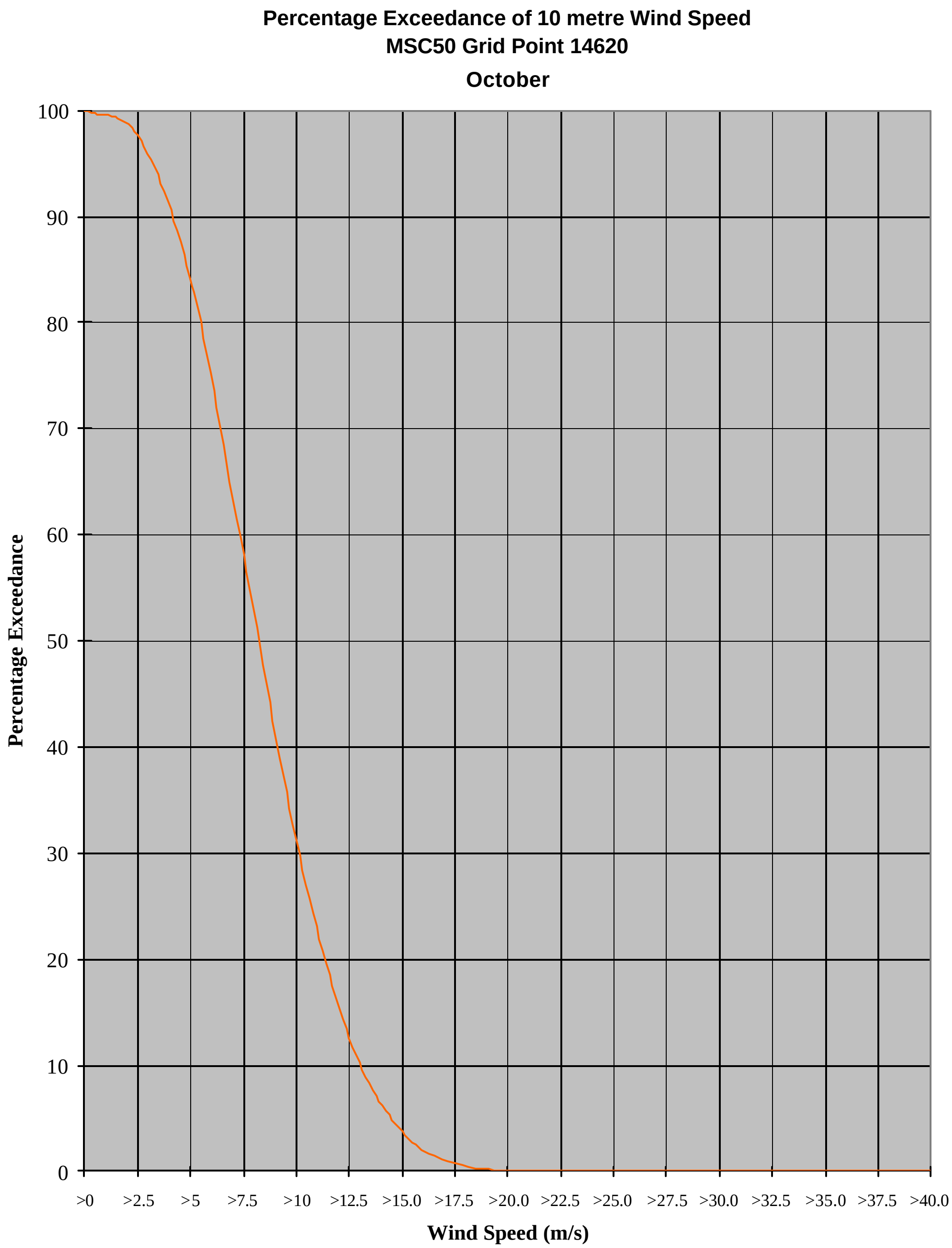


Figure B.9 September Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620



Source: MSC50 Grid Point 14620. Lat 48.8°N, Long 59.0°W, 1954 to 2005.

Figure B.10 October Percentage Exceedance for of 10-m Wind Speeds MSC50 Grid Point 14620

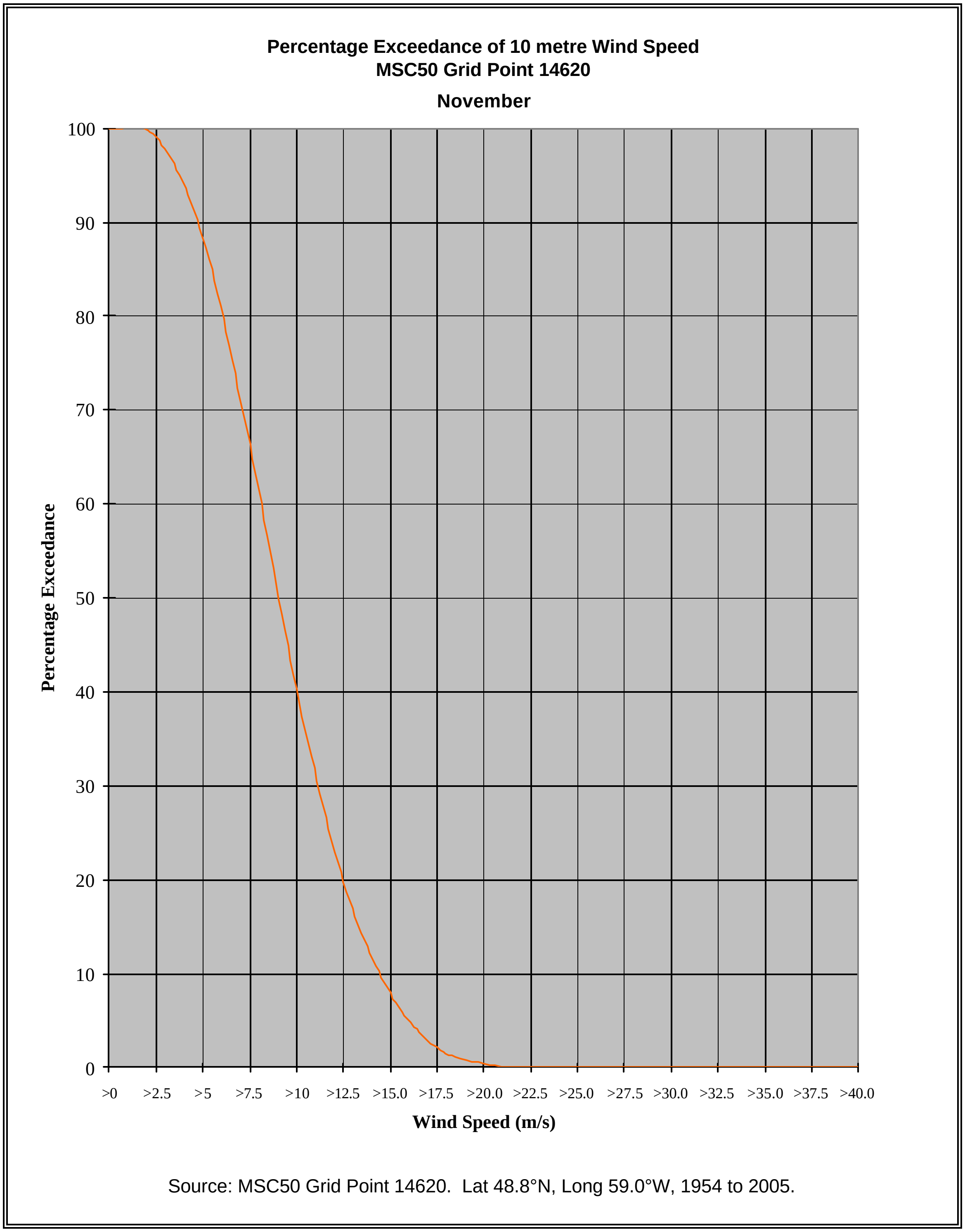


Figure B.11 November Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

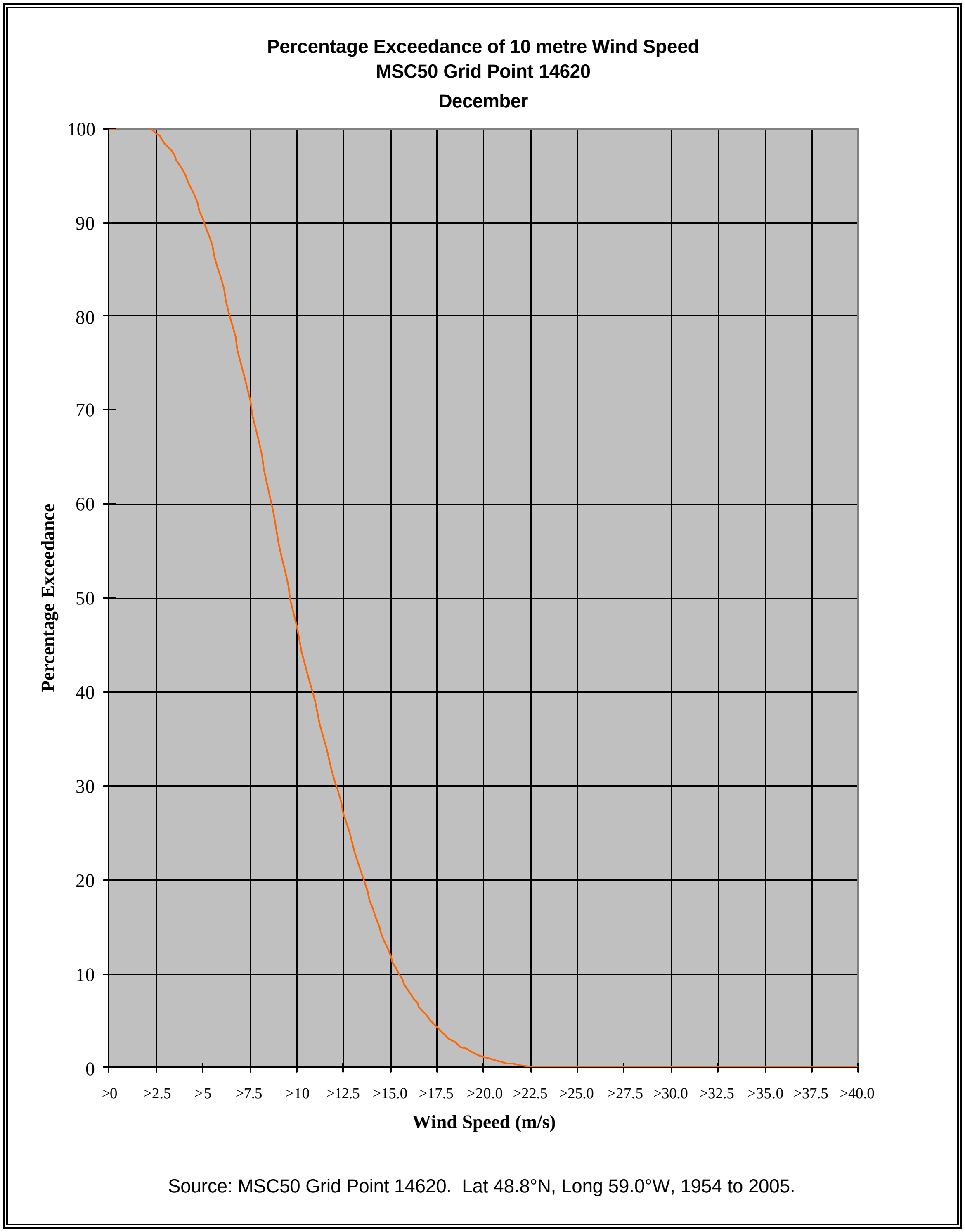


Figure B.12 December Percentage Exceedance of 10-m Wind Speeds for MSC50 Grid Point 14620

Appendix 3
Wave Rose and Frequency Distributions
for MSC50 GridPoint 14620

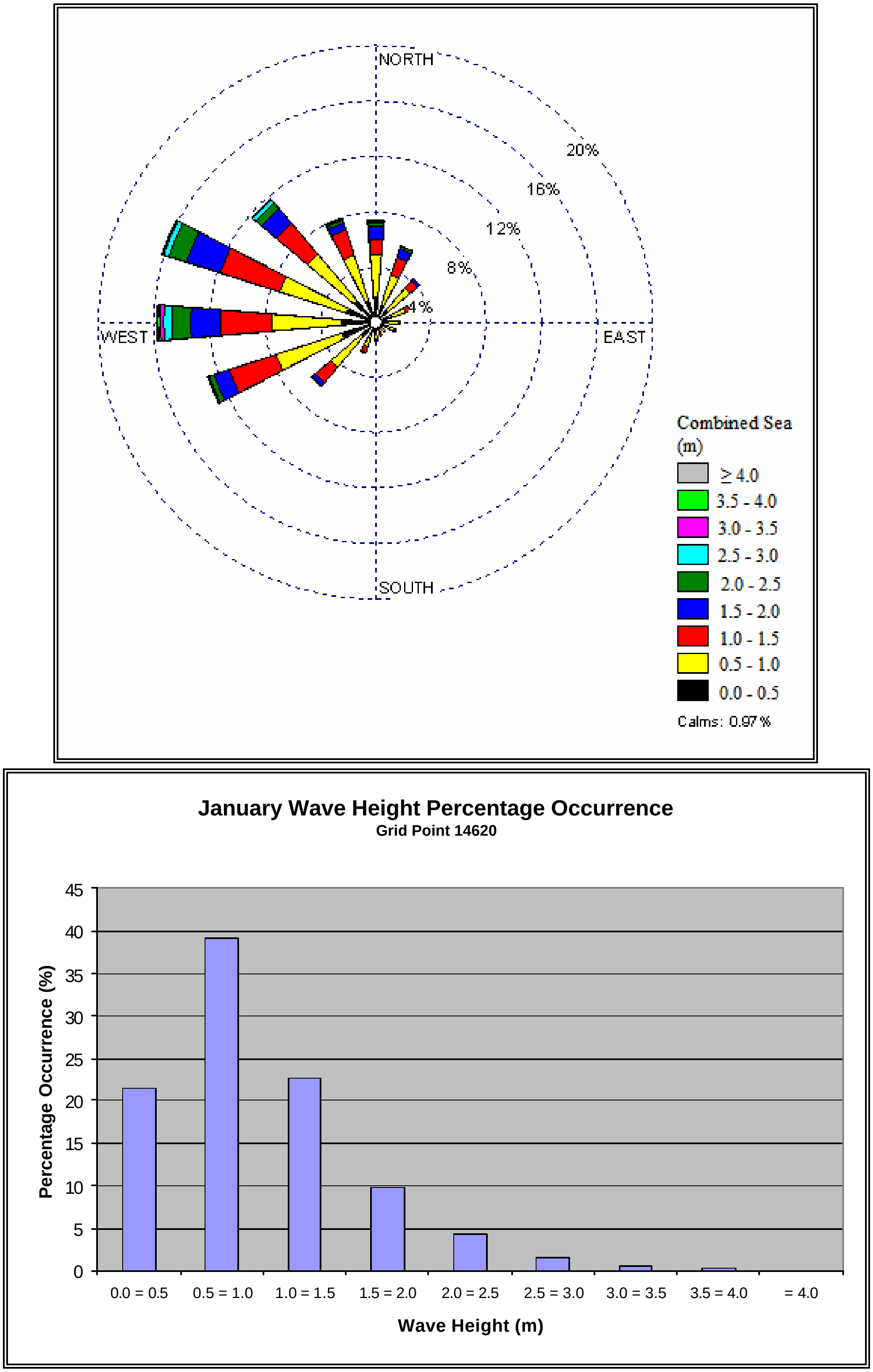
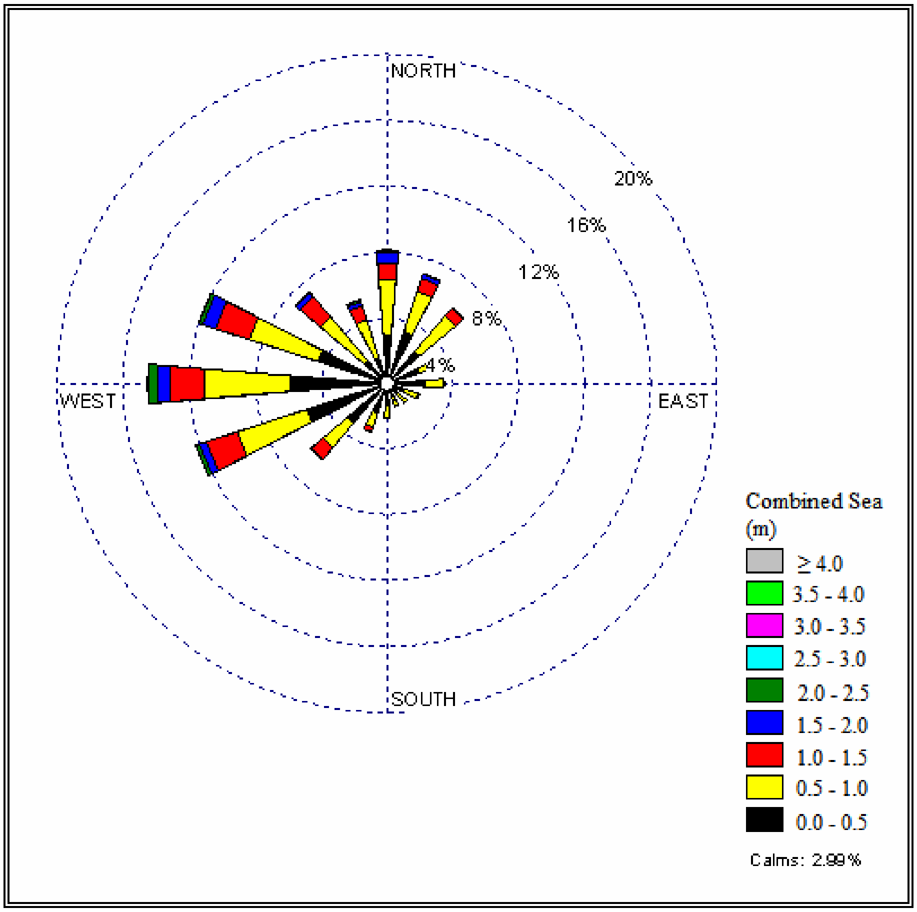


Figure C.1 January Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



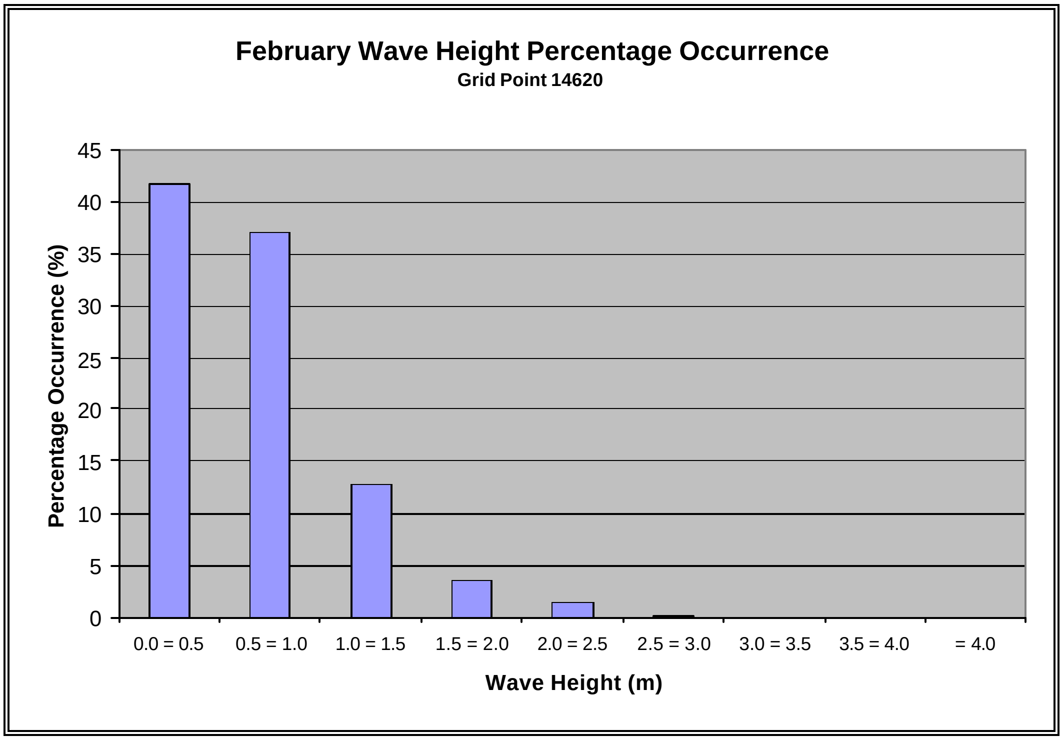
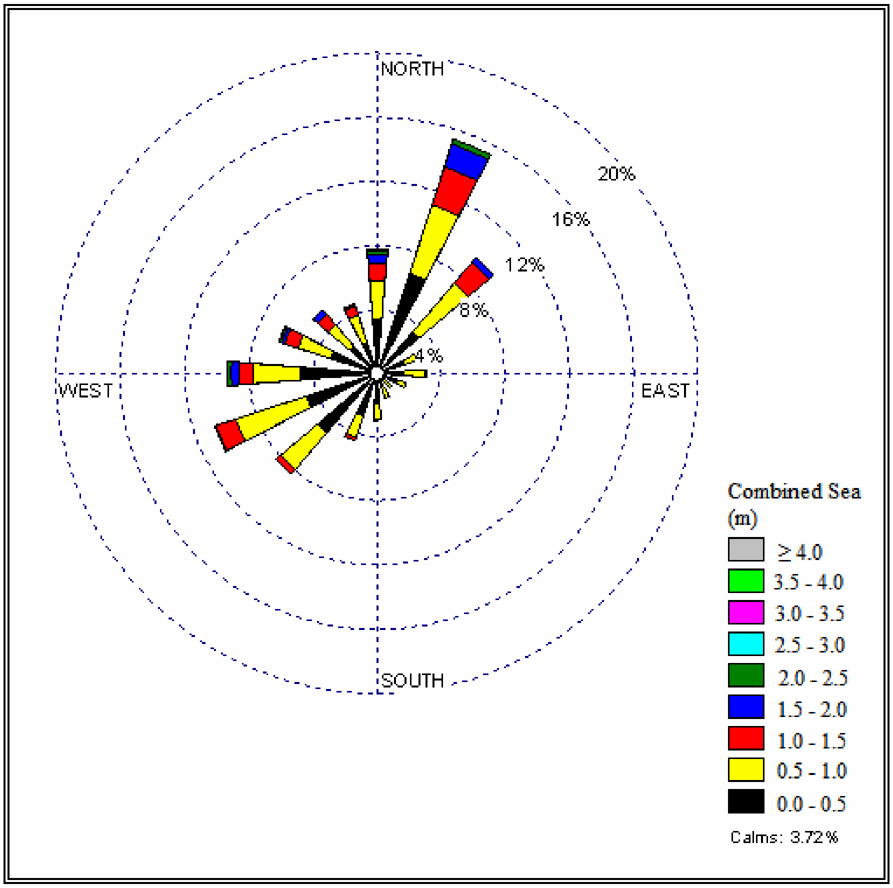


Figure C.2 February Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



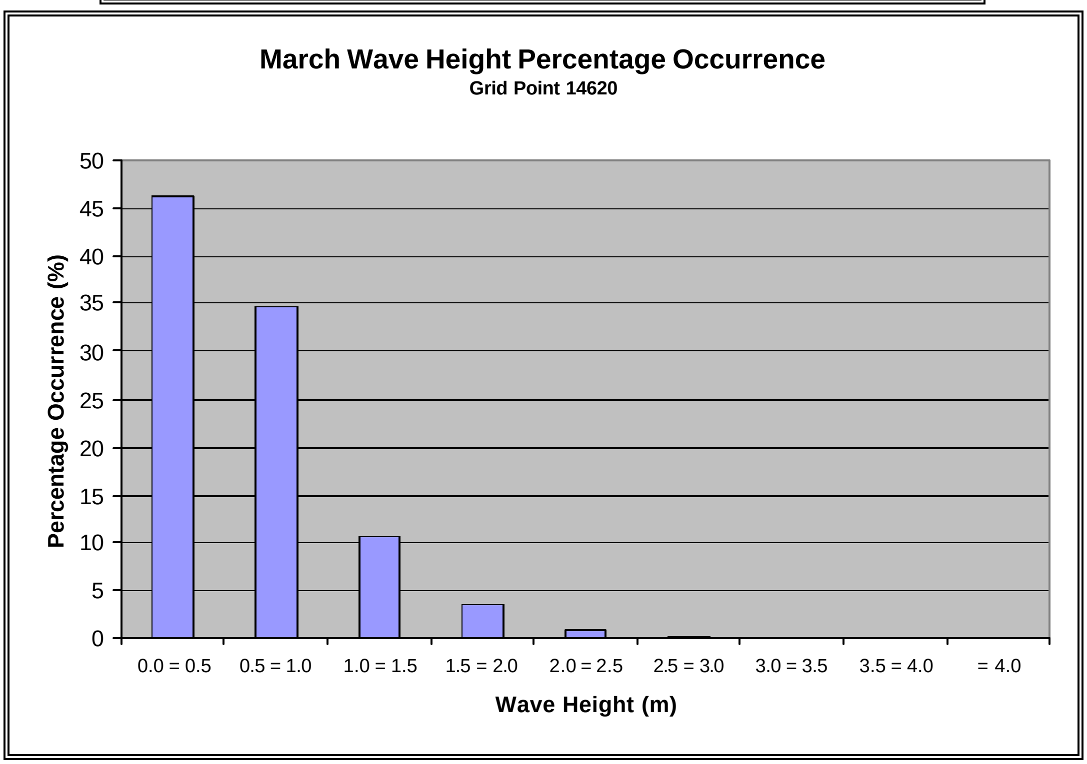
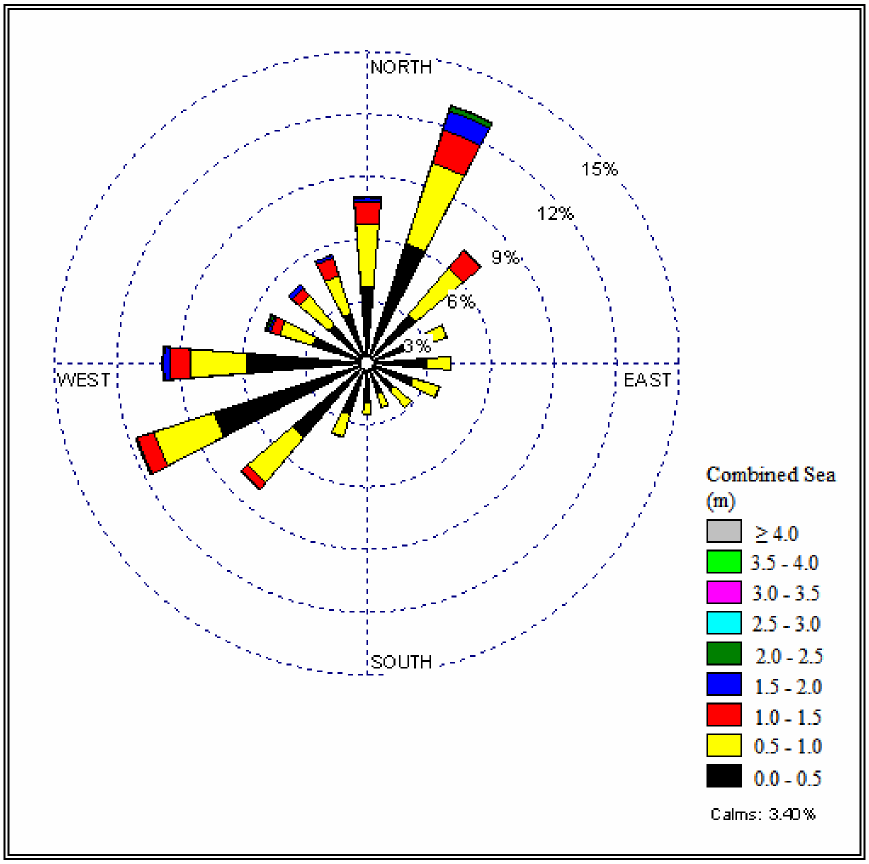


Figure C.3 March Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



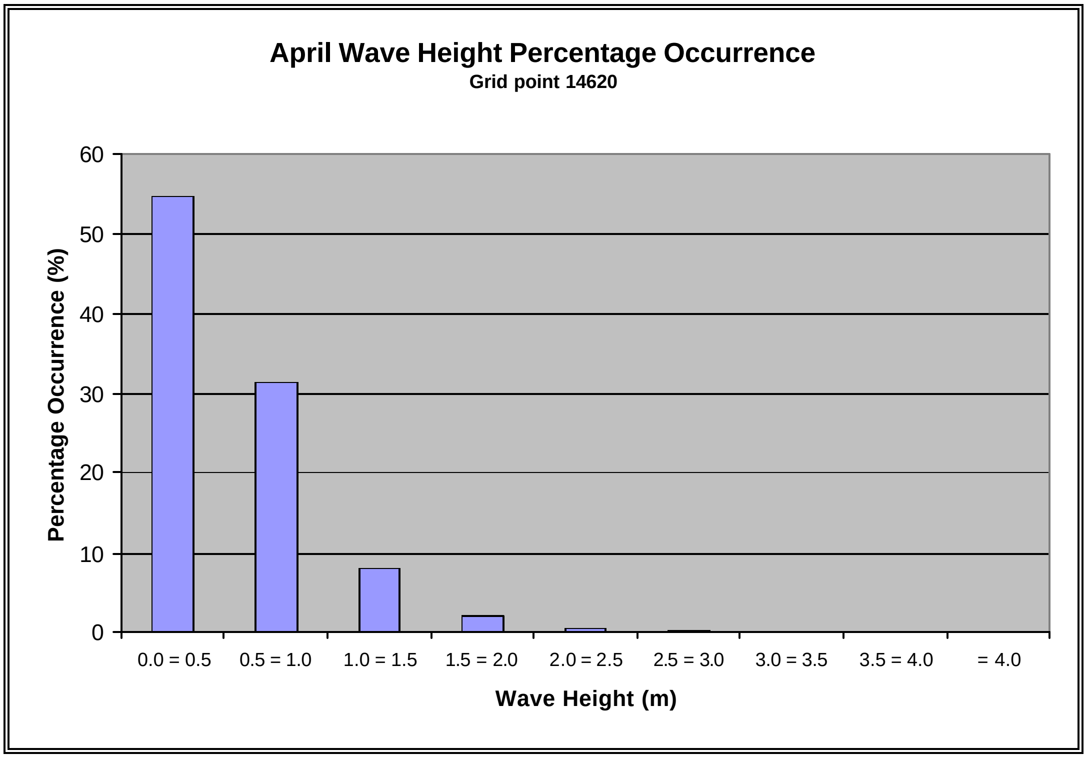
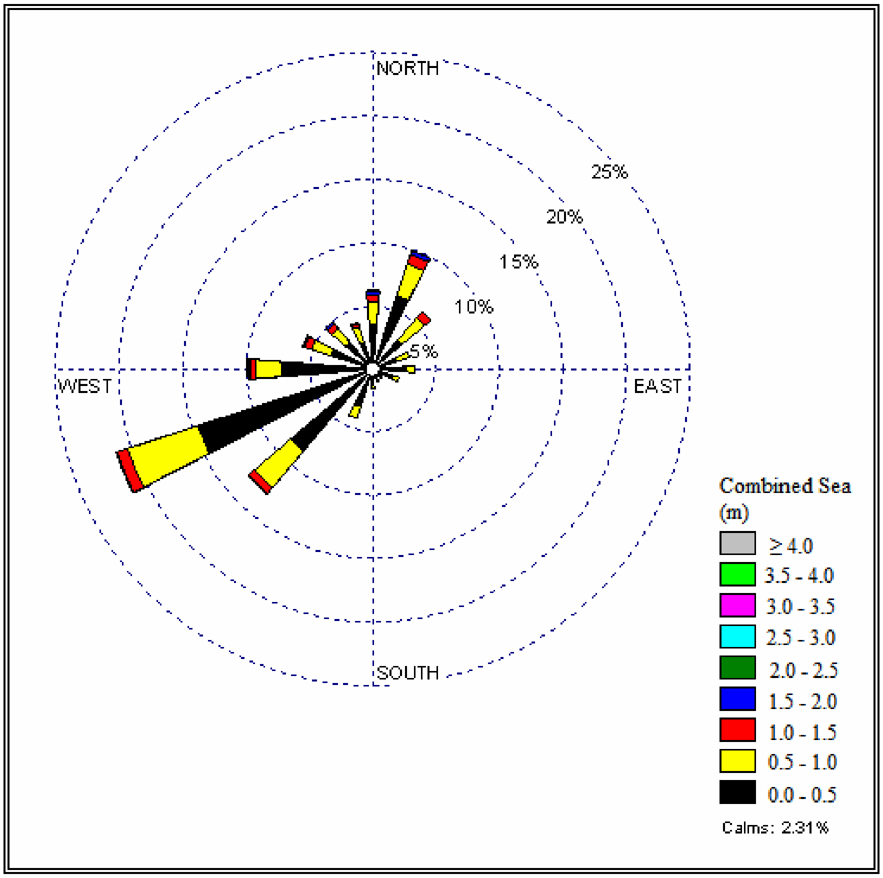


Figure C.4 April Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



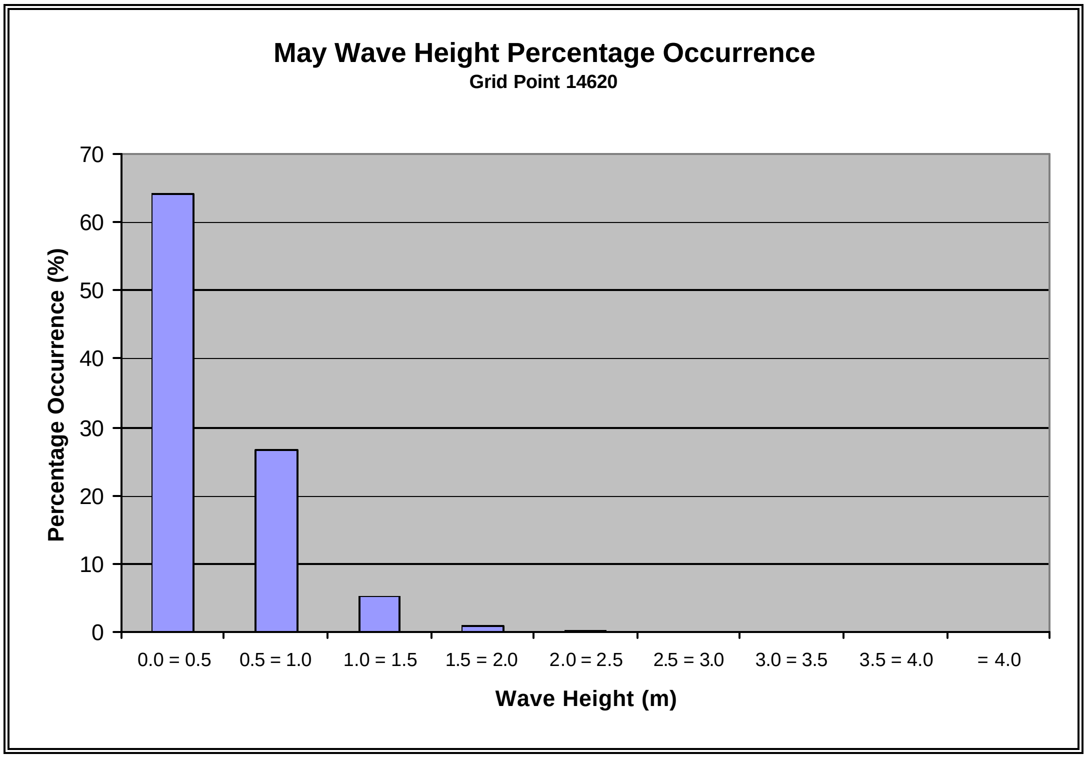
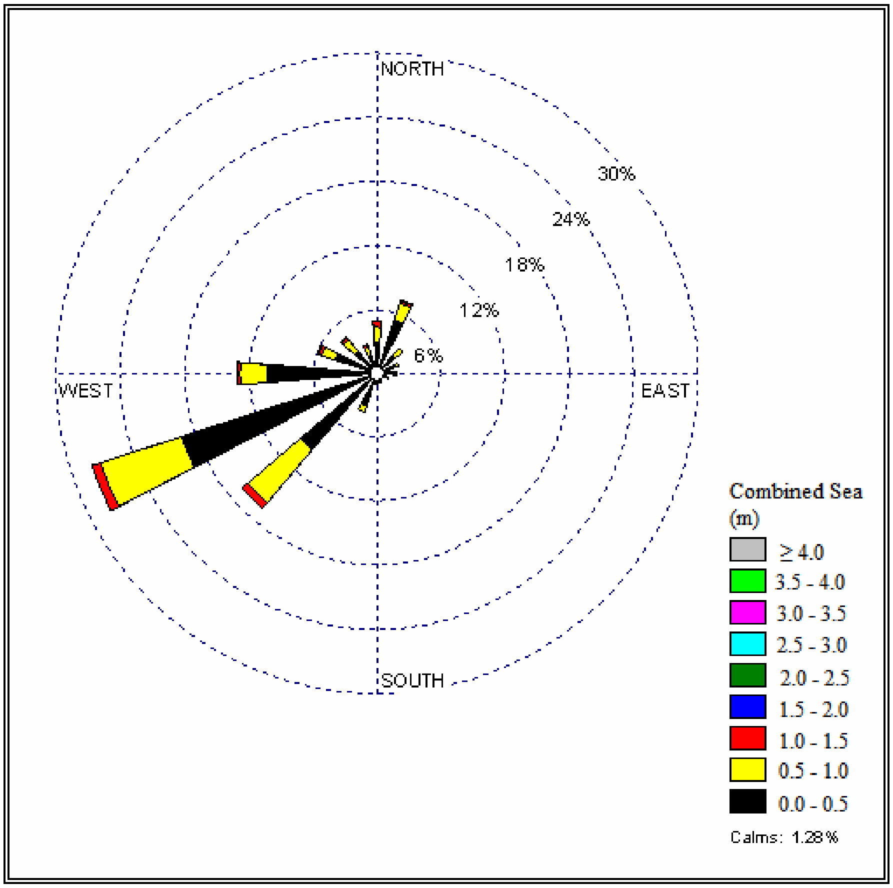


Figure C.5 May Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



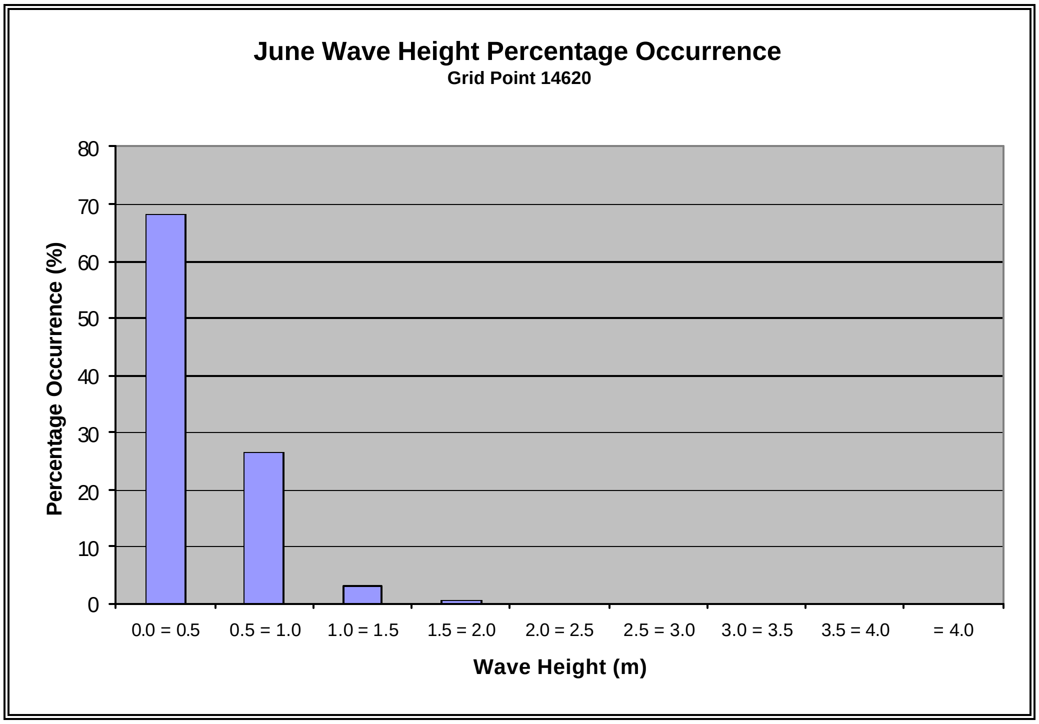
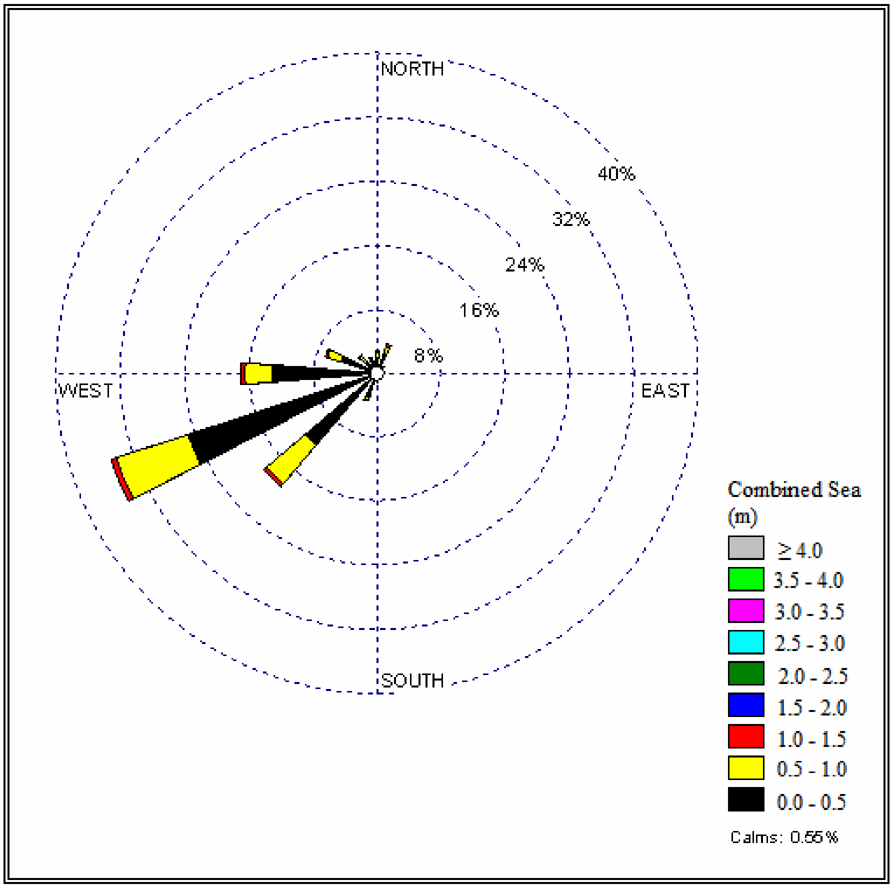


Figure C.6 June Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



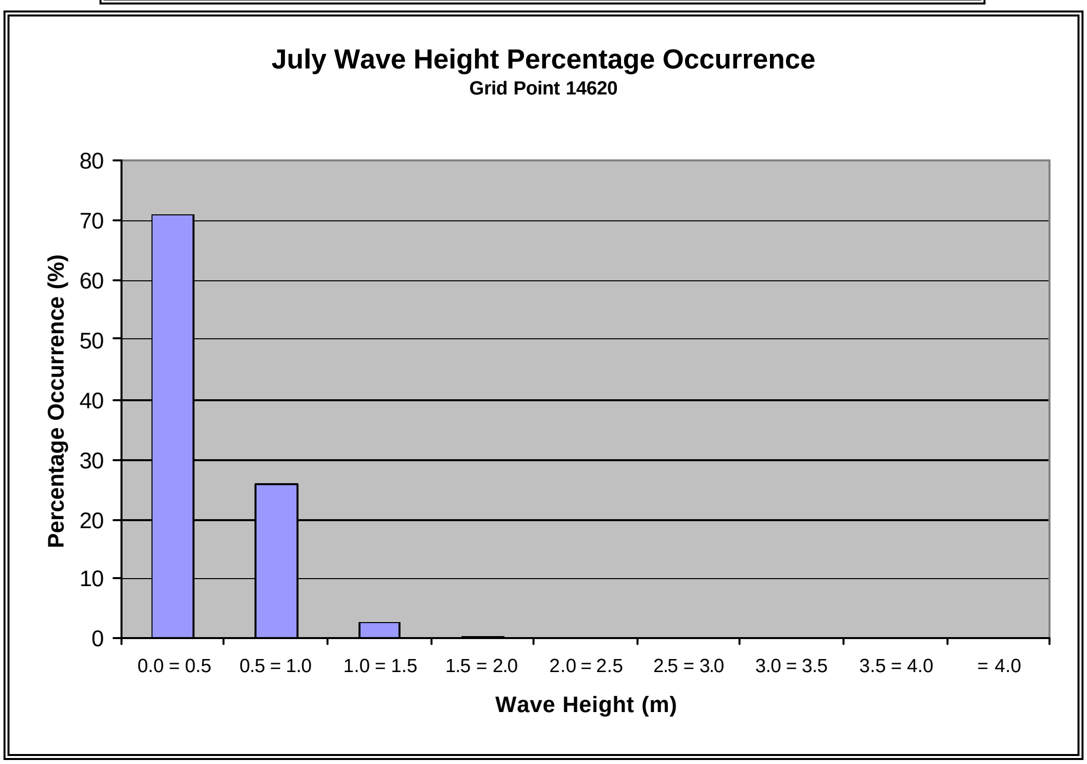
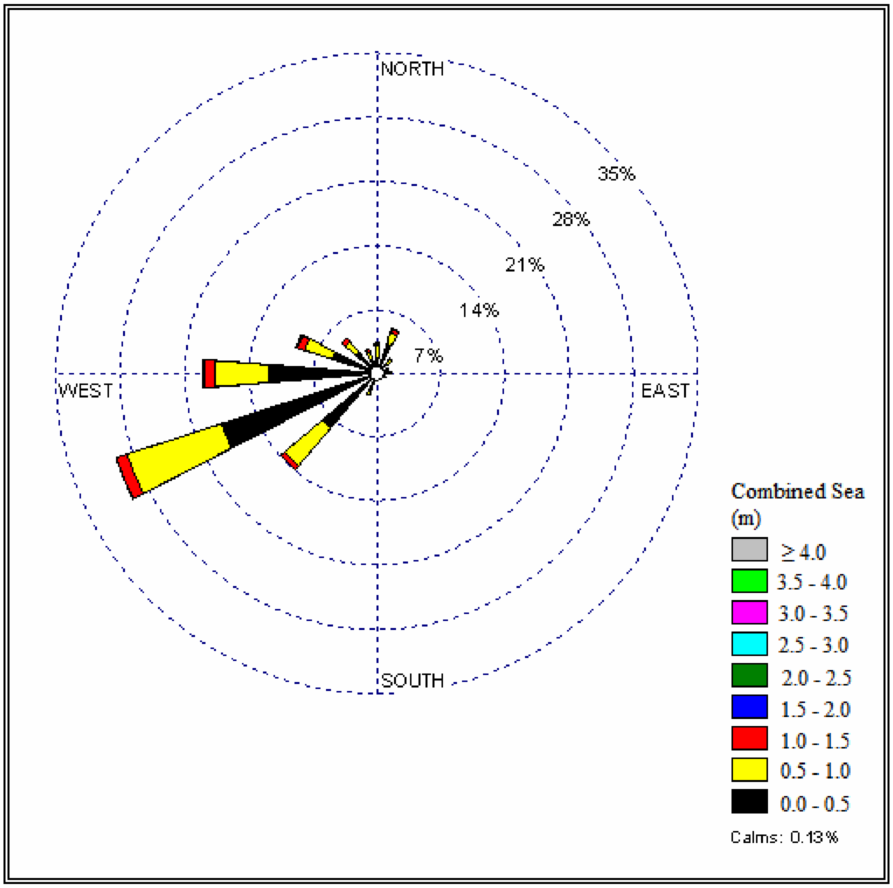


Figure C.7 July Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



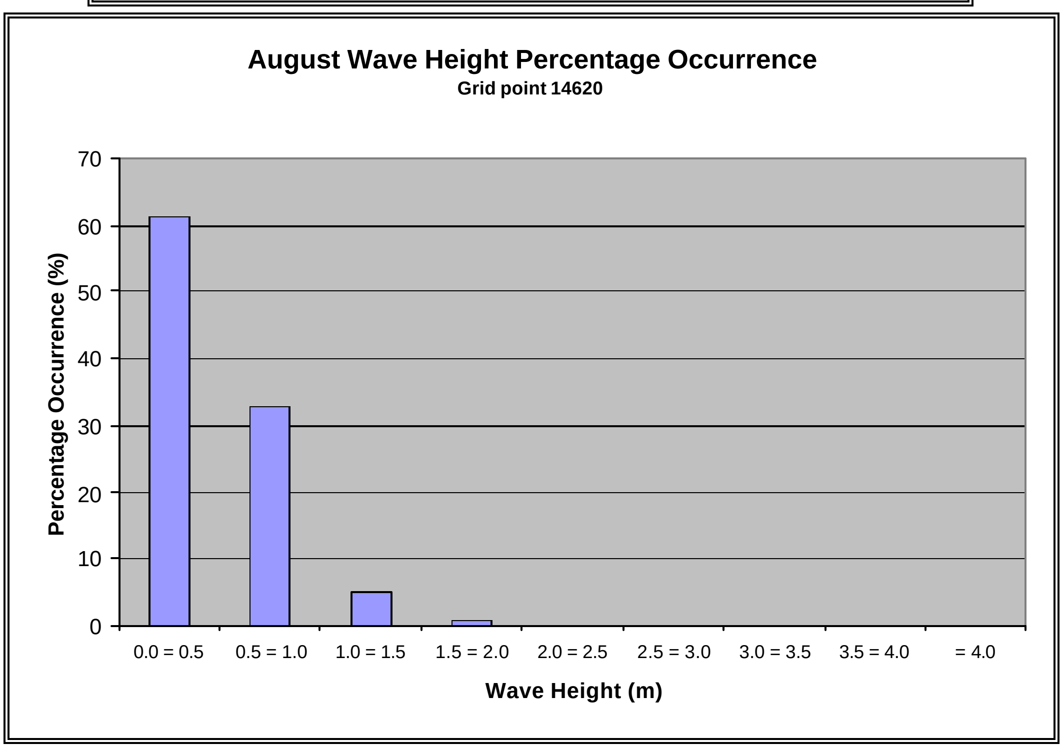
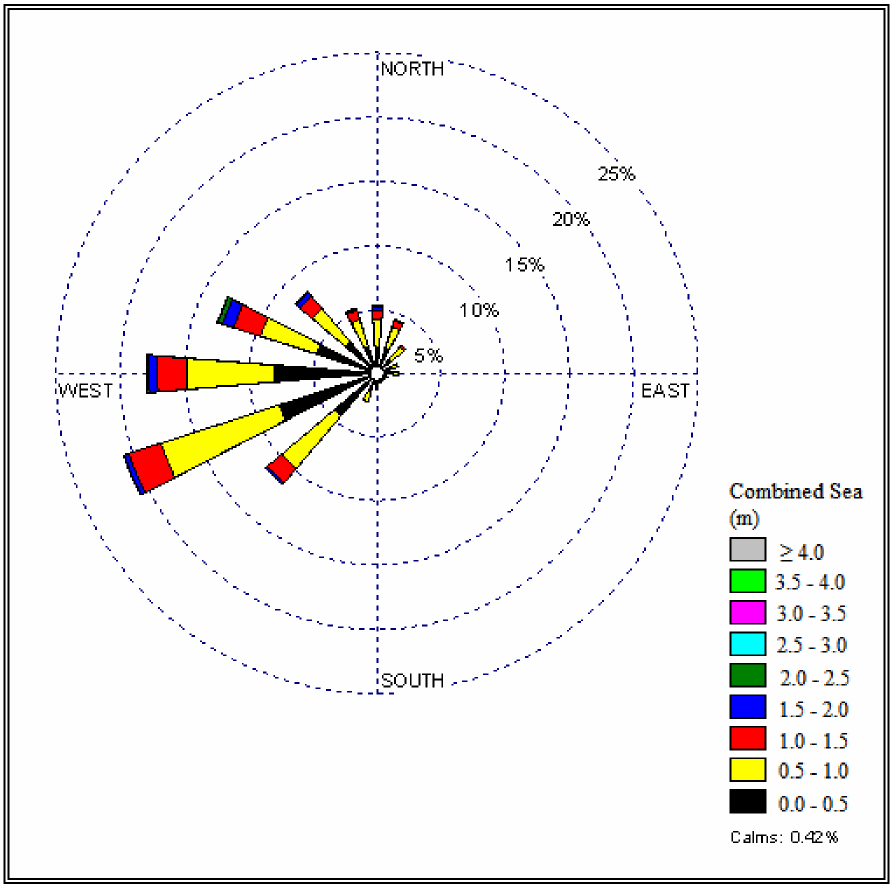


Figure C.8 August Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



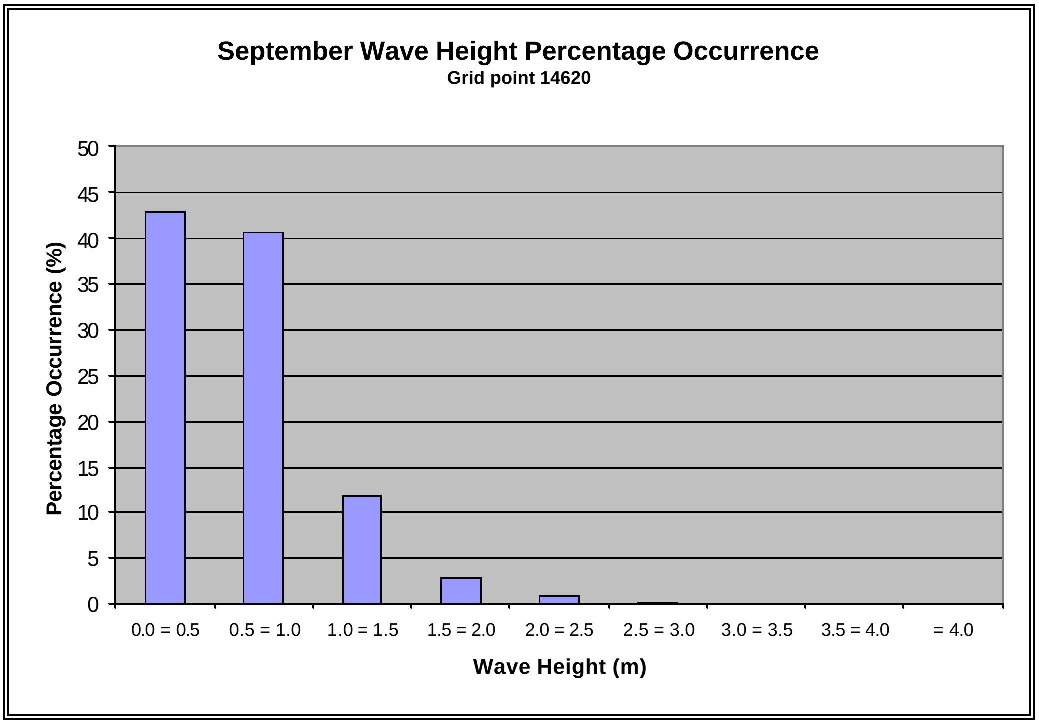
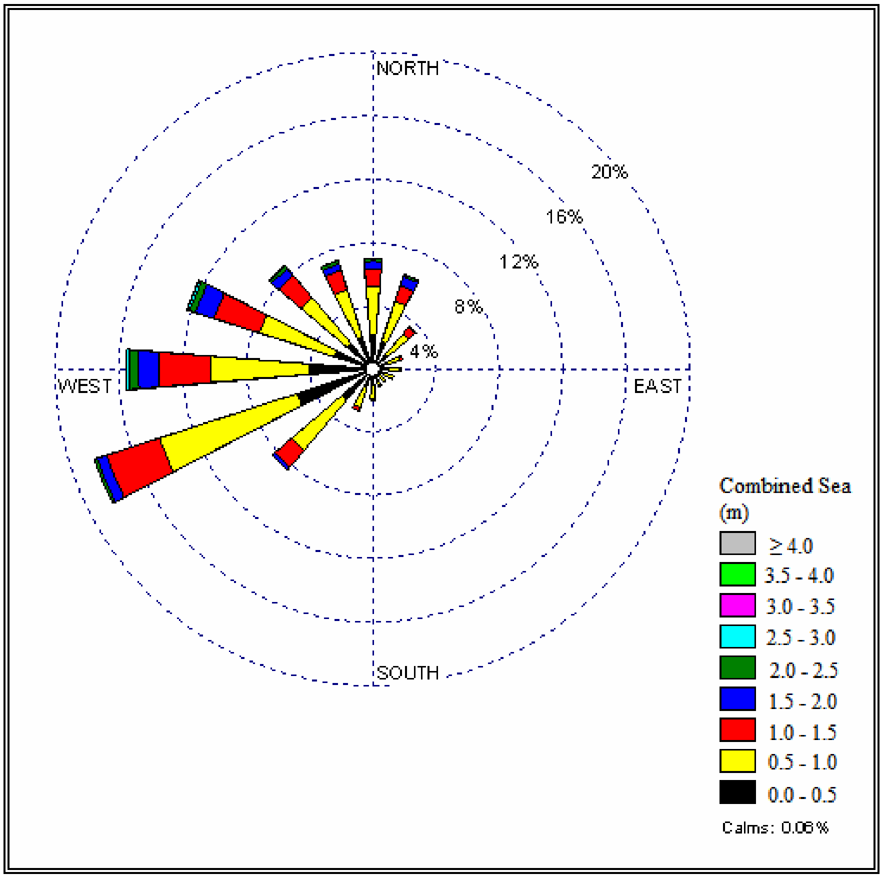


Figure C.9 September Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



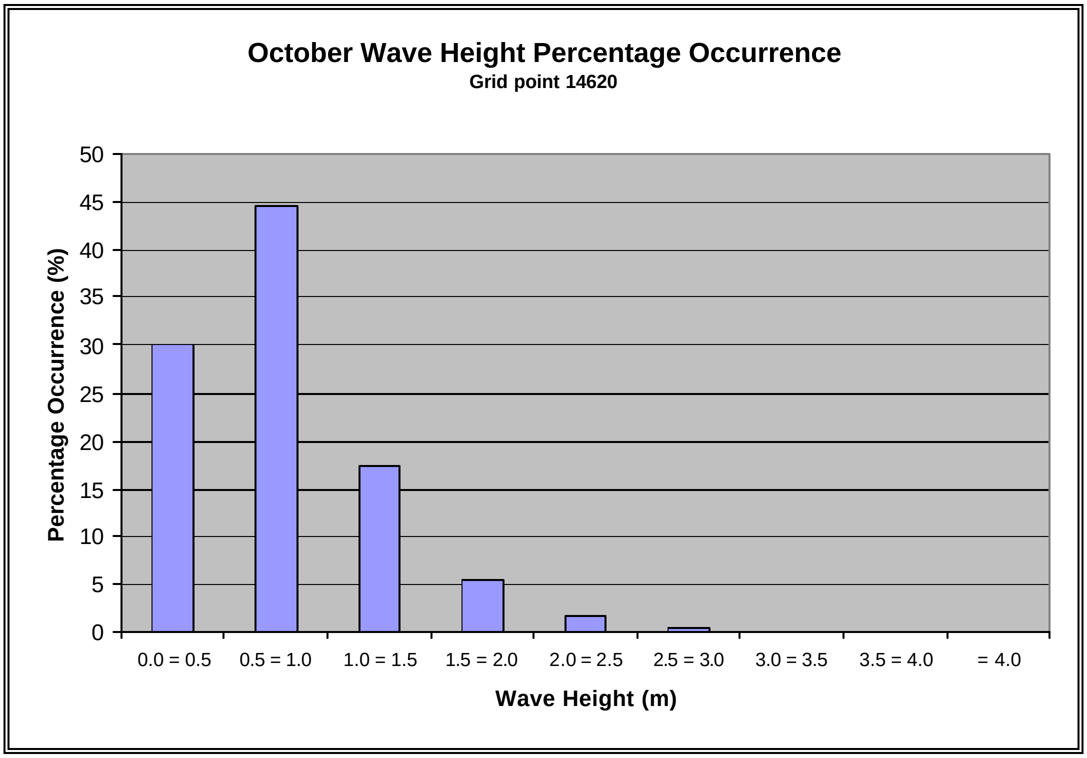
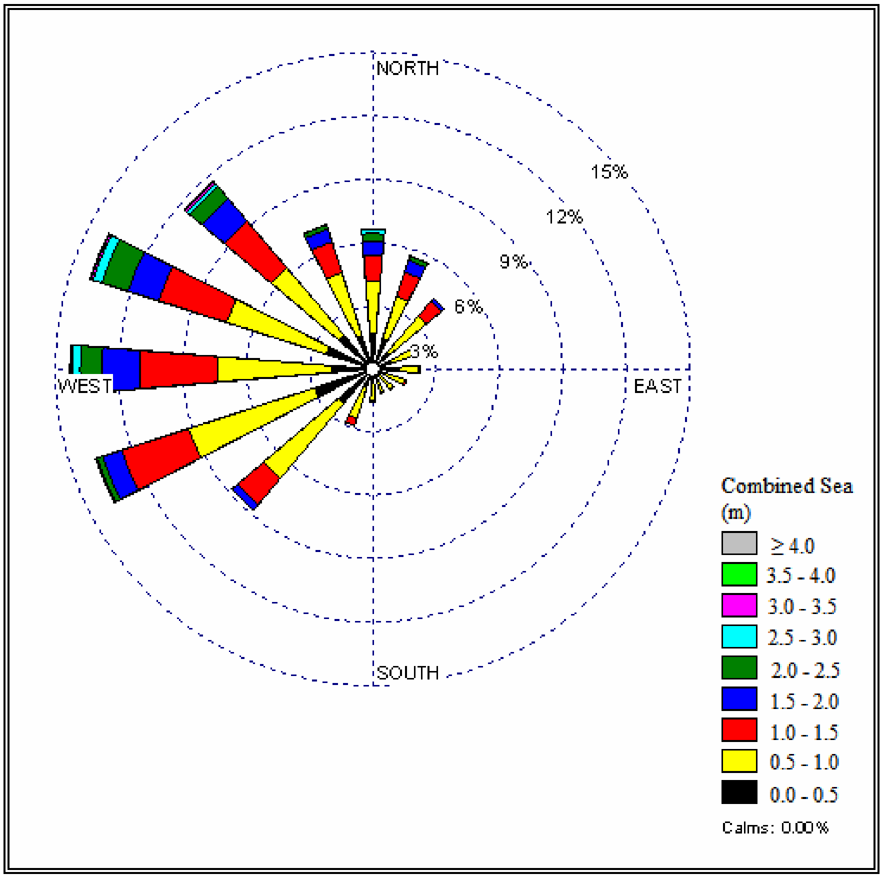


Figure C.10 October Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



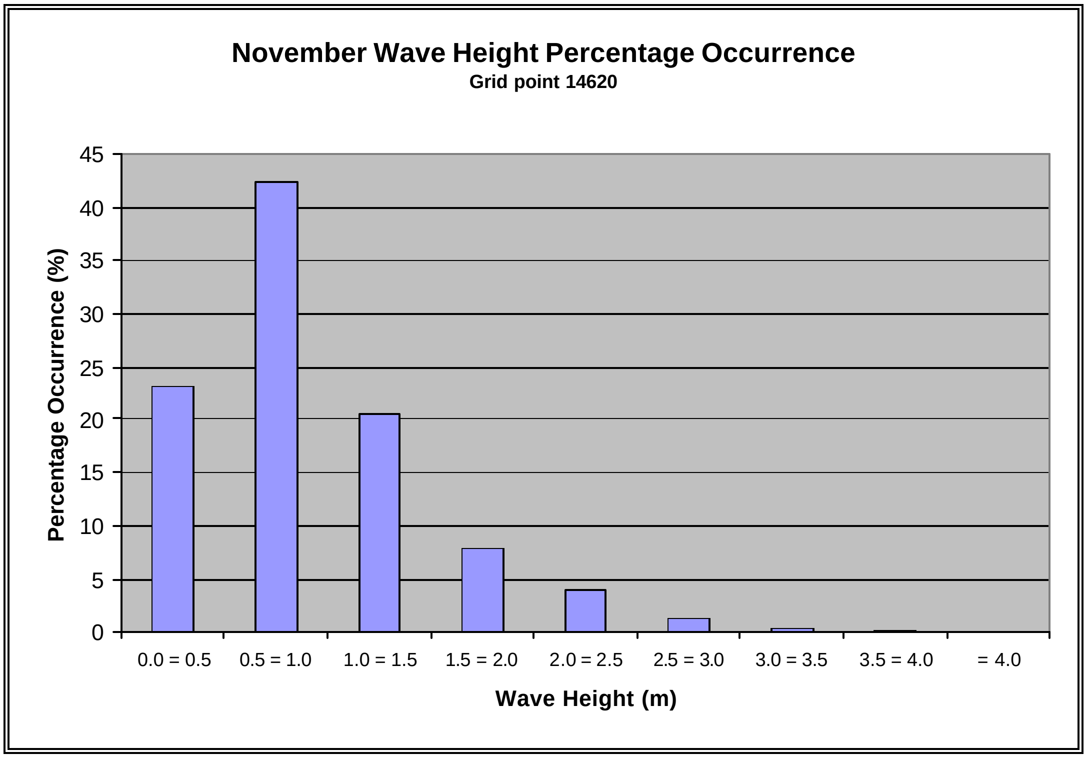
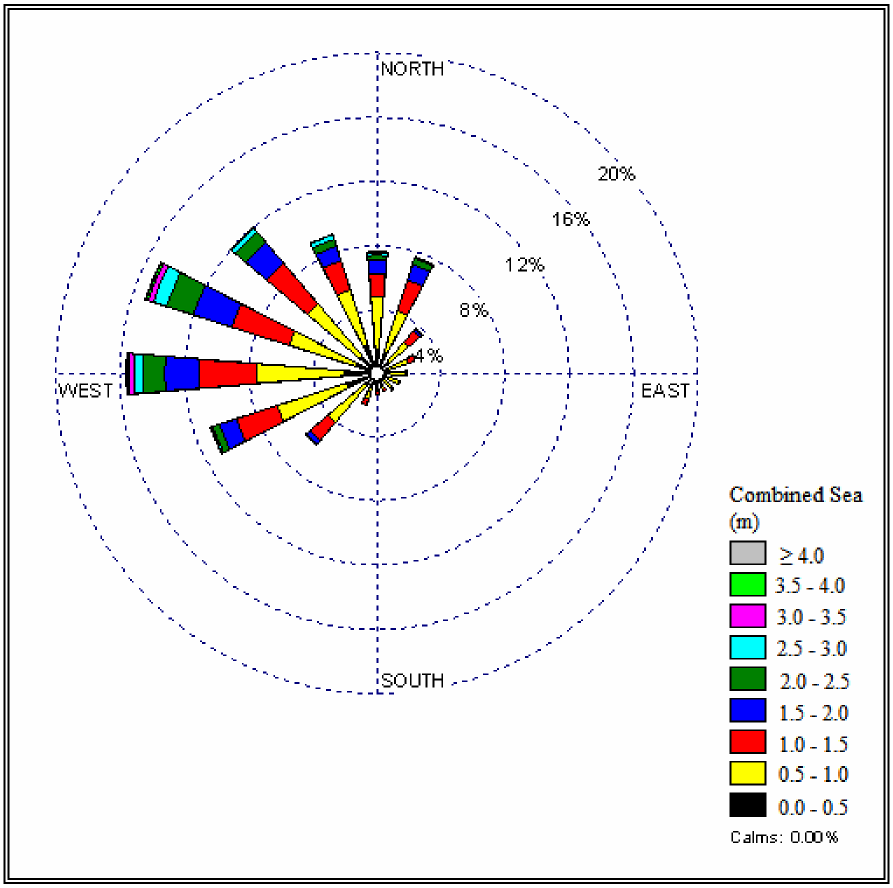


Figure C.11 November Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620



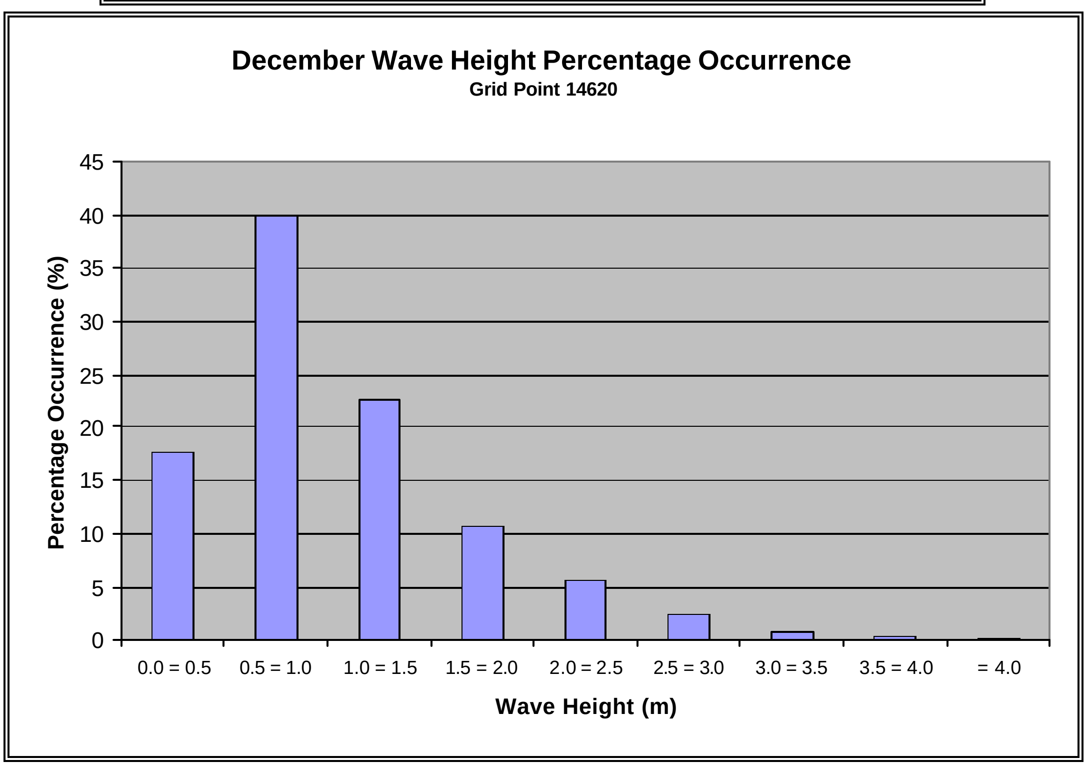


Figure C.12 December Wave Rose and Percentage Occurrence Graphs for MSC50 GridPoint 14620

Appendix 4
Percentage Exceedance of Wave Heights for MSC50 GridPoint 14620

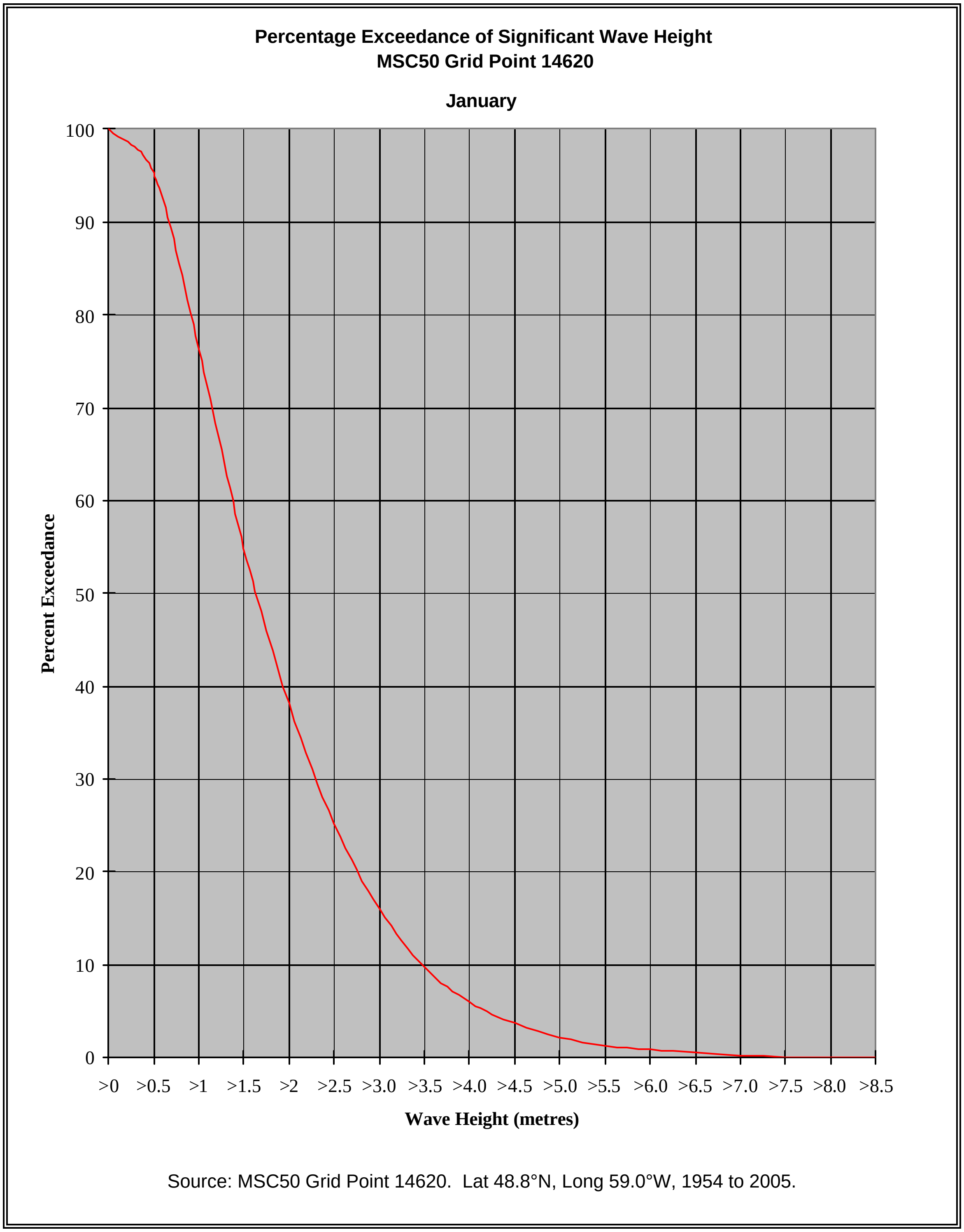


Figure D.1 January Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

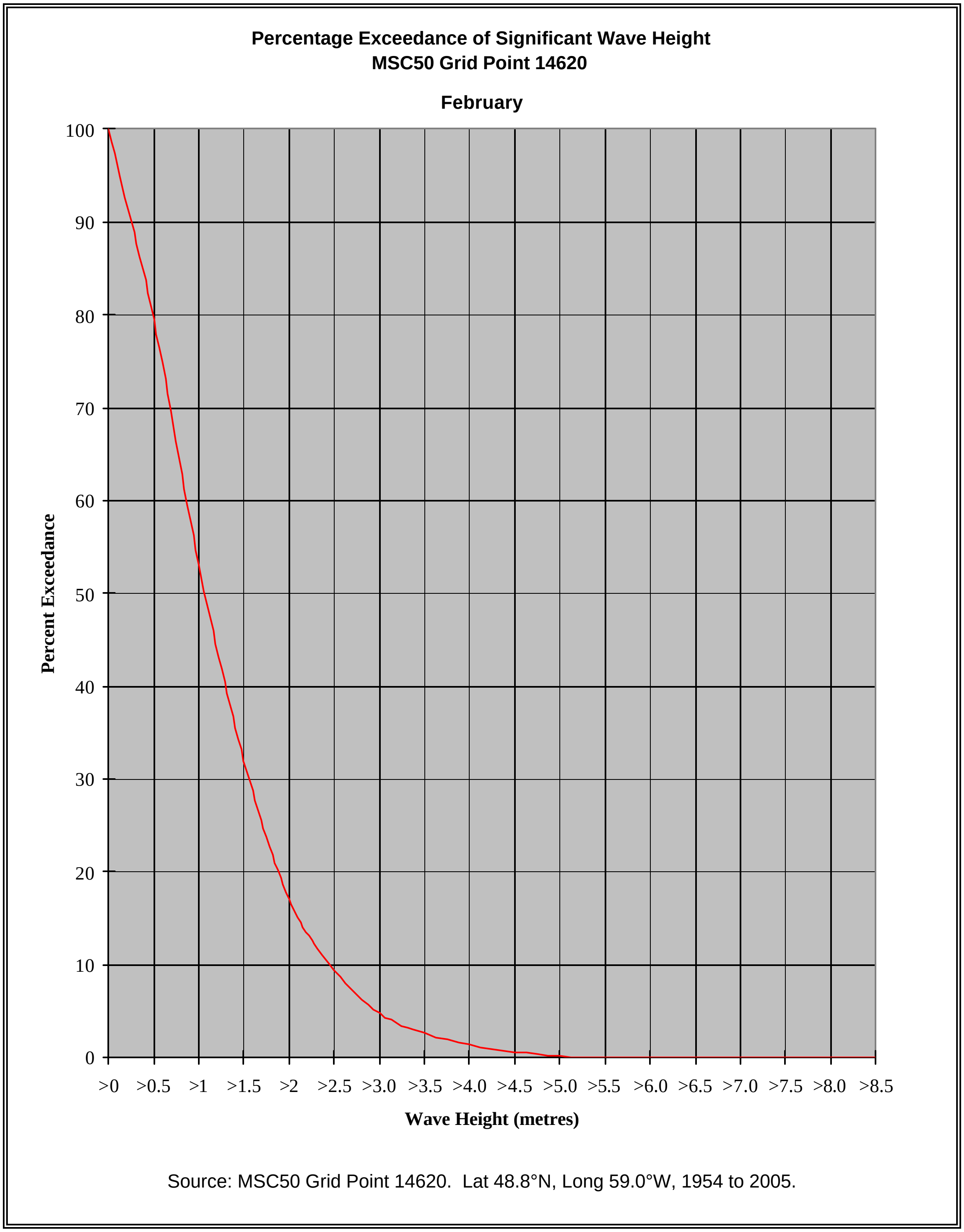


Figure D.2 February Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

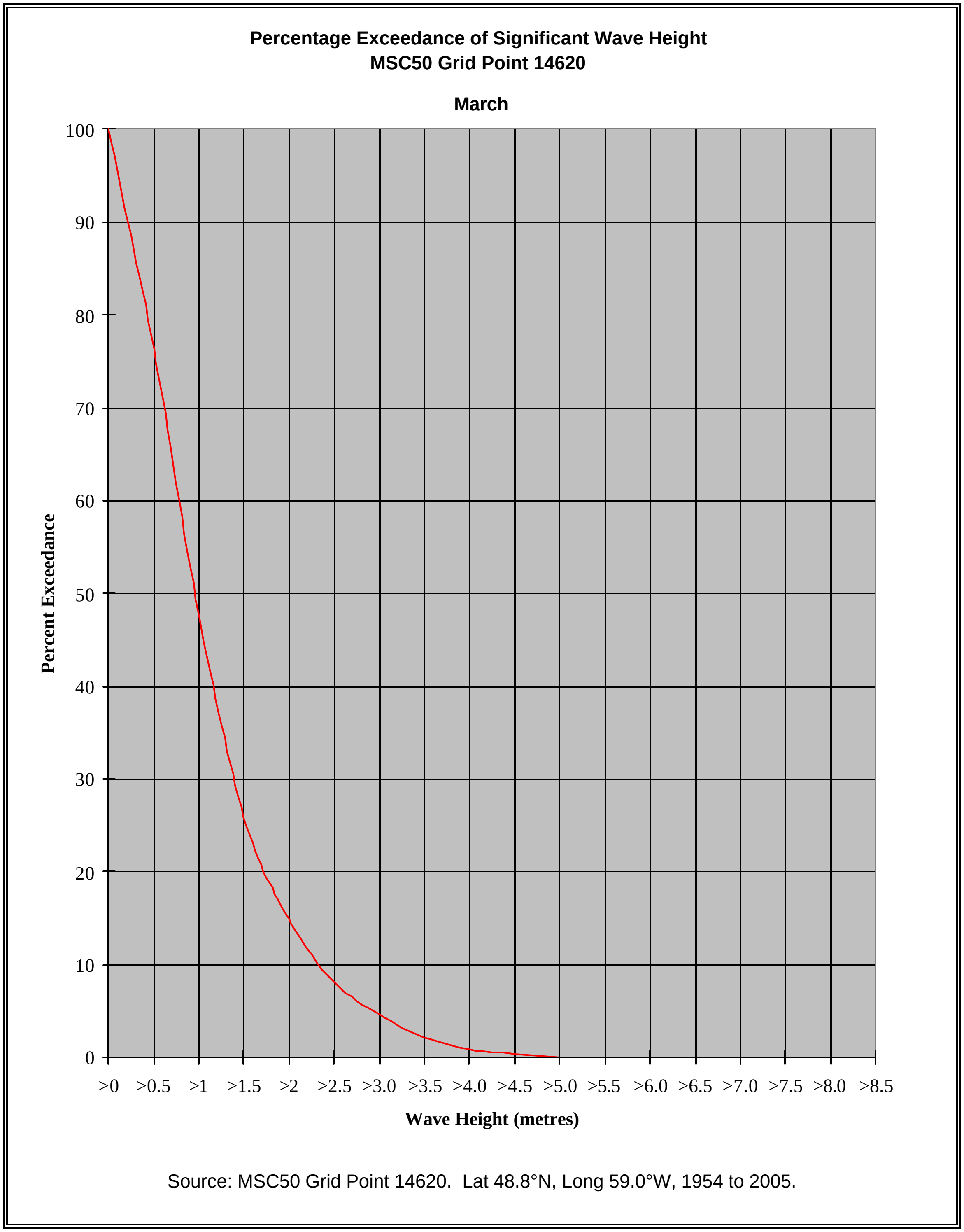


Figure D.3 March Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

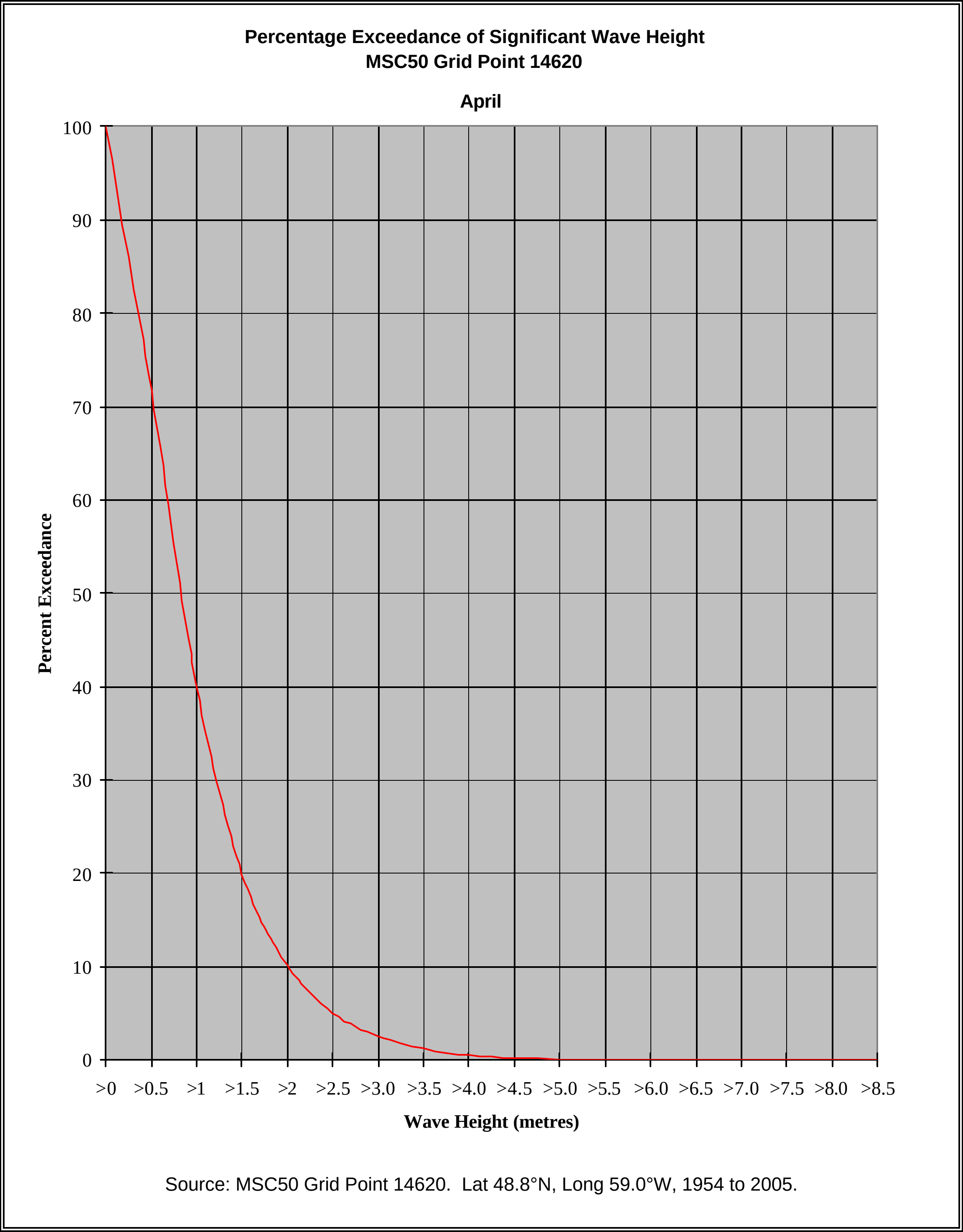


Figure D.4 April Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

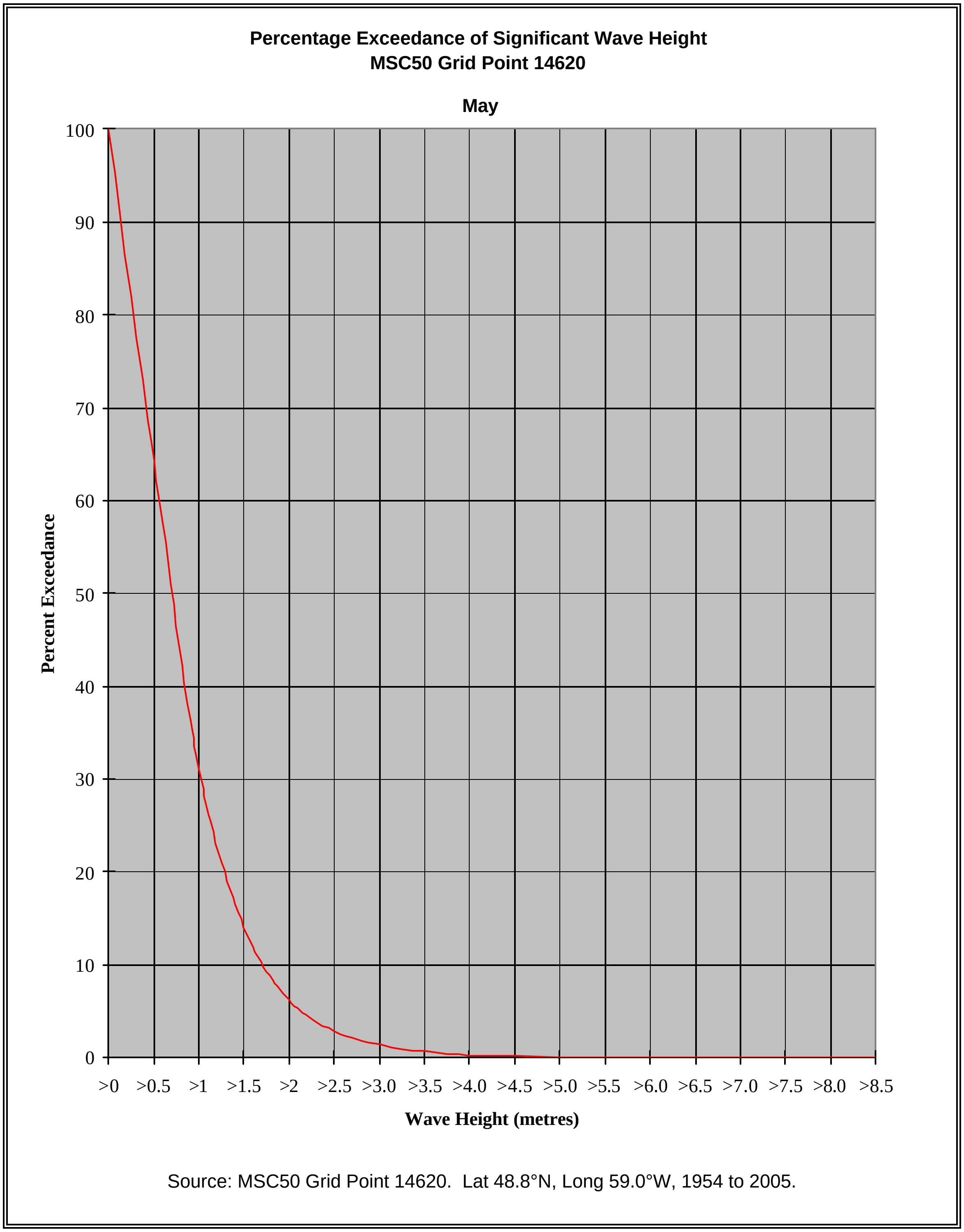


Figure D.5 May Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

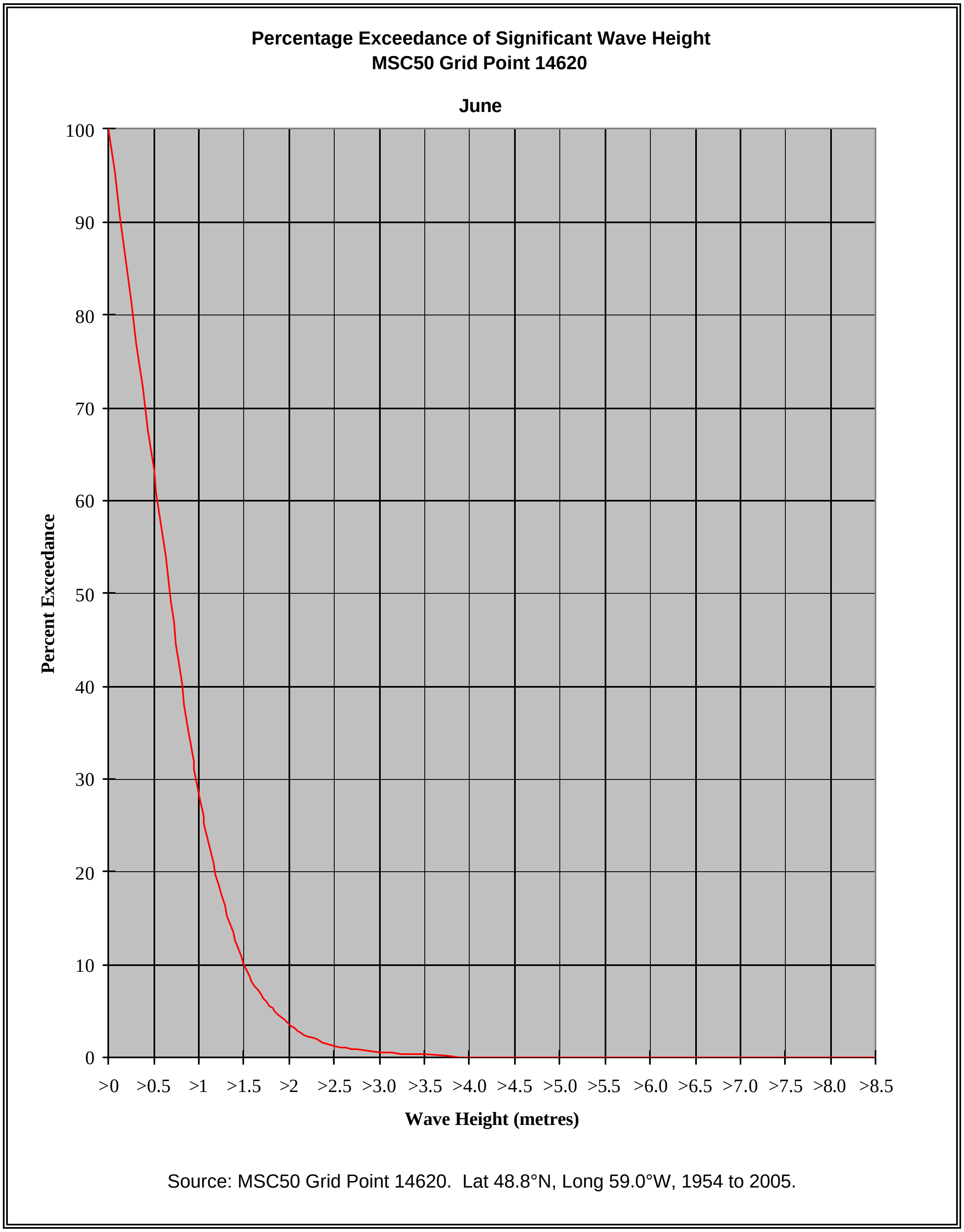
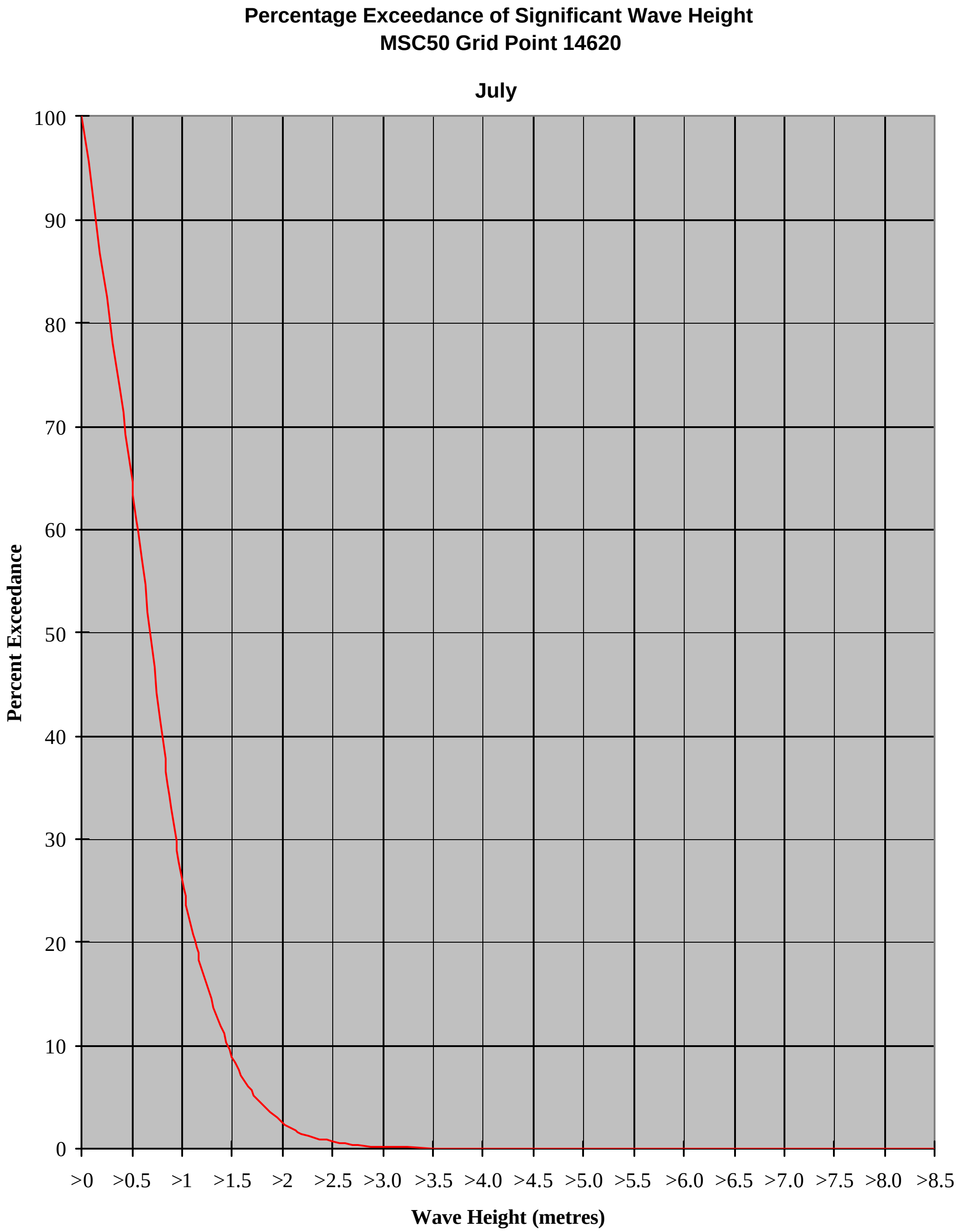


Figure D.6 June Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620



Source: MSC50 Grid Point 14620. Lat 48.8°N, Long 59.0°W, 1954 to 2005.

Figure D.7 July Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

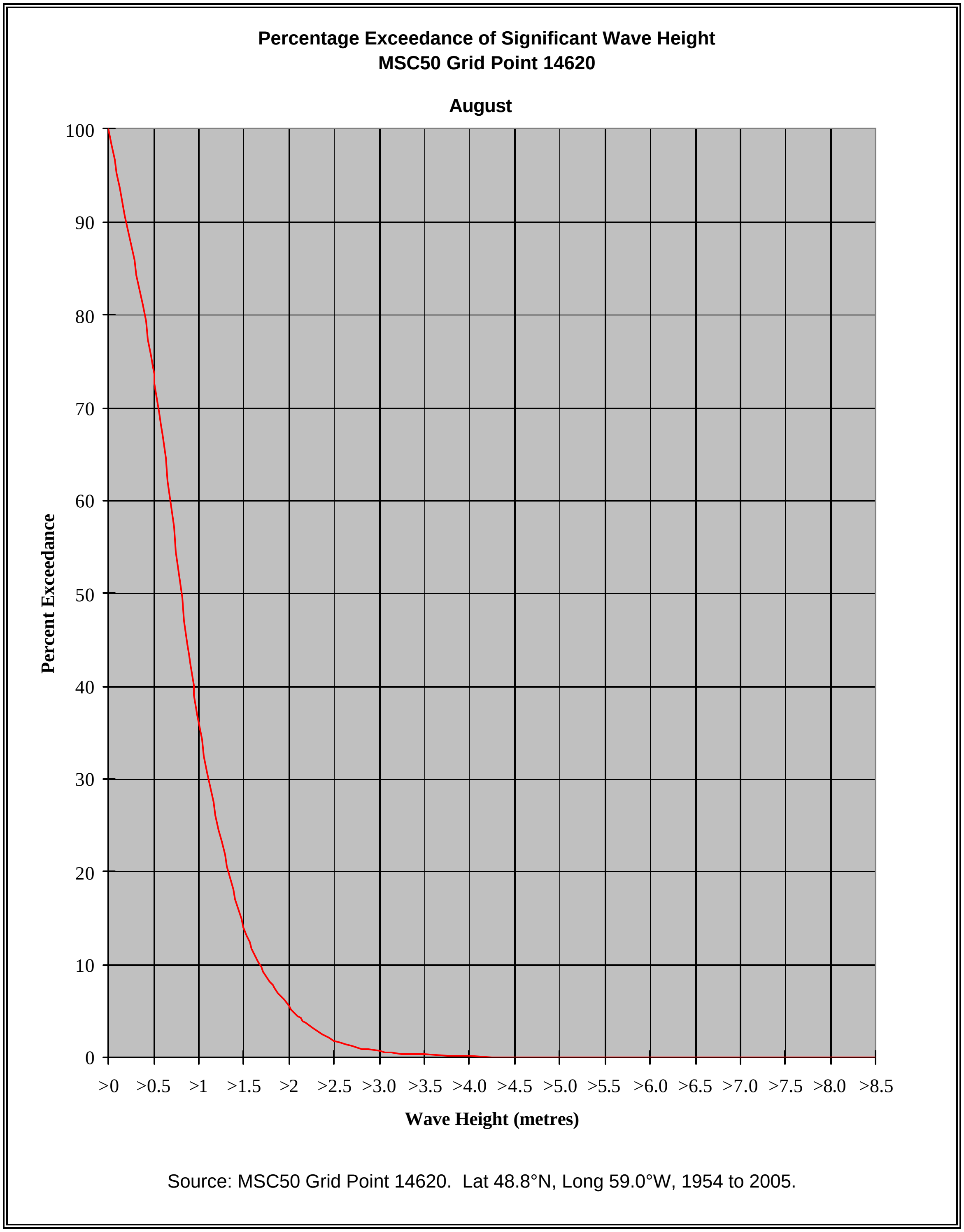


Figure D.8 August Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

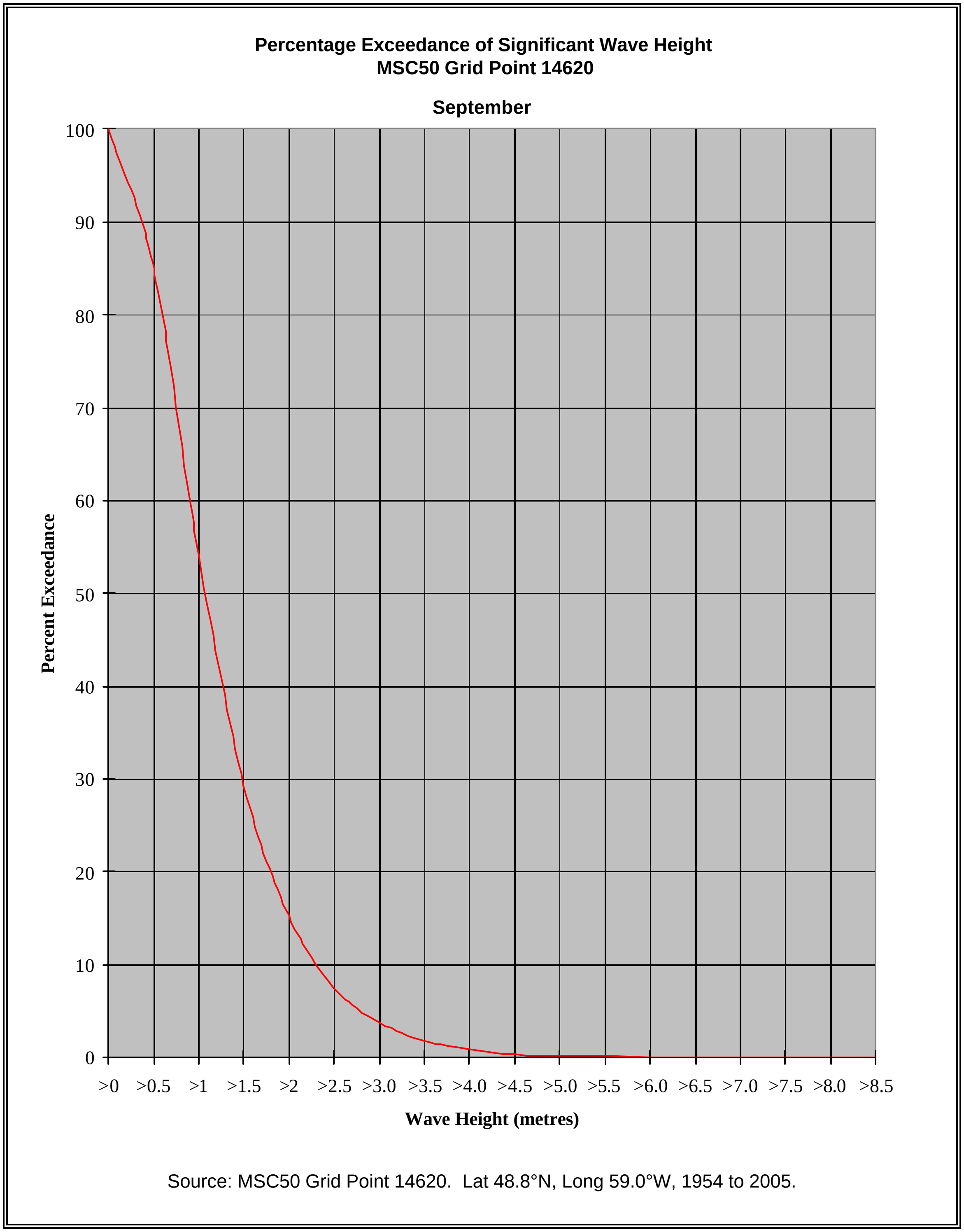


Figure D.9 September Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

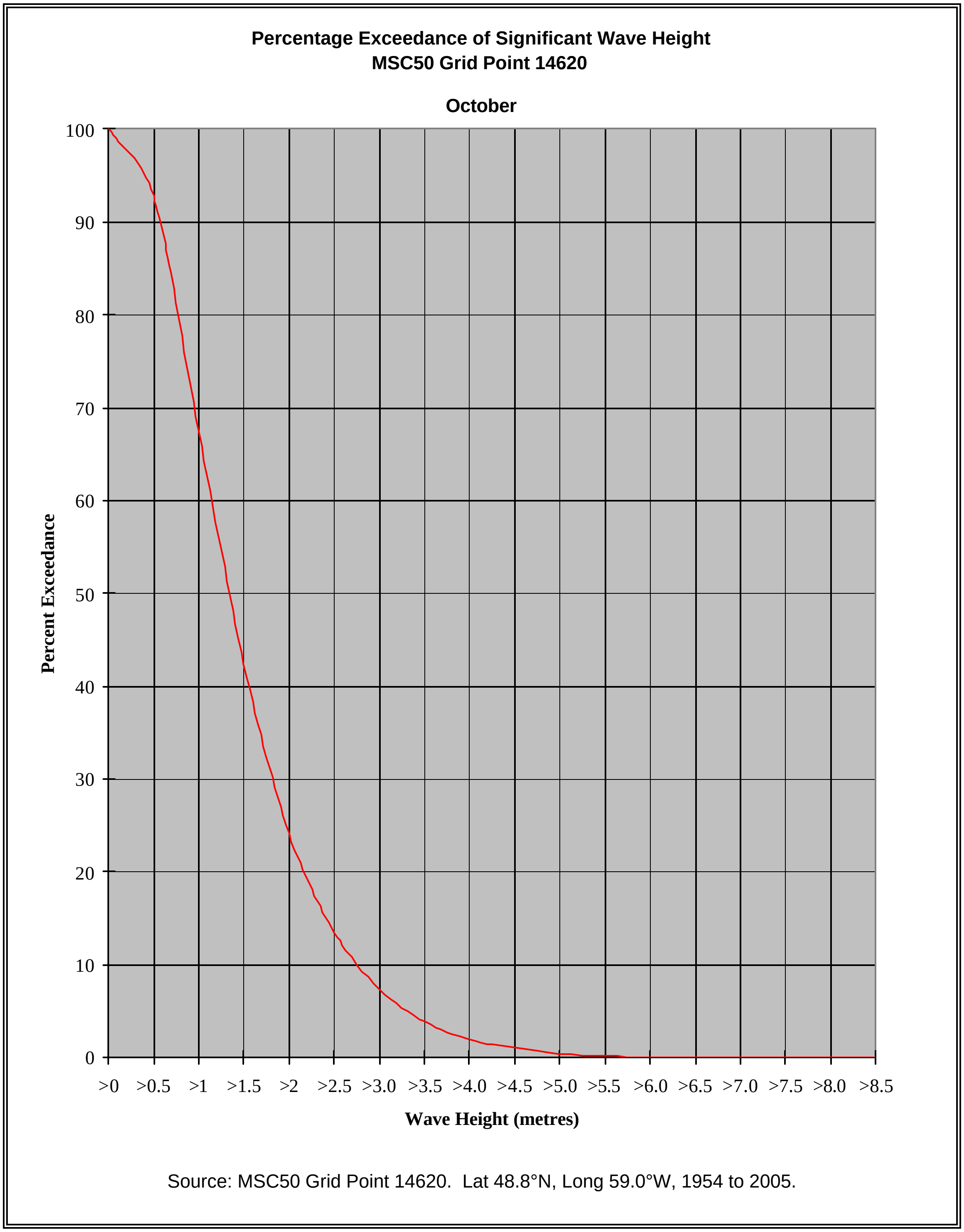


Figure D.10 October Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

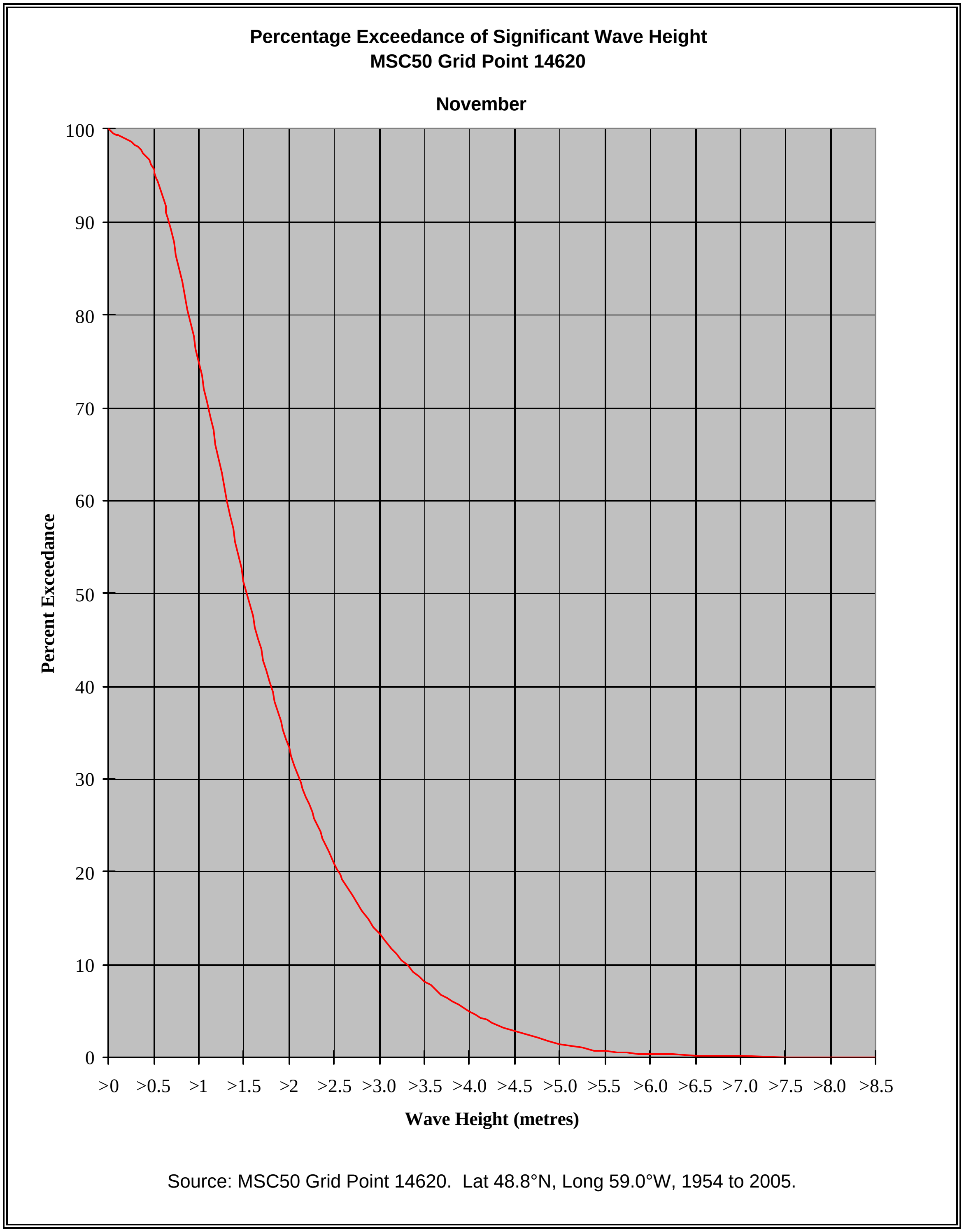


Figure D 11 November Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620

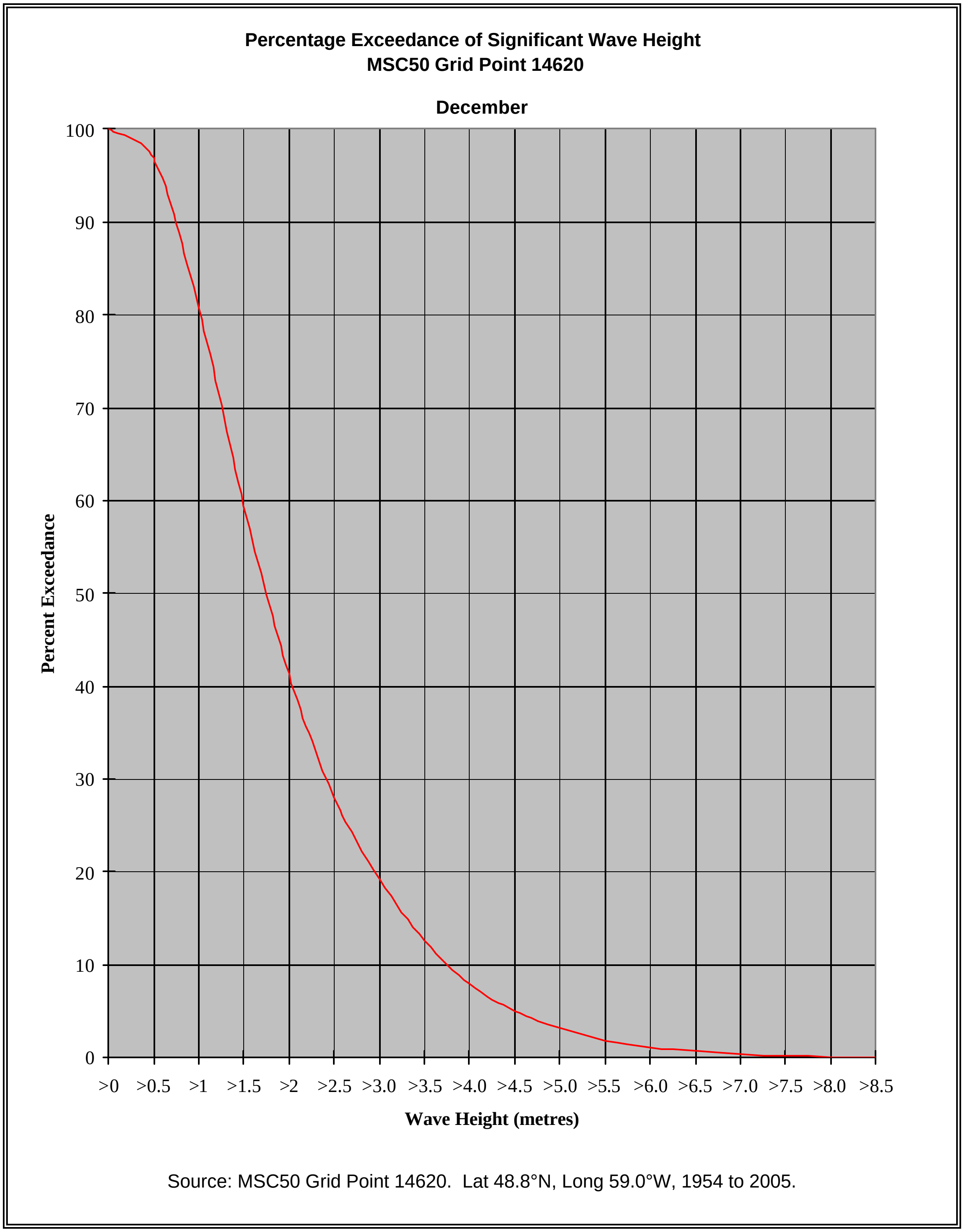
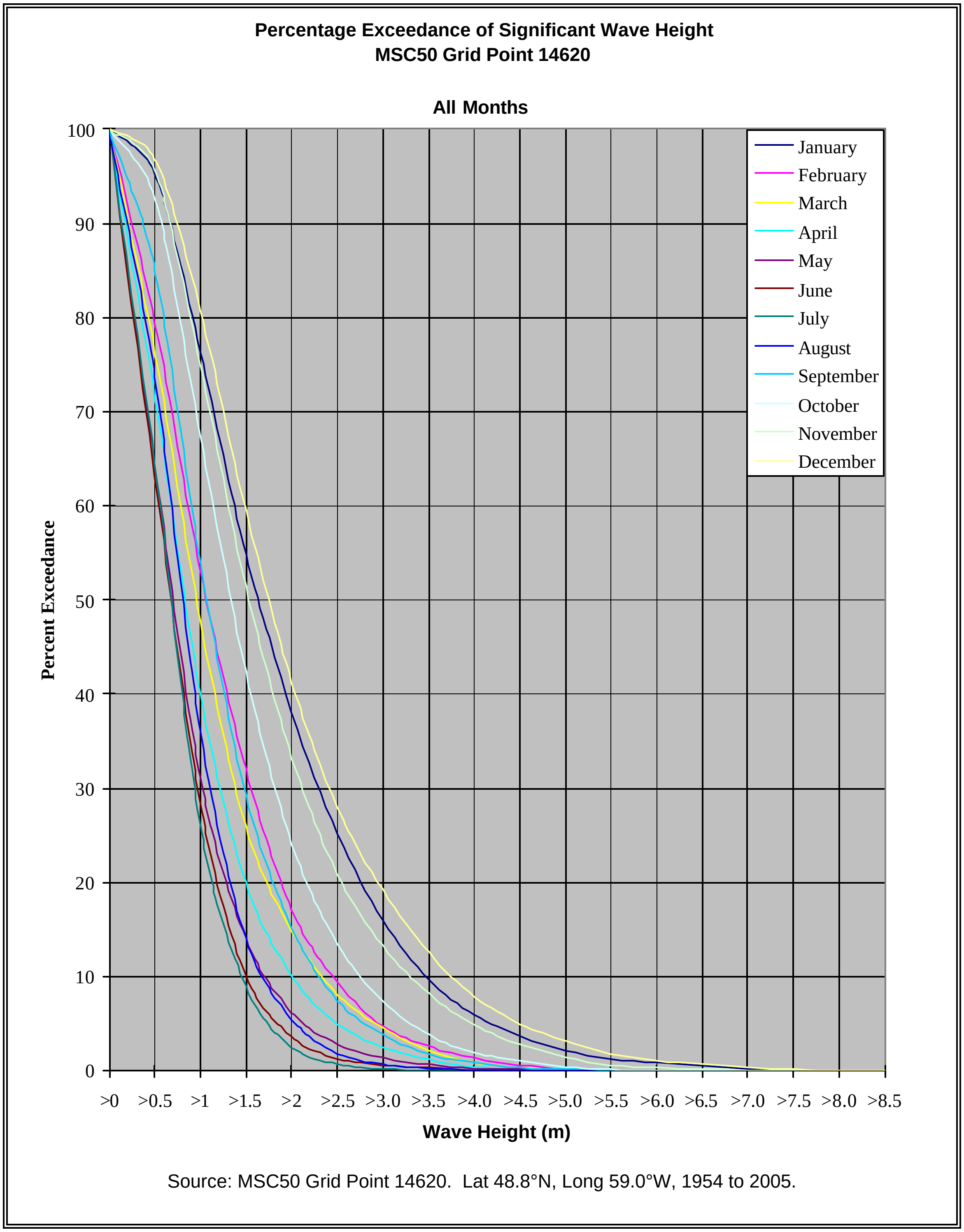


Figure D.12 December Percentage Exceedance of Significant Wave Height for MSC50 Grid Point 14620


Percentage Exceedance of Significant Wave Height
MSC50 Grid Point 14620
All Months
Percent Exceedance
100
90
80
70
60
50
40
30
20
10
0
>0
>0.5
>1
>1.5
>2
>2.5
>3.0
>3.5
>4.0
>4.5
>5.0
>5.5
>6.0
>6.5
>7.0
>7.5
>8.0
>8.5
Wave Height (m)
January
February
March
April
May
June
July
August
September
October
November
December
Source: MSC50 Grid Point 14620. Lat 48.8°N, Long 59.0°W, 1954 to 2005.