Physical Environmental Study for the Southern Grand Banks Seismic Program 2014-2018

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1.0 Introduction

The purpose of this report is to provide a description of the physical environment of the southern Grand Banks and adjacent areas for the purpose of providing information to assist with planning seismic surveys. The study area is shown in Figure 1.1

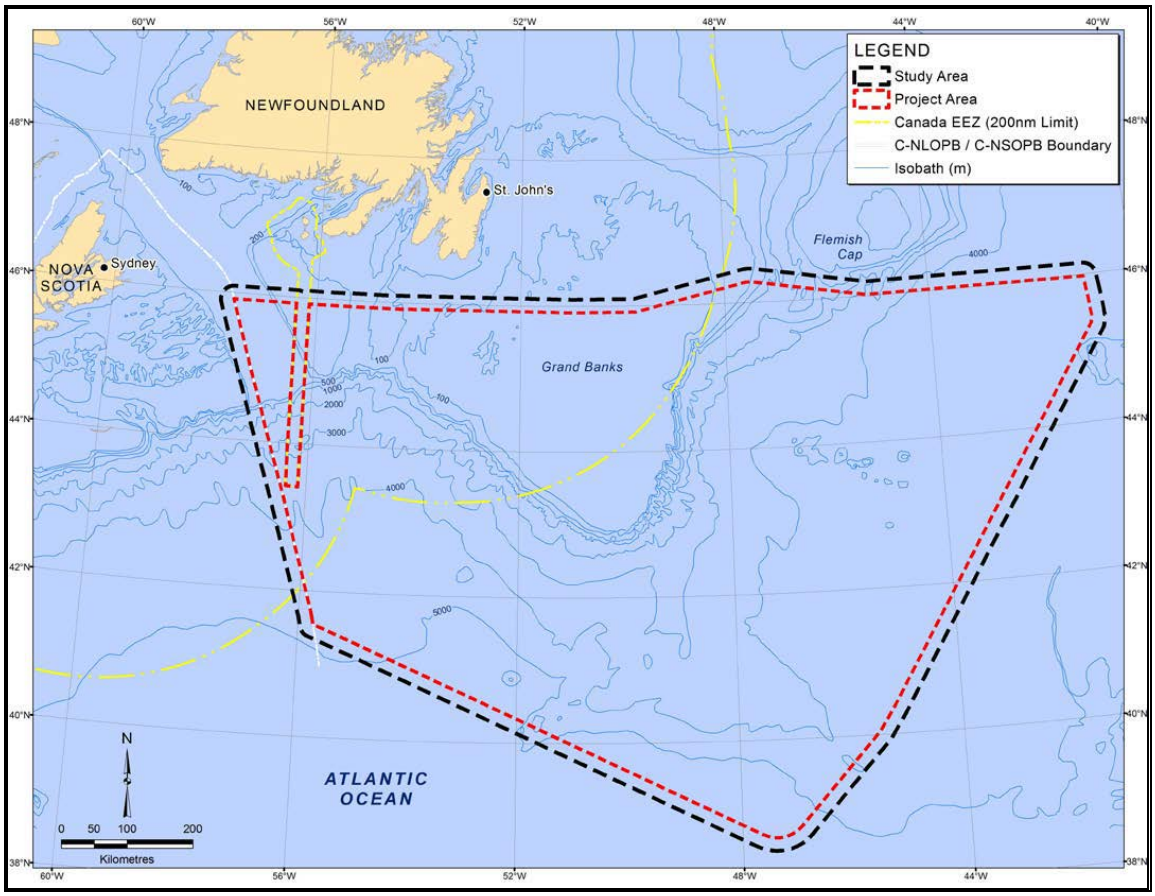


Figure 1.1 Study Area

The wind and wave climatology of the project area was prepared from the MSC50 hindcast data set prepared by Oceanweather Inc. for Environment Canada. The climate analysis was carried out using four grid points to represent the project area. The grid points are Grid Point 05000 at 43.5°N; 54.5°W; Grid Point 08026 at 45.0°N; 50.0°W; Grid Point 10537 at 41.5°N; 47.0°W; and Grid Point 11154 at 44.0°N; 45.0°N. The grid points were selected in the areas of Laurentian Sub-basin, Southern Grand Banks, Newfoundland Basin, and in the deep water south of the Grand Banks.

The report presents a general description of the weather systems and the influence of tropical systems. Statistics of mean and maximum wind speeds, and mean and maximum significant

wave heights are presented in the report together with the frequency distribution of wind speeds and wave heights from specific directions. The information on air temperature, sea surface temperature, visibility, precipitation, and sea spray icing has been prepared from the International Comprehensive Ocean Atmosphere Data Set (ICOADS).

An extremal analysis for wind and waves for return periods of 1-year, 10-years, 25-years, 50-years, and 100-years has been carried out using the Gumbel Distribution.

Information on sea ice, extracted from the recent Sea Ice Climate Atlas for the East Coast, and information on icebergs, from the International Ice Patrol Iceberg Sightings data base is presented in the report.

The physical oceanography section consists of a description of the currents and water properties in the area. The current data base consists of moored current data from the Bedford Institute of Oceanography archive. A general description of currents is presented for the area using information from published literature as well as statistics of mean velocities and monthly mean and maximum current speeds from current measurements. The water properties are described using published literature, hydrographic contours from data collected by Fisheries and Oceans Canada, statistics of temperature and salinity data, and T-S diagrams from data archived at the Bedford Institute of Oceanography.

2.0 General Description of Weather Systems

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

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

During the winter months, an upper level trough tends to lie over central Canada and an upper ridge over the North Atlantic resulting in three main storm tracks affecting the region: one from the Great Lakes Basin, one from Cape Hatteras, North Carolina and one from the Gulf of Mexico. These storm tracks, on average, bring eight low pressure systems per month over the area. The intensity of these systems ranges from relatively weak features to major winter storms. Recent studies (Archer and Caldeira, 2008) have shown that there exists a poleward shift of the jet stream, and consequently storm tracks, at a rate of 0.17 to 0.19 degrees/decade in the northern hemisphere. This shift has been related to an increase in the equator-to-pole temperature gradient. McCabe (2001) obtained similar results, finding that there has been a decrease in mid-latitude cyclone frequency and an increase in high-latitude cyclone frequency. In addition, McCabe (2001) found that storm intensity has increased in both the high and mid-latitudes.

In the case where the upper level long wave trough lies well west of the region, the main storm track will lie through the Gulf of St. Lawrence or Newfoundland. Under this regime, an east to southeast flow ahead of a warm front associated with a low will give way to winds from the south in the warm sector of the system. Typically, the periods of southerly winds and mild conditions will be of relatively long duration, and in general, the incidence of extended storm conditions is likely to be relatively infrequent. Strong frictional effects in the stable flow from the south results in a marked shear in the surface boundary layer and relatively lower winds at the sea surface. As a consequence, local wind wave development tends to be inhibited under such conditions. Precipitation types are more likely to be in the form of rain or drizzle, with relatively infrequent periods of continuous snow, although periods of snow showers prevail in the unstable air in the wake of cold fronts associated with the lows. Visibility will be reduced at times in frontal and advection fogs, in snow, and in snow shower activity.

At other times, with the upper long wave trough situated further to the east, the main storm track may lie through or to the east of the study area. With the lows passing closer to the study area and a higher potential for storm development, the incidence of strong gale and storm force conditions is greater. Longer bouts of cold, west to northwest winds behind cold fronts occur more frequently, and because the flow is colder than the surface water temperatures, the surface layer is unstable. The shear in the boundary layer is lower, resulting in relatively higher wind speeds near the surface, and consequently relatively higher sea state conditions. With cold air and sea surface temperatures coupled with high winds, the potential for freezing spray will occur quite frequently. In this synoptic situation, a greater incidence of precipitation in the form of snow is likely to occur. Freezing precipitation, either as rain or drizzle, occurs infrequently south of Newfoundland. Visibility will be reduced in frontal and advection fogs, and frequently by snow.

By summer, the main storm tracks have moved further north than in winter. Low-pressure systems are less frequent and much weaker. With increasing solar radiation during spring, there is a general warming of the atmosphere that is relatively greater at higher latitudes. This decreases the north-south temperature contrast, lowers the kinetic energy of the westerly flow aloft and decreases the potential energy available for storm development. Concurrently, there is a northward shift of the main band of westerly winds at upper levels and a marked development of the Bermuda-Azores sub-tropical high-pressure area to the south. This warm-core high-pressure cell extends from the surface through the entire troposphere. The main track of the weaker low-pressure systems typically lies through the Labrador region and tends to be oriented from the west-southwest to the east-northeast.

With low pressure systems normally passing to the north of the region in combination with the northwest sector of the sub-tropical high to the south, the prevailing flow across the Grand Banks is from the southwest during the summer season. Wind speed is lower during the summer and the incidence of gale or storm force winds relatively infrequent. There is also a corresponding decrease in significant wave heights.

The prevailing southwesterly flow during the late spring and early summer tends to be moist and it is relatively warmer than the underlying surface waters on the Grand Banks.

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

Rapidly deepening storms are a problem south of Newfoundland in the vicinity of the warm water of the Gulf Stream. Sometimes these explosively deepening oceanic cyclones develop into a “weather bomb”; defined as a storm that undergoes central pressure 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 near the southeast coast producing gale to storm force winds from the southwest to south over the study area.

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

A significant number of tropical cyclones which move into the mid-latitudes will undergo transition into extratropical cyclones. On average, 46% of tropical cyclones which formed in the Atlantic transform into extratropical cyclones. During this transformation, the system loses tropical characteristics and becomes more extratropical in nature. These systems frequently produce large waves, gale to hurricane force winds and intense rainfall. The likelihood that a tropical cyclone will undergo transition increases toward the second half of the tropical season, with October having the highest probability of transition. In the Atlantic, extratropical transition occurs at lower altitudes in the early and late hurricane season and at higher latitudes during the peak of the season (Hart and Evans, 2001).

2.1 Data Sources

The data sources to describe the climatology of the Study Area came from four main sources: the MSC50 North Atlantic wind and wave climatology database, the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), and the National Hurricane Centre's best-track dataset. The locations of the climate data sources are presented in Figure 2.1.

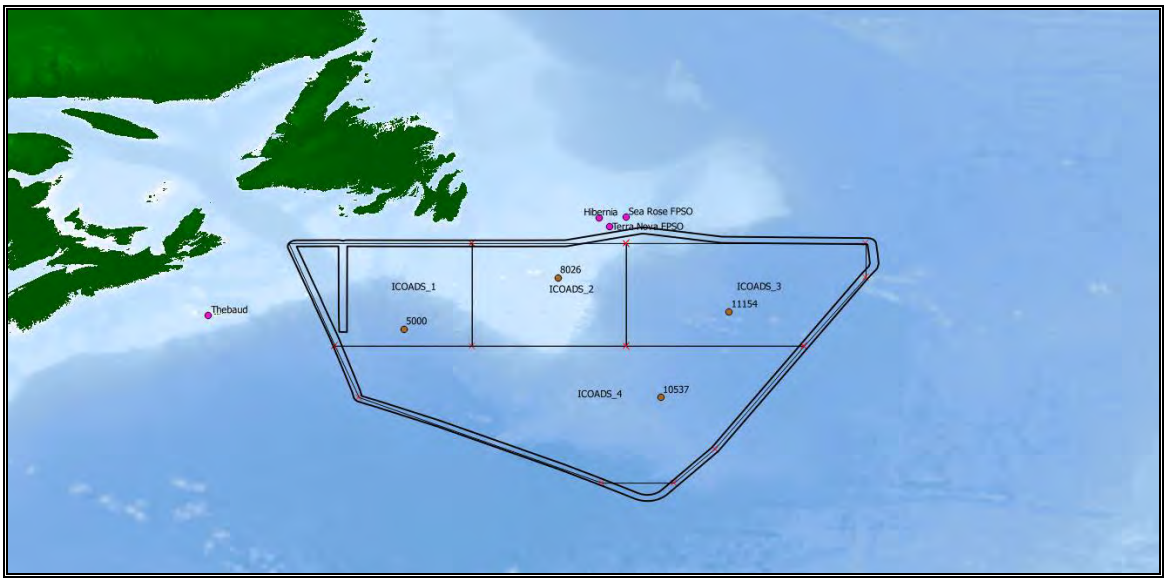


Figure 2.1 Climate Data Locations

2.1.1 MCS50

Wind and wave climate statistics for the area were extracted from the MSC50 North Atlantic wind and wave climatology database compiled by Oceanweather Inc under contract to Environment Canada. Four grid points were chosen from the MSC50 data set. Grid points 05000 and 08026 are 1-hour time steps of continuous wind and wave hindcast data from January 1954 to December 2010, on a 0.1° latitude by 0.1° longitude grid. Grid Points 10537 and 11154 are 3-hour time steps of continuous wind and wave hindcast data from January 1954 to December 2010, on a 0.5° latitude by 0.5° longitude grid.

A precise location of each grid point is located in Table 2.1.

Table 2.1 MSC50 Grid Point Locations

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

Winds from the MSC50 data set are 1-hour averages of the effective neutral wind at a height of 10 m (Harris, 2007).

Prior to 1962, 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. Since 1962, weekly ice data supplied by the Canadian Ice Service was used allowing the MSC50 hindcast to better represent the changing ice conditions (Swail et al., 2006).

2.1.2 ICOADS

Wind, air temperature, sea surface temperature, precipitation, visibility and probability of vessel icing statistics for the area 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 encompassing the study area and covering the period from January 1980 to September 2013 was used in this report.

The ICOADS data set has certain inherent limitations in that the observations are not spatially or temporally consistent. In addition, 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 an outlier trimming level of 5.5 standard deviations for wind speeds, and 3.5 standard deviations for air temperatures and sea surface temperatures. In an attempt not to exclude valid observations from the data set, any data greater than 4.5 standard deviations for wind speed and 2.8 standard deviations for air and sea surface temperature were flagged and subsequently analyzed for consistency with other data within the same region and same time. Despite this analysis valid observations may still have been excluded from the data set. Conversely, invalid data which fell within the limits of the quality control analysis may have been included in the data set.

While the ship-based reports have been quality controlled to the extent possible, they are likely to contain some observation errors, in addition to position report errors, particularly for the older reports. As well, the data set is known to contain a 'fair weather bias', which arises for the following reasons: ship's captains may choose to avoid areas of heavy weather, and since the reporting program is voluntary, fewer observations are likely to be taken under adverse weather and sea state conditions. This bias is more likely to be present during the winter season and over temperate and northern seas where vessel traffic is light.

Kent et al. (1993) demonstrated various systematic inconsistencies in the meteorological observations from voluntary observing ships. These inconsistencies were mostly dependent on the method of estimation used. Sea surface temperature data from engine intake thermometers were found to be biased high by an average of 0.3ºC. The dewpoint temperatures from fixed thermometer screens were biased high compared to psychrometer readings. The magnitude of the bias was of the order of 1ºC and varied with dewpoint temperature. Wind speeds from anemometers were biased high compared to visual winds by about two knots for winds up to about 25 knots. It was unknown whether visual winds or anemometer winds were more accurate. Compared to daytime values, visual winds at night were underestimated by about 1 m/sec at 15 m/sec and 5 m/sec at 25 m/sec.

2.1.3 National Hurricane Centre Best Track Data

Tropical cyclone climatology statistics were calculated from the National Hurricane Center's best-track data set (Neumann et al., 1993; Jarvinen et al., 1984). This data set provides positions and intensities at 6-hour intervals for every Atlantic tropical cyclone since 1886. In this report, a subset of the National Hurricane Center data set consisting of all storms of tropical origin from 1960 to 2010 which have tracked within 150 nm buffer zone surrounding the study area was used.

2.2 Wind

Low pressure systems crossing the area are more intense during the winter months. As a result, mean wind speeds tend to peak during this season. Mean wind speeds at all grid point's peak during the months of January and February (Table 2.2) with wind speeds ranging from 10.3 m/s to 11.2 m/s.

Table 2.2 Mean Wind Speed (m/s) Statistics

Month	Grid Point 05000	Grid Point 08026	Grid Point 10537	Grid Point 11154
January	11.2	10.4	10.8	11.2
February	11.2	10.3	10.8	11.2
March	10.3	9.3	10.0	10.2
April	9.0	8.0	8.9	9.0
May	7.5	6.6	7.4	7.6
June	6.8	6.2	6.8	7.0
July	6.3	5.8	6.1	6.2
August	6.7	6.1	6.3	6.5
September	7.9	7.1	7.3	7.6
October	9.1	8.3	8.4	8.9
November	10.1	9.1	9.5	9.7
December	11.2	10.1	10.5	10.9

Wind roses of the annual wind speed are presented in Figure 2.2 through Figure 2.5 and histograms of the wind speed frequency are presented in Figure 2.6 through Figure 2.9 for each grid point.

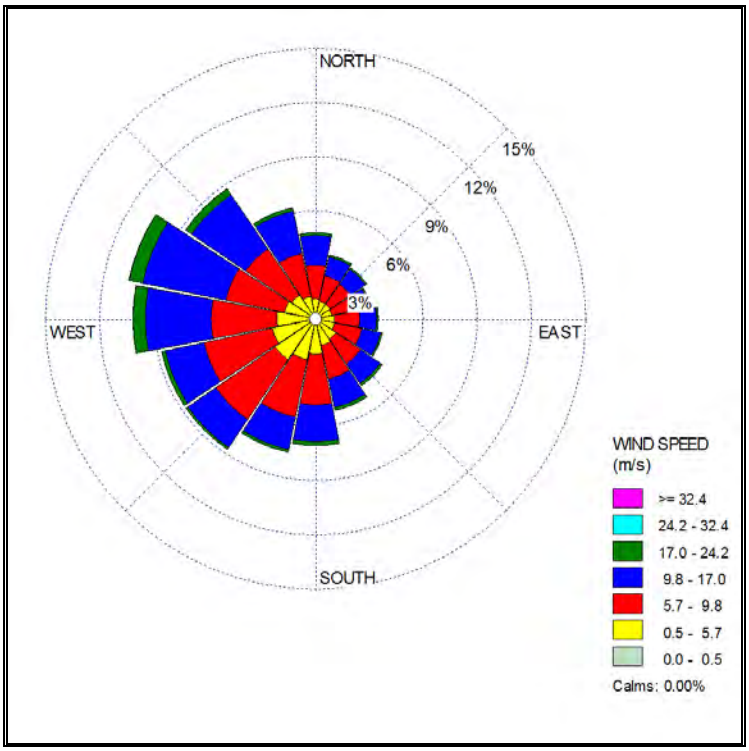


Figure 2.2 Annual Wind Rose for MSC50 Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

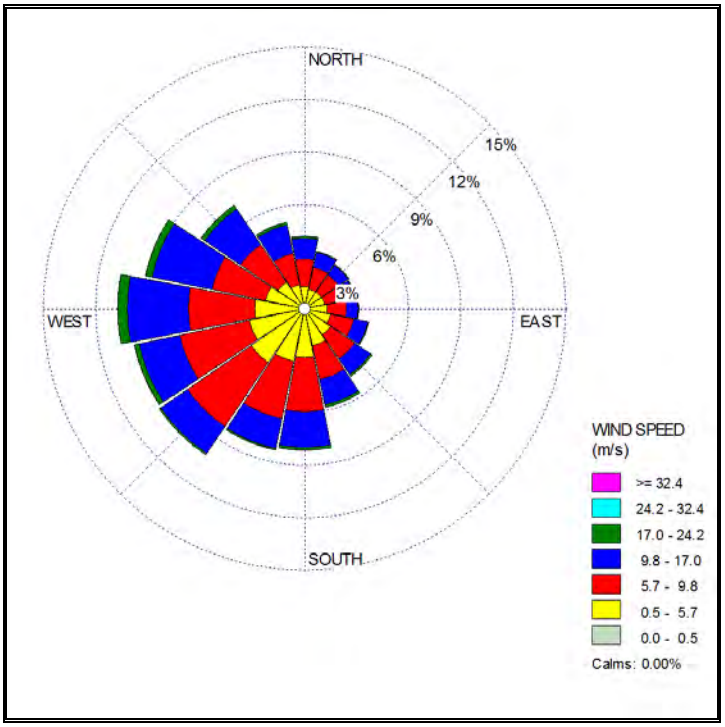


Figure 2.3 Annual Wind Rose for MSC50 Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

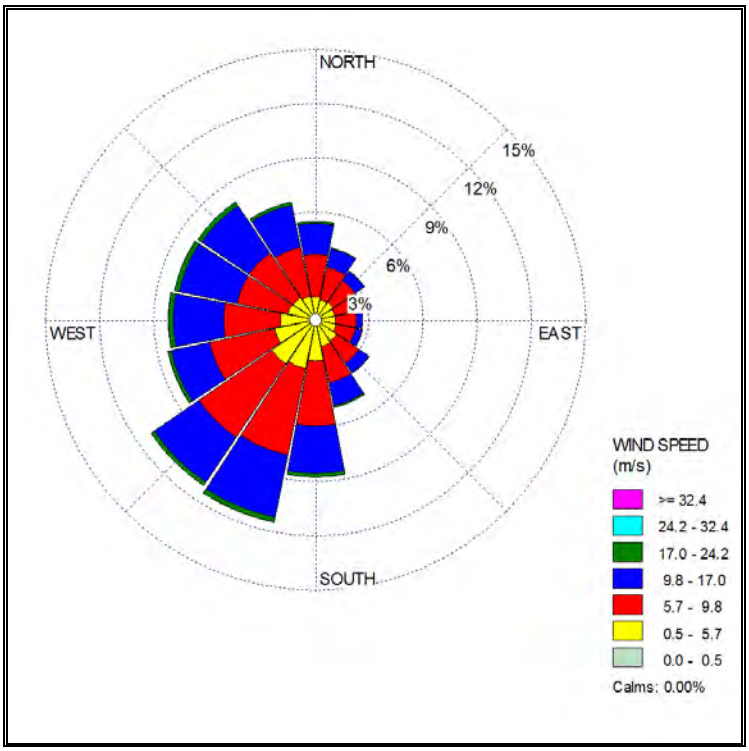


Figure 2.4 Annual Wind Rose for MSC50 Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

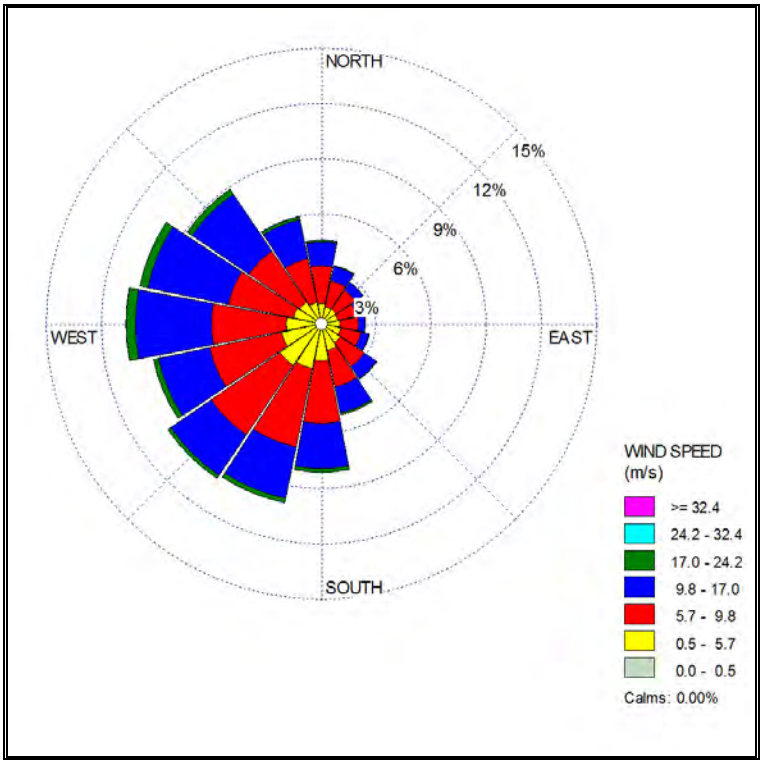


Figure 2.5 Annual Wind Rose for MSC50 Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

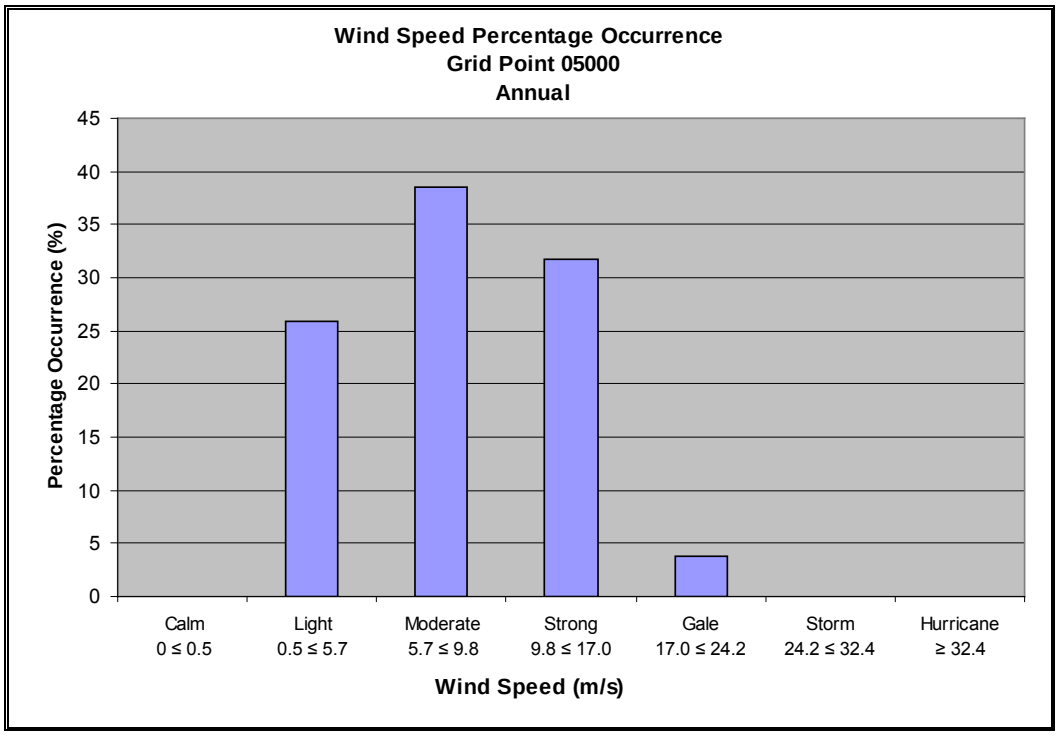


Figure 2.6 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

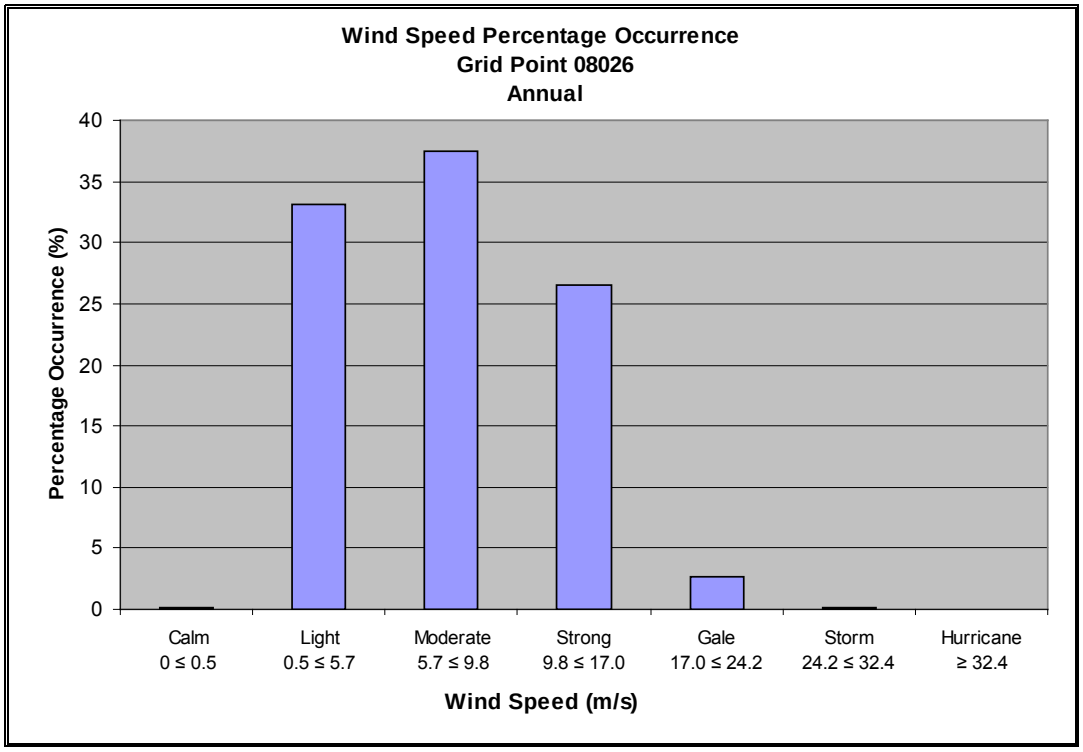


Figure 2.7 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

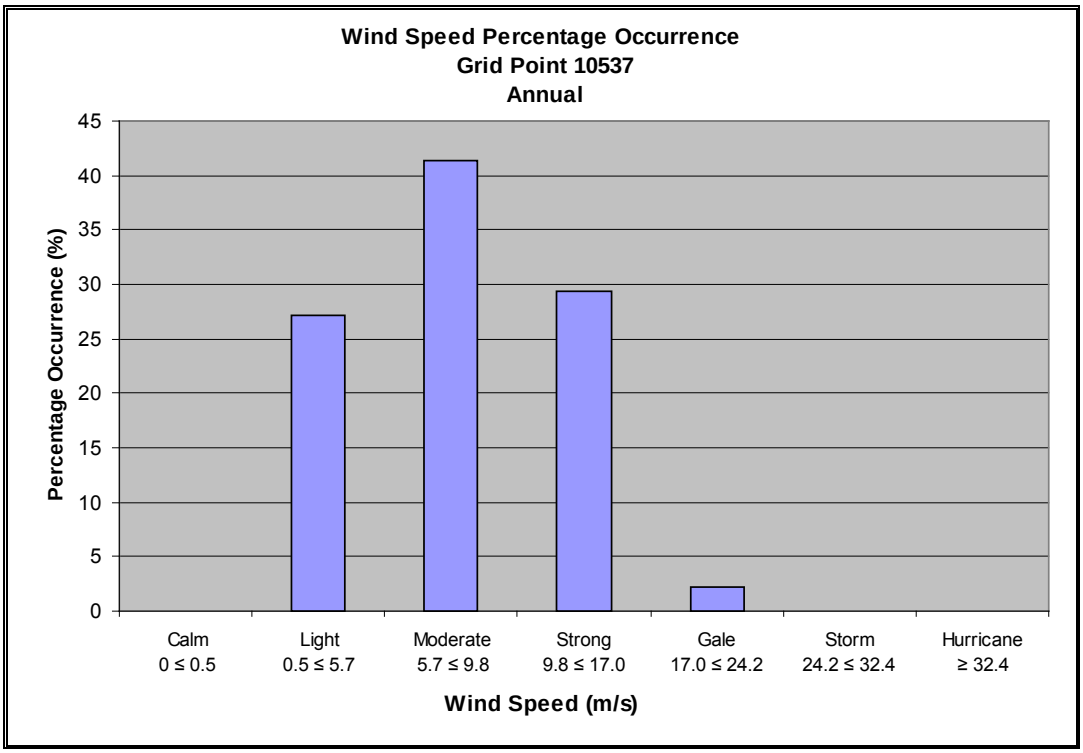


Figure 2.8 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

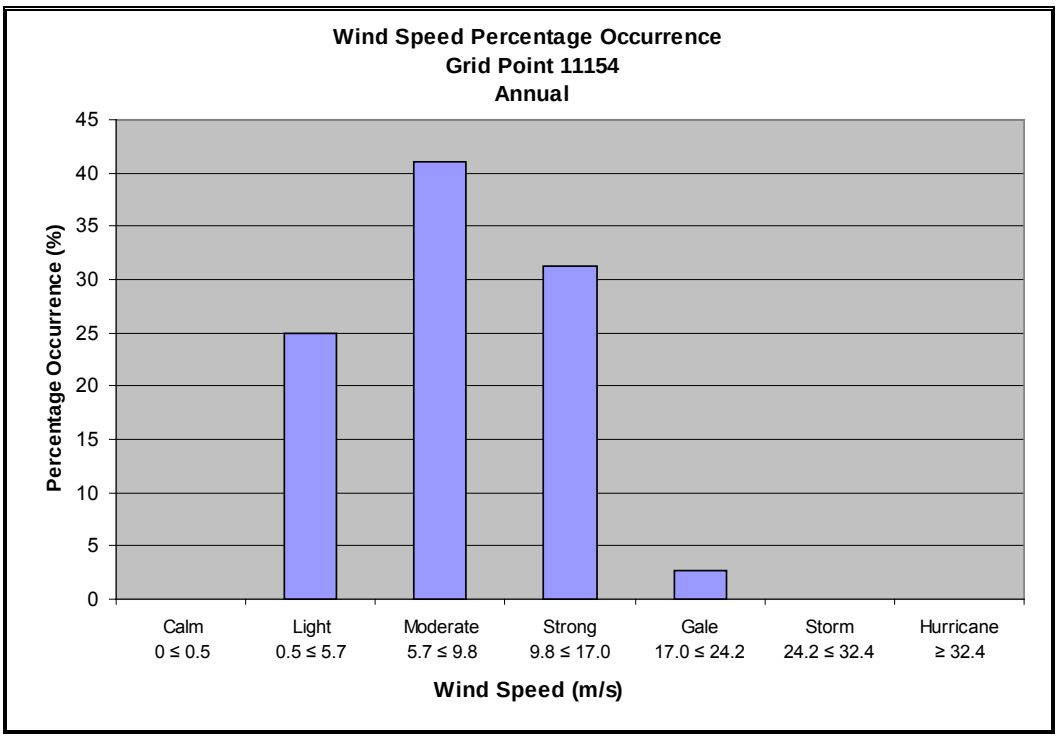


Figure 2.9 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

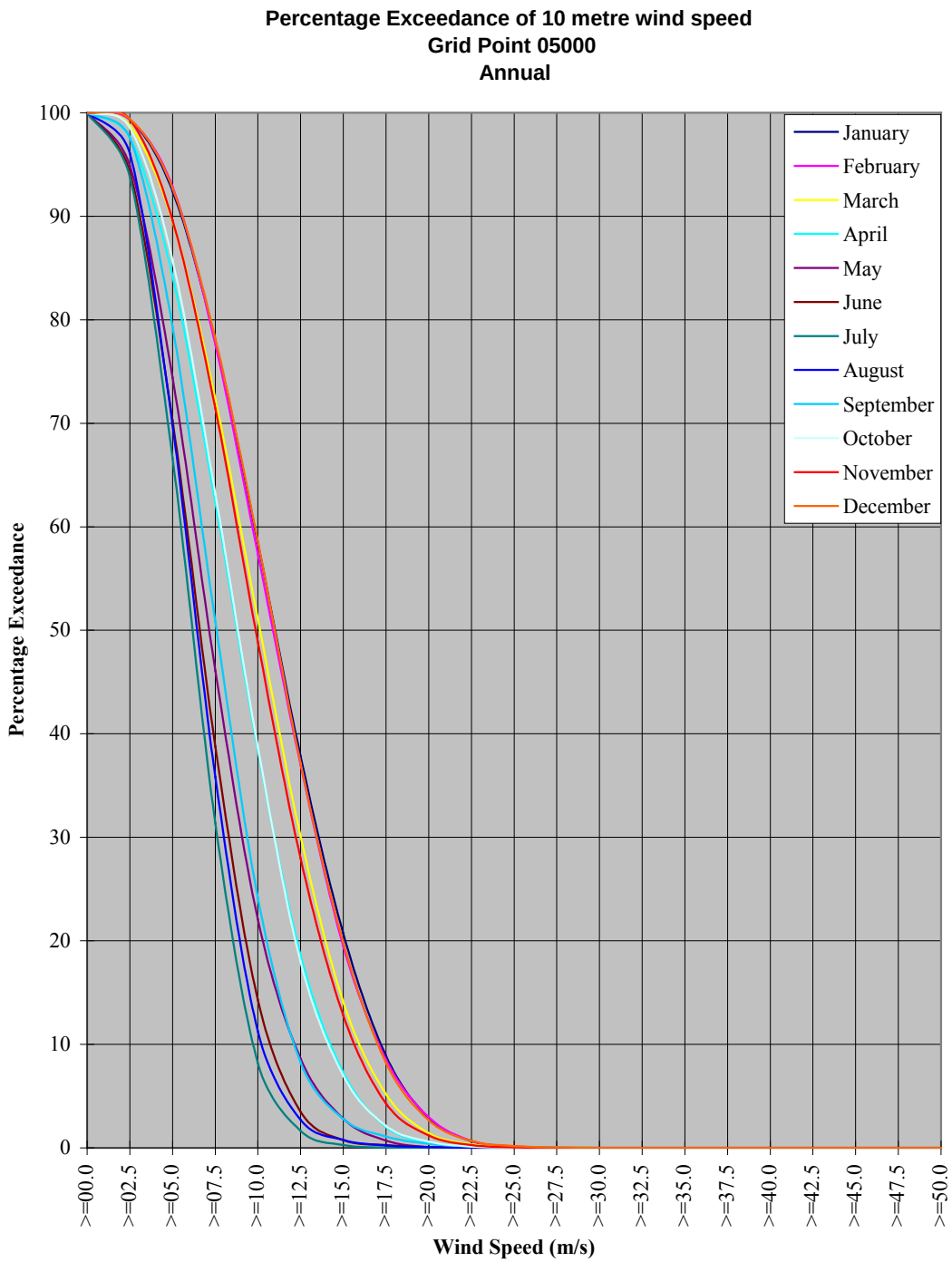
Intense mid-latitude low pressure systems occur frequently from early autumn to late spring. In addition, tropical systems frequently pass over the study area between spring and late fall. Therefore, while mean wind speeds tend to peak during the winter months, maximum wind speeds may occur at anytime during the year. A table of monthly maximum wind speeds for each of the data sets is presented in Table 2.3.

Rapidly deepening storm systems known as weather bombs frequently cross the waters south of Newfoundland. These storm systems typically develop in the warm waters of Cape Hatteras and move northeast crossing the Grand Banks. On January 09, 1991 a weak low pressure developed off Cape Hatteras and moved northeast across the study area with maximum sustained 10 m winds of 34.0 m/s. Sable Island reported peak winds of 21.1 m/s as this system passed.

Percentage exceedance curves of mean 10-m wind speed for each grid points is presented in Figure 2.10 through Figure 2.13.

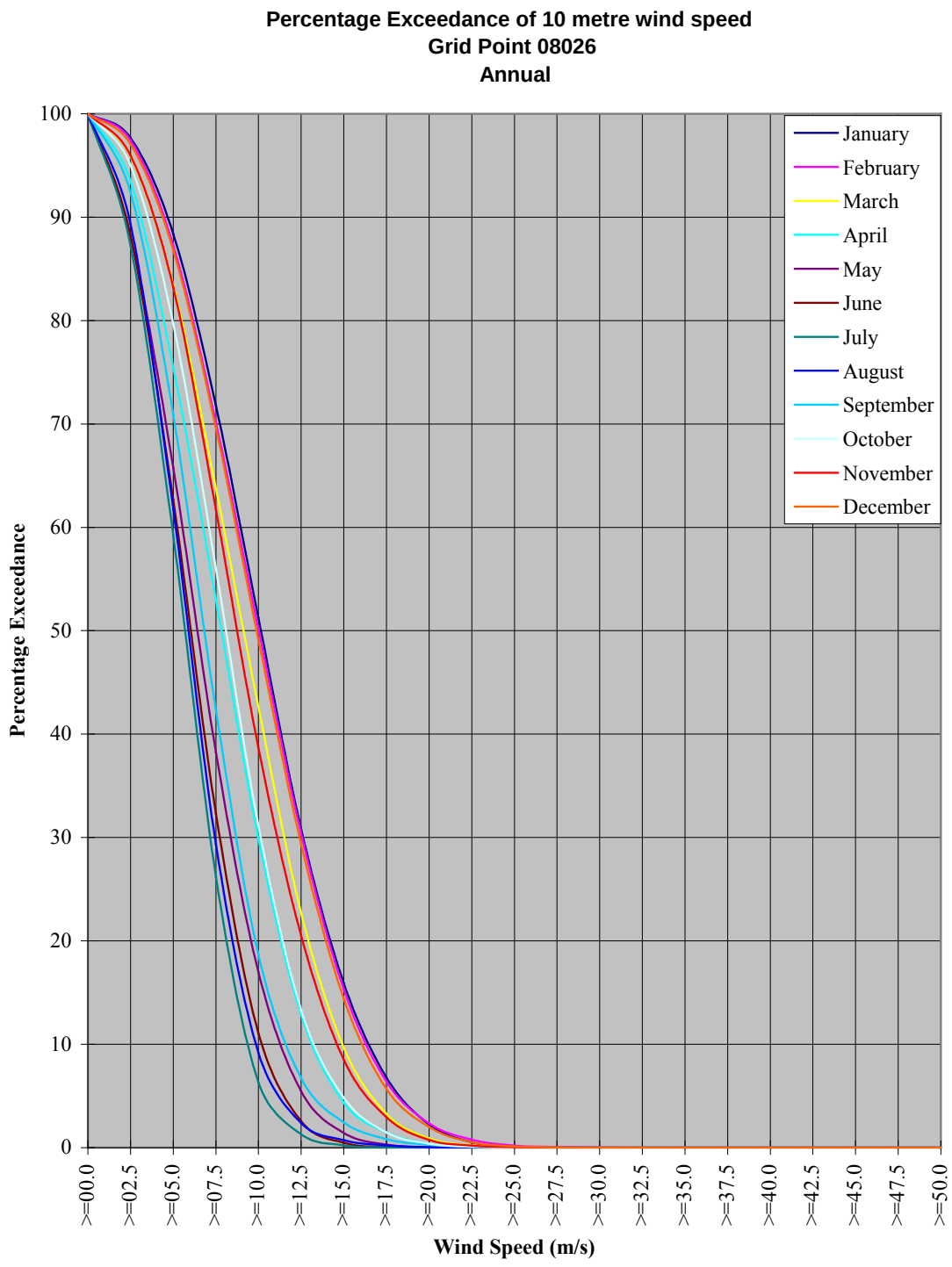
Table 2.3 Maximum Wind Speed (m/s) Statistics

Month	Grid Point 05000	Grid Point 08026	Grid Point 10537	Grid Point 11154
January	29.9	34.0	26.0	28.6
February	32.1	31.0	26.7	30.6
March	29.9	26.8	27.4	25.8
April	25.3	25.1	26.2	23.7
May	24.2	20.2	21.6	22.6
June	22.1	21.1	19.5	19.7
July	19.1	21.9	21.4	18.5
August	24.8	29.3	29.1	22.0
September	31.4	27.8	33.9	33.0
October	28.0	28.8	22.1	25.7
November	28.7	26.9	32.8	26.4
December	29.5	29.7	29.3	26.4



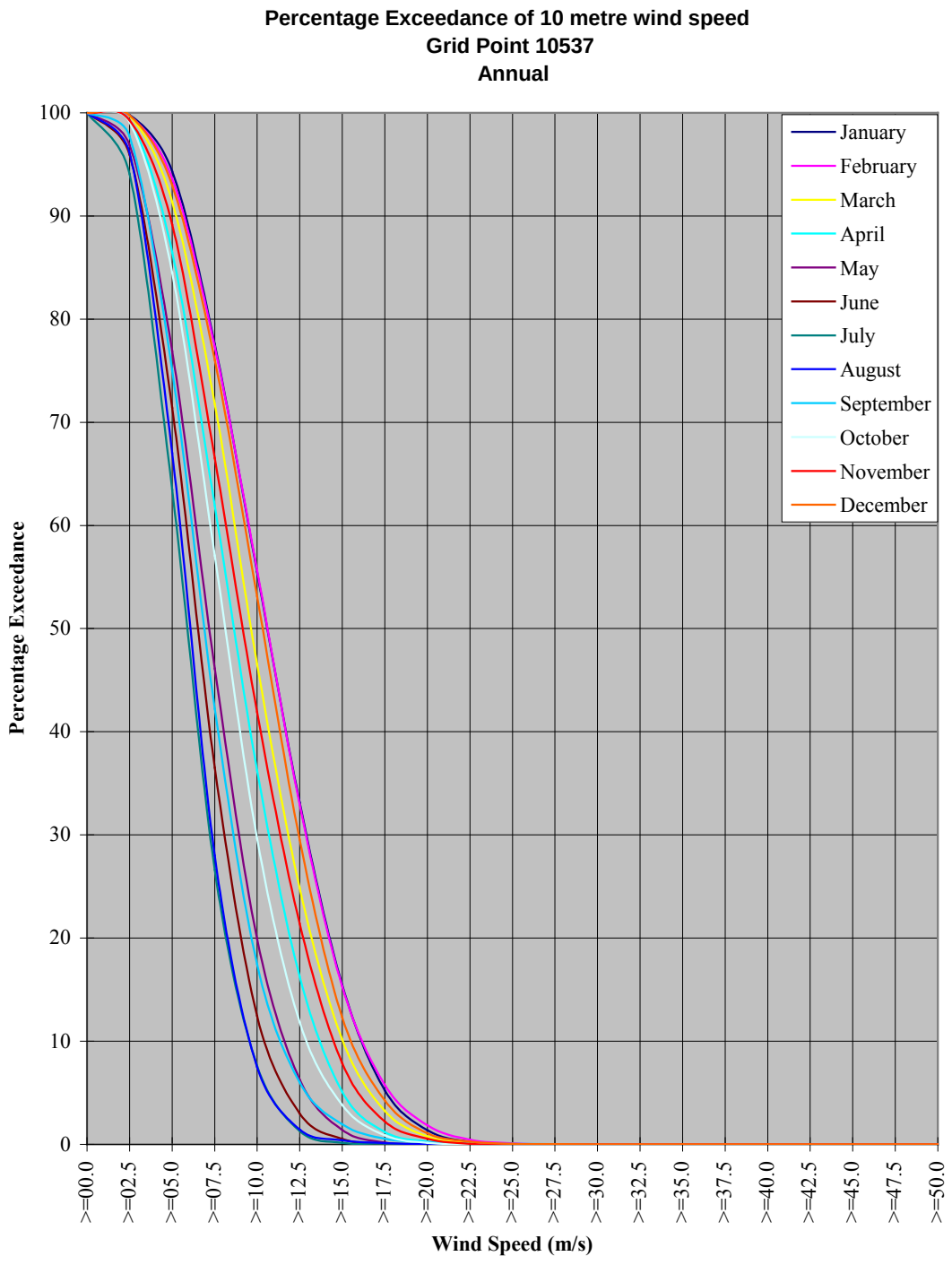
Source: MSC50 Grid Point 05000 Lat: 43.5°N Lon: 54.5°W, 1954 to 2010.

Figure 2.10 Percentage Exceedance of 10 m wind speed at Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010



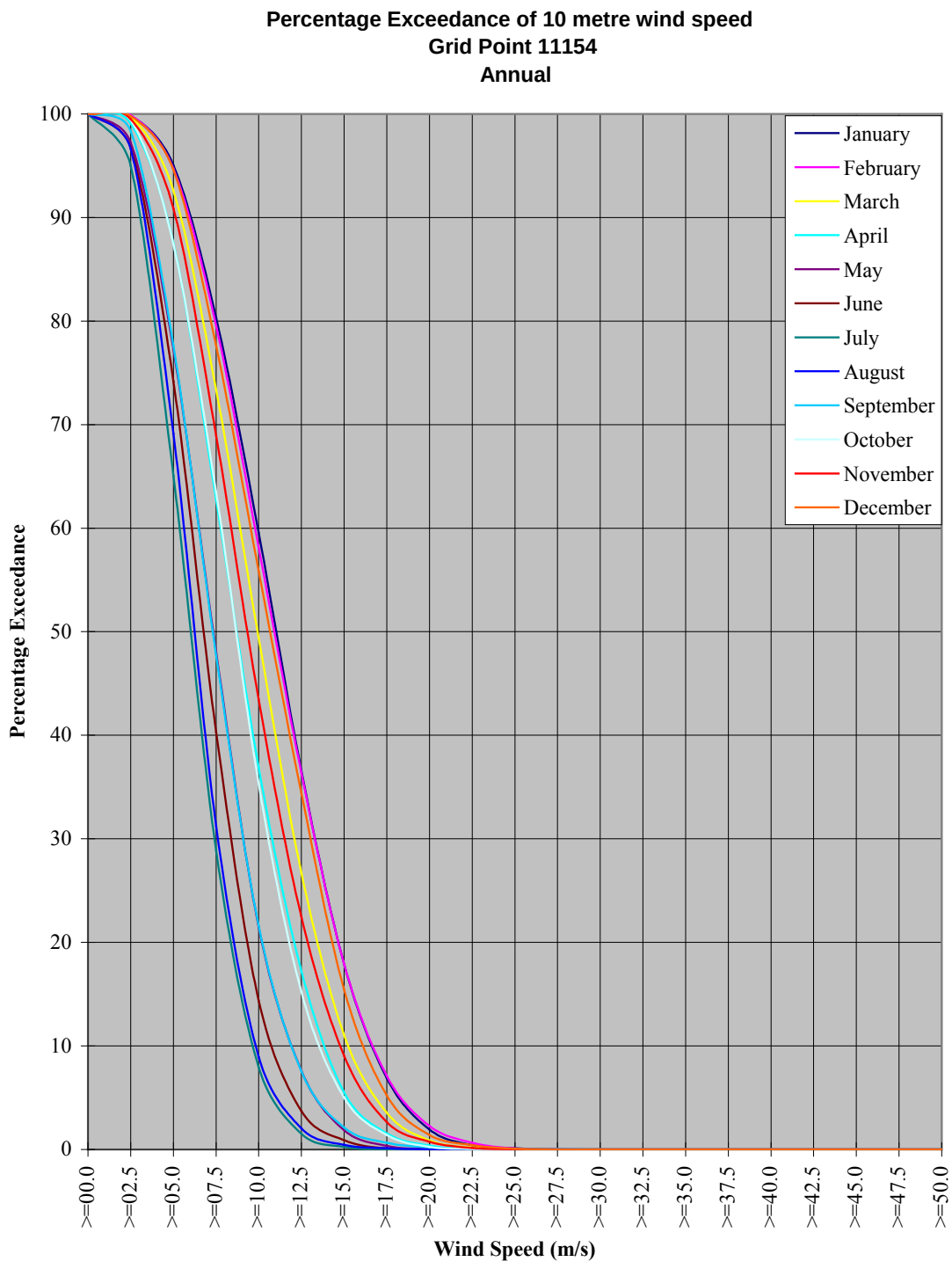
Source: MSC50 Grid Point 08026 Lat: 45.0°N Lon: 50.0°W, 1954 to 2010.

Figure 2.11 Percentage Exceedance of 10 m wind speed at Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010



Source: MSC50 Grid Point 10537 Lat: 41.5°N Lon: 47.0°W, 1954 to 2010.

Figure 2.12 Percentage Exceedance of 10 m wind speed at Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010



Source: MSC50 Grid Point 11154 Lat: 44.0°N Lon: 45.0°W, 1954 to 2010.

Figure 2.13 Percentage Exceedance of 10 m wind speed at Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

2.2.1 Tropical Systems

The hurricane season in the North Atlantic basin normally extends from June through November, although tropical storm systems occasionally occur outside this period. 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 a result of tropical systems. Once formed, a tropical storm or hurricane will maintain its energy as long as a sufficient supply of warm, moist air is available. Tropical storms and hurricanes obtain their energy from the latent heat of vapourization that is released during the condensation process. These systems typically move east to west over the warm water of the tropics. However, some of these systems turn northward and make their way towards the waters south of Newfoundland. Since the capacity of the air to hold water vapour is dependent on temperature, the hurricanes begin to lose their tropical characteristics as they move northward over the colder ocean waters. By the time these weakening cyclones reach Newfoundland, they are usually embedded into a mid-latitude low and their tropical characteristics are usually lost.

There has been a significant increase in the number of Hurricanes that have developed within the Atlantic Basin during the last 20 years. Figure 2.14 shows the 5-year average of tropical storms which have developed within the Atlantic Basin since 1961. This increase in activity has been attributed to naturally occurring cycles in tropical climate patterns near the equator called the tropical multi-decadal signal and typically lasts 20 to 30 years (Bell and Chelliah, 2006). As a result of the increase in tropical activity in the Atlantic Basin, there has also been an increase in tropical storms or their remnants entering the Canadian Hurricane Centre (CHC) Response zone. Despite this increase, there is little change in the 5-year trend for hurricanes coming within the study area.

The largest hurricane force wind radius within this database for the Atlantic Hurricane Basin measured 250 nautical miles from the centre of the hurricane. The largest storm within the study area had a hurricane force wind radius of 100 nm from the centre. To ensure all storms were captured, a buffer zone of 150 nm around the study area was used for the hurricane analysis. Since 1960, 214 tropical systems have passed within 150 nm of the study area. The tracks of these storms over the project area are shown in Figure 2.15. A table of all storms which passed within the buffer zone is presented in Appendix 1. It should be noted that the values in the table are the maximum 1-minute mean winds speeds occurring within the tropical system at the 10-m reference level as it passed.

On occasion, these systems still maintain their tropical characteristics when they reach the study area. Of these 214 storms, there was one Category 4, five Category 3, 18 Category 2 and 78 Category 1 hurricanes which crossed within 150 nm of the study area during this time period. The most intense of these storms was Hurricane Ella which entered the hurricane buffer zone on September 04, 1978 as a Category 4 hurricane with maximum sustained wind speeds of 59.2 m/s and a central pressure of 956 mb. The system was a Category 3 hurricane as it entered the study area. Hurricane Ella continued moving northward and crossed the Orphan Basin on September 05, 1978 with maximum sustained wind speeds 41.2 m/s and a central pressure of 975 mb. A storm track of Hurricane Ella as it passed over the study area is presented in Figure 2.16.

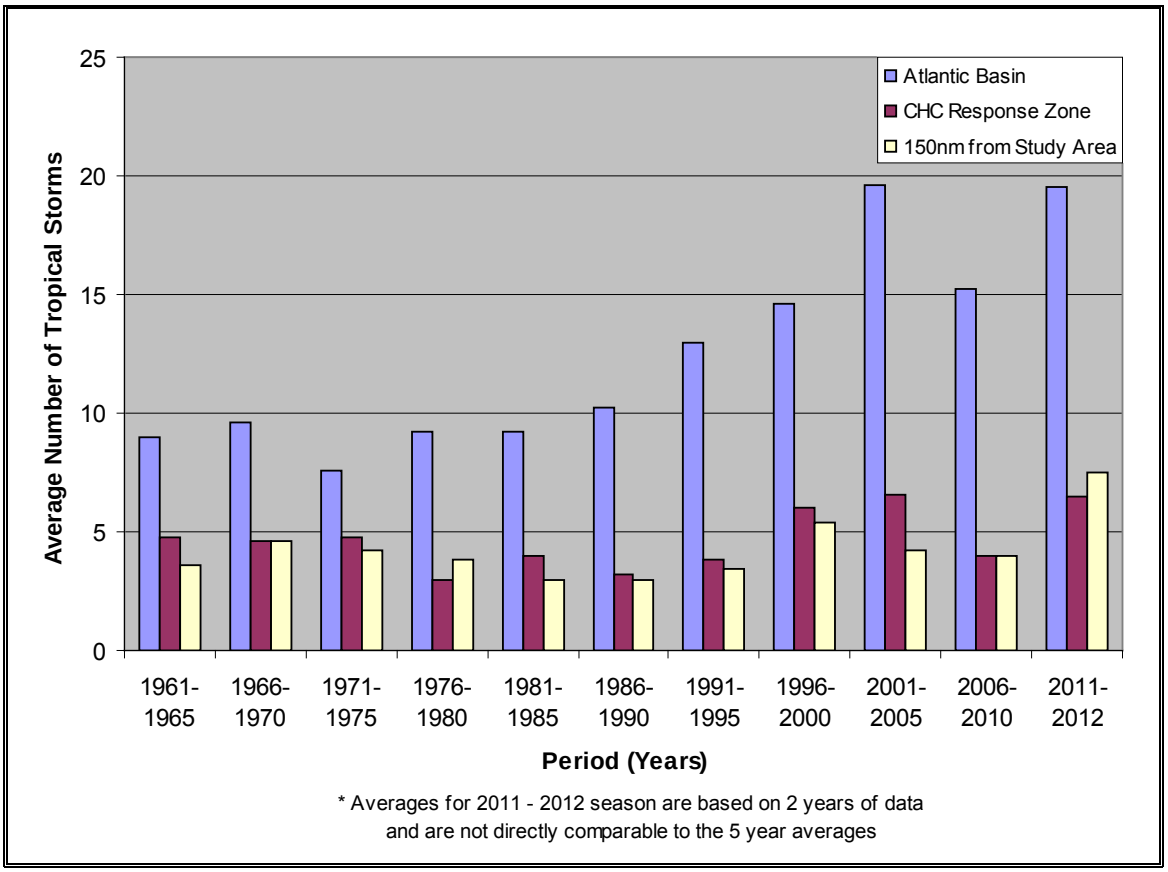


Figure 2.14 5-Year Average of the number of Tropical Storms which formed in the Atlantic Basin since 1961

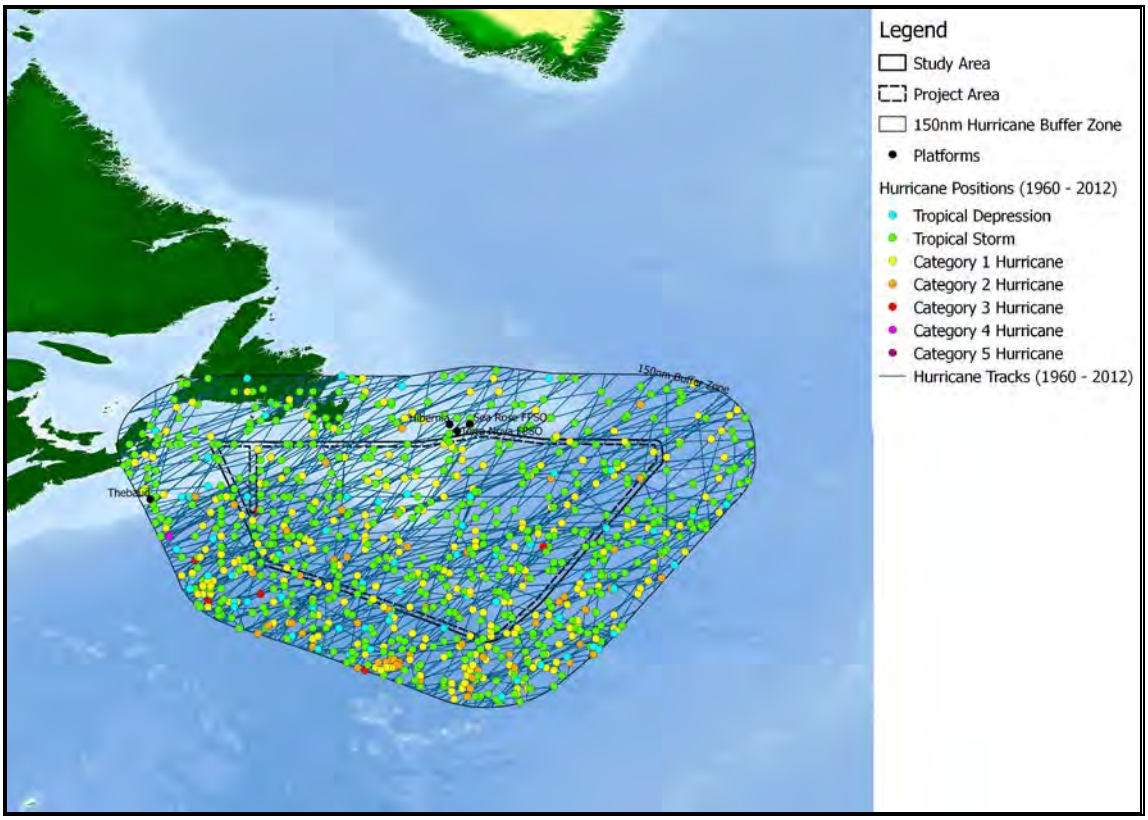


Figure 2.15 Storm Tracks of Tropical Systems Passing within 150 nm of the study area (1960 to 2012)

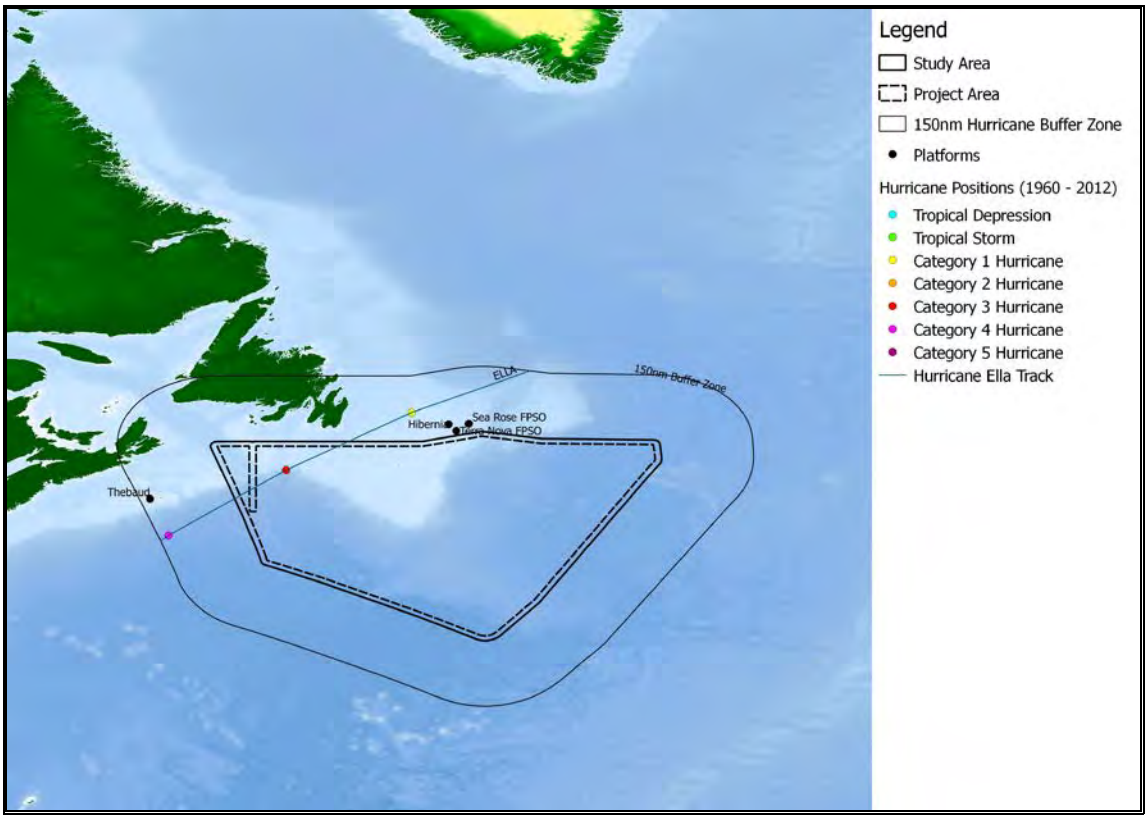


Figure 2.16 Storm Track of Hurricane Ella as it passed over the study area (September 04, 1978

2.3 Waves

The main parameters for describing wave conditions are the significant wave height, the maximum wave height, the peak spectral period, and the 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 are usually of low 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 wave climate south of Newfoundland is dominated by extra-tropical storms, primarily during October through March, however severe storms may, on occasion, occur outside these months. Storms of tropical origin may occur during the early summer and early winter, but most often from late August through October. Hurricanes are usually reduced to tropical storm strength or evolve into extra-tropical storms by the time they reach the area, however they are still capable of producing storm force winds and high waves.

The annual wave roses from the MSC50 data for the MSC50 Grid Points are presented in Figure 2.17 through Figure 2.20. The wave rose show that the majority of wave energy comes from the southwest to south-southwest.

Histograms depicting the percentage occurrence of significant wave heights (Figure 2.21 through Figure 2.24) show that the dominate wave height is between 1.0 to 3.0 m. There is a gradual decrease in frequency of wave heights above 3.0 m and only a small percentage of the wave heights exceeding 7.0 m.

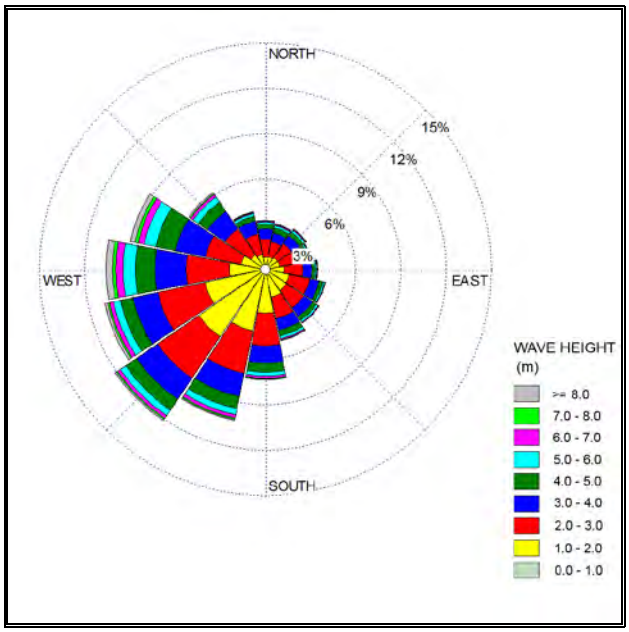


Figure 2.17 Annual Wave Rose for MSC50 Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

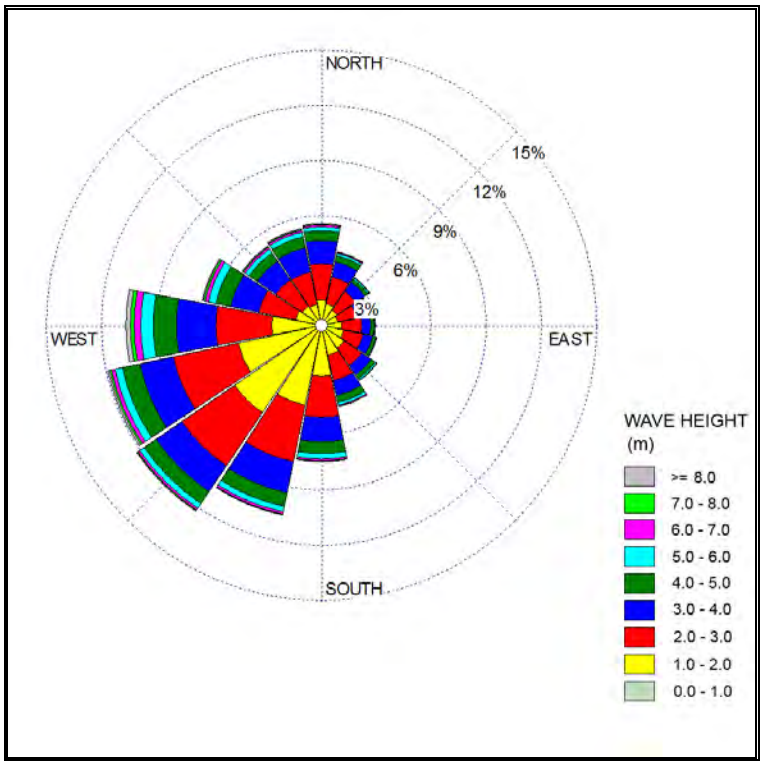


Figure 2.18 Annual Wave Rose for MSC50 Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

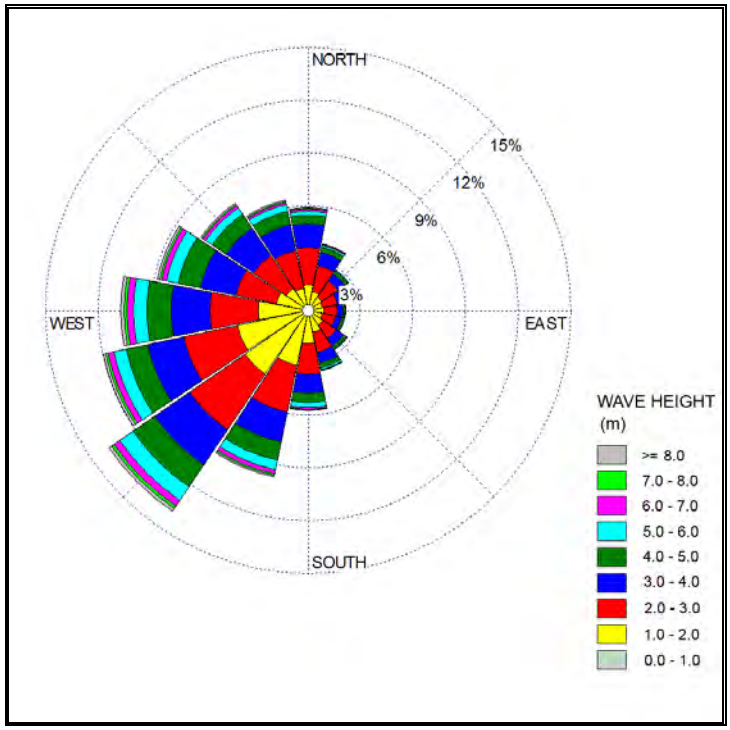


Figure 2.19 Annual Wave Rose for MSC50 Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

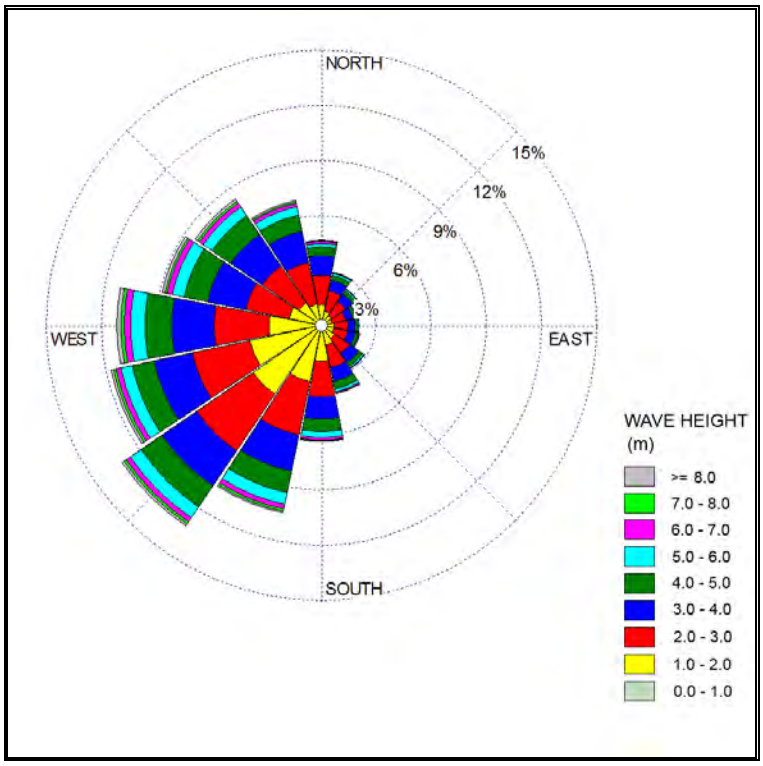


Figure 2.20 Annual Wave Rose for MSC50 Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

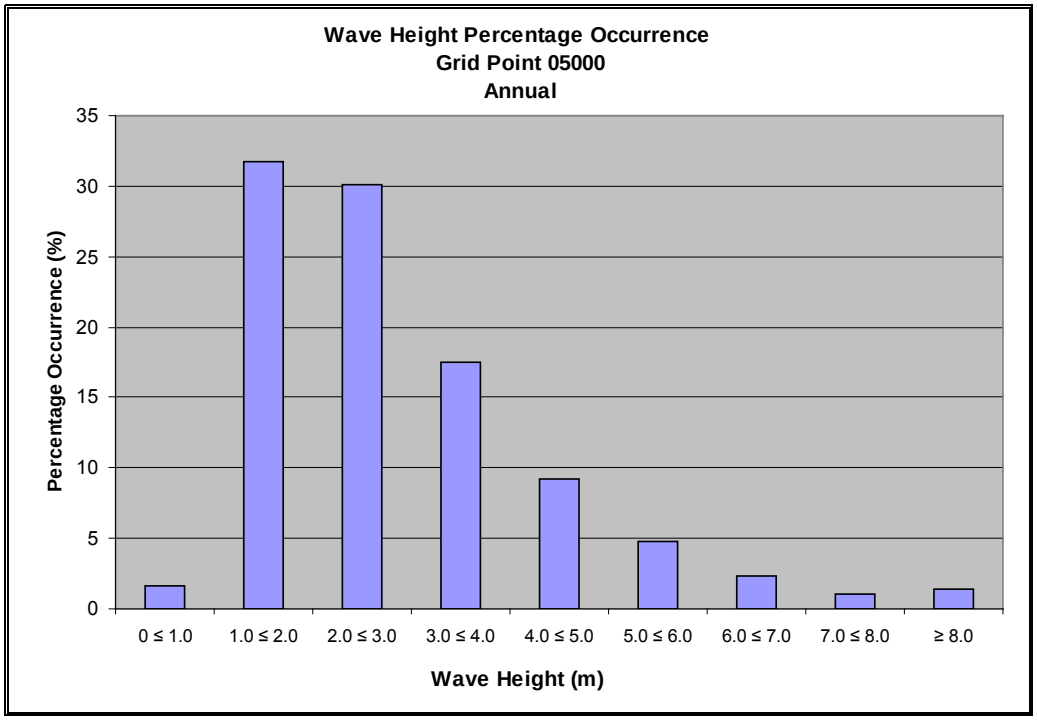


Figure 2.21 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

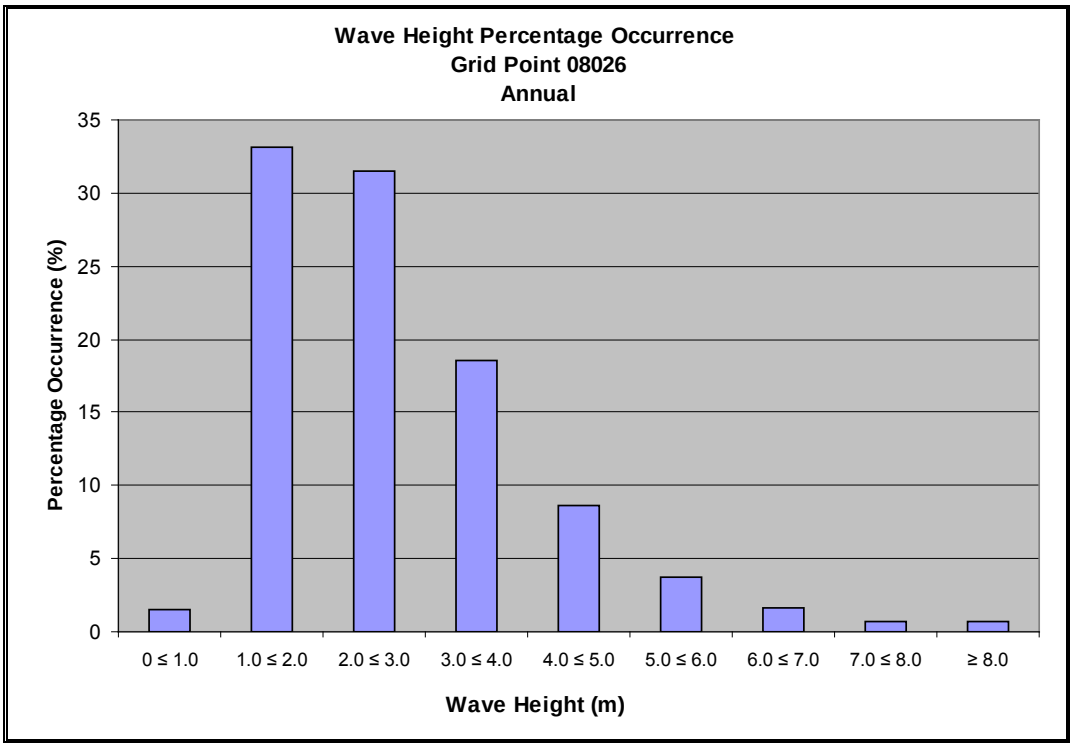


Figure 2.22 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

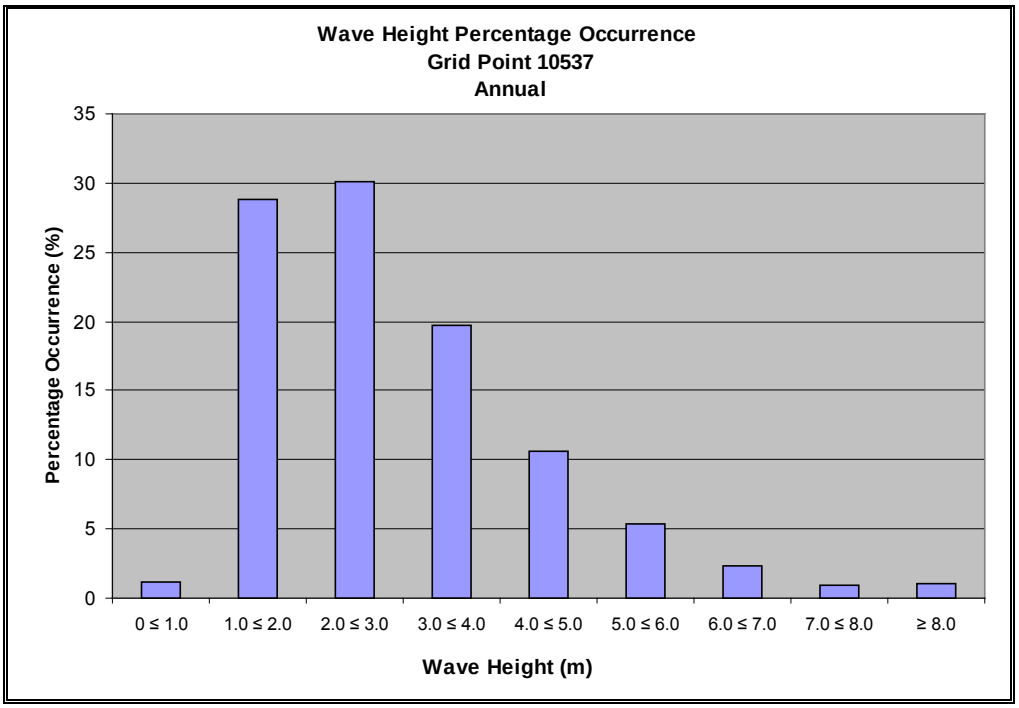


Figure 2.23 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

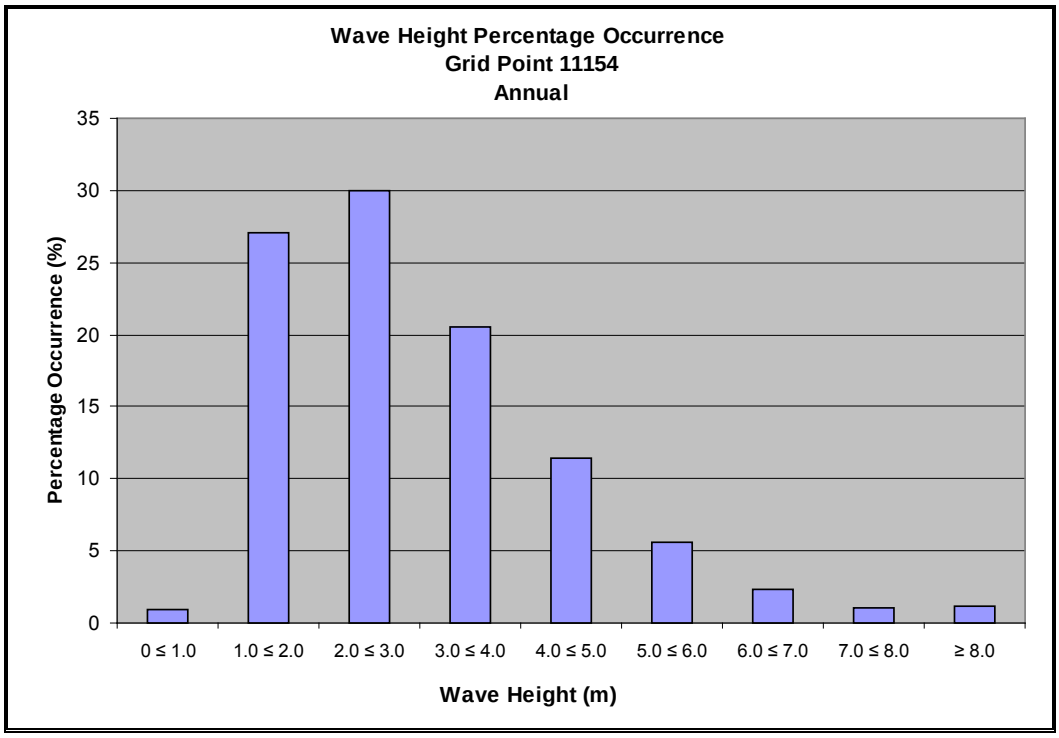


Figure 2.24 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

Significant wave heights peak during the winter months with Grid Point 11154 having the highest mean monthly significant wave height with a height of 4.3 m in both January and February. The lowest significant wave heights occur in the summer with July month having a mean monthly significant wave height of only 1.7 m for three of the grid points (Table 2.4).

Table 2.4 Combined Significant Wave Height Statistics (m)

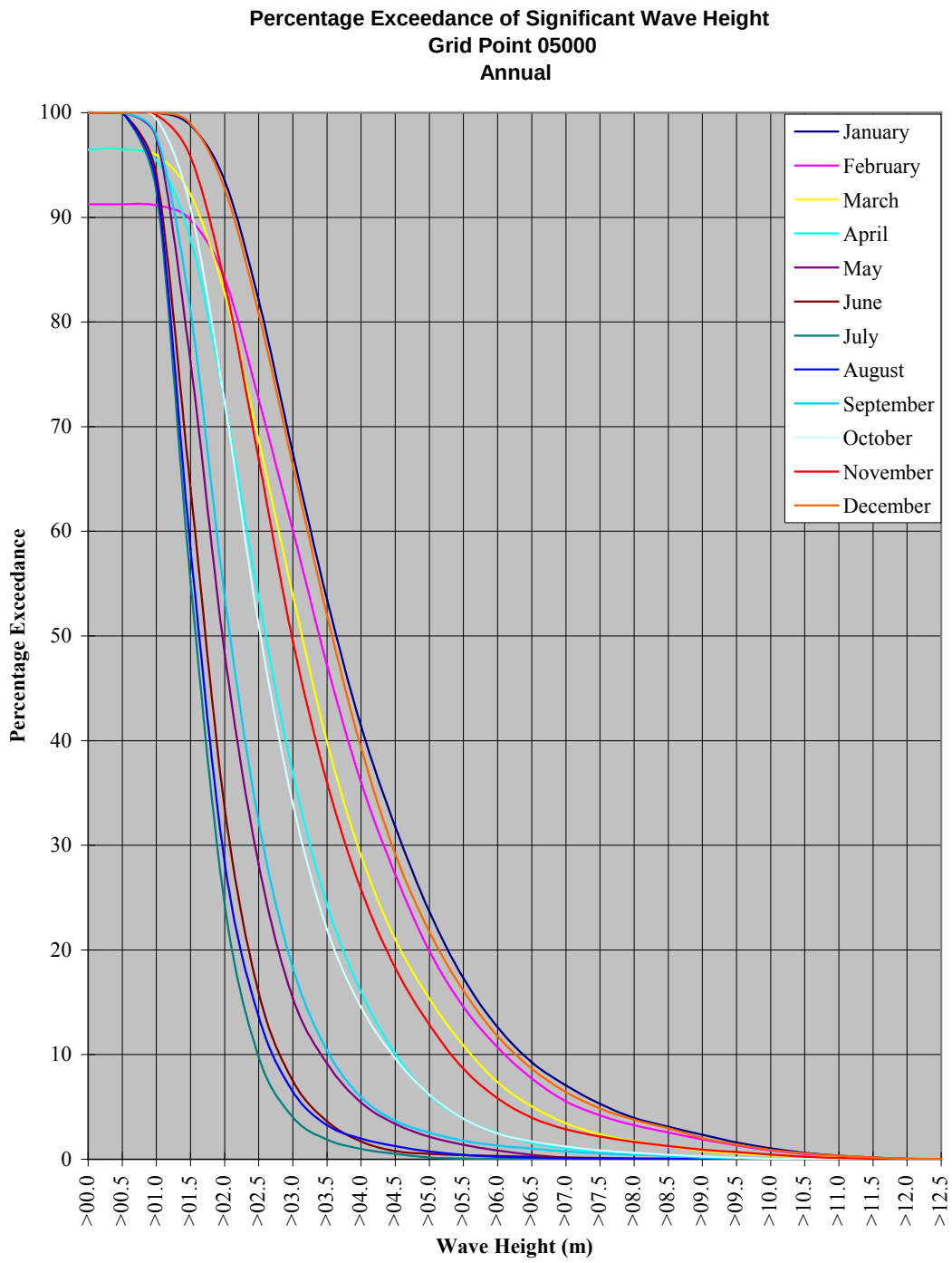
Month	Grid Point 05000	Grid Point 08026	Grid Point 10537	Grid Point 11154
January	4.0	3.8	4.2	4.3
February	3.9	3.7	4.2	4.3
March	3.5	3.2	3.7	3.7
April	2.9	2.7	3.1	3.1
May	2.2	2.1	2.3	2.3
June	1.9	1.8	1.9	2.0
July	1.7	1.6	1.7	1.7
August	1.8	1.7	1.8	1.8
September	2.3	2.2	2.3	2.4
October	2.8	2.8	2.8	2.9
November	3.3	3.1	3.3	3.4
December	4.0	3.7	4.0	4.0

Combined significant wave heights of 10.0 m or more occurred in each month between September and April with the highest waves occurring during the month of January at Grid Point 11154 (Table 2.5). Maximum wave heights were typically higher during the winter at grid point 11154. The maximum value of 15.4 m at grid point 11154 corresponds with the January 1991 storm mentioned previously. While maximum significant wave heights tend to peak during the winter months, a tropical system could pass through the area and produce wave heights during in any month. The 13.0 m maximum significant wave height in September at Grid Point 05000 corresponds with the passage of Category 3 Hurricane Debby on September 18, 1982 with maximum sustained wind speeds of 56.6 m/s and a central pressure of 952 mb.

Figure 2.25 through Figure 2.28 show percentage exceedance curves of significant wave heights for each MSC50 grid points. Percentage exceedance curves for the do not reach 100% for some months due of the presence of ice during these months.

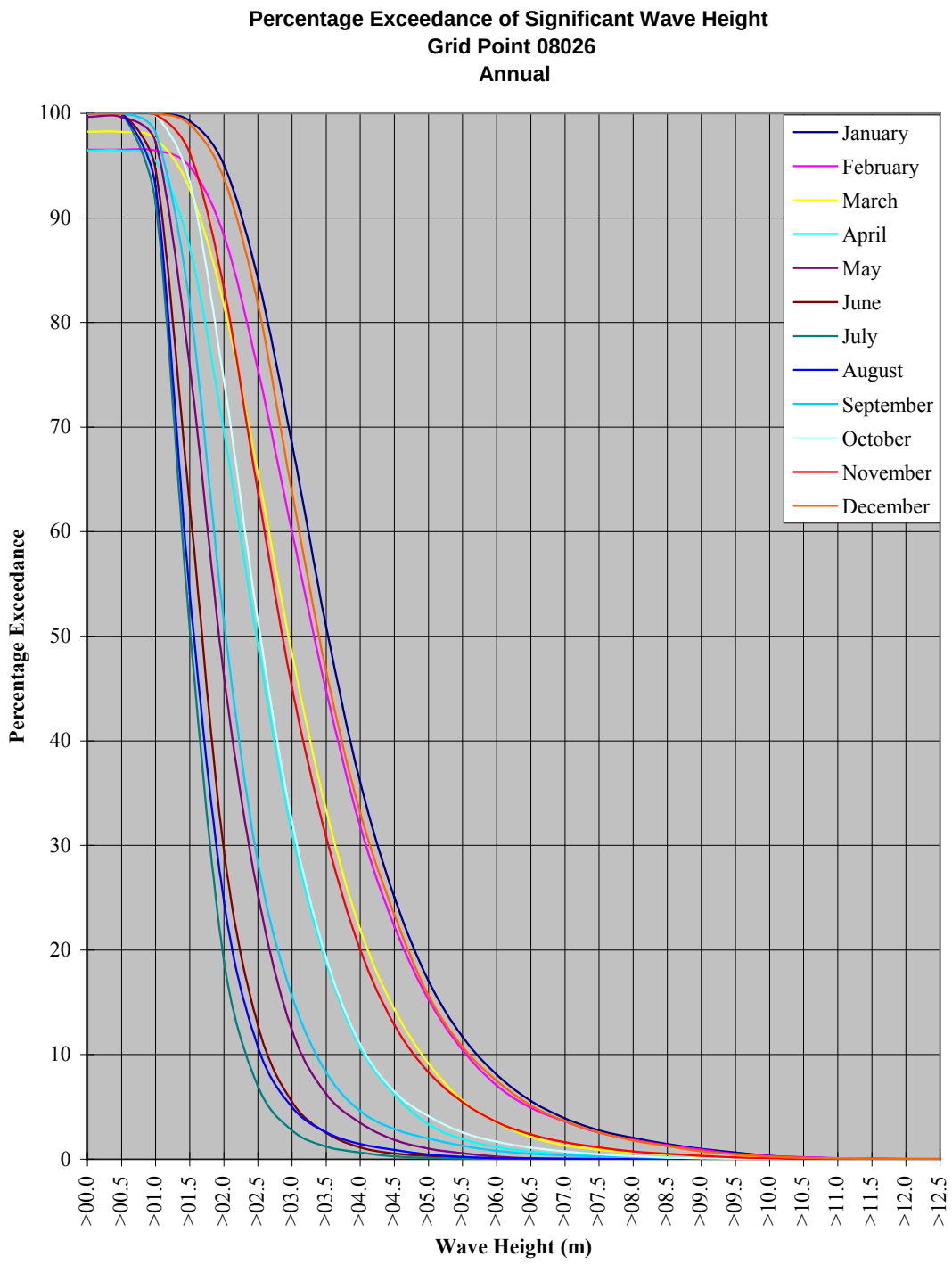
Table 2.5 Maximum Combined Significant Wave Height Statistics (m)

Month	Grid Point 05000	Grid Point 08026	Grid Point 10537	Grid Point 11154
January	14.1	14.1	13.1	15.4
February	13.3	12.8	12.6	14.1
March	12.6	12.3	13.2	13.1
April	11.2	10.7	11.3	10.2
May	10.2	7.9	9.5	9.2
June	9.7	8.2	8.0	7.7
July	6.7	7.0	8.3	7.1
August	10.1	9.4	9.7	7.9
September	13.0	11.0	12.5	11.3
October	12.7	10.8	9.7	12.0
November	11.8	11.1	11.8	12.0
December	12.6	12.6	13.7	12.9



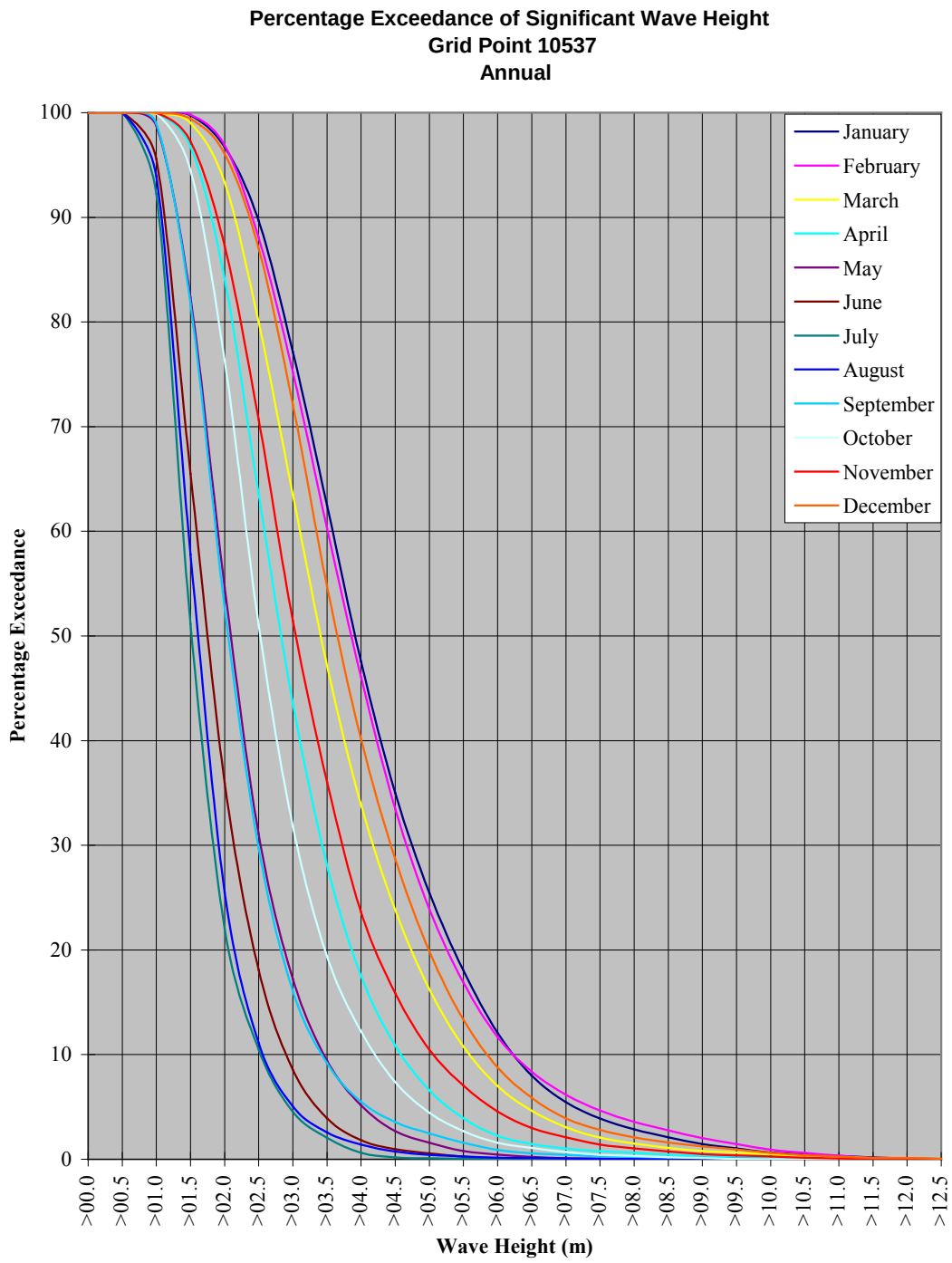
Source: MSC50 Grid Point 05000 Lat: 43.5°N Lon: 54.5°W, 1954 to 2010.

Figure 2.25 Percentage Exceedance of Significant Wave Height at Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010



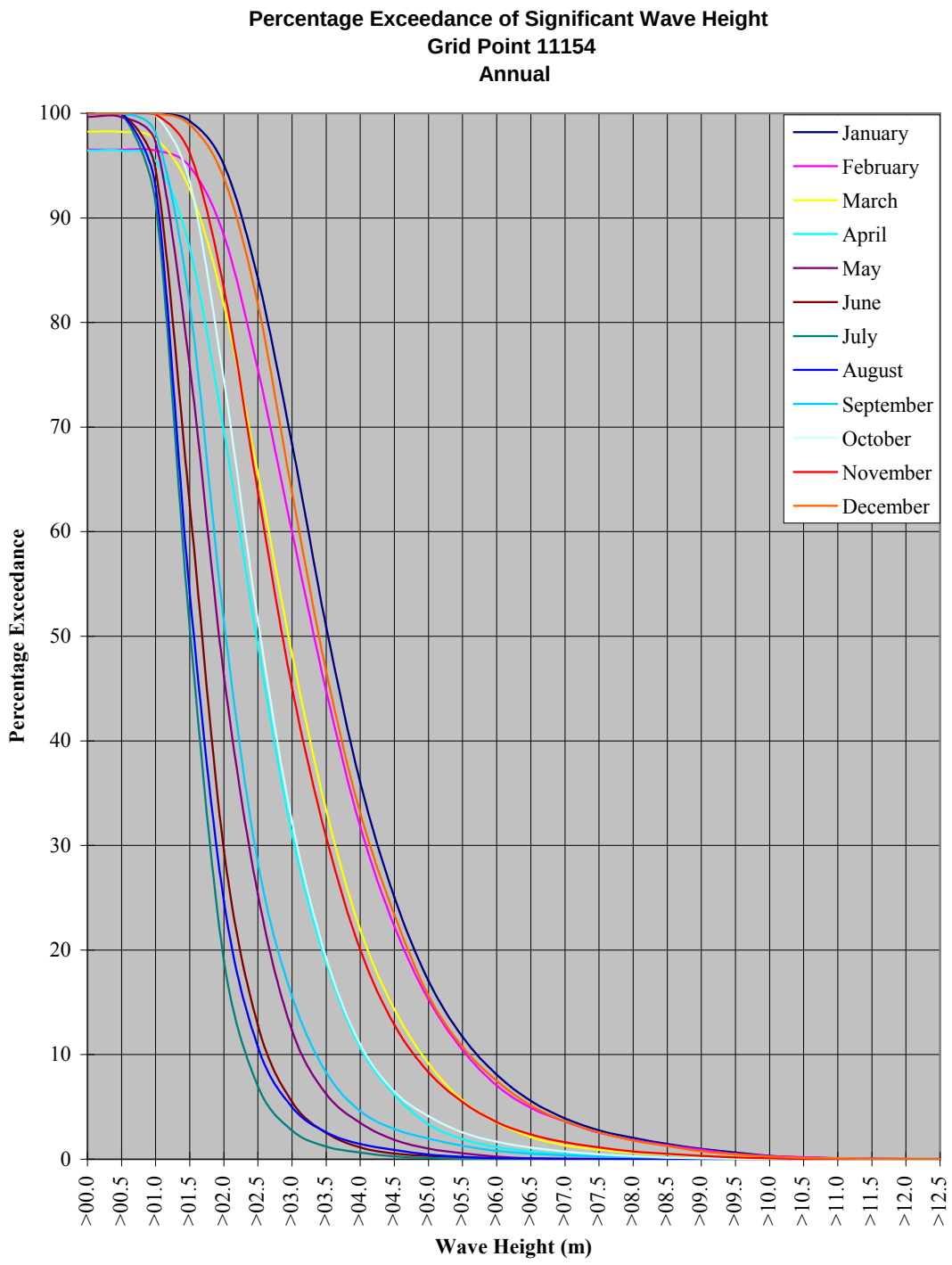
Source: MSC50 Grid Point 08026 Lat: 45.0°N Lon: 50.0°W, 1954 to 2010.

Figure 2.26 Percentage Exceedance of Significant Wave Height at Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010



Source: MSC50 Grid Point 10537 Lat: 41.5°N Lon: 47.0°W, 1954 to 2010.

Figure 2.27 Percentage Exceedance of Significant Wave Height at Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010



Source: MSC50 Grid Point 11154 Lat: 44.0°N Lon: 45.0°W, 1954 to 2010.

Figure 2.28 Percentage Exceedance of Significant Wave Height at Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

The spectral peak period of waves vary with season. Annually, the most common peak spectral period is 8 seconds at grid point 05000 and 9 seconds at the other three grid points. Periods above 12 seconds occur more frequently during the winter months; though they may occur at anytime during the year. Monthly, seasonal and annual statistics of the percentage occurrence of spectral peak period for each grid point is shown in Table 2.6 through Table 2.9 with the most common period highlighted for each period.

Table 2.6 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

	Peak Spectral Period (seconds)															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
January	0.0	0.0	0.0	0.0	0.6	2.5	9.0	13.5	**17.9**	17.4	17.5	10.3	8.8	2.1	0.3	0.1
February	0.0	0.0	0.0	0.1	0.7	3.3	8.9	13.3	**19.5**	17.0	17.2	10.0	7.4	2.2	0.3	0.1
March	0.0	0.0	0.0	0.2	1.3	4.4	11.2	15.7	**20.3**	17.0	13.6	8.1	6.2	1.7	0.3	0.1
April	0.0	0.0	0.0	0.2	1.8	6.1	15.2	19.5	**21.3**	16.9	9.4	5.7	2.8	0.9	0.1	0.1
May	0.0	0.0	0.0	0.3	3.1	10.2	22.0	**26.6**	17.6	10.6	4.2	4.2	0.7	0.3	0.1	0.1
June	0.0	0.0	0.0	0.4	5.5	15.4	**29.4**	24.4	14.4	5.8	1.4	1.3	1.2	0.5	0.3	0.1
July	0.0	0.0	0.0	0.5	6.1	17.3	**31.9**	23.6	12.6	4.1	0.9	1.1	0.8	0.4	0.2	0.4
August	0.0	0.0	0.0	0.6	6.7	19.1	**32.1**	20.6	9.4	4.7	1.9	2.4	1.6	0.8	0.2	0.1
September	0.0	0.0	0.0	0.3	3.7	11.4	**23.3**	22.1	14.6	8.0	3.8	7.1	4.1	0.9	0.3	0.4
October	0.0	0.0	0.0	0.2	2.0	6.9	19.0	**22.5**	18.6	12.8	6.0	7.6	3.2	0.7	0.2	0.2
November	0.0	0.0	0.0	0.1	1.3	5.1	13.4	18.1	**21.1**	17.8	10.5	7.5	3.7	1.3	0.1	0.0
December	0.0	0.0	0.0	0.0	0.6	2.7	8.3	14.2	**19.7**	19.2	14.7	11.5	7.3	1.5	0.2	0.2
Winter	0.0	0.0	0.0	0.1	0.6	2.8	8.7	13.7	**19.0**	17.9	16.5	10.6	7.8	1.9	0.3	0.1
Spring	0.0	0.0	0.0	0.2	2.1	6.9	16.1	**20.6**	19.7	14.8	9.1	6.0	3.2	1.0	0.2	0.1
Summer	0.0	0.0	0.0	0.5	6.1	17.3	**31.1**	22.8	12.1	4.9	1.4	1.6	1.2	0.6	0.2	0.2
Autumn	0.0	0.0	0.0	0.2	2.3	7.8	18.6	**20.9**	18.1	12.9	6.8	7.4	3.7	1.0	0.2	0.2
Annual	0.0	0.0	0.0	0.2	2.8	8.7	18.6	**19.5**	17.2	12.6	8.4	6.4	4.0	1.1	0.2	0.2

Table 2.7 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

	Peak Spectral Period (seconds)															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
January	0.0	0.0	0.0	0.0	0.4	2.0	6.0	10.1	17.0	**19.5**	18.1	9.9	11.7	4.3	0.9	0.1
February	0.0	0.0	0.0	0.1	0.7	2.6	7.5	11.3	**19.6**	18.7	17.1	9.5	8.9	3.1	0.7	0.2
March	0.0	0.0	0.0	0.2	1.3	3.9	9.6	13.0	**20.1**	18.4	14.2	8.6	7.0	3.1	0.4	0.2
April	0.0	0.0	0.0	0.2	1.6	4.8	11.2	17.8	**24.4**	18.6	10.0	5.3	4.1	1.7	0.3	0.0
May	0.0	0.0	0.0	0.1	2.3	6.2	18.2	**26.7**	23.7	12.5	4.6	4.0	1.4	0.4	0.0	0.0
June	0.0	0.0	0.0	0.3	3.6	11.9	26.6	**27.3**	19.6	7.2	1.8	0.9	0.7	0.0	0.0	0.0
July	0.0	0.0	0.0	0.4	4.7	14.1	**31.5**	28.0	13.9	5.0	0.9	0.7	0.5	0.1	0.0	0.0
August	0.0	0.0	0.0	0.5	5.0	14.7	**30.9**	25.7	13.7	4.7	1.6	1.6	1.0	0.4	0.1	0.0
September	0.0	0.0	0.0	0.1	2.3	8.3	18.7	**23.0**	20.3	9.6	6.3	6.1	3.4	1.5	0.3	0.1
October	0.0	0.0	0.0	0.1	1.1	4.5	12.6	19.9	**23.6**	14.9	9.4	6.6	5.0	2.0	0.3	0.1

November	0.0	0.0	0.0	0.0	0.8	3.5	9.2	14.5	**23.1**	18.3	13.1	6.8	7.3	2.9	0.2	0.2
December	0.0	0.0	0.0	0.0	0.4	1.9	6.0	11.2	18.7	**22.2**	15.7	10.0	9.7	3.4	0.6	0.2
Winter	0.0	0.0	0.0	0.1	0.5	2.2	6.5	10.9	18.4	**20.1**	17.0	9.8	10.1	3.6	0.8	0.2
Spring	0.0	0.0	0.0	0.2	1.7	5.0	13.0	19.1	**22.7**	16.5	9.6	6.0	4.1	1.7	0.3	0.1
Summer	0.0	0.0	0.0	0.4	4.4	13.6	**29.7**	27.0	15.8	5.6	1.5	1.1	0.8	0.1	0.0	0.0
Autumn	0.0	0.0	0.0	0.1	1.4	5.4	13.5	19.2	**22.3**	14.2	9.6	6.5	5.2	2.1	0.3	0.2
Annual	0.0	0.0	0.0	0.2	2.0	6.5	15.6	19.0	**19.8**	14.1	9.4	5.8	5.1	1.9	0.3	0.1

Table 2.8 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

	Peak Spectral Period (seconds)															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
January	0.0	0.0	0.0	0.0	0.1	1.0	4.1	8.3	15.1	**20.5**	19.6	13.8	10.3	5.1	1.4	0.6
February	0.0	0.0	0.0	0.0	0.1	1.1	4.4	9.0	16.2	**20.1**	19.3	12.9	9.7	5.1	1.1	0.8
March	0.0	0.0	0.0	0.0	0.3	2.1	6.4	10.8	19.9	**21.0**	17.9	9.2	7.3	3.5	1.1	0.4
April	0.0	0.0	0.0	0.0	0.6	3.0	10.2	17.0	**25.4**	18.0	14.8	4.0	3.7	2.0	1.1	0.4
May	0.0	0.0	0.0	0.1	2.2	7.5	19.7	**25.2**	24.3	9.7	6.2	2.2	1.5	0.8	0.3	0.1
June	0.0	0.0	0.0	0.2	5.3	12.2	**27.4**	24.2	18.6	5.7	2.8	1.0	1.3	0.7	0.4	0.4
July	0.0	0.0	0.0	0.4	6.6	16.7	**25.4**	25.3	16.5	3.5	2.2	1.1	1.0	0.5	0.3	0.4
August	0.0	0.0	0.0	0.3	5.4	16.3	**30.4**	22.5	13.0	4.2	2.9	1.7	2.0	0.7	0.3	0.2
September	0.0	0.0	0.0	0.1	2.4	8.9	20.5	**22.4**	17.6	8.6	8.6	3.5	3.8	2.2	0.9	0.4
October	0.0	0.0	0.0	0.0	0.8	3.9	14.3	**21.7**	21.1	14.4	11.9	4.6	3.8	2.1	1.0	0.3
November	0.0	0.0	0.0	0.0	0.6	3.0	8.9	14.4	**21.8**	19.3	15.6	6.8	4.9	3.1	1.2	0.4
December	0.0	0.0	0.0	0.0	0.2	1.1	4.9	9.3	18.3	**22.0**	18.4	11.9	7.3	4.7	1.4	0.4
Winter	0.0	0.0	0.0	0.0	0.2	1.1	4.5	8.9	16.6	**20.9**	19.1	12.9	9.1	5.0	1.3	0.6
Spring	0.0	0.0	0.0	0.0	1.0	4.2	12.1	17.7	**23.2**	16.2	13.0	5.2	4.1	2.1	0.8	0.3
Summer	0.0	0.0	0.0	0.3	5.7	15.0	**27.7**	24.0	16.0	4.5	2.6	1.3	1.4	0.6	0.3	0.3
Autumn	0.0	0.0	0.0	0.1	1.2	5.3	14.6	19.5	**20.2**	14.1	12.0	5.0	4.2	2.5	1.1	0.4
Annual	0.0	0.0	0.0	0.1	2.0	6.4	14.7	17.5	**19.0**	13.9	11.7	6.1	4.7	2.5	0.9	0.4

Table 2.9 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

	Peak Spectral Period (seconds)															
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
January	0.0	0.0	0.0	0.0	0.1	0.9	3.7	7.5	15.3	20.2	**21.2**	11.7	14.7	3.2	1.3	0.3
February	0.0	0.0	0.0	0.0	0.1	0.9	3.9	7.9	16.4	20.1	**21.5**	11.3	12.9	3.3	1.2	0.5
March	0.0	0.0	0.0	0.0	0.3	1.7	5.8	10.5	**20.7**	20.4	19.2	8.6	9.0	3.0	0.5	0.3
April	0.0	0.0	0.0	0.0	0.5	2.6	9.3	16.7	**26.0**	19.6	13.1	4.4	5.5	1.7	0.5	0.1
May	0.0	0.0	0.0	0.0	1.5	7.1	17.7	**28.1**	24.4	11.0	5.3	2.1	2.0	0.6	0.1	0.0
June	0.0	0.0	0.0	0.2	4.5	12.3	24.6	**29.6**	16.4	7.1	2.1	0.6	1.2	0.7	0.4	0.3
July	0.0	0.0	0.0	0.3	5.6	14.2	26.8	**32.1**	11.3	4.8	1.5	0.9	1.3	0.5	0.4	0.4
August	0.0	0.0	0.0	0.3	5.0	15.1	**29.1**	26.9	11.9	4.7	2.6	1.5	1.8	0.6	0.2	0.2
September	0.0	0.0	0.0	0.1	2.0	8.2	19.4	**22.3**	19.6	8.4	8.2	4.5	4.5	1.8	0.7	0.4
October	0.0	0.0	0.0	0.0	0.6	3.4	13.4	18.8	**23.9**	15.4	10.9	5.2	5.2	2.4	0.6	0.2
November	0.0	0.0	0.0	0.0	0.3	2.6	8.8	13.9	**21.9**	19.1	16.4	6.3	7.0	2.8	0.7	0.1

December	0.0	0.0	0.0	0.0	0.1	1.0	4.2	8.3	19.3	**22.0**	21.3	9.4	10.2	3.2	0.7	0.3
Winter	0.0	0.0	0.0	0.0	0.1	0.9	3.9	7.9	17.0	20.8	**21.3**	10.8	12.6	3.2	1.1	0.3
Spring	0.0	0.0	0.0	0.0	0.8	3.8	11.0	18.4	**23.7**	17.0	12.5	5.0	5.5	1.7	0.4	0.1
Summer	0.0	0.0	0.0	0.3	5.0	13.9	26.8	**29.5**	13.2	5.5	2.1	1.0	1.4	0.6	0.3	0.3
Autumn	0.0	0.0	0.0	0.0	1.0	4.7	13.9	18.3	**21.8**	14.3	11.8	5.3	5.6	2.3	0.6	0.2
Annual	0.0	0.0	0.0	0.1	1.7	5.8	13.9	18.5	**18.9**	14.4	11.9	5.5	6.3	2.0	0.6	0.3

A scatter diagram of the significant wave height versus spectral peak period for each grid point is presented in Table 2.10 through Table 2.13. The most common wave at grid point 05000 is 2 m with a peak spectral period of 7 seconds. For the remainder of the grid points, the most common period is 2 m with a spectral period of 9 seconds. Note that wave heights in these tables have been rounded to the nearest whole number. Therefore, the 1 m wave bin would include all waves from 0.51 m to 1.49 m.

Table 2.10 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

		Wave Height (m)														Total
		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	
Period (s)	0	1.27														1.27
	1	0.00														0.00
	2															0.00
	3		0.00													0.00
	4		0.19	0.05	0.00											0.24
	5		1.72	1.01	0.05	0.00										2.77
	6		3.03	5.19	0.43	0.01	0.00									8.67
	7		5.47	8.67	4.19	0.20	0.00									18.53
	8		3.37	7.78	6.01	2.05	0.11	0.00								19.32
	9	0.00	0.94	5.87	5.18	3.87	1.03	0.05	0.00	0.00						16.95
	10	0.00	0.62	2.61	3.29	2.75	2.39	0.64	0.05	0.00	0.00					12.36
	11	0.00	0.15	0.73	1.74	1.85	1.69	1.44	0.50	0.08	0.00					8.20
	12		0.37	1.69	1.12	0.73	0.58	0.61	0.60	0.38	0.17	0.02	0.00			6.28
	13		0.25	0.56	0.49	0.57	0.53	0.42	0.30	0.23	0.30	0.20	0.04	0.00		3.89
	14		0.12	0.25	0.12	0.06	0.08	0.10	0.07	0.04	0.05	0.08	0.08	0.02	0.00	1.08
	15		0.02	0.07	0.02	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.02	0.00	0.21
	16		0.03	0.04	0.04	0.03	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.15
	17		0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00				0.06
	18		0.00	0.00	0.00						0.00	0.00				0.01
		1.27	16.32	34.53	22.71	12.15	6.43	3.29	1.53	0.75	0.52	0.31	0.14	0.04	0.01	99.99

Table 2.11 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

		Wave Height (m)														Total
		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	
Period (s)	0	0.74														0.74
	1	0.00														0.00
	2	0.00														0.00
	3	0.00	0.00													0.00
	4		0.14	0.04												0.18
	5		1.14	0.82	0.05	0.00										2.01
	6		2.19	3.88	0.44	0.03	0.00									6.54
	7		5.86	6.12	3.34	0.30	0.01	0.00								15.62
	8		4.86	7.81	4.38	1.79	0.13	0.01								18.97
	9	0.00	1.71	8.97	4.79	3.17	0.90	0.06	0.00							19.62
	10	0.00	0.52	4.11	4.67	2.38	1.75	0.48	0.04	0.00						13.96
	11	0.00	0.18	1.91	2.94	1.79	1.22	0.89	0.30	0.03	0.00					9.26
	12		0.20	1.29	1.65	1.07	0.48	0.43	0.36	0.19	0.06	0.01				5.76
	13	0.00	0.14	0.81	1.26	1.19	0.67	0.30	0.20	0.20	0.16	0.05	0.01			4.99
	14	0.00	0.06	0.21	0.58	0.45	0.23	0.13	0.05	0.03	0.05	0.06	0.03	0.00		1.88
	15		0.00	0.02	0.07	0.11	0.07	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.32
	16		0.00	0.02	0.02	0.02	0.02	0.01	0.00	0.00			0.00			0.10
	17		0.00	0.01	0.01	0.00	0.00	0.00		0.00						0.03
	18						0.00	0.00								0.00
		0.75	17.01	36.03	24.20	12.31	5.49	2.34	0.97	0.46	0.27	0.13	0.04	0.01	0.00	100.00

Table 2.12 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

		Wave Height (m)														Total
		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	
Period (s)	0	0.00														0.00
	1															0.00
	2															0.00
	3															0.00
	4		0.09	0.01												0.10
	5		1.46	0.58	0.01	0.00										2.05
	6		2.33	3.81	0.27	0.01										6.42
	7		4.52	7.09	2.96	0.19	0.00									14.76
	8		3.65	7.49	4.82	1.50	0.08									17.54
	9		1.36	7.83	5.39	3.61	0.76	0.04								18.98
	10		0.32	2.64	5.28	3.19	1.98	0.44	0.02	0.00						13.88
	11		0.37	1.87	3.54	2.63	1.75	1.18	0.28	0.03	0.00					11.64
	12		0.19	0.42	0.84	1.68	1.32	0.83	0.47	0.22	0.07	0.01				6.05
	13		0.18	0.64	0.66	0.89	0.89	0.58	0.35	0.22	0.18	0.10	0.01			4.69
	14		0.08	0.31	0.41	0.34	0.38	0.39	0.24	0.10	0.09	0.10	0.08	0.02		2.53
	15		0.03	0.16	0.26	0.16	0.06	0.05	0.04	0.02	0.01	0.02	0.02	0.02	0.01	0.87

	16		0.05	0.08	0.12	0.09	0.03	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.41
	17		0.02	0.02	0.01	0.00	0.00				0.00	0.00				0.07
	18		0.00	0.01					0.00							0.01
		0.00	14.66	32.95	24.57	14.28	7.26	3.51	1.40	0.60	0.36	0.23	0.11	0.04	0.01	99.99

Table 2.13 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

		Wave Height (m)														Total
		<1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
Period (s)	**0**	0.28														0.28
	1															0.00
	2															0.00
	3															0.00
	4		0.08	0.01												0.09
	5	0.00	1.22	0.52	0.01	0.00										1.75
	6		1.73	3.86	0.25	0.00	0.00									5.85
	7	0.00	3.94	6.66	3.09	0.23	0.01									13.93
	8	0.00	4.24	7.67	4.85	1.70	0.10	0.00								18.56
	9		0.86	7.75	5.34	3.98	0.89	0.05	0.00							18.86
	10		0.29	2.70	5.11	3.22	2.44	0.51	0.03	0.00						14.29
	11		0.22	1.59	3.48	2.83	1.94	1.37	0.35	0.04	0.00	0.00				11.83
	12		0.13	0.53	0.93	1.21	0.97	0.74	0.56	0.29	0.12	0.01				5.49
	13		0.17	0.71	1.26	1.43	1.04	0.59	0.34	0.26	0.25	0.13	0.02	0.00		6.22
	14		0.06	0.29	0.42	0.34	0.28	0.18	0.12	0.07	0.03	0.07	0.07	0.02		1.94
	15		0.03	0.07	0.10	0.17	0.09	0.04	0.03	0.02	0.01	0.01	0.01	0.02	0.00	0.59
	16		0.03	0.04	0.05	0.03	0.05	0.02	0.01	0.01	0.00	0.00		0.00	0.00	0.25
	17		0.01	0.02	0.00	0.00	0.00			0.00	0.00	0.00				0.04
	18		0.00	0.01	0.00	0.00										0.01
		0.29	13.01	32.43	24.90	15.16	7.80	3.49	1.44	0.69	0.42	0.23	0.09	0.04	0.01	99.99

2.4 Weather Variables

2.4.1 Air and Sea Surface Temperature

The moderating influence of the ocean serves to limit both the diurnal and the annual temperature variation within the project area. Diurnal temperature variations due to the day/night cycles are very small. Short-term, random temperature changes are due mainly to a change of air mass following a warm or cold frontal passage. In general, air mass temperature contrasts across frontal zones are greater during the winter than during the summer season.

Air and sea surface temperatures for the area were extracted from the ICOADS data set. A monthly plot of air temperature versus sea surface temperature is presented in Figure 2.29 through Figure 2.32. Temperature statistics presented show that the atmosphere in all

regions is coldest in February and warmest in August. Air temperature in Region 4 is warmer than the other three regions due to the location of the Gulf Stream. The sea surface temperature is warmest in August in each region and coldest in February and March.

Table 2.14 ICOADS Region 1 Air and Sea Surface Temperature Statistics

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	1.9	15.5	-11.5	4.3	15.0	-1.6
February	0.8	14.4	-15.0	3.2	14.0	-1.8
March	1.4	13.8	-11.9	2.9	15.0	-1.8
April	4.0	14.8	-5.6	3.7	16.3	-1.8
May	6.9	16.6	-0.5	6.1	18.0	-1.5
June	10.6	20.0	1.1	10.3	21.1	0.7
July	16.0	25.0	5.0	15.3	26.0	5.0
August	18.3	26.2	10.0	18.3	25.7	10.0
September	16.2	25.0	6.5	17.0	26.0	9.4
October	12.3	23.5	1.1	13.4	24.4	5.0
November	8.6	20.5	-3.0	10.0	25.0	1.2
December	4.8	17.0	-11.0	7.0	19.0	-1.5

(Source: ICOADS Data set (January 1980- September 2013))

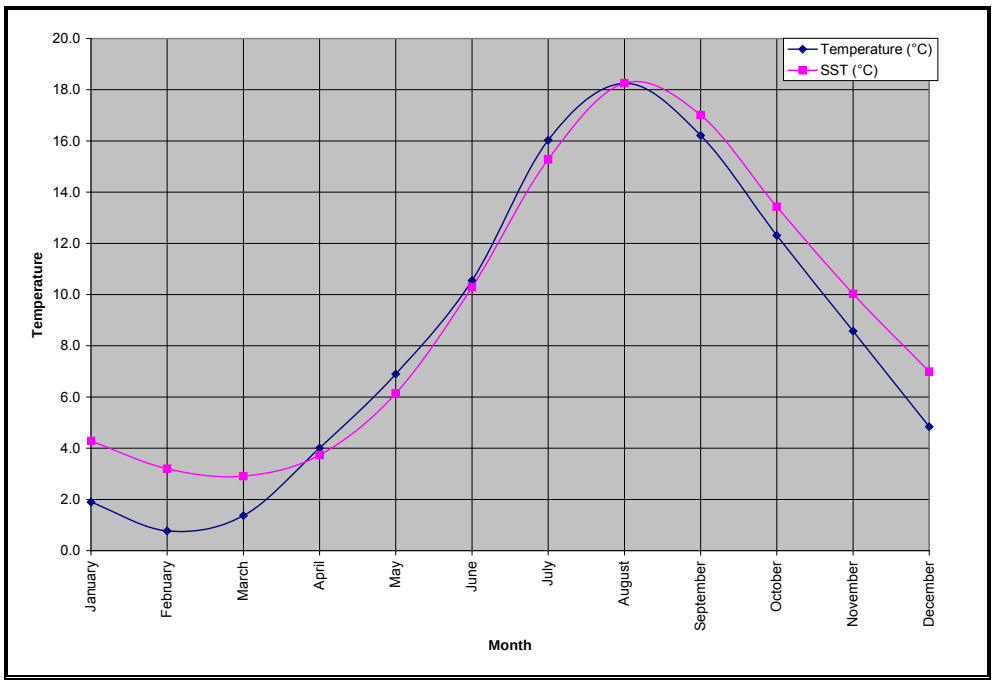


Figure 2.29 ICOADS Region 1 Monthly Mean Air and Sea Surface Temperature

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.15 ICOADS Region 2 Air and Sea Surface Temperature Statistics

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	2.3	14.0	-9.0	3.6	9.5	-1.8
February	1.3	14.0	-13.0	2.5	11.3	-1.8
March	2.0	12.8	-11.0	2.2	10.8	-1.8
April	3.9	15.0	-5.0	2.8	9.8	-1.8
May	6.2	18.0	-4.0	5.2	12.0	-1.1
June	9.9	20.5	-1.6	8.9	16.5	0.4
July	15.4	26.0	4.6	14.5	23.3	2.2
August	17.7	28.0	7.0	17.9	24.4	7.8
September	15.6	26.0	5.1	17.1	24.7	6.3
October	12.5	23.1	1.0	13.0	20.6	2.0
November	8.0	18.1	-3.0	8.9	16.0	-1.1
December	5.1	17.0	-7.8	6.0	13.0	-1.7

(Source: ICOADS Data set (January 1980- September 2013))

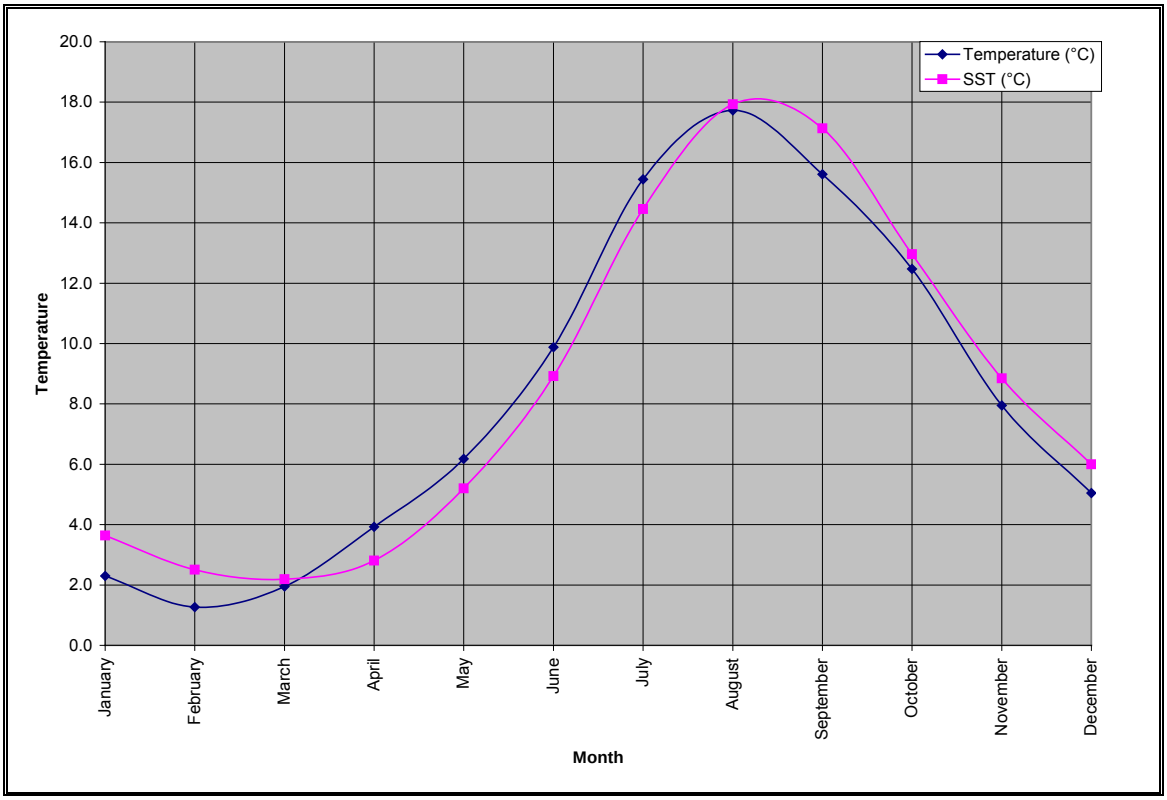


Figure 2.30 ICOADS Region 2 Monthly Mean Air and Sea Surface Temperature

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.16 ICOADS Region 3 Air and Sea Surface Temperature Statistics

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	6.4	21.0	-8.0	11.7	23.0	-1.1
February	6.0	20.4	-9.4	10.2	22.5	-1.7
March	6.8	21.1	-7.5	9.9	21.6	-1.7
April	9.6	22.5	-3.8	9.9	24.2	-1.5
May	11.1	23.5	-1.0	11.8	24.0	-1.0
June	13.6	24.0	2.0	14.0	24.4	0.2
July	17.6	27.5	5.4	17.5	27.4	4.7
August	18.7	28.5	9.0	20.3	28.0	9.0
September	17.1	27.0	7.0	18.8	26.7	7.8
October	14.0	24.8	2.5	16.3	26.0	3.7
November	11.2	23.0	-0.1	14.9	24.0	0.8
December	8.5	23.0	-7.8	13.2	24.0	-1.0

(Source: ICOADS Data set (January 1980- September 2013))

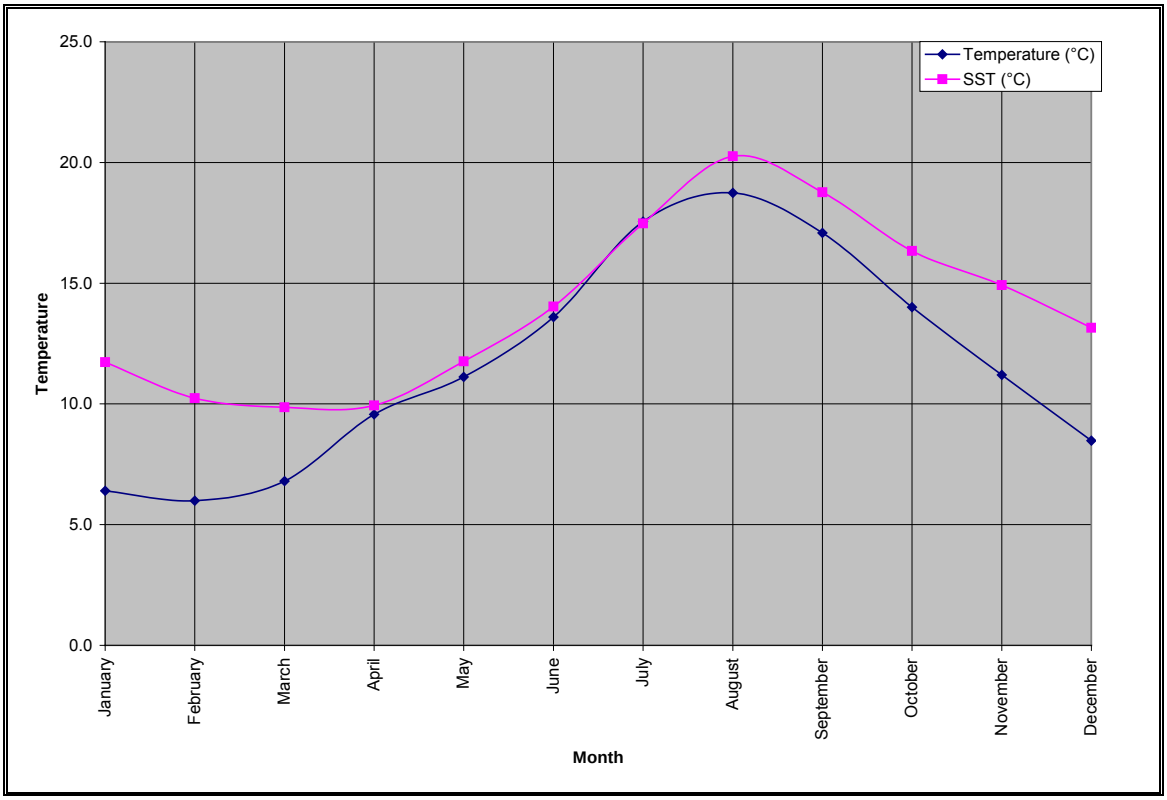


Figure 2.31 ICOADS Region 3 Monthly Mean Air and Sea Surface Temperature

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.17 ICOADS Region 4 Air and Sea Surface Temperature Statistics

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	9.6	24.0	-3.6	13.2	26.0	-0.5
February	9.2	25.0	-6.1	12.7	26.0	-1.1
March	9.7	26.0	-4.4	12.9	28.0	-1.0
April	11.4	25.7	-3.0	13.2	26.5	-0.9
May	14.0	27.3	0.8	14.6	27.3	0.1
June	17.0	28.3	4.0	17.1	28.5	3.5
July	21.2	30.6	8.0	21.1	30.9	10.1
August	22.1	32.3	12.0	22.9	32.0	13.5
September	20.1	30.3	10.7	21.5	30.3	11.9
October	17.1	29.5	5.0	19.0	29.0	8.0
November	13.7	26.5	1.0	17.1	29.0	3.5
December	11.0	25.6	-2.0	14.7	26.6	-0.7

(Source: ICOADS Data set (January 1980- September 2013))

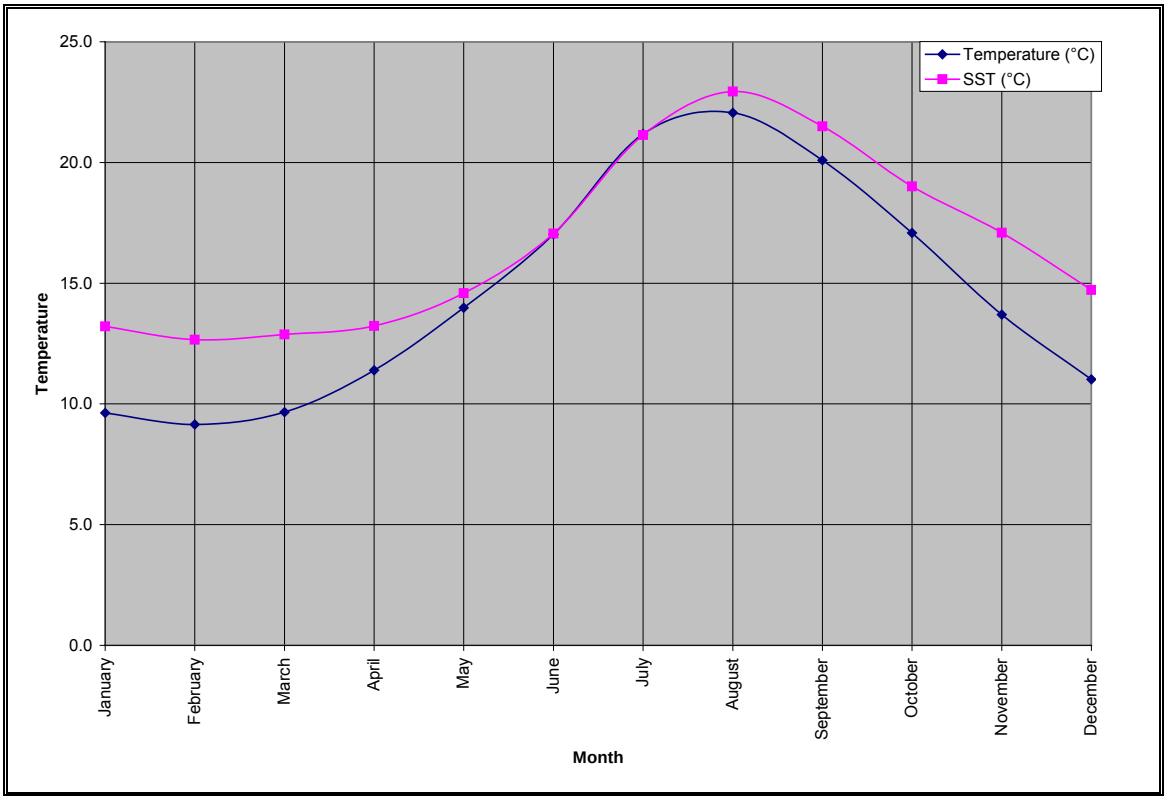


Figure 2.32 ICOADS Region 4 Monthly Mean Air and Sea Surface Temperature

(Source: ICOADS Data set (January 1980- September 2013))

2.4.2 Precipitation

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

Liquid Precipitation
- Drizzle
- Rain

Freezing Precipitation
- Freezing Drizzle
- Freezing Rain

Frozen Precipitation
- Snow
- Snow Pellets
- Snow Grains
- Ice Pellets
- Hail
- Ice Crystals

The migratory high and low pressure systems transiting the temperate middle latitude of the Northern Hemisphere cause a variety of precipitation types in their paths. The frequency of precipitation type for the study area was calculated using data from the ICOADS data set, with each occurrence counting as one event. Precipitation statistics for these regions may be low due a fair weather bias. That is, ships tend to either avoid regions of inclement weather, or simply do not report during these events.

The frequency of precipitation type in Table 2.18 through Table 2.21 shows that annually, precipitation occurs about 22% of the time in Regions 1, 3, and 4 and 18.5% of the time in Region 2. Winter has the highest frequency of precipitation with Region 1 having precipitation 35.4% of the time. Snow accounts for the majority of precipitation during the winter months. Summer has the lowest frequency of precipitation with a total frequency of occurrence of 11.2% in Region 2. Snow has been reported in each month; however this is probably due to coding error rather than the actual presence of snow.

The percentage of occurrences of freezing precipitation data was also calculated from the ICOADS data set. 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 frequency of freezing precipitation was slightly higher in the winter months than during the spring. Region 1 had the highest occurrence of freezing precipitation. No freezing precipitation was recorded in Region 4.

Thunderstorms occur relatively infrequently over the study area though they may occur in any month of the year. It should be noted that hail only occurs in the presence of severe thunderstorms, yet in the table the frequency of hail is higher than the frequency of thunderstorms for several of the months. This may be due to observer inexperience, classifying what should be ice pellets (formed through entirely different atmospheric

processes) as hail or through coding error. Region 4 has the highest occurrence of thunderstorms.

Table 2.18 Region 1 Percentage Frequency (%) Distribution of Precipitation

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	10.9	0.4	1.8	25.2	0.2	0.2	38.7
February	9.8	0.7	2.2	23.8	0.1	0.1	36.8
March	11.5	0.5	1.0	14.4	0.2	0.2	27.8
April	14.0	0.1	0.5	4.7	0.1	0.1	19.5
May	11.4	0.0	0.0	0.8	0.2	0.0	12.4
June	14.4	0.0	0.0	0.4	0.3	0.1	15.2
July	9.5	0.0	0.0	0.3	0.4	0.1	10.3
August	13.4	0.0	0.1	0.2	0.7	0.1	14.4
September	15.6	0.0	0.1	0.5	0.3	0.1	16.5
October	19.7	0.0	0.2	0.7	0.2	0.1	20.9
November	20.0	0.0	1.1	4.1	0.2	0.6	26.0
December	15.1	0.1	1.8	13.0	0.3	0.4	30.8
Winter	11.9	0.4	1.9	20.7	0.2	0.2	35.4
Spring	12.3	0.2	0.5	6.7	0.2	0.1	19.9
Summer	12.4	0.0	0.0	0.3	0.4	0.1	13.3
Autumn	18.4	0.0	0.4	1.7	0.2	0.3	21.1
Total	13.7	0.2	0.7	6.7	0.3	0.2	21.7

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.19 Region 2 Percentage Frequency (%) Distribution of Precipitation

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	12.5	0.2	1.4	12.3	0.2	0.0	26.7
February	11.6	0.4	1.5	15.4	0.4	0.4	29.5
March	12.4	0.4	0.9	10.9	0.2	0.2	25.0
April	12.8	0.1	0.4	4.0	0.1	0.0	17.4
May	13.5	0.0	0.2	0.9	0.0	0.0	14.7
June	11.1	0.0	0.0	0.4	0.1	0.0	11.7
July	8.6	0.0	0.0	0.1	0.3	0.0	9.0
August	11.9	0.0	0.1	0.4	0.5	0.1	13.0
September	16.4	0.0	0.0	0.3	0.3	0.0	17.1
October	17.5	0.0	0.1	0.6	0.4	0.1	18.7
November	15.7	0.0	0.7	2.5	0.4	0.3	19.6
December	16.8	0.0	0.8	8.6	0.1	0.2	26.6
Winter	13.6	0.2	1.2	12.2	0.3	0.2	27.7
Spring	12.9	0.2	0.5	4.8	0.1	0.1	18.6

Summer	10.5	0.0	0.0	0.3	0.3	0.0	11.2
Autumn	16.5	0.0	0.3	1.1	0.4	0.2	18.5
Total	13.3	0.1	0.5	4.3	0.3	0.1	18.5

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.20 Region 3 Percentage Frequency (%) Distribution of Precipitation

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	19.6	0.0	1.6	7.9	0.4	1.4	30.9
February	19.9	0.2	1.6	9.0	0.5	1.0	32.1
March	20.2	0.0	1.0	6.8	0.3	0.9	29.2
April	16.7	0.0	0.3	1.9	0.1	0.3	19.3
May	15.1	0.0	0.1	0.8	0.3	0.0	16.3
June	14.3	0.0	0.1	0.7	0.2	0.0	15.2
July	10.5	0.0	0.1	0.3	0.4	0.1	11.5
August	14.5	0.0	0.1	0.2	0.5	0.1	15.4
September	17.1	0.0	0.1	0.5	0.4	0.0	18.1
October	19.7	0.0	0.1	0.4	0.5	0.2	20.9
November	21.2	0.0	0.3	1.6	0.6	0.8	24.5
December	23.8	0.0	1.1	4.3	0.7	1.4	31.3
Winter	20.9	0.1	1.5	7.2	0.5	1.2	31.4
Spring	17.5	0.0	0.5	3.3	0.2	0.4	21.9
Summer	13.0	0.0	0.1	0.4	0.4	0.1	14.0
Autumn	19.3	0.0	0.2	0.9	0.5	0.3	21.2
Total	17.5	0.0	0.5	2.9	0.4	0.5	21.8

(Source: ICOADS Data set (January 1980- September 2013))

Table 2.21 Region 4 Percentage Frequency (%) Distribution of Precipitation

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	26.7	0.0	0.7	2.6	1.0	0.5	31.5
February	24.5	0.0	0.9	3.5	1.0	0.5	30.3
March	22.8	0.0	0.5	2.4	1.1	0.6	27.3
April	21.4	0.0	0.4	1.3	1.1	0.2	24.4
May	17.0	0.0	0.2	0.7	0.6	0.1	18.6
June	16.0	0.0	0.1	0.9	0.7	0.0	17.7
July	12.7	0.0	0.1	0.7	1.3	0.1	15.0
August	15.5	0.0	0.1	0.5	2.3	0.1	18.5
September	14.9	0.0	0.1	0.7	1.2	0.2	17.1
October	19.6	0.0	0.1	0.5	0.9	0.1	21.2
November	23.4	0.0	0.2	0.9	0.9	0.5	25.8
December	26.4	0.0	0.3	1.8	0.9	0.7	30.1

Winter	25.8	0.0	0.6	2.6	0.9	0.6	30.6
Spring	20.1	0.0	0.3	1.4	0.9	0.3	23.0
Summer	14.7	0.0	0.1	0.7	1.4	0.1	17.0
Autumn	19.2	0.0	0.1	0.7	1.0	0.2	21.3
Total	19.6	0.0	0.3	1.3	1.1	0.3	22.6

(Source: ICOADS Data set (January 1980- September 2013))

2.4.3 Visibility

Visibility is defined as the greatest distance at which objects of suitable dimensions can be seen and identified. Horizontal visibility may be reduced by any of the following phenomena, either alone or in combination:

- Fog
- Mist
- Haze
- Smoke
- Liquid Precipitation (e.g., drizzle)
- Freezing Precipitation (e.g., freezing rain)
- Frozen Precipitation (e.g., snow)
- Blowing Snow

A plot of the frequency distribution of visibility from the ICOADS data set for each region is presented in Figure 2.33 through Figure 2.36. These figures show that obstructions to vision can occur in any month. Region 2 had the highest occurrence of obstructions to vision with good visibility occurring only 62.2% of the time. There is little seasonal variation in visibility in Region 4. Seasonal variations are present in the other three regions.

During the winter months in Regions 1 and 2, the main obstruction is snow; however, mist and fog may also reduce visibilities at times. As spring approaches, the amount of visibility reduction attributed to snow decreases. As the air temperature increases, so does the occurrence of advection fog. Advection fog forms when warm moist air moves over cooler waters. By April, the sea surface temperature south of Newfoundland is cooler than the surrounding air. As warm moist air from the south moves over the colder sea surface, 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. The presence of advection fog increases from April through July. The month of July has the highest percentage of obscuration to visibility, most of which is in the form of advection fog, although frontal fog can also contribute to the reduction in visibility. In August the temperature difference between the air and the sea begins to narrow and by September, the air

temperature begins to fall below the sea surface temperature. As the air temperature drops, the occurrence of fog decreases. Reduction in visibility during autumn and winter is relatively low and is mainly attributed to the passage of low-pressure systems. Fog is the main the cause of the reduced visibilities in autumn and snow is the main cause of reduced visibilities in the winter. October has the lowest occurrence of reduced visibility since the air temperature has, on average, decreased below the sea surface temperature and it is not yet cold enough for snow.

Regions 3 and 4 experience a warmer climate than Regions 1 and 2 and there is less of an influence from advection fog. As a result, reductions to visibilities in these regions can mainly be attributed to the passage of low pressure systems. Since the occurrence of snow in Region 4 is small, most of the obstructions to visibility are due to fog throughout the year.

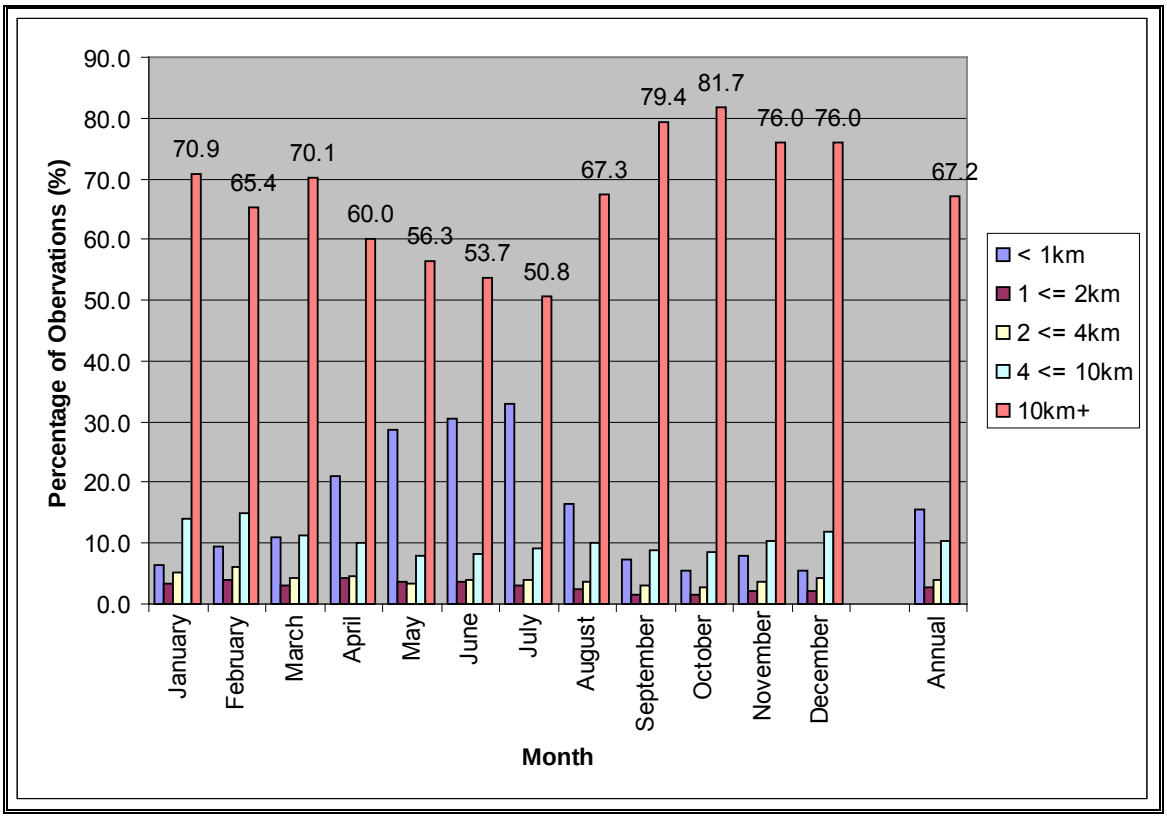


Figure 2.33 Region 1 Monthly and Annual Percentage Occurrence of Visibility

(Source: ICOADS Data set (January 1980- September 2013))

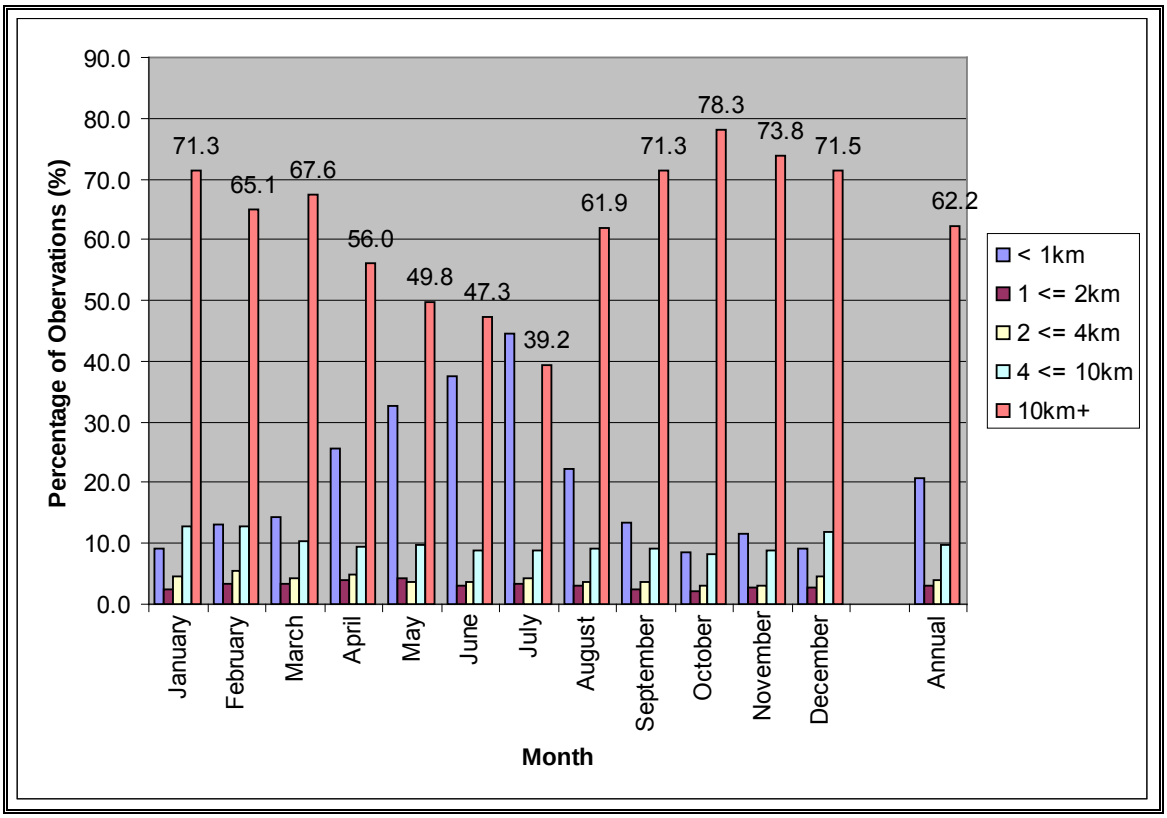


Figure 2.34 Region 2 Monthly and Annual Percentage Occurrence of Visibility

(Source: ICOADS Data set (January 1980- September 2013))

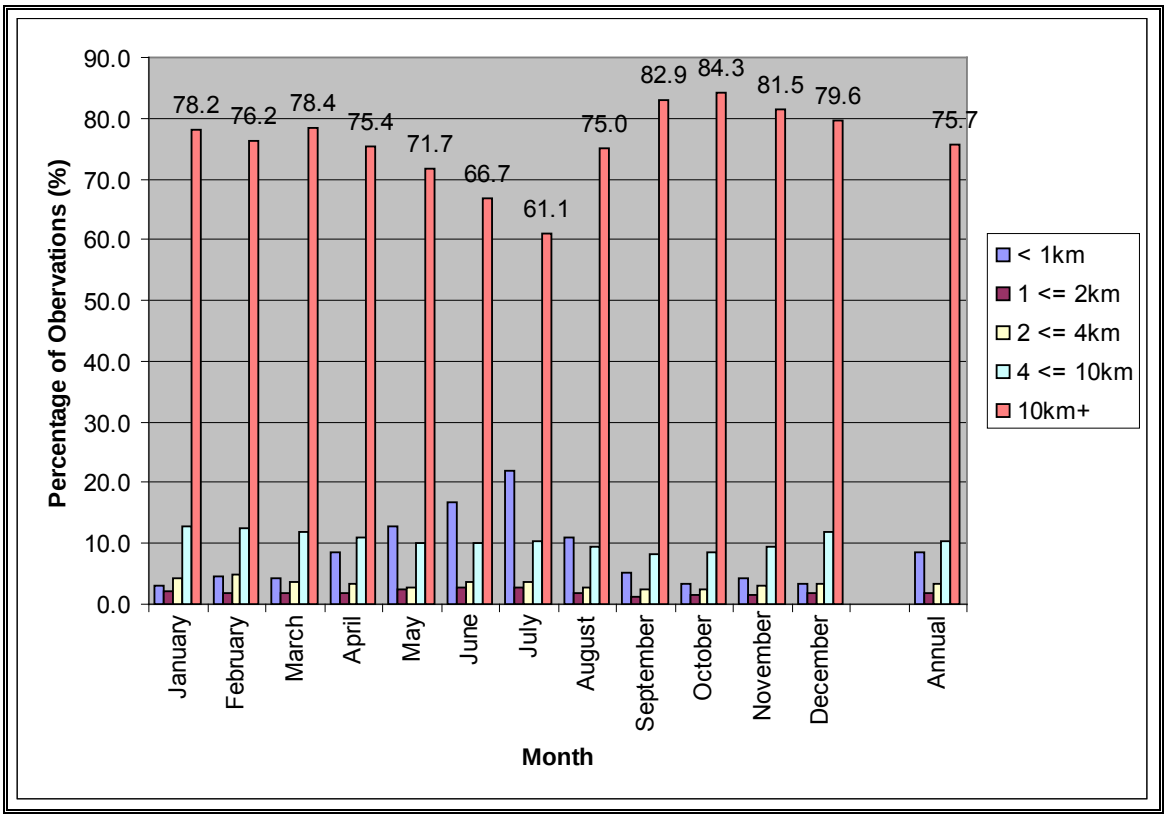


Figure 2.35 Region 3 Monthly and Annual Percentage Occurrence of Visibility

(Source: ICOADS Data set (January 1980- September 2013))

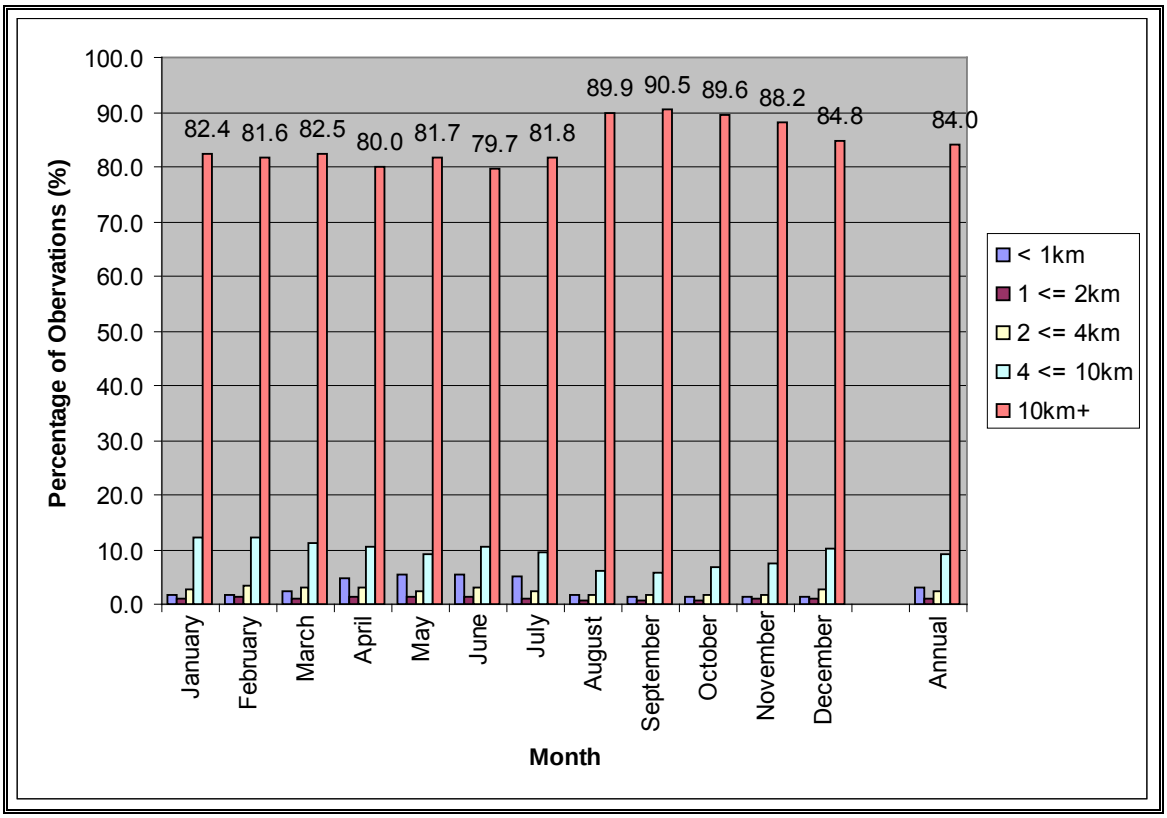


Figure 2.36 Region 4 Monthly and Annual Percentage Occurrence of Visibility

(Source: ICOADS Data set (January 1980- September 2013))

2.4.4 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, water salinity, wave conditions, and wind speed which 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). These algorithms are based primarily on reports from vessels that were 20 to 75 m in length. Here is the algorithm presented by Overland (1990).

$$PPR = \frac{V_a (T_f - T_a)}{1 + 0.3(T_w - T_f)}$$

PPR = Icing Predictor ($m°Cs^{-1}$)
Va = Wind Speed (ms^{-1})

Tf = Freezing point of seawater (usually -1.7°C or -1.8°C)
Ta = Air Temperature (°C)
Tw = Sea temperature (°C)

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). Based on the above algorithm the terminology and associated vessel icing rates for freezing spray forecasts are shown in Table 2.22. These rates and terminology are used when forecasting freezing spray on the Grand Banks.

Table 2.22 Intensity of Freezing Spray

Intensity Term	Icing Rate (centimeters (cm) per hour)
Light	less than 0.7 cm/hr
Moderate	0.7 to 2.0 cm/hr inclusive
Heavy	2.0 – 4.0 cm/hr
Extreme	greater than 4.0 cm/hr

Potential icing rates were computed using wind speed and air sea surface temperature observations from the ICOADS data set. Monthly, seasonal, and annual summaries are presented in Table 2.23 through Table 2.26 and Figure 2.37 through Figure 2.40.

Region 1 experiences the highest percentage of freezing spray occurring 4.6% of the time annually, while Region 4 experiences the least percentage, occurring only 0.08% of the time annually. Potential sea spray icing conditions start in Region 1 during the month of November. As temperatures cool throughout the winter, the frequency of icing potential increases to a maximum of 20.8% of the time in February. Extreme sea spray icing conditions were calculated to occur 0.5% of the time during February. Icing potential decreases rapidly after February in response to warming air and sea surface temperatures, and by April the frequency of icing conditions is only 0.8%. Only light freezing spray has been reported in Region 4.

Table 2.23 Region 1 Frequency of Occurrence of Potential Spray Icing Conditions

	None (0cm/hr)	Light (<0.7cm/hr)	Moderate (0.7- 2.0cm/hr)	Heavy (2.0-4.0cm/hr)	Extreme (>4.0cm/hr)
January	84.3	13.9	1.7	0.1	0.1
February	79.2	17.2	2.5	0.5	0.5
March	85.5	12.2	1.7	0.4	0.1
April	99.2	0.8	0.0	0.0	0.0

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	100.0	0.0	0.0	0.0	0.0
November	100.0	0.0	0.0	0.0	0.0
December	97.2	2.7	0.2	0.0	0.0
Winter	86.9	11.3	1.5	0.2	0.2
Spring	94.9	4.3	0.6	0.1	0.0
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	95.4	3.9	0.5	0.1	0.1

(Source: ICOADS Data set (January 1980- September 2013))

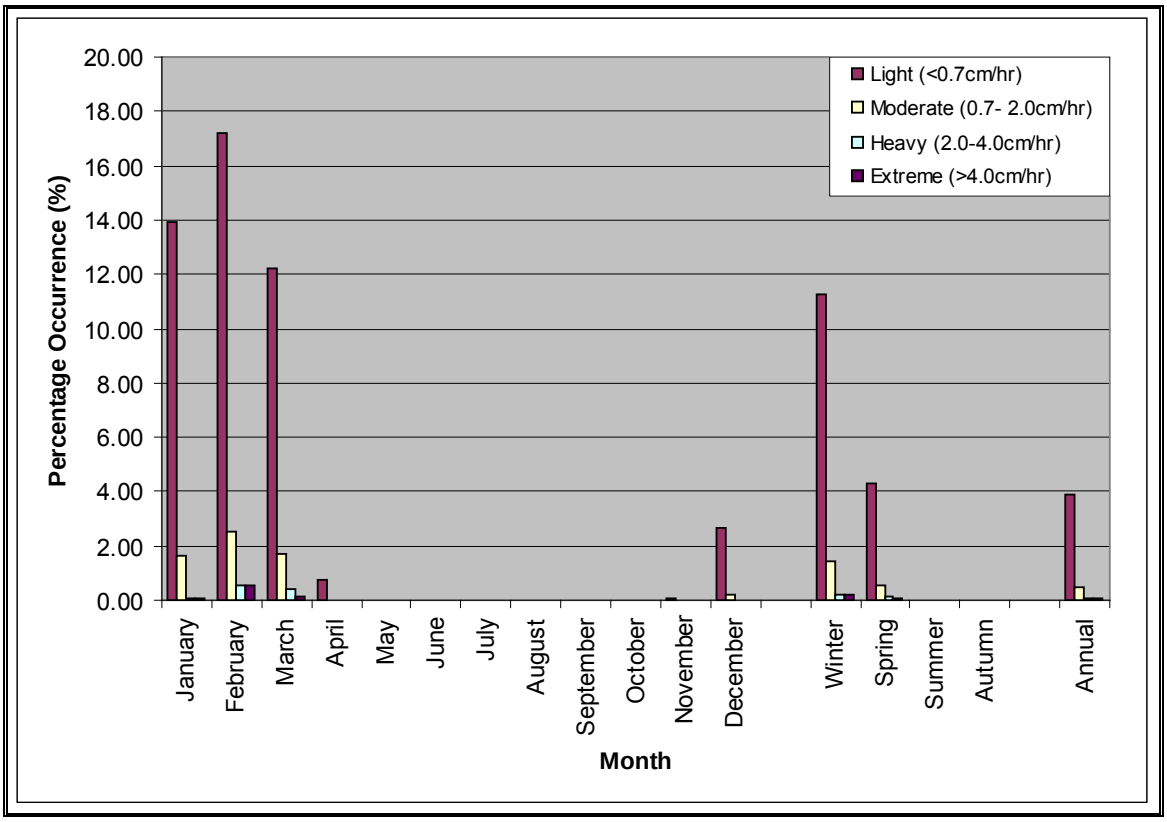


Figure 2.37 Region 1 Frequency of Occurrence of Potential Spray Icing Conditions
(Source: ICOADS Data set (January 1980- September 2013))

Table 2.24 Region 2 Frequency of Occurrence of Potential Spray Icing Conditions

	None (0cm/hr)	Light (<0.7cm/hr)	Moderate (0.7- 2.0cm/hr)	Heavy (2.0-4.0cm/hr)	Extreme (>4.0cm/hr)
January	90.7	8.2	0.9	0.2	0.0
February	85.1	12.8	1.5	0.2	0.4
March	91.0	8.3	0.5	0.1	0.0
April	98.6	1.4	0.0	0.0	0.0
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	100.0	0.0	0.0	0.0	0.0
November	100.0	0.0	0.0	0.0	0.0
December	98.0	1.9	0.1	0.0	0.0
Winter	91.3	7.6	0.8	0.1	0.1
Spring	96.5	3.2	0.2	0.0	0.0
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	96.9	2.7	0.3	0.0	0.0

(Source: ICOADS Data set (January 1980- September 2013))

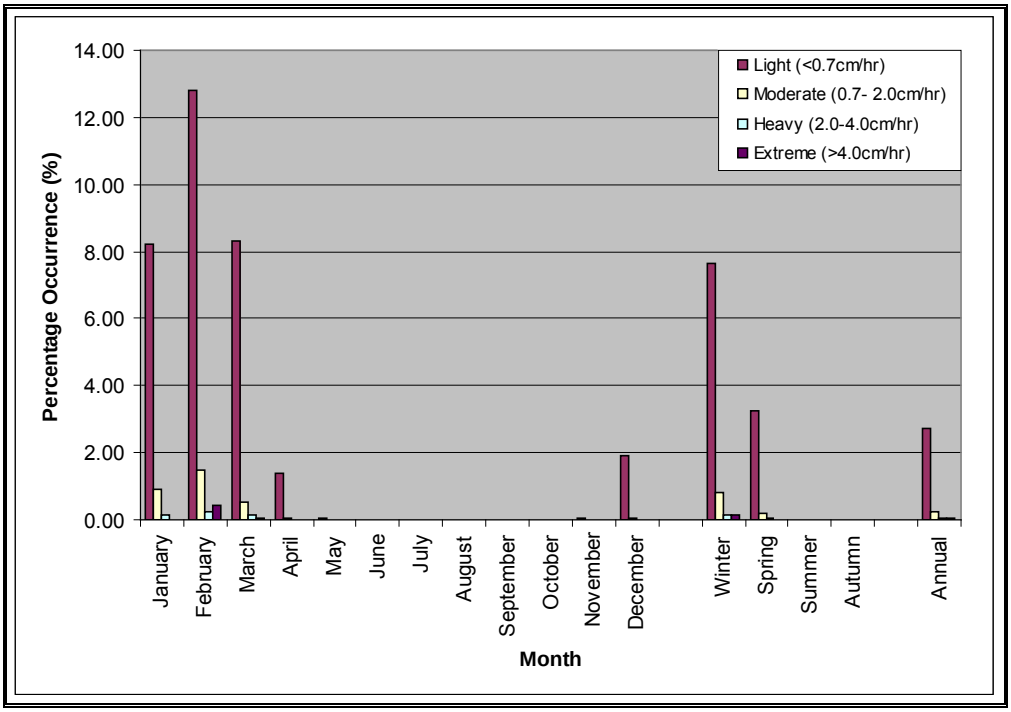


Figure 2.38 Region 2 Frequency of Occurrence of Potential Spray Icing Conditions
(Source: ICOADS Data set (January 1980- September 2013))

Table 2.25 Region 3 Frequency of Occurrence of Potential Spray Icing Conditions

	None (0cm/hr)	Light (<0.7cm/hr)	Moderate (0.7- 2.0cm/hr)	Heavy (2.0-4.0cm/hr)	Extreme (>4.0cm/hr)
January	96.7	3.0	0.4	0.0	0.0
February	94.8	4.8	0.2	0.1	0.0
March	97.4	2.5	0.2	0.0	0.0
April	99.8	0.2	0.0	0.0	0.0
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	100.0	0.0	0.0	0.0	0.0
November	100.0	0.0	0.0	0.0	0.0
December	99.3	0.6	0.0	0.0	0.0
Winter	96.9	2.8	0.2	0.0	0.0
Spring	99.0	0.9	0.1	0.0	0.0
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	99.0	0.9	0.1	0.0	0.0

(Source: ICOADS Data set (January 1980- September 2013))

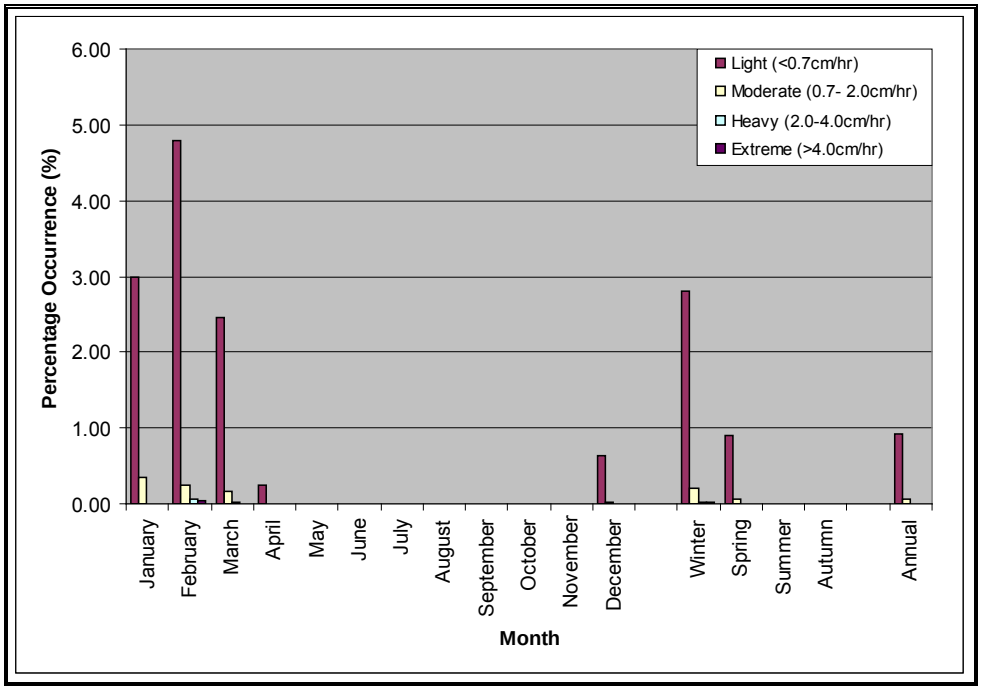


Figure 2.39 Region 3 Frequency of Occurrence of Potential Spray Icing Conditions
(Source: ICOADS Data set (January 1980- September 2013))

Table 2.26 Region 4 Frequency of Occurrence of Potential Spray Icing Conditions

	None (0cm/hr)	Light (<0.7cm/hr)	Moderate (0.7- 2.0cm/hr)	Heavy (2.0-4.0cm/hr)	Extreme (>4.0cm/hr)
January	99.8	0.2	0.0	0.0	0.0
February	99.5	0.5	0.0	0.0	0.0
March	99.8	0.2	0.0	0.0	0.0
April	100.0	0.0	0.0	0.0	0.0
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	100.0	0.0	0.0	0.0	0.0
November	100.0	0.0	0.0	0.0	0.0
December	100.0	0.0	0.0	0.0	0.0
Winter	99.8	0.2	0.0	0.0	0.0
Spring	99.9	0.1	0.0	0.0	0.0
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	99.9	0.1	0.0	0.0	0.0

(Source: ICOADS Data set (January 1980- September 2013))

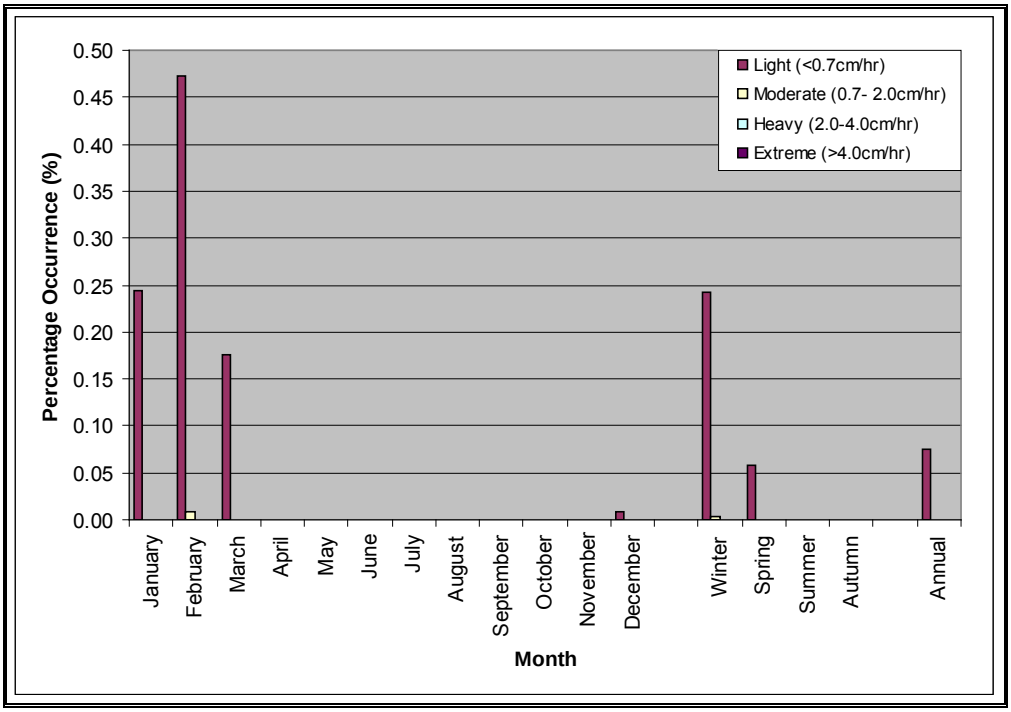


Figure 2.40 Region 4 Frequency of Occurrence of Potential Spray Icing Conditions
(Source: ICOADS Data set (January 1980- September 2013

3.0 Extreme Wind and Wave Analysis

An analysis of extreme wind and waves was performed using the same MSC50 grid point as the wind and wave analysis in the previous section. This data set was determined to be the most representative of the available data sets, as it provides a continuous 57-year period of hourly data for the study area. The extreme values for wind and waves 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 the number storms to use. The number of storms determined to provide the best fit annually and monthly for each grid point is presented in Table 3.1.

Table 3.1 Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves

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

3.1 Extreme Value for Winds from the Gumbel Distribution

The extreme value estimates for wind were calculated using Oceanweather's Osmosis software program for the return periods of 1-year, 10-years, 25-years, 50-years and 100-years. The calculated annual and monthly values for 1-hour, 10-minutes and 1-minute are presented in Table 3.2 through Table 3.4. The analysis used hourly mean wind values for the reference height of 10 m above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ratio of 1.06 and 1.22, respectively (U.S. Geological Survey, 1979). Of the four grid points analyzed, Grid Point 08026 had the highest wind speed estimates. The annual 100-year extreme 1-hour wind speed was determined to be 32.3 m/s for grid point 08026. Monthly, the highest 100-year extreme winds of 31.5 m/s occurred during the month of February.

While peak winds usually occur during the winter months, tropical systems can result in extreme wind speeds in any month. Grid points 05000 and 10537 both have monthly peaks in the 100-year estimates occurring in the month of September.

Table 3.2 1-hr Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years

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

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

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

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

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

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

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

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

3.2 Extreme Value for Waves from the 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 was 15.2 m at grid point 15016. A storm with a return period of 100 years means that the calculated significant wave height will occur once every 100 years, averaged over a long period of time.

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

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

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

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, and 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 individual wave heights and extreme associated peak periods are presented in Table 3.6. Maximum individual wave heights and the extreme associated peak periods peak during the month of December at grid point 15016.

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

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

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

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

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

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

3.3 Joint Probability of Extreme Wave Heights and Spectral Peak Periods

The joint probability of extreme wave height and spectral peak period analysis was carried out on a 3-hourly subset of the MSC50 data set. In order to examine the period ranges of storm events, an environmental contour plot was produced showing the probability of the joint occurrence of significant wave heights and the spectral peak periods using the methodology of Winterstein et al. (1993). The wave heights were fitted to a Weibull distribution and the peak periods to a lognormal distribution. The wave data was divided into bins of 1 m for significant wave heights and 1 second for peak periods. Since the lower wave values were having too much of an impact on the wave extremes, the wave heights below 2 m were modeled separately in a Weibull distribution. The two Weibull curves were combined near 2 m, the point where both functions had the same probability.

Three-parameter Weibull distributions were used with a scaling parameter α, shape parameter β, and location parameter γ. The three parameters were solved by using a least square method, the maximum log likelihood, and the method of moments. The following equation was minimized to get the coefficients:

$$LS(\alpha,\beta,\gamma) := \sum_{i=0}^{13}\left[\ln\left(-\ln\left(1-FP_i\right)\right)-\beta\cdot\ln\left[\frac{\left(h_i-\gamma\right)}{\alpha}\right]\right]^2$$

where h_i is the endpoint of the height bin (0.5, 1.5, …) and FP_i is the cumulative probability of the height bin. Using a minimizing function the three parameters α, β and γ were calculated.

A lognormal distribution was fitted to the spectral peak periods in each wave height bin. The coefficient of the lognormal distribution was then calculated. Using the coefficients and the two distribution functions, the joint wave height and period combinations were calculated for the various return periods.

Contour plots for each grid point depicting the joint wave height and spectral peak period combination values for return periods of 1-year, 10-years, 25-years, 50-years and 100-years are presented in Figure 3.1 through Figure 3.4. The annual values for the significant wave height estimates and the associated spectral peak periods for each grid point are given in Table 3.8. The extreme wave height for all return periods was higher using the Weibull Distribution when compared to the Gumbel Distribution.

Table 3.8 Annual Extreme Significant Wave Estimates and Spectral Peak Periods for Return Periods of 1, 10, 25, 50 and 100 Years

Grid Point	Return Period (years)	Combined Significant Wave Height (m)	Spectral Peak Period Median Value (s)
05000	1	12.4	14.9
	10	14.2	15.9
	25	14.9	16.3
	50	15.4	16.6
	100	15.8	16.9
08026	1	11.7	14.5
	10	13.8	15.5
	25	14.6	15.9
	50	15.2	16.2
	100	15.7	16.5
10537	1	11.8	14.7
	10	14.2	15.8

	25	15.1	16.2
	50	15.8	16.5
	100	16.5	16.8
11154	**1**	11.6	14.4
	10	14.0	15.5
	25	14.8	15.9
	50	15.5	16.2
	100	16.1	16.4

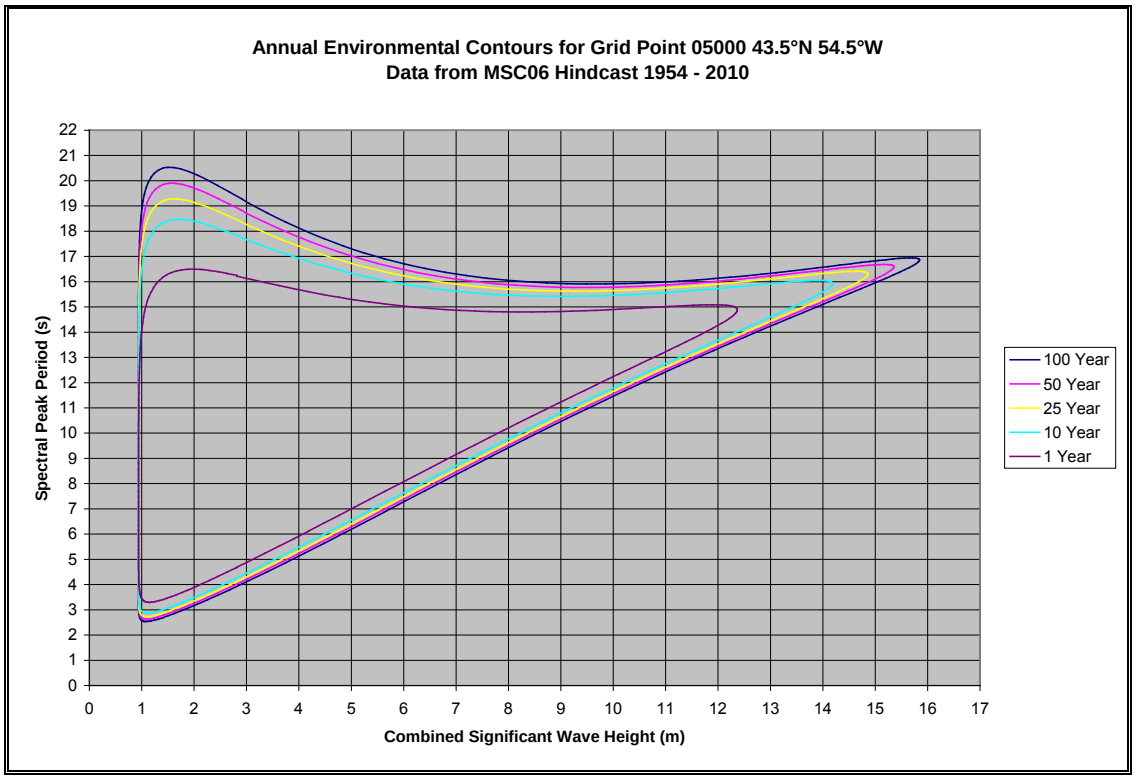


Figure 3.1 Environmental Contour Plot for Grid Point 05000 located near 43.5°N; 54.5°W. 1954 – 2010

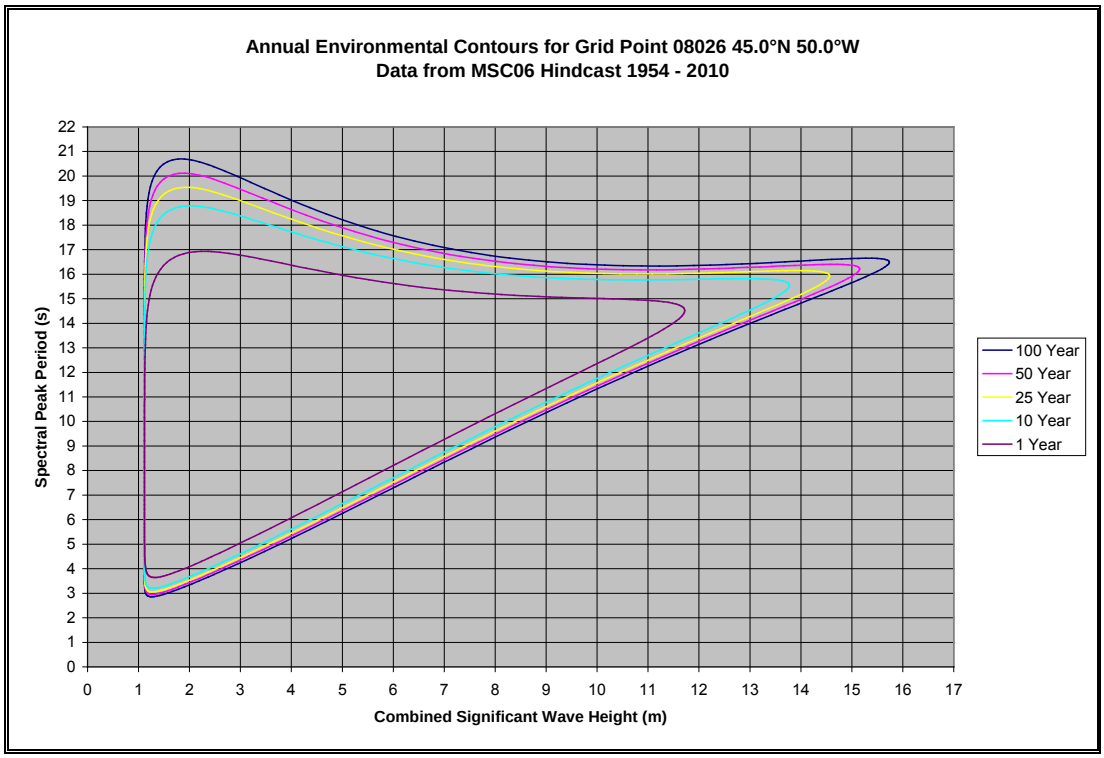


Figure 3.2 Environmental Contour Plot for Grid Point 08026 located near 45.0°N; 50.0°W. 1954 – 2010

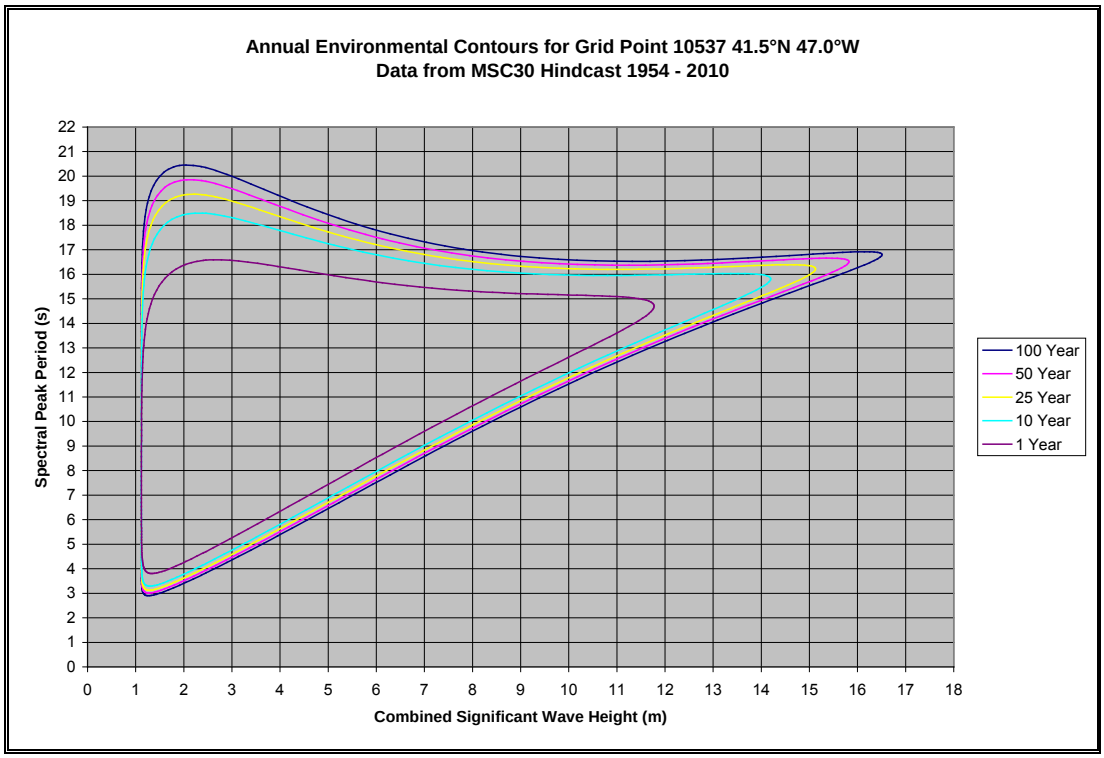


Figure 3.3 Environmental Contour Plot for Grid Point 10537 located near 41.5°N; 47.0°W. 1954 – 2010

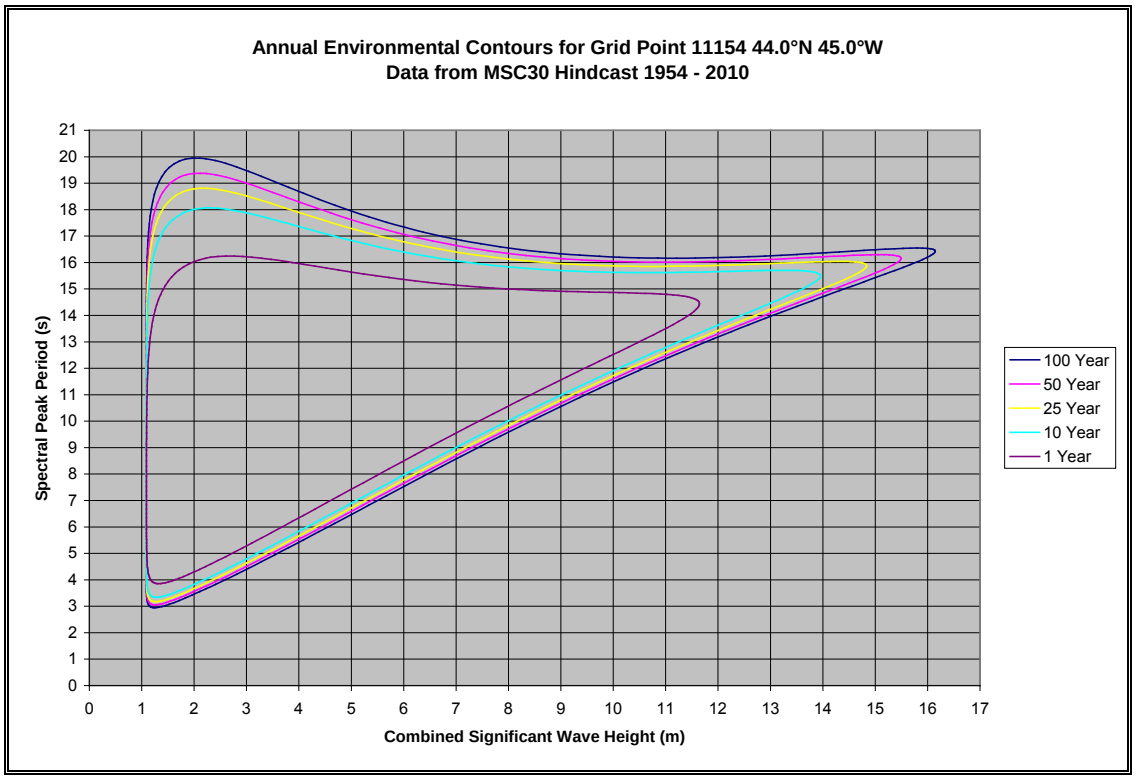


Figure 3.4 Environmental Contour Plot for Grid Point 11154 located near 44.0°N; 45.0°W. 1954 – 2010

4.0 Physical Oceanography

4.1 Major Currents in the Study Area

The study area is the southern part of the Grand Banks and its surrounding ocean waters including the Laurentian sub-basin and Newfoundland Basin. The ocean circulation in this area is influenced by the Labrador Current, the Gulf Stream, the Slope Water, and the water exchange with the Gulf of St. Lawrence through the Laurentian Channel. The main current pattern is shown in Figure 4.1.

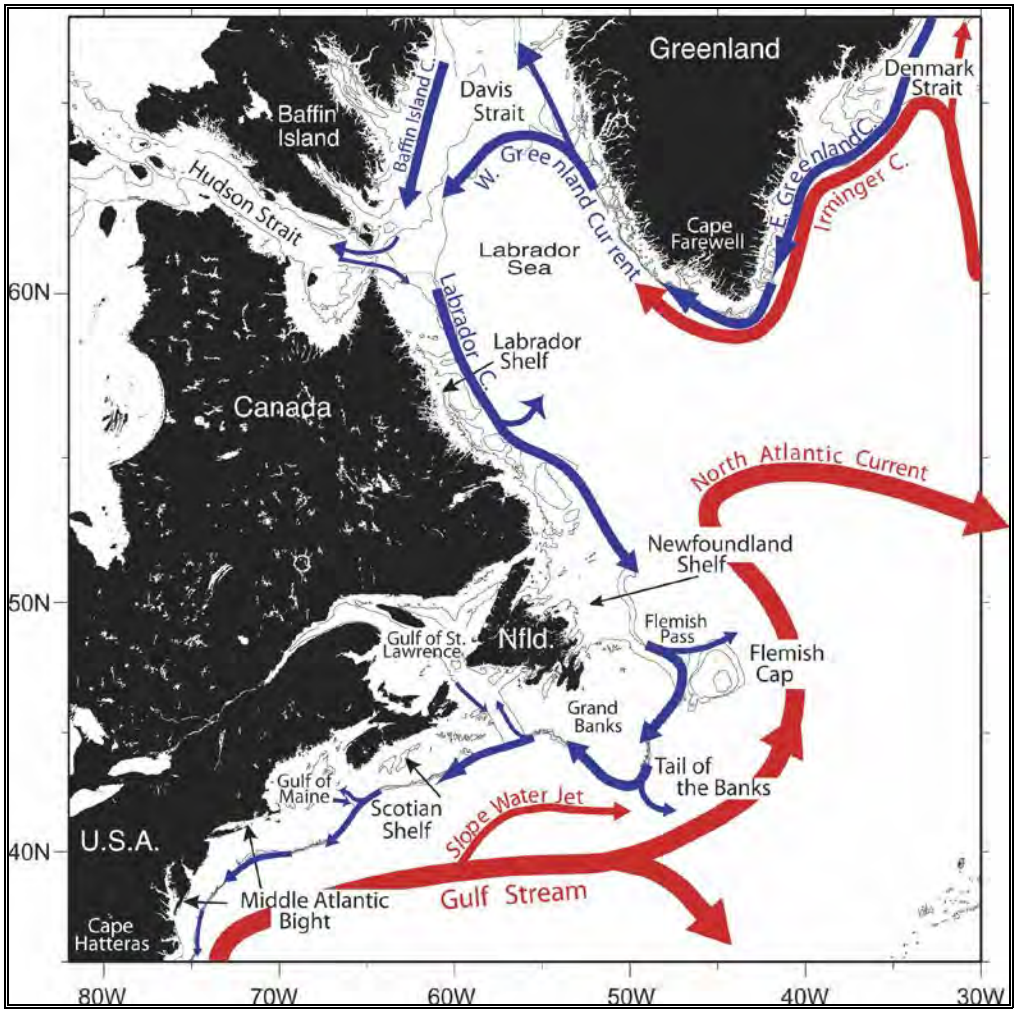


Figure 4.1 Schematic diagram of the main features of the surface circulation in the Western Atlantic Ocean. Cold shelf break waters are shown in blue while warm Gulf Stream waters are shown in red.

Source: Fratantoni and Pickart, 2007

4.1.1 The Labrador Current

The Labrador Current is the main current on the Grand Banks. As first described by Smith et al. (1937), the current is a continuation of the Baffin Island Current, which transports the cold and relatively low salinity water flowing out of Baffin Bay and the warmer and more saline waters of the branch of the warmer and saltier water of a branch of the West Greenland Current. The Labrador Current divides into two major branches on northern Grand Banks.

The inshore branch, which is approximately 100 km wide (Stein, 2007), is steered by the local underwater topography through the Avalon Channel, and then continues to follow the bathymetry around the Avalon Peninsula and southern Newfoundland. Petrie and Anderson (1983) estimated that approximately 10 percent of the Labrador Current follows the inshore route. After the current exits Avalon Channel it becomes a westward flowing current and reported to have speeds of 5 to 20 cm/s (Petrie and Anderson, 1983). This branch then divides into two parts, one flowing west and around the north side of St. Pierre Bank and the other flowing south in Haddock Channel between Green Bank and Whale Bank (Figure 4.2). The steam to the north of St. Pierre Bank has been reported to further divide, flowing along both sides of Burgeo Bank (Colbourne and Murphy, 2005).

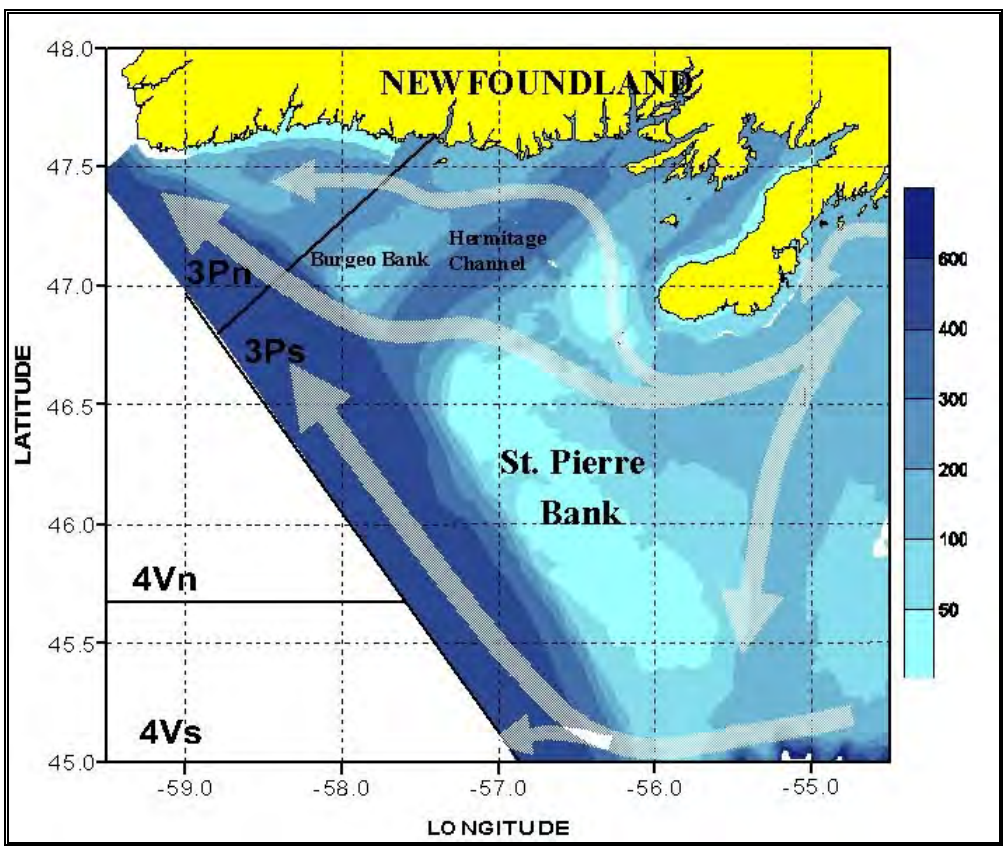


Figure 4.2 Schematic diagram of the divided inshore branch of Labrador Current after it exits Avalon Channel.

Source: Colbourne and Murphy, 2005

The stronger offshore branch of the Labrador Current flows along the shelf break over the upper portion of the Continental Slope. It flows around the eastern edge of the Grand Banks and through Flemish Pass. The offshore branch consists two streams, one of which flows to the east around Flemish Cap and the other stream flows south around the eastern edge of the Grand Banks and through Flemish Pass. Within Flemish Pass the width of the Labrador Current is reduced to 50 km (Stein, 2007). Characteristic current speeds on the Slope are in the order of 30 cm/s to 50 cm/s (Colbourne, 2000). While those on the central part of the Grand Banks are generally much lower; averaging between 5 and 15 cm/s.

The southward flowing stream of the offshore branch of the Labrador Current splits into two parts south of the Grand Banks (Figure 4.1). One section continues eastward as a broad flow, part of which breaking off to return southward in rather diffuse fashion around the Sargasso Sea (Iselin, 1936; Clarke et al., 1980),and the other part swings offshore at the tail of the Grand Banks to flow northward along the edge of the North Atlantic Current (Smith et al., 1937).

4.1.2 The Gulf Stream

The Gulf Stream and its associated eddies play an important part in the southern region of the study area. This extensive western boundary current plays a significant role in the poleward transfer of heat and salt and serves to warm the European subcontinent. Between 65°W and 50°W the Gulf Stream flows eastward. Shortly after passing east of 50°W the Gulf Stream splits into two currents: the North Atlantic Current and the Azores Current (Lazier, 1994). The Gulf Stream is usually located south of 40°N. However, one of the inherent features of this current system is its meandering path. These meanders may be formed both in northward and southward directions. Northward forming meanders at certain stages of their development separate from the main stream and generates rings or eddies, which start moving independently from the Gulf Stream flow. These eddies contain a warm water core that makes them easily identifiable in sea surface temperature satellite images.

Once eddies are formed, they drift in different directions and can be sustained for a considerable period of time. Their size may be of 100 to 300 km in diameter and can reach considerable depths. The trajectory of these warm water rings, once they depart from the Gulf Steam jet, together with their interaction with the bathymetry of the Continental Slope and with other current flows, influence the dynamic regime in the vicinity of the shelf break of the Grand Banks and the Scotian Shelf.

The structure of the Gulf Stream changes from a single, meandering front to multiple, branching fronts when it reaches the Grand Banks (Krauss 1986; Johns et al., 1995). Mann (1967) showed two branches at 38°N; 44°W. One branch curves north along the continental slope eventually turning east between 50° and 52°N. This branch is called the North Atlantic Current. The other branch flows southeastward towards the Mid-Atlantic Ridge and is called the Azores Current.

The Gulf Stream transport varies not only in space, but also in time. According to Geosat altimetry results, the current transports a maximum amount of water in the fall and a minimum in the spring, in phase with the north-south shifts of its position (Kelly, 1991).

Rossby and Rago (1985) and Fu et al. (1987) obtained similar results when they looked at sea level differences across the Stream. All of these studies found that the Gulf Stream has a marked seasonal variability, with peak-to-peak amplitude in sea surface height of 10-15 cm. The fluctuation is mostly confined to the upper 200-300 m of the water column and is a result of seasonal heating and expansion of the surface waters (Hogg and Johns, 1995).

4.1.3 The Slope Water

There is a third major current between the eastward flowing Gulf Stream and the westward flowing Labrador Current, referred as the Slope Water (Fratantoni and Pickart, 2007). This current is described as the northern bifurcation of the Gulf Stream that runs east-northeast along the continental slope south of Newfoundland. The Slope Water has been found to have distinct and unique properties because of mixing with coastal waters and underlying water masses.

The Slope Water position varies laterally with the Gulf Stream at 55°W and its transport varies with the transport of the Labrador Current, as well as with changes in the deeper components of the slope water, at about 50°W (Haza, 2004; Pickart et al., 1999). Although Pickart (1999) finds that the Slope Water strength and position spins up and down on inter-annual timescales, coincident with strengthening and weakening of the overflow component of the deep western boundary current, statistical analysis of the outputs of a high resolution numerical model (MICOM) indicate sub-annual to annual timescales for the same type of variability, predominantly at 9-10 month and 1 year timescales (Haza, 2004).

4.1.4 Water Exchange with the Gulf of St. Lawrence through the Laurentian Channel

In Laurentian Channel, the currents flow into the Gulf of St. Lawrence along the east side of the channel and out of the Gulf along the west side. Han et al. (1999) numerically computed the associated circulation fields from temperature and salinity across the Cabot Strait and reported the flow into the Gulf of St. Lawrence on the eastern side of Cabot Strait to be mainly barotropic with a speed of 20 cm/s. The flow out of the Gulf of St. Lawrence on the western side of the Cabot Strait flows mainly along the western side of Laurentian Channel. A smaller portion flows along the inner Scotian Shelf and onto the Mid-shelf (Han, 2003).

4.1.5 Characteristics of the Circulation

The interaction among these circulations is known to correlate with the behaviour of the North Atlantic Oscillation (NAO) index. The NAO index, as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland, and is a measure of the strength of the winter westerly winds over the northern North Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High which creates strong northwest winds, cod air and sea temperatures and heavy ice in the Labrador Sea and Newfoundland Shelf regions (Colbourne et al., 1994; Drinkwater, 1996). In low index years, the north wall of the Gulf Stream is displaced to the south and the southward transport associated with the Labrador Current is

intensified. As a consequence of these north-south displacements of the shelf/slope front, the area is subject to thermal anomaly oscillations (Mason et al., 1999; DFO, 2002).

At all locations in the project area, the currents vary on different time scales related to tides, wind stress, atmospheric pressure changes from the passage of storm systems, volume transport of the Labrador Current, seasonal temperature changes, salinity variations, etc. The current variability in the Slope Region is influenced by the intermittent presence of Gulf Stream rings as well as by the relative position of the northern boundary of the Gulf Stream. Han (2004) calculated from current model information combined with altimeter data that the geotropic current anomalies associated with Gulf Stream rings offshore Nova Scotia can be over 1 m/s.

The volume transport of the Labrador Current was lowest in summer and highest in winter. On an inter-annual scale the baroclinic transport component of the Labrador Current is negatively correlated with the NAO index (Han, 2006). The relative strength of the two pressure systems control the strength and direction of westerly winds and the position of storm tracks in the North Atlantic, which in turn impacts the volume transport of the Labrador Current. Similarly, the current variability on a synoptic scale is directly linked to the passage of low pressure systems.

Han (2006) used current model information and altimeter data between 1992 and 2002 to investigate the current variability over the Grand Banks and Continental Slope. He found that the current variability increased in an offshore direction towards the Gulf Stream and North Atlantic Current. He calculated the current anomalies to have magnitudes of 10 cm/s - 20 cm/s over most of the Grand Banks and about 50 cm/s over the Slope.

4.2 Water Mass Structure

4.2.1 Southern Grand Banks

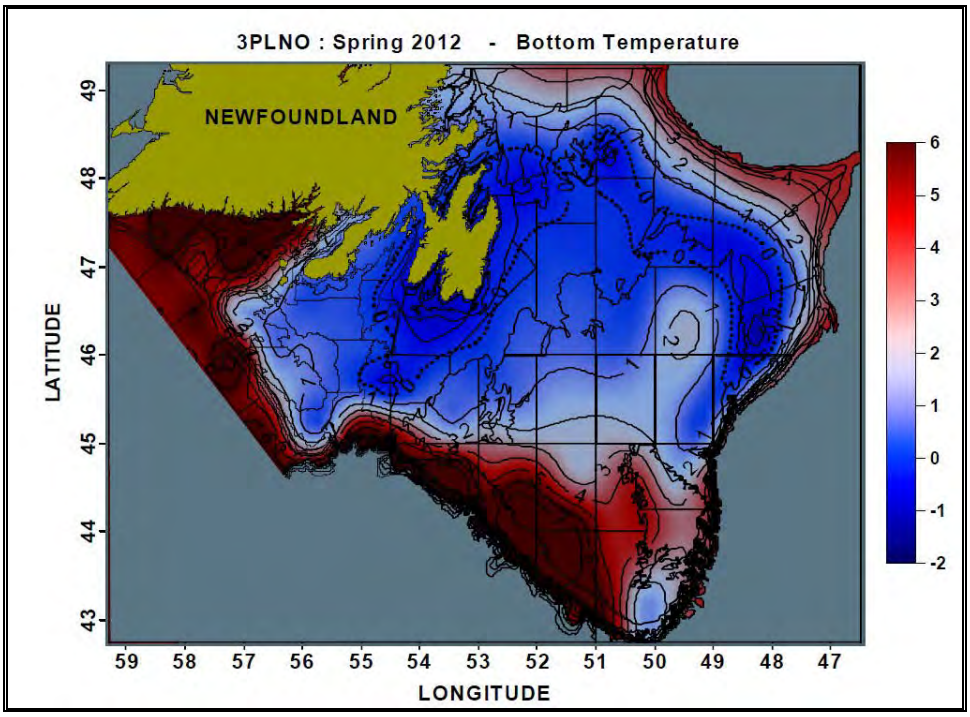
The waters on the southern Grand Banks are mixed waters from different sources. The water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3°C - 4°C and salinities in the range of 34.00 psu - 34.75 psu. Surface temperatures normally warm to 10°C - 12°C during late summer, while bottom temperatures remain < 0°C over much of the Grand Banks but increase to 1.0°C -3.5°C near the shelf edge below 200 m and in the deep troughs between the banks (Colbourne et al., 2013).

During spring and fall of 2012, NAFO Subdivision S and Divisions 3LNO on the Grand Banks were also surveyed and in the fall Divisions 2HJ in the north to 3NO in the south were also surveyed. Colbourne et al. (2013) presented an analysis of the near-bottom temperature fields and their anomalies based on these data sets for both spring and fall surveys of 2012 (Figures 4.3 and 4.5). Over the central and southern areas of the Grand Banks (3NO), bottom temperatures ranged from 1°C to 7°C. In the northern areas of Division 3NO bottom temperatures generally ranged from 1°C to 2°C. Bottom temperature anomalies were above normal by 0.5°C to 1.0°C over most of the region except for southern 3NO where they were > 3°C above normal.

Colbourne et al. (2013) also presented the climate indices based on the temperature data collected during the spring multi-species survey for the years 1990-2012 (Figure 4.4). In 3LNO which includes the southern Grand Banks, spring bottom temperatures were generally lower than normal from 1990 to 1995, with anomalies often exceeding 1.5 standard deviation below the mean. By 1996, conditions had moderated to near-normal values but decreased again in the spring of 1997 to colder than normal. Temperatures were above normal from 1998 to 2012, with the exception of 2003. The spring of 2011 had the warmest bottom temperatures on record.

Over the southern areas of the Grand Banks, bottom temperatures ranged from 2°C to 6°C with the warmest bottom waters found on the Southeast Shoal and along the edge of the Grand Bank in Division 3O (Figure 4.5). Except for a few isolated areas, temperatures were slightly above normal over the southern Grand Banks (Division 3NO) where anomalies were up to 2°C above the long-term mean (Figure 4.5) (Colbourne et al., 2013). In the southern Grand Banks, the bottom temperatures were somewhat cooler than farther north, with record high values in 1999, warm conditions in 2010-2011 and a sharp decrease to near normal values in 2012 (Figure 4.6).

Beginning in 1998 under the AZMP program (Therriault et al., 1998), a section crossing the Southeast Grand Bank was added to the spring and fall monitoring surveys. In 2012, this section was sampled in April and December. In 2013, this section was sampled once in April. The temperature and salinity properties on the southeast part of the Grand Banks are shown in Figure 7, Figure 8 and Figure 9. These figures presents temperature and salinity contours between Station 27 (47.55°N; 52.59°W) and the tail of the Grand Bank for April and December, 2012, and April 2013, respectively.



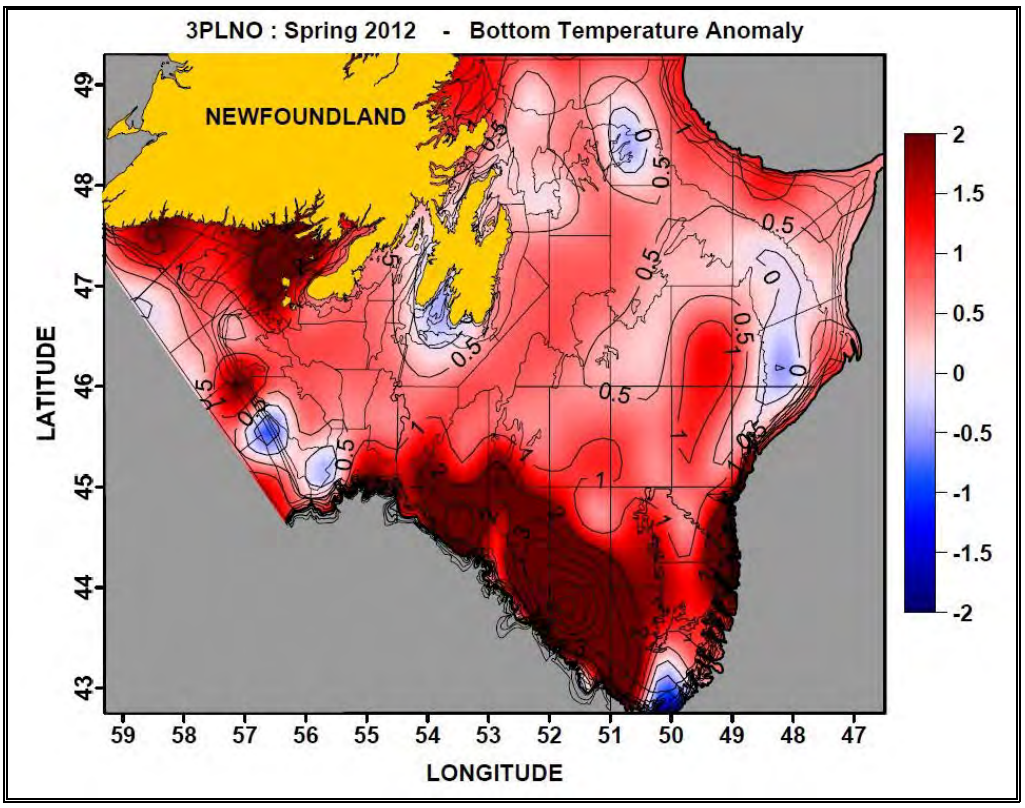


Figure 4.3 Contour maps of bottom temperature (top panel) and bottom temperature anomalies (bottom Panel) (°C) during the spring of 2012 in NAFO Division 3PLNO. The anomalies are referenced to the period 1981-2010.

Source: Colbourne et al., 2013.

REGION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	BOTTOM TEMPERATURES	-1.9	-1.7	-1.3	-0.8	-0.8	-0.8	-0.2	-0.6	0.4	0.8	0.8	0.1	0.1	-0.5	1.3	0.6		0.5	0.5	0.5	0.8	1.9	1.3
NAFO DIV. 3LNO	BOTTOM TEMPERATURES <100 M	-1.3	-1.7	-1.3	-0.5	-1.1	-0.3	0.0	-0.9	0.9	1.8	0.5	-0.2	0.1	-1.1	1.2	0.7	0.5	0.1	0.3	0.9	1.2	2.4	1.5
SPRING	THERMAL HABITAT AREA >2°C	-1.7	-1.6	-1.3	-0.6	-0.7	-0.5	-0.2	-0.4	0.6	1.8	0.7	-0.3	-0.2	-0.3	1.8	1.0	-0.3	0.7	0.5	0.9	1.1	2.5	1.4
	THERMAL HABITAT AREA <0°C	1.1	1.5	1.1	1.2	0.8	0.5	-0.3	0.7	-1.0	-1.5	-0.7	-0.5	-0.3	0.5	-2.0	-1.2	-1.7	-0.1	-0.2	0.2	-1.7	-2.2	-1.3

Figure 4.4 Temperature indices derived from data collected during spring multi-species surveys. The Grey shaded cells indicate years without observations.

Source: Colbourne et al., 2013.

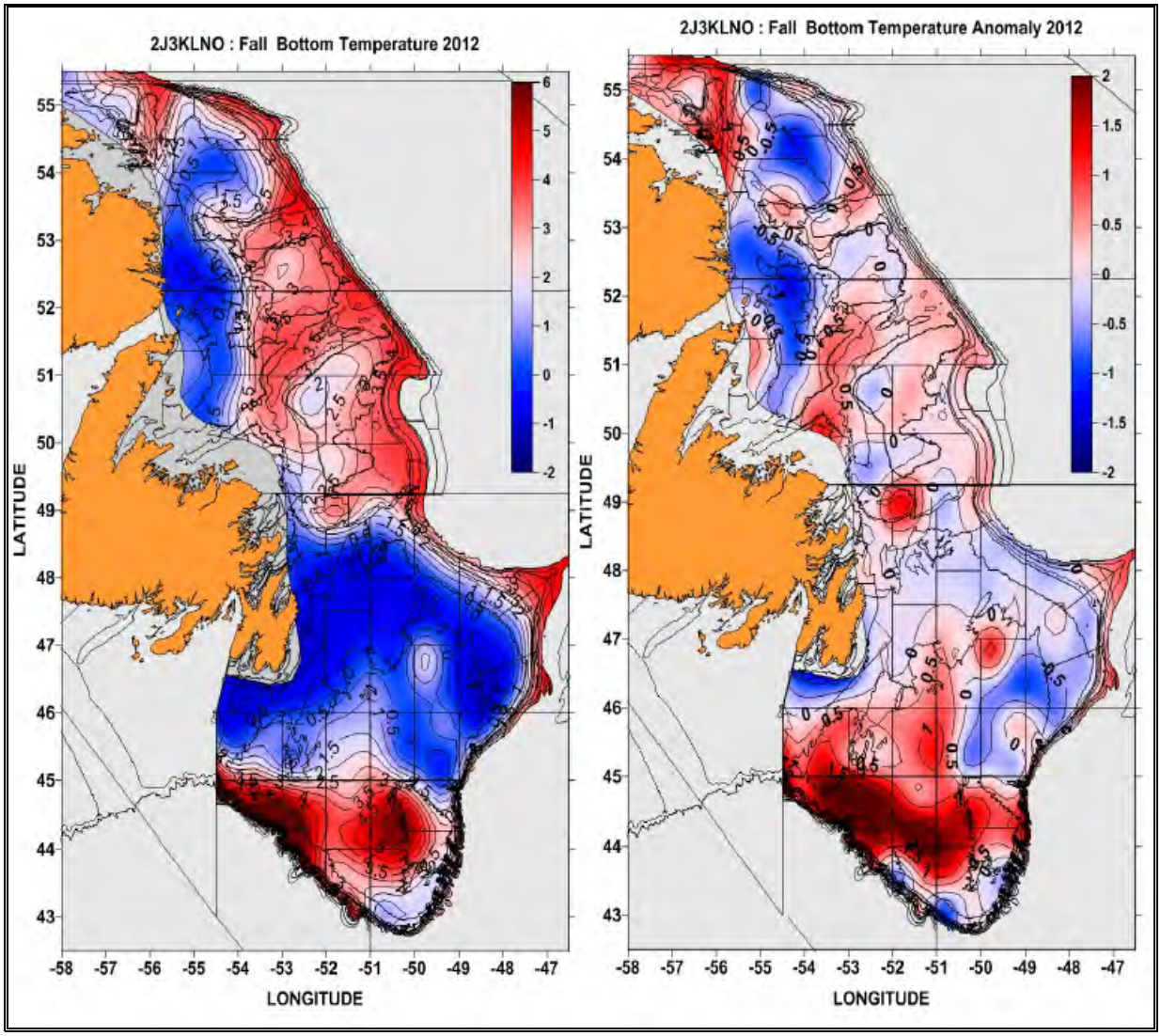


Figure 4.5 Contour maps of bottom temperature and bottom temperature anomalies (referenced to the period 1981-2010) (°C) during the fall of 2012 in NAFO Division 2J3KLNO.

Source: Colbourne et al., 2013.

REGION	INDEX	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
NAFO DIV. 3LNO FALL	BOTTOM TEMPERATURES	-0.6	-0.3	-1.5	-1.9	-1.8	-0.1	-0.1	0.1	0.3	2.2	-0.1	0.1	-0.1	0.0	0.8	1.8	0.0	0.1	-0.2	0.0	1.1	1.8	0.2
	BOTTOM TEMPERATURES <100 M	-0.1	-1.0	-1.0	-1.4	-1.5	0.3	0.6	0.4	0.6	2.4	0.0	-0.4	-0.6	-0.2	0.4	1.4	-0.3	-0.9	-0.5	0.0	1.7	1.2	0.3
	THERMAL HABITAT AREA >2°C	-1.2	-0.5	-1.0	-1.1	-0.9	-0.2	0.2	0.2	0.7	2.8	0.1	0.1	-0.5	-0.1	0.4	0.4	-0.2	-0.2	-0.6	0.8	1.7	1.5	0.4
	THERMAL HABITAT AREA <0°C	0.4	1.4	1.5	1.9	1.7	-0.7	-0.1	0.3	-0.5	-1.3	0.6	-0.1	-0.6	0.0	-1.4	-1.1	-1.3	-0.1	0.6	-0.1	-1.1	-2.3	-0.1

Figure 4.6 Temperature indices derived from data collected during spring multi-species surveys.

Source: Colbourne et al., 2013.

The temperature contour plots clearly show the position of the two branches of the Labrador Current by the presence of the colder water (-1°C in April 2012 and 2013, and 3°C in December 2012) and at the Shelf Break (0°C in April 2012 and 2013, and 3°C in December 2012). In the central part of the Grand Banks the temperature was warmer in April 2012 (4°C) than that in April 2013 (1°C). The temperature of the central part of Grand Banks is higher in December, with a value of approximately 8°C. The salinity contours (Figures 7, 8, 9) confirmed the presence of the less salty water transported south by the two branches of the Labrador Current.

4.2.2 Laurentian Sub-basin

There are four water masses in the Laurentian Sub-basin area: the water masses on the Shelf which consist of coastal water due to a mixture local run-off, Labrador Current water, warm Slope Water below a depth at 250 m, and some mixed Slope and Atlantic water near the bottom. The area of the Laurentian Fan has surface water to a depth of 50 m that is much warmer than surface water found on the Shelf or in Laurentian Channel. These warmer temperatures were probably due to the intrusion of the North Atlantic central water. These different currents appear to act as a coupled system, and their position and intensity vary on inter-annual to decadal time scales (Pickart et al., 1999).

The near-bottom portion of the water column in the Laurentian Sub-basin region consists of two distinct oceanographic regimes. One is influenced by cold, fresh water from the eastern Newfoundland Shelf, which includes much of St. Pierre Bank and areas to the east. In this region temperatures generally range from 0°C to 2°C, but are often less than 0°C in many years. The other regime includes the deeper regions of the Laurentian and Hermitage channels and areas to the west of St. Pierre Bank. This region appears to be influenced mostly by warmer Slope Water from the south (Colbourne et al., 2002).

Drinkwater et al. (2002) describe the Slope Water as being a combination of the colder, fresher Labrador Current water and the warmer saltier North Atlantic Central water. The Slope water properties at a particular location depend on whether the North Atlantic Central water or the Labrador Current water is dominant. Labrador Slope water was defined as having a lower salinity and temperatures in the range of 34.3 psu to 35 psu and 4°C to 8°C. The warm Slope water was defined as having salinities ranging from 34.7 psu to 35.5 psu and temperature ranging from 8°C to 12°C (Drinkwater et al., 2002).

The waters of the Laurentian Channel are highly stratified. In the summer, a warm surface layer is superimposed on an intermediate cold-water layer overlying a deep warm layer. In winter, a single mixed of sub-zero temperature overlies the deep warm layer (Lauzier and Trites, 1958).

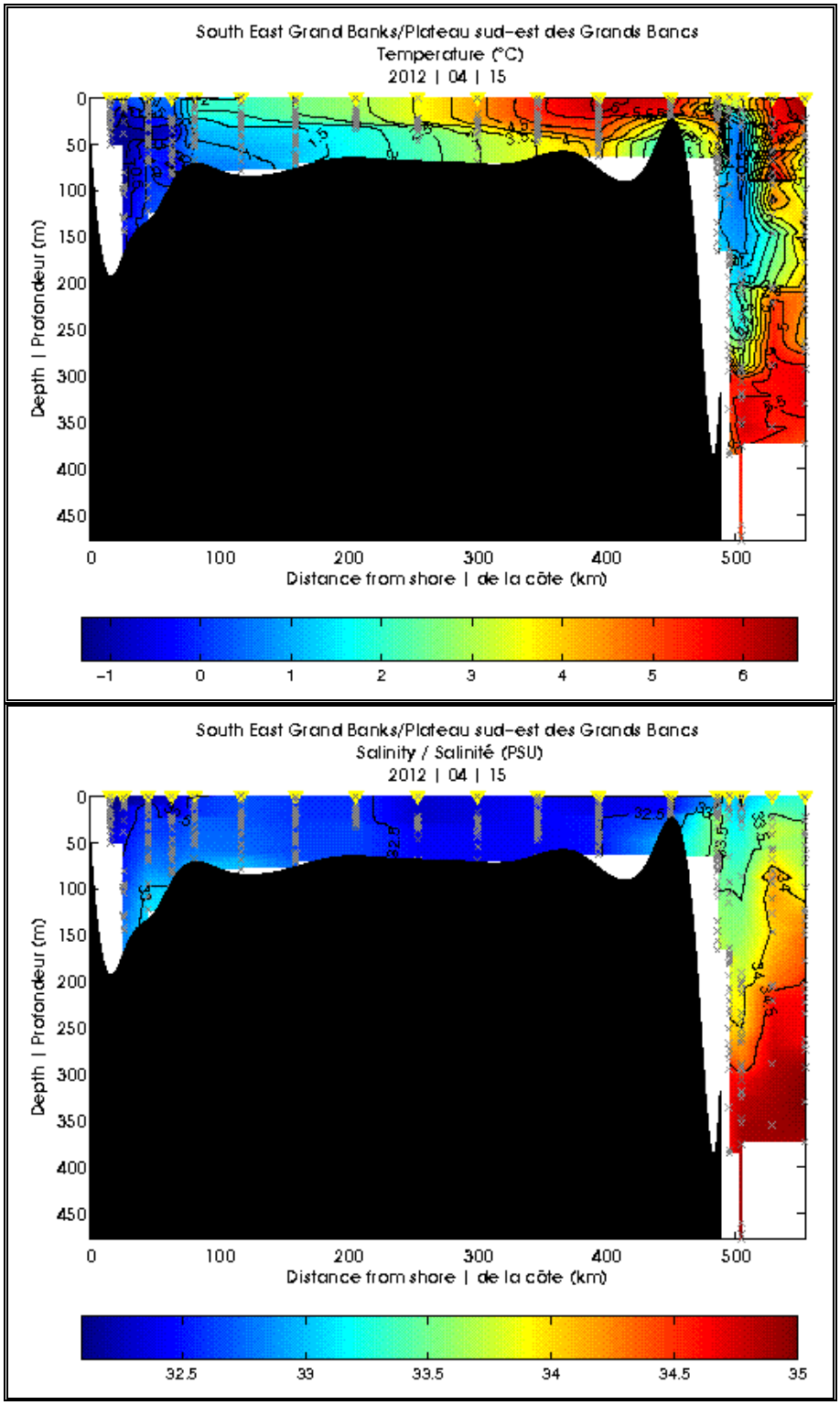


Figure 4.7 Hydrographic Contours along the Southeast Grand Banks transect during April 2012.

Source: DFO Marine Environmental Data Service Website

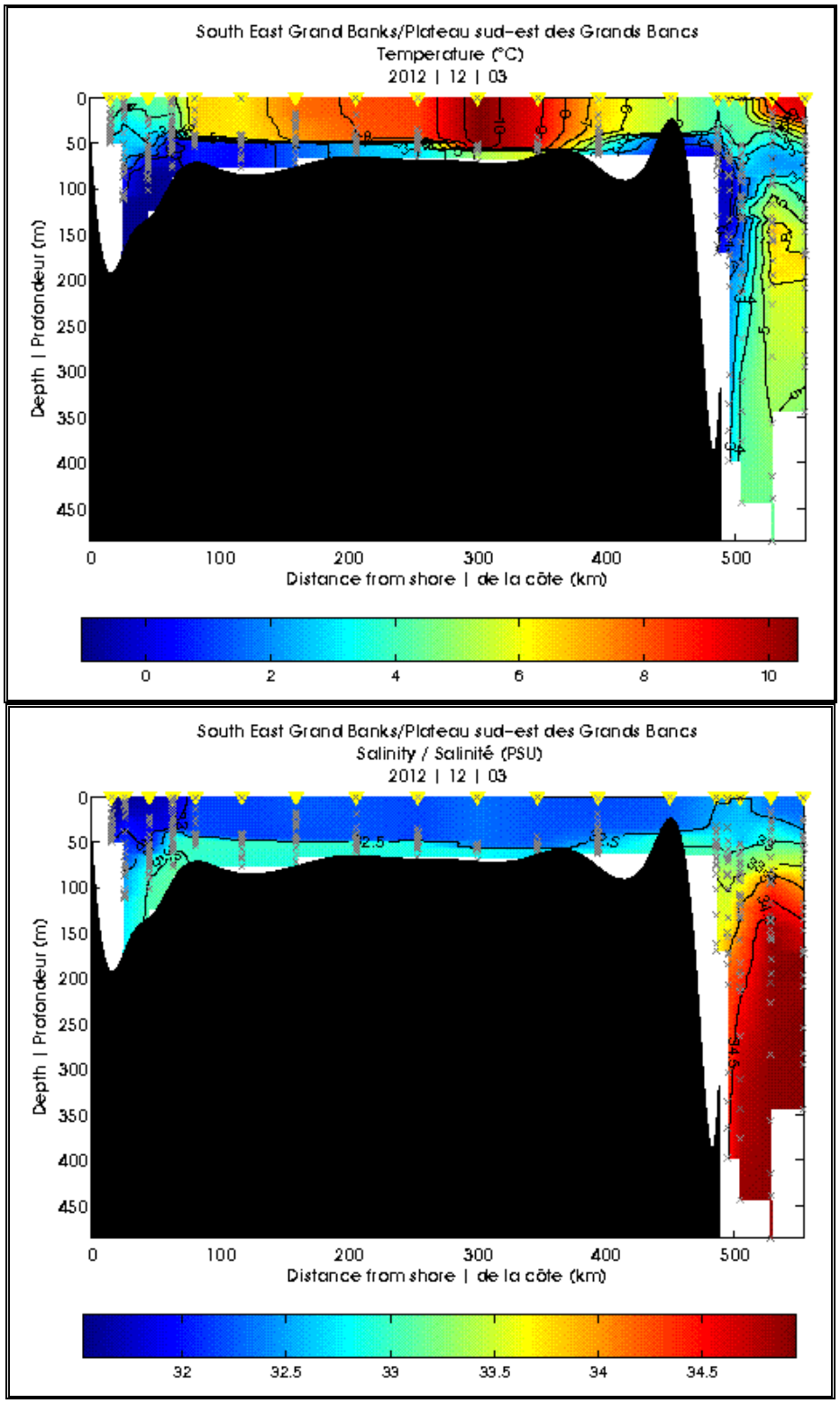


Figure 4.8 Hydrographic Contours along the Southeast Grand Banks transect during December, 2012.

Source: DFO Marine Environmental Data Service Website

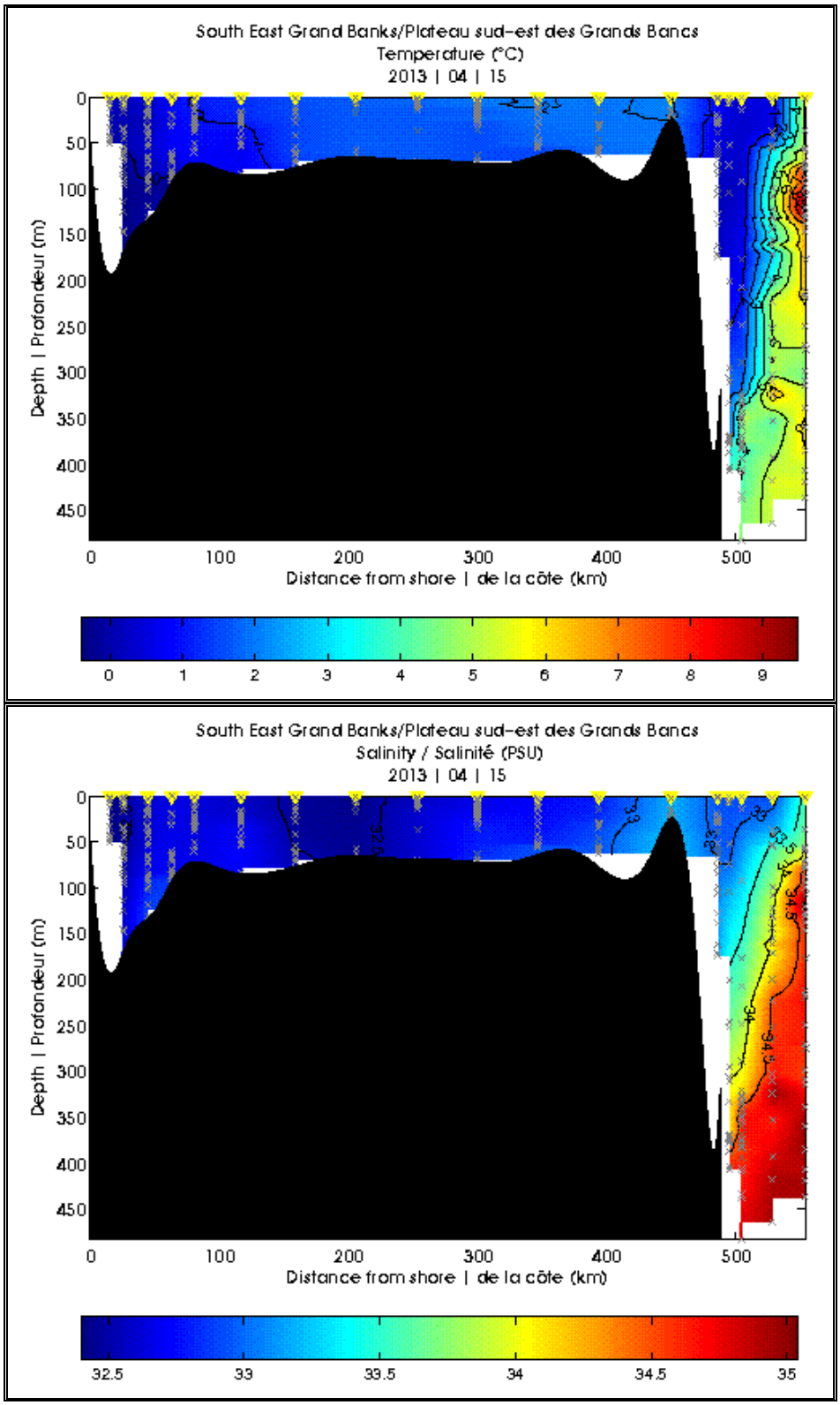


Figure 4.9 Hydrographic Contours along the Southeast Grand Banks transect during April 2013.

Source: DFO Marine Environmental Data Service Website

Colbourne (2000, 2002) provided an overview of long-term average water temperature and salinity conditions on the banks and channels which comprise the Laurentian Sub-basin area (for the spring period). Over the St. Pierre Bank, average water temperature range from 1°C near the bottom to 2°C near the surface and 1°C - 2°C beyond the shelf edge in the upper 100 m of the water column. In the deeper waters of the channels and on the continental slope, water temperatures generally range from 2°C at approximately 125 m to 130 m depth, to between 5 and 6°C near the bottom. The average bottom temperature for April in the Laurentian Channel is approximately 5°C. On the St. Pierre Bank, bottom temperatures range from 0°C on the eastern side to between 2 and 3°C on the western portion of the bank. In general, the bottom isotherms follow the bathymetry around the Laurentian Channel and the southwestern Grand Banks, decreasing from 2°C at approximately 200 m depth to 5°C below 300 m.

Colbourne (2000, 2002) found that over the St. Pierre Bank, water salinities in April generally range from 32.5 psu near the bottom to 32.1 psu near the surface. In the deeper channel waters and on the continental slope region, salinities increase from 33 psu at 130 m to 34.5 psu near bottom. On the slopes of the St. Pierre Bank in water depths of 100 m to 300 m, salinities generally range from 33 psu to 34.5 psu.

4.2.3 Newfoundland Basin

There is a distinct maximum of the surface heat fluxes near the Sub-polar front in the Newfoundland Basin. The position and magnitude of this maximum reflects certain oceanographic conditions, such as the sharp thermal contrasts at the fronts, the curvature of the stream pathways, and atmospheric processes such as cold continental air outbreaks and a merger of the most frequent storm-tracks.

To the south and east of the Grand Banks the Gulf Stream produces several branches, which transport warm and salty water to different parts of the North Atlantic. To the east of the Southeast Newfoundland Rise the Gulf Stream abruptly changes its direction, forming a large meander, which is known as the North Atlantic Current. Yashayaev (2000) divided the water mass in the Newfoundland Basin into cold and warm sectors. The cold sector includes the Labrador Current, Shelf Water, Subarctic Intermediate Water and Labrador Sea Water. The major residents of the warm sector are the Gulf Stream, North Atlantic Current, Central North Atlantic Waters and Newfoundland Basin waters. Yashayaev (2000) presented that in the warm sector of the Newfoundland Basin, the seasonal cycle dominates variability of temperature, salinity and density in the upper 200 m. The contribution of the seasonal cycle to the variability of temperature decreases monotonically from 94% at 20 m to 17% at 300 m. In the case of salinity, the contribution fluctuates around 50% in the upper 150 m layer and decrease monotonically with depth at deeper levels.

In the cold sector the contribution of the season cycle to the total variability is generally less than in the warm sector, mostly in a result of the dominance of the low frequency variability associated with large year-to-year variations in the temperature and salinity. The contribution of the seasonal cycle to the temperature variability in the upper 30 m layer in the cold sector exceeds 80% and rapidly decreases below 30 m. The contribution of the seasonal

cycle to the total variability of salinity is even smaller. It ranges between 40% and 50% above 30 m and drops to 6% at 75 m (Yashayaev, 2000).

4.3 Water Properties in the Project Area

Temperature and salinity data from historical measurements were extracted from the Bedford Institute of Oceanography archive. The project area was divided into three areas: the southern Grand Banks, the Laurentian Sub-basin, and the Newfoundland Basin (Figure 4.10).

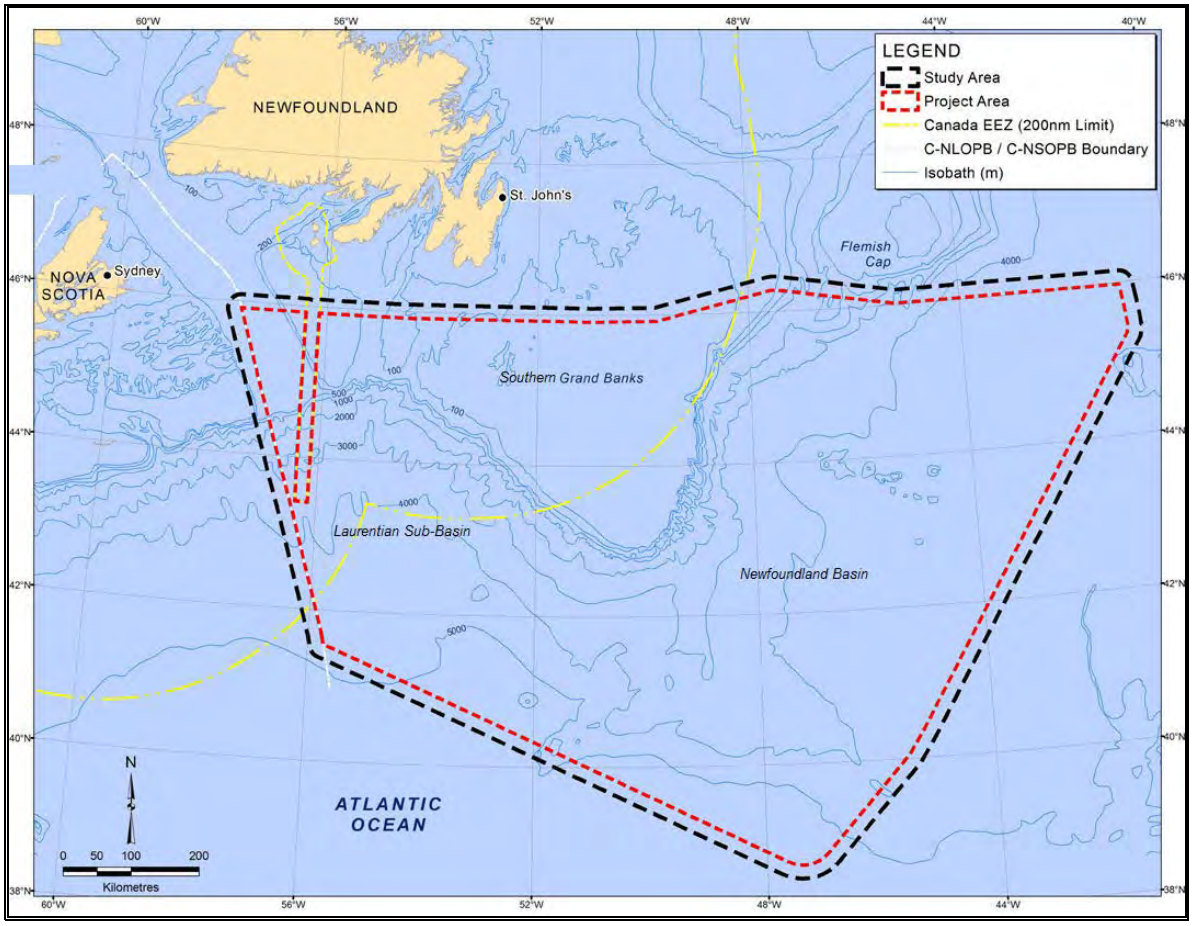


Figure 4.10 Study and Project areas and sub-areas for the Southern Grand Banks seismic program. The numbers represents the location of where the data were collected.

4.3.1 Southern Grand Banks

The waters on the southern Grand Banks are mixed waters from different sources. The water mass is generally warmer and saltier than the sub-polar shelf waters. Waters in this area is normally shallower than 100 m, except on the shelf edge which is below 200 m. In this study, the water mass in the southern Grand Banks was sub-divided according to water

depth: 0 m, 50 m, and 100 m. Table 4.1 to Table 4.3 present the temperature and salinity data by month at the surface (0 m), 50 m and 100 m, respectively.

Table 4.1 Monthly temperature and salinity statistics for the surface water on southern Grand Banks from historical CTD data

0 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	51	0.76	-0.29	3.90	1.17
FEBRUARY	100	2.16	-1.27	3.95	1.55
MARCH	193	0.94	-1.40	4.90	1.72
APRIL	596	1.88	-1.30	13.77	1.46
MAY	1772	3.85	-0.54	13.25	2.14
JUNE	669	6.68	1.02	17.20	3.24
JULY	135	12.50	6.15	18.12	2.53
AUGUST	558	15.73	7.26	20.63	2.12
SEPTEMBER	412	13.87	5.28	19.93	2.88
OCTOBER	1338	10.23	2.14	16.57	2.70
NOVEMBER	634	6.87	0.91	13.52	2.55
DECEMBER	99	5.41	1.12	10.13	2.46

0 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	51	33.04	32.30	33.84	0.39
FEBRUARY	100	32.55	32.02	33.69	0.25
MARCH	193	32.76	31.62	34.09	0.40
APRIL	596	32.61	31.67	35.52	0.36
MAY	1772	32.66	31.41	35.54	0.32
JUNE	669	32.60	31.89	34.60	0.31
JULY	135	32.39	31.80	34.28	0.40
AUGUST	558	32.15	30.97	33.86	0.32
SEPTEMBER	412	32.07	31.16	32.86	0.28
OCTOBER	1338	32.25	31.07	33.91	0.35
NOVEMBER	634	32.32	31.54	33.70	0.38
DECEMBER	99	32.56	31.47	33.88	0.46

The surface water were the warmest throughout the years, with mean temperatures ranging from 0.76°C in January to 15.73°C in August (Table 4.1, Figure 4.11). Waters on the surface of southern Grand Banks were coldest in January and March with mean temperatures of 0.76°C and 0.94°C, respectively. The warmest water occurred in August and September, with mean temperatures of 15.73°C and 13.87°C, and maximum temperature of 20.63°C and 19.93°C, respectively. The mean salinities ranged between 32.07 psu in September and 33.04 psu in January (Table 4.1, Figure 4.11).

At a depth of 50 m, waters were colder than that on the surface. The mean temperatures ranged from 0.51°C in March to 3.22°C in December. In October, November and December, temperatures were higher than temperatures in the rest of the year (Table 4.2, Figure 4.11). The mean salinities ranged between 32.66 psu in February and 33.11 psu in January (Table 2).

At a depth of 100 m, the waters were colder comparing to that on the surface and at a 50 m depth. The mean temperatures ranged from - 0.39°C in September to 1.48°C in December. Temperature at 100 m depth showed less monthly variability than that at the upper waters (Table 4.3, Figure 4.11). The mean salinities ranged from 33.17 psu in March to 33.74 psu in July.

The data is also presented in seasonal T-S plots in Figure 4.12. The seasons are spring (March-May), summer (June-August), fall/autumn (September-November), and winter (December-February). The T-S diagrams show that the water properties vary with seasons throughout the water column. In summer and autumn, the water is stratified to a depth of 50 m. However, below 50 m the water was less stratified and shows negative temperatures below 100 m. In winter and spring the water is less stratified.

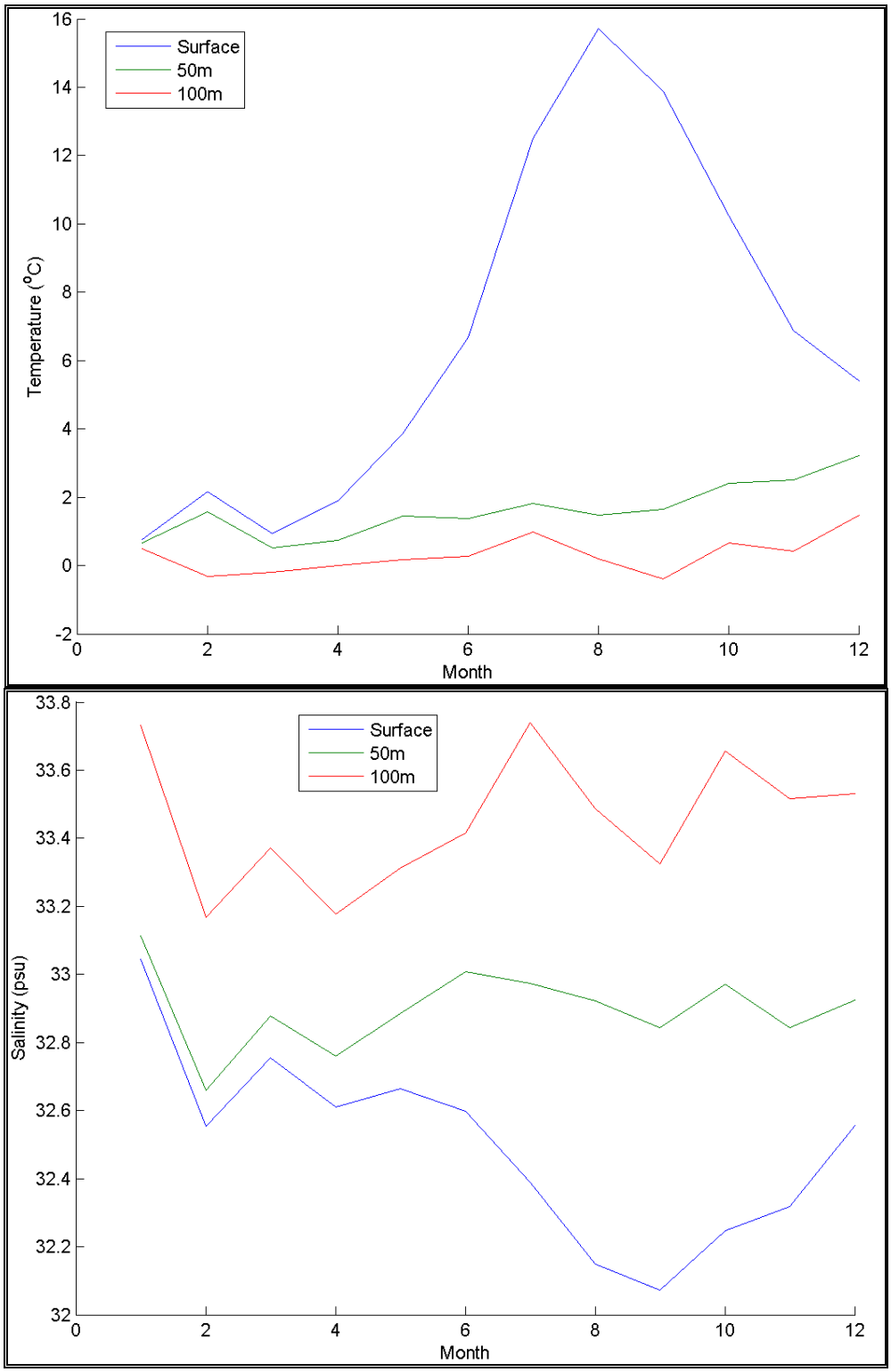


Figure 4.11 Monthly mean temperatures and salinities on southern Grand Banks.

Note: From the surface (0 m) to 100 m, lines depict depths in meters.

Table 4.2 Monthly temperature and salinity statistics for a water depth of 50 m on southern Grand Banks from historical CTD data

50 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	18	0.67	-0.57	3.83	1.14
FEBRUARY	78	1.58	-1.37	3.86	1.46
MARCH	196	0.51	-1.78	3.76	1.51
APRIL	517	0.74	-1.64	8.35	1.44
MAY	1693	1.45	-1.70	13.26	1.60
JUNE	661	1.37	-1.66	6.98	1.79
JULY	141	1.82	-1.59	11.80	2.07
AUGUST	560	1.48	-1.65	9.42	1.61
SEPTEMBER	412	1.66	-1.64	7.98	2.07
OCTOBER	1311	2.40	-1.33	11.61	2.32
NOVEMBER	636	2.51	-1.36	10.65	2.40
DECEMBER	100	3.22	-0.37	10.45	2.06

50 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	18	33.11	32.47	34.03	0.46
FEBRUARY	78	32.66	31.94	33.71	0.27
MARCH	196	32.88	32.06	34.26	0.37
APRIL	517	32.76	31.94	34.70	0.40
MAY	1693	32.89	31.83	35.64	0.36
JUNE	661	33.01	32.19	34.29	0.33
JULY	141	32.97	32.21	35.24	0.51
AUGUST	560	32.92	31.05	34.14	0.31
SEPTEMBER	412	32.84	32.21	33.93	0.28
OCTOBER	1311	32.97	31.96	34.31	0.33
NOVEMBER	636	32.84	32.06	33.99	0.37
DECEMBER	100	32.92	32.01	34.03	0.42

Table 4.3 Monthly temperature and salinity statistics for a water depth of 100 m on southern Grand Banks from historical CTD data

100 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	7	0.49	-0.55	1.47	0.61
FEBRUARY	10	-0.32	-0.91	0.82	0.47
MARCH	27	-0.20	-1.77	4.94	1.36
APRIL	122	-0.00	-1.62	12.46	2.15
MAY	382	0.18	-1.63	13.06	1.91
JUNE	193	0.28	-1.50	8.63	1.69
JULY	23	0.98	-1.74	11.66	3.80
AUGUST	123	0.19	-1.66	7.72	2.13
SEPTEMBER	66	-0.39	-1.90	7.77	1.58
OCTOBER	362	0.67	-1.30	11.00	1.65
NOVEMBER	158	0.43	-1.28	4.34	1.04
DECEMBER	36	1.48	-0.44	4.27	1.38

100 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	7	33.73	33.05	34.09	0.33
FEBRUARY	10	33.17	32.92	33.94	0.30
MARCH	27	33.37	32.88	34.35	0.37
APRIL	122	33.18	32.52	35.05	0.49
MAY	382	33.31	32.20	35.63	0.40
JUNE	193	33.42	32.88	34.66	0.34
JULY	23	33.74	32.87	35.34	0.67
AUGUST	123	33.49	32.78	34.81	0.49
SEPTEMBER	66	33.33	32.65	34.76	0.46
OCTOBER	362	33.66	32.63	35.12	0.42
NOVEMBER	158	33.52	32.78	34.42	0.31
DECEMBER	36	33.53	32.94	34.22	0.43

4.3.2 Laurentian Sub-basin

The water depth in the Laurentian Sub Basin varies from less than 200 m to deeper than 4500 m. In this study, the water mass in the project area was sub-divided into seven depths: 0 m, 50 m, 100 m, 200 m, 550 m, 1000 m, and ≥ 3000 m (including any depths that were or deeper than 3000 m). Table 4.4 to Table 4.10 present the temperature and salinity data by month at those different water depths, respectively.

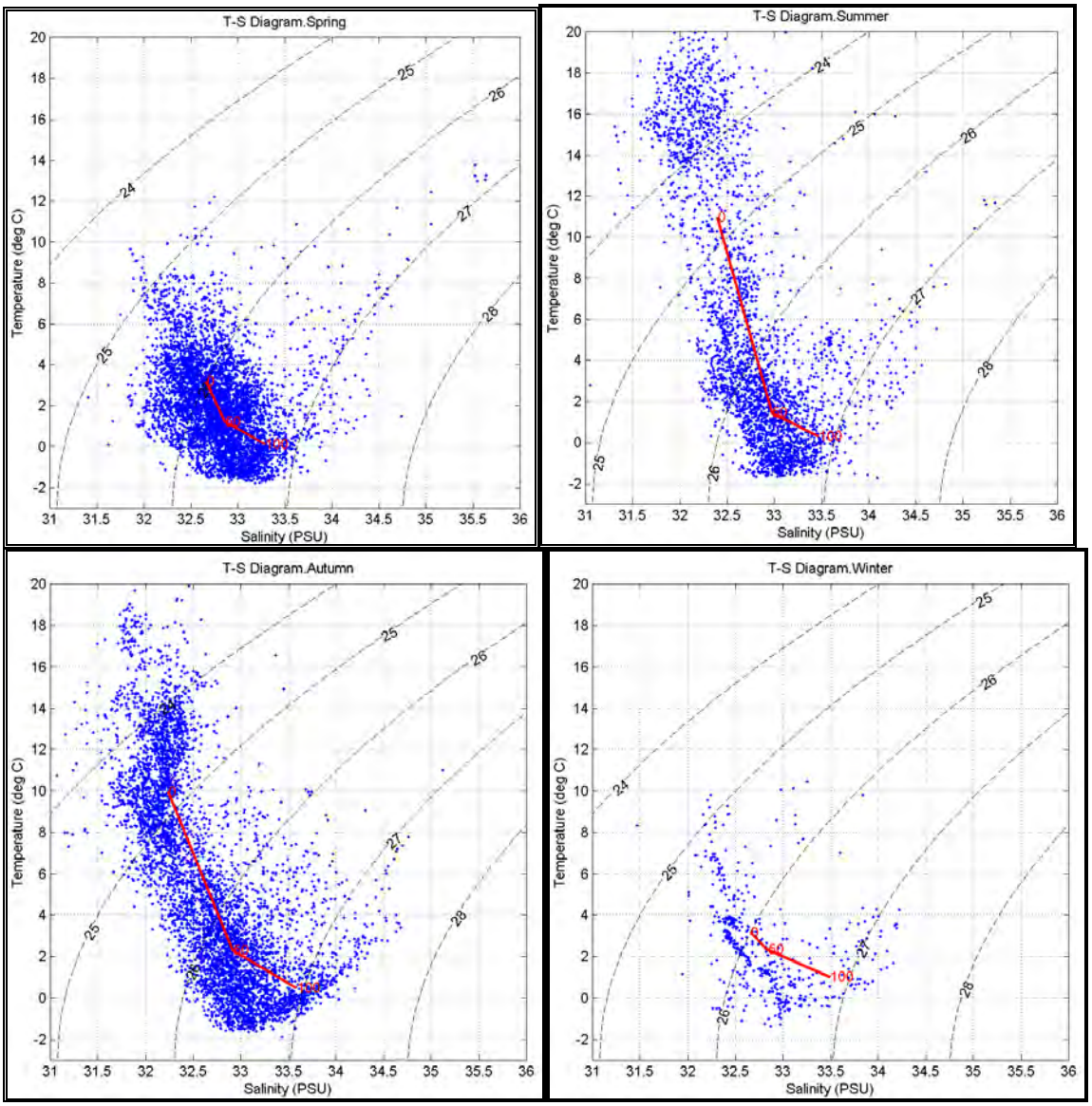


Figure 4.12 Seasonal T-S plots for the southern Grand Banks.

Note: The red lines correspond to the average TS curve of each area. The numbers on the curves represent the water depth in meters.

The surface waters were warmest during the months July to September with mean temperatures ranging from 14.65°C to 16.54°C. The coldest temperatures were in February and April with mean temperatures of 1.29°C and 2.13°C, respectively. In February, March and April, the minimum temperatures were below zero with measurements of -1.67°C, -1.57°C, and -1.20°C, respectively (Table 4.4). The mean salinities ranged from 31.98 psu in August to 32.78 psu in March and May. The lowest measurement of salinity (26.00 psu) at the surface waters was collected in October. The highest salinity was collected in May with the value of 36.69 psu (Table 4.4).

Table 4.4 Monthly temperature and salinity statistics for the surface water in Laurentian Sub-Basin from historical CTD data

0 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	37	3.39	0.68	18.33	3.71
FEBRUARY	249	1.29	-1.67	17.83	2.79
MARCH	359	2.53	-1.57	16.85	3.82
APRIL	1148	2.13	-1.20	19.72	2.26
MAY	1123	5.25	0.02	21.60	3.30
JUNE	578	9.30	0.00	24.66	3.43
JULY	308	14.65	5.30	24.75	3.00
AUGUST	705	16.54	9.96	25.91	2.27
SEPTEMBER	248	15.86	9.09	25.69	2.37
OCTOBER	790	13.07	2.31	25.08	2.49
NOVEMBER	135	8.56	3.27	19.79	2.40
DECEMBER	99	6.44	2.00	16.18	3.16

0 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	37	32.52	31.00	36.49	1.02
FEBRUARY	249	32.48	31.62	36.45	0.68
MARCH	359	32.78	30.81	36.27	0.97
APRIL	1148	32.59	29.41	36.51	0.56
MAY	1123	32.78	30.84	36.69	0.71
JUNE	578	32.67	30.50	36.04	0.75
JULY	308	32.04	29.81	36.34	1.24
AUGUST	705	31.98	29.21	36.23	0.92
SEPTEMBER	248	32.19	29.97	36.23	0.91
OCTOBER	790	32.23	26.00	36.29	0.64
NOVEMBER	135	32.14	30.72	34.88	0.56
DECEMBER	99	32.62	31.10	35.38	0.78

At a depth of 50 m, the mean temperatures ranged from 1.17°C in February and 4.79°C in October. The minimum temperatures were below zero in all the months except January with a value of 0.36°C, which is slightly higher than zero (Table 4.5). The mean salinities were higher in May (33.14 psu) and June (33.24 psu) than the salinities in the other months of the year (Table 4.5).

Table 4.5 Monthly temperature and salinity statistics for a water depth of 50 m in Laurentian Sub-Basin from historical CTD data.

50 m Temperature(°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	33	2.84	0.36	8.00	1.86
FEBRUARY	214	1.17	-1.60	11.10	2.09
MARCH	301	3.18	-1.53	16.85	4.19
APRIL	1089	1.67	-1.50	15.63	2.46
MAY	1041	3.62	-1.40	20.60	3.31
JUNE	249	4.37	-1.12	22.18	4.88
JULY	250	3.96	-0.64	20.91	4.42
AUGUST	650	2.96	-1.36	24.92	3.87
SEPTEMBER	232	3.74	-1.25	24.85	3.68
OCTOBER	753	4.79	-1.23	20.34	3.48
NOVEMBER	133	3.98	-1.42	20.45	3.35
DECEMBER	92	4.69	-1.05	15.72	3.69

50 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	33	32.58	31.64	34.35	0.58
FEBRUARY	214	32.53	31.73	35.01	0.50
MARCH	301	33.10	31.55	36.29	0.99
APRIL	1089	32.76	31.72	36.11	0.60
MAY	1041	33.14	31.65	36.47	0.73
JUNE	249	33.24	32.00	36.18	0.96
JULY	250	33.04	31.55	36.51	0.96
AUGUST	650	32.94	31.62	36.64	0.70
SEPTEMBER	232	33.06	31.94	36.57	0.60
OCTOBER	753	33.05	31.19	36.15	0.52
NOVEMBER	133	32.74	31.73	35.41	0.48
DECEMBER	92	32.87	31.96	35.07	0.58

At a depth of 100 m, the mean temperatures ranged from 2.25°C in November to 5.05°C in December. The minimum temperatures were below zero for all 12 months ranged from -1.69°C in August to -0.79°C in January (Table 4.6). At this depth, the mean salinities were higher in May, October, December, and September with the values of 33.95 psu, 33.95 psu, 33.93 psu, and 33.92 psu, respectively. The range of the mean salinities was from 33.36 psu in February and 33.95 psu in May and October (Table 4.6).

Table 4.6 Monthly temperature and salinity statistics for a water depth of 100 m in Laurentian Sub-Basin from historical CTD data.

100 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	33	4.50	-0.79	18.36	4.60
FEBRUARY	184	3.09	-1.02	14.65	4.01
MARCH	290	4.57	-1.10	16.04	4.35
APRIL	689	2.65	-1.45	18.69	3.74
MAY	783	4.88	-1.60	21.60	4.23
JUNE	316	4.71	-1.43	16.08	4.35
JULY	205	3.82	-1.30	19.05	4.68
AUGUST	520	2.90	-1.69	21.97	4.39
SEPTEMBER	207	4.30	-1.58	21.36	4.77
OCTOBER	619	4.41	-1.62	24.23	3.97
NOVEMBER	99	2.25	-1.46	10.93	2.93
DECEMBER	83	5.05	-1.12	17.06	5.21

100 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	33	33.69	32.36	36.46	1.03
FEBRUARY	184	33.36	32.01	35.76	0.88
MARCH	290	33.70	32.02	36.15	0.93
APRIL	689	33.39	32.34	36.49	0.78
MAY	783	33.95	32.18	36.69	0.81
JUNE	316	33.69	31.61	36.08	0.91
JULY	205	33.66	32.54	36.53	0.95
AUGUST	520	33.59	32.49	36.71	0.82
SEPTEMBER	207	33.92	32.64	36.67	0.85
OCTOBER	619	33.95	32.79	36.58	0.66
NOVEMBER	99	33.53	32.68	34.99	0.57
DECEMBER	83	33.93	32.65	36.08	0.88

At a depth of 200 m, the mean temperatures were relatively higher than the temperatures at depth of 100 m and 550 m. The mean temperatures ranged from 5.56°C in November to 7.79°C in June. The minimum temperatures were relatively higher in February (2.64°C) and July (2.71°C) (Table 4.7). The mean salinities at 200 m depth ranged from 34.47 psu in November to 34.80 psu in December (Table 4.7).

Table 4.7 Monthly temperature and salinity statistics for a water depth of 200 m in Laurentian Sub-Basin from historical CTD data.

200 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	29	7.19	0.51	17.74	3.55
FEBRUARY	126	7.24	2.64	14.38	2.28
MARCH	239	7.19	-0.49	14.44	2.89
APRIL	445	6.42	-1.22	18.14	2.52
MAY	537	6.98	-0.12	18.30	2.76
JUNE	237	7.79	0.07	15.62	2.89
JULY	175	7.13	2.71	17.49	2.62
AUGUST	416	6.55	-0.48	18.95	2.75
SEPTEMBER	138	6.84	0.25	18.86	2.42
OCTOBER	450	6.68	-0.57	19.89	2.76
NOVEMBER	79	5.56	-0.31	12.62	2.75
DECEMBER	60	7.68	0.75	15.98	3.29

200 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	29	34.64	33.67	36.46	0.64
FEBRUARY	126	34.61	33.72	35.77	0.40
MARCH	239	34.64	33.06	35.84	0.47
APRIL	445	34.57	33.13	36.48	0.40
MAY	537	34.69	33.44	36.56	0.44
JUNE	237	34.78	33.46	36.00	0.47
JULY	175	34.66	33.72	36.44	0.46
AUGUST	416	34.61	33.28	36.59	0.42
SEPTEMBER	138	34.75	33.30	36.51	0.39
OCTOBER	450	34.72	33.26	36.58	0.39
NOVEMBER	79	34.47	33.43	35.53	0.40
DECEMBER	60	34.80	33.53	36.06	0.52

At a depth of 550 m, the mean temperatures ranged from 4.19°C in January to 5.79°C in August. Mean temperatures were relatively high in June (5.06°C), July (5.07°C) and August (5.79°C). All of the temperature measurements were above zero throughout the year at this depth (Table 4.8). The mean salinities ranged from 34.80 psu in January to 35.01 psu in August (Table 4.8).

Table 4.8 Monthly temperature and salinity statistics for a water depth of 550 m in Laurentian Sub-Basin from historical CTD data.

550 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	5	4.19	3.24	4.81	0.58
FEBRUARY	8	4.91	4.72	5.29	0.18
MARCH	21	4.97	4.14	5.96	0.49
APRIL	51	4.50	3.17	7.23	0.68
MAY	134	4.60	2.78	7.63	0.72
JUNE	76	5.06	3.78	6.40	0.51
JULY	31	5.07	3.79	9.69	1.27
AUGUST	42	5.79	3.80	13.38	2.47
SEPTEMBER	66	4.82	3.43	15.24	1.37
OCTOBER	163	4.49	3.21	6.18	0.57
NOVEMBER	22	4.48	3.59	5.47	0.52
DECEMBER	25	4.60	3.61	5.38	0.52

550 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	5	34.80	34.72	34.89	0.06
FEBRUARY	8	34.96	34.94	35.00	0.02
MARCH	21	34.93	34.79	35.03	0.06
APRIL	51	34.91	34.62	35.23	0.09
MAY	134	34.89	34.51	35.22	0.10
JUNE	76	34.93	34.74	35.06	0.07
JULY	31	34.92	34.78	35.22	0.09
AUGUST	42	35.01	34.83	35.73	0.21
SEPTEMBER	66	34.96	34.72	36.01	0.15
OCTOBER	163	34.90	34.40	35.23	0.11
NOVEMBER	22	34.88	34.72	34.98	0.07
DECEMBER	25	34.89	34.74	34.99	0.08

At a depth of 1000 m, the mean temperatures ranged from 3.95°C in October and December to 4.47°C in January. The water temperature at this depth was more stable with the minimum temperatures all above 3.30°C and the maximum temperatures all below 5.80°C. The standard deviations of temperatures were less than 0.72°C (Table 4.9). The range of the mean salinities was between 34.91 psu in December and 35.00 psu in January. The standard deviations of salinities were less than 0.12 psu (Table 4.9).

Table 4.9 Monthly temperature and salinity statistics for a water depth of 1000 m in Laurentian Sub-Basin from historical CTD data.

1000 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	3	4.47	3.67	5.05	0.72
FEBRUARY	11	4.16	3.64	4.70	0.35
MARCH	35	4.08	3.69	4.50	0.20
APRIL	60	3.98	3.44	5.26	0.34
MAY	47	4.18	3.61	4.77	0.31
JUNE	88	4.17	3.49	4.57	0.20
JULY	43	4.19	3.57	5.00	0.35
AUGUST	60	4.15	3.58	5.38	0.46
SEPTEMBER	51	4.06	3.63	5.80	0.39
OCTOBER	88	3.95	3.30	4.80	0.25
NOVEMBER	13	4.04	3.77	4.32	0.16
DECEMBER	19	3.95	3.59	4.59	0.33

1000 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	3	35.00	34.87	35.10	0.12
FEBRUARY	11	34.96	34.81	35.06	0.08
MARCH	35	34.95	34.90	35.01	0.03
APRIL	60	34.94	34.86	35.05	0.04
MAY	47	34.94	34.73	35.03	0.05
JUNE	88	34.95	34.81	35.08	0.05
JULY	43	34.96	34.83	35.13	0.06
AUGUST	60	34.94	34.81	35.03	0.06
SEPTEMBER	51	34.92	34.81	35.02	0.05
OCTOBER	88	34.93	34.72	35.05	0.06
NOVEMBER	13	34.93	34.86	34.99	0.04
DECEMBER	19	34.91	34.84	35.11	0.07

For waters at a depth of ≥ 3000 m, there were no available data in January, February and November. The range of the mean temperature was between 2.21°C in March and May and 2.77°C in September. Water temperatures at a depth of ≥ 3000 m were relatively stable. The minimum temperature was 2.21°C in March and the maximum temperature was 3.10°C in August (Table 4.10). The standard deviations of temperatures were less than 0.40°C. The mean salinities ranged from 34.89 psu in June to 34.94 psu in December. The salinities at waters deeper than 3000 m had no significant variations with the minimum salinity of 34.85 psu in August and the maximum salinity of 35.01 psu in August as well. The standard deviations for salinities were less than 0.03 psu (Table 4.10).

Table 4.10 Monthly temperature and salinity statistics for a water depth that is ≥ 3000 m in Laurentian Sub-Basin from historical CTD data.

≥ 3000 m Temperature (°C)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	0	NaN	NaN	NaN	NaN
FEBRUARY	0	NaN	NaN	NaN	NaN
MARCH	17	2.59	2.21	2.96	0.27
APRIL	16	2.48	2.23	2.85	0.25
MAY	20	2.55	2.21	2.90	0.28
JUNE	2	2.52	2.24	2.80	0.40
JULY	28	2.55	2.24	2.99	0.30
AUGUST	43	2.58	2.25	3.10	0.30
SEPTEMBER	1	2.77	2.77	2.77	0.00
OCTOBER	6	2.70	2.30	3.08	0.32
NOVEMBER	0	NaN	NaN	NaN	NaN
DECEMBER	1	2.43	2.43	2.43	0.00

≥ 3000 m Salinity (psu)

MONTH	# OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	0	NaN	NaN	NaN	NaN
FEBRUARY	0	NaN	NaN	NaN	NaN
MARCH	17	34.92	34.89	34.96	0.02
APRIL	16	34.92	34.89	34.94	0.02
MAY	20	34.92	34.89	34.96	0.02
JUNE	2	34.89	34.88	34.91	0.02
JULY	28	34.92	34.89	34.95	0.02
AUGUST	43	34.92	34.85	35.01	0.03
SEPTEMBER	1	34.93	34.93	34.93	0.00
OCTOBER	6	34.91	34.88	34.96	0.03
NOVEMBER	0	NaN	NaN	NaN	NaN
DECEMBER	1	34.94	34.94	34.94	0.00

At the surface, mean temperatures showed significant variations among months throughout the year (Figure 4.13). From June to November, mean surface temperatures were higher than the temperatures in the deeper waters. At a depth of 200 m, the mean temperatures were higher than at the other water depths from January to December except for the surface waters (Figure 4.13). At water depths of 1000 m and ≥ 3000 m, mean temperatures had no significant intra-annual variability. The mean salinities of the surface waters were lower than the salinity of the deeper water mass. At depths of 550 m, 1000 m, and ≥ 3000 m, the mean salinities had less intra-annual variability than salinities at shallower water masses (Figure 4.13).

T-S diagrams in Figure 4.14 show how the water properties vary with season throughout the water column. In summer and fall, three distinct water masses were indicated in Figure 4.14. The upper 50 m shows strong stratification in summer and fall and a weak stratification in spring and winter. Throughout the year, there was little distinction between the water

properties at the water depths of 550 m and 1000 m. Less stratification occurred at waters with depths of ≥ 550 m in all four seasons.

The T-S diagrams in Figure 4.14 show a distinct water mass with the characteristic of Slope Water at a depth of 200 m. Drinkwater et al. (2002) describe the Slope Water as being a combination of the colder, fresher Labrador Current water and the warmer saltier North Atlantic Central Water. The Slope Water properties at a particular location depend upon whether the North Atlantic Central Water or the Labrador Current Water is dominant. Labrador Slope Water is defined as having salinities and temperature in the range of 34.3 psu to 35 psu and 4°C to 8°C, respectively. The warm Slope Water is defined as having water properties ranging from 34.7 psu to 35.5 psu and 8°C to 12°C (Drinkwater et al., 2002)

The Labrador Slope Water occurs outside the southern Grand Banks over the Continental Slope inshore of the Warm Slope Water. The water mass at 200 m is distinctively Labrador Slope Water (Figure 4.14). Depending on the location in the Laurentian Sub-basin region, there were also measurements at this depth with higher salinities and temperatures corresponding to the water properties of the Warm Slope Water. The water properties at depths of 550 m and 1000 m indicate the presence of Slope Water.

North Atlantic Deep Water, characterized by temperatures between 2.2°C and 3.5°C, and salinities between 34.90 psu and 34.97 psu, is found at a depth of 3000 m in the Laurentian Sub-basin. The T-S diagrams show that the water properties of the Slope Water below the 550 m depth and the North Atlantic Deep Water at 3000 m and below are seasonally independent.

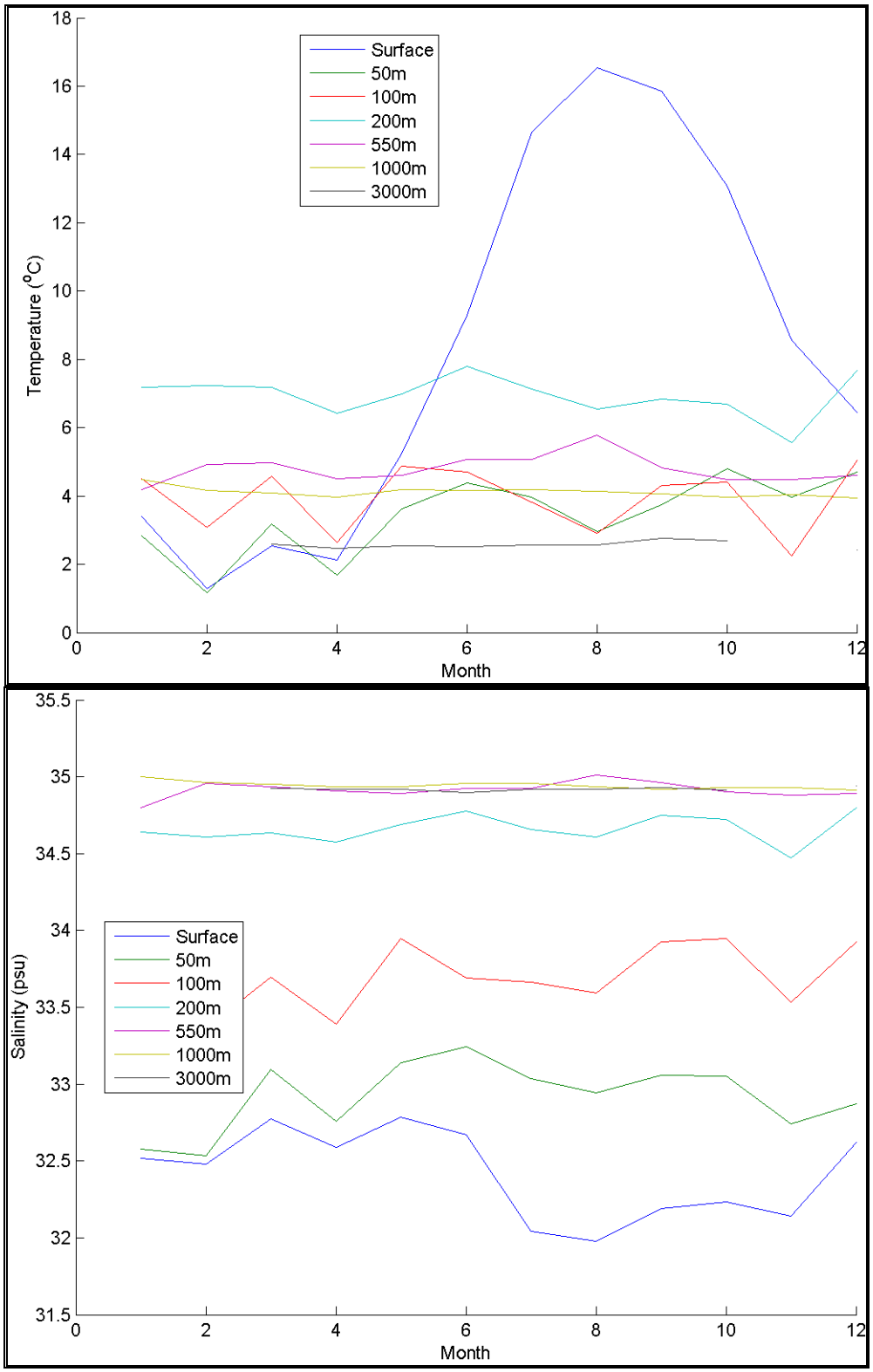


Figure 4.13 Monthly mean temperatures and salinities in the Laurentian Sub-basin.

Note: From the surface (0 m) to ≥ 3000 m, lines depict depths in meters.

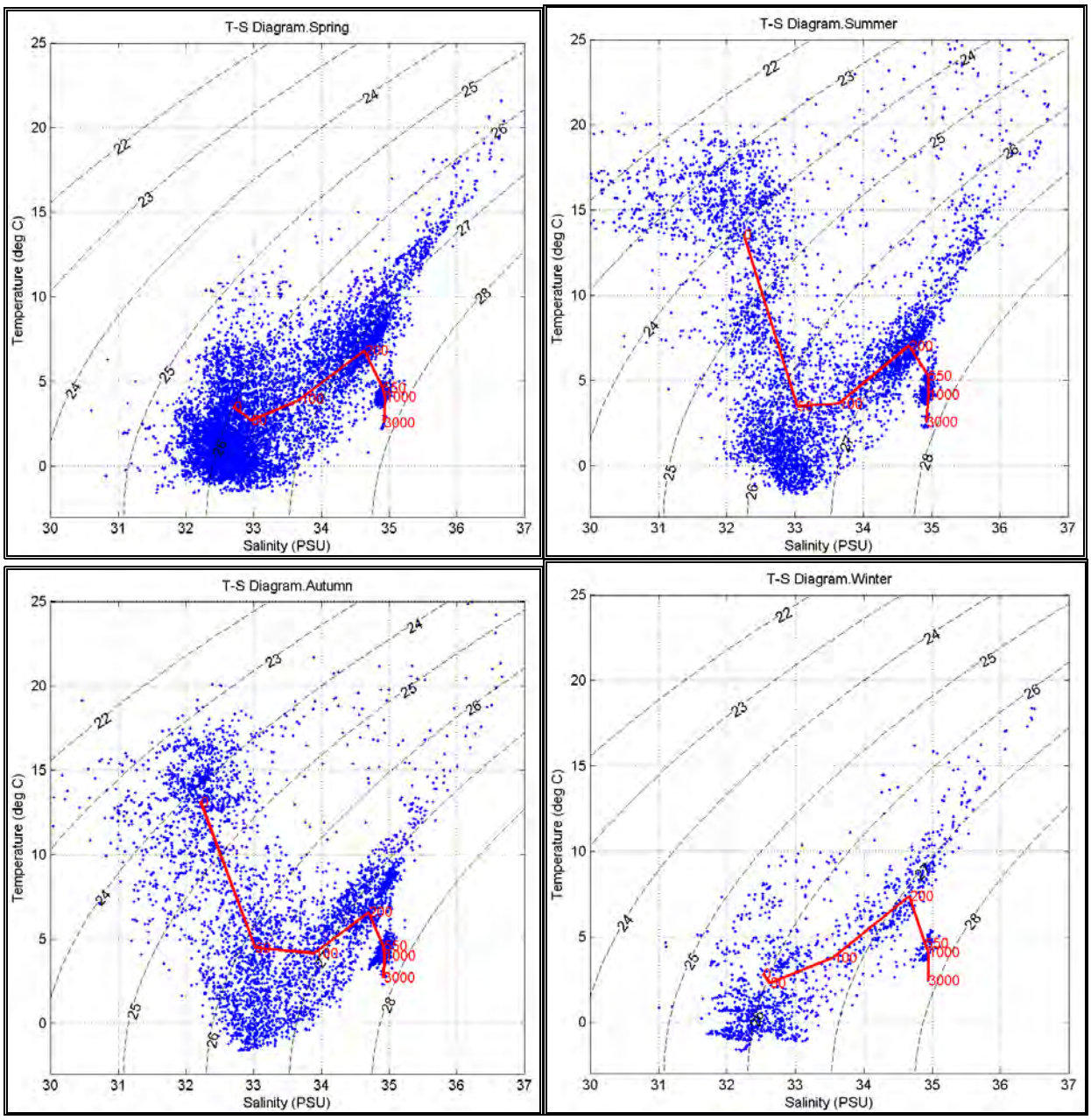


Figure 4.14 Seasonal T-S plots for the Laurentian Sub-basin.

Note: The red lines correspond to the average TS curve of each area. The numbers on the curves represent the water depth in meters. 3000 m represents water depths that are equal to or deeper than 3000 m.

4.3.3 Newfoundland Basin

Waters depths in Newfoundland Basin ranged from 200 m near the shelf to around 5000 m. Table 4.11 to Table 4.17 present the temperature and salinity data by month at the surface (0 m), 50 m, 100 m, 200 m, 550 m, 1000 m, and ≥ 3000 m.

The surface waters were warmest during the months of July to September with mean temperatures ranging from 11.17°C to 14.53°C. The coldest temperatures were in April and January with mean temperatures of 5.03°C and 5.43°C, respectively. In August, the minimum and maximum water temperature at surface was the highest with measurements of 8.90°C and 25.95°C (Table 4.11). Mean surface water salinities ranged from 33.46 psu in October to 35.20 psu in March (Table 4.11).

Table 4.11 Monthly temperature and salinity statistics for the surface waters in Newfoundland Basin from historical CTD data.

0 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	303	5.43	-1.43	17.07	2.99
FEBRUARY	91	8.06	-0.88	17.64	6.11
MARCH	156	10.06	-0.87	17.32	6.23
APRIL	705	5.03	-0.97	19.19	3.80
MAY	488	6.47	-0.88	18.43	3.95
JUNE	479	8.26	1.24	22.18	3.99
JULY	958	11.17	5.57	23.32	2.36
AUGUST	223	15.71	8.90	25.95	4.48
SEPTEMBER	115	14.53	7.73	23.50	4.03
OCTOBER	157	10.45	2.55	21.61	3.77
NOVEMBER	277	9.55	2.25	21.58	4.73
DECEMBER	169	10.55	1.66	21.51	5.28

0 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	303	34.09	32.33	36.38	0.59
FEBRUARY	91	34.75	33.31	36.43	1.06
MARCH	156	35.20	32.77	36.48	1.06
APRIL	705	34.24	32.29	36.36	0.71
MAY	488	34.16	32.32	36.56	0.78
JUNE	479	33.81	32.28	36.54	0.83
JULY	958	33.64	31.85	36.38	0.53
AUGUST	223	33.83	31.48	36.32	1.30
SEPTEMBER	115	33.74	31.84	36.31	1.11
OCTOBER	157	33.46	31.82	36.38	0.86
NOVEMBER	277	33.92	31.87	36.42	1.18
DECEMBER	169	34.63	32.90	36.45	1.32

At a depth of 50 m, waters were warmest in August, September and October, with mean temperatures of 7.61°C, 8.9°C and 10.9°C, respectively. Minimum temperatures were positive in February and December (Table 4.12). Mean salinities at 50 m depths ranged from 33.91 psu in December to 34.67 psu in October (Table 4.12).

Table 4.12 Monthly temperature and salinity statistics for waters at a depth of 50 m in Newfoundland Basin from historical CTD data.

50 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	145	5.13	-0.58	16.94	2.89
FEBRUARY	62	5.95	0.30	16.69	5.41
MARCH	85	5.30	-0.61	16.52	4.95
APRIL	632	4.42	-1.62	17.40	3.58
MAY	464	5.27	-1.69	18.10	4.35
JUNE	490	4.40	-1.58	20.70	3.65
JULY	962	4.89	-0.39	20.64	2.17
AUGUST	203	7.61	-1.46	22.82	6.52
SEPTEMBER	84	8.91	-1.12	21.28	5.30
OCTOBER	327	10.95	-1.14	22.02	5.97
NOVEMBER	258	7.22	-0.71	20.85	4.92
DECEMBER	115	6.45	1.27	17.91	2.99

50 m Salinities (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	145	34.24	33.31	36.24	0.50
FEBRUARY	62	34.44	33.46	36.24	0.89
MARCH	85	34.50	33.13	36.27	0.81
APRIL	632	34.31	32.56	36.49	0.62
MAY	464	34.34	32.84	36.47	0.73
JUNE	490	34.09	32.74	36.47	0.63
JULY	962	34.18	33.03	36.38	0.36
AUGUST	203	34.55	33.07	36.62	0.95
SEPTEMBER	84	34.24	32.83	36.26	0.82
OCTOBER	327	34.67	32.95	36.81	0.97
NOVEMBER	258	34.08	32.74	36.43	0.85
DECEMBER	115	33.91	33.30	36.00	0.50

At a depth of 100 m, the water mass was warmest in October and March, with mean temperatures of 9.01°C and 7.75°C, respectively. Mean temperatures were lowest in June (3.91°C) and July (4.03°C) (Table 4.13). The range of mean salinities was between 34.40 psu in June and 35.10 in October (Table 4.13).

Table 4.13 Monthly temperature and salinity statistics for waters at a depth of 100 m in Newfoundland Basin from historical CTD data.

100 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	160	5.04	0.50	16.83	3.10
FEBRUARY	63	6.60	0.82	17.67	5.65
MARCH	93	7.75	0.70	17.36	5.98
APRIL	605	4.30	-1.51	17.91	3.49
MAY	428	5.27	-1.56	17.74	4.64
JUNE	489	3.91	-1.52	18.92	3.65
JULY	953	4.03	0.04	19.84	2.22
AUGUST	195	6.21	-0.49	19.50	5.37
SEPTEMBER	87	6.56	-0.49	20.98	5.98
OCTOBER	334	9.01	-0.65	20.15	5.81
NOVEMBER	265	5.99	-0.61	21.13	5.63
DECEMBER	118	4.72	-0.03	18.07	3.20

100 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	160	34.46	33.66	36.32	0.46
FEBRUARY	63	34.69	33.63	36.42	0.86
MARCH	93	34.95	33.41	36.48	0.90
APRIL	605	34.49	32.78	36.34	0.55
MAY	428	34.62	33.02	36.47	0.67
JUNE	489	34.40	33.04	36.56	0.58
JULY	953	34.48	33.68	36.57	0.32
AUGUST	195	34.80	33.61	36.58	0.75
SEPTEMBER	87	34.78	33.71	36.64	0.81
OCTOBER	334	35.10	33.39	36.57	0.77
NOVEMBER	265	34.66	33.44	36.53	0.79
DECEMBER	118	34.47	33.82	36.32	0.45

Mean temperature of sea water at depth of 200 m were ranged from 4.15°C in July to 8.75°C in March. Waters in October were relatively warm as well, with mean temperature of 8.08°C. In June and July, waters were the coldest with mean temperature of 4.31°C and 4.15°C, respectively. Except for months of May, June, and November, minimum temperatures were all above zero in all the other months (Table 4.14). Mean salinities ranged from 34.74 psu in June to 35.28 psu in March (Table 4.14).

Table 4.14 Monthly temperature and salinity statistics for waters at a depth of 200 m in Newfoundland Basin from historical CTD data.

200 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	155	5.08	1.43	16.88	2.83
FEBRUARY	80	5.99	1.59	17.24	4.44
MARCH	90	8.75	1.65	17.37	5.70
APRIL	470	5.06	0.03	17.24	3.46
MAY	361	5.56	-0.03	18.00	4.16
JUNE	422	4.31	-1.01	17.76	3.09
JULY	757	4.15	2.41	17.53	1.60
AUGUST	169	6.25	0.82	18.02	4.63
SEPTEMBER	69	5.67	0.63	17.61	4.20
OCTOBER	307	8.08	0.80	17.91	4.46
NOVEMBER	182	5.13	-0.13	18.41	4.17
DECEMBER	98	6.06	2.17	18.55	4.62

200 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	155	34.84	34.29	36.37	0.31
FEBRUARY	80	34.93	34.27	36.38	0.52
MARCH	90	35.28	34.02	36.49	0.72
APRIL	470	34.85	33.93	36.36	0.42
MAY	361	34.89	33.64	36.52	0.50
JUNE	422	34.74	33.28	36.45	0.41
JULY	757	34.77	34.18	36.47	0.18
AUGUST	169	35.00	34.10	36.54	0.56
SEPTEMBER	69	34.90	34.05	36.40	0.48
OCTOBER	307	35.12	33.87	36.45	0.49
NOVEMBER	182	34.79	33.77	36.58	0.53
DECEMBER	98	34.98	34.26	36.50	0.54

At a depth of 550 m, waters were warmest in September with mean temperature of 7.13°C. In October, waters were coldest with mean temperature of 4.00°C. Table 4.15 shows that the minimum temperatures were all positive with lowest value in April (2.91°C). Mean salinities ranged from 34.88 psu in January to 35.16 psu in September. The range of the minimum salinities was from 34.64 psu in March to 34.83 psu in August, September, January and February (Table 4.15).

Table 4.15 Monthly temperature and salinity statistics for waters at a depth of 550 m in Newfoundland Basin from historical CTD data.

550 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	51	4.07	3.36	13.83	1.53
FEBRUARY	9	5.59	3.55	12.66	3.27
MARCH	29	5.30	3.38	14.55	3.21
APRIL	97	5.32	2.91	14.84	2.94
MAY	66	5.87	3.24	13.46	3.36
JUNE	69	4.29	3.20	15.11	2.35
JULY	103	4.21	3.24	10.56	1.61
AUGUST	66	4.84	3.23	15.65	2.66
SEPTEMBER	10	7.13	3.30	13.48	4.41
OCTOBER	52	4.00	3.21	11.84	1.65
NOVEMBER	49	4.42	3.01	16.27	2.26
DECEMBER	59	4.17	3.17	15.05	2.06

550 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	51	34.88	34.83	35.81	0.14
FEBRUARY	9	34.99	34.83	35.61	0.26
MARCH	29	35.00	34.64	35.93	0.27
APRIL	97	35.00	34.79	36.16	0.25
MAY	66	35.05	34.75	35.76	0.26
JUNE	69	34.91	34.77	36.02	0.22
JULY	103	34.90	34.74	35.32	0.10
AUGUST	66	34.96	34.83	36.08	0.23
SEPTEMBER	10	35.16	34.83	35.77	0.39
OCTOBER	52	34.89	34.78	35.55	0.13
NOVEMBER	49	34.89	34.75	36.28	0.23
DECEMBER	59	34.90	34.78	36.01	0.18

At a depth of 1000 m, waters were warmest in February and March, with mean temperatures of 4.82°C and 5.09°C, respectively. The coldest mean temperatures were observed in January and July with the measurements of 3.87°C and 3.88°C, respectively. The minimum temperatures were above zero throughout the year (Table 4.16). The range of mean salinities was between 34.90 psu in January and 34.99 psu in March. Mean salinities had no significant difference among months with a difference of less than 0.1 psu. The standard deviations of salinities were equal or less than 0.1 psu (Table 4.16).

Table 4.16 Monthly temperature and salinity statistics for waters at a depth of 1000 m in Newfoundland Basin from historical CTD data.

1000 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	57	3.87	3.31	7.04	0.98
FEBRUARY	32	4.82	3.24	8.04	1.10
MARCH	65	5.09	2.96	8.37	1.49
APRIL	169	4.14	3.10	9.08	1.08
MAY	129	4.34	3.03	10.05	1.35
JUNE	111	4.08	3.21	7.57	1.01
JULY	113	3.88	2.93	6.82	0.86
AUGUST	86	4.52	3.20	9.10	1.57
SEPTEMBER	26	4.62	3.32	7.64	1.28
OCTOBER	49	3.95	3.03	9.48	1.29
NOVEMBER	41	4.41	2.84	7.21	1.29
DECEMBER	49	4.30	2.93	7.62	1.61

1000 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	57	34.90	34.84	35.21	0.07
FEBRUARY	32	34.98	34.82	35.18	0.09
MARCH	65	34.99	34.75	35.22	0.10
APRIL	169	34.94	34.84	35.22	0.09
MAY	129	34.95	34.81	35.30	0.10
JUNE	111	34.93	34.82	35.17	0.08
JULY	113	34.91	34.81	35.10	0.06
AUGUST	86	34.94	34.81	35.18	0.09
SEPTEMBER	26	34.96	34.84	35.11	0.09
OCTOBER	49	34.93	34.84	35.35	0.10
NOVEMBER	41	34.92	34.76	35.29	0.10
DECEMBER	49	34.92	34.84	35.17	0.09

There was less number of observations at depths of ≥ 3000 m. No data were collected in February at these depths of waters. The mean temperatures ranged from 2.32°C in January to 2.95°C in August. Minimum temperature was positive from January to December (Table 4.17). The range of the mean salinities was between 34.90 psu in June and 34.95 in April. Mean salinities had no significant differences among months. The differences between minimum and maximum temperatures for each month was not significant with the standard deviations were equal or less than 0.05 psu (Table 4.17).

Table 4.17 Monthly temperature and salinity statistics for waters at a depth of ≥ 3000 m in Newfoundland Basin from historical CTD data.

3000 m Temperature (°C)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	2	2.32	2.30	2.34	0.03
FEBRUARY	0	NaN	NaN	NaN	NaN
MARCH	10	2.62	2.26	3.24	0.41
APRIL	56	2.65	2.23	3.27	0.34
MAY	57	2.70	2.04	3.25	0.38
JUNE	32	2.50	1.80	3.15	0.38
JULY	28	2.55	1.92	3.14	0.36
AUGUST	1	2.95	2.95	2.95	0.00
SEPTEMBER	15	2.62	2.08	3.14	0.37
OCTOBER	12	2.61	2.24	3.18	0.36
NOVEMBER	12	2.42	1.87	3.17	0.40
DECEMBER	9	2.56	1.98	3.05	0.36

3000 m Salinity (psu)

MONTH	#. OBSERVATIONS	MEAN	MIN	MAX	STD
JANUARY	2	34.91	34.91	34.91	0.00
FEBRUARY	0	NaN	NaN	NaN	NaN
MARCH	10	34.94	34.90	34.97	0.02
APRIL	56	34.95	34.90	35.04	0.05
MAY	57	34.94	34.87	35.04	0.04
JUNE	32	34.90	34.87	34.96	0.02
JULY	28	34.92	34.89	34.94	0.02
AUGUST	1	34.94	34.94	34.94	0.00
SEPTEMBER	15	34.93	34.90	34.97	0.02
OCTOBER	12	34.93	34.90	35.00	0.03
NOVEMBER	12	34.92	34.90	34.96	0.02
DECEMBER	9	34.92	34.90	34.94	0.02

The surface waters were generally warmer than the deeper water masses and had more seasonal variability (Figure 4.15). The warmest temperatures at each depth tended to occur during August and October. In March, the mean temperatures reached a small peak at depth of 0 m, 100 m, and 200 m, higher than temperature at the other water depths. At depths of 1000 m and ≥ 3000 m, mean water temperatures had no significant intra-annual changes, with little fluctuation among the months. At any depths, sea water in this region was generally colder in winter (December, January, and February) than in the other three seasons.

The mean surface sea water salinities were lower in most months except in March and December. At all water depths, salinities in March were relatively higher than in the other months. Basically, waters with shallower depths had lower mean salinities (Figure 4.15). At depths of 1000 m and ≥ 3000 m, the mean salinities were stable throughout the year with slightly variation among months. Generally, water masses with deeper depths had higher mean salinities (Figure 4.15).

T-S diagrams in Figure 4.16 show how the water properties vary with depth throughout the four seasons. In winter and spring, water was less stratified. In summer and autumn, waters showed more stratification to a depth of 50 m and 100 m, respectively. In spring and summer, there is little distinction between the water properties at the depths of 200 m and 550 m. In autumn and winter, no significant distinction was observed between the water properties at the depths of 550 m and 1000 m.

In the Newfoundland Basin the water properties at water depths of 550 m and 1000 m are those of the North Atlantic Central Water and at 3000 m the water mass is the North Atlantic Deep Water.

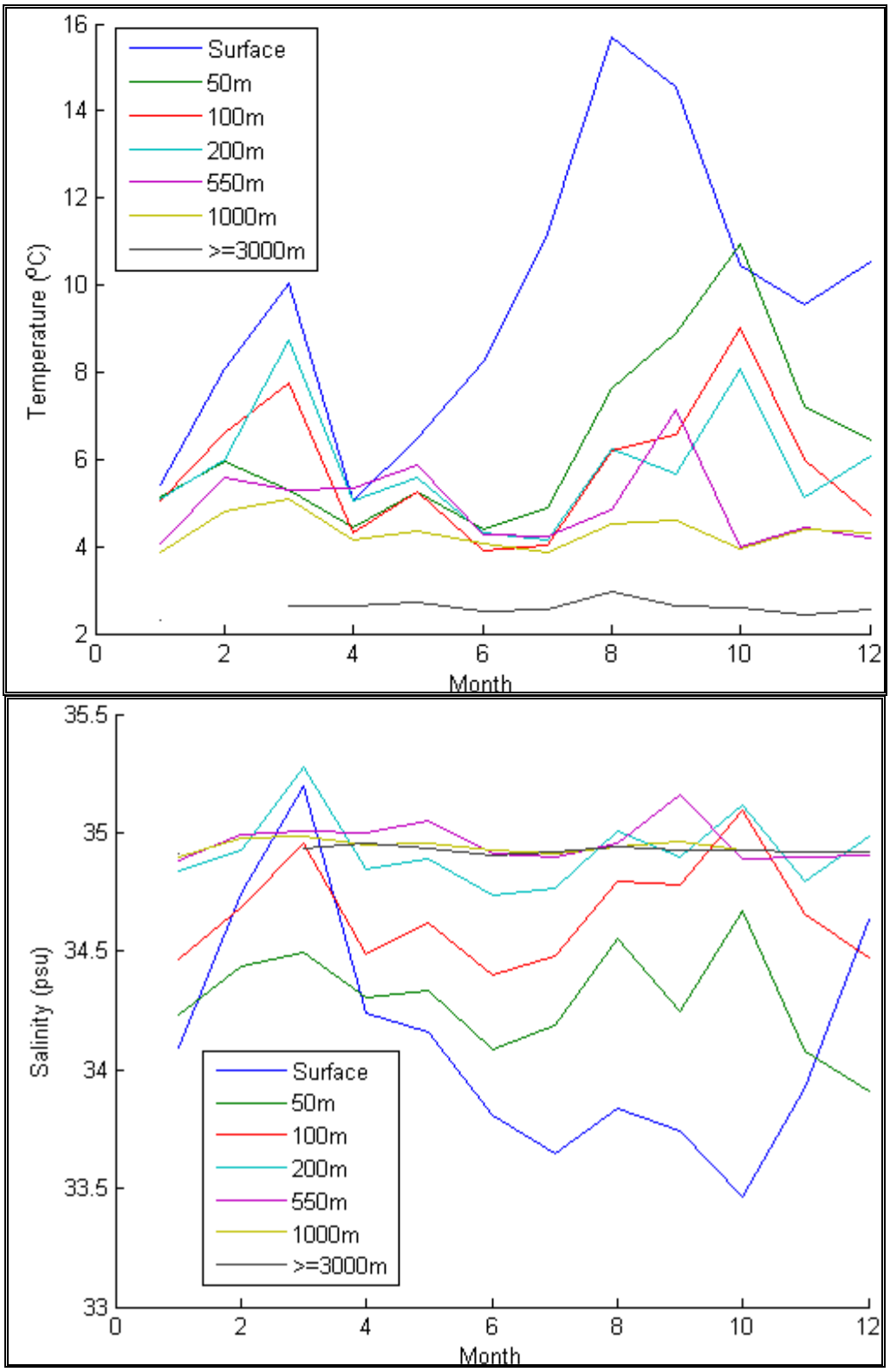


Figure 4.15 Monthly mean temperatures and salinities in the Newfoundland Basin.

Note: From the surface (0 m) to ≥ 3000 m, lines depict depths in meters.

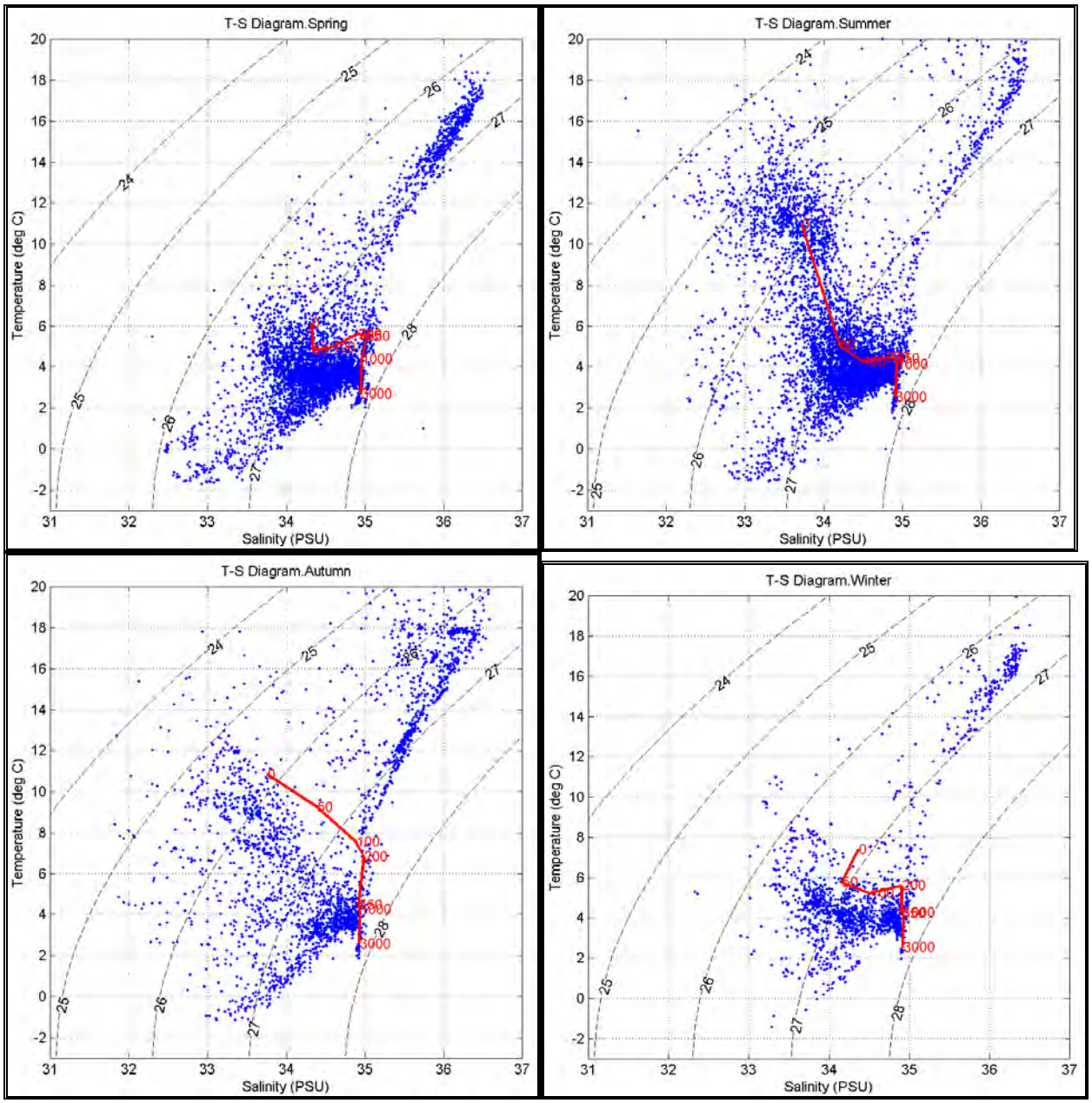


Figure 4.16 Seasonal T-S plots for the Newfoundland Basin.

Note: The red lines correspond to the average TS curve of each area. The numbers on the curves represent the water depth in meters. 3000 m represents water depths that are equal to or deeper than 3000 m.

4.4 Currents in the Project Area

Moored current data was obtained from the Bedford Institute of Oceanography for locations in the study area; Southern Grand Banks, Laurentian Sub-basin, and Newfoundland Basin. The locations of the moorings are shown in Figure 4.17.

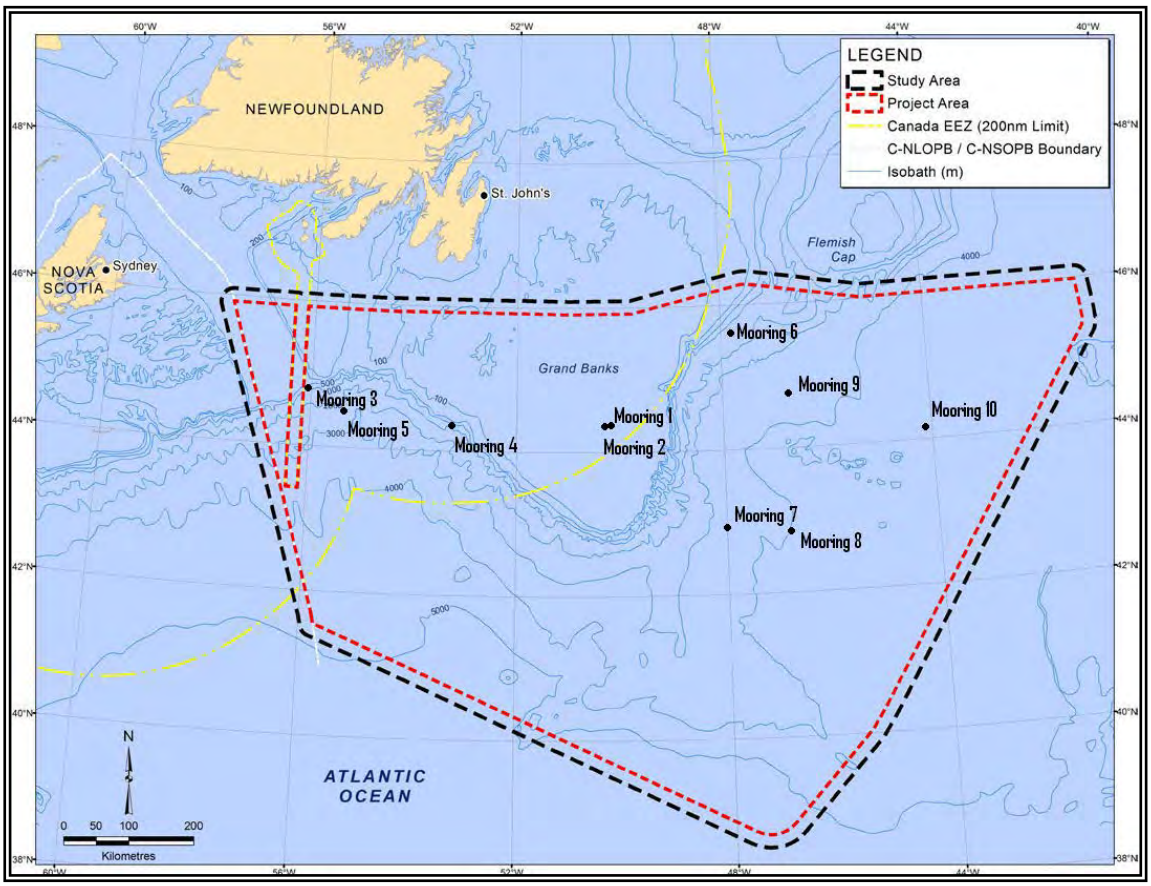


Figure 4.17 Location of current meter moorings

4.4.1 Southern Grand Banks

Information on the currents on the Southern Grand Banks is presented from two mooring programs in 1987 and 1988 at the locations of Mooring # 1 and Mooring # 2, shown in Figure 4.17. The water depth at these locations was 71 m and 73 m, respectively. Information on the data sets is presented in Table 4.18.

The mean current speeds were 19.9 cm/s, 14.8 cm/s, 8.8 cm/sec, and 8.3 cm/s at water depths of 7 m, 14 m, 43 m, and 59 m, respectively (Table 4.19). The maximum current speeds were 64.4 cm/s and 25.0 cm/s at water depths of 7 m and 59 m, respectively, and occurred during

the summer in 1988. In 1987, the maximum current speeds of 57.5 cm/s and 28.1 cm/s at water depths of 14 m and 43 m, respectively, occurred during October.

Progressive water diagrams are presented in Figure 4.18 which show that there is variability in the current flow with no preferred direction. At a point in time, the current can be flowing in any direction as shown by the diagrams in Figure 4.18.

Table 4.18 Current meter data for Southern Grand Banks

Mooring #	Meter Depth	Latitude	Longitude	Start Date	End Date	Water Depth
#1	14 m	44.25°N	50.98°W	May 3, 1987	Oct 19, 1987	71 m
	43 m	44.25°N	50.98°W	May 3, 1987	Oct 19, 1987	71 m
# 2	7 m	44.25°N	51.00°W	Apr 30, 1988	Sep 18, 1988	73 m
	59 m	44.25°	51.00°W	Apr 30, 1988	Sep 18, 1988	73 m

Table 4.19 Current statistics for specific water depth on the Southern Grand Banks

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
7 m	May	15.7	38.8
	Jun	17.3	44.0
	Jul	20.8	54.5
	Aug	22.8	64.4
	Sep	17.2	42.9
14 m	Jun	14.4	34.9
	Jul	12.2	30.7
	Aug	13.9	14.6
	Sep	16.1	44.5
	Oct	16.1	57.5
43 m	Jun	8.7	23.8
	Jul	7.9	22.2
	Aug	9.5	26.4
	Sep	8.6	19.9
	Oct	10.0	28.1
59 m	May	7.9	20.2
	Jun	8.5	25.0
	Jul	9.0	25.0
	Aug	8.3	23.0
	Sep	7.3	17.9

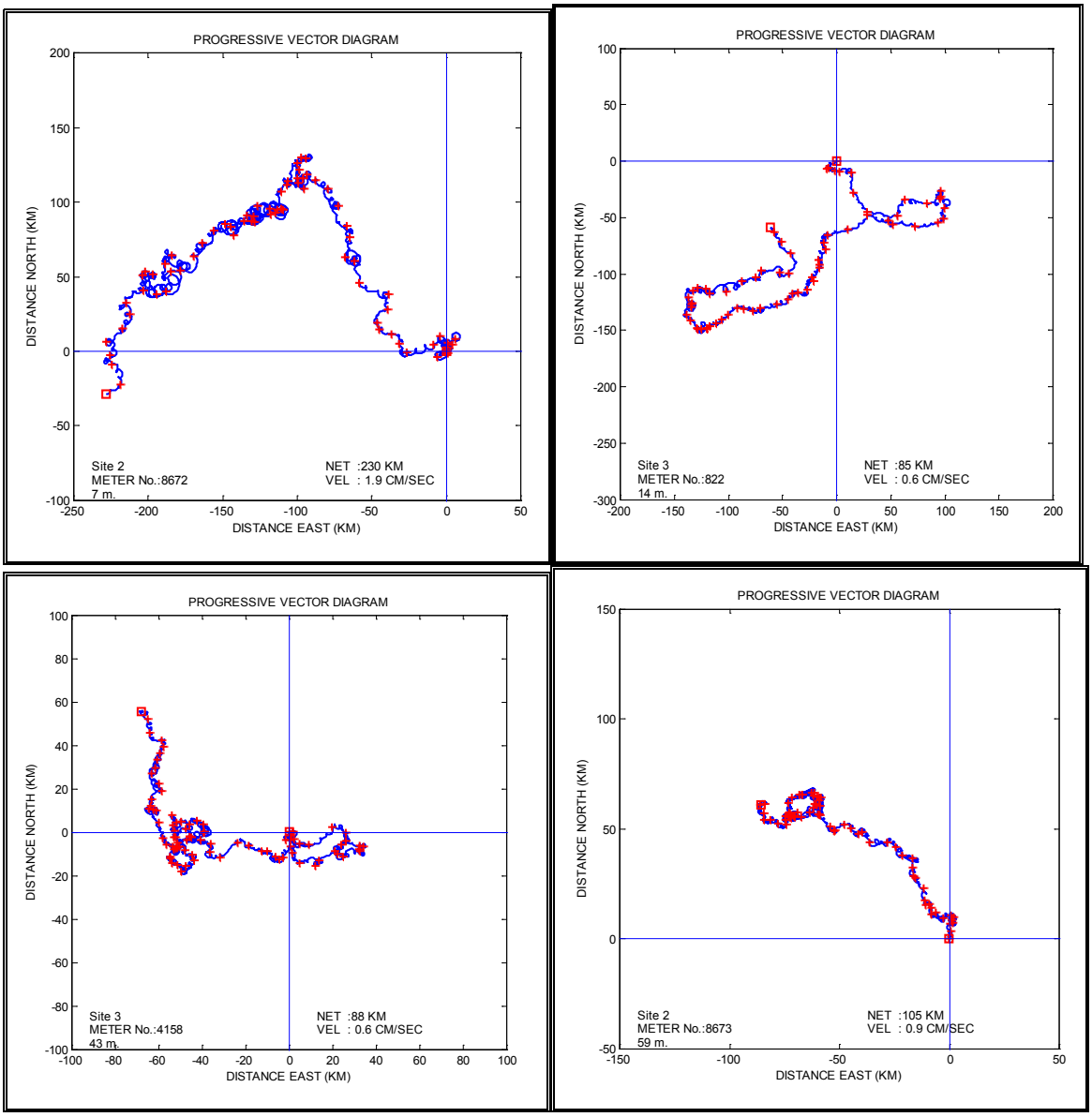


Figure 4.18 Progressive Vector Diagrams for the currents on Southern Grand Banks

4.4.2 Laurentian Sub-basin

The moored current data in the Laurentian Sub-basin are from the region of the Continental Slope, west of the Southern Grand Banks. The positions of the moorings are shown in Figure 4.17 and designated at Moorings # 3, # 4, and # 5. The water depth varies from approximately 400 m at mooring # 3 to 1950 m at mooring # 5. Information on the data sets are given in Table 4.20 and current statistics are given in Tables 4.21, 4.22, and 4.23.

At mooring # 3 the mean current speeds were 17.4 cm/s, 14.9 cm/s, 13. 1 cm/s, 12.9 cm/s, 15.1 cm/s at water depths of 60 m, 121 m, 196 m, 296 m, and 371 m. respectively. The

maximum speeds were 55.3 cm/s, 49.6 cm/s, 49.3 cm/s, 42.4 cm/s and 69.7 cm/s as water depths of 60 m, 121 m, 196 m, 296 m, and 371 m, respectively. The maximum speeds occurred in November at 60 m and 121 m, in January at 196 m and 296 m, and in December at 371 m.

Progressive Vector Diagrams of the currents measured at theses moorings are presented in Figure 4.19, 4.20, and 4.21. In the upper 200 m the current is usually flowing in a northwest direction but there are occasions when the flow is in the reverse direction. At depths of 828 m, 933 m and 1546 m the current flow is also towards the northwest. At depths of 371 m and 1783 m the current was flowing southwest and west, respectively.

Table 4.20 Current meter data for Laurentian Sub-basin

Mooring #	Meter Depth	Latitude	Longitude	Start Date	End Date	Water Depth
#3	60 m	44.83°N	56.18°W	Jul 2003	Jun 2004	~400 m
	121 m	44.83°N	56.18°W	Jul 2003	Jun 2004	~400 m
	196 m	44.83°N	56.18°W	Jul 2003	Jun 2004	~400 m
	296 m	44.83°N	56.18°W	Jul 2003	Jun 2004	~400 m
	371 m	44.83°N	56.18°W	Jul 2003	Jun 2004	~400 m
#4	88 m	44.38°N	53.77°W	Aug 5, 1987	Sep 19,1987	1600 m
	828 m	44.38°N	53.77°W	Aug 5, 1987	Sep 19,1987	1600 m
	1546 m	44.38°N	53.77°W	Aug 5, 1987	Sep 19,1987	1600 m
#5	54 m	44.75°N	55.08°W	Dec 14, 2009	Feb 9, 2010	1950 m
	158 m	44.75°N	55.08°W	Dec 14, 2009	Feb 9, 2010	1950 m
	933 m	44.75°N	55.08°W	Dec 14, 2009	Apr 9, 2010	1950 m
	1783 m	44.75°N	55.08°W	Dec 14, 2009	Apr 9, 2010	1950 m

Table 4.21 Current statistics for specific depths in the Laurentian Sub-basin at mooring #3

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
60 m	Jan	15.2	49.8
	Feb	16.4	44.2
	Apr	25.0	54.3
	May	19.9	50.4
	Jun	19.0	41.8
	Jul	9.3	28.5
	Aug	15.6	34.2
	Sep	18.3	47.5
	Oct	18.9	44.6
	Nov	15.8	55.3
	Dec	13.2	38.9
121 m	Jan	11.8	38.6
	Feb	12.3	36.6
	Mar	14.4	44.4

	Apr	17.4	37.4
	May	18.7	46.1
	Jun	15.5	40.3
	Jul	8.6	24.1
	Aug	15.6	31.6
	Sep	16.2	44.7
	Oct	16.0	40.9
	Nov	16.0	49.6
	Dec	13.2	47.3
196 m	Jan	12.8	49.3
	Feb	11.7	41.2
	Mar	13.3	42.4
	Apr	12.3	31.9
	May	15.4	42.1
	Jun	13.4	30.7
	Jul	10.8	23.8
	Aug	13.5	30.5
	Sep	13.7	38.0
	Nov	13.1	35.7
	Dec	13.3	47.0
296 m	Jan	14.6	42.4
	Feb	12.3	41.5
	Mar	13.0	37.7
	Apr	11.4	32.8
	May	14.0	39.2
	Jun	13.6	29.9
	Jul	8.3	28.4
	Aug	12.7	27.5
	Sep	12.7	36.6
	Oct	11.7	37.4
	Nov	14.7	34.8
	Dec	14.5	40.9
371 m	Jan	16.7	60.4
	Feb	14.9	44.7
	Mar	14.5	48.8
	Apr	15.1	54.6
	May	16.3	52.2
	Jun	18.5	43.2
	Jul	10.1	36.8
	Aug	14.4	39.7
	Sep	14.5	48.3
	Oct	13.7	47.6
	Nov	16.3	53.7
	Dec	16.6	69.7

Table 4.22 Current statistics for specific depths in Laurentian Sub-basin at Mooring # 4

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
88 m	Aug	15.8	42.0
828 m	Aug	4.3	13.0
1546	Aug	3.0	12.0

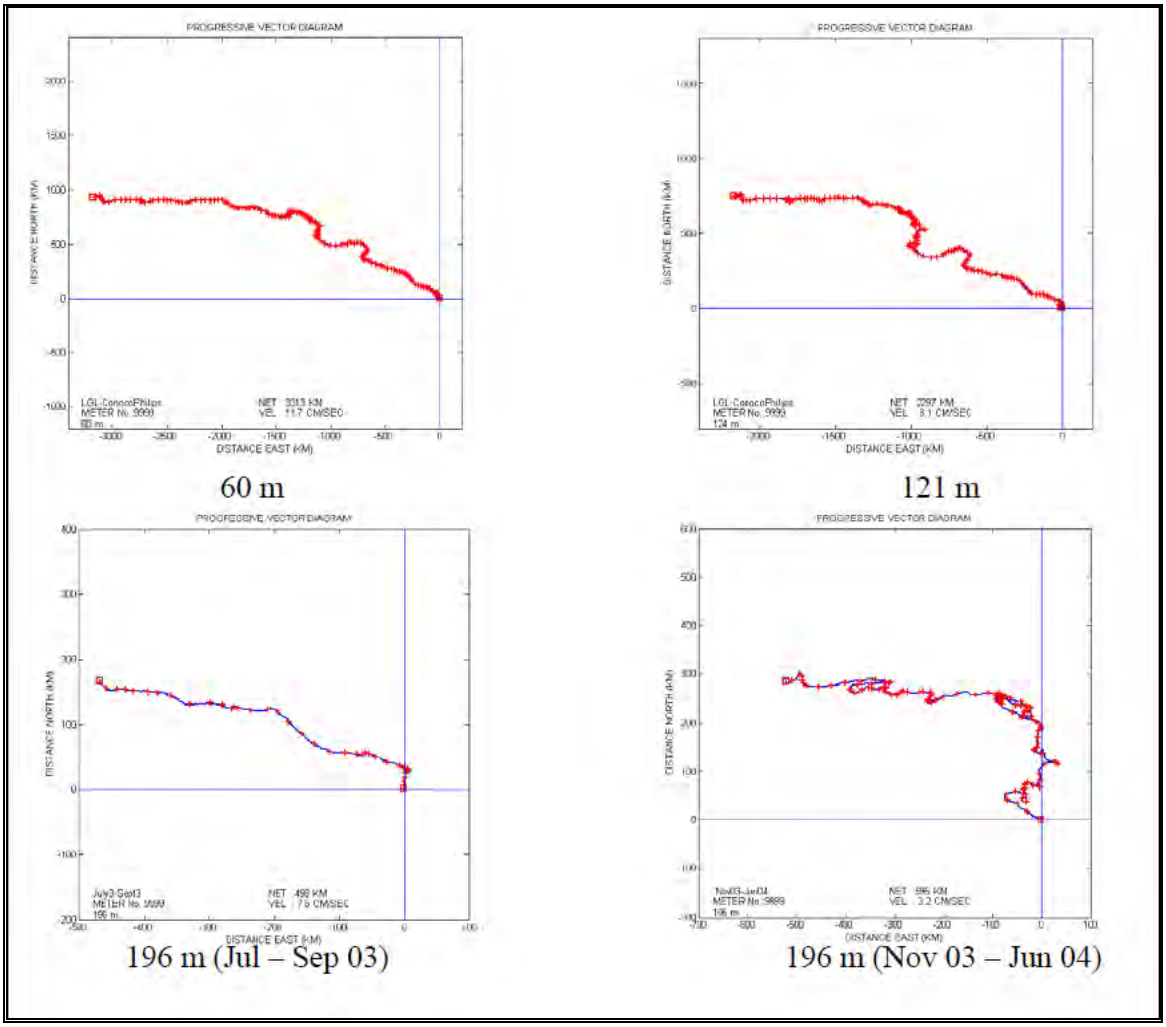


Figure 4.19 Progressive Vector diagrams for the currents at Mooring # 3 in Laurentian Sub-basin

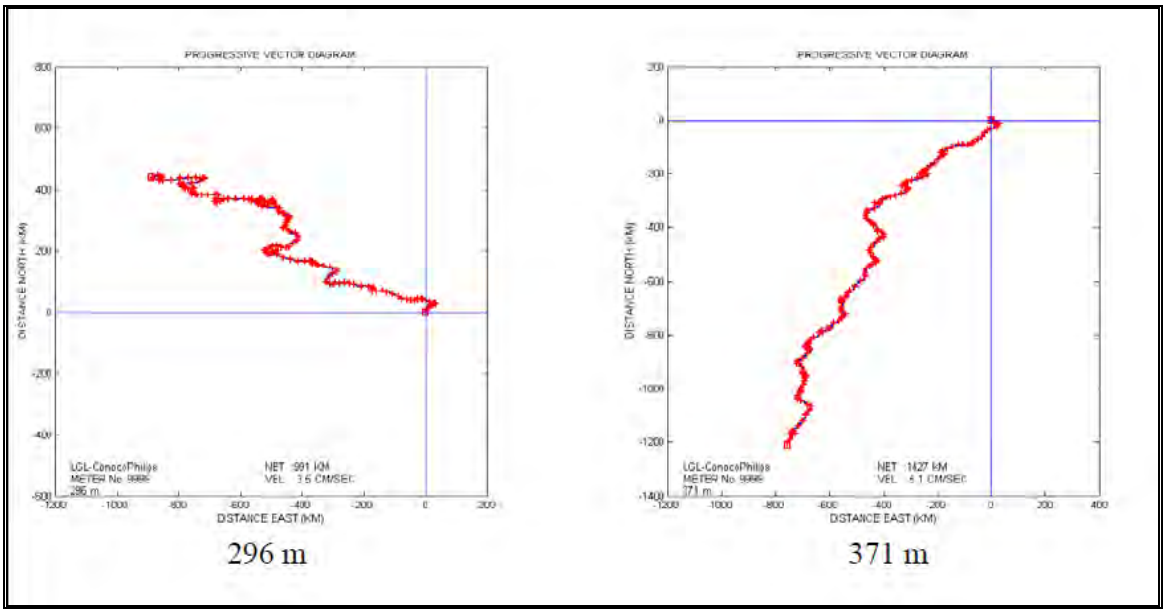


Figure 4.19 (cont) Progressive vector diagrams for the currents at Mooring # 3 in Laurentian Sub-basin

Table 4.23 Current statistics for specific depths in Laurentian Sub-basin at Mooring #5

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
54 m	Dec	16.4	76.6
	Jan	16.2	47.0
	Feb	16.0	42.1
158 m	Dec	10.2	30.0
	Jan	10.1	29.8
	Feb	11.7	29.7
933 m	Dec	7.3	17.8
	Jan	6.4	16.1
	Feb	5.2	13.0
	Mar	6.4	19.2
	Apr	3.4	9.7
1738 m	Dec	10.3	22.5
	Jan	8.3	25.1
	Feb	7.9	21.0
	Mar	7.5	22.8
	Apr	6.8	17.2

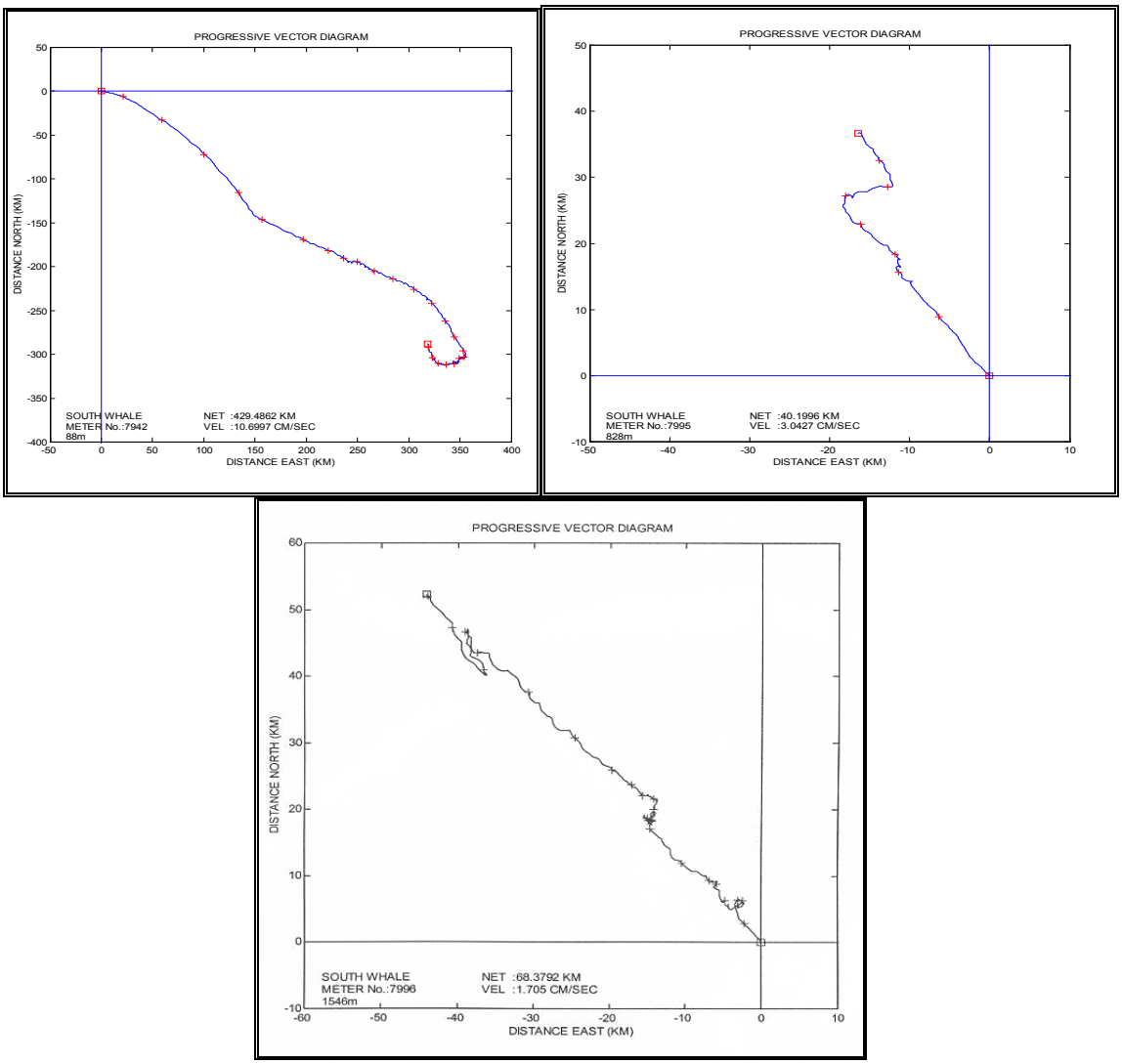


Figure 4.20 Progressive Vector Diagrams for the currents at Mooring # 4 in Laurentian Sub-basin

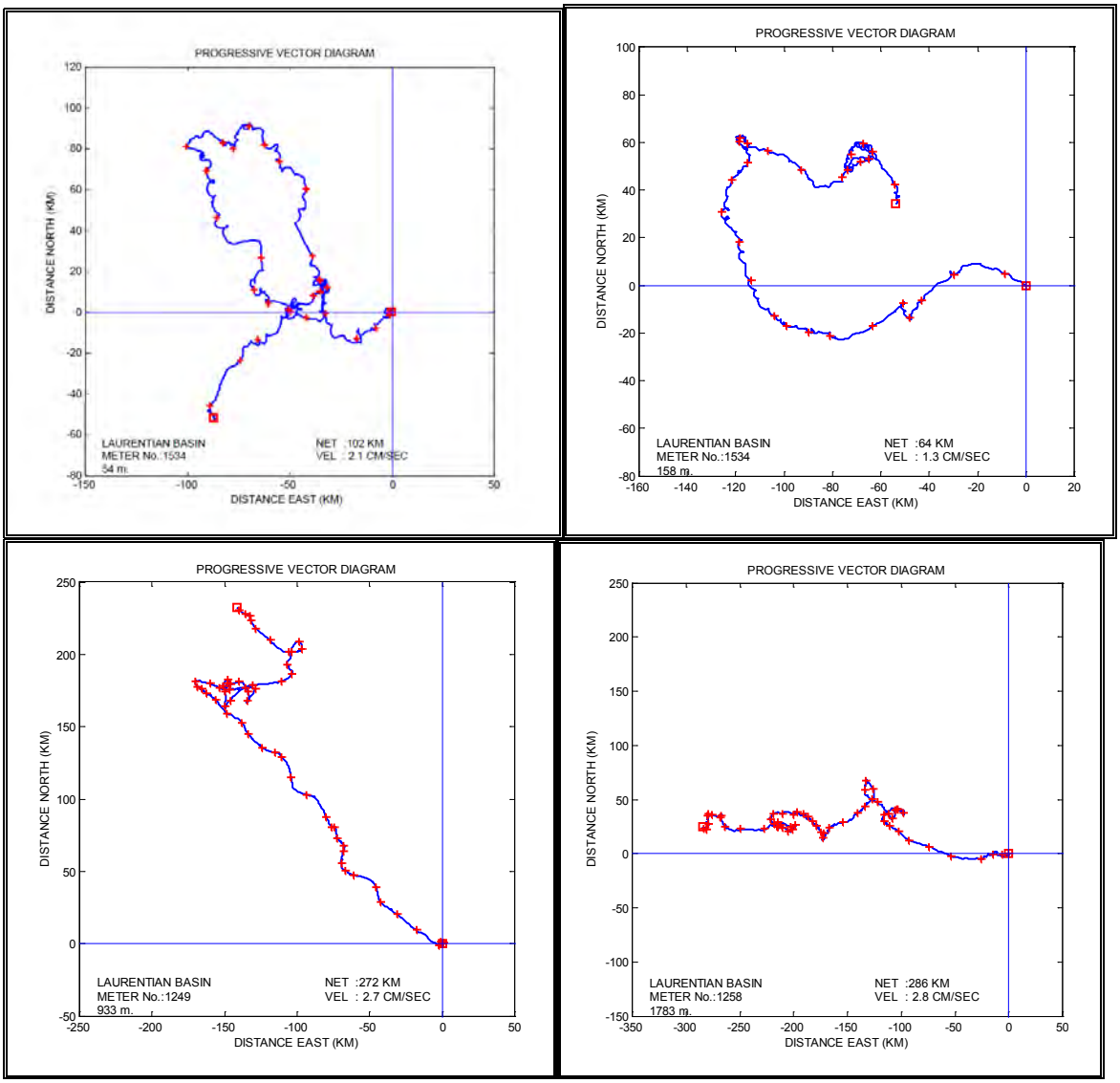


Figure 4.21 Progressive vector diagrams for the currents at Mooring # 5 in Laurentian Sub-basin

4.4.3 Newfoundland Basin and Continental Slope

Moored current data in this region is presented for currents on the Continental Slope offshore the southeast Grand Banks and for the deep water in Newfoundland Basin. The location of Mooring # 6 is shown in Figure 4.17 and information on the data set is presented in Table 4.24. Statistics of the currents on the Continental Slope are presented in Table 4.25 for currents at water depths of 687 m and 1462 m. At these depths the mean current speeds were 10.0 cm/s and 5.8 cm/s, and the maximum current speeds were 26.9 cm/s and 18.4 cm/s at depths of 687 m and 1462 m, respectively. Progressive vector diagrams for these depths are

presented in Figure 4.22 which show that the current flow is in a southwest direction following the bathymetric contours.

Moored current data for the deep water of Newfoundland Basin is presented from two mooring offshore southeast Grand Banks and in the northeast section of the study area. The locations of Moorings # 7, # 8, # 9, and # 10 are shown in Figure 4.17.

Table 4.24 Current meter data for the Continental Slope

Mooring #	Meter Depth	Latitude	Longitude	Start Date	End Date	Water Depth
# 6	687	45.54°N	47.73°W	Apr 11, 2003	Apr 27, 2003	1560 m
	1462	45.54°N	47.73°W	Apr 11, 2003	Jul 24, 2003	1560 m

Table 4.25 Current Statistics for specific depths on the Continental Slope

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
687 m	Apr	10.2	26.9
1462 m	Apr	7.3	17.4
	May	5.1	18.4
	Jun	5.5	15.1
	Jul	5.6	14.2

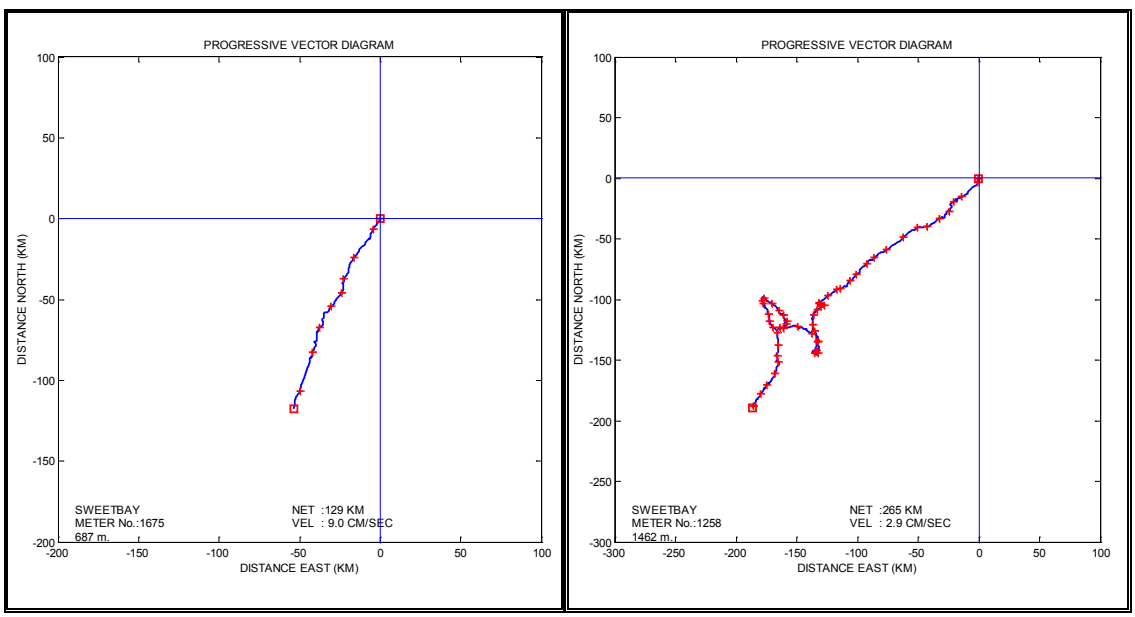


Figure 4.22 Progressive vector diagram for the currents at Mooring # 6 on the Continental Slope

Information on the data set is presented in Table 4.26 and statistics on the currents at Moorings # 7 and # 8 are presented in Tables 4.27 and 4.28. At Mooring # 7, the mean current speeds are 12.9 cm/s at 346 m and 9.7 cm/s at 3162 m. The maximum current speeds are 49.0 cm/s in December and 38.1 cm/s in February at depths of 346 m and 3162 m, respectively. At Mooring # 8, which is located further offshore, the mean current speeds are 32.5 cm/s at 402 m and 10.6 cm/s at 1523 m. The maximum current speeds are 134.1 cm/s in February at 402 m and 40.6 cm/s in February at 1523 m.

Progressive vector diagrams for Moorings # 7 and # 8 are presented in Figures 4.23 and 4.24. The Progressive vector diagrams in Figure 4.23 show that the current is flowing northeast at 346 m and in a reverse direction (southwest) in the deeper water at 3162 m. Figure 4.23 shows that the current is flowing northeast at 402 m and northwest, north and northeast at 1523 m. At a depth of 402 m the mean water temperature is 10.7°C. The warm temperatures together with the high current speeds indicate the presence of the North Atlantic Current in this region.

Table 4.26 Current meter data for Newfoundland Basin

Mooring #	Meter Depth	Latitude	Longitude	Start Date	End Date	Water Depth
# 7	346	42.95°N	48.18°W	Aug 11, 1993	May 3, 1995	3262
	3162	42.95°N	48.18°W	Aug 2, 1993	May 3, 1995	3262
# 8	402	42.57°	46.69°W	Aug 3, 1993	Mar 1, 1995	4392
	1523	42.57°	46.69°W	Aug 3, 1993	Mar 1, 1995	4392
# 9	2120	44.70°N	46.48°W	May 14, 1986	Oct 28, 1987	3539
	3469	44.70°N	46.48°W	May 14, 1986	Oct 28, 1987	3539
# 10	542	44.11°N	44.77°W	May 12, 1986	May 9, 1987	4413
	842	44.11°N	44.77°W	May 12, 1986	May 9, 1987	4413
	2042	44.11°N	44.77°W	May 12, 1986	May 9, 1987	4413
	4042	44.11°N	44.77°W	May 12, 1986	May 9, 1987	4413
	4342	44.11°N	44.77°W	May 12, 1986	May 9, 1987	4413

Table 4.27 Current statistics for specific depths in Newfoundland Basin offshore the southeast Grand Banks at Mooring # 7

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
346 m	Jan	18.5	46.7
	Feb	11.3	33.1
	Mar	10.3	32.3
	Apr	16.5	43.9
	May	5.1	19.5
	Jun	7.0	20.7
	Jul	9.1	23.9
	Aug	10.7	44.8
	Sep	14.2	29.1
	Oct	13.9	31.0
	Nov	15.8	46.7
	Dec	13.6	49.0

3162 m	Jan	8.9	27.8
	Feb	12.3	38.1
	Mar	10.6	34.4
	Apr	9.6	25.7
	May	8.0	19.1
	Jun	12.2	26.3
	Jul	9.6	23.1
	Aug	10.1	27.7
	Sep	12.4	31.7
	Oct	5.9	20.4
	Nov	9.3	32.8
	Dec	8.1	22.3

Table 4.28 Current statistics for specific depths in Newfoundland Basin offshore the southeast Grand Banks at Mooring # 8

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
402 m	Jan	40.2	83.9
	Feb	51.6	134.1
	Mar	31.0	60.9
	Apr	53.6	82.6
	May	41.4	78.2
	Jun	19.5	39.4
	Jul	39.3	68.5
	Aug	15.3	42.3
	Sep	19.7	45.8
	Oct	23.8	55.2
	Nov	31.7	64.3
	Dec	34.5	87.8
1523 m	Jan	10.2	20.4
	Feb	13.7	40.6
	Mar	8.4	19.8
	Apr	14.7	32.4
	May	12.1	24.7
	Aug	12.1	22.0
	Sep	7.5	16.0
	Oct	7.5	14.5
	Nov	8.4	16.9
	Dec	9.2	18.9

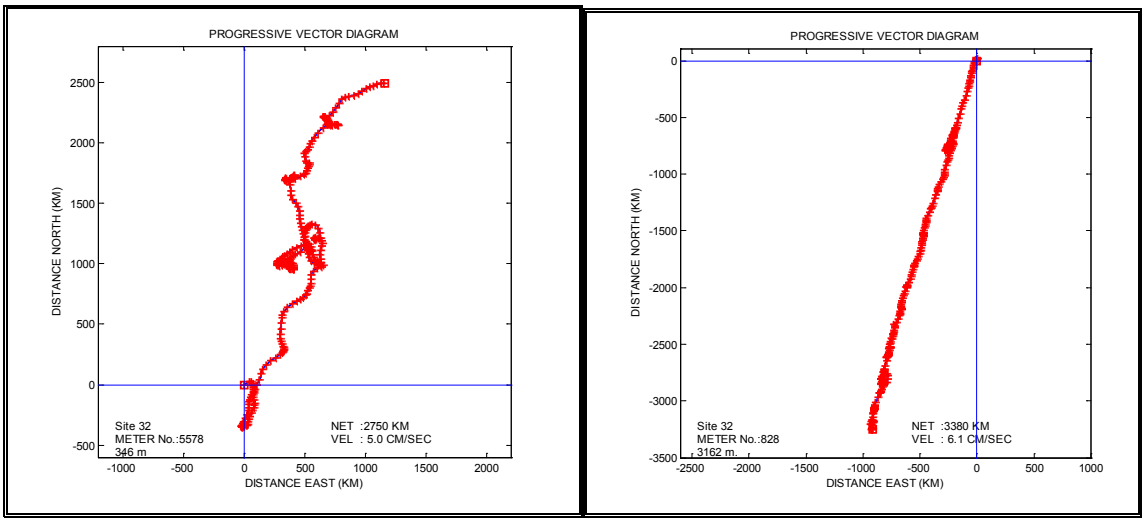


Figure 4.23 Progressive vector diagrams for Mooring # 7 in Newfoundland Basin offshore southeast Grand Banks

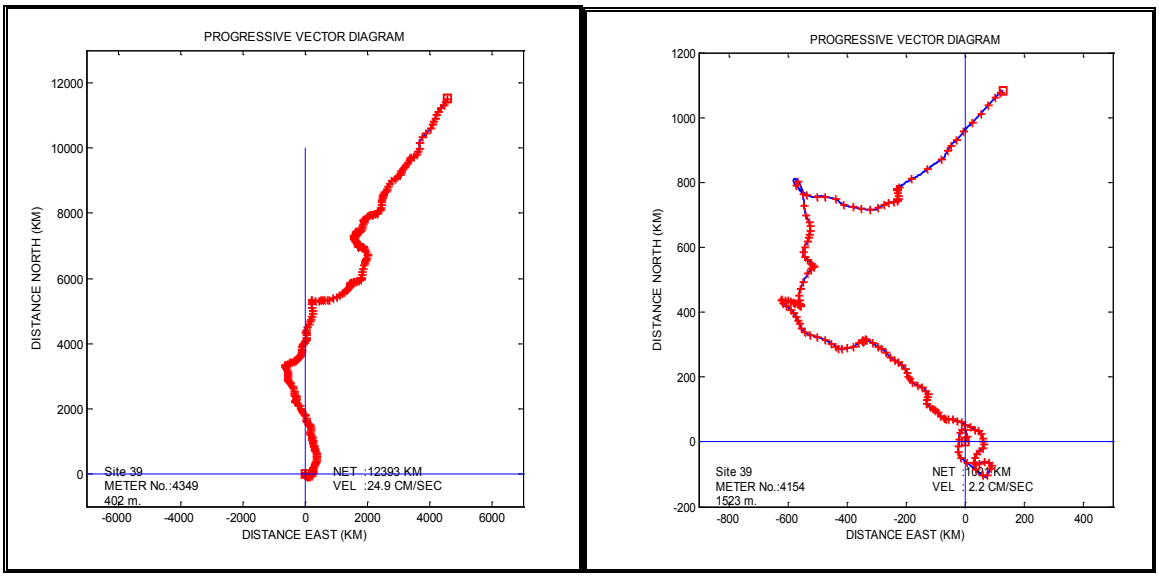


Figure 4.24 Progressive vector diagrams for the currents at Mooring # 8 in Newfoundland Basin offshore the southeast Grand Banks

Mooring # 9 and # 10 are located in the northeast section of the study area (Figure 4.17). At mooring # 9, the mean current speeds are 7.4 cm/s at 2120 m and 9.8 cm/s at 3469 m. The maximum current speeds at these depths are 36.2 cm/s and 39.3 cm/s, respectively. At Mooring # 10 the mean current speeds are 21.4 cm/s, 20.8 cm/s, 15.4 cm/s, 18.6 cm/s, and 20.1 cm/s at depths of 542 m, 842 m, 2042 m, 4042 m, and 4342 m, respectively. The

maximum current speeds at these depths are 65.9 cm/s, 59.0 cm/s, 50.3 cm/s, 52.6 cm/s, and 54.9 cm/s, respectively.

Progressive vector diagrams for Moorings # 9 and # 10 are presented in Figures 4.25 and 4.26. The Progressive vector diagrams for the deep water at Mooring # 9 show that the current has a lot of variability at 2120 m with the net flow being in a southerly direction. At 3469 m, the current is flowing towards the west. At Mooring # 10 the current is flowing towards the southeast at depths of 542 m and 842 m, and towards the south at depths of 2042 m, 4042 m, and 4342 m. There is variability in the flow at all depths.

Table 4.29 Current statistics for the deep water in Newfoundland Basin at Mooring # 9

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
542 m	Jan	5.7	12.6
	Feb	11.5	36.2
	Mar	6.7	23.5
	Apr	6.0	17.2
	May	7.7	22.8
	Jun	5.9	20.5
	Jul	5.1	16.7
	Aug	6.7	18.8
	Sep	9.2	20.8
	Oct	6.8	25.6
	Nov	13.9	35.2
	Dec	7.8	17.2
842 m	Jan	14.1	24.1
	Feb	13.1	30.6
	Mar	5.3	17.7
	Apr	13.5	39.3
	May	11.0	26.8
	Jun	8.3	22.9
	Jul	8.5	21.7
	Aug	11.6	30.1
	Sep	8.8	24.8
	Oct	7.4	23.6
	Nov	11.4	24.9
	Dec	8.3	21.8

Table 4.30 Current statistics for Newfoundland Basin at Mooring # 10

Depth	Month	Mean Speed (cm/s)	Max Speed (cm/s)
542 m	Jan	17.3	44.9
	Feb	24.5	49.3
	Mar	25.3	49.1
	Apr	35.7	56.5

	May	23.3	65.9
	Jun	22.1	39.3
	Jul	20.9	44.8
	Aug	17.5	53.5
	Sep	12.2	28.6
	Oct	9.16	40.8
	Nov	16.4	50.8
	Dec	21.7	38.1
842 m	Jan	18.3	39.1
	Feb	37.4	58.1
	Mar	31.6	59.0
	Apr	20.1	39.9
	May	10.9	33.8
	Jun	19.0	39.7
	Jul	20.2	39.9
	Aug	15.7	38.8
	Sep	12.9	20.5
	Oct	19.6	33.7
	Nov	16.4	34.3
	Dec	21.7	27.3
2042	Jan	11.6	33.0
	Feb	15.1	26.5
	Mar	21.9	50.3
	Apr	15.1	34.8
	May	10.4	21.9
	Jun	16.6	39.3
	Jul	20.1	30.5
	Aug	18.0	44.4
	Sep	12.8	21.7
	Oct	16.5	39.4
	Nov	12.0	25.3
	Dec	14.0	22.2
4042 m	Jan	14.4	33.5
	Feb	18.5	39.4
	Mar	21.2	36.3
	Apr	11.0	35.6
	May	11.7	25.4
	Jun	18.7	33.0
	Jul	27.7	43.4
	Aug	26.8	48.4
	Sep	21.0	35.6
	Oct	24.1	52.6
	Nov	11.4	32.6
	Dec	15.1	26.0
4342 m	Jan	16.5	37.1
	Feb	19.4	35.6
	Mar	23.4	39.9
	Apr	11.9	34.2

	May	13.2	27.9
	Jun	20.0	31.7
	Jul	30.0	44.7
	Aug	27.9	47.4
	Sep	22.0	38.9
	Oct	25.3	54.9
	Nov	13.0	31.9
	Dec	17.0	30.7

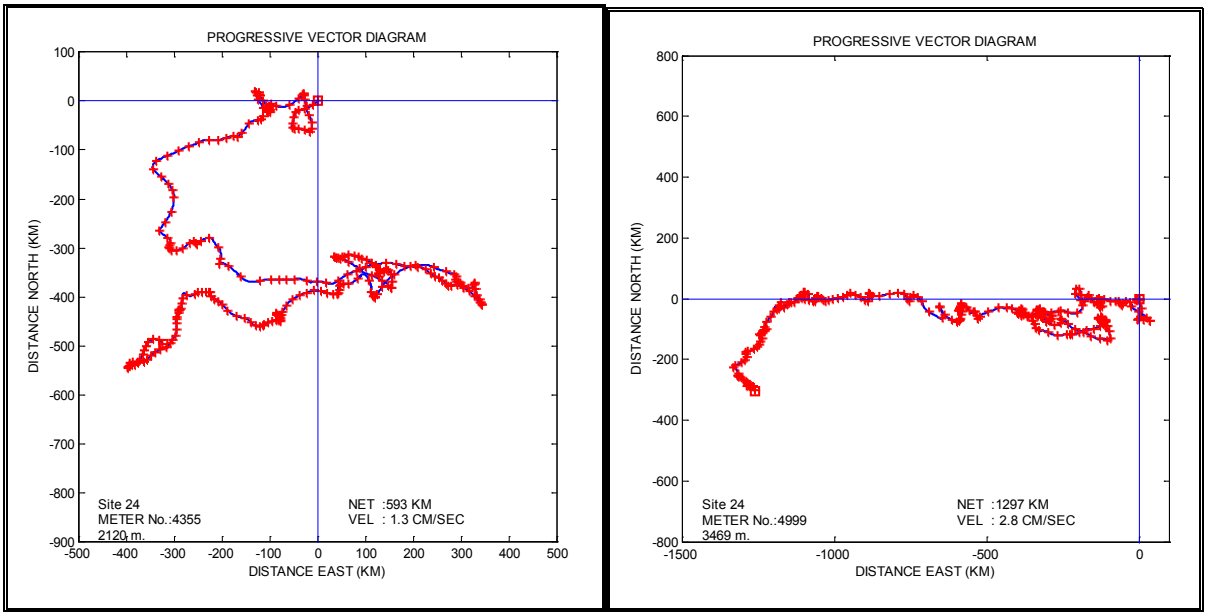


Figure 4.25 Progressive Vector diagram for the deep water currents at Mooring # 9 in Newfoundland Basin

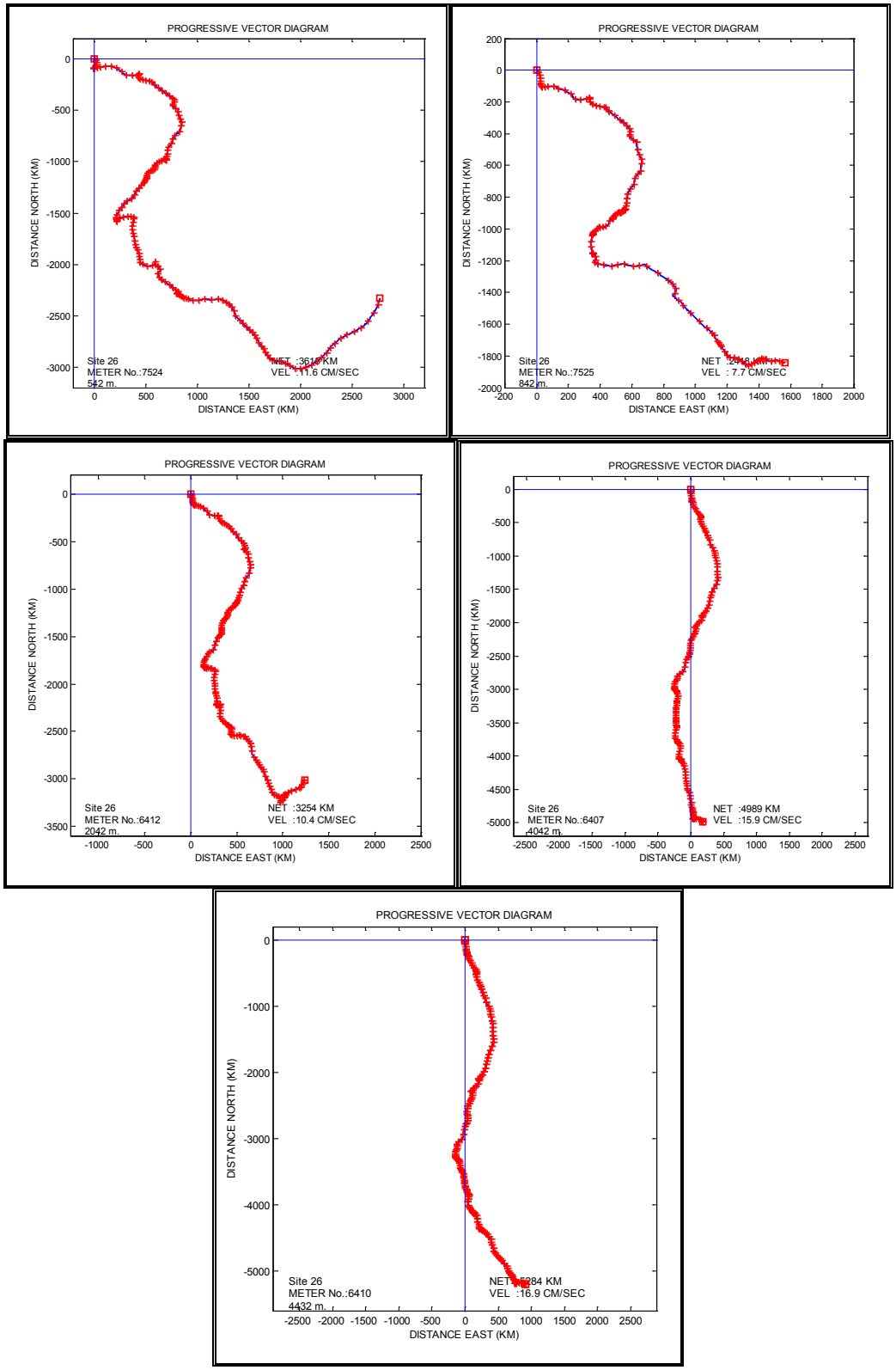


Figure 4.26 Progressive vector diagrams for the currents at Mooring # 10 in Newfoundland Basin

5.0 Sea Ice and Icebergs

5.1 Sea Ice

Classification of ice commonly found in the waters along Canada's Eastern Seaboard is according to internationally accepted terminology (Canadian Ice Service, 2011).

Sea Ice

Any form of ice found at sea which has originated from the freezing of sea water.

A. Ages of Sea Ice

New Ice

A general term for recently formed ice which includes; frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat. In Canada, the term 'new ice' is applied to all recently formed sea ice having thickness up to 10 cm. This includes ice rind, light nilas and dark nilas.

Frazil Ice – Fine spicules or plates of ice suspended in water.

Grease Ice – A later stage of freezing than Frazil Ice when crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.

Slush – Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Shuga – An accumulation of spongy white ice lumps, a few centimeters across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

Nilas

A thin elastic crust of ice, easily bending on the waves and swell and under pressure, thrusting in a pattern of interlocking 'fingers' (finger rafting). Has a matt surface and may be subdivided into darl nilas and light nilas.

Dark Nilas – Nilas which is under 5 cm in thickness and is very dark in colour.

Light Nilas – Nilas which is more than 5 cm in thickness and rather lighter in colour than dark nilas.

Young Ice

Ice in the transition stage between nilas and first year ice, 10 -30 cm in thickness. May be subdivided into grey ice and grey-white ice.

Grey Ice

Young ice 10-15 cm thick. Less elastic than nilas and breaks in swell. Usually rafts under pressure.

Grey-white Ice

Young ice 15-30 cm thick. Under pressure is more likely to ridge than raft.

First-year Ice

Sea ice of not more than one winter's growth, developing from young ice; thickness 30 cm to 2 m, and sometimes slightly more. May be subdivided into thin first-year ice/white ice, medium first-year ice and thick first-year ice.

Thin First-year Ice/white ice

First-year ice 30-70 cm thick. May be subdivided into thin first-year ice of the first stage 30-50 cm thick and thin first-year ice of the second stage 50-70 cm thick.

Medium First-year Ice

First-year ice 70-120 cm thick.

Thick First-year Ice

First-year ice over 120 cm thick.

Old Ice

Sea ice which has survived at least one summer's melt. Most topographic features are smoother than first-year ice.

B. Concentration of Sea Ice

Concentration is the ratio expressed in tenths describing the amount of the sea surface covered by ice as a fraction of the whole area being considered. Total concentration includes all stages of development that are present, partial concentration may refer to the amount of a particular stage or a particular form of ice and represents only a part of the total. The following terms are used:

Compact Ice

Floating ice in which the concentration is 10/10 and no water is visible.

Consolidated Ice

Floating ice in which the concentration is 10/10 and the floes are frozen together.

Very Close Ice

Floating ice in which the concentration is 9/10 to less than 10/10.

Close Ice

Floating ice, in which the concentration is 7/10 to less than 8/10, composed of floes mostly in contact.

Open Ice

Floating ice in which the concentration is 4/10 to less than 6/10 with many leads and polynyas, and the floes are generally not in contact with one another.

Very Open Water

Floating ice in which the concentration is 1/10 to less than 3/10 and water preponderates over ice.

Open Water

A large area of freely navigable water in which sea ice is present in concentration less than 1/10. No ice of land origin is present.

Ice Free

No ice present.

Bergy Water

An area of freely navigable water in which ice of land origin is present in concentrations less than 1/10. There may be sea ice present, although the total concentration of all ice shall not exceed 1/10.

(Ice of land origin is defined as ice formed on land or in an ice shelf, found floating in water.)

C. *Forms of Sea Ice*

Ice Floe

Any relatively flat piece of sea ice 20 m or more across.

D. *Surface features of Sea Ice*

Rafted Ice

Type of deformed ice formed by one piece of ice overriding another.

Ridge

A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure is termed an ***ice keel***

5.1.1 30-Year Median Ice Concentration

The 30-year median concentration of sea ice reaches its maximum extent the week of March 05. As can be seen from Figure 5.1 the median of ice concentration does not extend into the study area. The maximum median sea ice extent reaches to approximately 48°N 49°W.

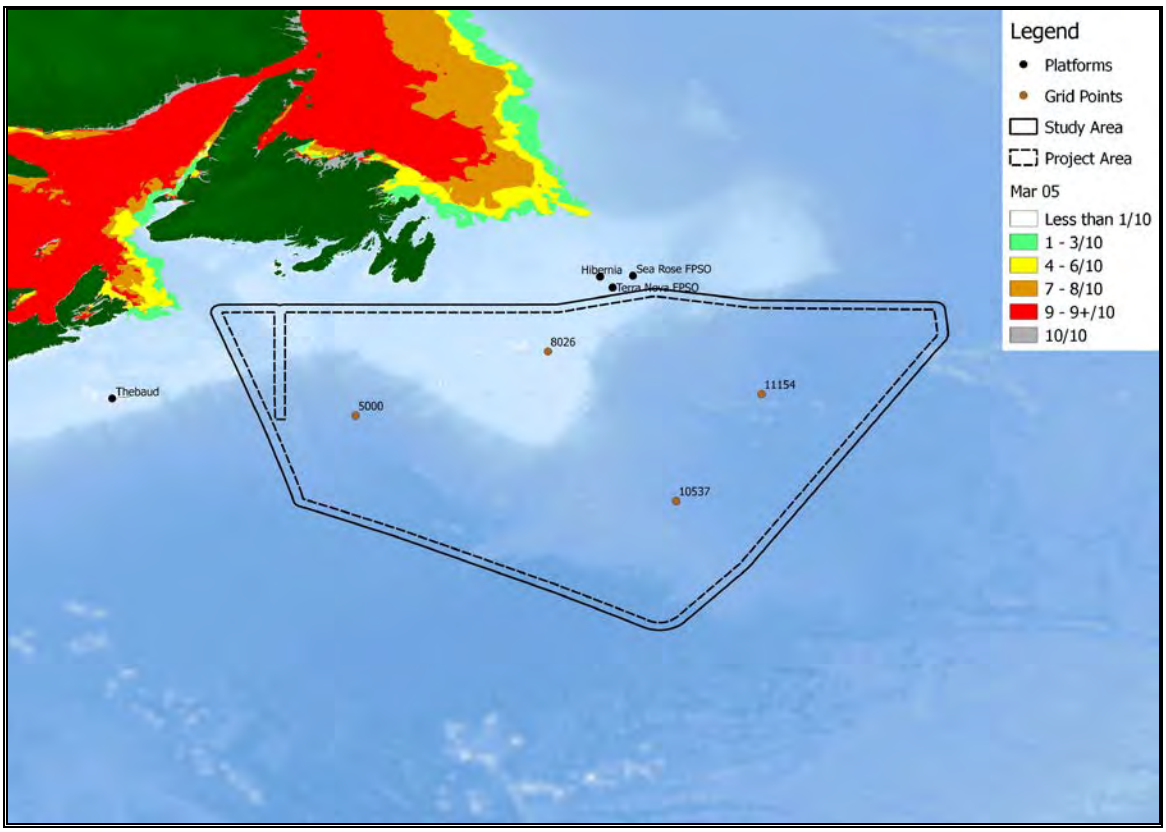


Figure 5.1 30-Year Frequency of Presence of Sea Ice within the Study Area (March 05)

(Source: Canadian Ice Service, 2011).

5.1.2 30-Year Median Ice Concentration when Ice is Present

The 30-year median concentration of sea ice when ice is present reaches its maximum extent the week of March 12 (Figure 5.2). A table containing the percent coverage of ice for each week is presented in Table 5.1.

Table 5.1 Weekly Median Ice Concentration when Ice is Present

	< 1/10	1 - 3/10	4 - 6/10	7 - 8/10	9 - 9+/10	10/10
Jan 01	100.00	0.00	0.00	0.00	0.00	0.00
Jan 08	100.00	0.00	0.00	0.00	0.00	0.00
Jan 15	99.93	0.07	0.00	0.00	0.00	0.00
Jan 22	99.50	0.44	0.01	0.00	0.05	0.00
Jan 29	99.97	0.00	0.00	0.03	0.00	0.00
Feb 05	99.48	0.00	0.01	0.29	0.23	0.00
Feb 12	97.43	1.47	0.75	0.27	0.09	0.00
Feb 19	96.77	1.97	0.48	0.50	0.28	0.00
Feb 26	96.27	2.06	1.25	0.32	0.11	0.00
Mar 05	97.49	0.82	0.72	0.55	0.41	0.00
Mar 12	94.32	1.44	2.34	0.88	1.02	0.00
Mar 19	94.78	1.53	1.95	0.47	1.27	0.00
Mar 26	97.46	0.73	0.94	0.81	0.06	0.00
Apr 02	95.89	1.19	2.29	0.59	0.04	0.00
Apr 09	98.15	0.89	0.62	0.32	0.03	0.00
Apr 16	99.18	0.25	0.56	0.00	0.00	0.00
Apr 23	99.29	0.55	0.07	0.01	0.08	0.00
Apr 30	99.82	0.18	0.00	0.00	0.00	0.00
May 07	100.00	0.00	0.00	0.00	0.00	0.00
May 14	100.00	0.00	0.00	0.00	0.00	0.00
May 21	100.00	0.00	0.00	0.00	0.00	0.00
May 28	99.97	0.03	0.00	0.00	0.00	0.00
Jun 04	99.96	0.04	0.00	0.00	0.00	0.00

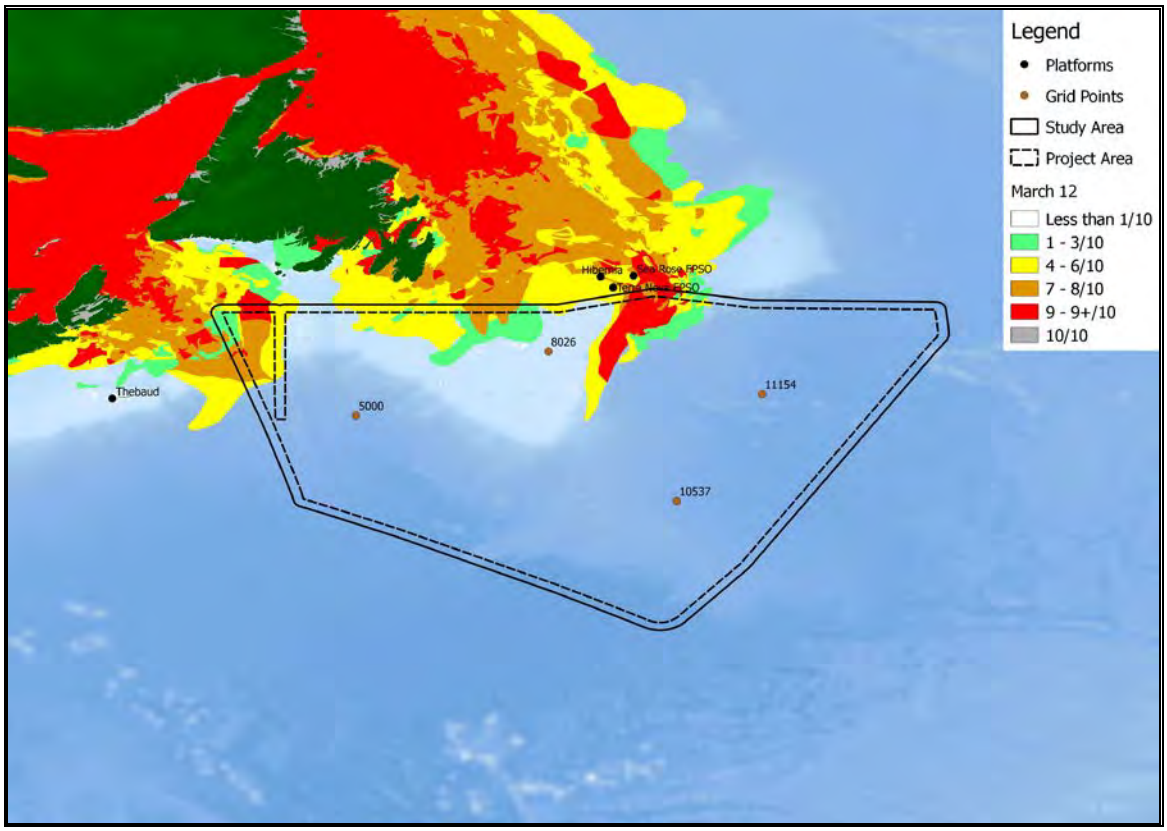


Figure 5.2 30-Year Frequency of Presence of Sea Ice when Ice is Present within the Study Area (March 12)

(Source: Canadian Ice Service, 2011).

5.1.3 30-Year Frequency of Presence of Sea Ice

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice over the area shows that the study area is first affected by sea ice beginning the week of January 15 and lasting until the week beginning June 04. Figure 5.3 shows the week of March 12, the period when the frequency of presence of sea ice is the greatest over the project area. Table 5.2 details the weekly frequency of presence of sea ice within the study area.

Table 5.2 30-Year Frequency of Presence of Sea Ice within the Study Area

	0%	1 - 15%	16 - 33%	34 - 50%	51 - 66%	67 - 84%	85 - 99%	100%
Jan 01	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan 08	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan 15	99.93	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Jan 22	99.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Jan 29	99.97	0.03	0.00	0.00	0.00	0.00	0.00	0.00

Feb 05	99.48	0.52	0.00	0.00	0.00	0.00	0.00	0.00
Feb 12	97.43	2.57	0.00	0.00	0.00	0.00	0.00	0.00
Feb 19	96.77	3.23	0.00	0.00	0.00	0.00	0.00	0.00
Feb 26	96.27	3.70	0.03	0.00	0.00	0.00	0.00	0.00
Mar 05	97.49	2.46	0.05	0.00	0.00	0.00	0.00	0.00
Mar 12	94.32	5.38	0.30	0.00	0.00	0.00	0.00	0.00
Mar 19	94.78	4.95	0.27	0.00	0.00	0.00	0.00	0.00
Mar 26	97.46	2.38	0.17	0.00	0.00	0.00	0.00	0.00
Apr 02	95.89	4.11	0.01	0.00	0.00	0.00	0.00	0.00
Apr 09	98.15	1.85	0.00	0.00	0.00	0.00	0.00	0.00
Apr 16	99.18	0.82	0.00	0.00	0.00	0.00	0.00	0.00
Apr 23	99.29	0.71	0.00	0.00	0.00	0.00	0.00	0.00
Apr 30	99.82	0.18	0.00	0.00	0.00	0.00	0.00	0.00
May 07	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 14	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 21	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 28	99.97	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Jun 04	99.96	0.04	0.00	0.00	0.00	0.00	0.00	0.00

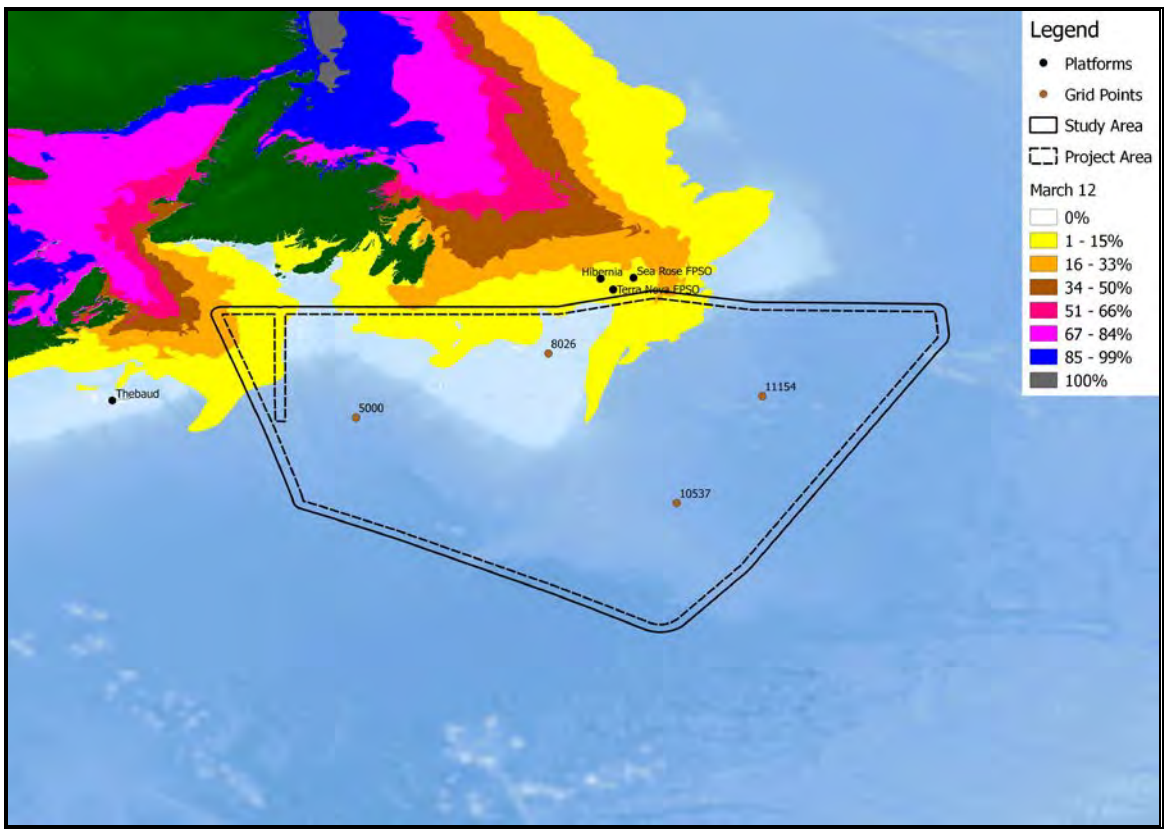


Figure 5.3 30-Year Frequency of Presence of Sea Ice within the Study Area (March 12)

(Source: Canadian Ice Service, 2011)

5.1.4 30-Year Median of Predominant Ice Type when Ice is Present

The predominant ice type within the area from January 15th to the week of February 05th is a mixture of grey and grey-white. By February 12th, thin first-year ice begins to form and is the predominate ice type from February 19 until the week of April, with a small amount of Grey-White and new ice also present. Medium first-year ice begins to appear by the week of March 05, and some thick first-year by the week of March 26. Small amounts of old ice are present within the study area by the week of March 26.

	Open	New Ice	Grey Ice	Grey-White Ice	First-Year Ice	Thin First-Year Ice	Medium First-Year Ice	Thick First-Year Ice	Old Ice
Jan 01	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan 08	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan 15	99.93	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Jan 22	99.50	0.00	0.05	0.45	0.00	0.00	0.00	0.00	0.00
Jan 29	99.97	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Feb 05	99.48	0.29	0.23	0.00	0.00	0.00	0.00	0.00	0.00
Feb 12	97.43	0.25	0.57	1.21	0.00	0.55	0.00	0.00	0.00
Feb 19	96.77	0.27	0.00	0.53	0.00	2.43	0.00	0.00	0.00
Feb 26	96.27	1.26	0.09	1.24	0.00	1.15	0.00	0.00	0.00
Mar 05	97.49	0.07	0.02	0.99	0.00	1.23	0.19	0.00	0.00
Mar 12	94.32	0.45	0.30	1.27	0.00	3.65	0.01	0.00	0.00
Mar 19	94.78	0.26	0.00	0.86	0.00	4.01	0.10	0.00	0.00
Mar 26	97.46	0.02	0.00	0.26	0.00	1.90	0.17	0.07	0.13
Apr 02	95.89	0.07	0.00	0.00	0.00	3.23	0.64	0.18	0.00
Apr 09	98.15	0.00	0.00	0.21	0.00	0.28	1.25	0.11	0.00
Apr 16	99.18	0.00	0.00	0.00	0.00	0.07	0.42	0.33	0.00
Apr 23	99.29	0.00	0.00	0.00	0.00	0.01	0.23	0.47	0.00
Apr 30	99.82	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.09
May 07	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 14	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 21	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May 28	99.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Jun 04	99.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Jun 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jun 18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jun 25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul 02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul 09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul 23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul 30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug 06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug 20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5.2 Icebergs

An analysis was performed to determine the threat posed by icebergs in the study area. The International Ice Patrol Iceberg Sightings Database from 1980-2011 was used as the primary data source in this analysis, (NSIDC, 1995).

Overall there is a good distribution of iceberg sightings ranging from a total of 1288 in 1993 to none in other years (Figure 5.4). Only iceberg sightings that occurred within the study area were considered in this analysis. Duplicate sightings of the same iceberg were also eliminated from the data set so that only the initial sighting was counted.

Figure 5.5 shows the positions of all icebergs within the study area from 1980-2011. Iceberg concentration is concentrated towards the Southern Grand Banks portion of the region. Over the 31 years studied, 15902 icebergs have been sighted within the study area. Environmental factors such as iceberg concentration, ocean currents and wind determine how icebergs drift through the area.

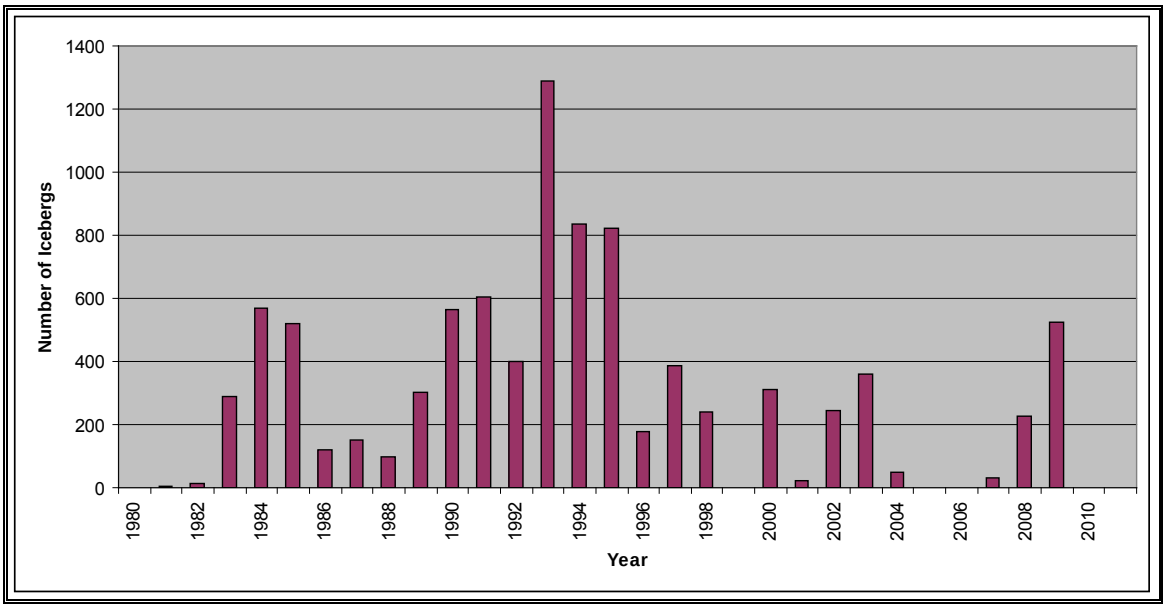


Figure 5.4 Iceberg Sightings within the Study Area (1980 to 2011)

(Source: NSIDC 1995)

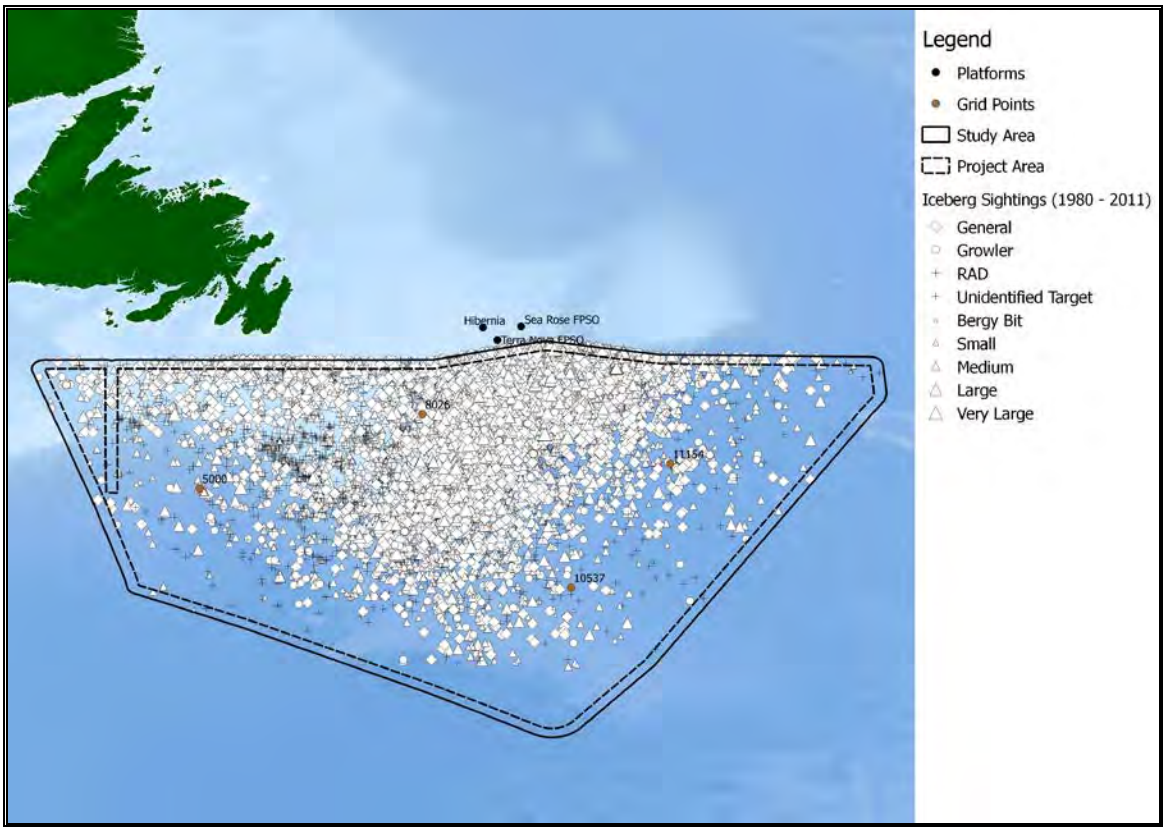


Figure 5.5 Iceberg sightings within the Project Area from 1960 – 2011

(Source: NSIDC 1995)

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APPENDIX 1
Hurricane Data

NHC Cyclone Number	Name	Storm Duration (hours)	Year	Month	Day	Hour	Latitude (°T)	Longitude (°T)	Wind (m/s)	Pressure (mb)	Category
AL041960	CLEO	90	1960	08	21	0000	44.20	-60.50	18.0		Tropical Storm
AL021961	BETSY	246	1961	09	09	1800	37.60	-57.90	46.3	976	Category 2
AL071961	FRANCES	246	1961	10	10	0600	46.00	-59.20	18.0		Post-tropical
AL081961	GERDA	168	1961	10	21	1200	43.40	-61.60	20.6	994	Post-tropical
AL011962	ALMA	180	1962	09	02	1200	42.20	-61.00	7.7		Post-tropical
AL031962	CELIA	240	1962	09	21	1200	38.00	-52.60	12.9		Post-tropical
AL041962	DAISY	246	1962	10	08	1200	44.70	-62.80	28.3		Post-tropical
AL051962	ELLA	216	1962	10	22	0000	39.50	-59.70	33.4		Category 1
AL011963	ARLENE	258	1963	08	10	1200	38.00	-56.10	43.7	985	Category 2
AL021963	BEULAH	204	1963	08	27	0600	36.30	-53.60	38.6		Category 1
AL031963	UNNAMED	126	1963	09	12	1200	37.20	-51.30	25.7		Tropical Storm
AL071963	FLORA	414	1963	10	11	1800	38.30	-56.00	41.2	963	Category 1
AL011964	UNNAMED	228	1964	06	11	1200	39.00	-55.80	18.0		Tropical Storm
AL021964	UNNAMED	156	1964	08	01	1200	37.70	-53.50	23.1		Tropical Storm
AL051964	CLEO	384	1964	09	04	0000	38.70	-56.90	38.6		Category 1
AL061964	DORA	450	1964	09	15	0600	44.60	-61.70	28.3		Post-tropical
AL071964	ETHEL	294	1964	09	14	0000	38.40	-59.40	41.2		Category 1
AL091964	GLADYS	288	1964	09	24	1800	44.70	-60.30	30.9	990	Post-tropical
AL021965	ANNA	132	1965	08	24	1800	41.10	-48.80	41.2		Category 1
AL061965	ELENA	162	1965	10	18	0000	35.80	-50.00	36.0		Category 1
AL021966	BECKY	54	1966	07	02	1200	37.60	-54.40	33.4	985	Category 1
AL031966	CELIA	216	1966	07	21	1200	42.90	-62.00	33.4	998	Category 1
AL041966	DOROTHY	222	1966	07	28	0000	39.20	-40.10	38.6		Category 1
AL061966	FAITH	414	1966	09	03	0600	37.50	-57.00	46.3	950	Category 2
AL111967	ARLENE	174	1967	09	03	1800	43.30	-52.00	38.6		Category 1
AL121967	CHLOE	408	1967	09	16	1200	37.80	-57.80	41.2		Category 1
AL251967	HEIDI	324	1967	10	26	0000	35.30	-46.90	41.2		Category 1
AL021968	BRENDA	222	1968	06	25	0600	36.20	-51.50	30.9		Tropical Storm
AL051968	DOLLY	174	1968	08	14	1200	39.80	-51.30	36.0	992	Category 1
AL091968	UNNAMED	228	1968	09	20	1800	37.60	-46.50	36.0		Category 1
AL141968	GLADYS	204	1968	10	21	1200	43.90	-62.90	33.4	975	Post-tropical
AL061969	ANNA	276	1969	08	04	0600	42.00	-57.50	23.1		Post-tropical
AL071969	BLANCHE	60	1969	08	12	1200	44.30	-60.40	33.4	998	Category 1
AL081969	DEBBIE	270	1969	08	23	1200	39.20	-54.80	48.9		Category 2
AL091969	CAMILLE	192	1969	08	22	0600	40.80	-58.20	28.3		Tropical Storm
AL211969	UNNAMED	114	1969	09	25	1200	42.00	-60.00	33.4	985	Category 1
AL221969	UNNAMED	138	1969	09	29	0600	42.80	-39.50	30.9		Tropical Storm
AL251969	KARA	288	1969	10	18	0000	43.30	-50.80	46.3		Category 2
AL281969	UNNAMED	186	1969	11	01	0000	38.50	-52.00	30.9		Tropical Storm
AL031970	UNNAMED	132	1970	08	01	0000	37.50	-57.30	12.9		Tropical Depression
AL081970	UNNAMED	90	1970	08	18	1800	42.50	-58.50	30.9	992	Tropical Storm
AL171970	UNNAMED	54	1970	10	01	0000	37.00	-55.50	12.9		Tropical Depression
AL181970	UNNAMED	138	1970	10	17	1800	42.50	-57.50	36.0	980	Category 1
AL011971	ARLENE	90	1971	07	07	0600	43.10	-59.50	23.1	1002	Tropical Storm

AL041971	UNNAMED	102	1971	08	06	1200	46.00	-49.00	38.6	974	Category 1
AL061971	BETH	174	1971	08	16	1200	44.00	-62.50	33.4	984	Category 1
AL051972	UNNAMED	108	1972	07	17	1200	38.50	-41.00	12.9		Tropical Depression
AL101972	BETTY	252	1972	08	28	0000	40.50	-42.60	46.3	976	Category 2
AL141972	CHARLIE	66	1972	09	21	0600	46.00	-40.00	30.9	992	Post-tropical
AL161972	UNNAMED	54	1972	10	03	0000	37.00	-52.50	12.9		Tropical Depression
AL041973	ALICE	132	1973	07	06	0600	42.50	-61.60	30.9		Tropical Storm
AL121973	ELLEN	222	1973	09	22	1200	42.10	-45.20	51.4		Category 3
AL161973	GILDA	336	1973	10	27	1200	41.20	-60.80	28.3		Tropical Storm
AL041974	UNNAMED	114	1974	07	18	1200	39.00	-58.40	23.1	1006	Tropical Storm
AL091974	BECKY	168	1974	08	31	0000	39.30	-59.20	51.4		Category 3
AL121974	DOLLY	72	1974	09	05	1200	44.20	-60.30	18.0	1004	Post-tropical
AL131974	ELAINE	228	1974	09	13	0000	39.60	-58.30	23.1		Tropical Storm
AL011975	UNNAMED	126	1975	06	29	0000	37.80	-56.20	12.9		Tropical Depression
AL021975	AMY	186	1975	07	03	1200	39.30	-59.60	28.3	986	Tropical Storm
AL081975	DORIS	174	1975	09	02	0600	36.40	-44.50	48.9	965	Category 2
AL121975	UNNAMED	84	1975	09	14	0000	37.50	-55.20	15.4		Tropical Depression
AL141975	FAYE	276	1975	09	28	0600	39.80	-60.50	41.2	985	Category 1
AL151975	GLADYS	276	1975	10	03	0600	43.70	-57.00	43.7	960	Category 2
AL231975	UNNAMED	102	1975	12	10	1200	38.30	-43.40	30.9	992	Tropical Storm
AL091976	CANDICE	150	1976	08	22	1800	41.30	-56.40	41.2	964	Category 1
AL171976	GLORIA	210	1976	10	01	1800	36.10	-52.60	38.6	992	Category 1
AL211976	HOLLY	156	1976	10	27	1800	35.60	-48.00	20.6		Tropical Storm
AL071977	CLARA	162	1977	09	12	0000	40.50	-57.50	23.1	1001	Post-tropical
AL101977	DOROTHY	90	1977	09	29	0000	38.30	-57.00	38.6	980	Category 1
AL131977	EVELYN	60	1977	10	15	0600	42.40	-61.50	36.0	996	Category 1
AL101978	ELLA	162	1978	09	04	1800	42.50	-59.50	59.2	956	Category 4
AL151978	HOPE	234	1978	09	18	1800	39.10	-43.00	28.3	990	Tropical Storm
AL231978	KENDRA	144	1978	11	02	0000	40.50	-55.50	20.6		Post-tropical
AL031979	UNNAMED	126	1979	07	13	1200	40.20	-55.20	10.3		Tropical Depression
AL081979	UNNAMED	150	1979	08	05	1800	46.00	-60.00	12.9		Tropical Depression
AL161979	UNNAMED	126	1979	09	20	1200	35.90	-50.40	12.9		Tropical Depression
AL181979	UNNAMED	54	1979	10	25	0000	43.50	-61.00	30.9	980	Tropical Storm
AL061980	BONNIE	144	1980	08	19	0600	41.90	-39.80	33.4	990	Category 1
AL071980	CHARLEY	132	1980	08	24	1800	37.90	-58.20	23.1	1000	Tropical Storm
AL091980	GEORGES	192	1980	09	08	0000	40.20	-59.00	36.0	993	Category 1
AL101980	EARL	162	1980	09	09	0600	36.30	-43.80	33.4	990	Category 1
AL121980	FRANCES	366	1980	09	17	1200	34.70	-46.40	41.2	970	Category 1
AL181980	KARL	78	1980	11	26	0600	37.00	-44.20	38.6	985	Category 1
AL091981	CINDY	72	1981	08	04	1200	40.40	-60.70	25.7	1003	Tropical Storm
AL131981	EMILY	282	1981	09	05	1800	39.40	-59.90	41.2	966	Category 1
AL151981	GERT	216	1981	09	13	1800	37.70	-53.20	23.1	1010	Tropical Storm
AL161981	HARVEY	204	1981	09	17	1200	36.20	-52.70	33.4	993	Category 1
AL181981	IRENE	288	1981	09	30	0000	35.90	-47.50	43.7	976	Category 2
AL021982	UNNAMED	72	1982	06	20	1200	44.50	-60.00	30.9	984	Tropical Storm
AL061982	DEBBY	180	1982	09	18	0600	40.10	-60.70	56.6	952	Category 3
AL051983	CHANTAL	120	1983	09	13	1800	36.30	-53.90	20.6	1005	Tropical Storm

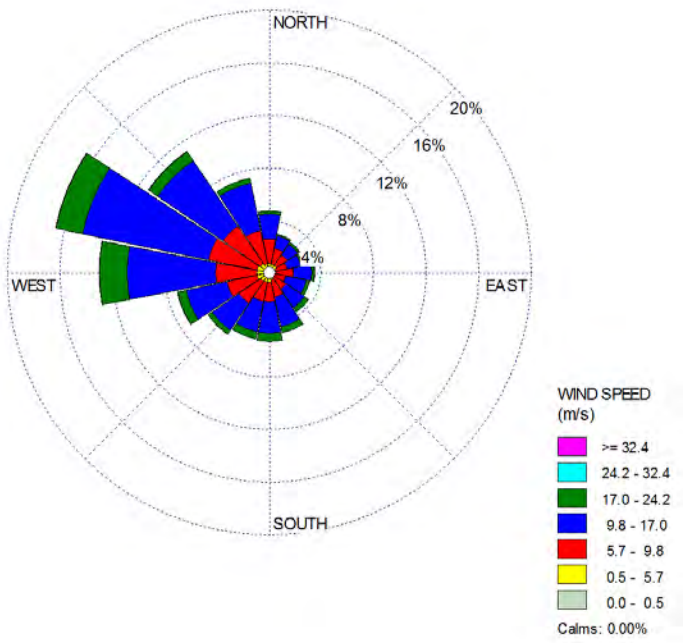
AL051984	UNNAMED	84	1984	08	20	1200	43.70	-48.30	25.7	1001	Tropical Storm
AL081984	CESAR	72	1984	09	02	1200	46.00	-50.40	25.7	994	Tropical Storm
AL101984	DIANA	192	1984	09	16	0000	43.50	-61.90	30.9	994	Tropical Storm
AL141984	HORTENSE	240	1984	10	01	1200	40.00	-54.00	25.7	998	Tropical Storm
AL161984	JOSEPHINE	336	1984	10	16	1200	39.90	-59.70	33.4	982	Category 1
AL181984	KLAUS	198	1984	11	13	0000	36.50	-52.80	30.9	986	Tropical Storm
AL011985	ANA	96	1985	07	19	0000	44.20	-60.30	30.9	996	Tropical Storm
AL051986	CHARLEY	402	1986	08	21	1800	41.30	-51.20	23.1	991	Post-tropical
AL091986	EARL	228	1986	09	18	0600	36.00	-49.60	33.4	988	Category 1
AL021987	ARLENE	486	1987	08	22	0600	36.50	-43.00	33.4	988	Category 1
AL121987	EMILY	168	1987	09	26	0000	38.00	-55.00	38.6	976	Category 1
AL031988	CHRIS	228	1988	08	30	1800	46.50	-60.00	12.9	1008	Tropical Depression
AL091988	HELENE	264	1988	09	29	0000	36.10	-48.50	46.3	970	Category 2
AL121988	KEITH	222	1988	11	26	0000	48.00	-43.00	33.4	950	Post-tropical
AL051989	DEAN	222	1989	08	08	0600	44.10	-59.70	33.4	978	Category 1
AL081989	FELIX	378	1989	09	05	1800	36.70	-48.30	38.6	979	Category 1
AL101989	GABRIELLE	342	1989	09	09	1800	38.90	-60.10	33.4	990	Category 1
AL031990	BERTHA	222	1990	08	02	0000	44.20	-60.50	36.0	973	Category 1
AL081990	GUSTAV	246	1990	09	01	1200	36.80	-53.20	43.7	970	Category 2
AL101990	ISIDORE	330	1990	09	13	1800	35.40	-50.60	33.4	987	Category 1
AL121990	JOSEPHINE	372	1990	10	06	0600	38.90	-40.00	36.0	985	Category 1
AL141990	LILI	228	1990	10	06	1200	35.70	-44.10	25.7	999	Tropical Storm
AL011991	ANA	150	1991	07	05	0000	38.00	-57.50	23.1	1001	Tropical Storm
AL121991	UNNAMED	126	1991	10	30	0000	39.00	-59.50	28.3	981	Post-tropical
AL051992	BONNIE	366	1992	09	21	1800	37.50	-52.30	48.9	965	Category 2
AL101992	FRANCES	186	1992	10	25	1200	37.70	-53.70	33.4	982	Category 1
AL051993	EMILY	366	1993	09	03	0000	38.60	-59.60	41.2	975	Category 1
AL071993	FLOYD	138	1993	09	09	1800	41.70	-58.30	33.4	990	Category 1
AL091993	HARVEY	78	1993	09	21	0000	37.80	-52.50	30.9	992	Tropical Storm
AL041994	CHRIS	180	1994	08	23	1200	42.20	-55.50	23.1	1003	Tropical Storm
AL111994	FLORENCE	168	1994	11	08	0000	37.00	-49.90	48.9	972	Category 2
AL011995	ALLISON	210	1995	06	08	1800	45.20	-61.20	23.1	993	Post-tropical
AL021995	BARRY	144	1995	07	09	1800	44.30	-61.70	25.7	991	Tropical Storm
AL031995	CHANTAL	246	1995	07	20	0000	39.50	-57.60	25.7	999	Tropical Storm
AL071995	FELIX	414	1995	08	22	0000	42.50	-59.80	25.7	987	Tropical Storm
AL091995	HUMBERTO	246	1995	08	30	1800	35.20	-44.00	41.2	971	Category 1
AL101995	IRIS	396	1995	09	03	1800	39.20	-55.50	36.0	985	Category 1
AL131995	LUIS	396	1995	09	10	1800	40.90	-60.90	41.2	966	Category 1
AL151995	MARILYN	474	1995	09	21	1200	39.40	-60.60	33.4	987	Category 1
AL011996	ARTHUR	132	1996	06	21	1800	37.80	-56.20	23.1	1000	Post-tropical
AL021996	BERTHA	306	1996	07	14	1800	47.00	-62.00	25.7	995	Post-tropical
AL051996	EDOUARD	438	1996	09	04	0000	43.20	-59.80	25.7	997	Post-tropical
AL081996	HORTENSE	318	1996	09	15	0300	44.80	-62.50	36.0	978	Category 1
AL101996	JOSEPHINE	282	1996	10	10	0000	46.50	-62.50	23.1	985	Post-tropical
AL021997	ANA	114	1997	07	04	1800	39.50	-59.50	12.9	1004	Post-tropical
AL031997	BILL	60	1997	07	12	1500	38.80	-60.00	33.4	986	Category 1
AL051997	DANNY	270	1997	07	27	0000	41.70	-60.40	20.6	1004	Post-tropical

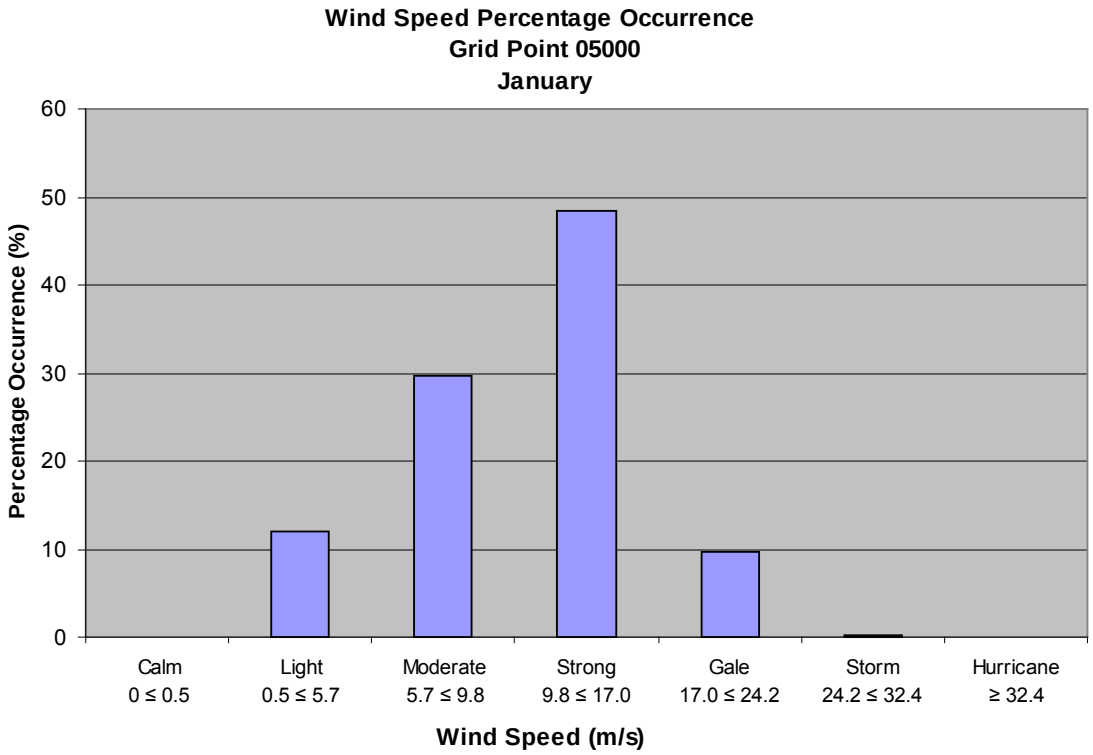
AL071997	ERIKA	402	1997	09	11	1200	36.40	-53.60	36.0	984	Category 1
AL021998	BONNIE	288	1998	08	30	0000	42.90	-61.50	23.1	1000	Tropical Storm
AL041998	DANIELLE	366	1998	09	03	0000	39.90	-60.10	36.0	970	Category 1
AL051998	EARL	198	1998	09	06	1200	49.00	-52.00	28.3	964	Post-tropical
AL121998	LISA	126	1998	10	09	1200	41.60	-38.70	33.4	995	Category 1
AL131998	MITCH	456	1998	11	07	1800	44.50	-42.00	30.9	972	Post-tropical
AL041999	CINDY	306	1999	08	31	0000	37.00	-52.60	36.0	984	Category 1
AL081999	FLOYD	288	1999	09	19	1200	49.50	-48.00	20.6	992	Post-tropical
AL091999	GERT	294	1999	09	22	1800	40.30	-57.90	33.4	963	Category 1
AL131999	IRENE	186	1999	10	19	0000	41.50	-61.00	41.2	968	Category 1
AL141999	JOSE	192	1999	10	25	0600	37.90	-55.80	28.3	994	Tropical Storm
AL032000	ALBERTO	522	2000	08	12	1800	36.80	-53.80	56.6	954	Category 3
AL102000	FLORENCE	174	2000	09	17	0600	40.10	-57.40	28.3	995	Tropical Storm
AL122000	HELENE	252	2000	09	25	1200	44.00	-55.50	28.3	988	Tropical Storm
AL132000	ISAAC	312	2000	09	30	1200	37.00	-51.80	38.6	979	Category 1
AL162000	LESLIE	156	2000	10	08	0600	43.00	-60.00	20.6	1003	Post-tropical
AL172000	MICHAEL	132	2000	10	19	1800	44.00	-58.50	43.7	965	Category 2
AL182000	NADINE	78	2000	10	22	0000	35.70	-50.50	20.6	1004	Post-tropical
AL192000	UNNAMED	114	2000	10	29	0600	44.00	-60.00	25.7	980	Post-tropical
AL052001	DEAN	174	2001	08	27	1800	40.60	-59.40	30.9	994	Tropical Storm
AL062001	ERIN	372	2001	09	13	1800	39.60	-60.20	36.0	982	Category 1
AL082001	GABRIELLE	246	2001	09	18	1800	40.20	-58.90	30.9	980	Tropical Storm
AL102001	HUMBERTO	156	2001	09	26	1200	41.00	-59.20	46.3	970	Category 2
AL162001	NOEL	72	2001	11	05	1200	37.80	-50.30	33.4	986	Category 1
AL012002	ARTHUR	120	2002	07	16	1200	40.50	-57.90	25.7	998	Tropical Storm
AL082002	GUSTAV	180	2002	09	12	0400	45.30	-60.80	41.2	960	Category 1
AL112002	JOSEPHINE	54	2002	09	19	1200	41.50	-43.30	25.7	1004	Post-tropical
AL052003	DANNY	264	2003	07	18	1800	39.20	-53.40	33.4	1002	Category 1
AL102003	FABIAN	318	2003	09	07	0000	37.90	-58.20	46.3	962	Category 2
AL162003	KATE	348	2003	10	06	1800	36.90	-55.00	36.0	983	Category 1
AL012004	ALEX	150	2004	08	05	1200	40.80	-59.60	51.4	962	Category 3
AL072004	GASTON	168	2004	09	01	1200	43.00	-59.60	23.1	999	Post-tropical
AL122004	KARL	288	2004	09	24	0000	36.80	-41.90	41.2	957	Category 1
AL132004	LISA	330	2004	10	02	0600	40.30	-41.60	33.4	987	Category 1
AL062005	FRANKLIN	228	2005	07	29	1800	42.20	-60.20	25.7	999	Tropical Storm
AL082005	HARVEY	276	2005	08	09	0600	41.80	-43.00	25.7	995	Post-tropical
AL092005	IRENE	336	2005	08	17	1800	37.60	-57.30	33.4	987	Category 1
AL142005	MARIA	306	2005	09	07	1200	35.60	-51.80	38.6	980	Category 1
AL162005	OPHELIA	414	2005	09	18	0600	44.80	-62.60	23.1	1000	Post-tropical
AL252005	WILMA	288	2005	10	26	0000	42.50	-60.00	30.9	978	Post-tropical
AL012006	ALBERTO	228	2006	06	16	0000	44.00	-62.00	28.3	969	Post-tropical
AL022006	UNNAMED	78	2006	07	18	0000	42.40	-62.10	20.6	999	Tropical Storm
AL032006	BERYL	108	2006	07	22	0000	45.50	-63.30	18.0	1002	Post-tropical
AL072006	FLORENCE	372	2006	09	13	0000	40.60	-57.90	36.0	978	Post-tropical
AL082006	GORDON	342	2006	09	18	1800	37.50	-46.30	43.7	972	Category 2
AL092006	HELENE	372	2006	09	23	0600	36.40	-49.60	41.2	962	Category 1
AL102006	ISAAC	144	2006	10	02	0600	39.80	-58.00	33.4	989	Category 1

AL032007	CHANTAL	138	2007	08	01	1800	49.00	-49.50	30.9	988	Post-tropical
AL112007	JERRY	48	2007	09	23	0600	36.20	-46.10	18.0	1007	Tropical Storm
AL022008	BERTHA	444	2008	07	18	1800	36.90	-51.50	33.4	989	Category 1
AL032008	CRISTOBAL	108	2008	07	23	0000	43.30	-60.70	23.1	1001	Tropical Storm
AL082008	HANNA	294	2008	09	07	1800	45.70	-63.70	23.1	995	Post-tropical
AL122008	LAURA	204	2008	09	28	1200	37.00	-42.50	25.7	995	Post-tropical
AL152008	OMAR	192	2008	10	19	0600	34.50	-49.00	15.4	1009	Tropical Depression
AL012009	ONE	90	2009	05	30	0000	40.60	-61.00	12.9	1007	Tropical Depression
AL032009	BILL	276	2009	08	23	1800	44.40	-62.50	33.4	970	Category 1
AL092009	GRACE	222	2009	09	27	1800	46.00	-43.20	28.3	995	Post-tropical
AL062010	DANIELLE	306	2010	08	29	1800	37.30	-55.00	38.6	968	Category 1
AL112010	IGOR	366	2010	09	21	1500	46.60	-53.20	38.6	950	Category 1
AL212010	TOMAS	324	2010	11	10	1200	39.00	-53.50	18.0	995	Post-tropical
AL022011	BRET	174	2011	07	23	0000	39.20	-60.10	12.9	1010	Tropical Depression
AL032011	CINDY	78	2011	07	21	1800	41.30	-46.10	30.9	994	Tropical Storm
AL062011	FRANKLIN	90	2011	08	13	1200	38.60	-59.00	20.6	1004	Tropical Storm
AL072011	GERT	114	2011	08	16	1800	38.60	-55.80	20.6	1008	Tropical Storm
AL122011	KATIA	384	2011	09	10	0000	41.00	-60.50	38.6	958	Category 1
AL202011	UNNAMED	84	2011	09	03	0000	40.00	-60.70	15.4	1004	Post-tropical
AL142011	MARIA	252	2011	09	16	1200	42.90	-58.20	33.4	983	Category 1
AL162011	OPHELIA	354	2011	10	02	1800	40.10	-60.80	46.3	960	Category 2
AL192011	SEAN	168	2011	11	12	0600	38.00	-57.20	18.0	1000	Post-tropical
AL022012	BERYL	198	2012	06	01	1200	39.40	-59.80	18.0	1001	Post-tropical
AL032012	CHRIS	186	2012	06	21	1200	40.50	-43.90	38.6	974	Category 1
AL112012	KIRK	132	2012	09	01	0600	34.60	-48.90	33.4	990	Category 1
AL122012	LESLIE	360	2012	09	11	0000	41.10	-58.60	33.4	970	Category 1
AL132012	MICHAEL	252	2012	09	11	0000	34.80	-47.80	30.9	991	Tropical Storm
AL172012	RAFAEL	336	2012	10	17	1800	38.80	-58.00	33.4	972	Post-tropical

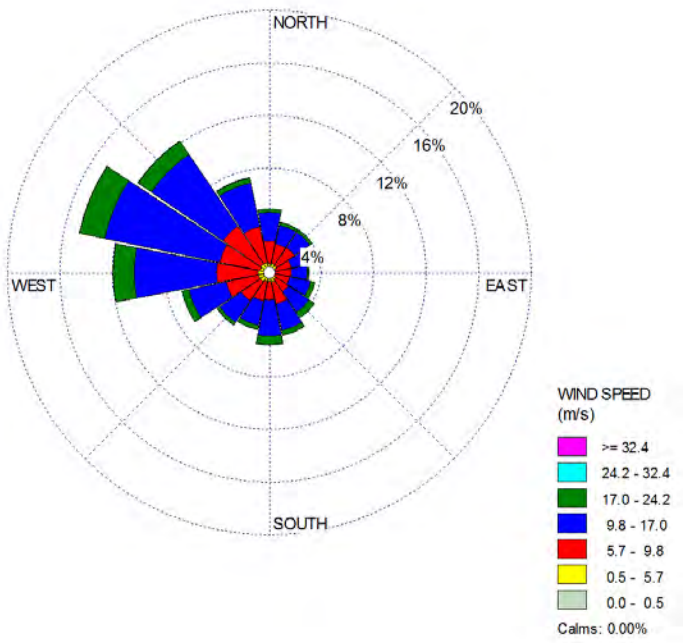
Appendix 2
Wind Roses
and
Wind Speed Frequency Distributions
for MSC50 Grid Point 05000

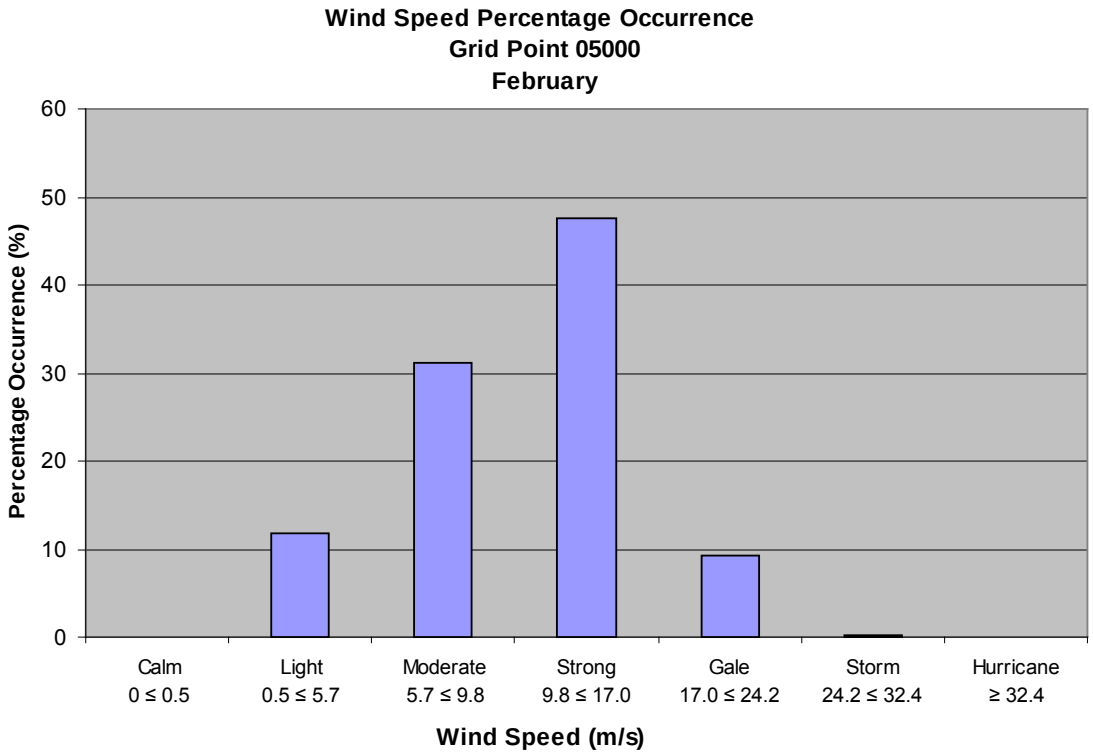
January


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

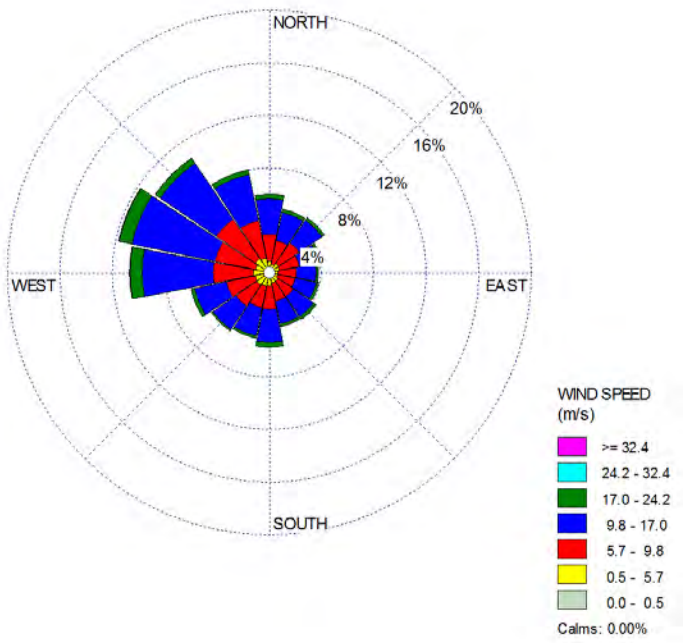

Wind Speed Percentage Occurrence
Grid Point 05000
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

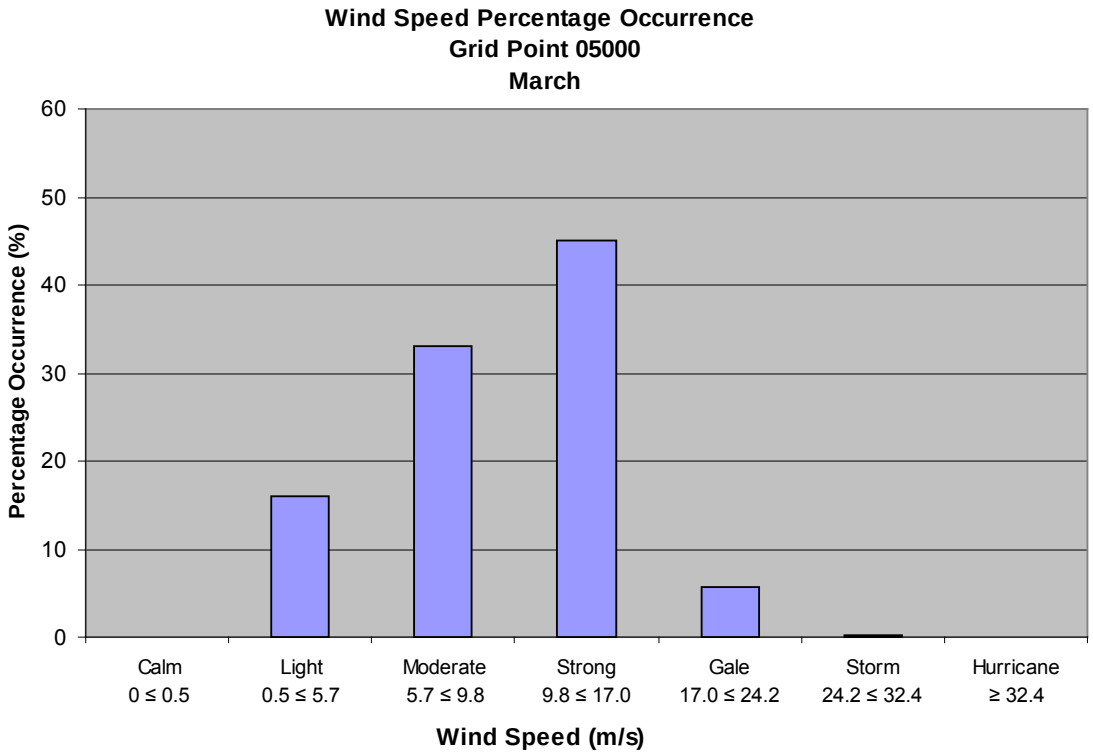
February


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

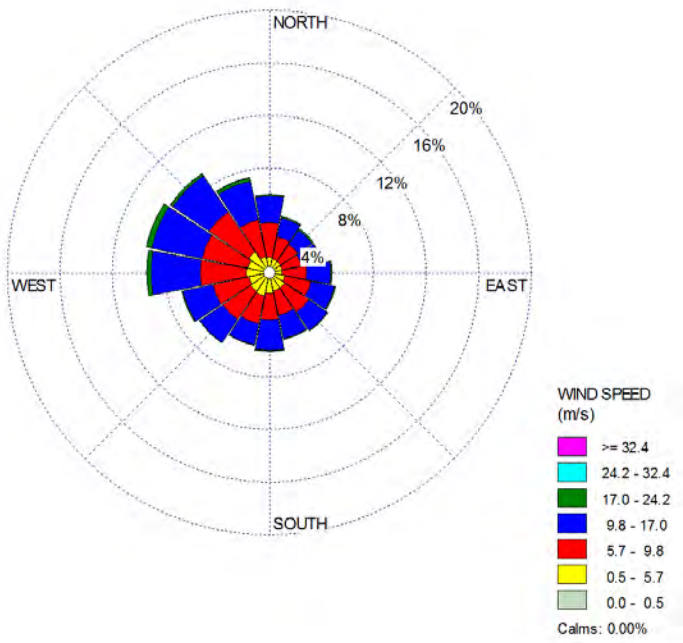

Wind Speed Percentage Occurrence
Grid Point 05000
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

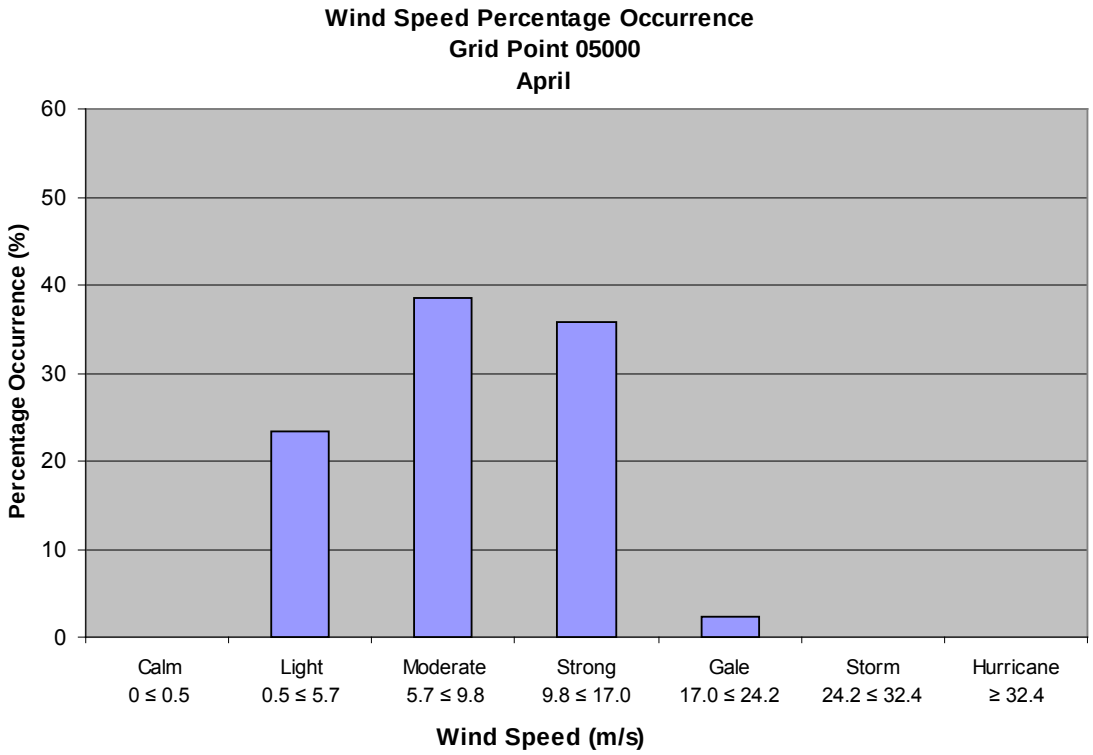
March


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

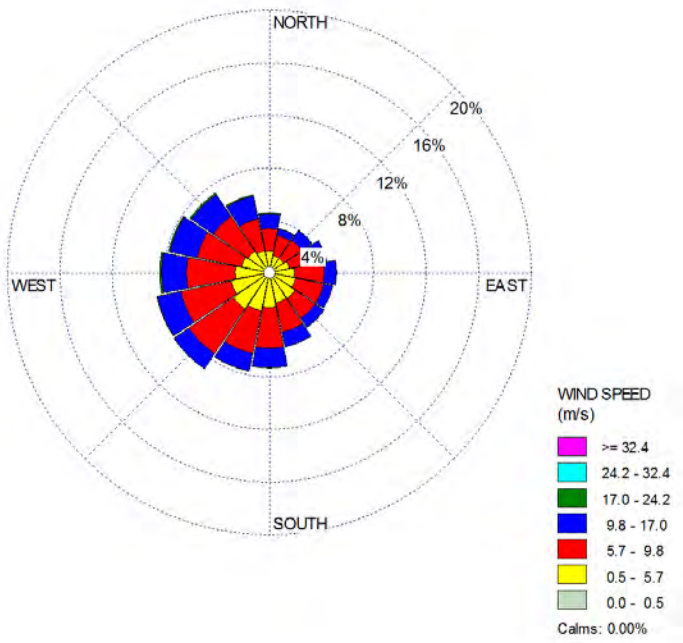

Wind Speed Percentage Occurrence
Grid Point 05000
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

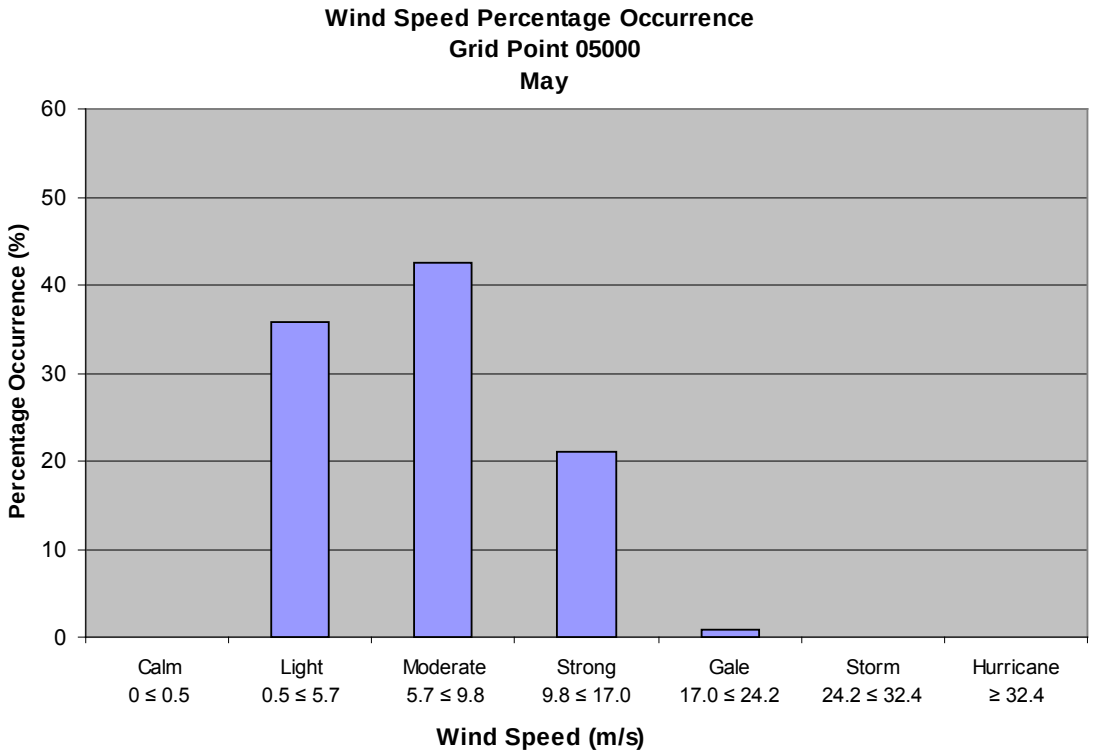
April


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

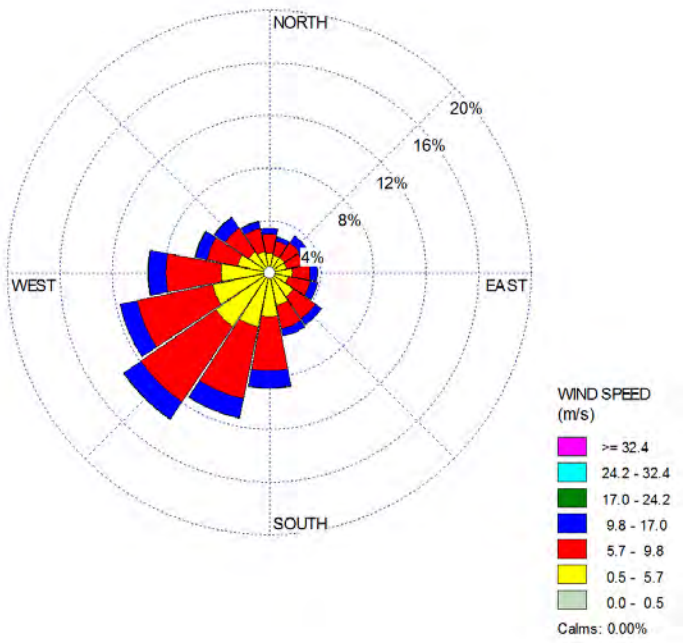

Wind Speed Percentage Occurrence
Grid Point 05000
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

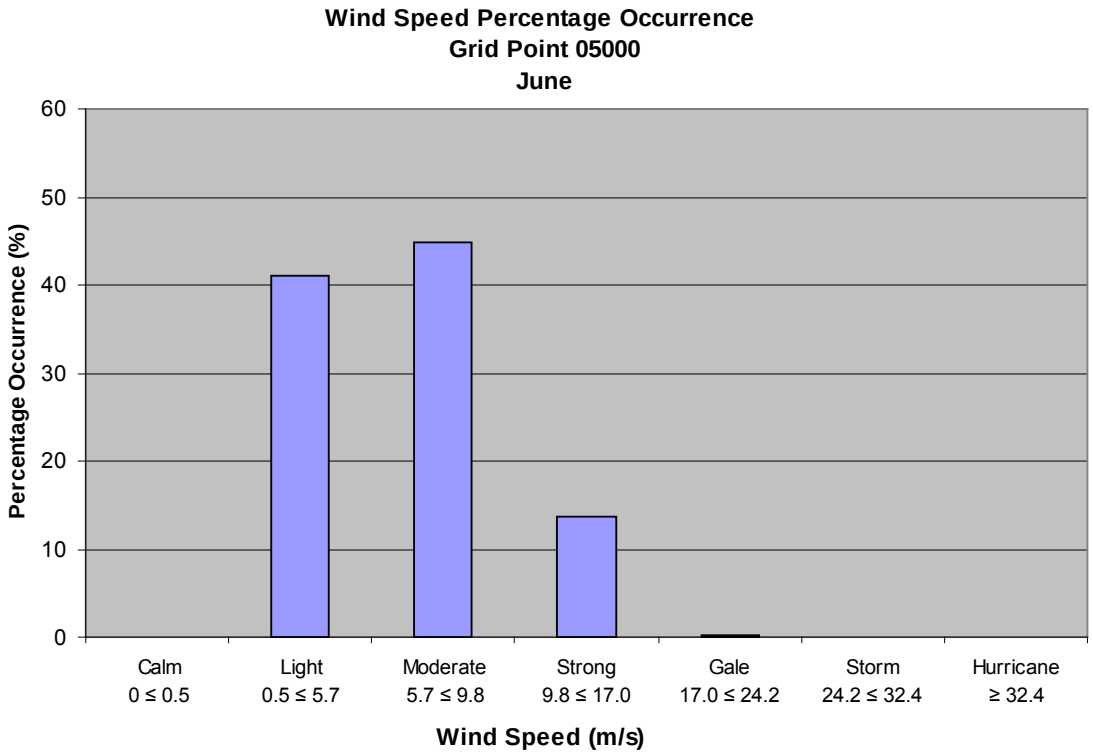
May


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

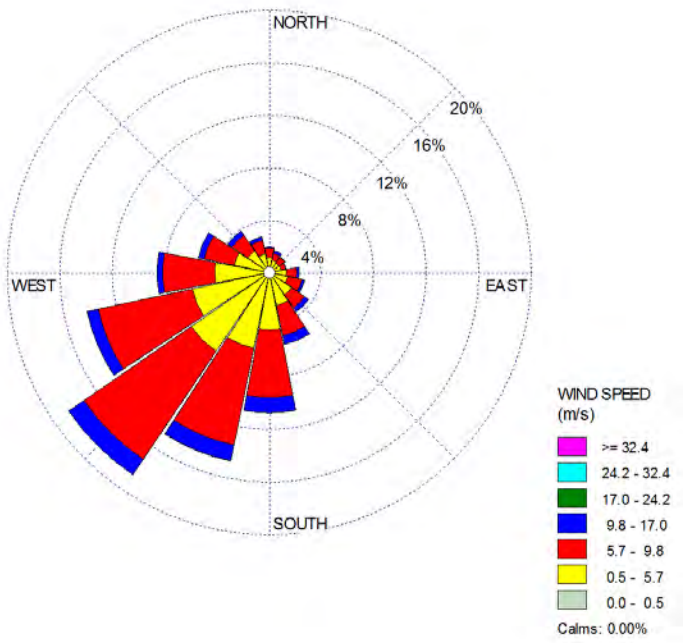

Wind Speed Percentage Occurrence
Grid Point 05000
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

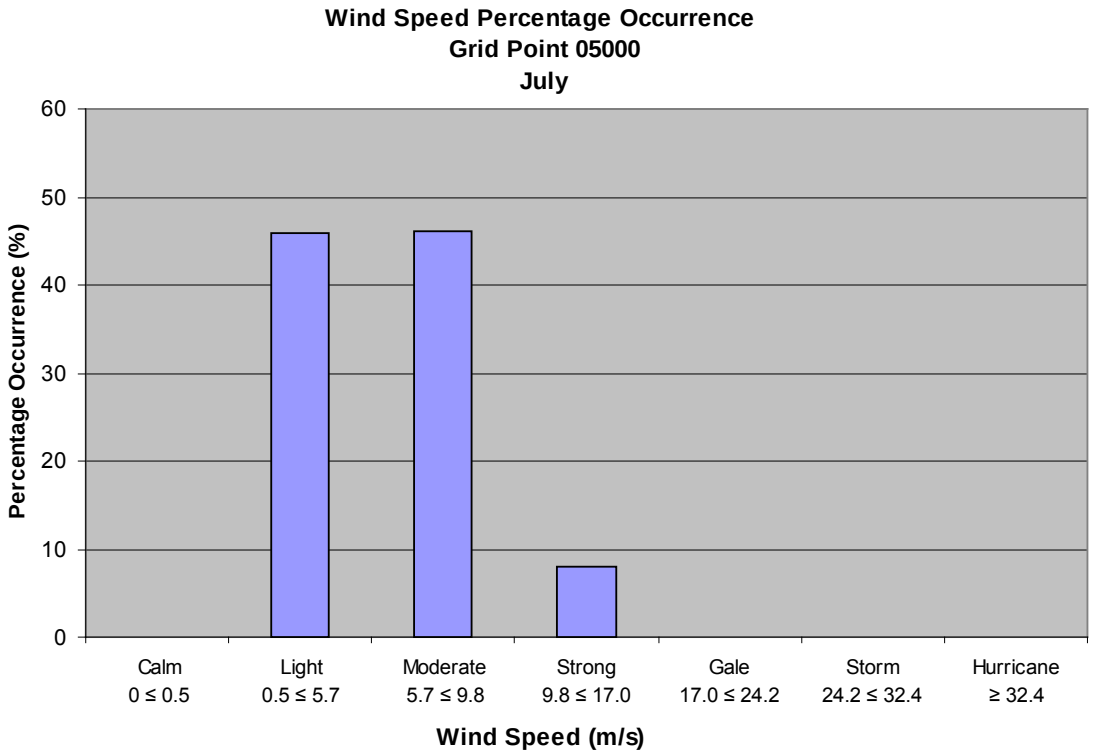
June


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

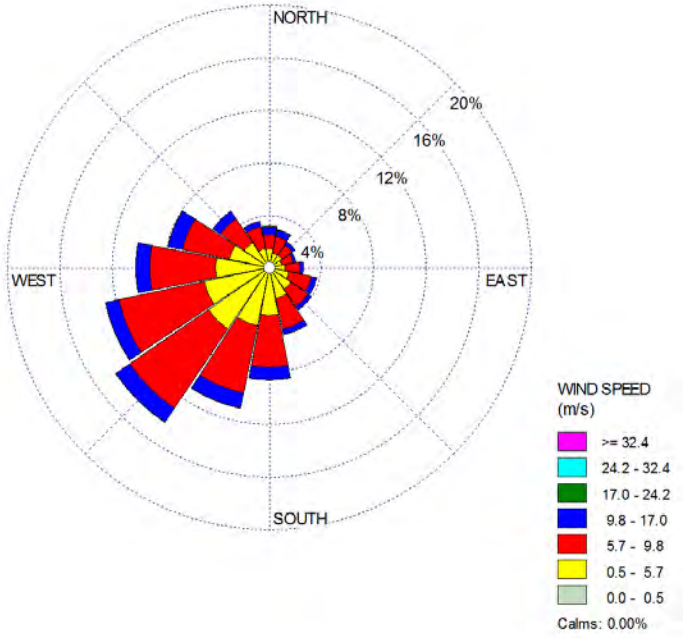

Wind Speed Percentage Occurrence
Grid Point 05000
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

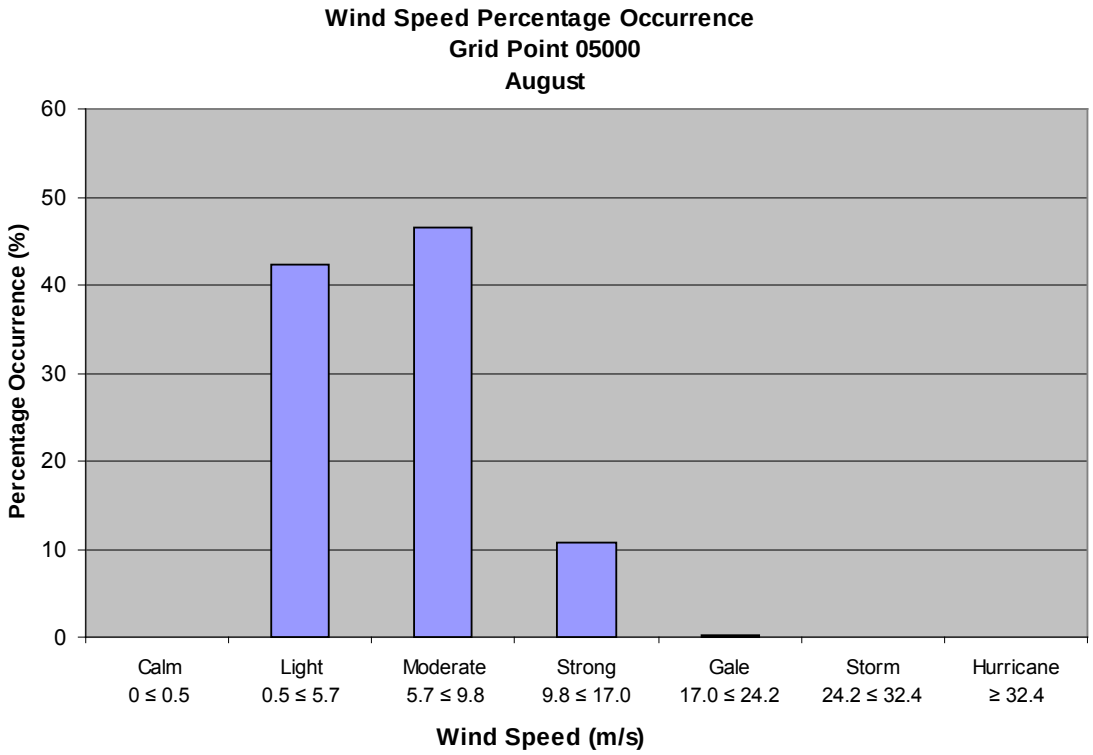
July


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

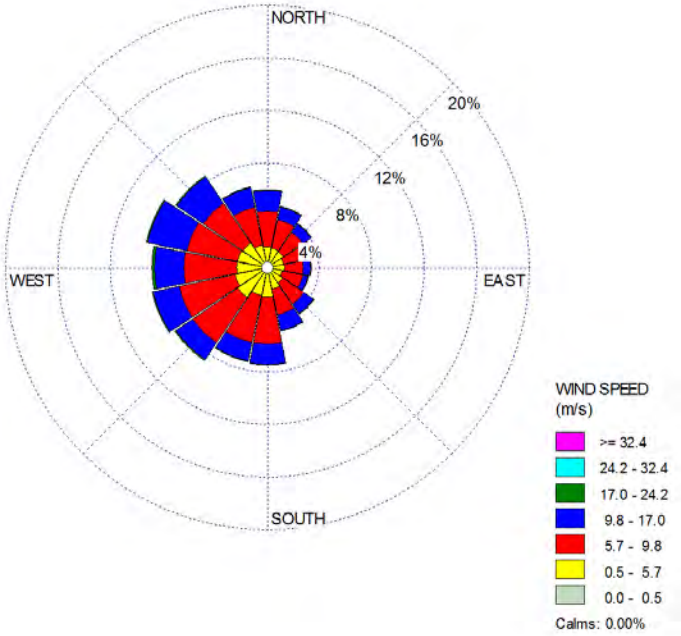

Wind Speed Percentage Occurrence
Grid Point 05000
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

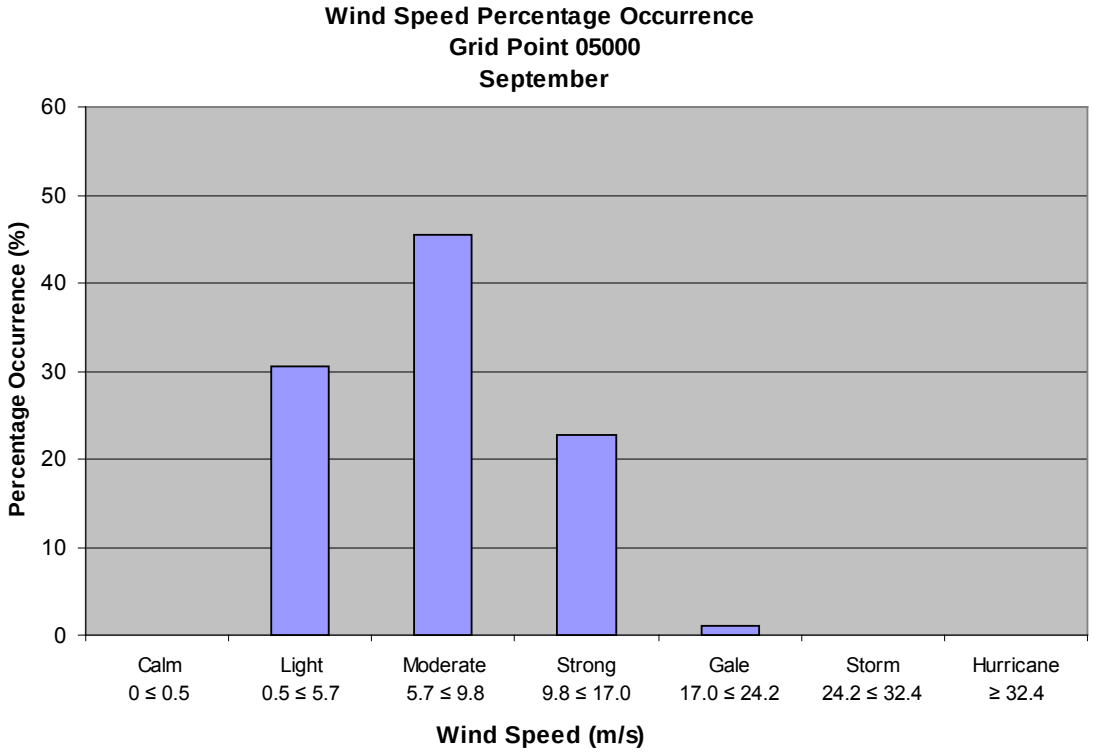
August


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

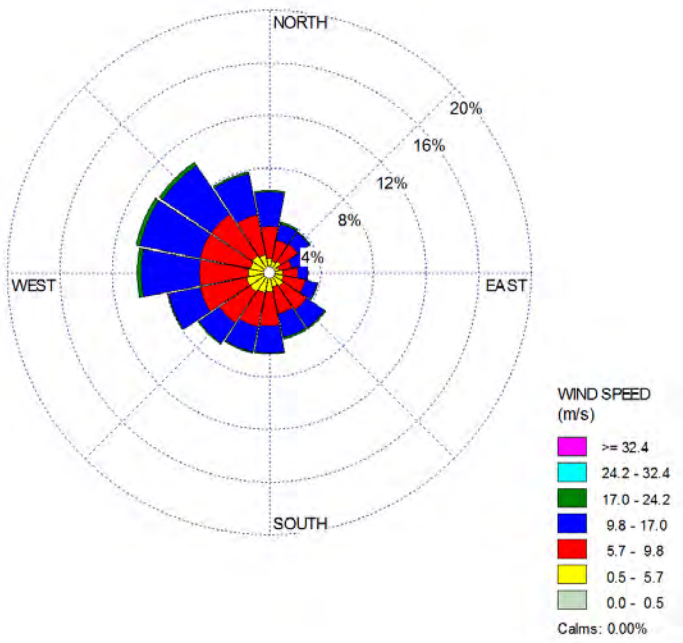

Wind Speed Percentage Occurrence
Grid Point 05000
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

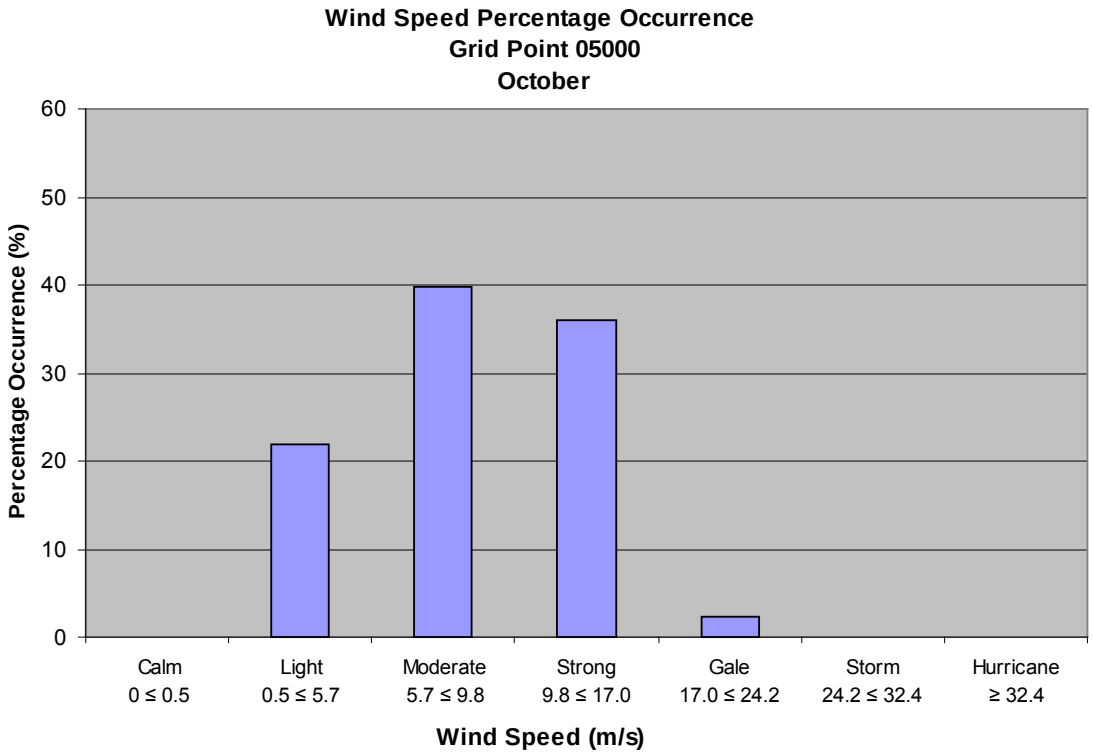
September


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

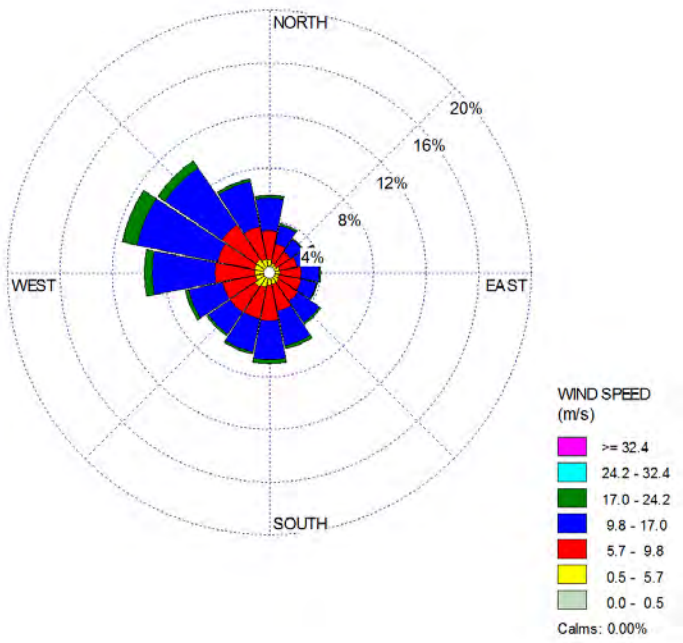

Wind Speed Percentage Occurrence
Grid Point 05000
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

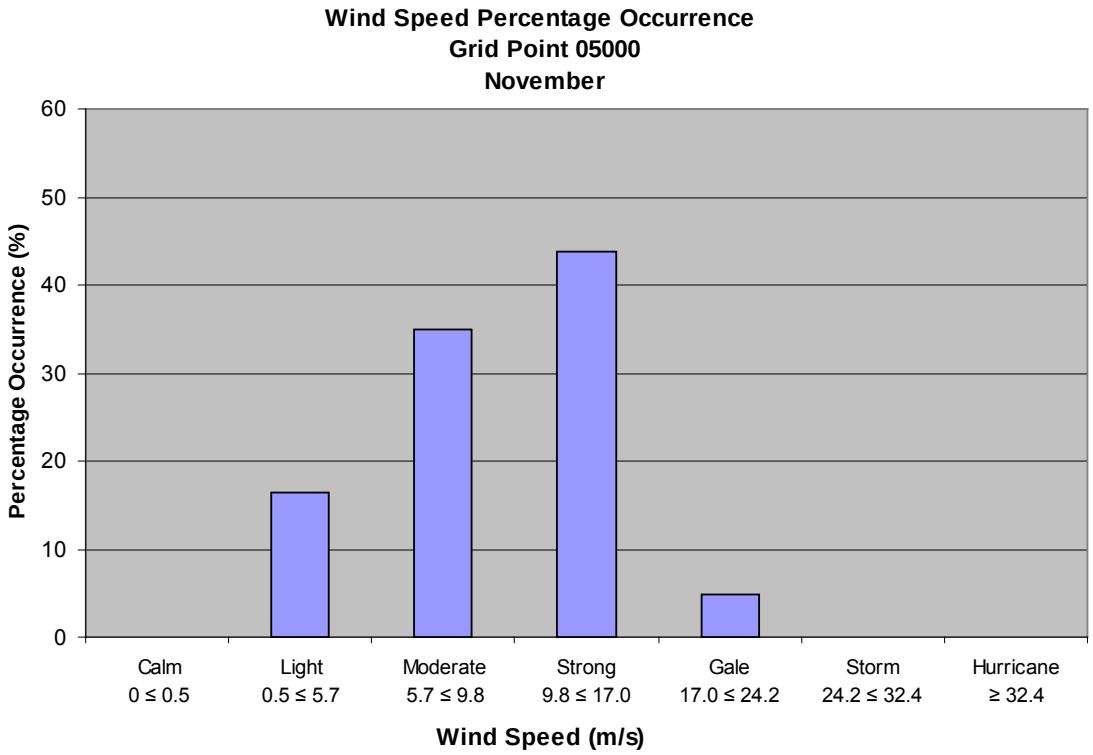
October


NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

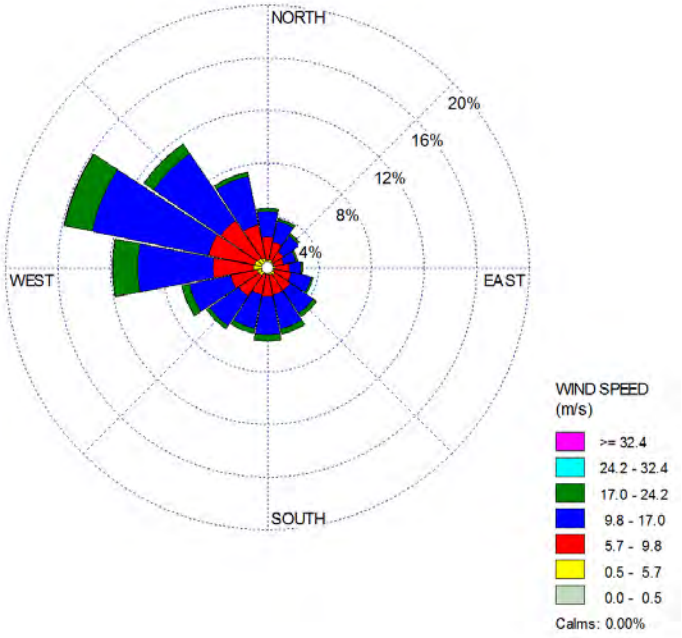

Wind Speed Percentage Occurrence
Grid Point 05000
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

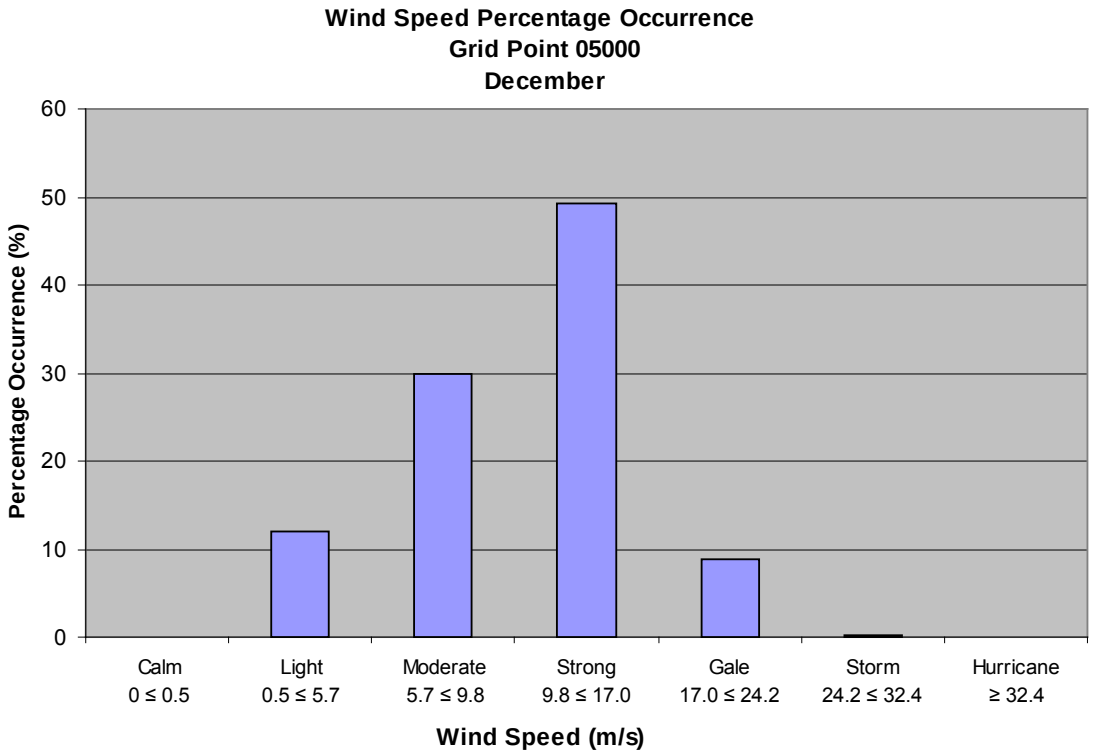
November


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 05000
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

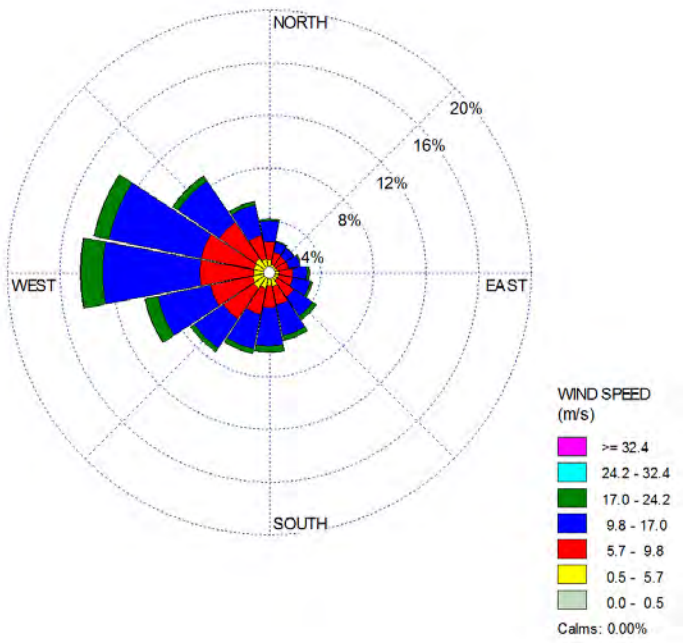
December

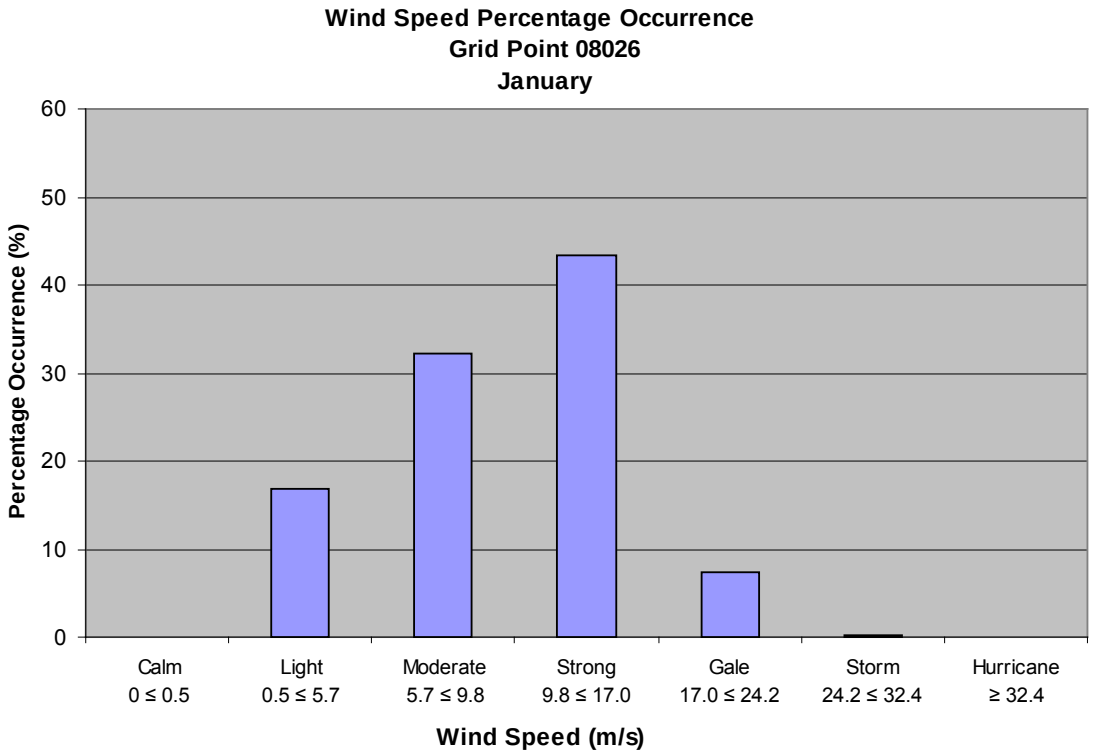

NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 05000
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

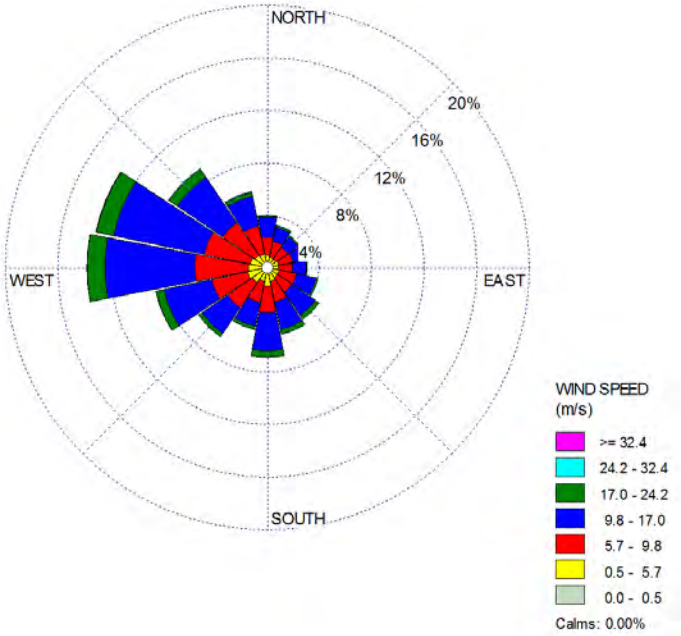
Appendix 3
Wind Roses
and
Wind Speed Frequency Distributions
for MSC50 Grid Point 08026

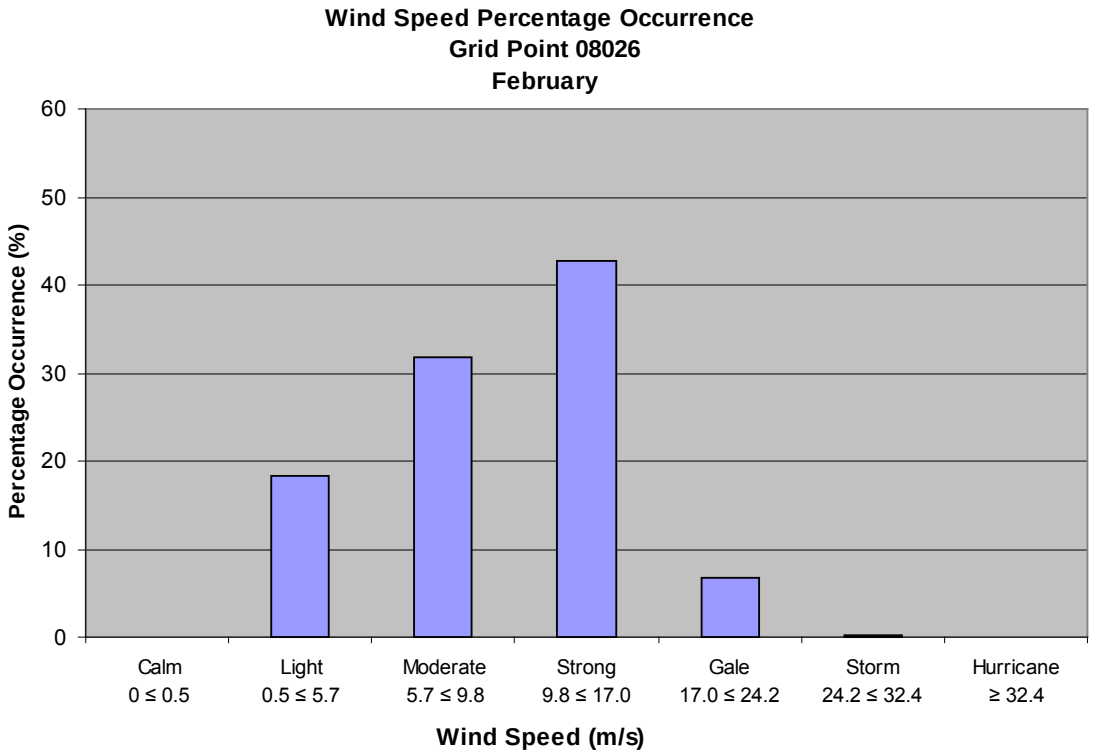
January


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

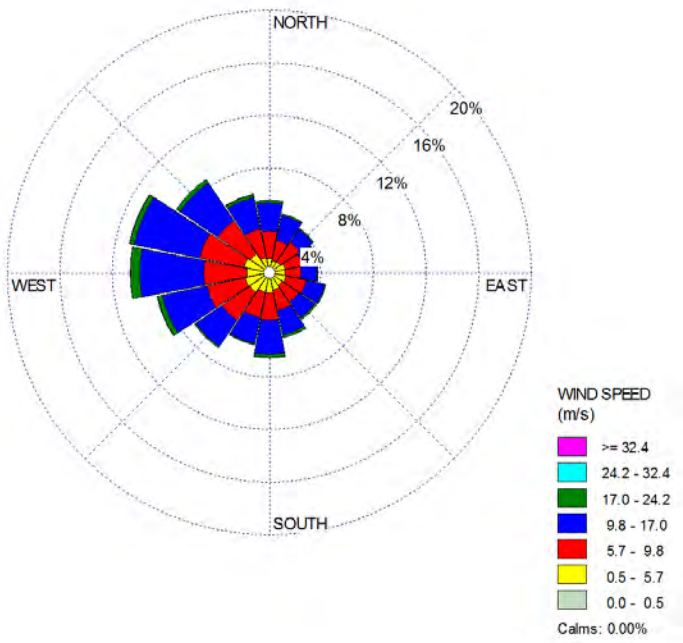

Wind Speed Percentage Occurrence
Grid Point 08026
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

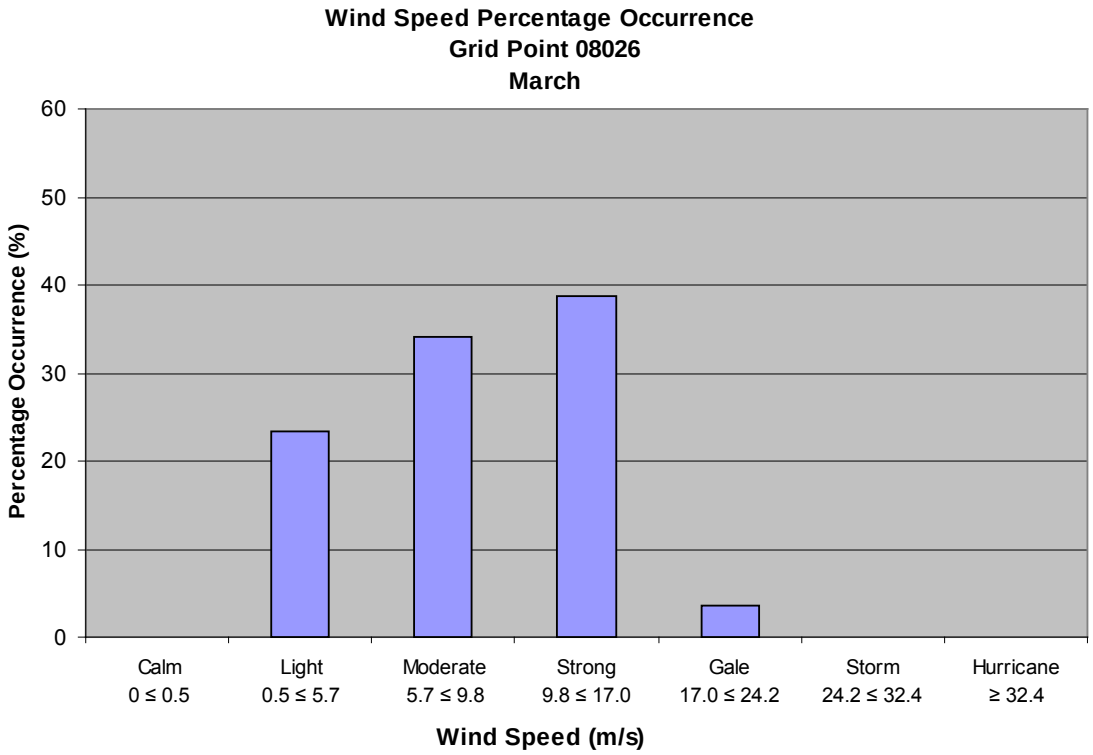
February


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

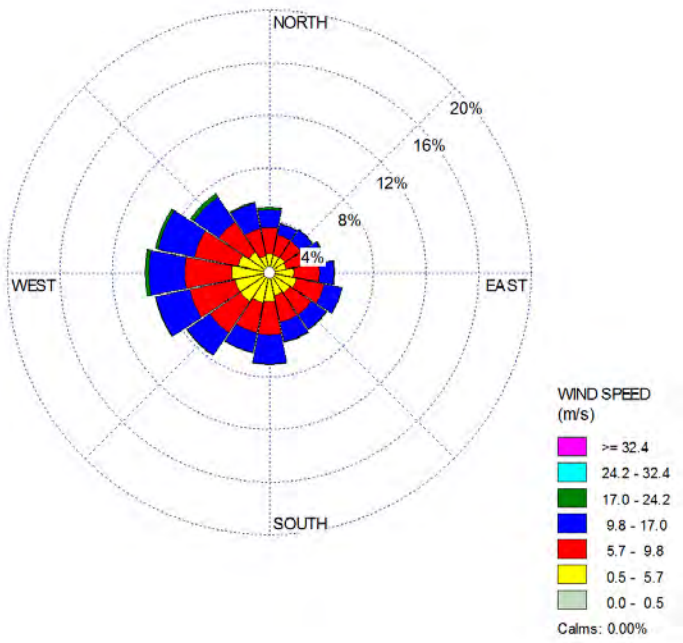

Wind Speed Percentage Occurrence
Grid Point 08026
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

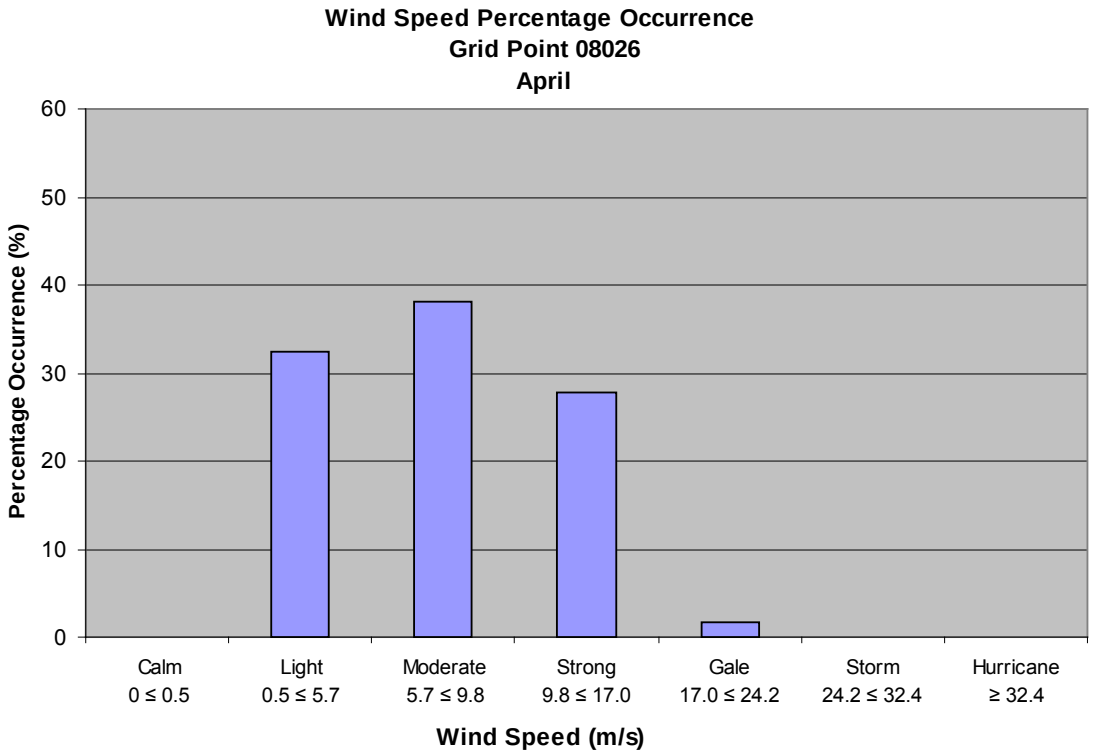
March


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

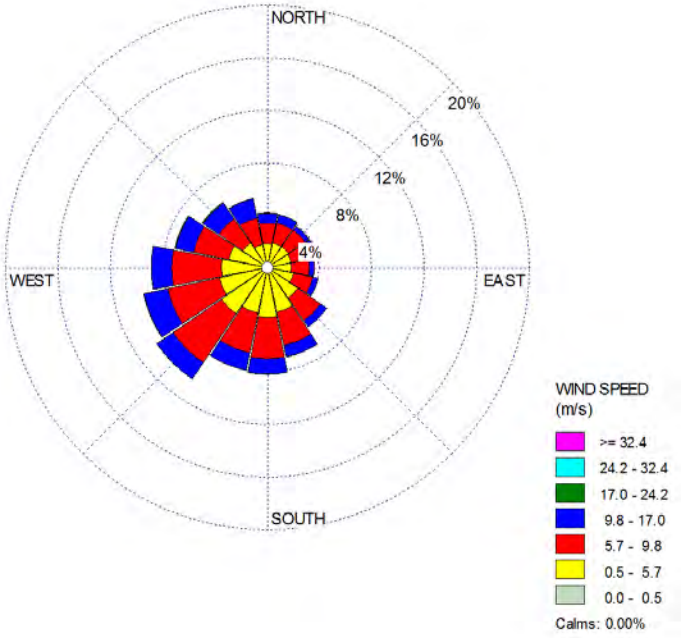

Wind Speed Percentage Occurrence
Grid Point 08026
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

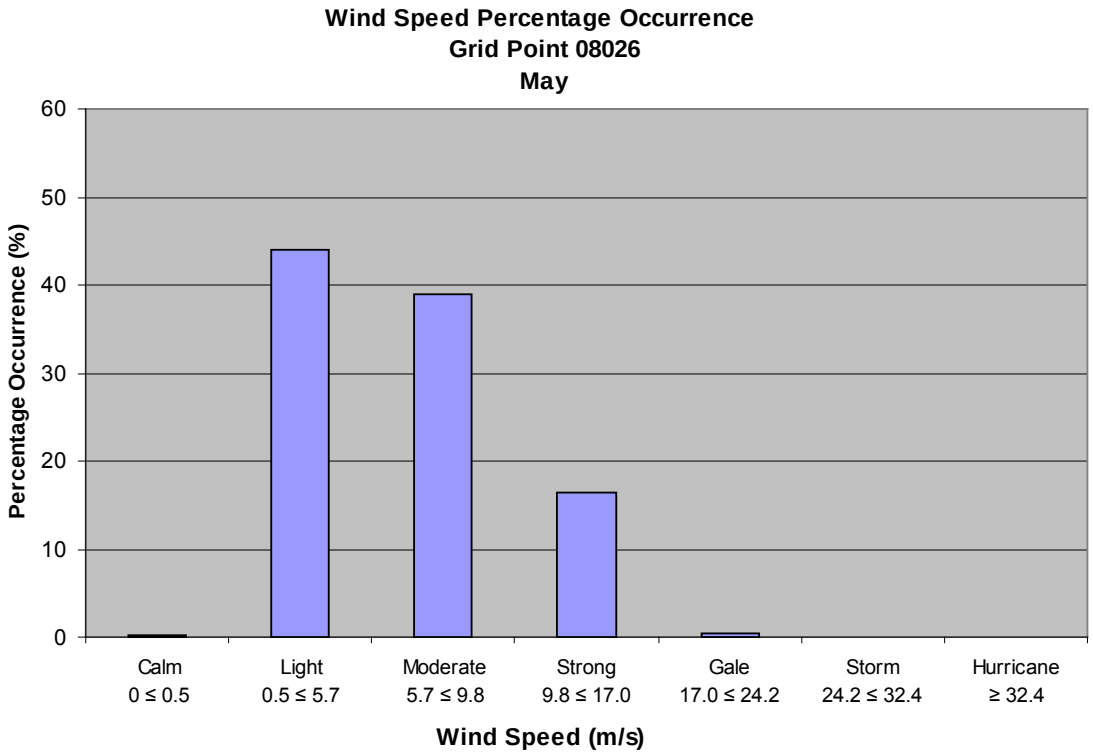
April


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

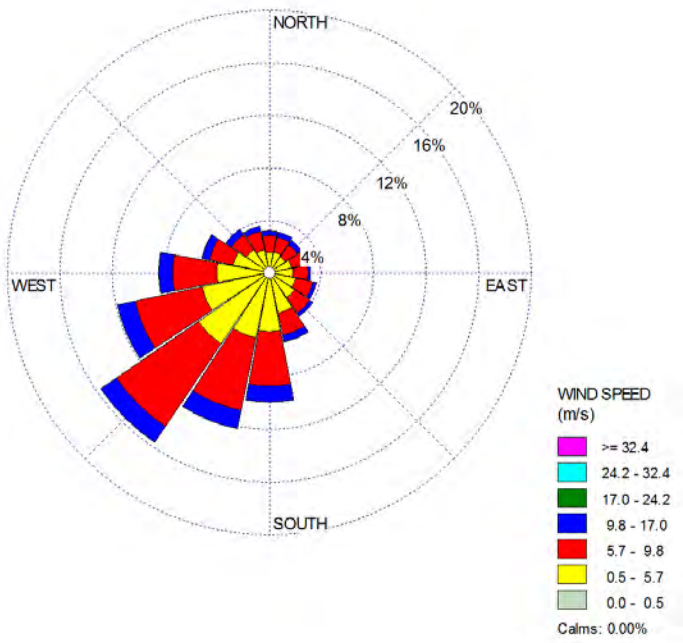

Wind Speed Percentage Occurrence
Grid Point 08026
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

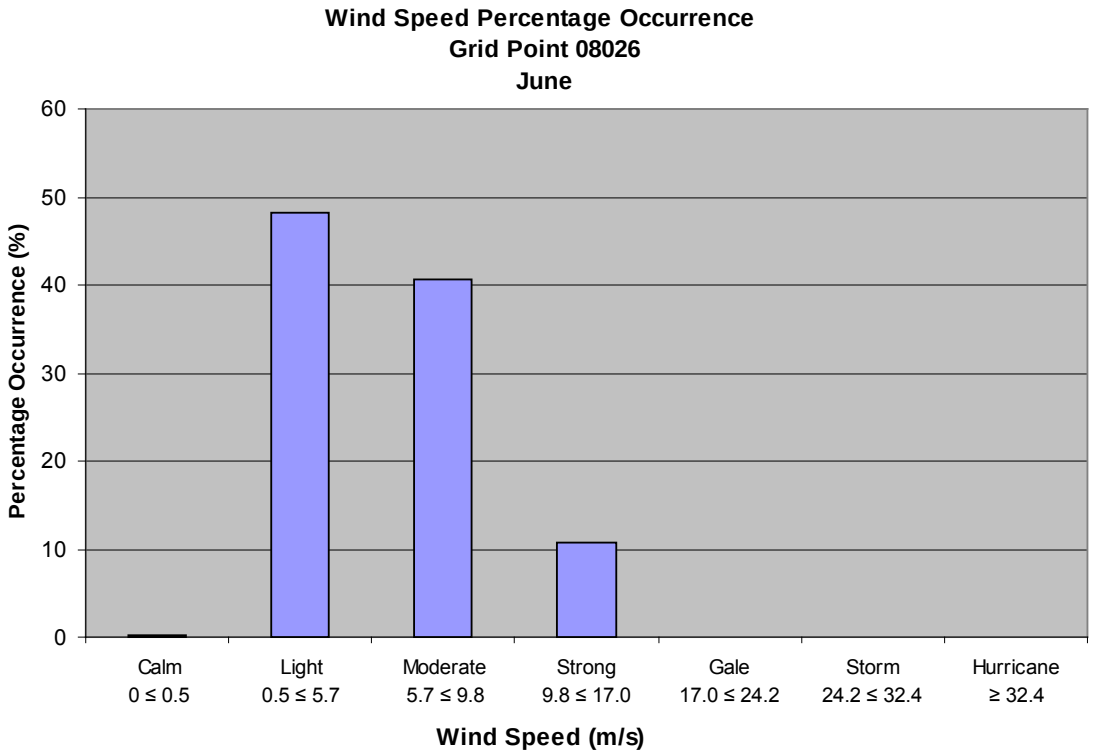
May


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

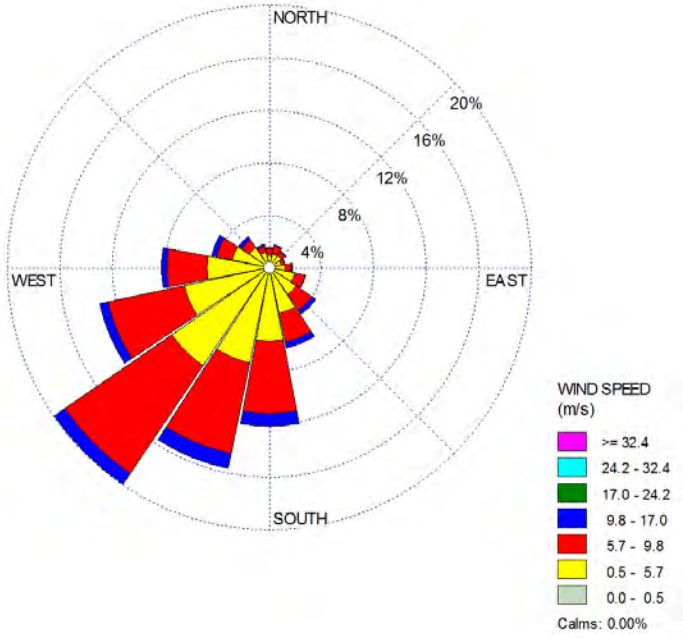

Wind Speed Percentage Occurrence
Grid Point 08026
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

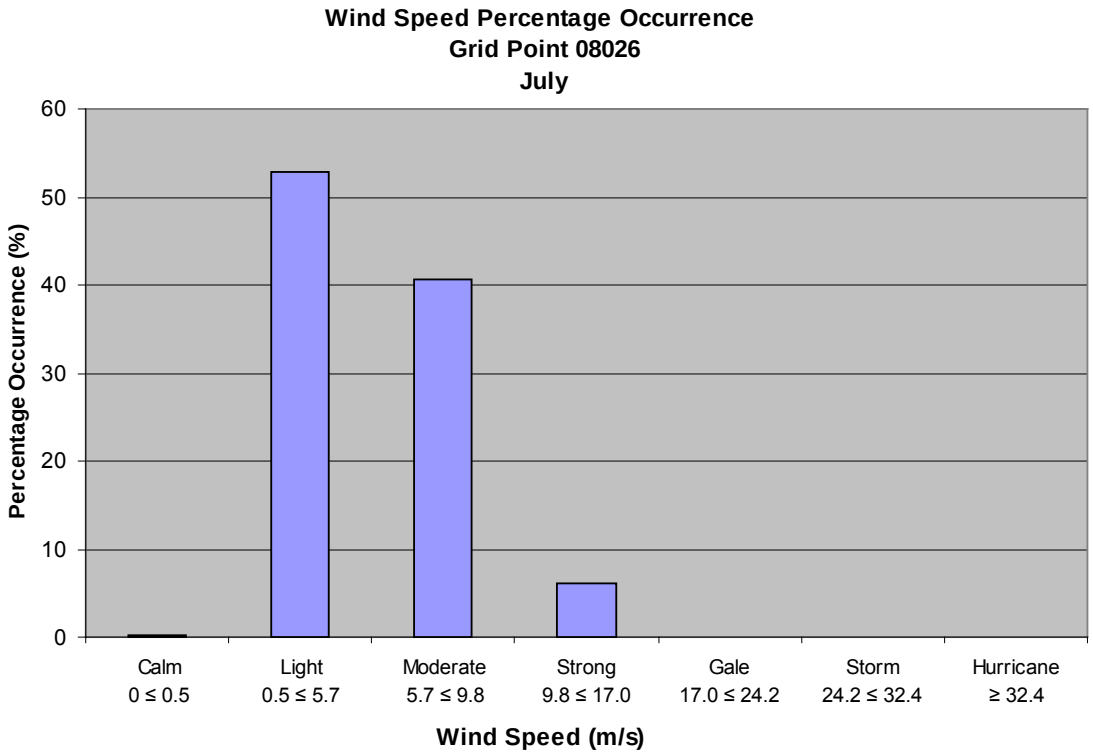
June


NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

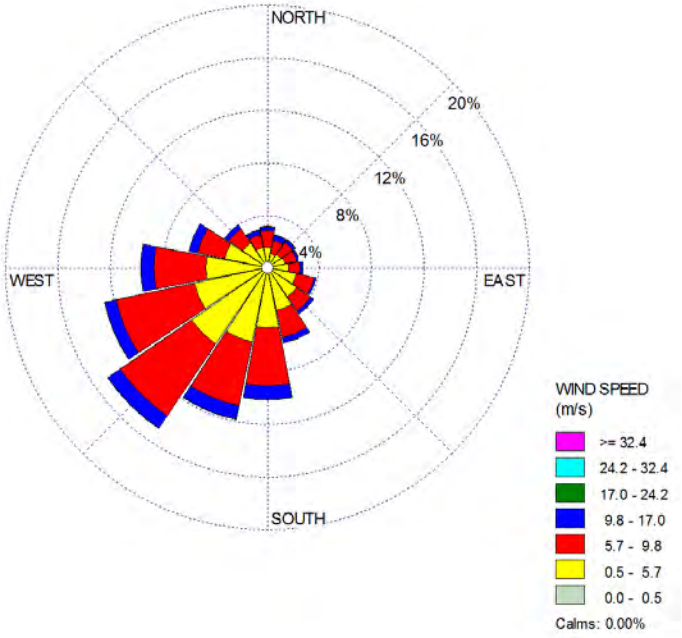

Wind Speed Percentage Occurrence
Grid Point 08026
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

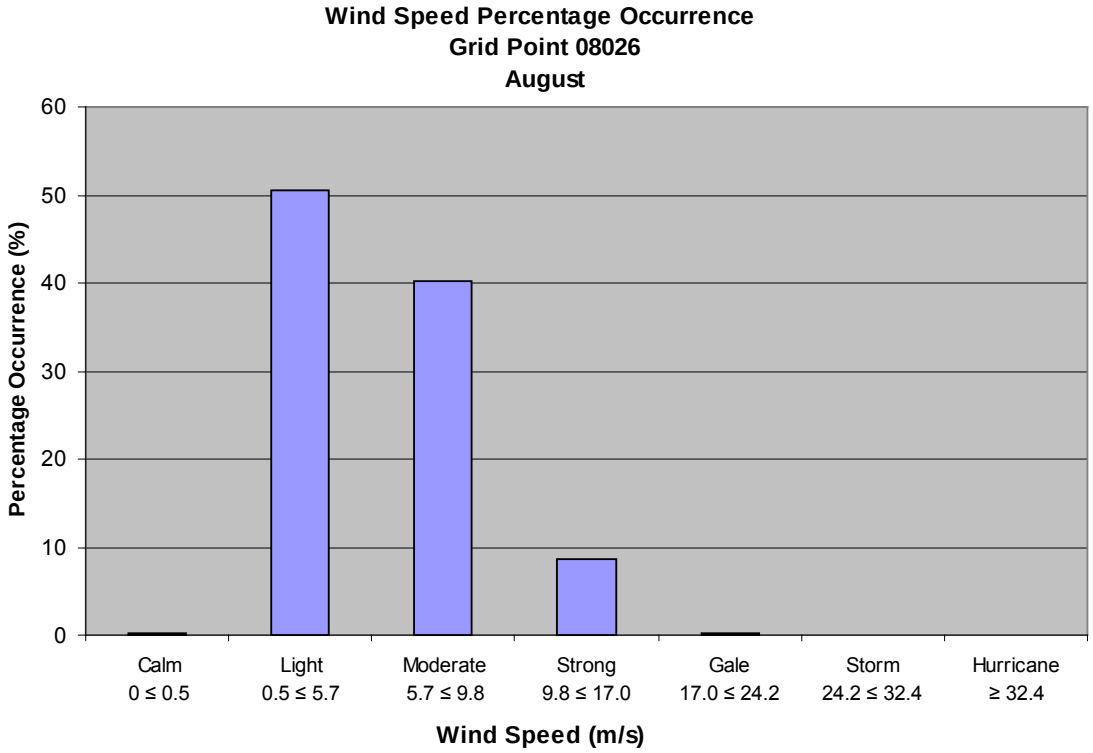
July


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

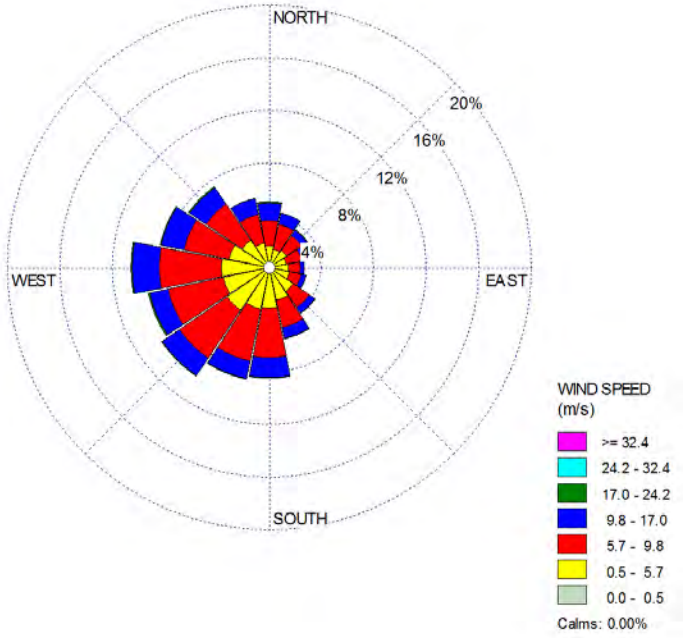

Wind Speed Percentage Occurrence
Grid Point 08026
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

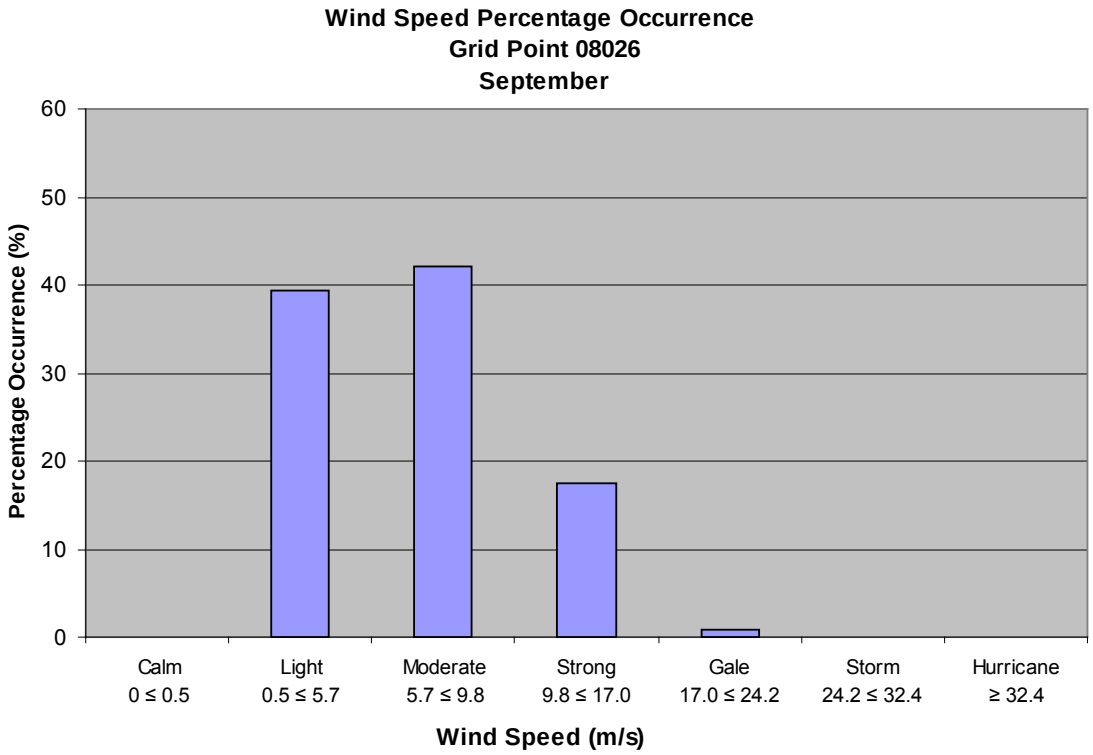
August


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

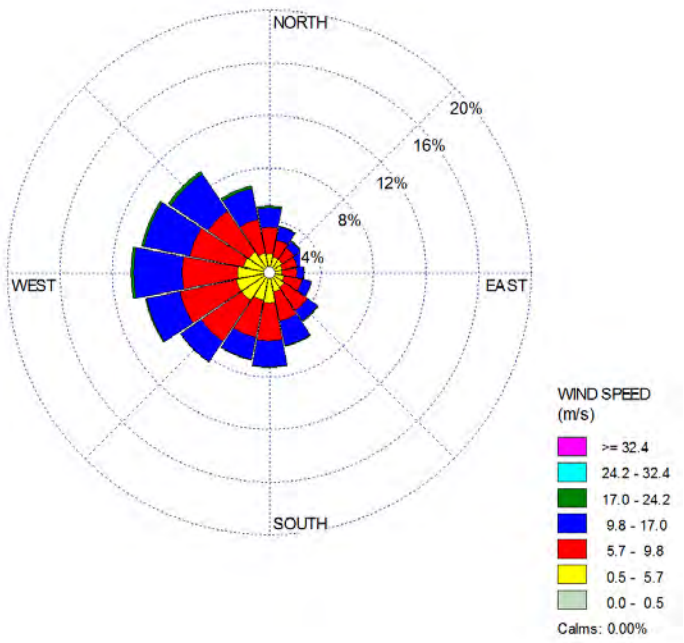

Wind Speed Percentage Occurrence
Grid Point 08026
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

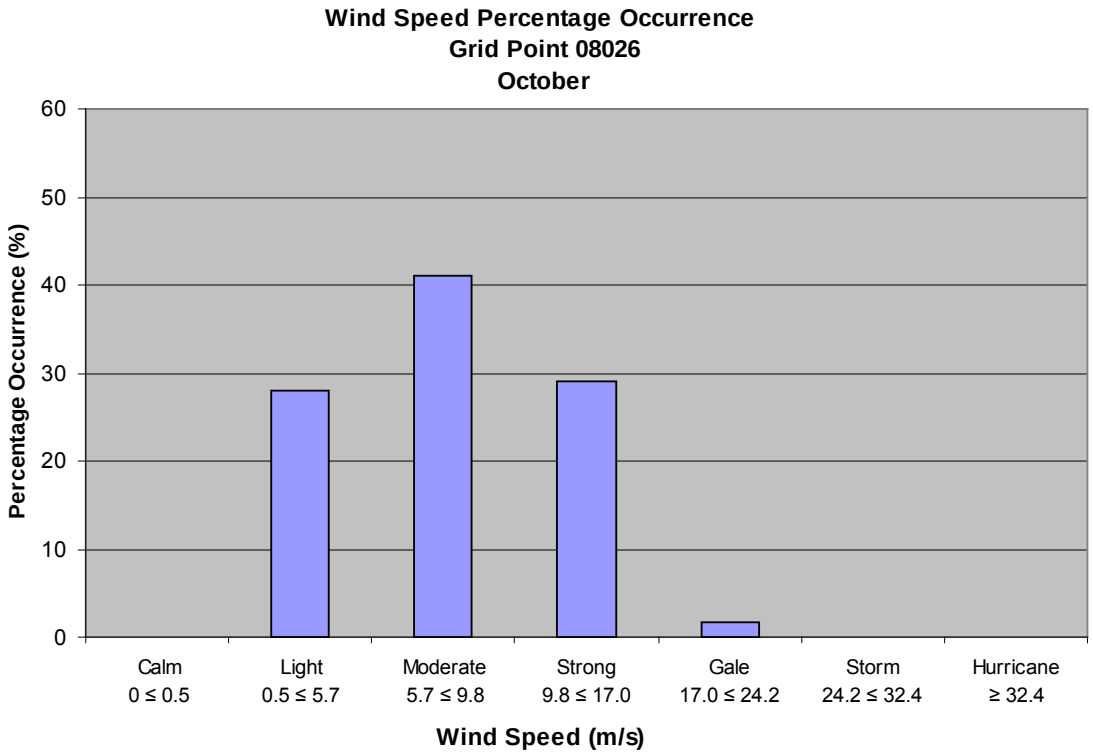
September


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

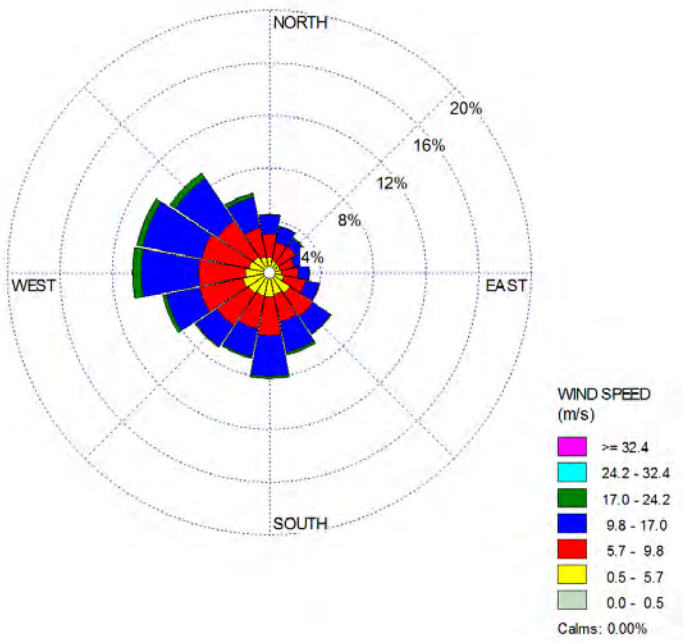

Wind Speed Percentage Occurrence
Grid Point 08026
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

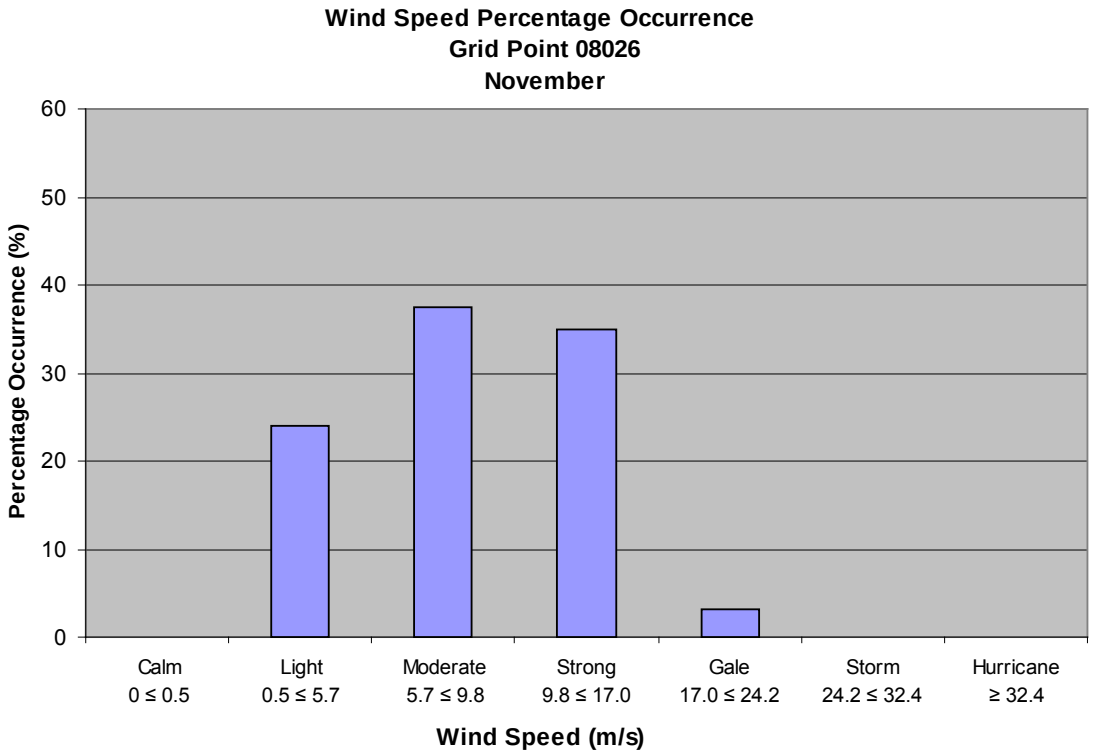
October


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

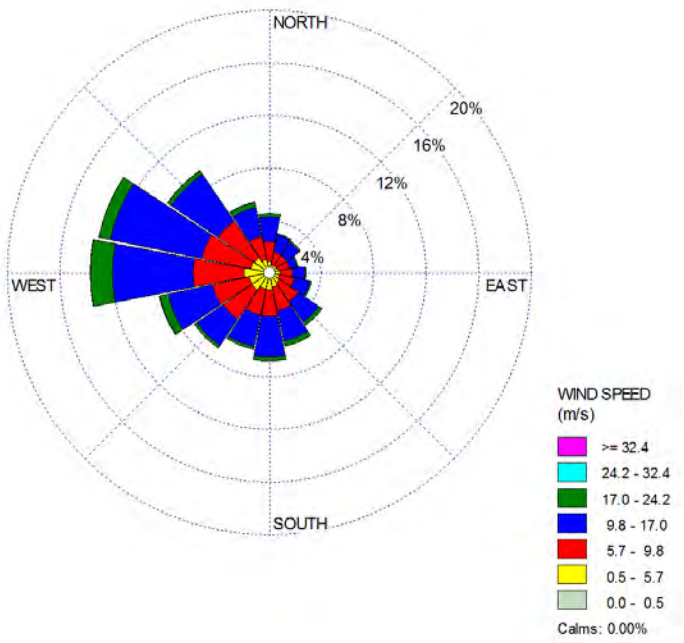

Wind Speed Percentage Occurrence
Grid Point 08026
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

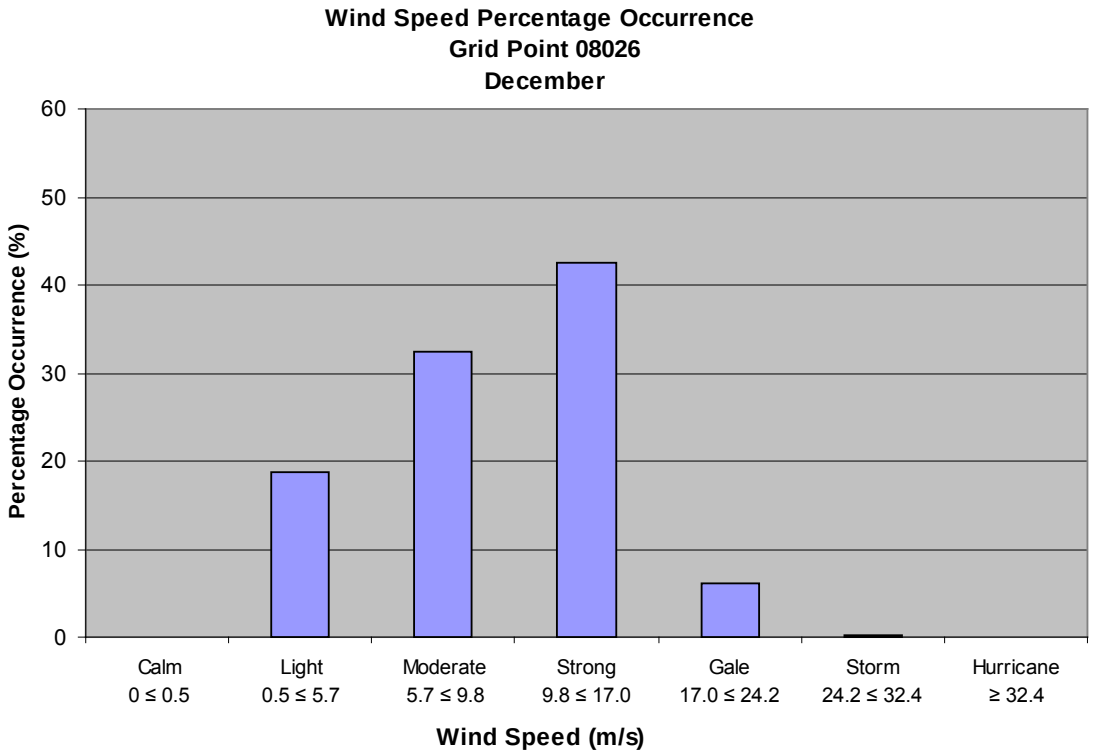
November


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 08026
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

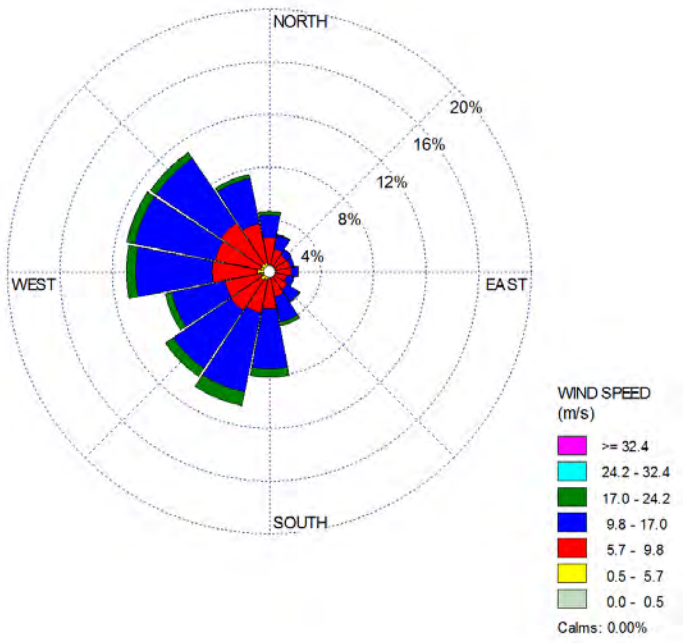
December

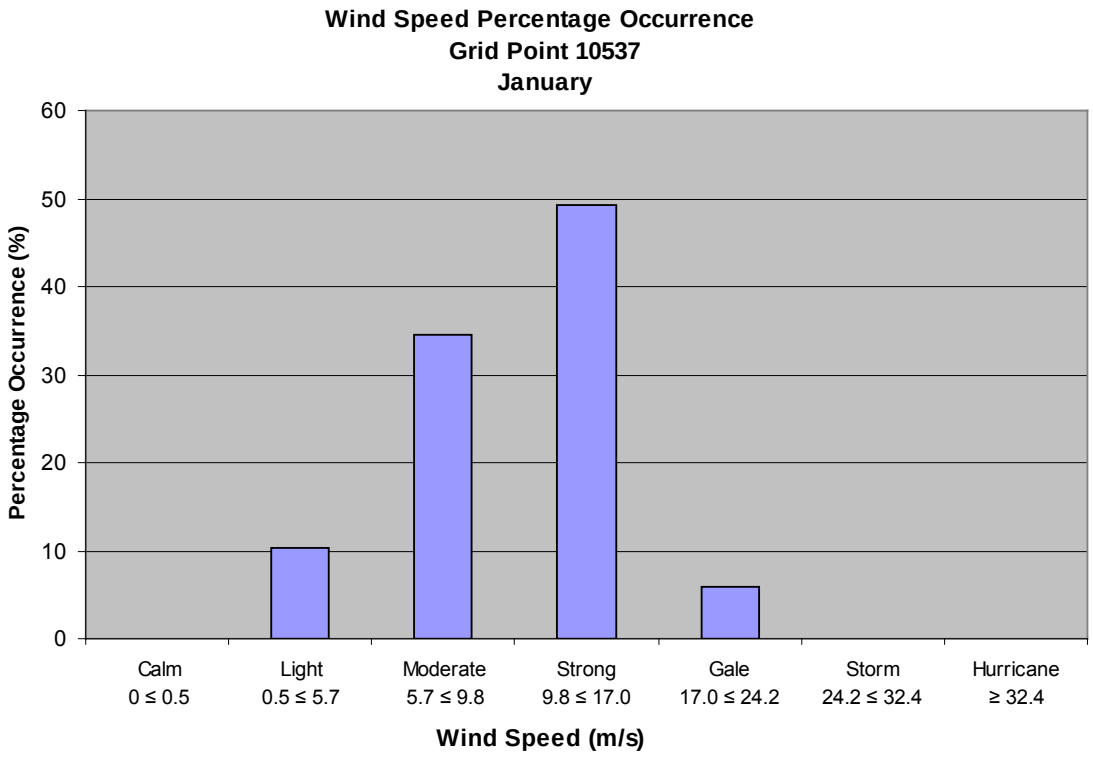

NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 08026
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

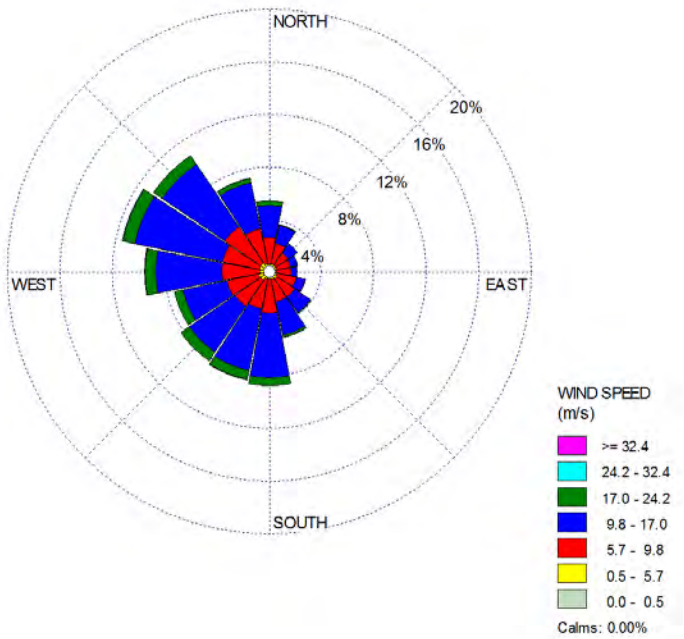
Appendix 4
Wind Roses
and
Wind Speed Frequency Distributions
for MSC50 Grid Point 10537

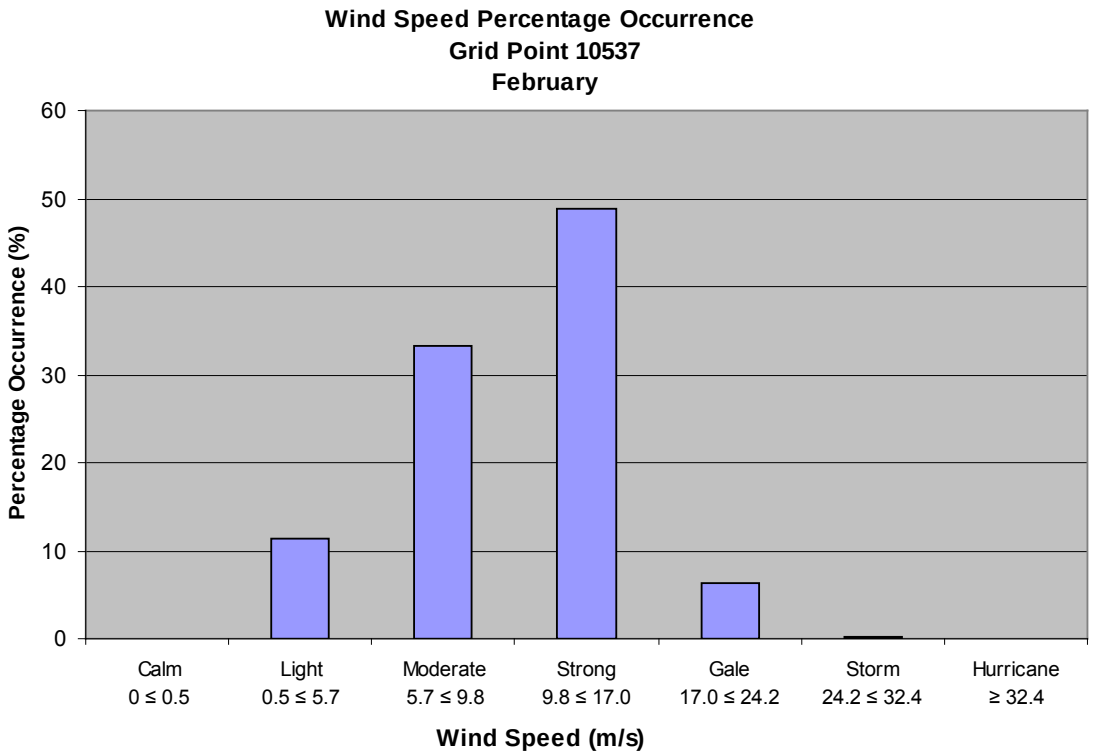
January


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

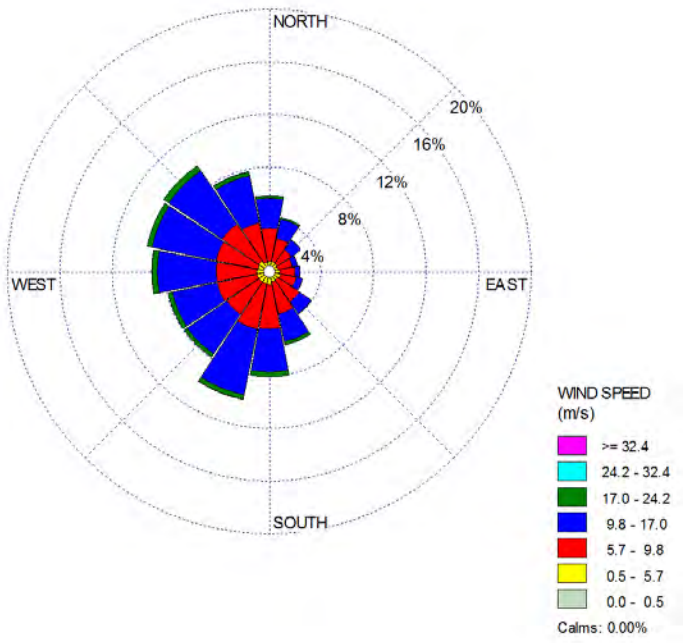

Wind Speed Percentage Occurrence
Grid Point 10537
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

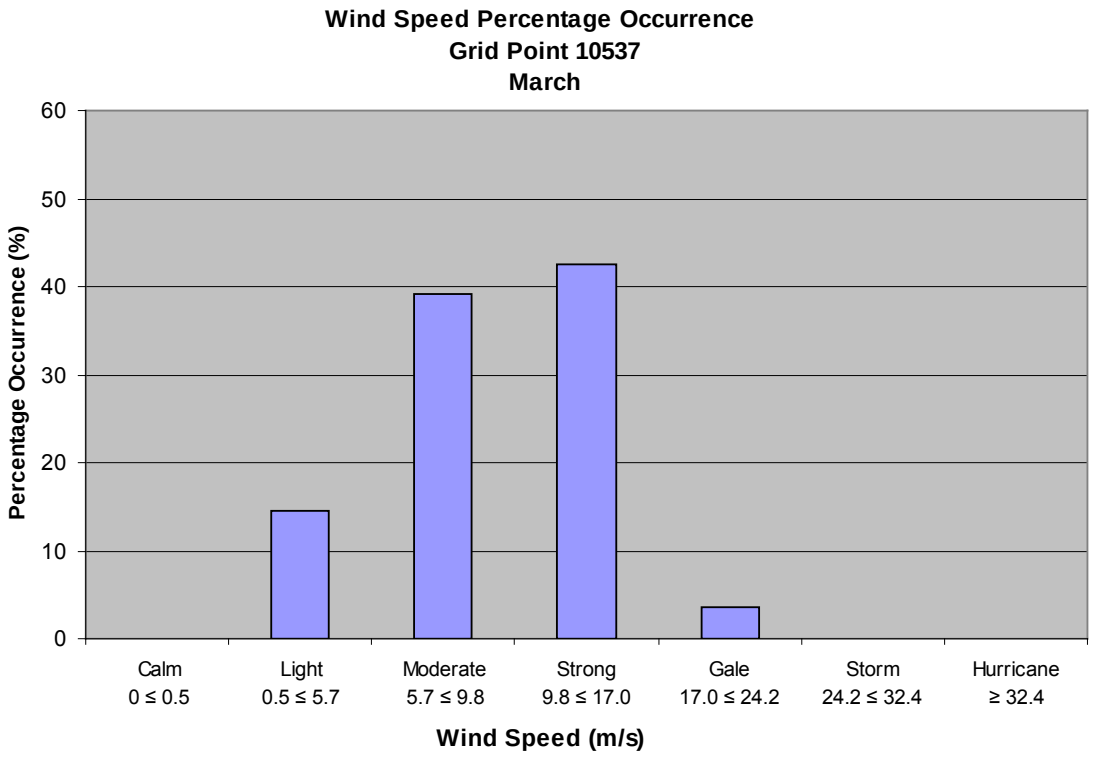
February


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

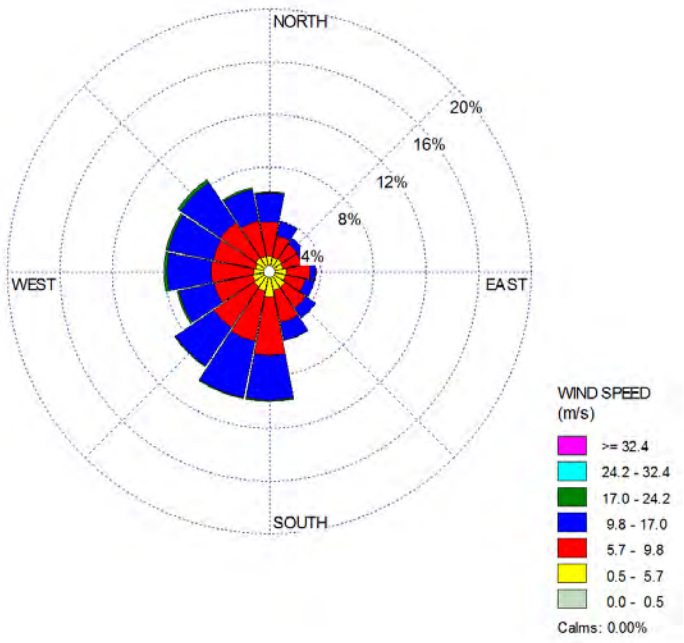

Wind Speed Percentage Occurrence
Grid Point 10537
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

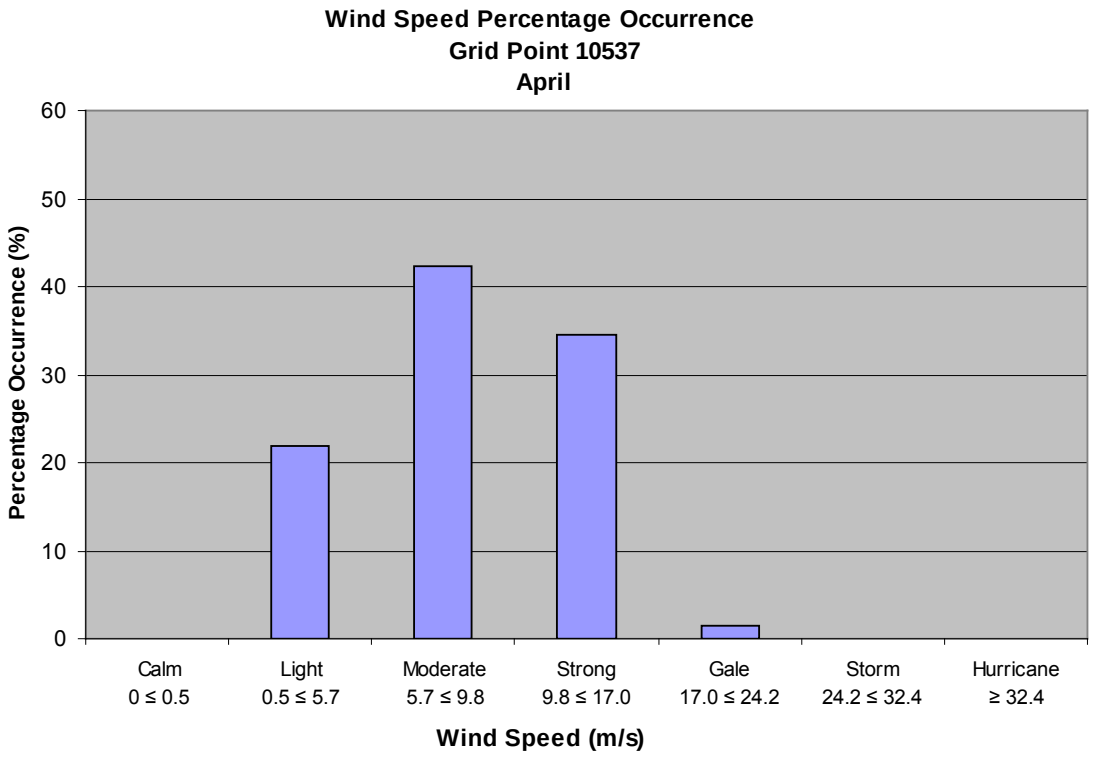
March


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

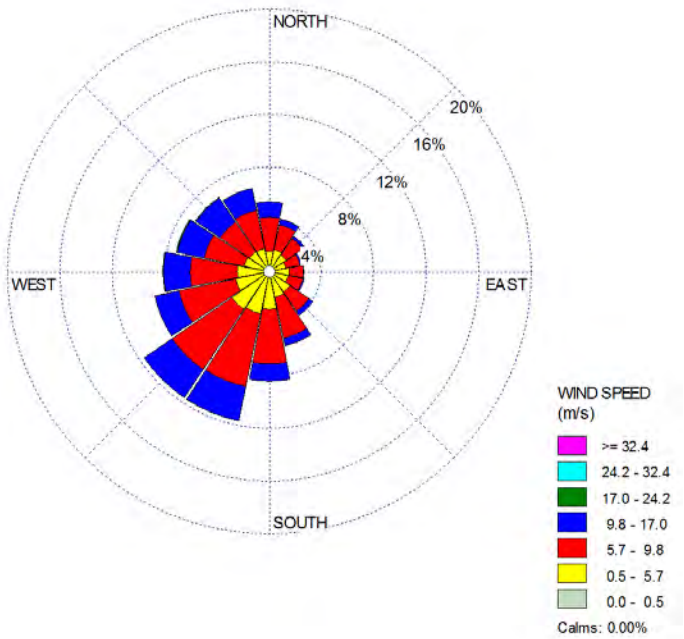

Wind Speed Percentage Occurrence
Grid Point 10537
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

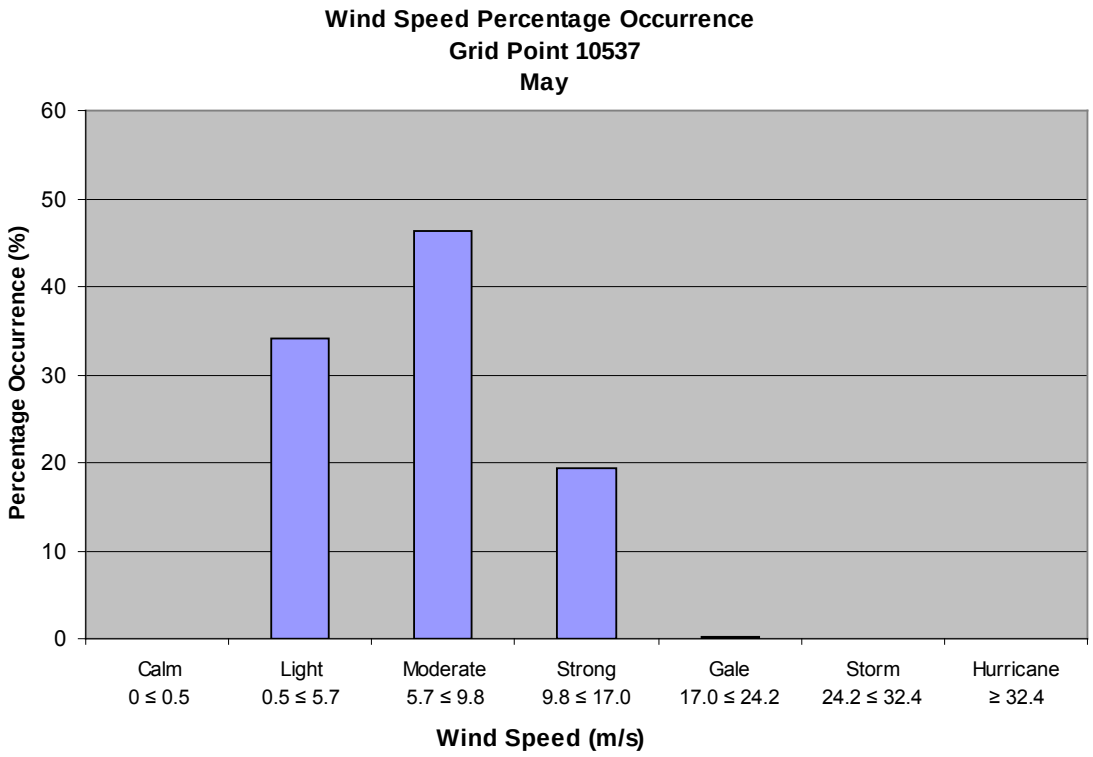
April


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

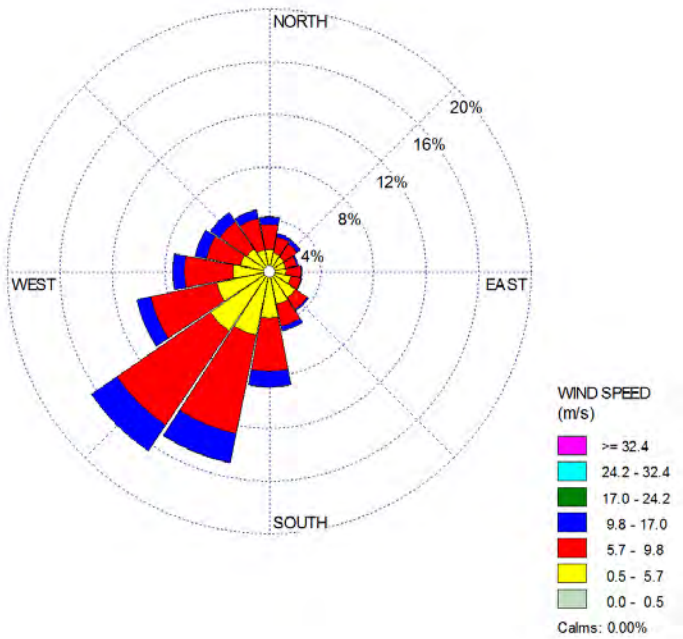

Wind Speed Percentage Occurrence
Grid Point 10537
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

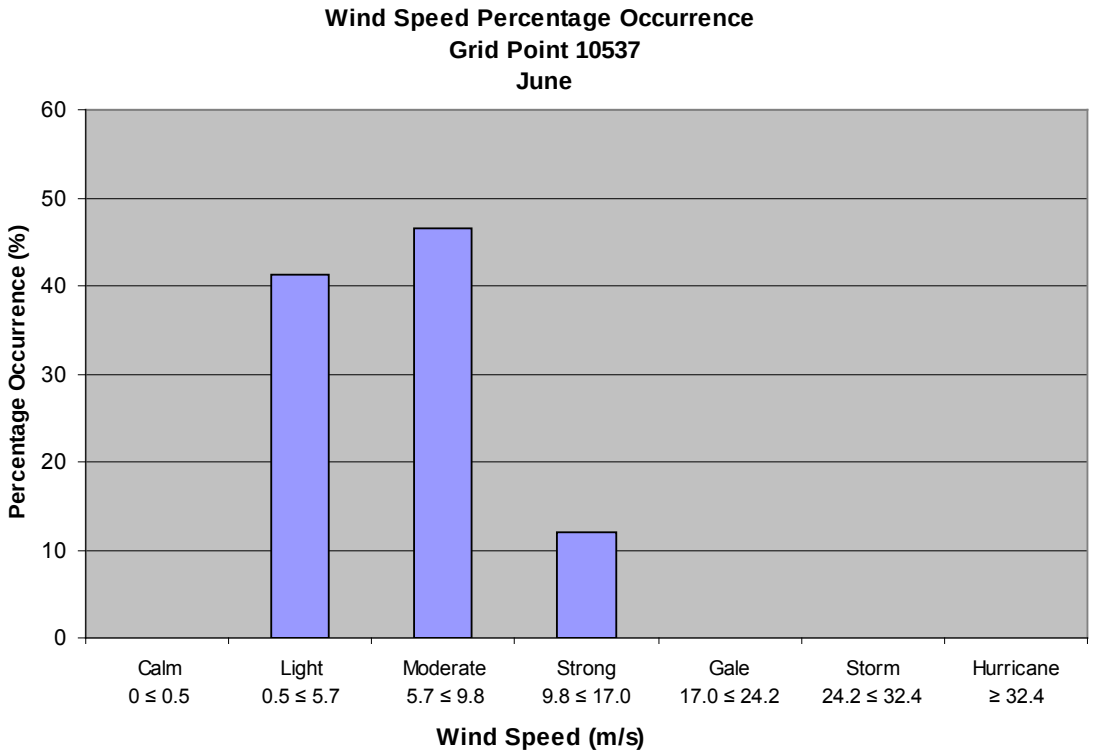
May


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

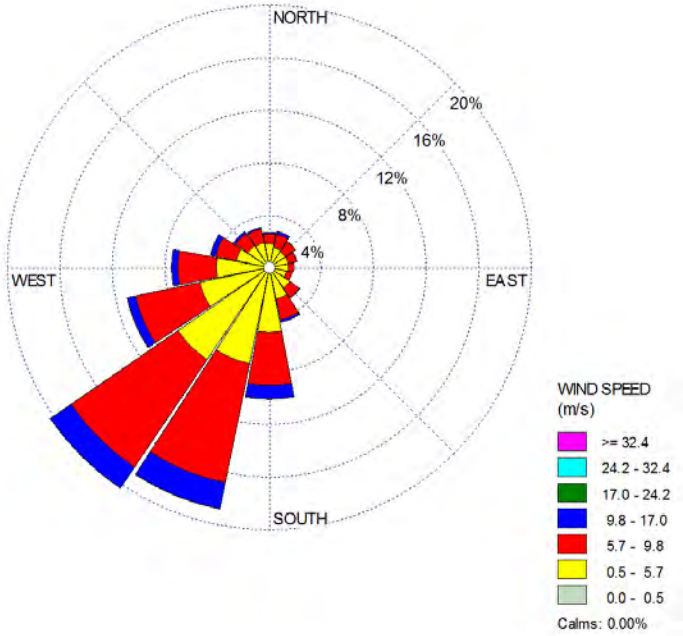

Wind Speed Percentage Occurrence
Grid Point 10537
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

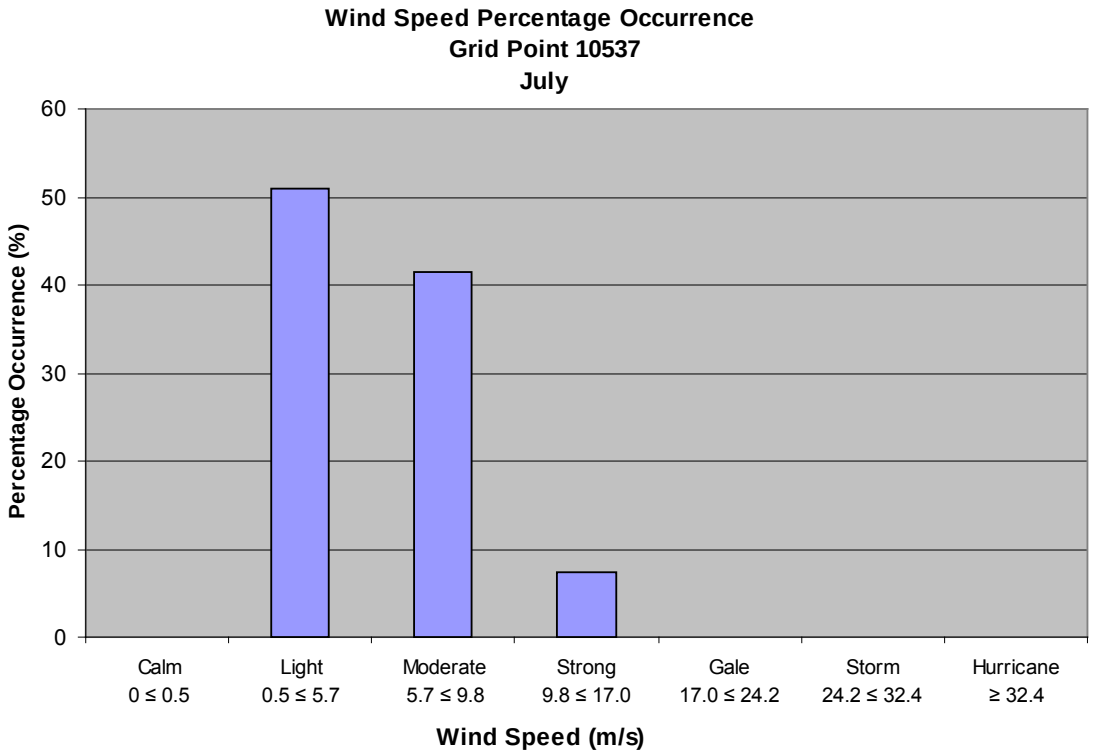
June


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

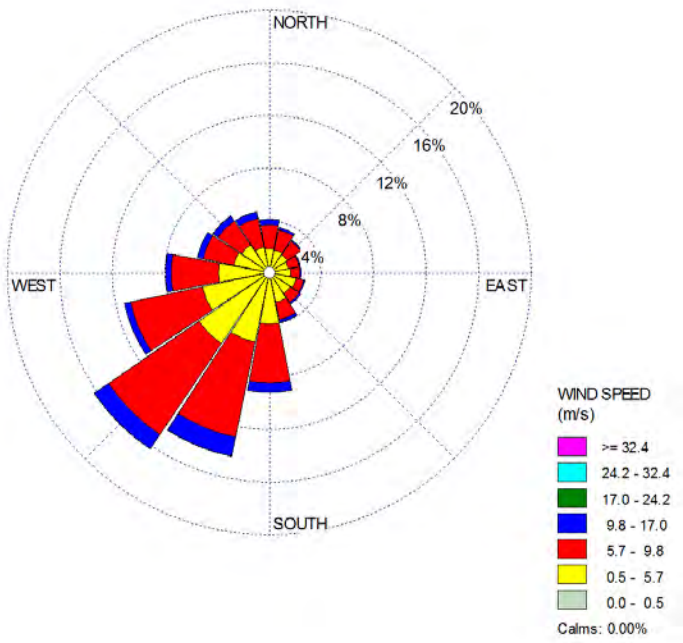

Wind Speed Percentage Occurrence
Grid Point 10537
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

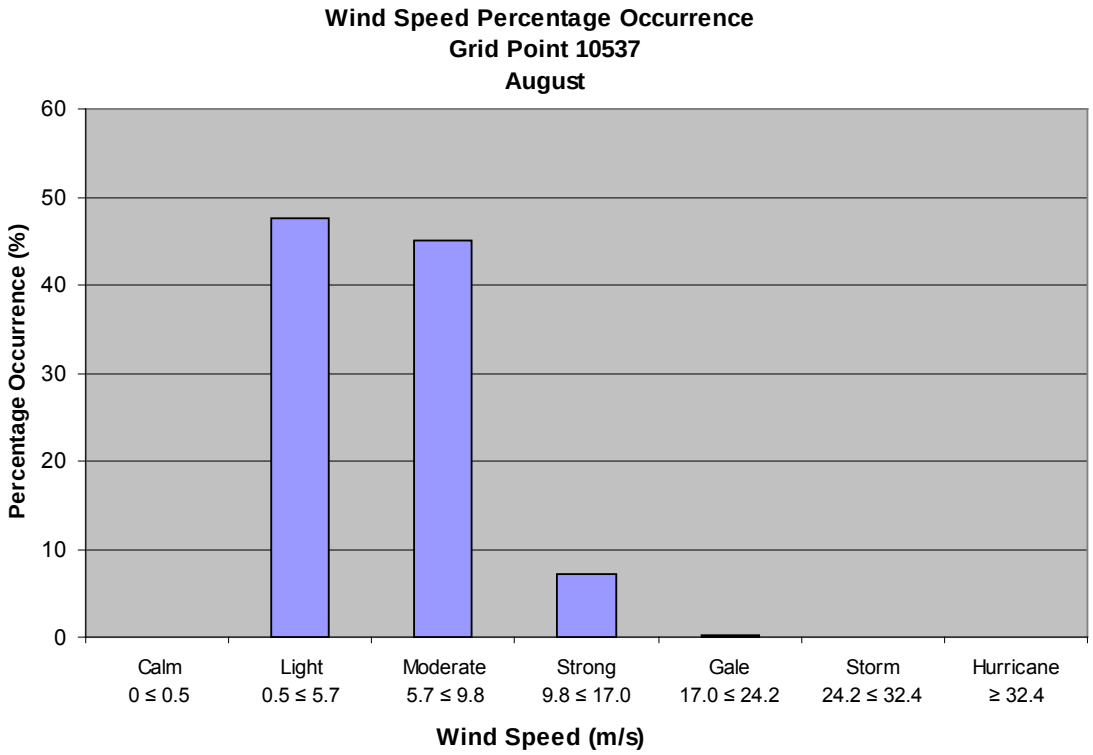
July


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

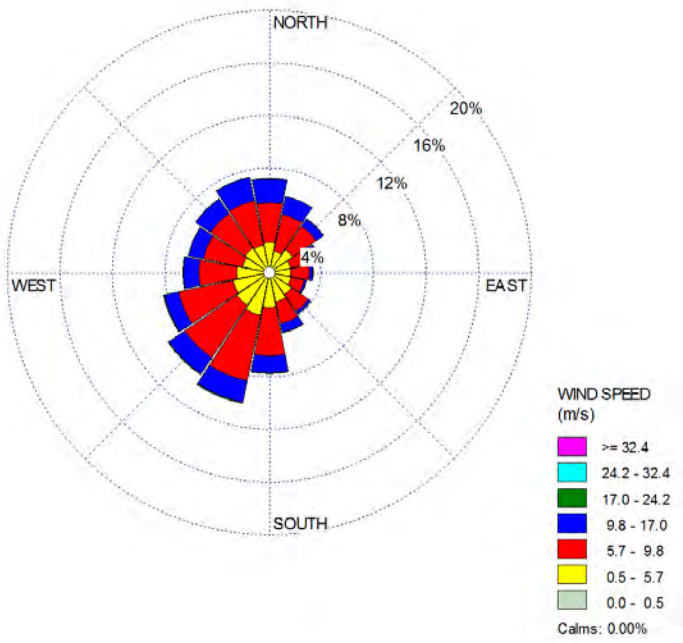

Wind Speed Percentage Occurrence
Grid Point 10537
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

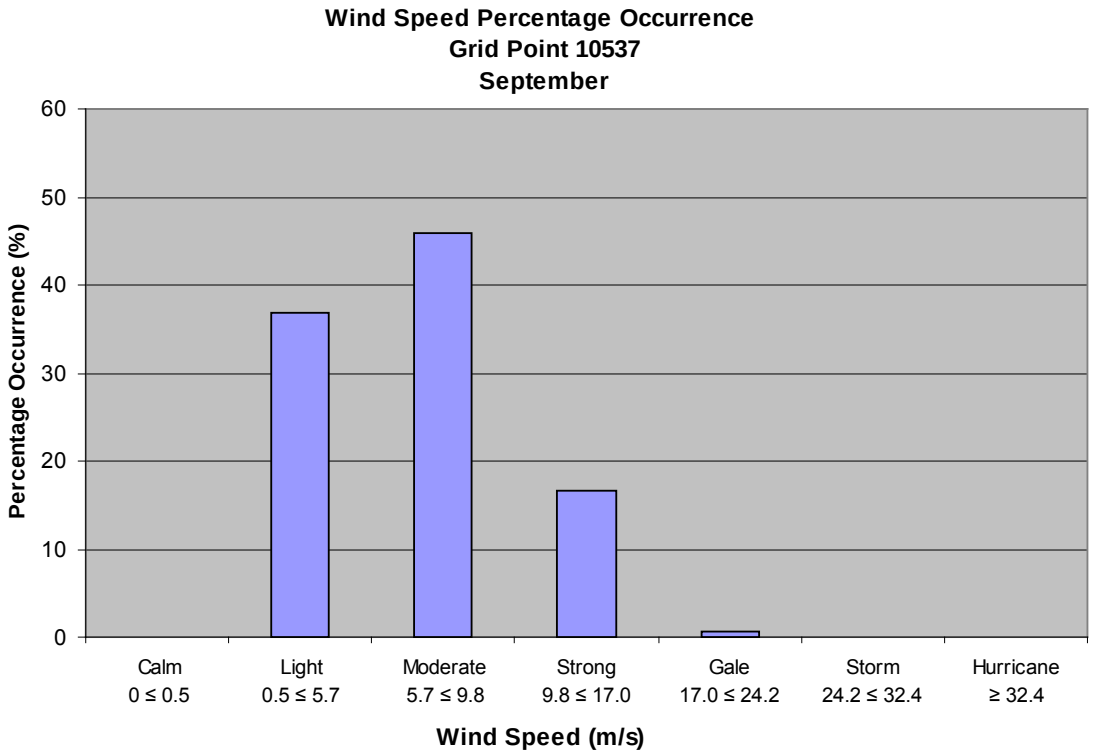
August


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

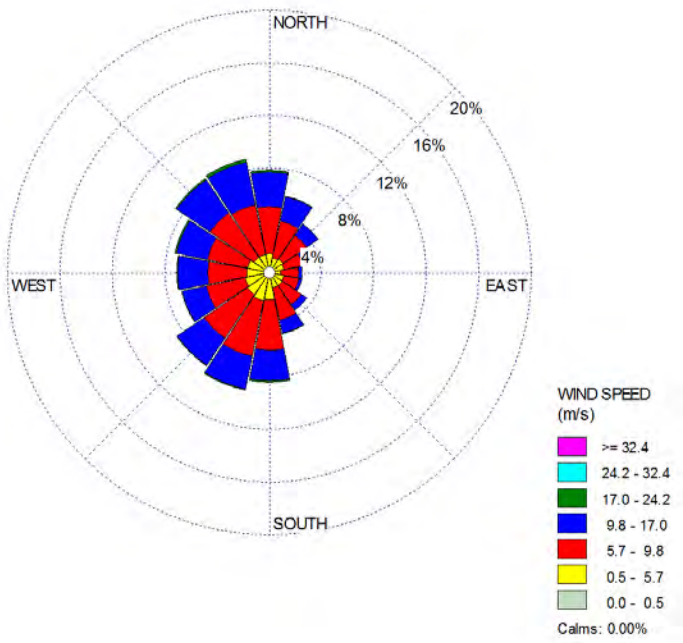

Wind Speed Percentage Occurrence
Grid Point 10537
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

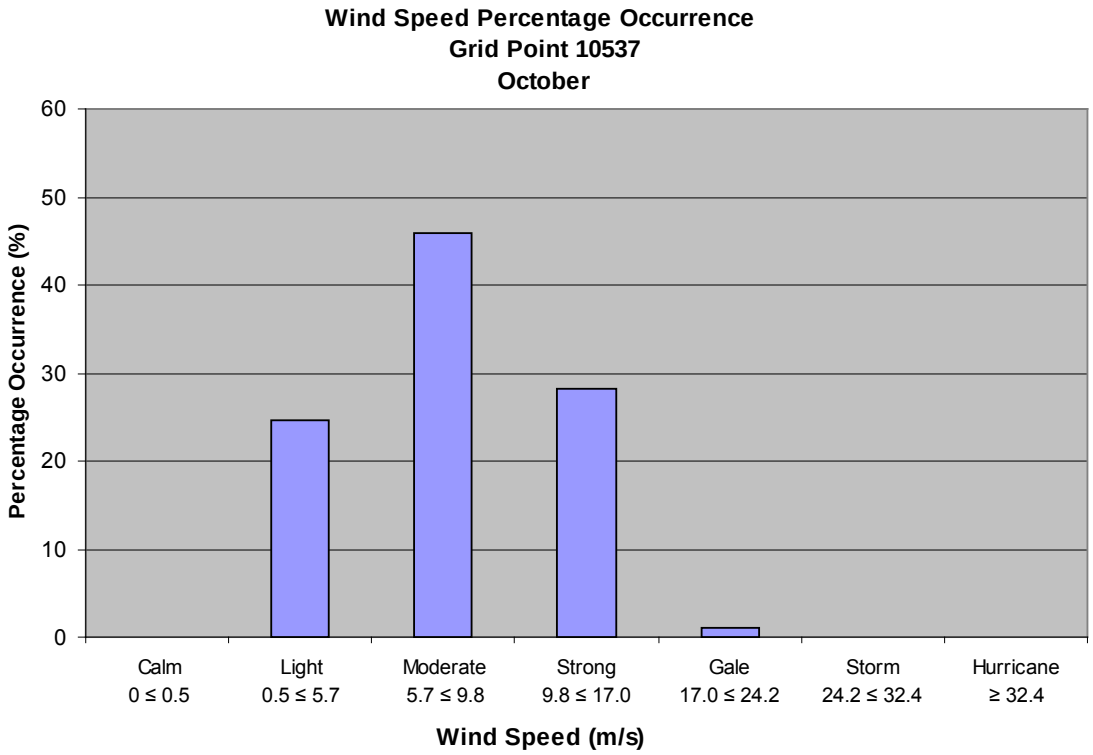
September


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

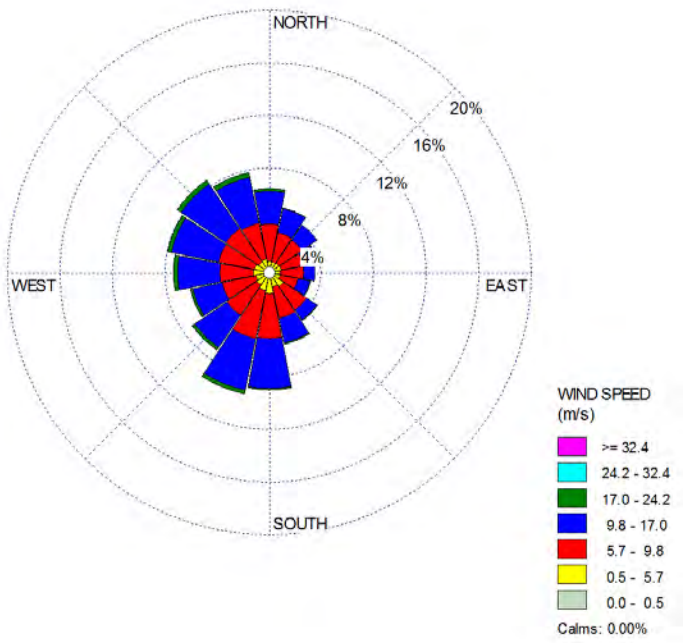

Wind Speed Percentage Occurrence
Grid Point 10537
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

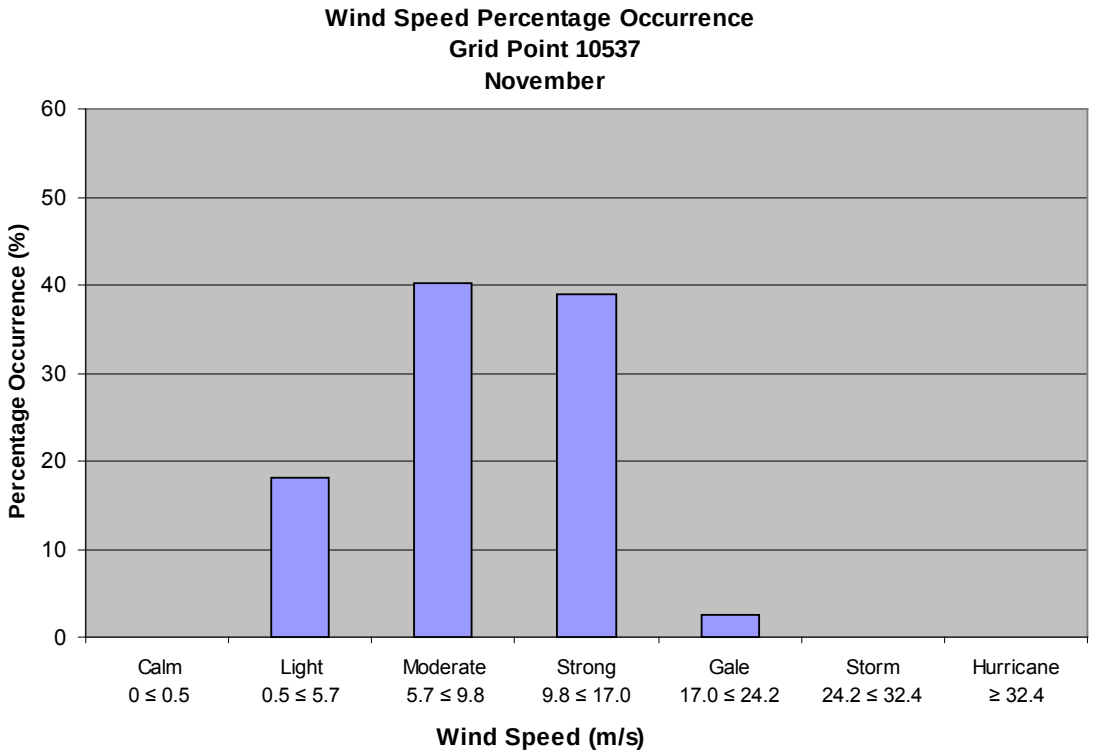
October


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

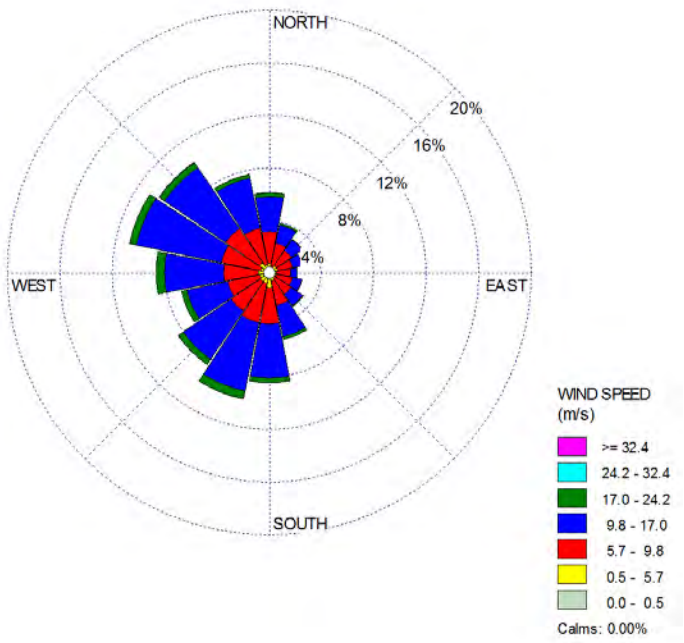

Wind Speed Percentage Occurrence
Grid Point 10537
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

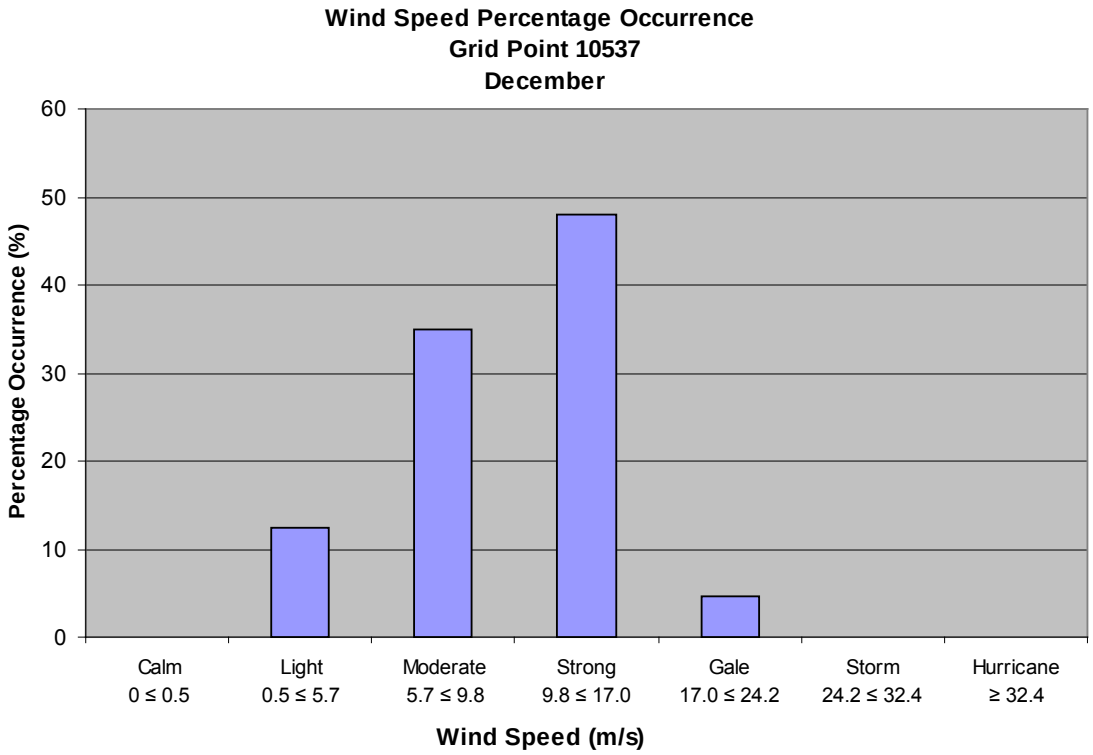
November


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 10537
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

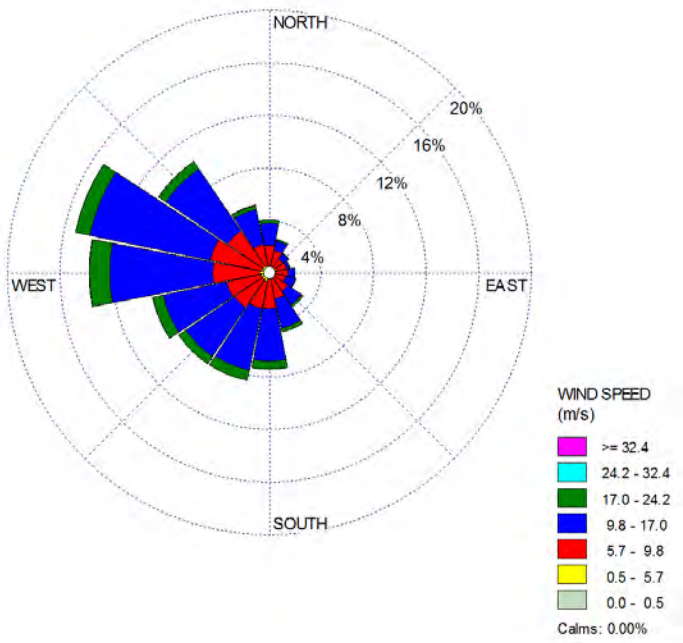
December

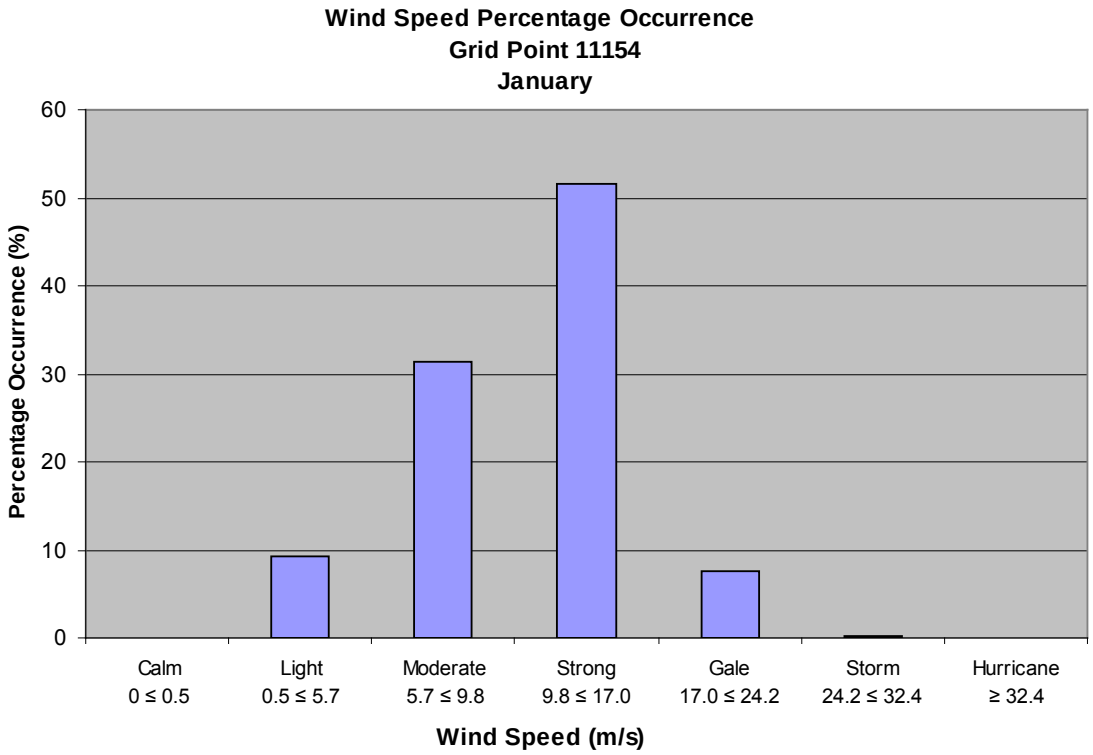

NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 10537
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

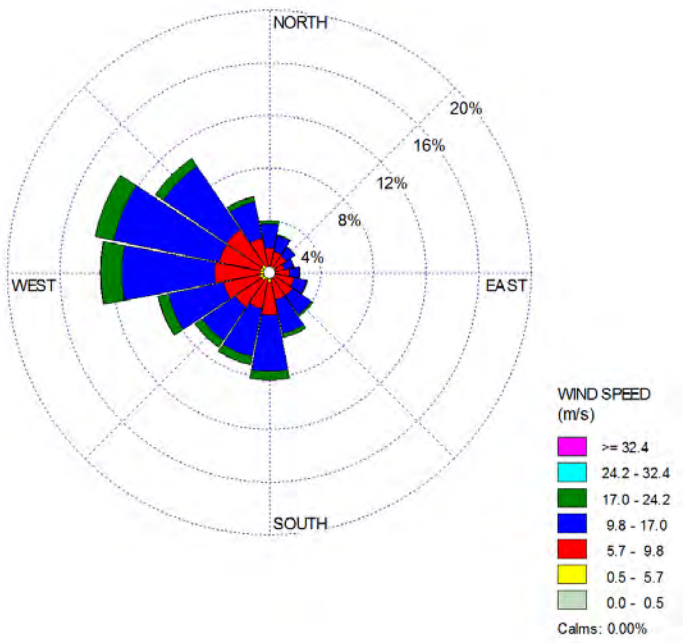
Appendix 5
Wind Roses
and
Wind Speed Frequency Distributions
for MSC50 Grid Point 11154

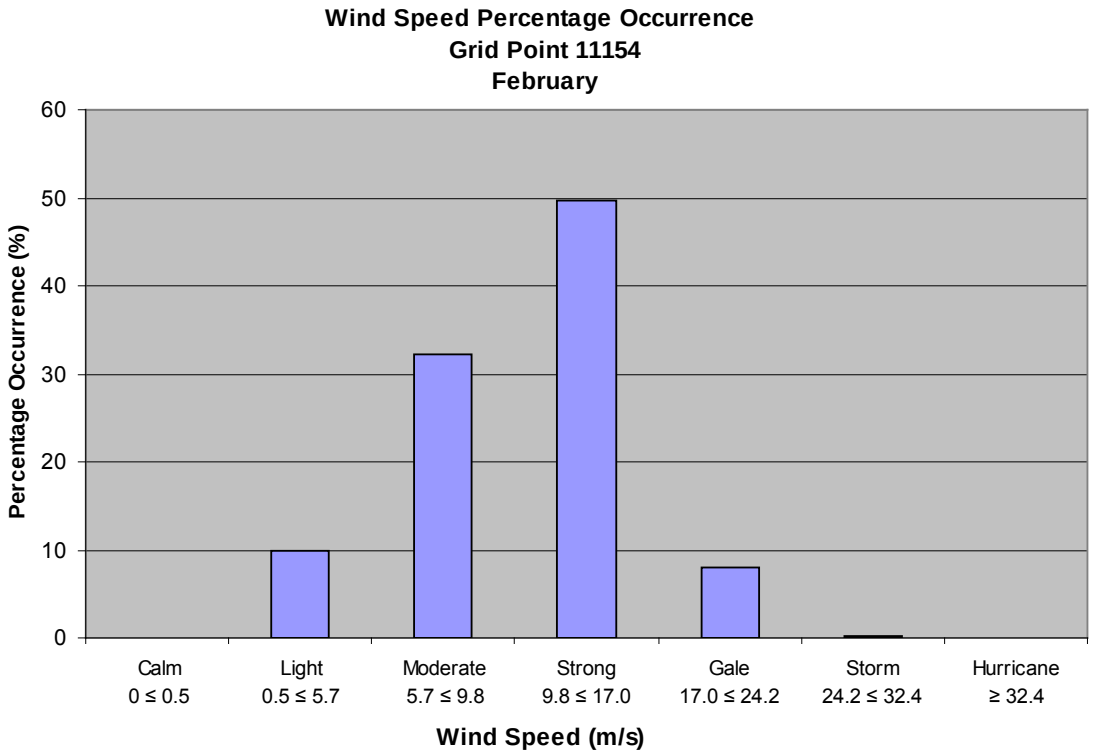
January


NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

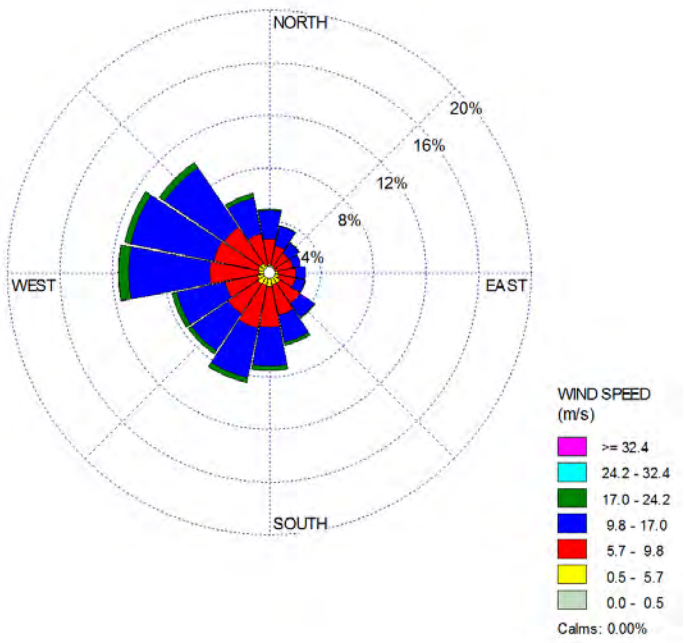

Wind Speed Percentage Occurrence
Grid Point 11154
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

February

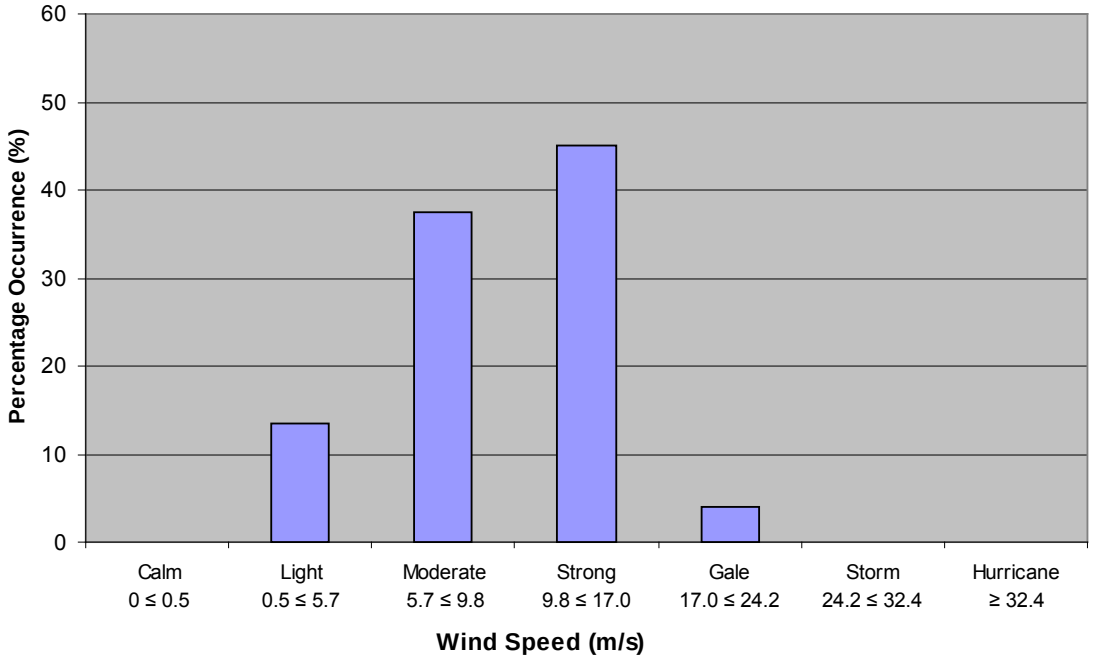

NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 11154
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

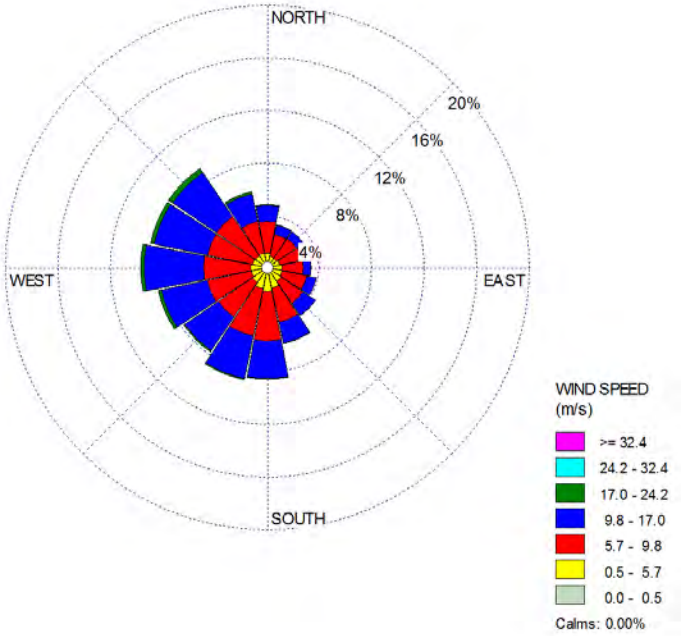
March

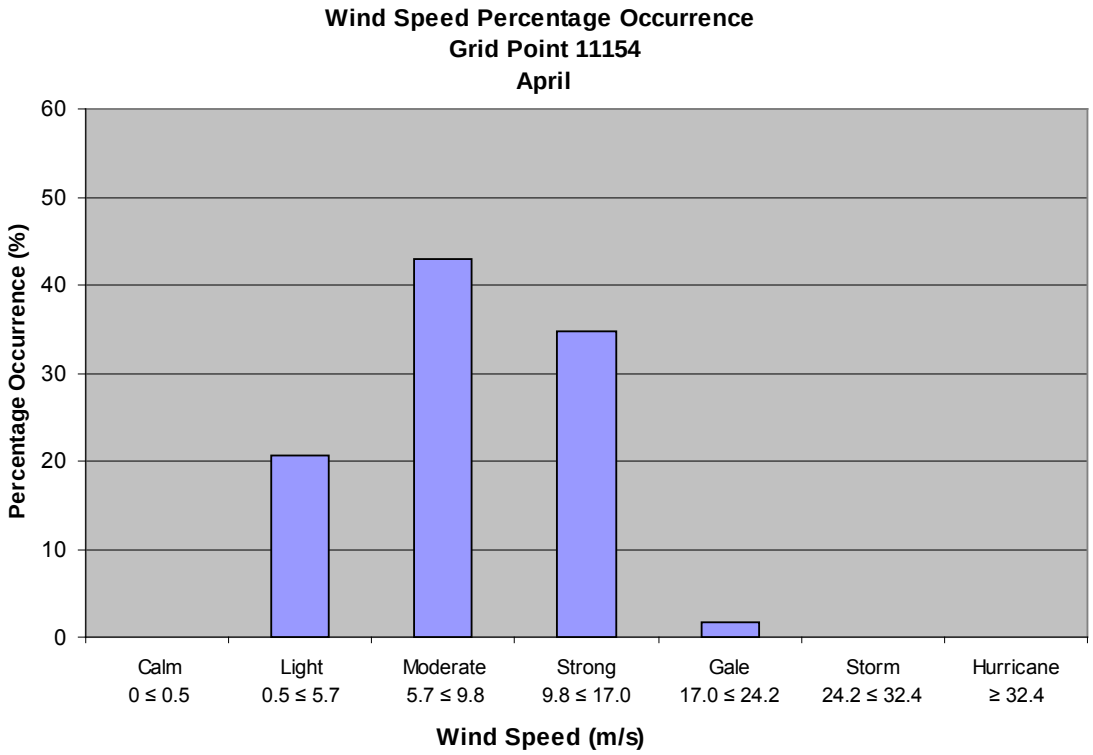


Wind Speed Percentage Occurrence
Grid Point 11154
March

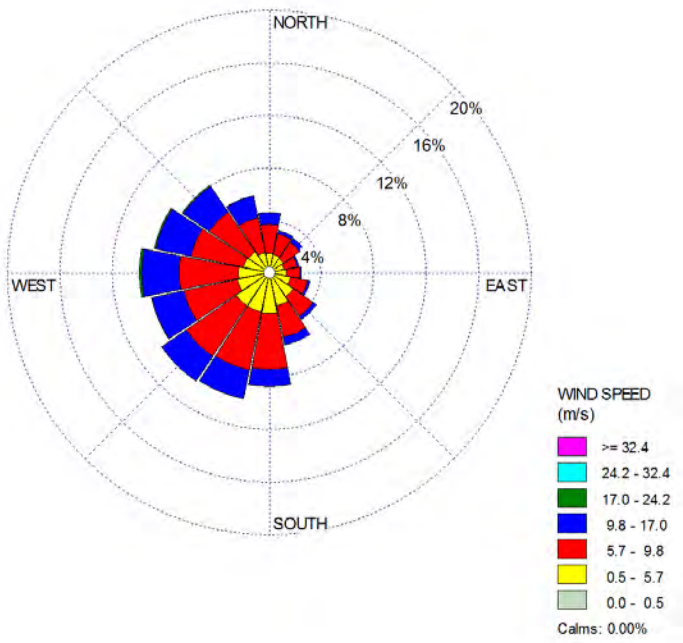


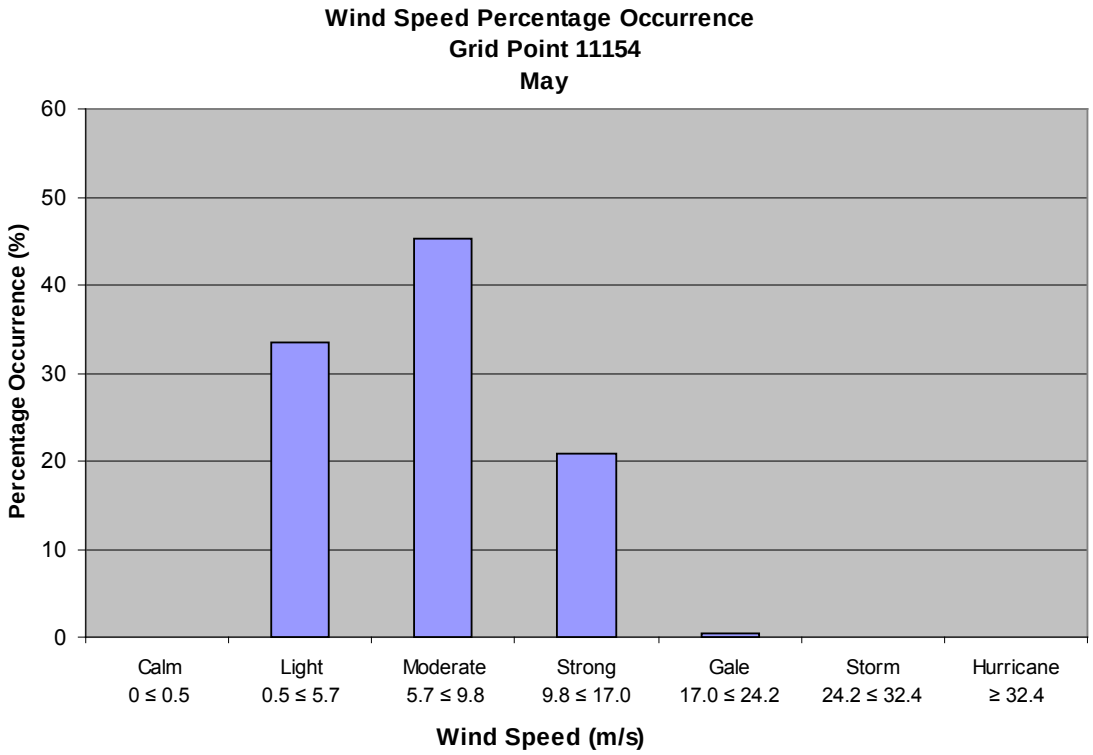
April


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

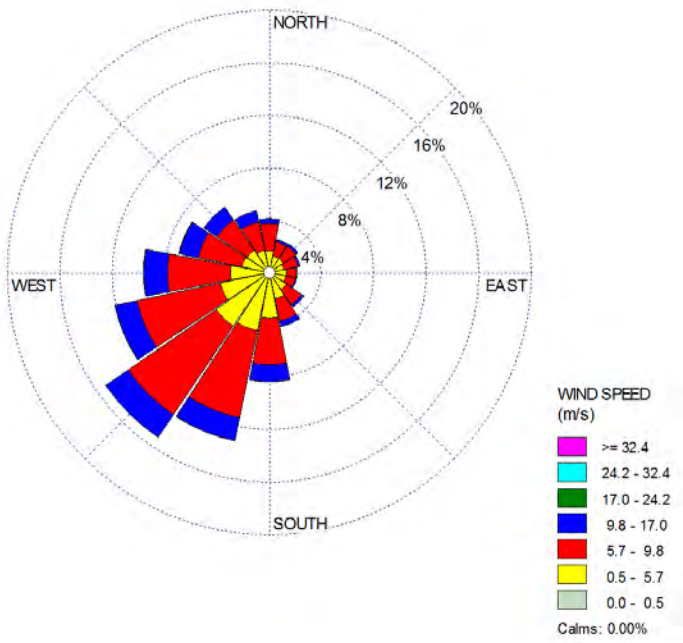

Wind Speed Percentage Occurrence
Grid Point 11154
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

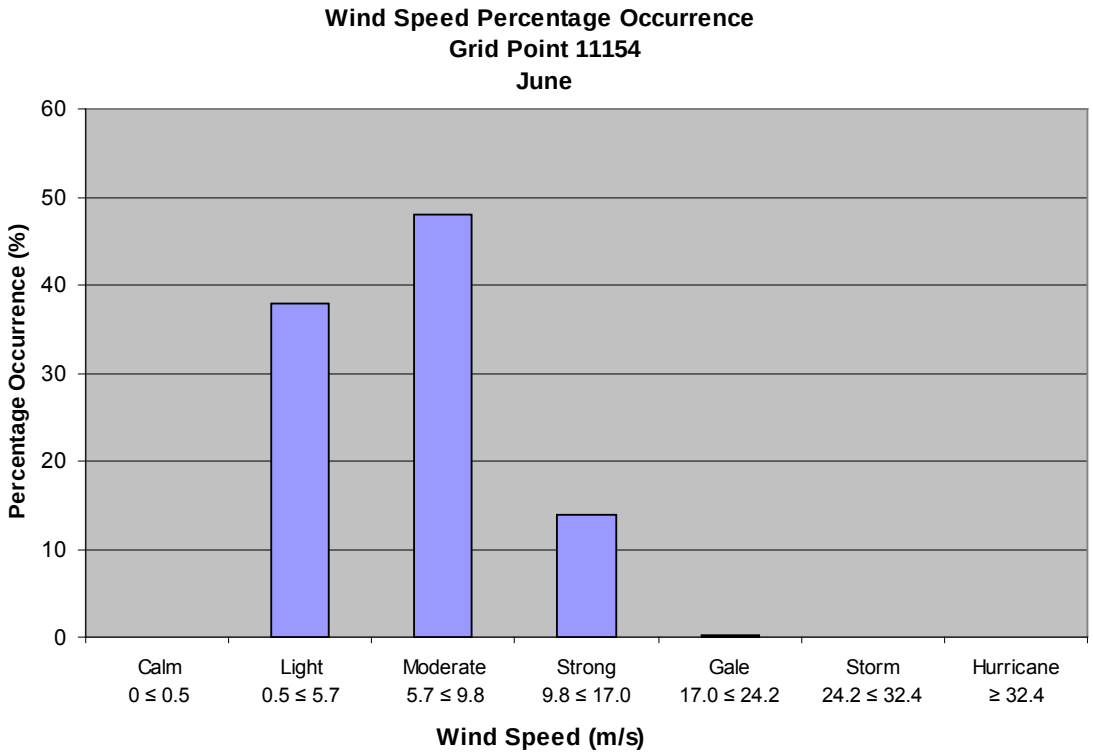
May


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

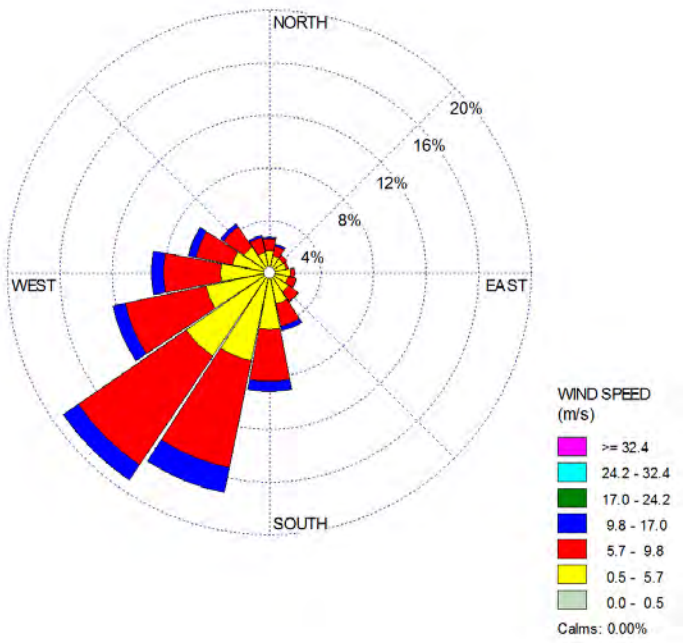

Wind Speed Percentage Occurrence
Grid Point 11154
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

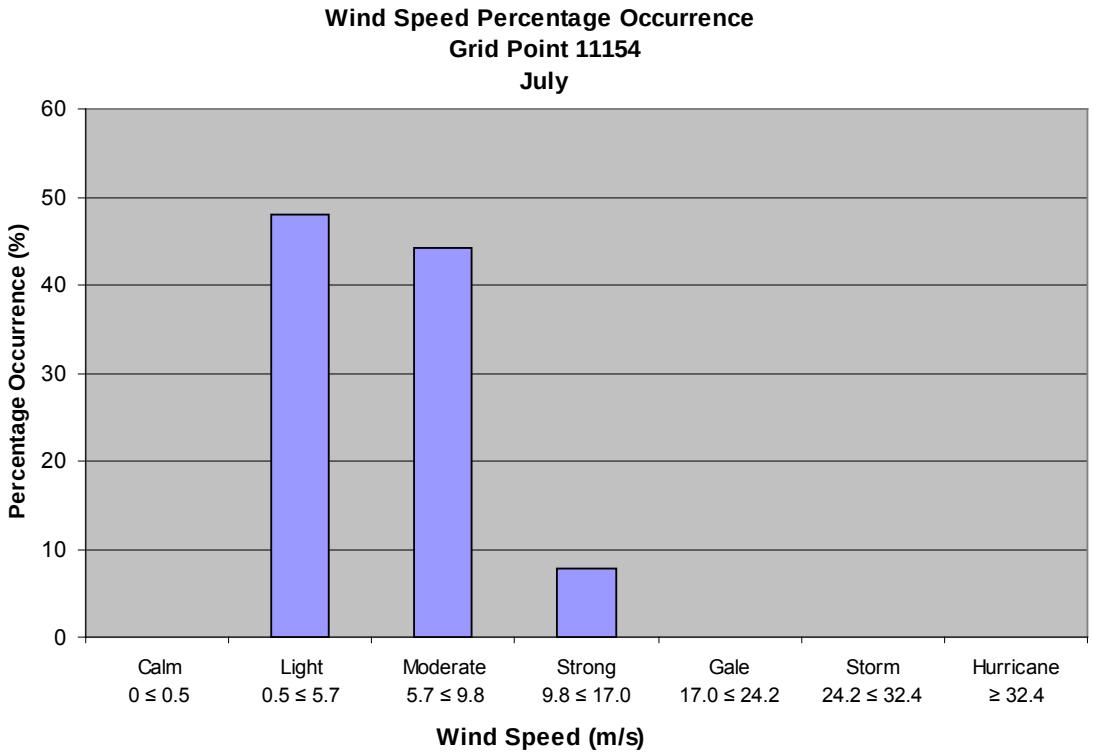
June


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

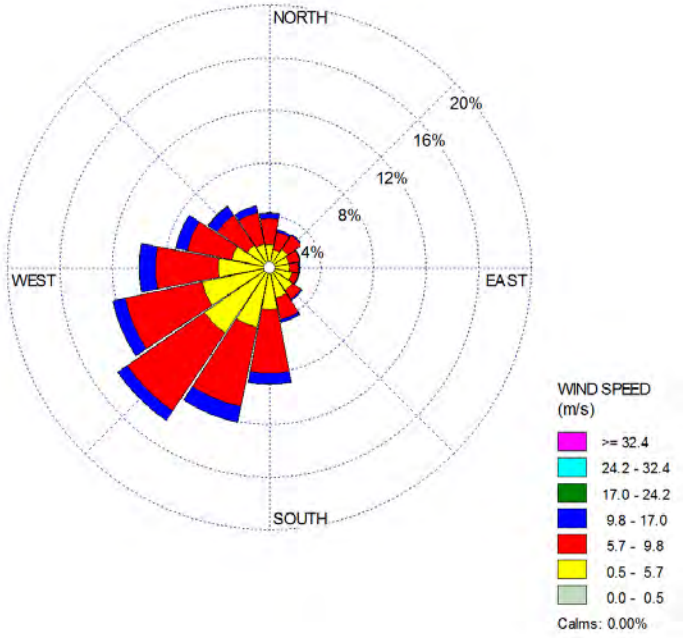

Wind Speed Percentage Occurrence
Grid Point 11154
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

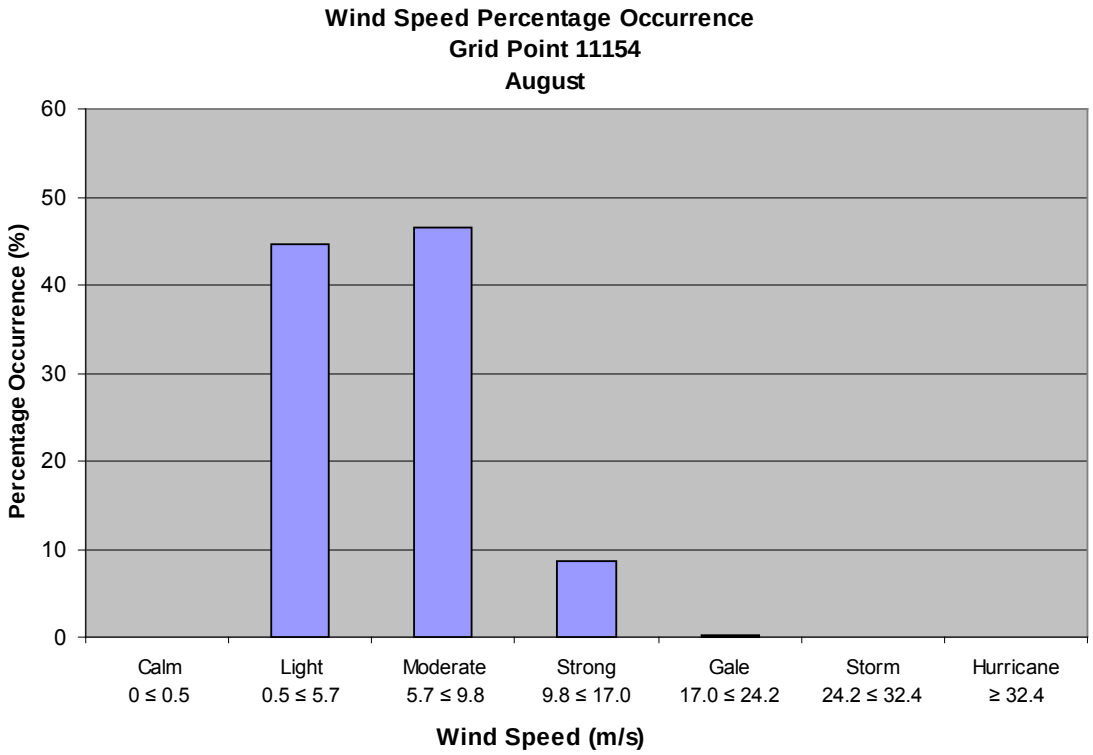
July


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

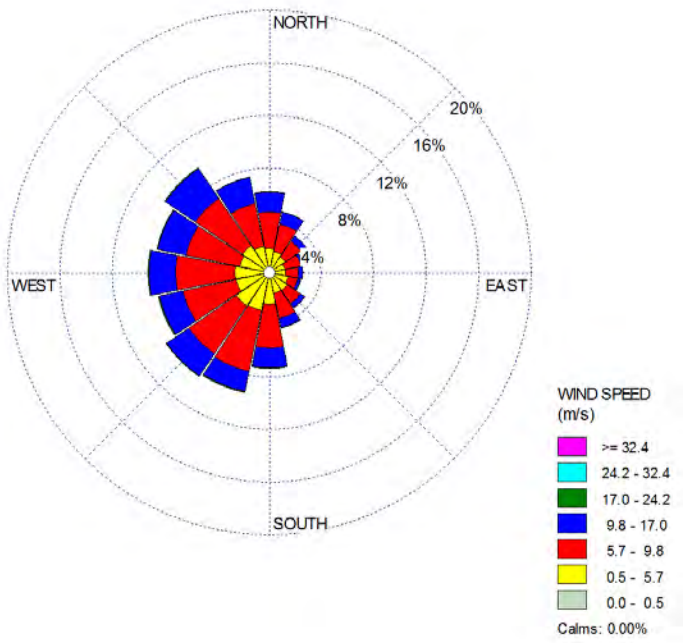

Wind Speed Percentage Occurrence
Grid Point 11154
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

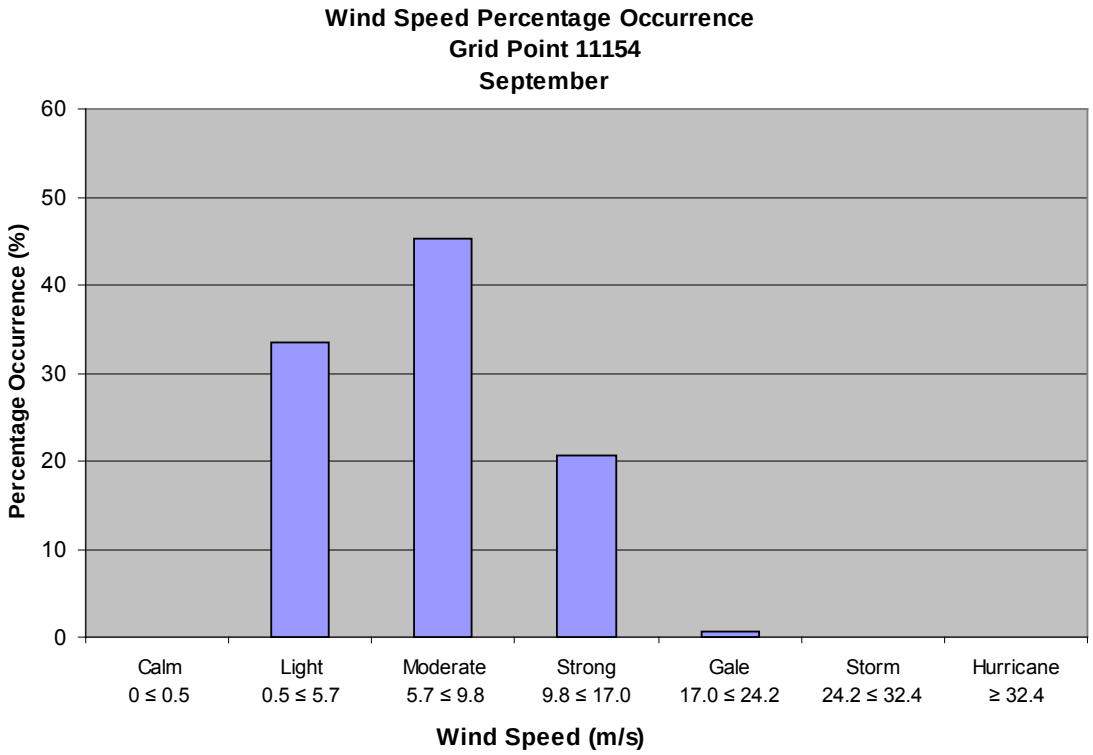
August


NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

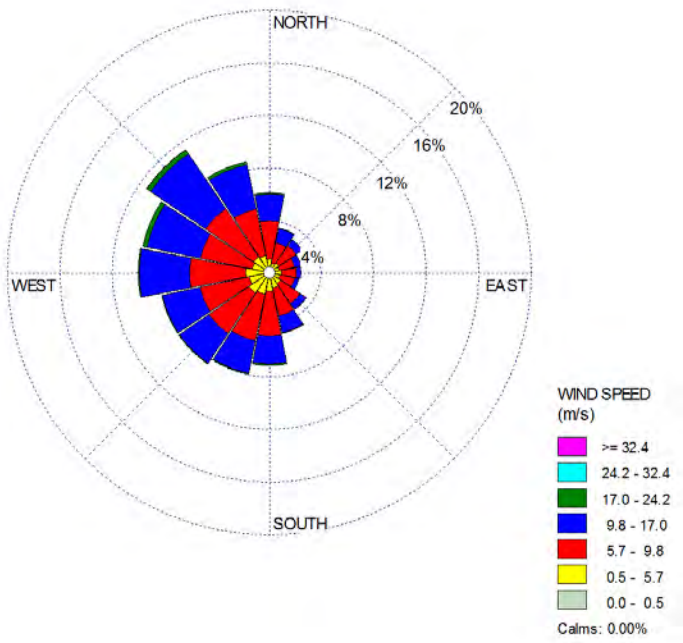

Wind Speed Percentage Occurrence
Grid Point 11154
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

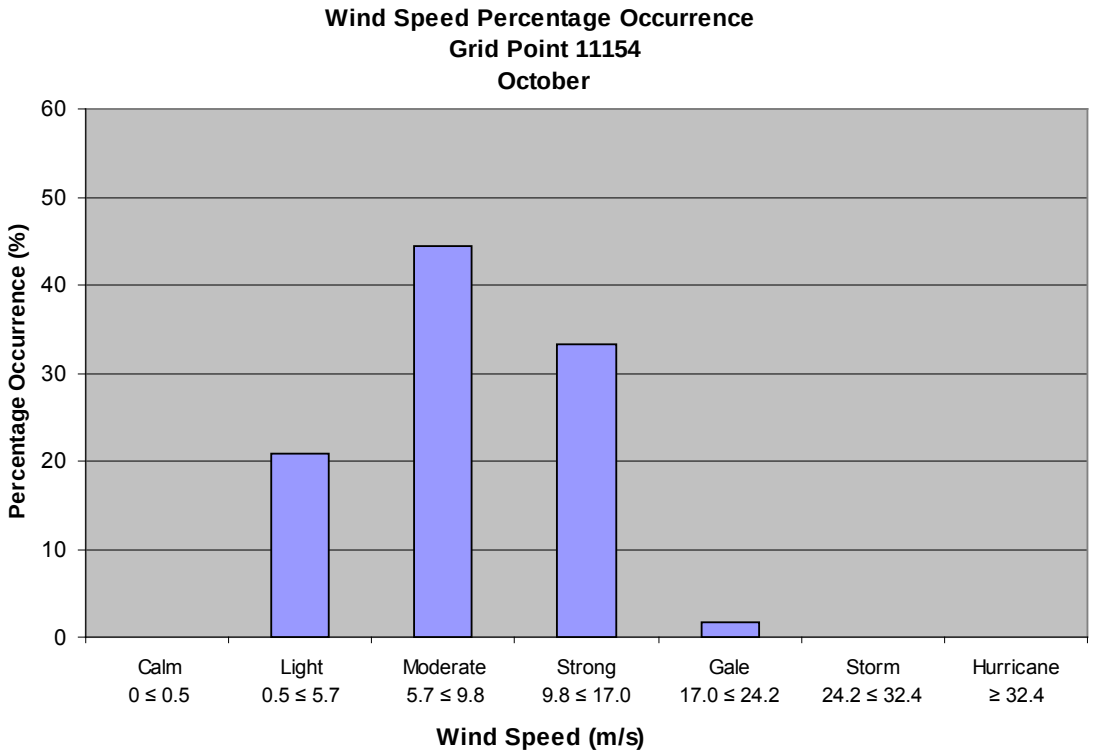
September


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

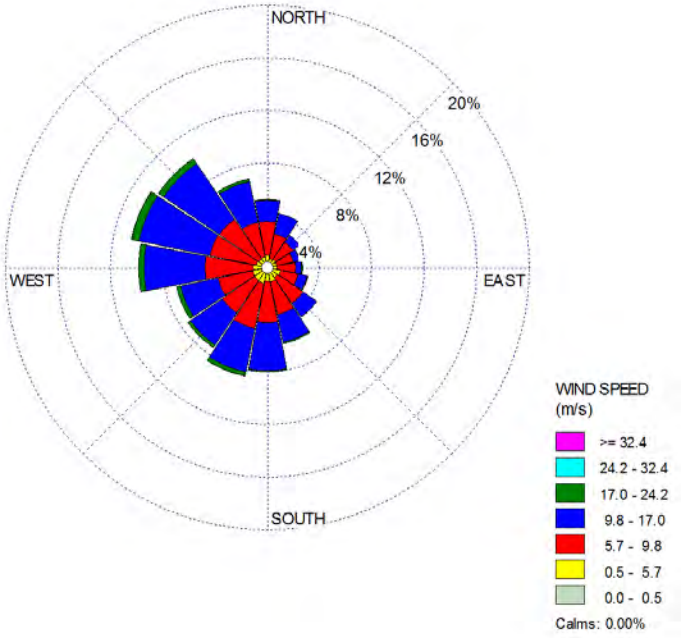

Wind Speed Percentage Occurrence
Grid Point 11154
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

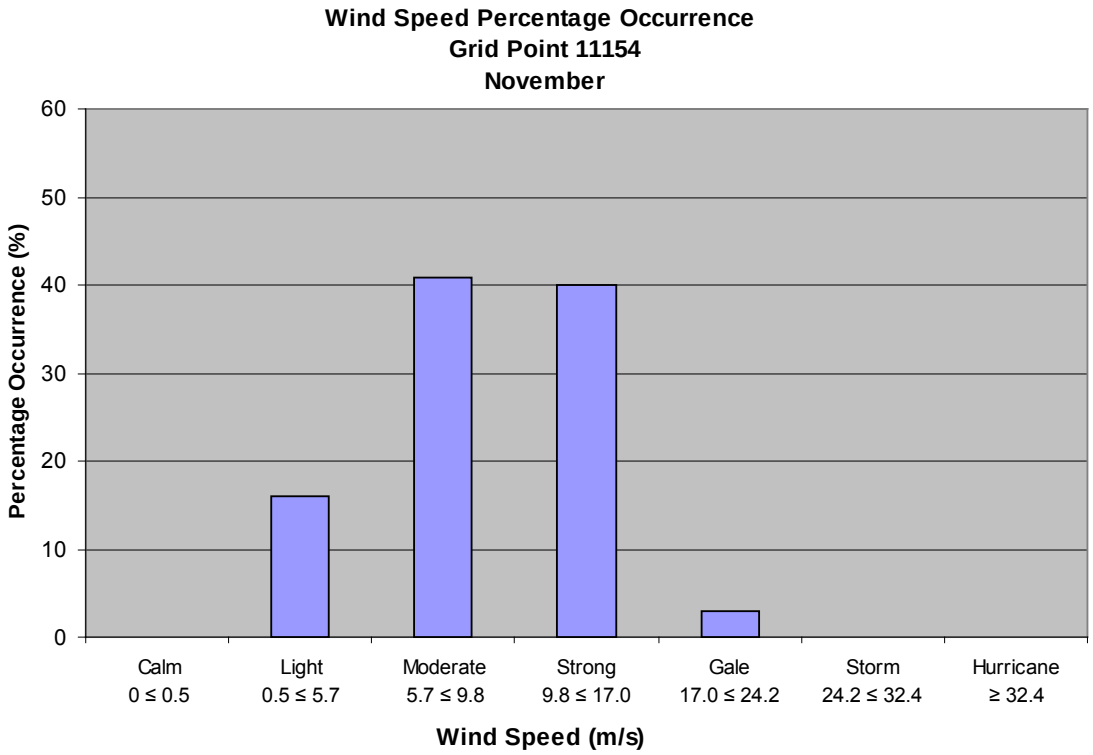
October


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

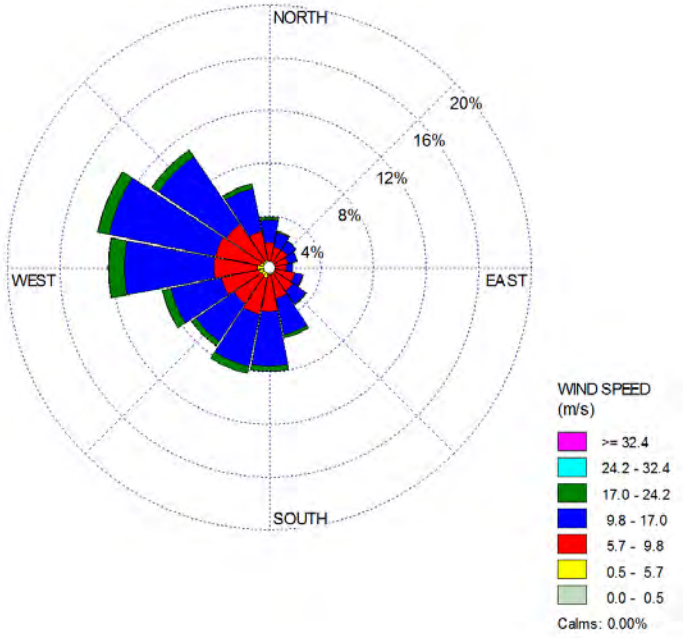

Wind Speed Percentage Occurrence
Grid Point 11154
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

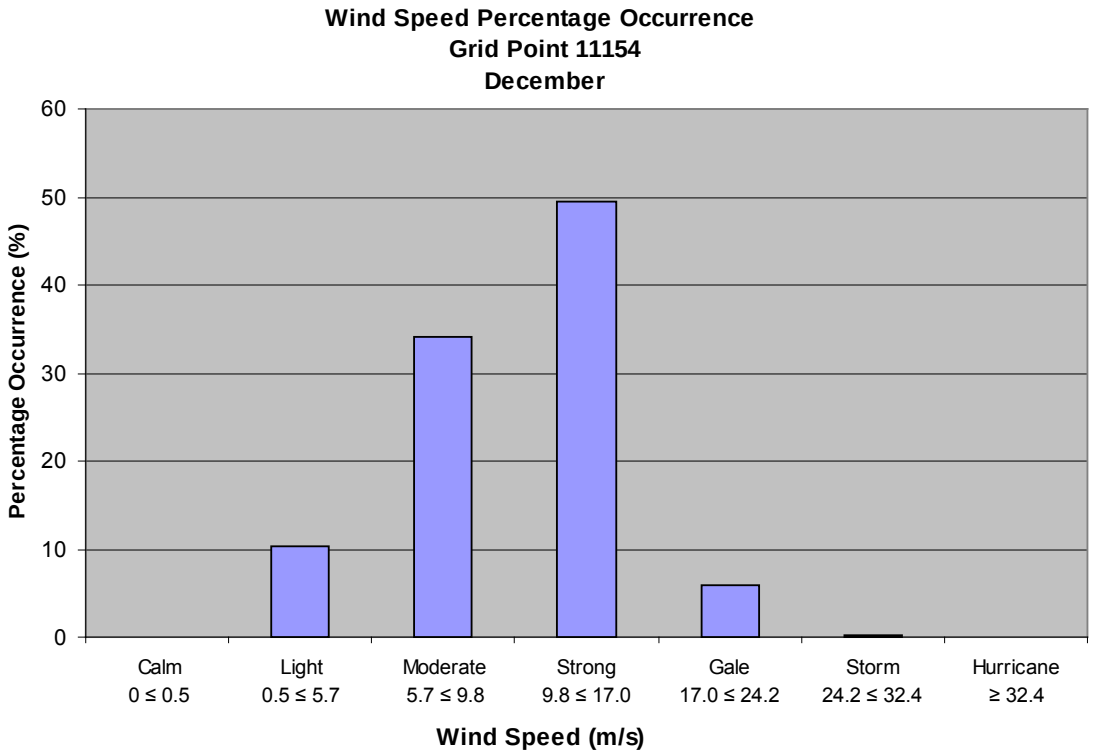
November


NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 11154
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

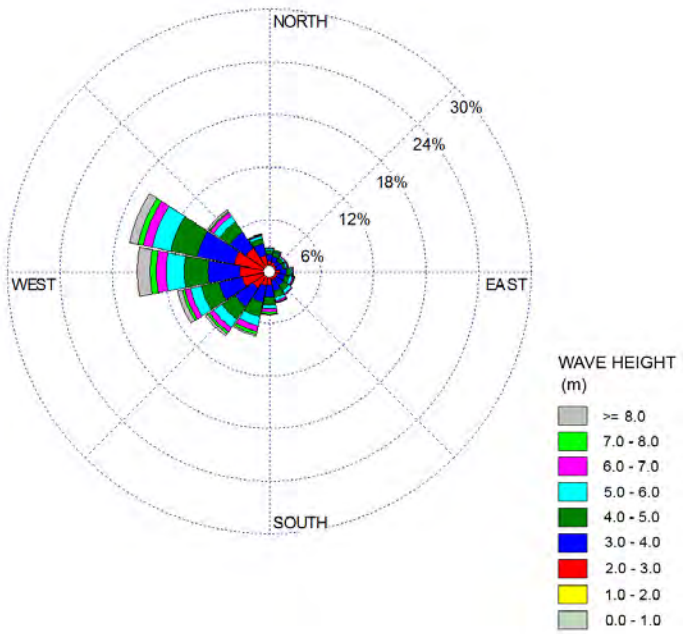
December

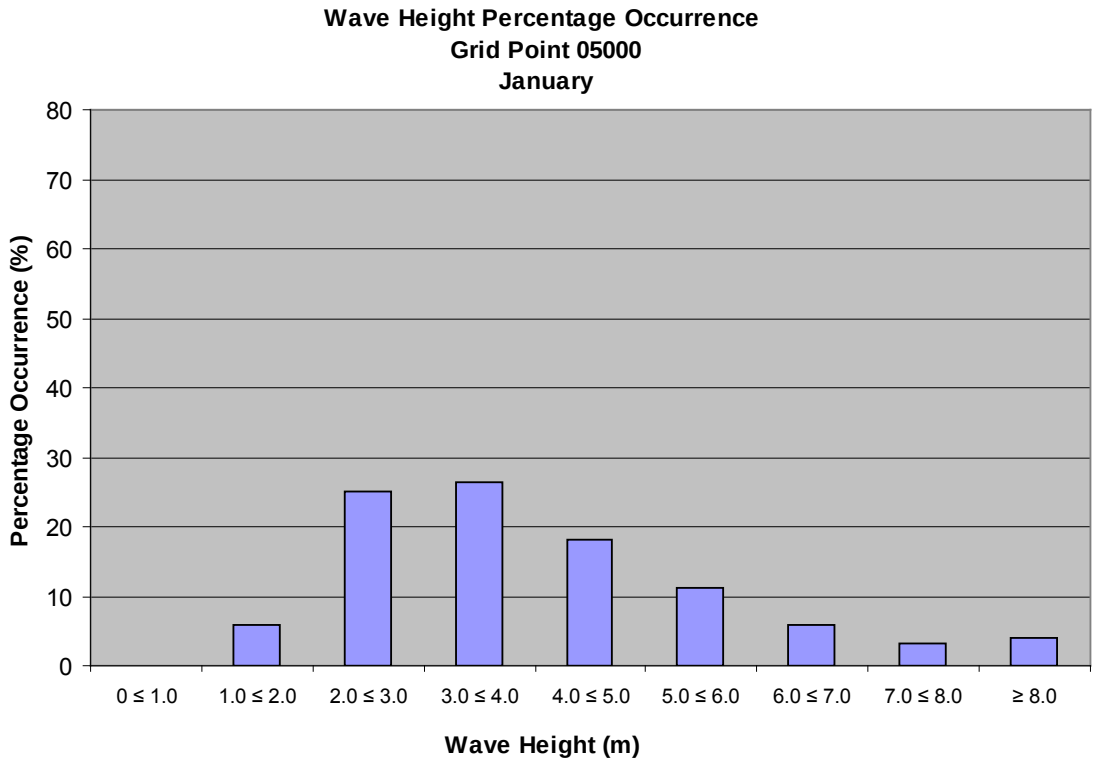

NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 11154
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

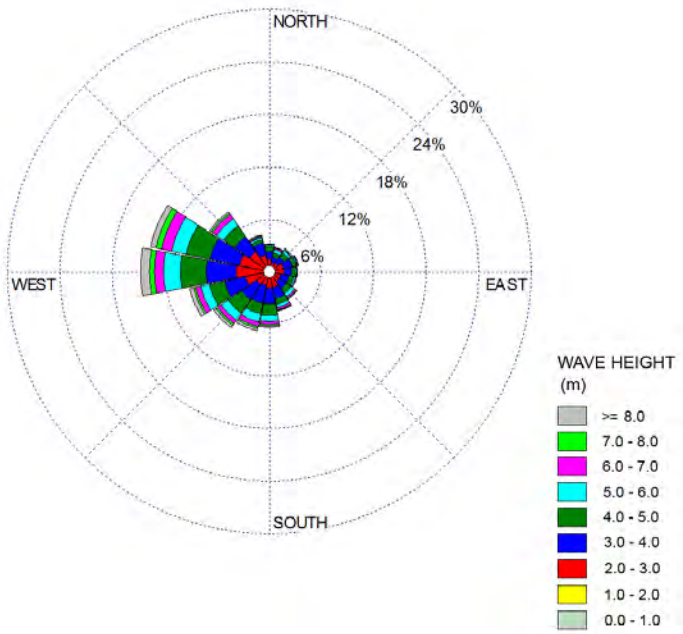
Appendix 6
Wave Roses
and
Wave Height Frequency Distributions
for MSC50 Grid Point 05000

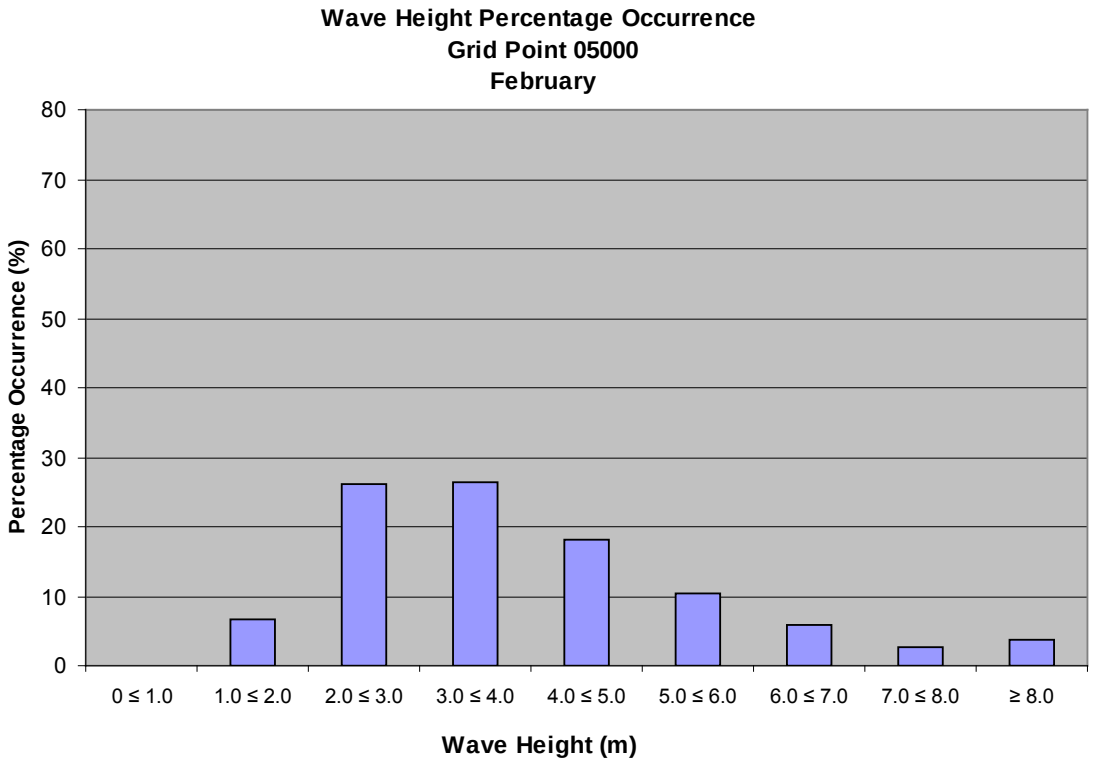
January


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

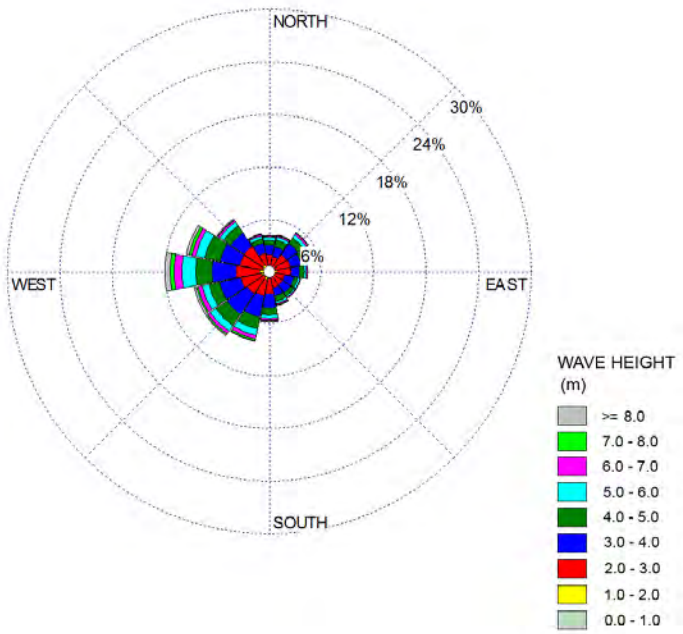

Wave Height Percentage Occurrence
Grid Point 05000
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

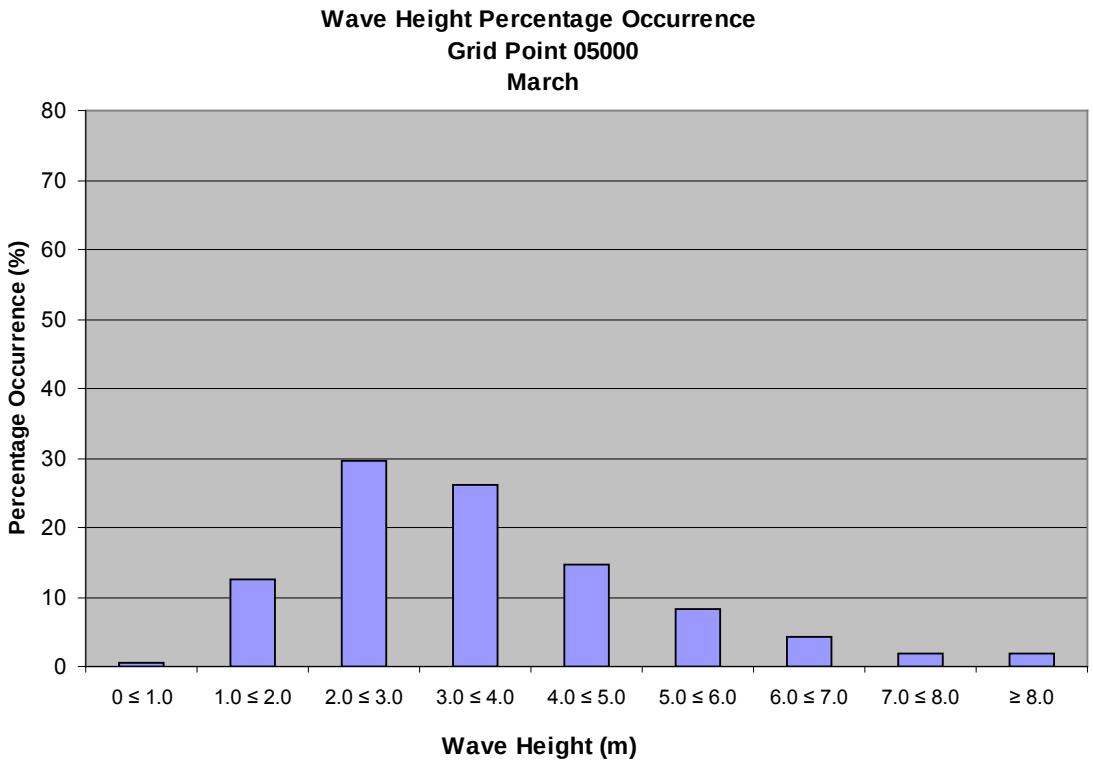
February


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

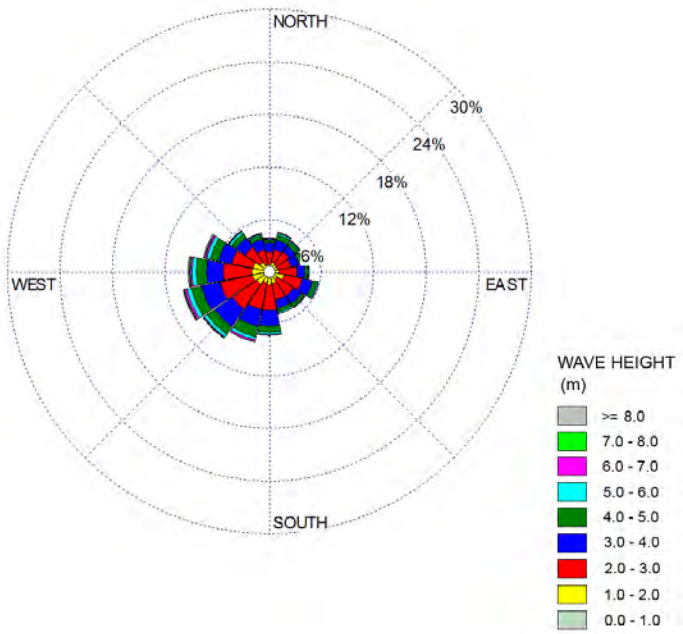

Wave Height Percentage Occurrence
Grid Point 05000
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

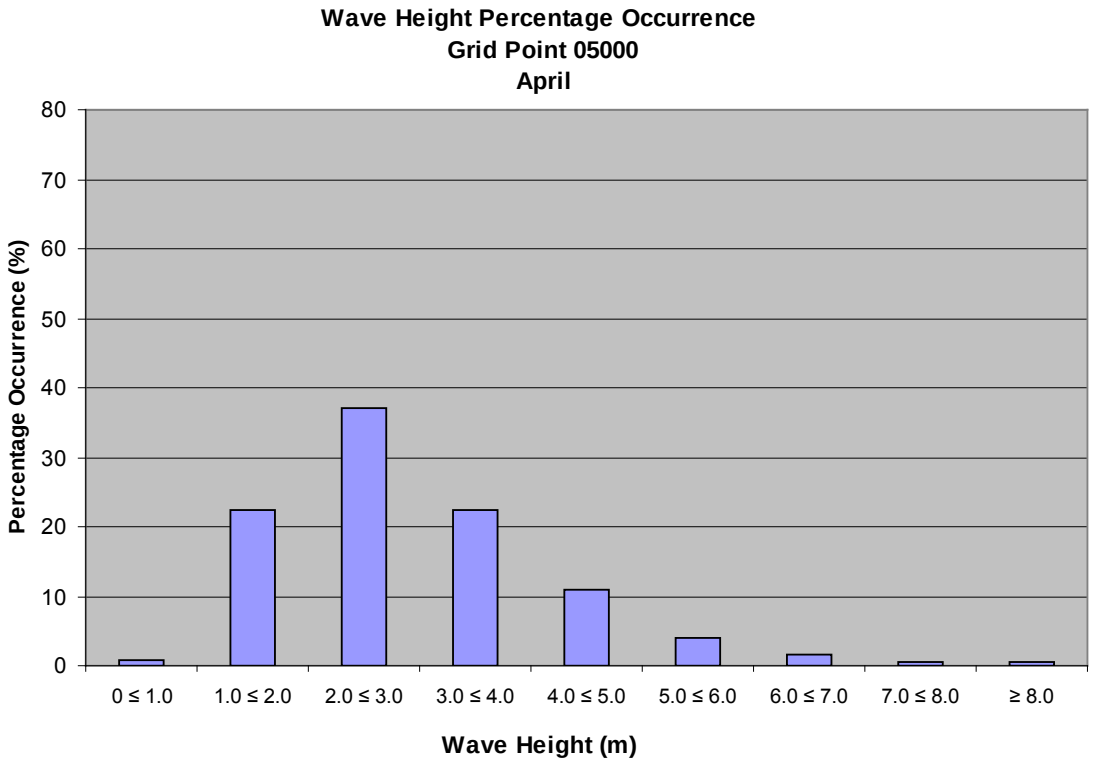
March


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

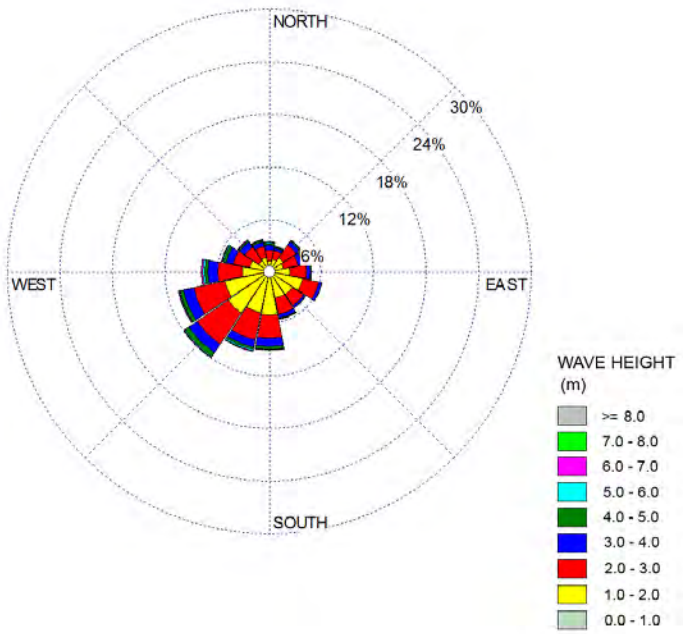

Wave Height Percentage Occurrence
Grid Point 05000
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

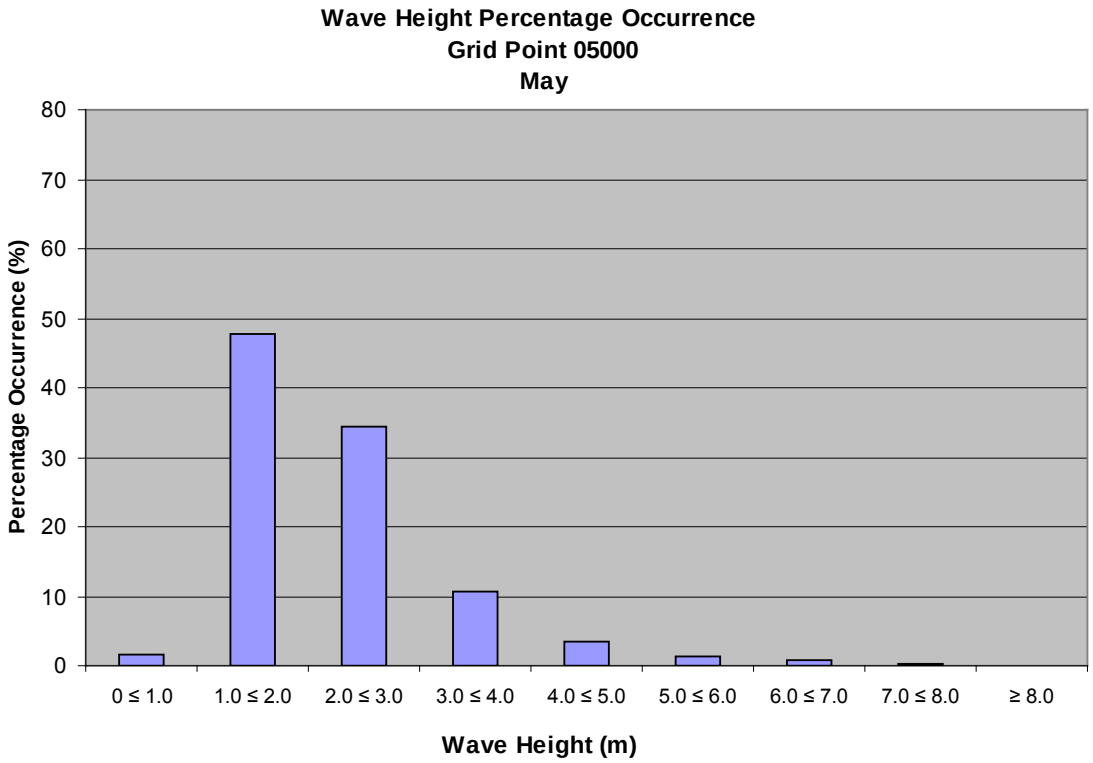
April


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

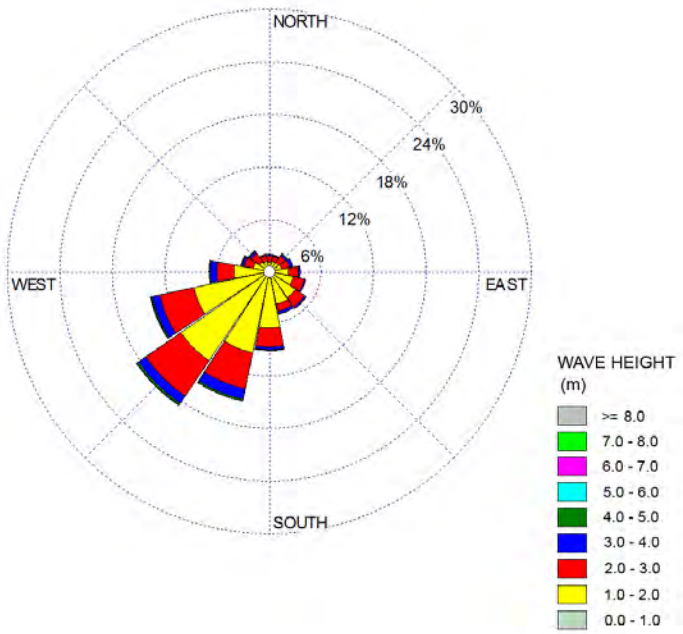

Wave Height Percentage Occurrence
Grid Point 05000
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

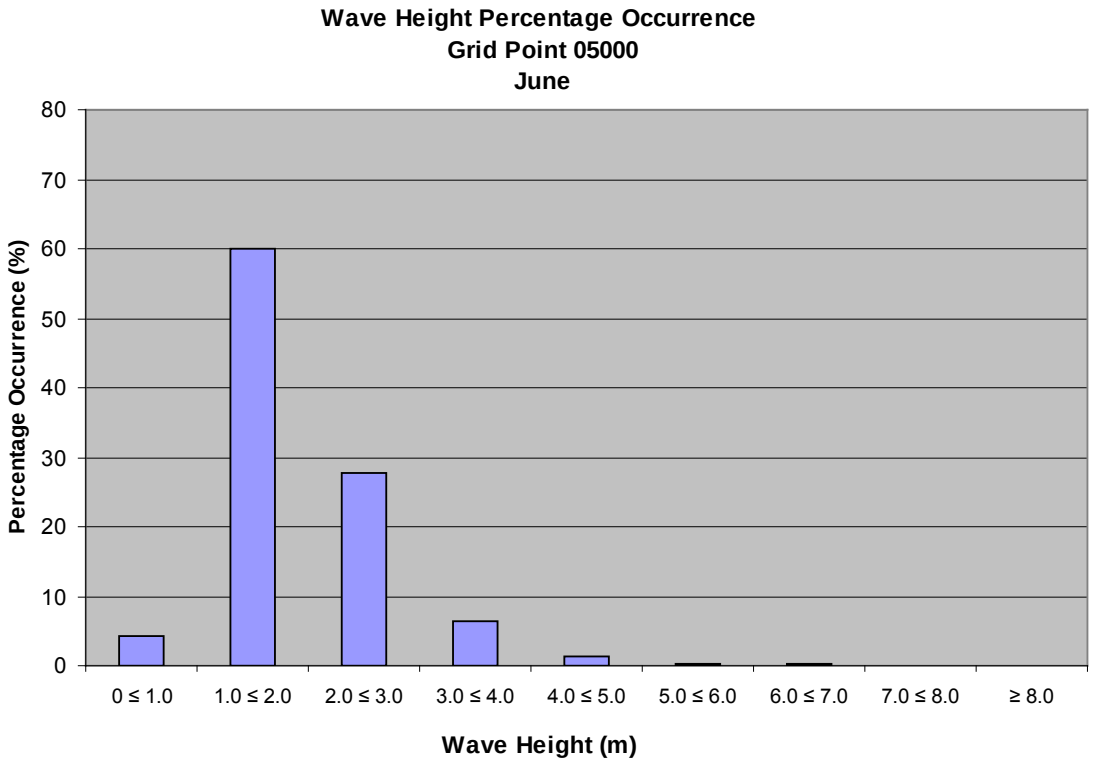
May


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

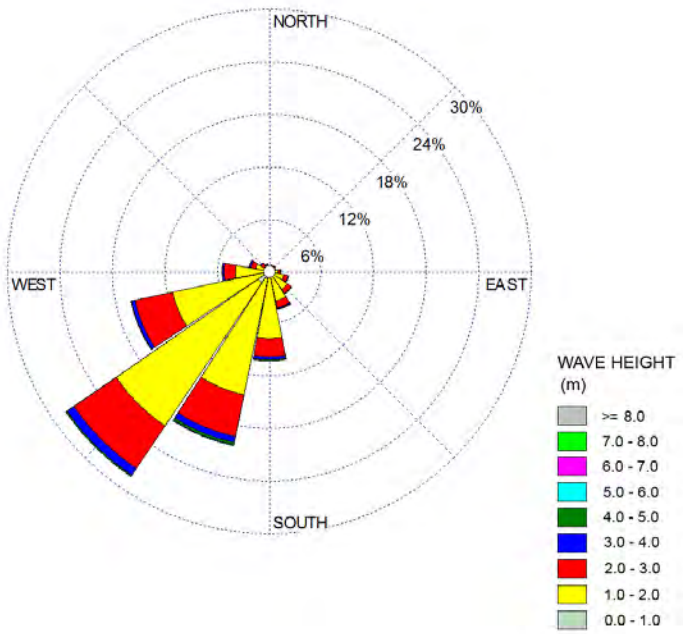

Wave Height Percentage Occurrence
Grid Point 05000
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

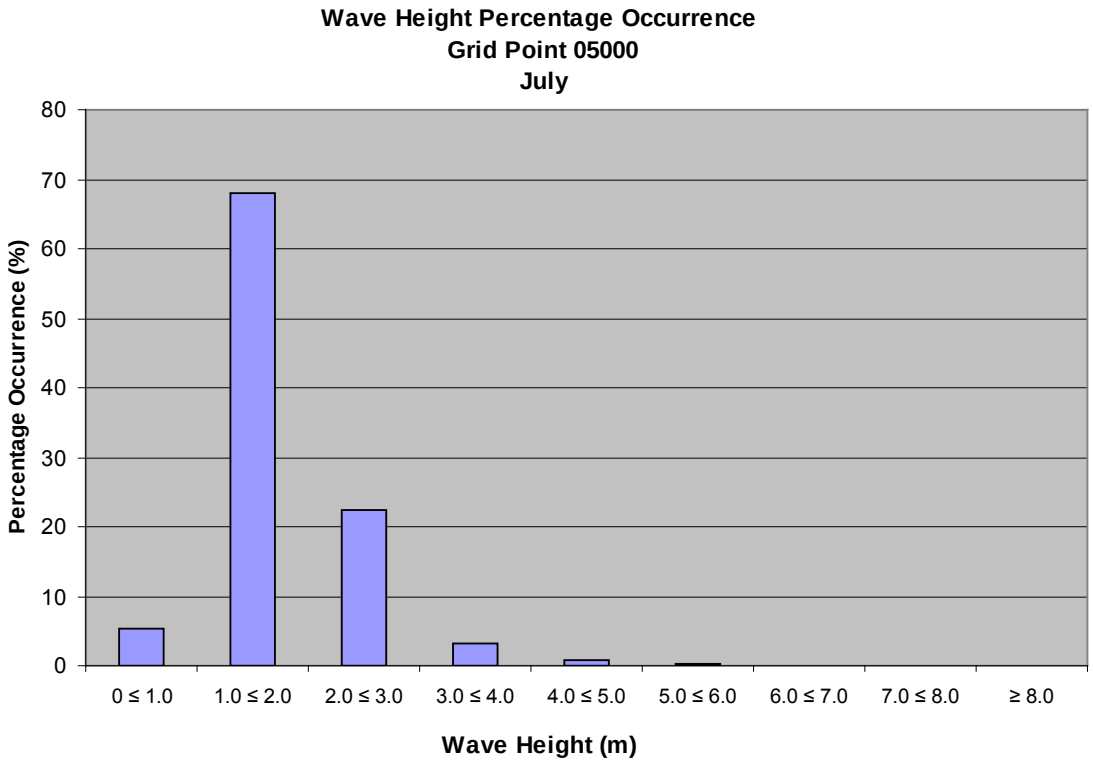
June


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

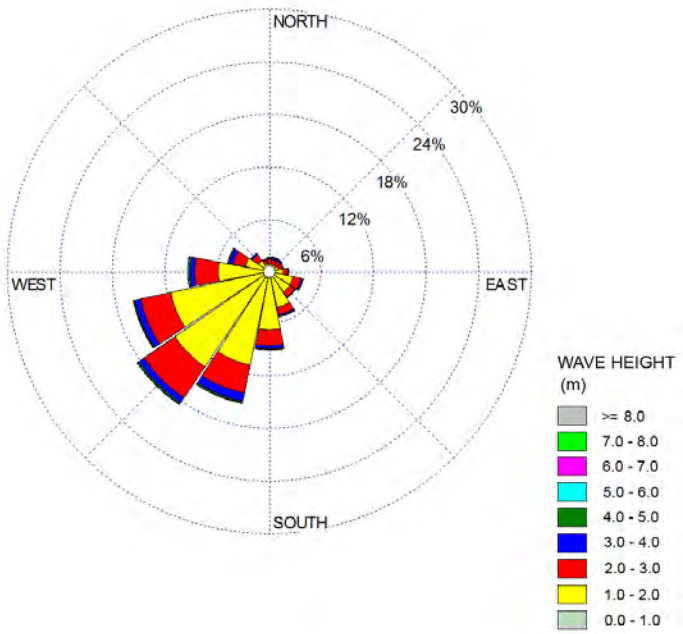

Wave Height Percentage Occurrence
Grid Point 05000
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

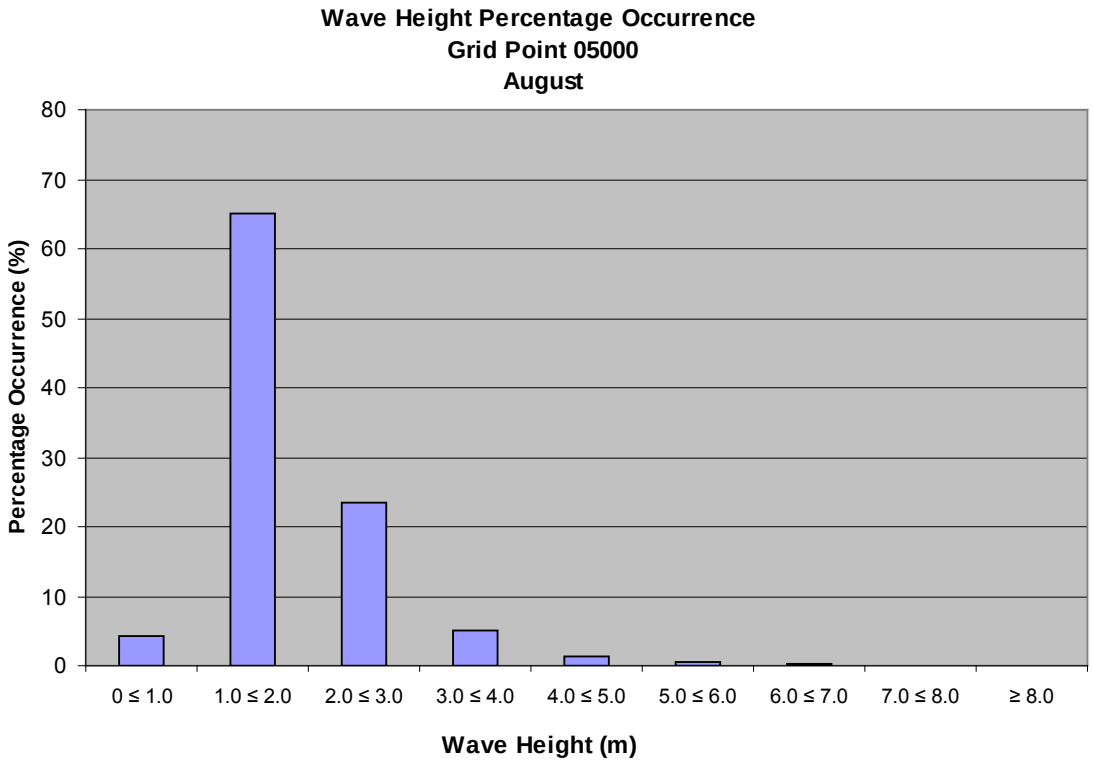
July


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

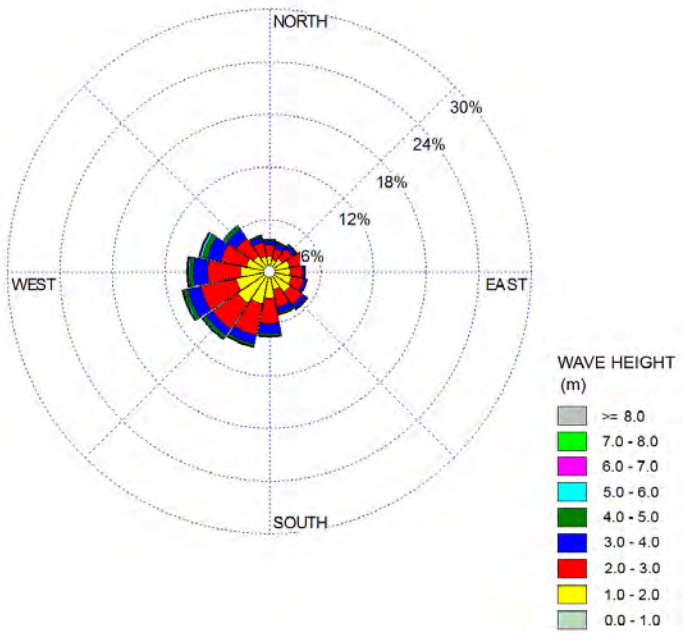

Wave Height Percentage Occurrence
Grid Point 05000
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

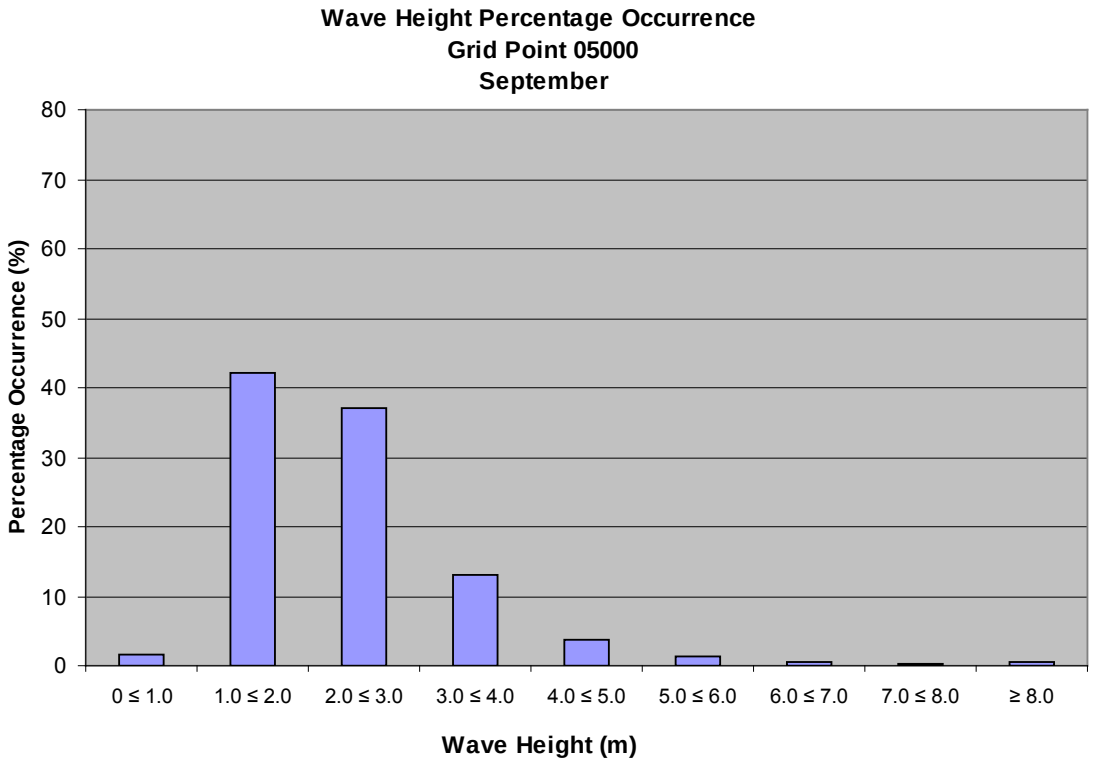
August


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

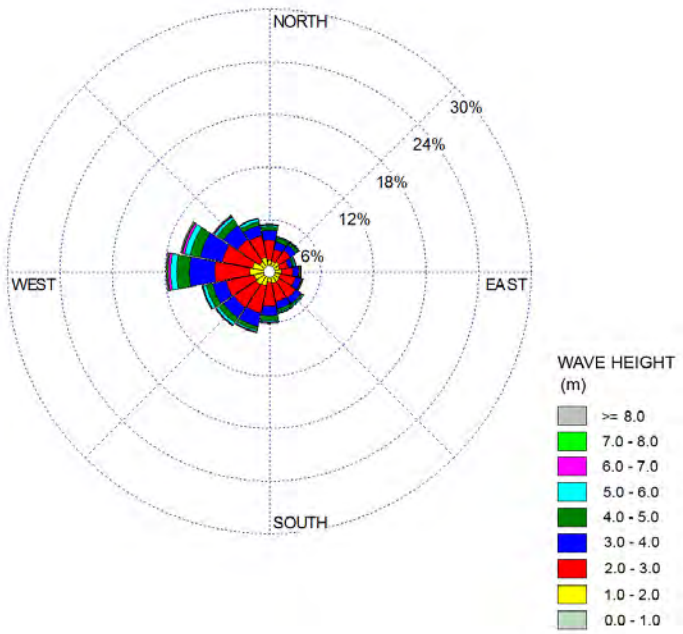

Wave Height Percentage Occurrence
Grid Point 05000
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

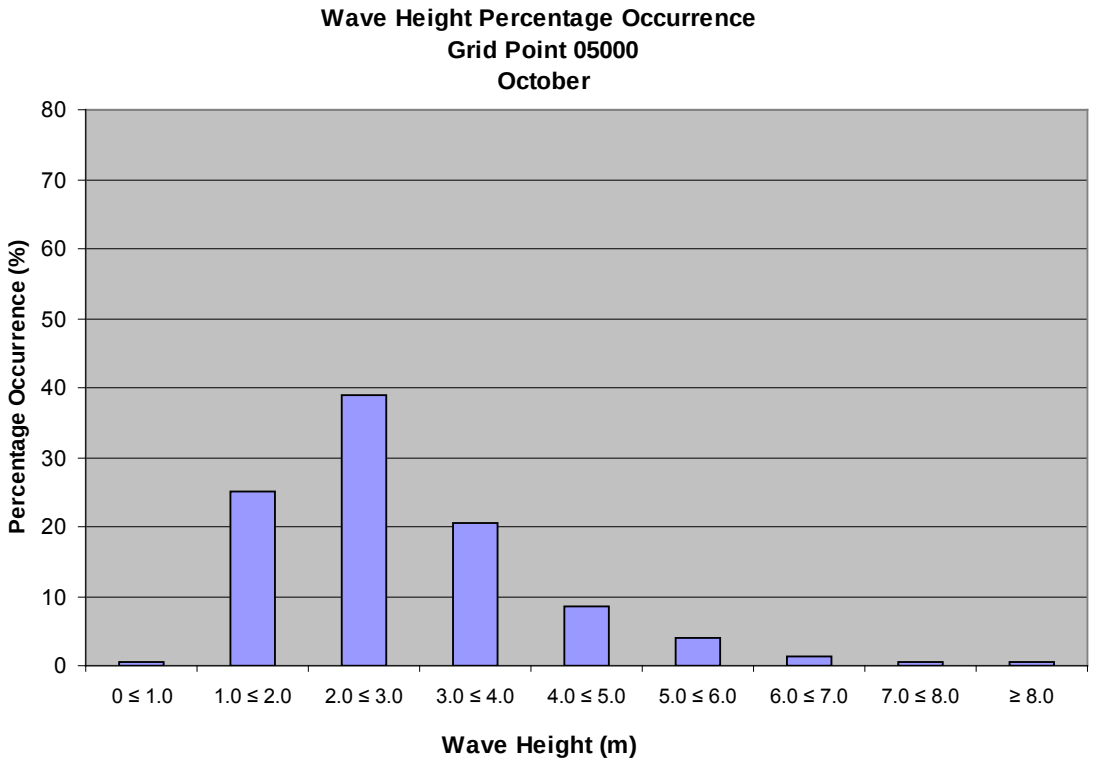
September


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

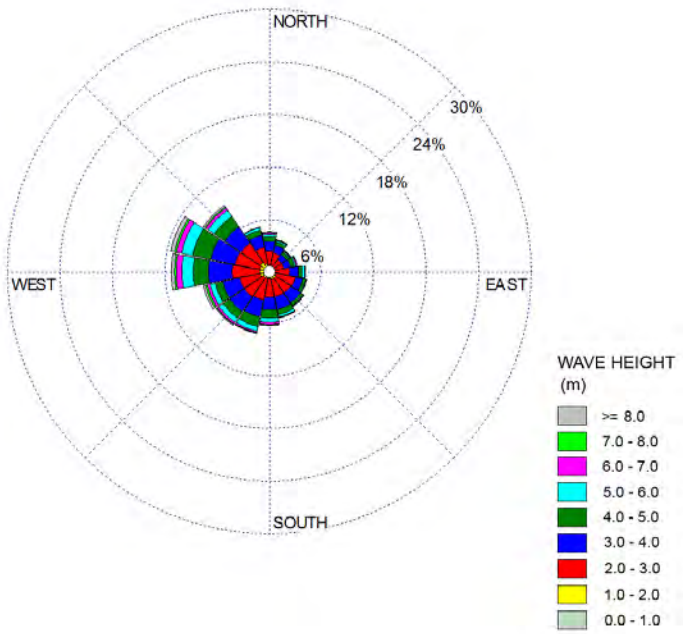

Wave Height Percentage Occurrence
Grid Point 05000
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

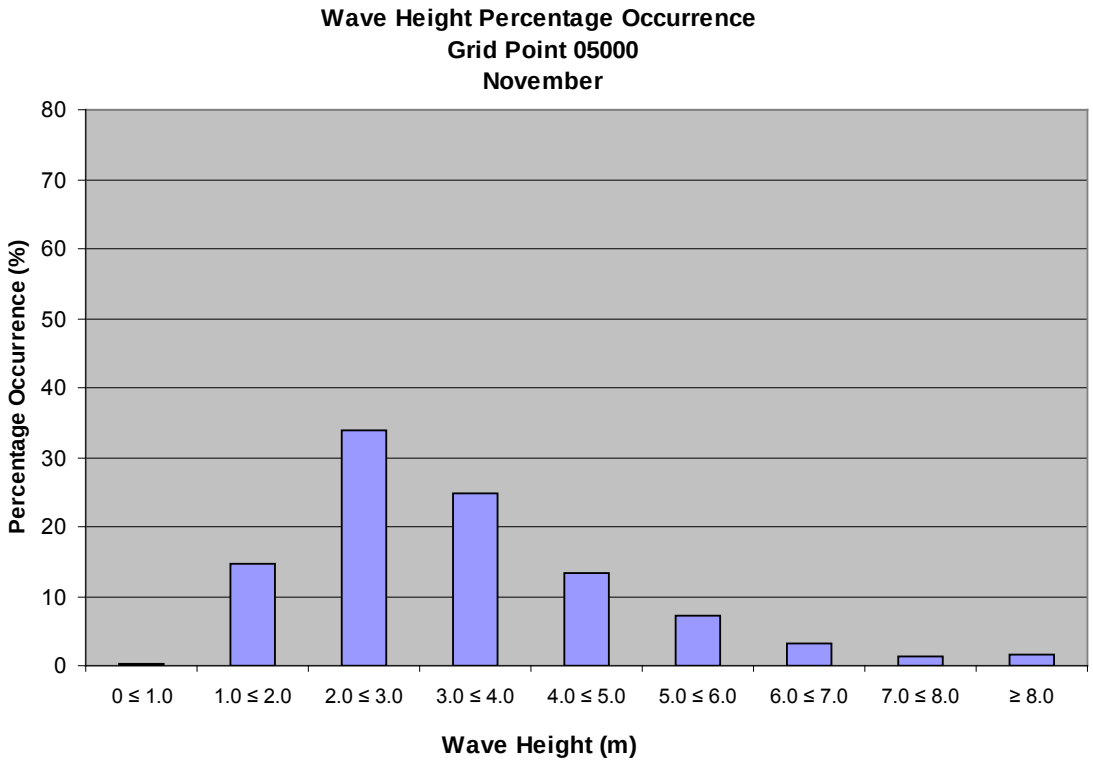
October


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

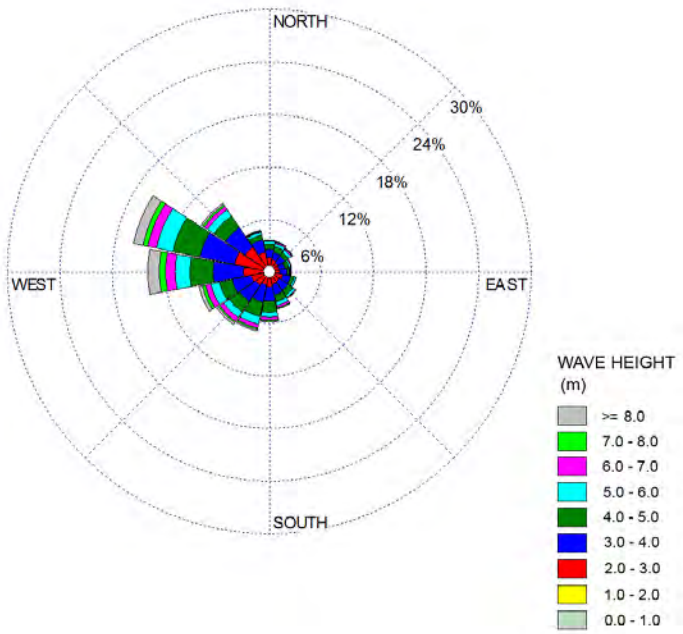

Wave Height Percentage Occurrence
Grid Point 05000
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

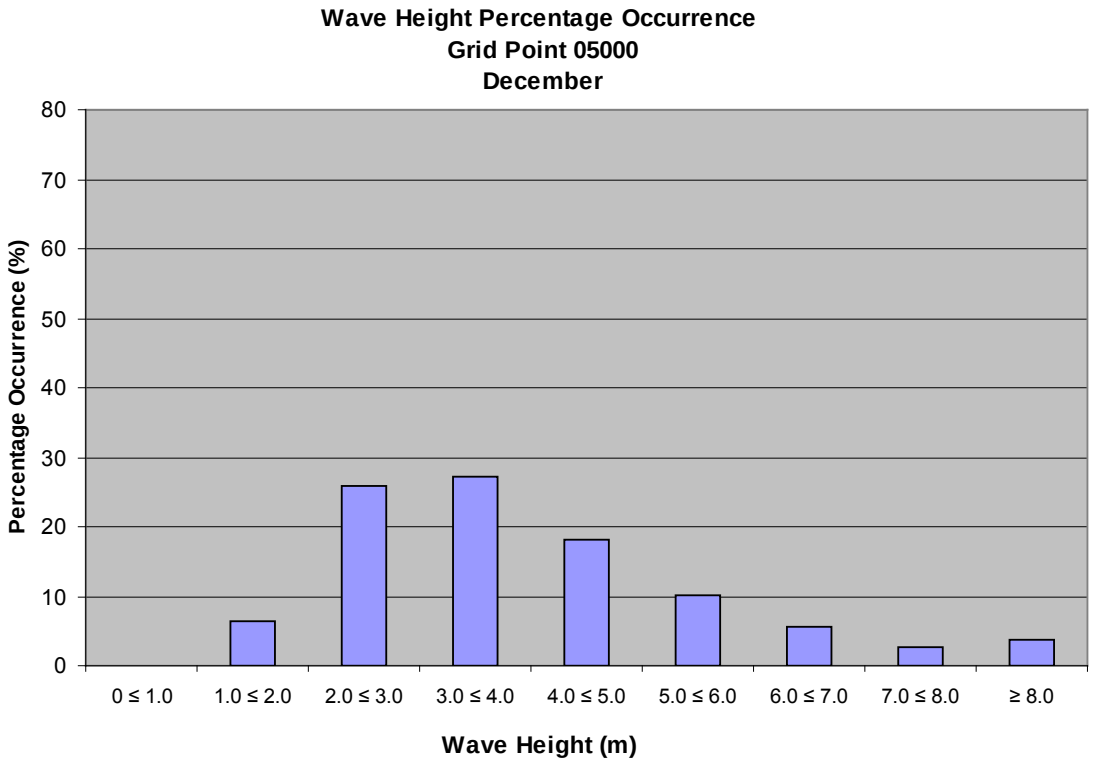
November


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 05000
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

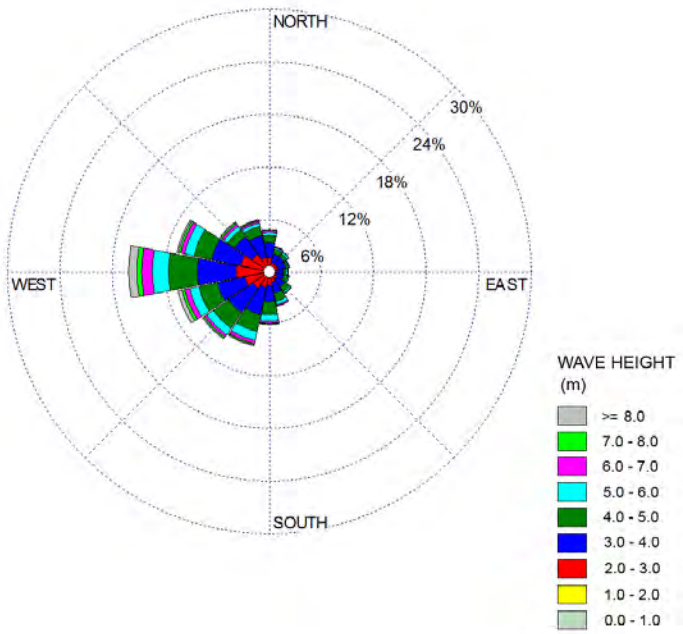
December

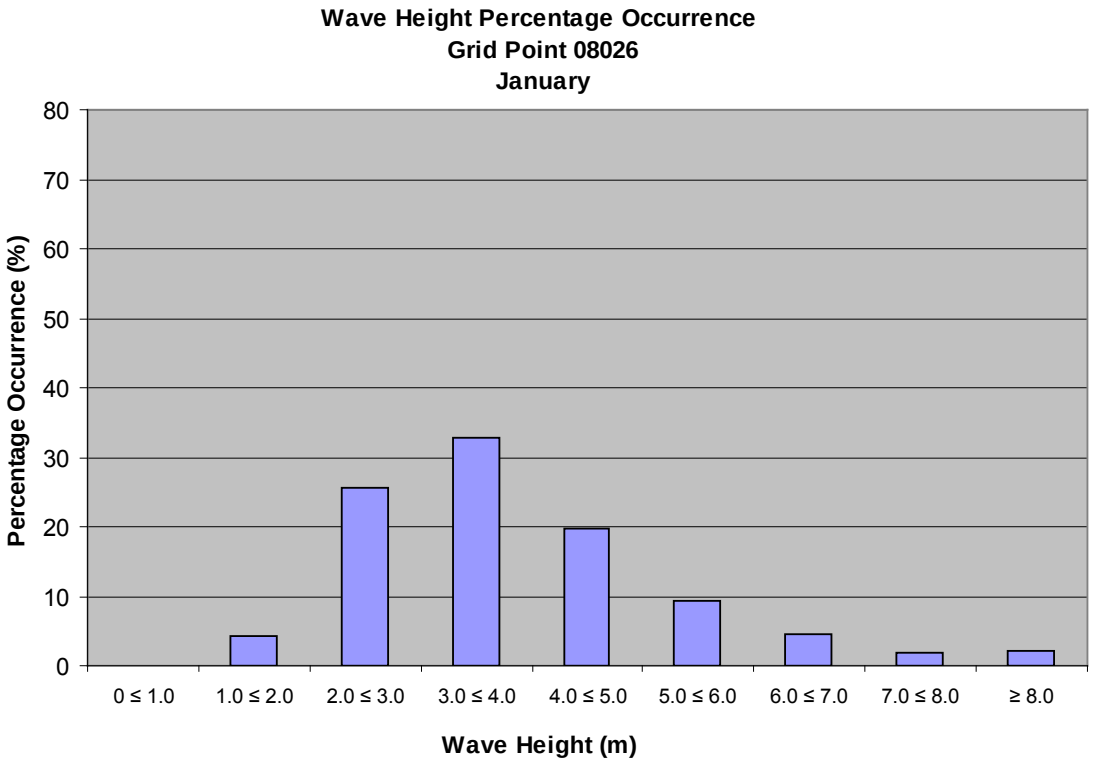

NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 05000
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

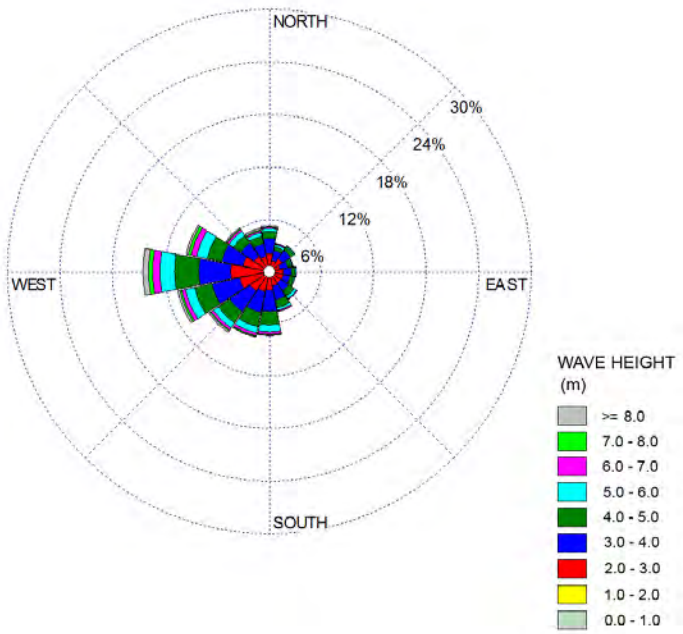
Appendix 7
Wave Roses
and
Wave Height Frequency Distributions
for MSC50 Grid Point 08026

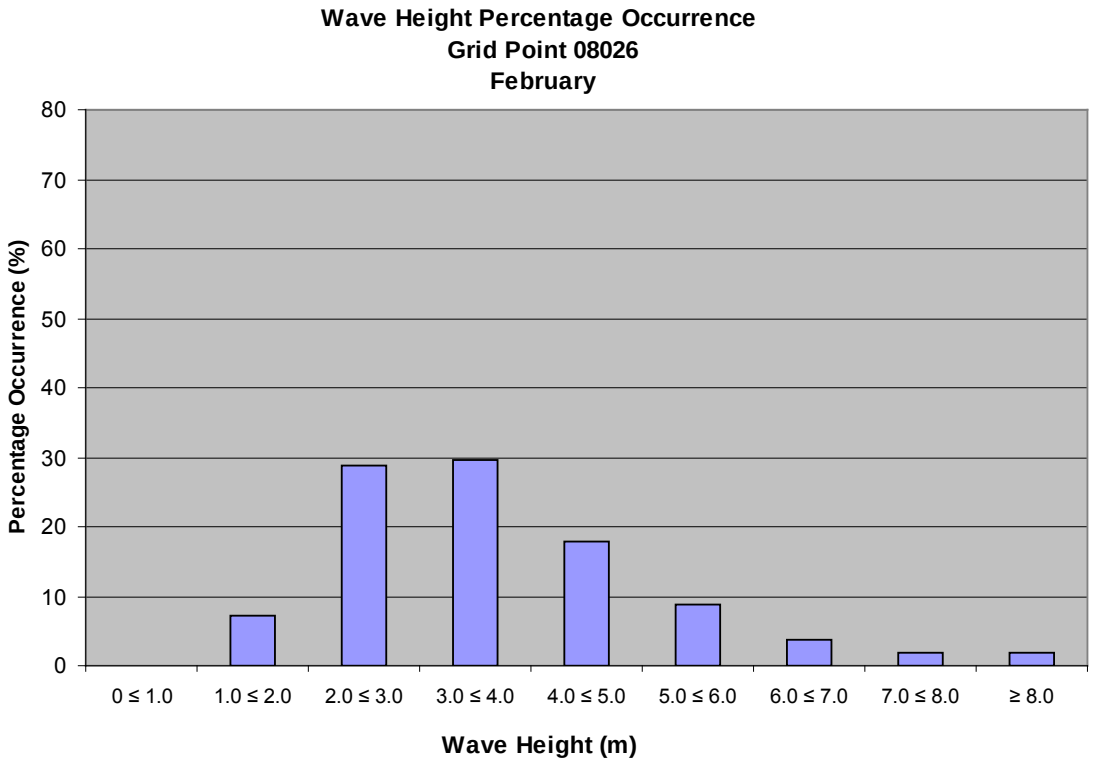
January


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

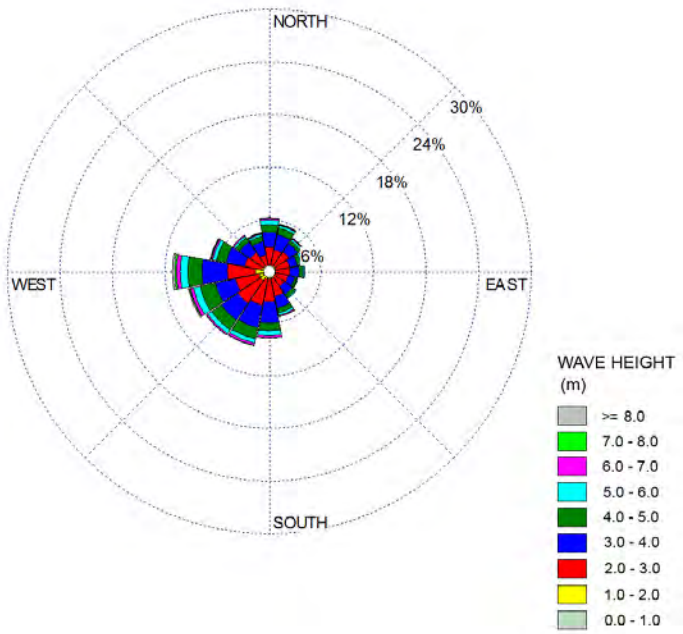

Wave Height Percentage Occurrence
Grid Point 08026
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

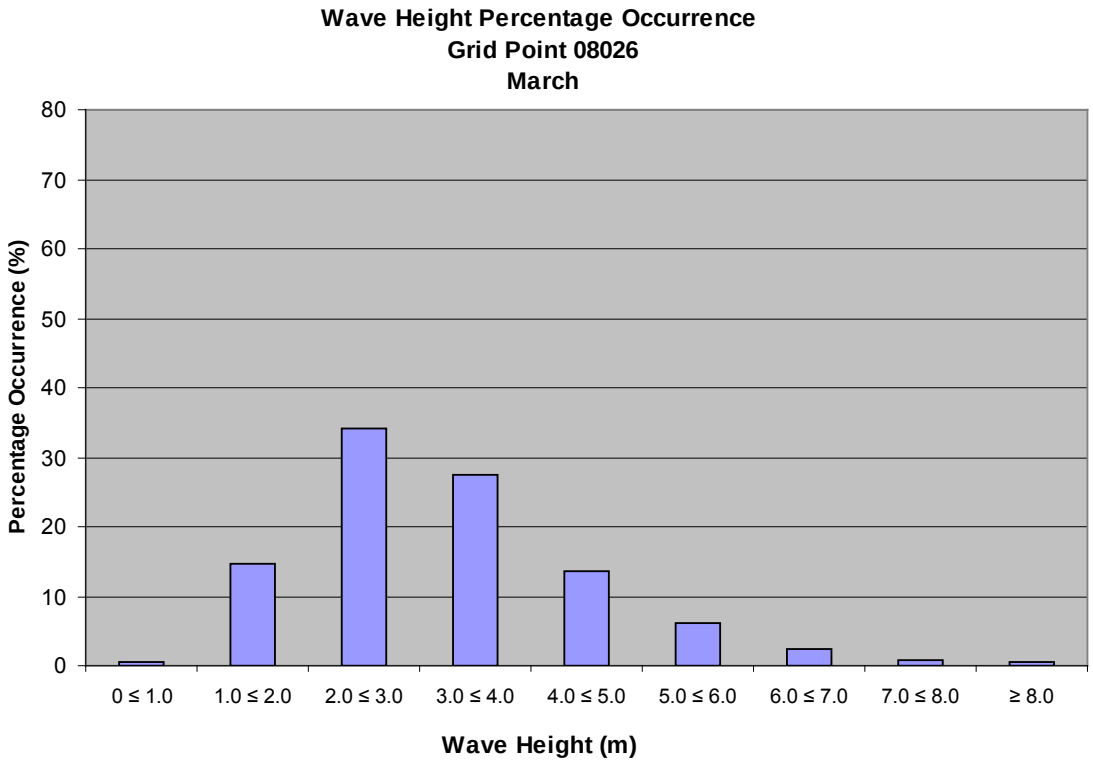
February


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

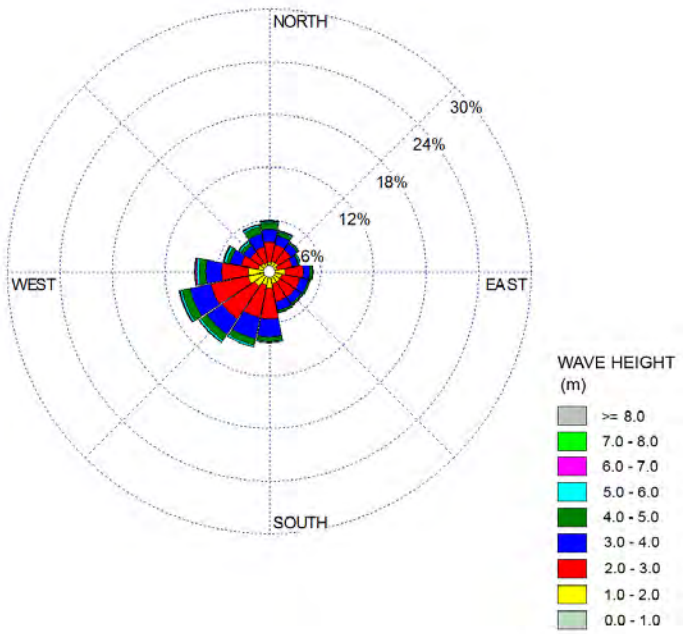

Wave Height Percentage Occurrence
Grid Point 08026
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

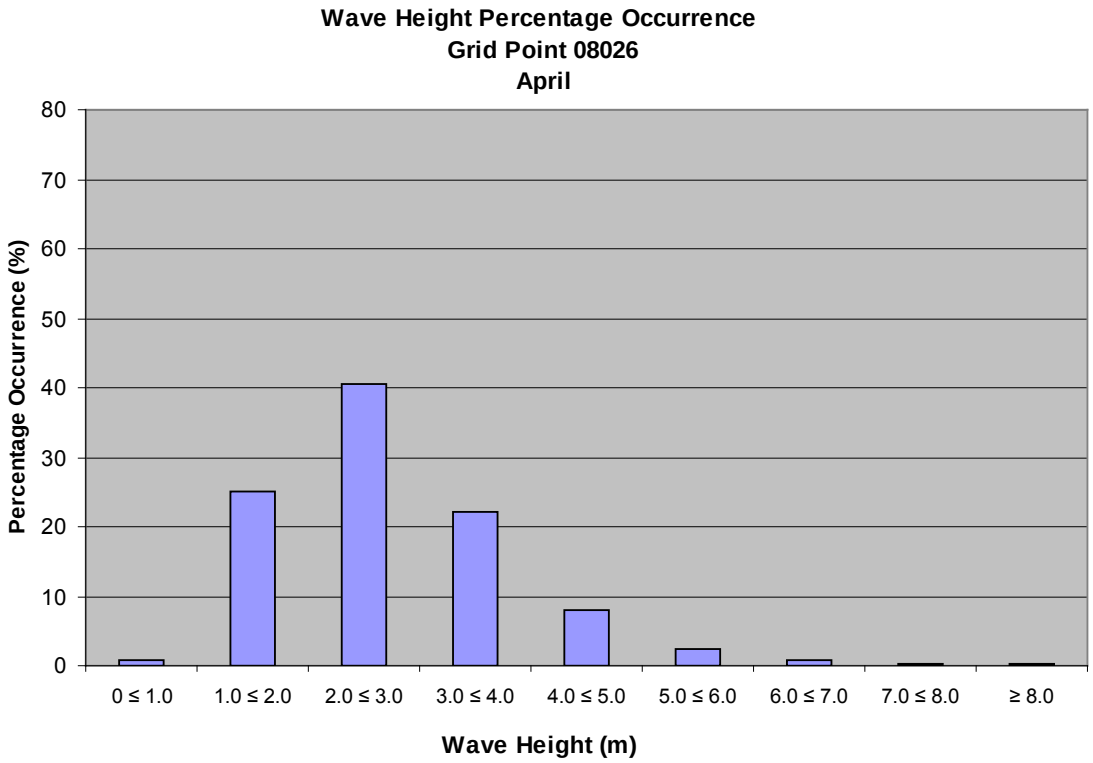
March


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

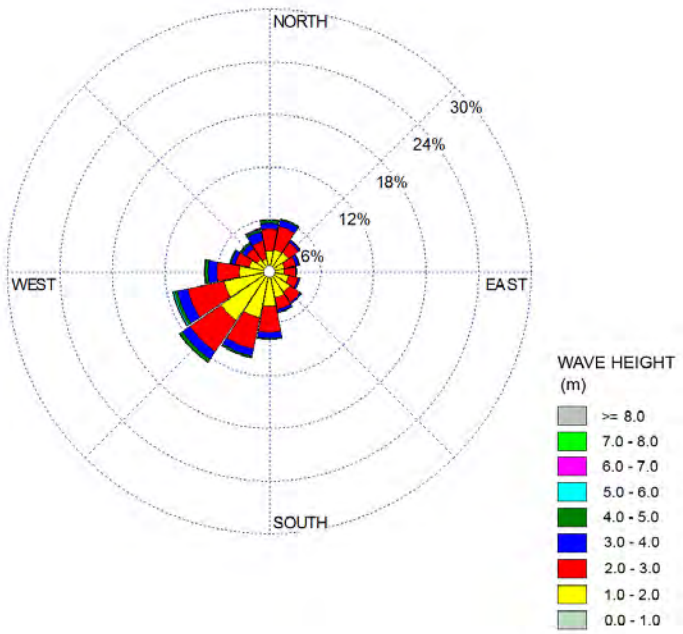

Wave Height Percentage Occurrence
Grid Point 08026
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

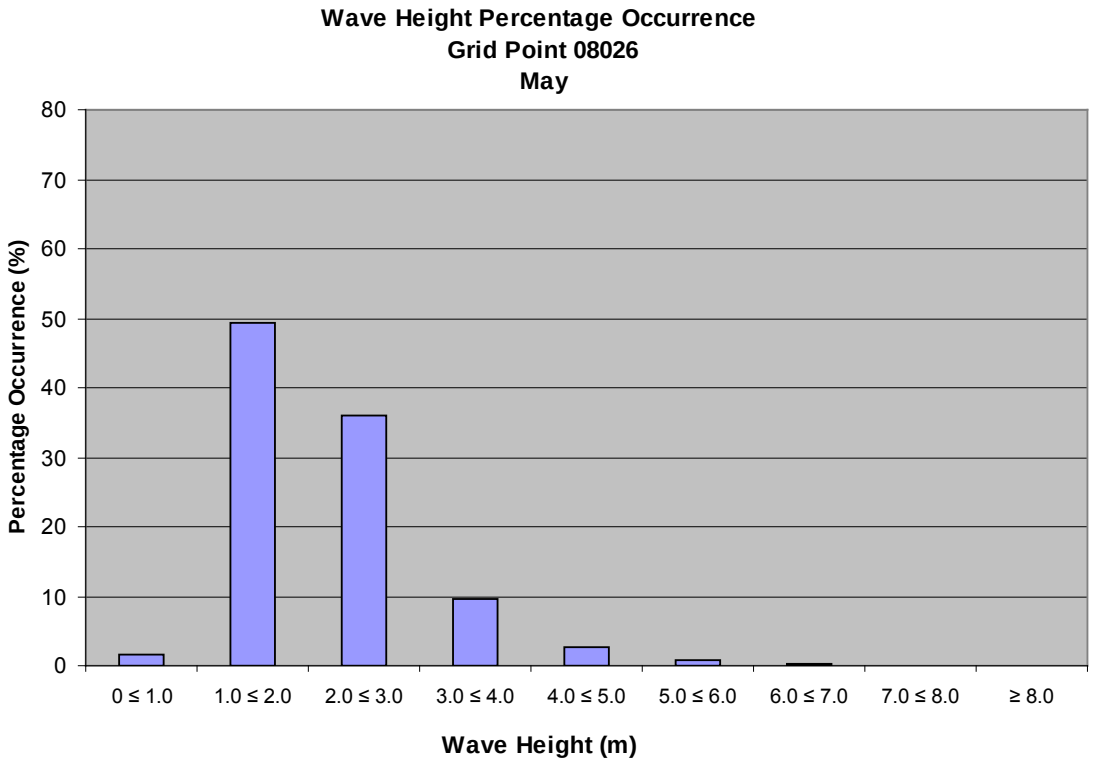
April


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

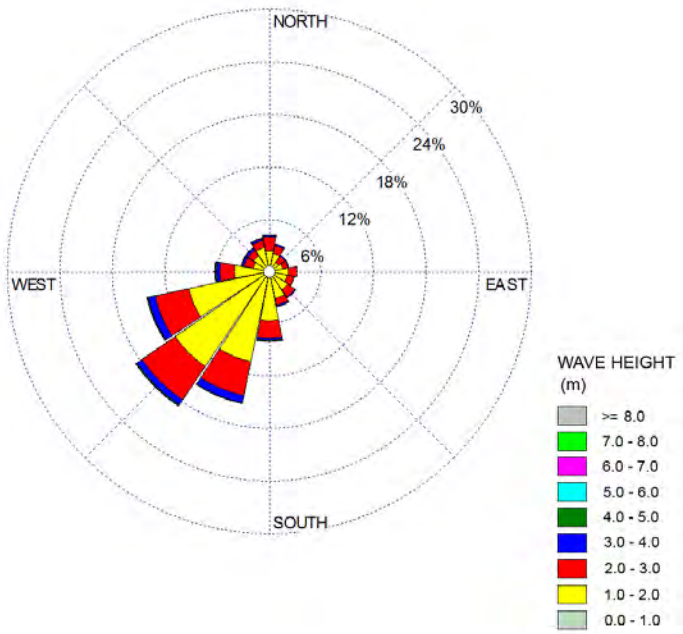

Wave Height Percentage Occurrence
Grid Point 08026
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

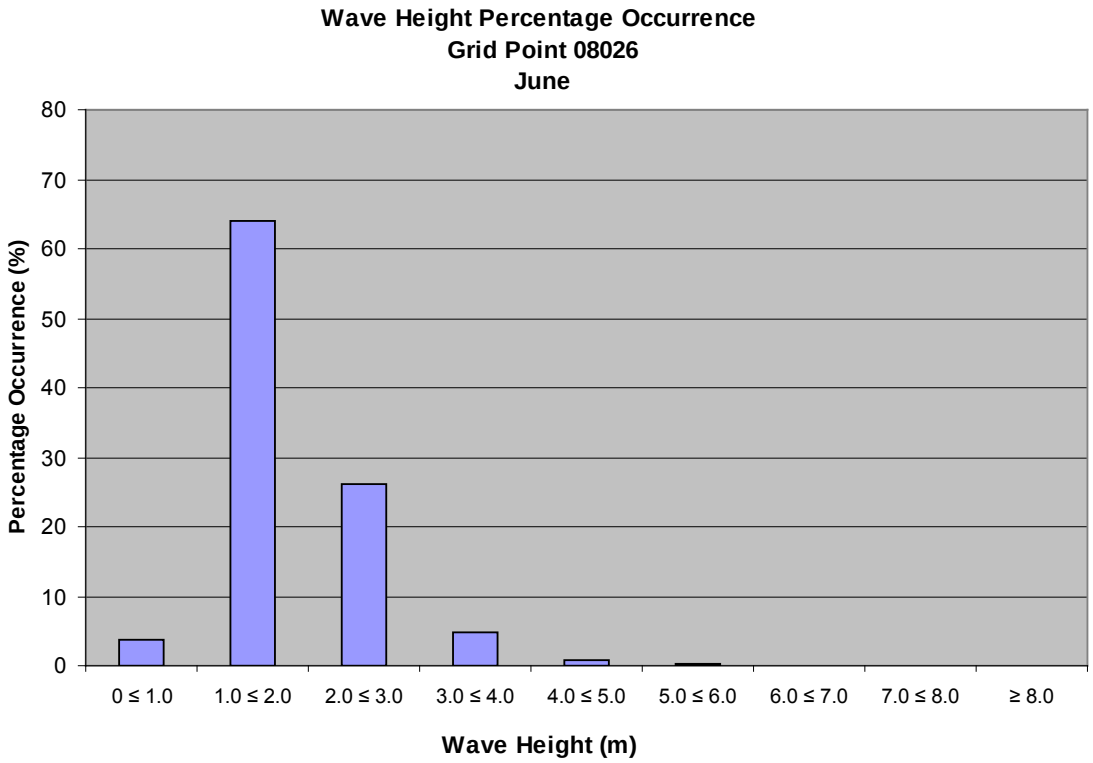
May


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

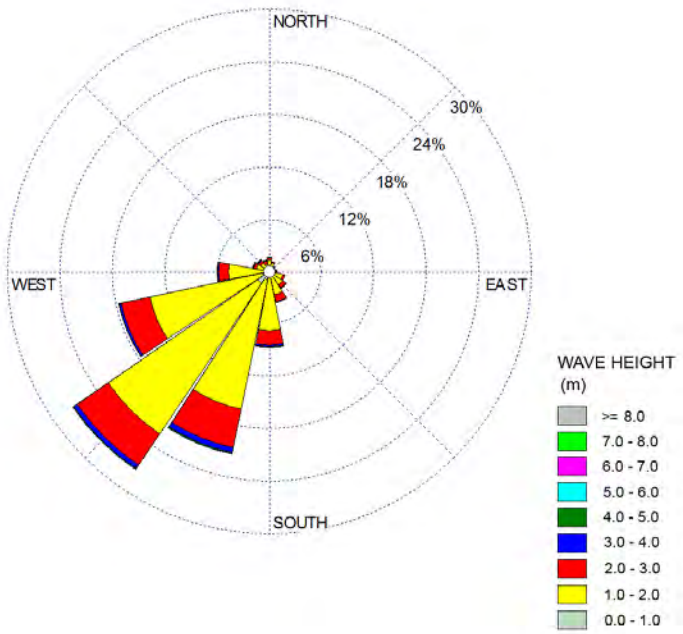

Wave Height Percentage Occurrence
Grid Point 08026
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

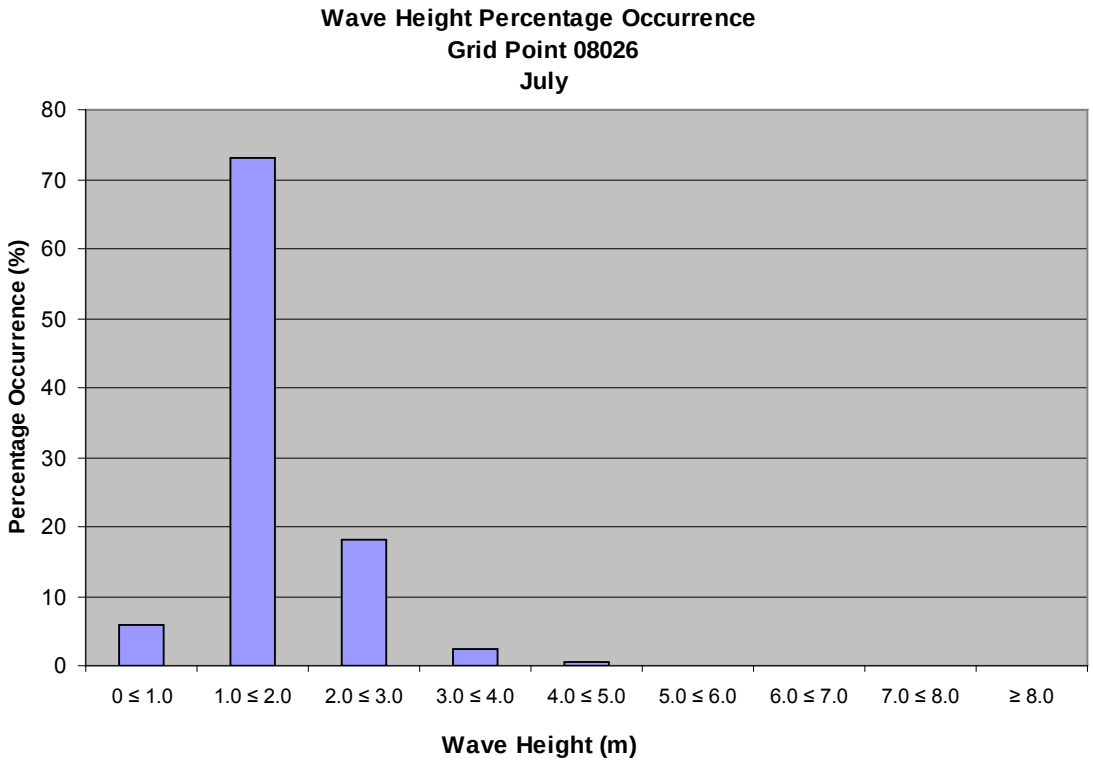
June


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

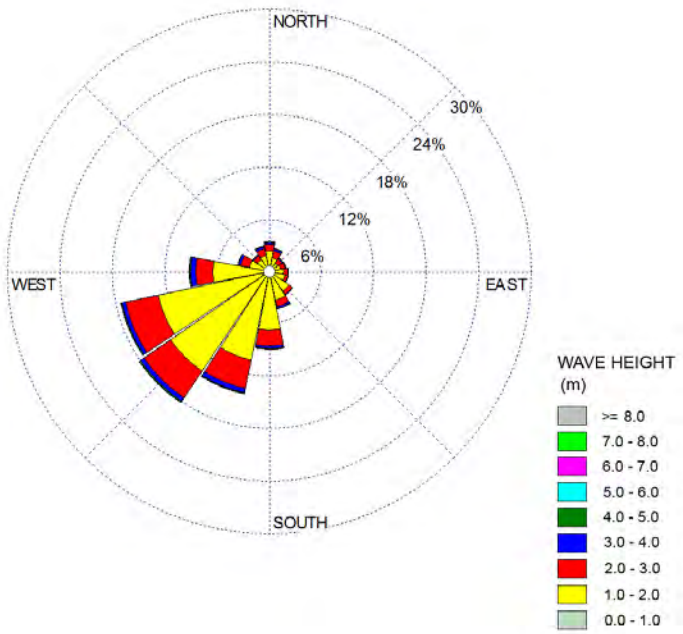

Wave Height Percentage Occurrence
Grid Point 08026
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

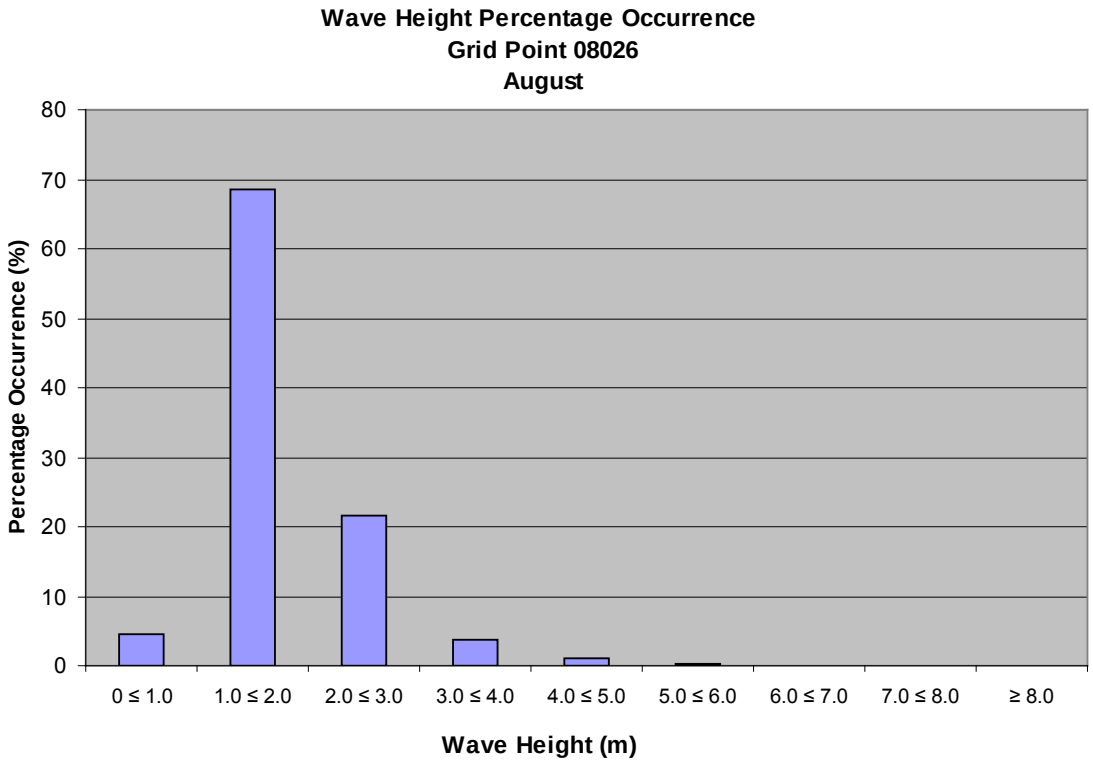
July


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

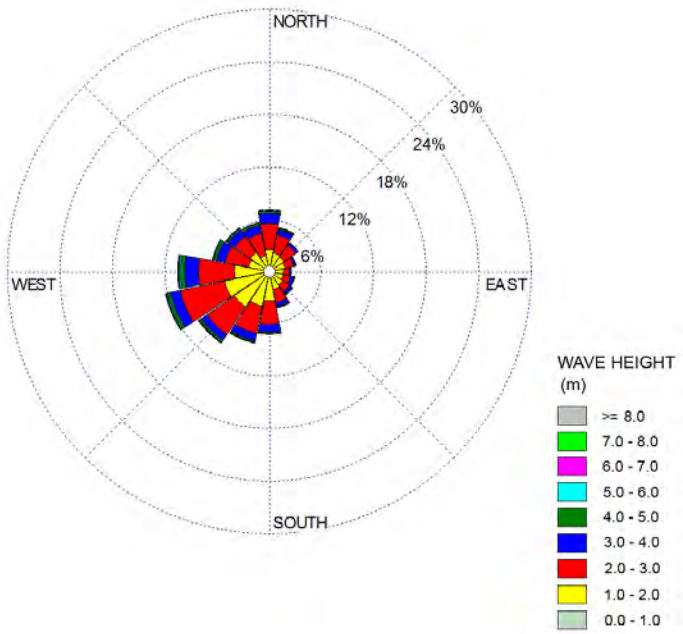

Wave Height Percentage Occurrence
Grid Point 08026
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

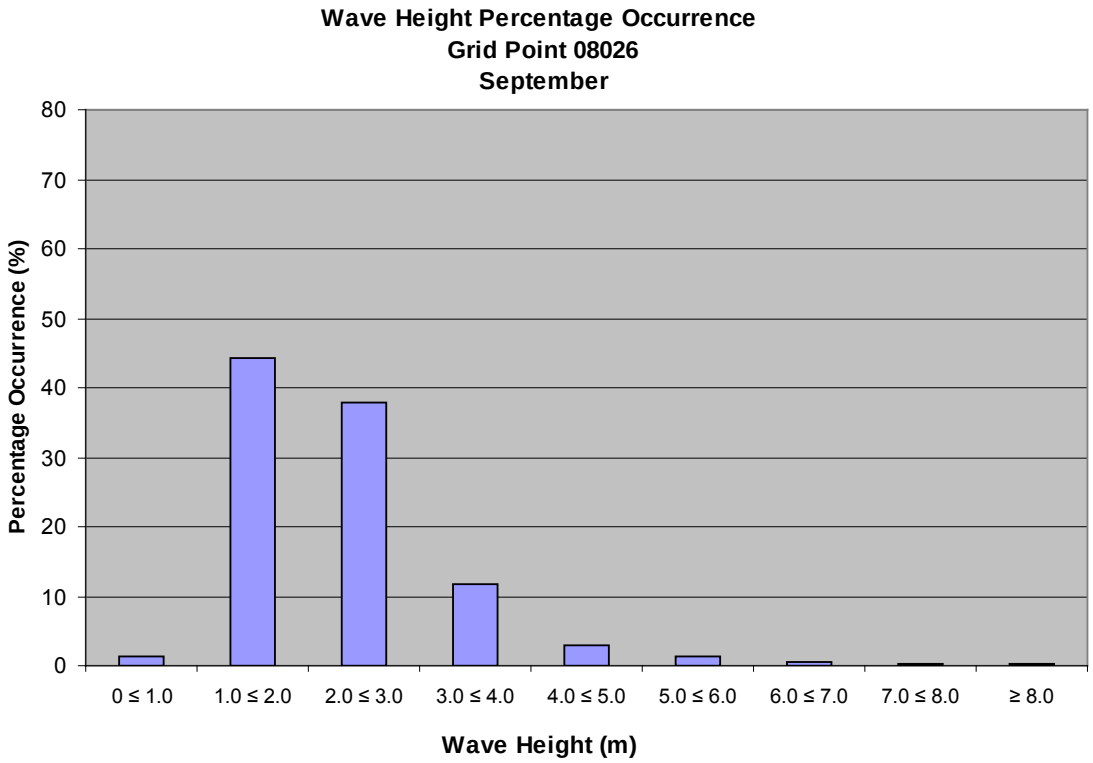
August


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

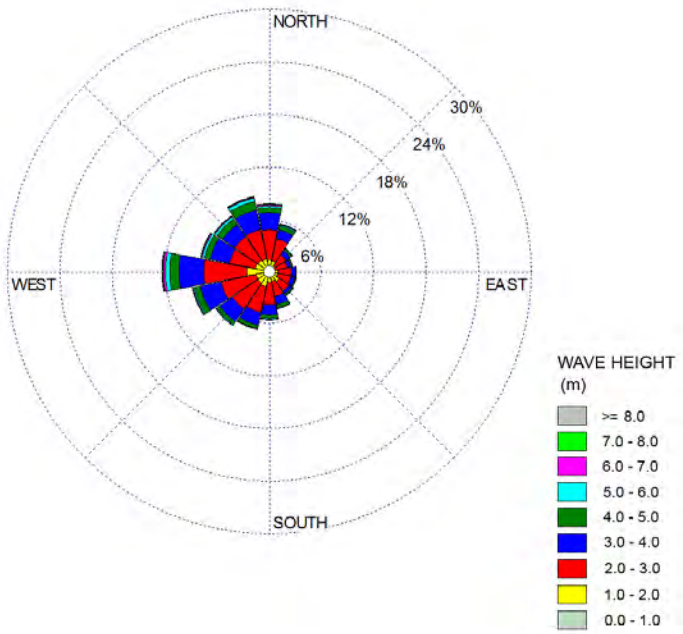

Wave Height Percentage Occurrence
Grid Point 08026
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

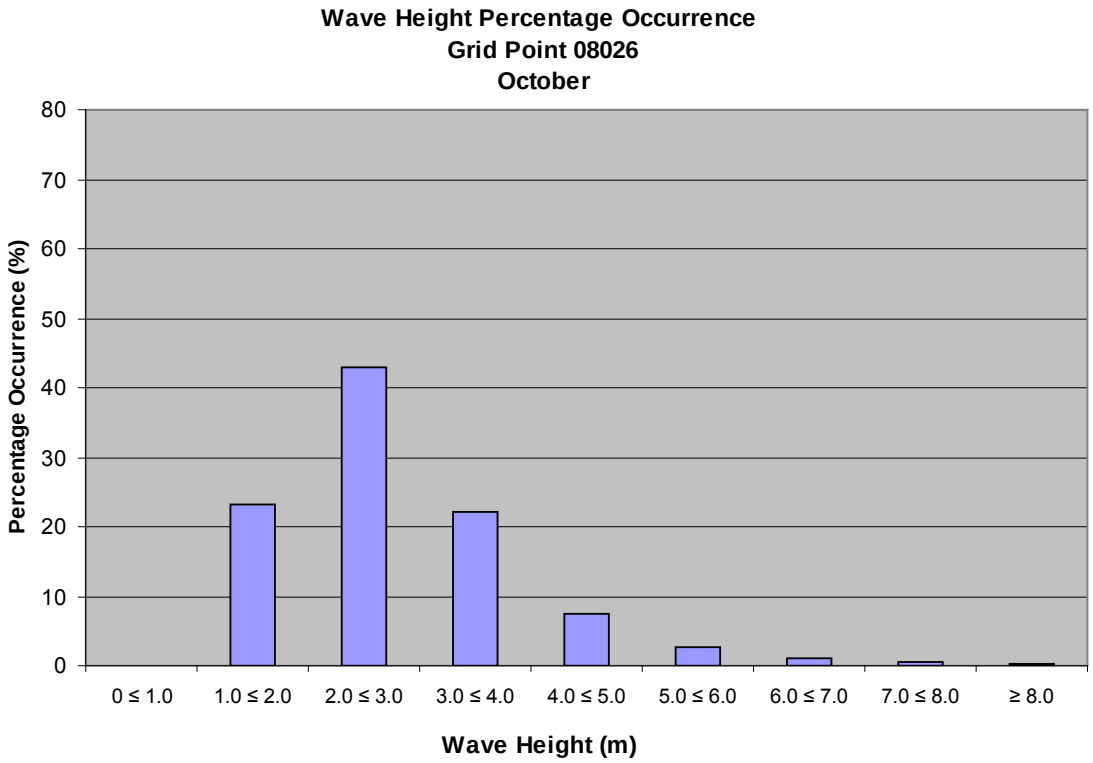
September


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

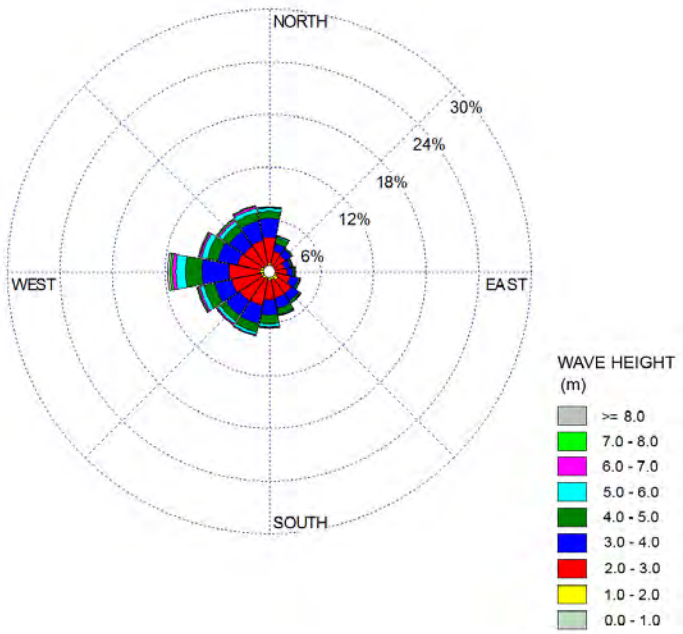

Wave Height Percentage Occurrence
Grid Point 08026
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

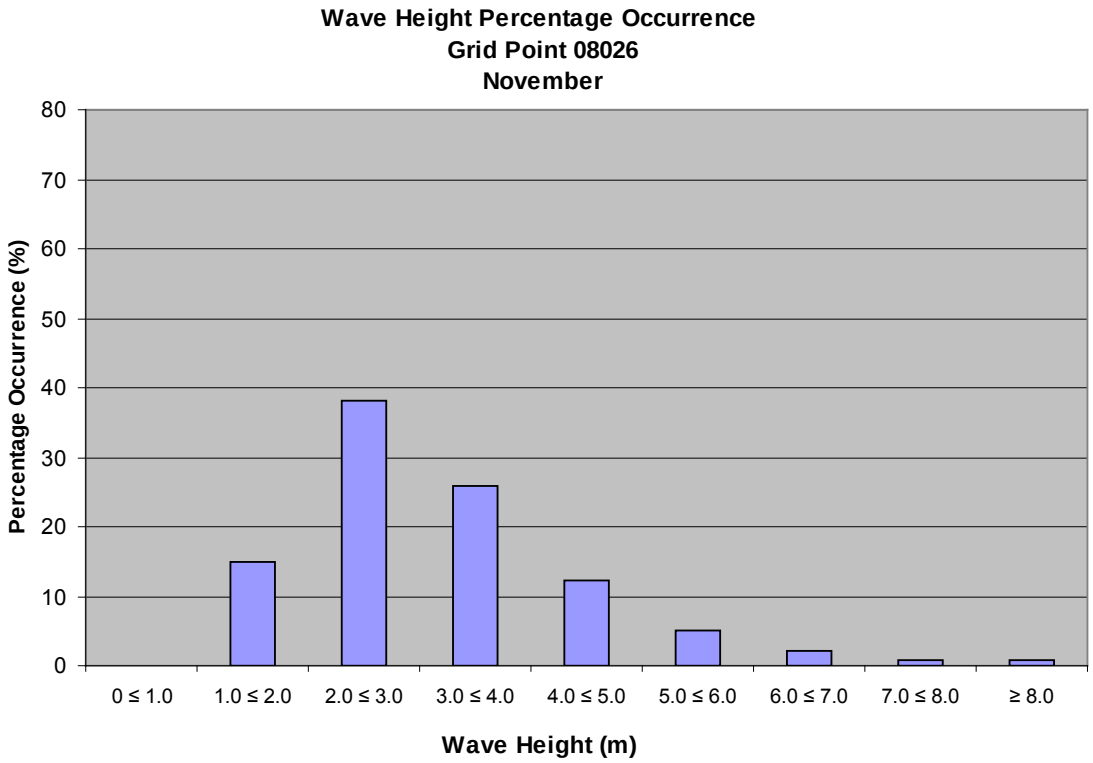
October


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

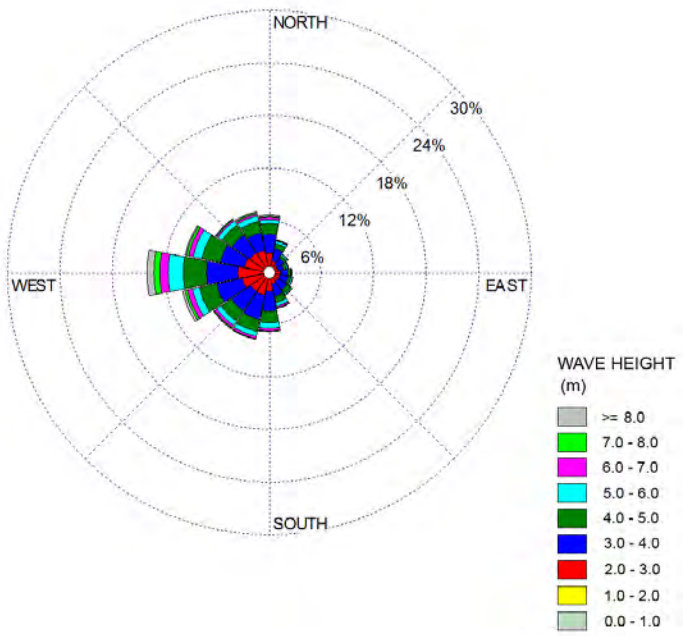

Wave Height Percentage Occurrence
Grid Point 08026
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

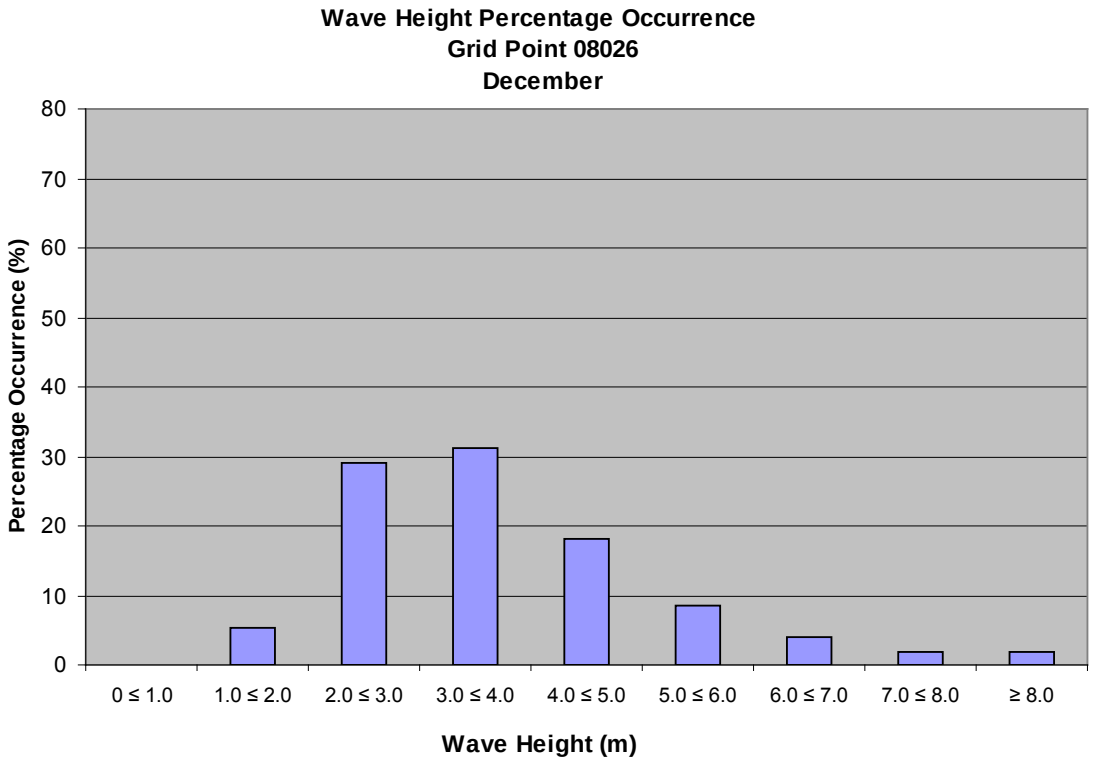
November


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 08026
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

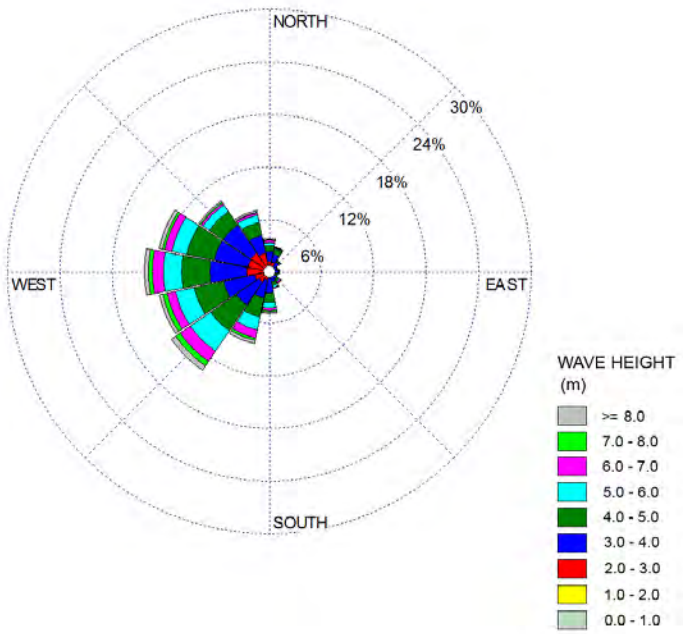
December

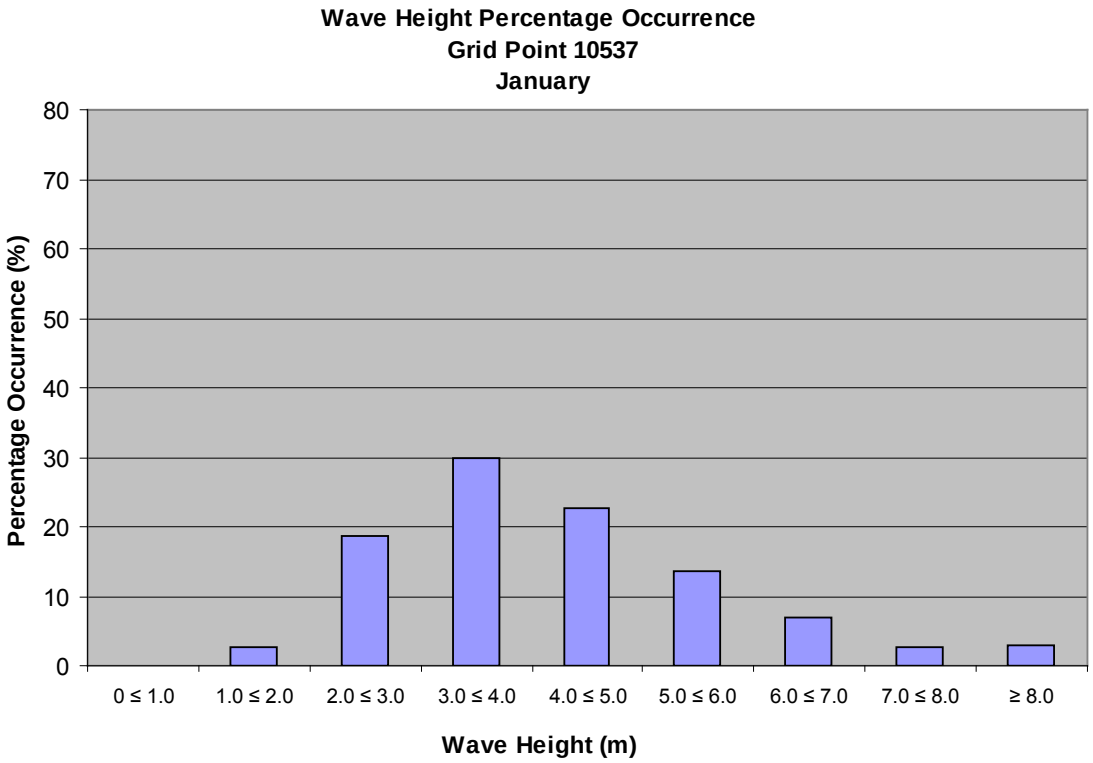

NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT
(m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 08026
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

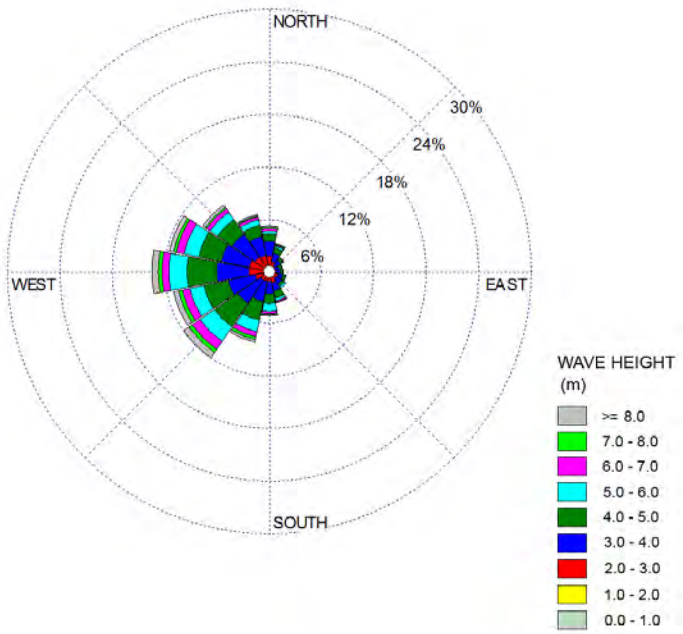
Appendix 8
Wave Roses
and
Wave Height Frequency Distributions
for MSC50 Grid Point 10537

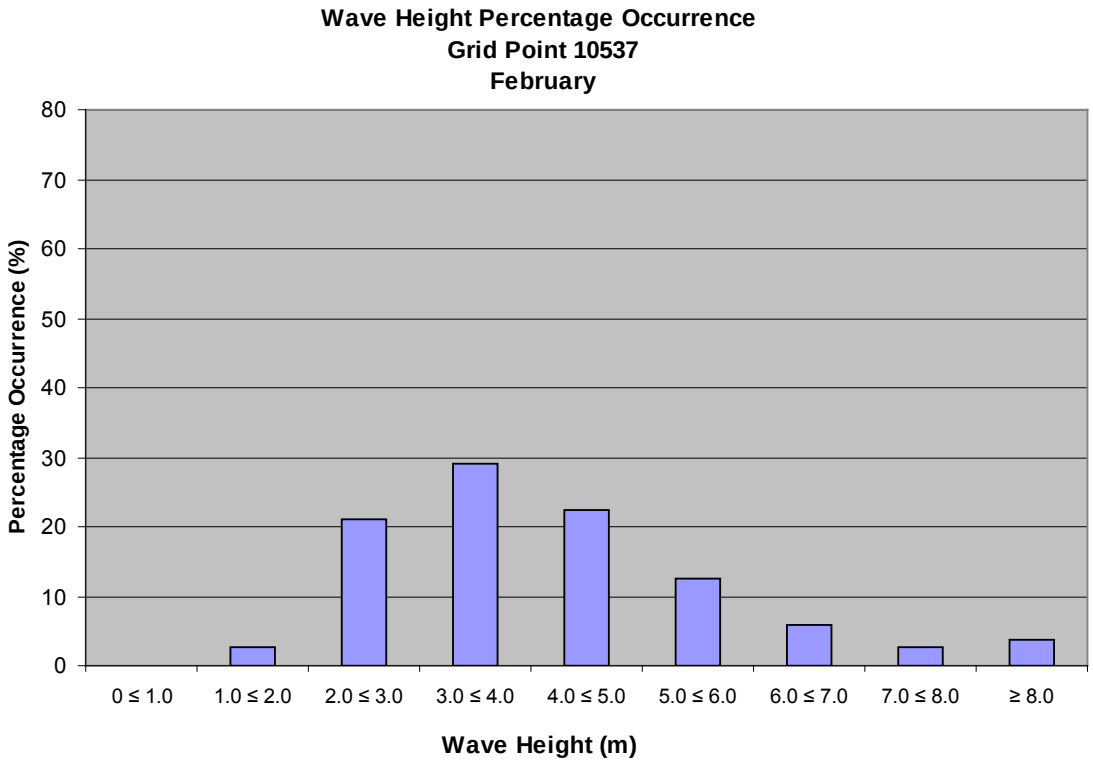
January


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

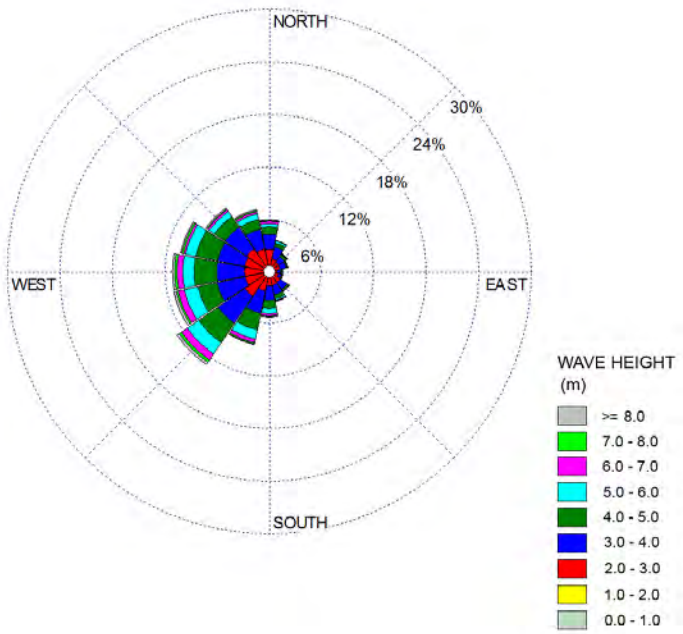

Wave Height Percentage Occurrence
Grid Point 10537
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

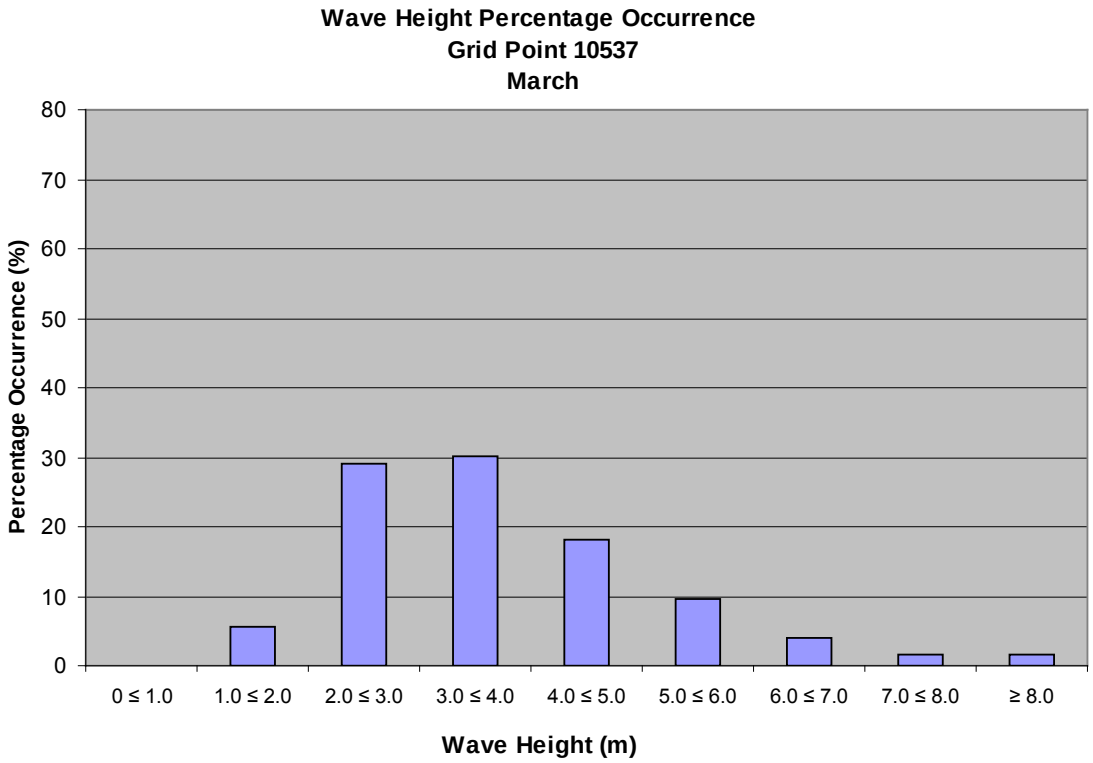
February


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

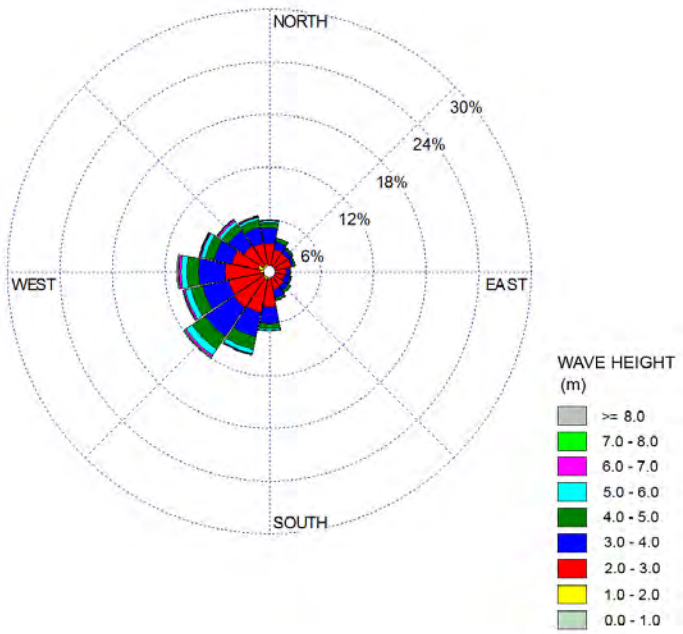

Wave Height Percentage Occurrence
Grid Point 10537
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

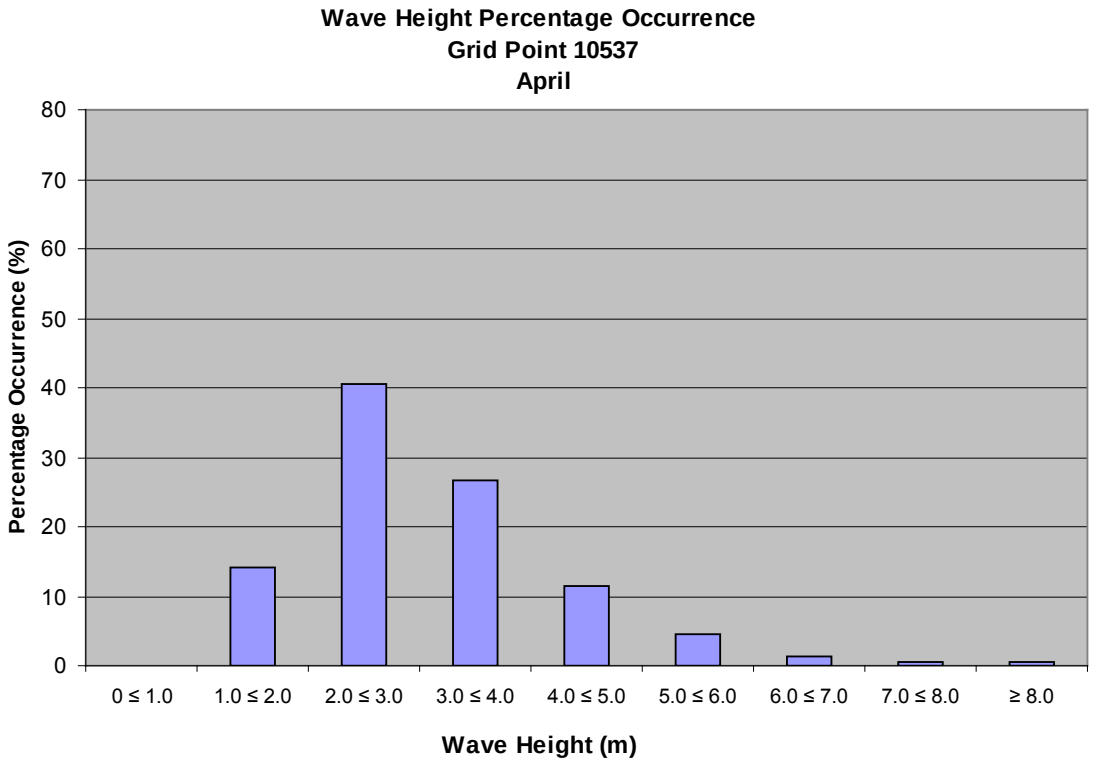
March


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

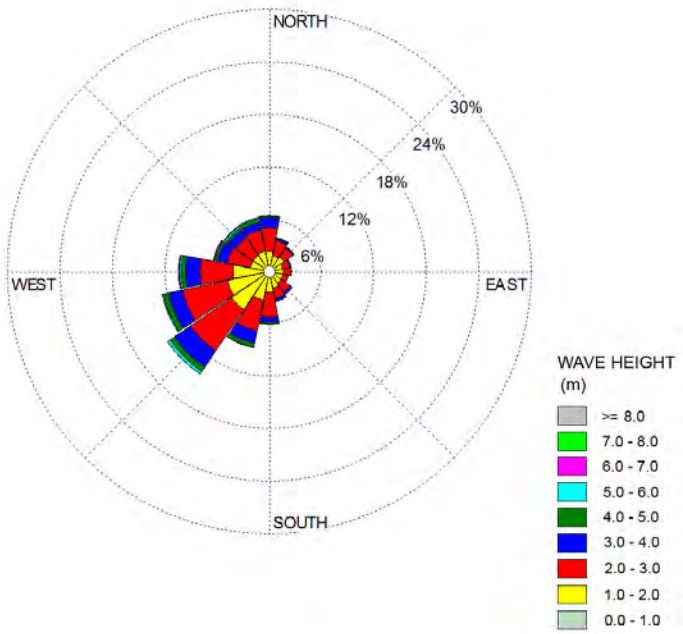

Wave Height Percentage Occurrence
Grid Point 10537
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

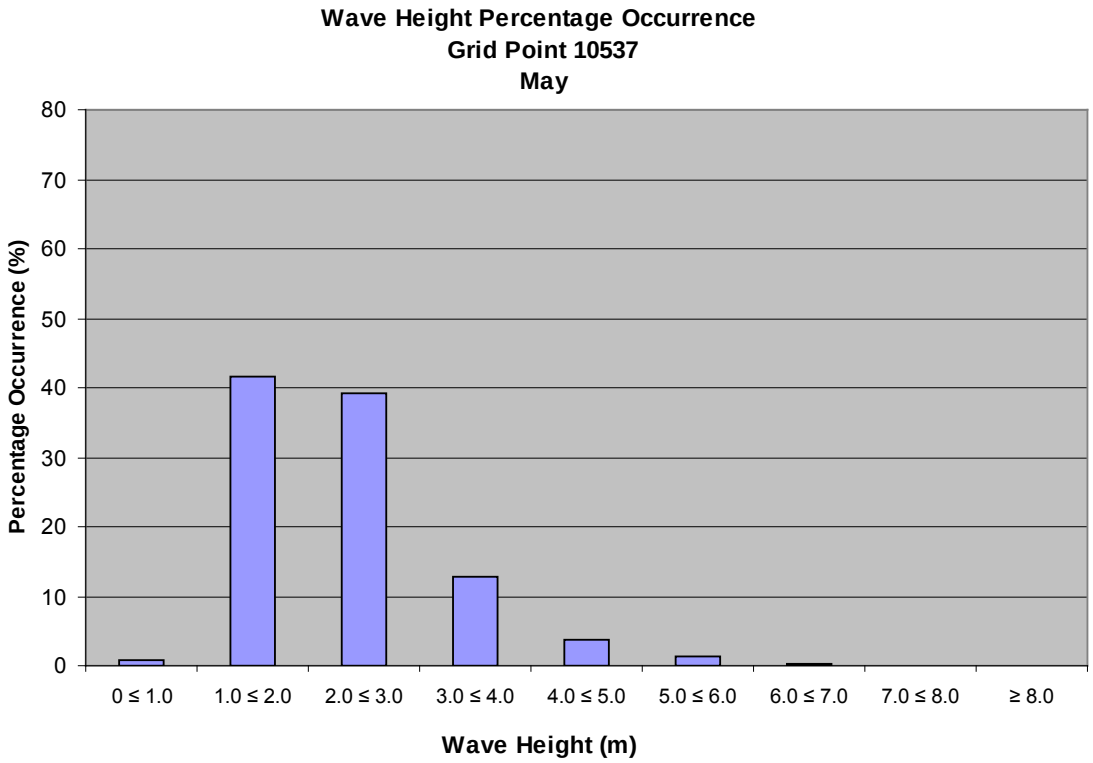
April


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

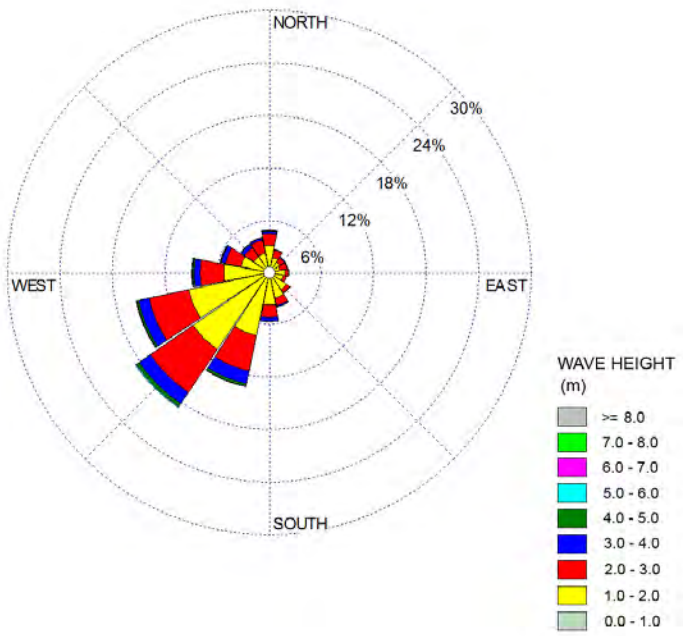

Wave Height Percentage Occurrence
Grid Point 10537
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

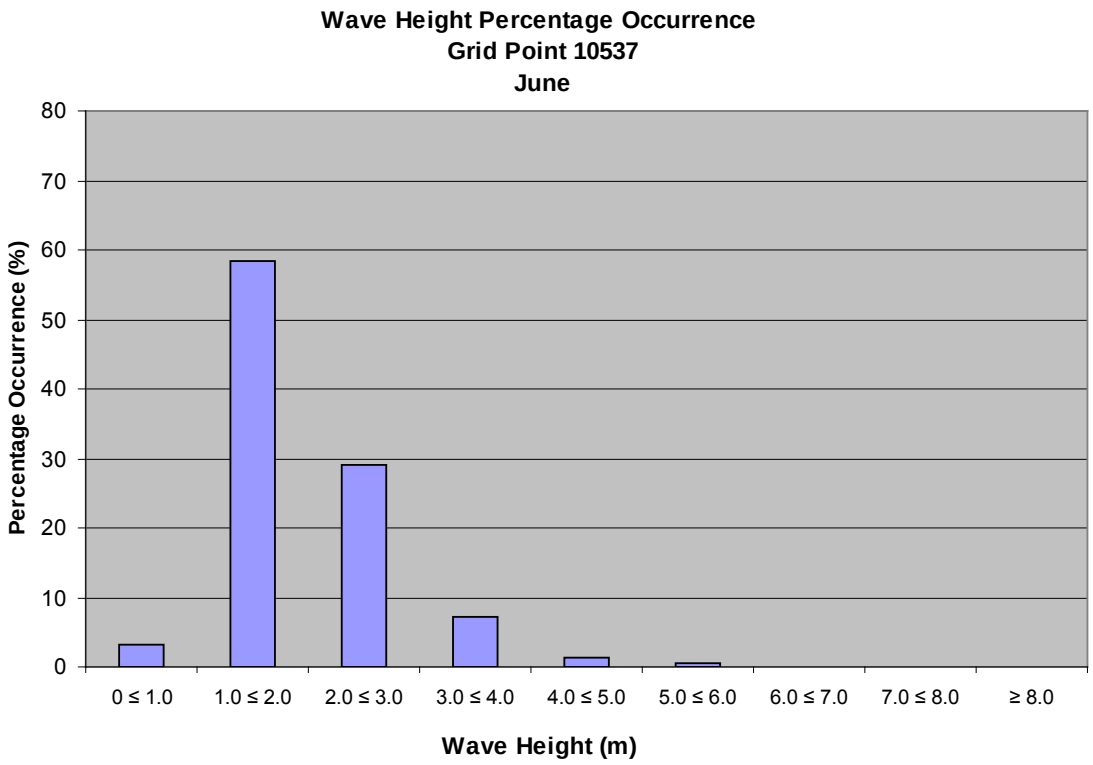
May


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

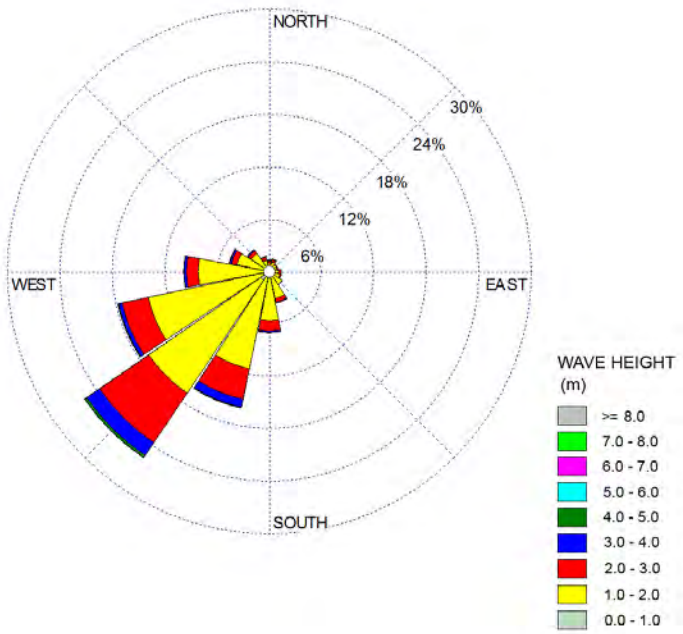

Wave Height Percentage Occurrence
Grid Point 10537
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

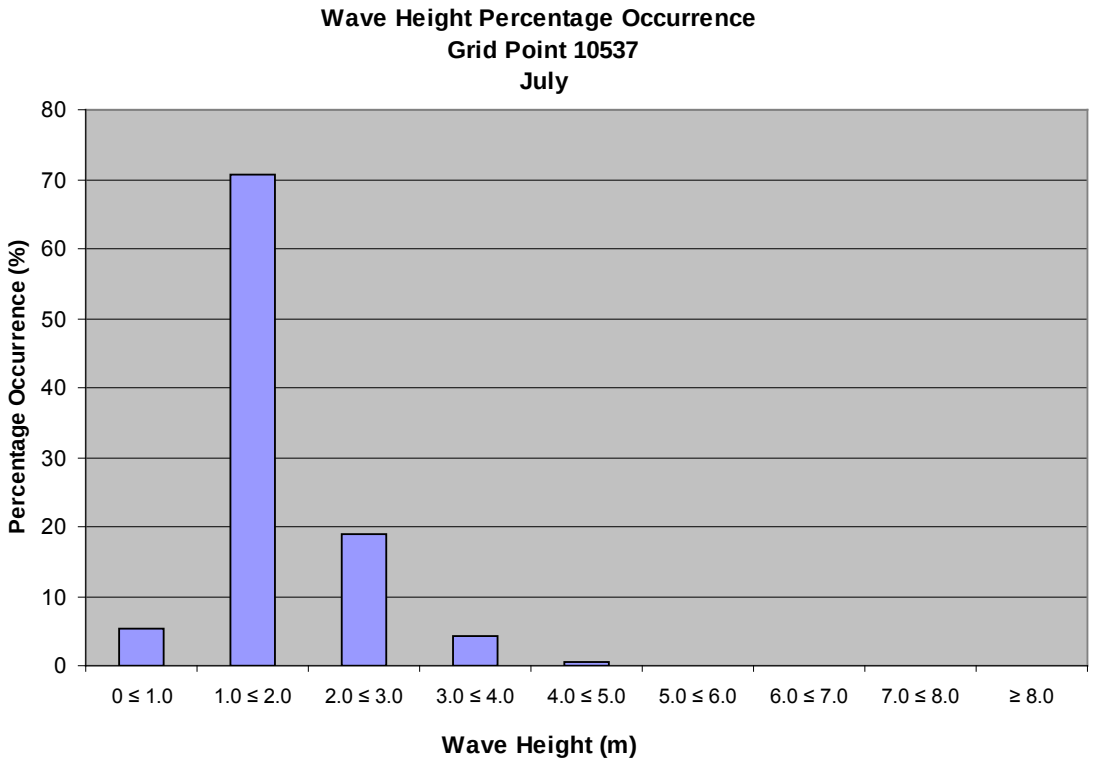
June


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT
(m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

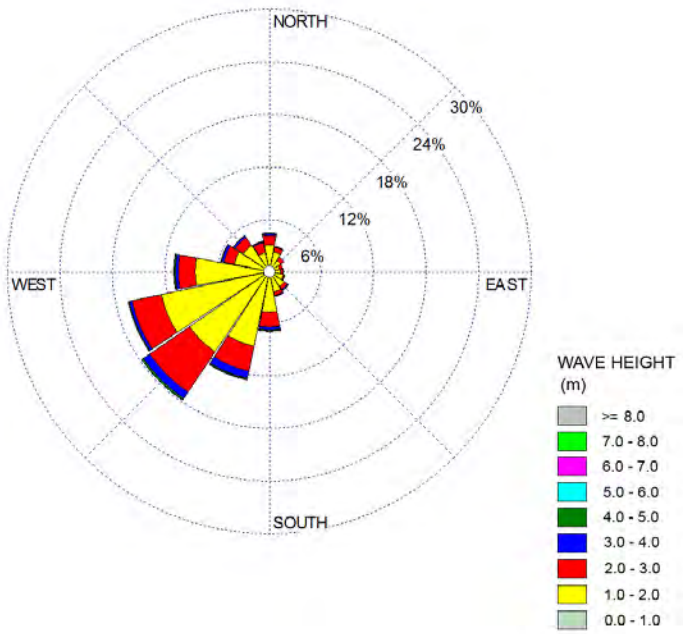

Wave Height Percentage Occurrence
Grid Point 10537
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

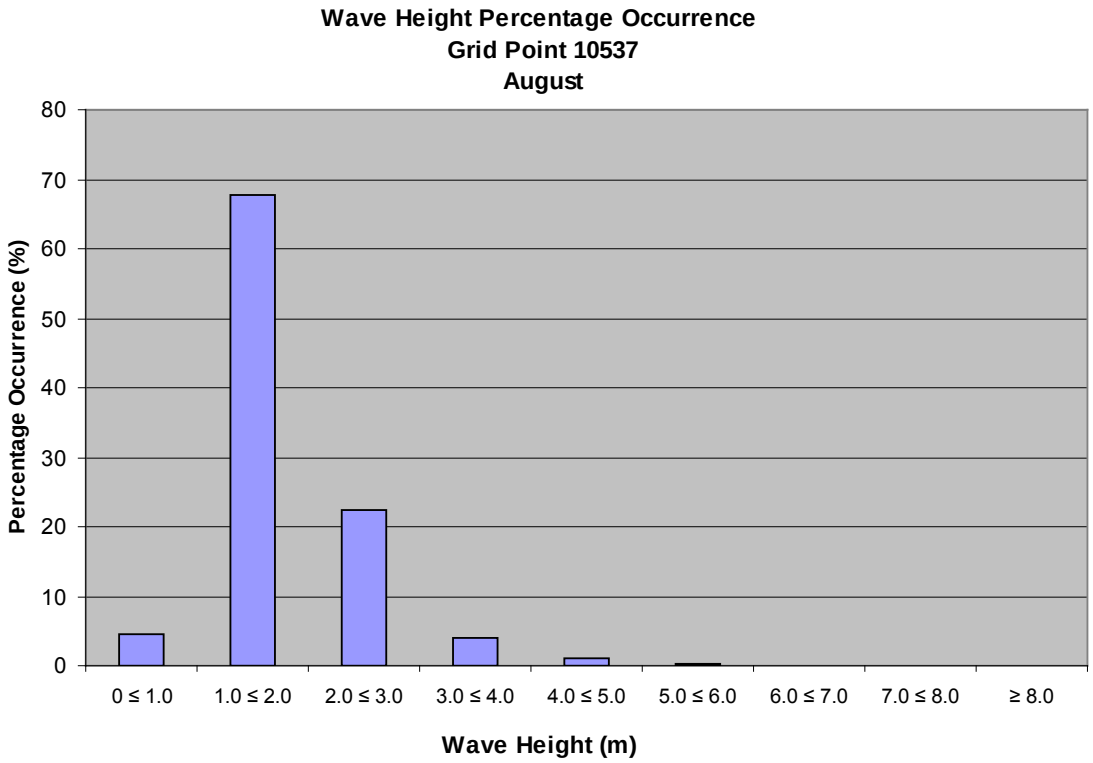
July


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

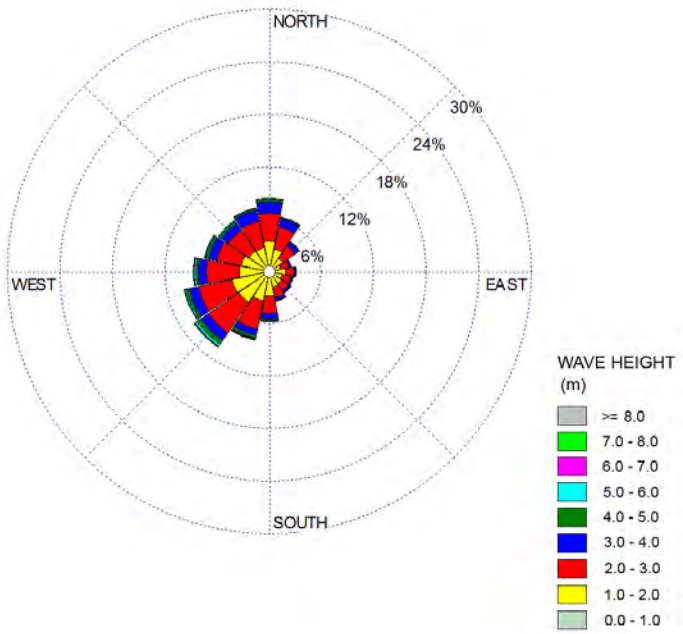

Wave Height Percentage Occurrence
Grid Point 10537
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

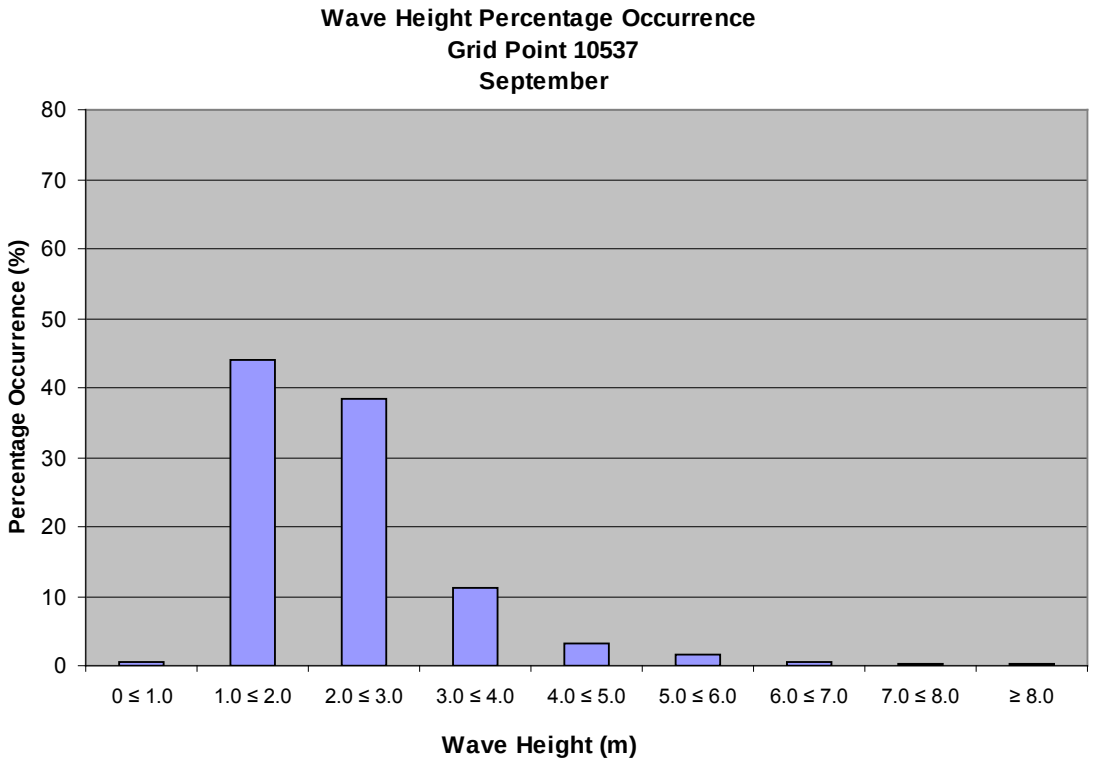
August


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

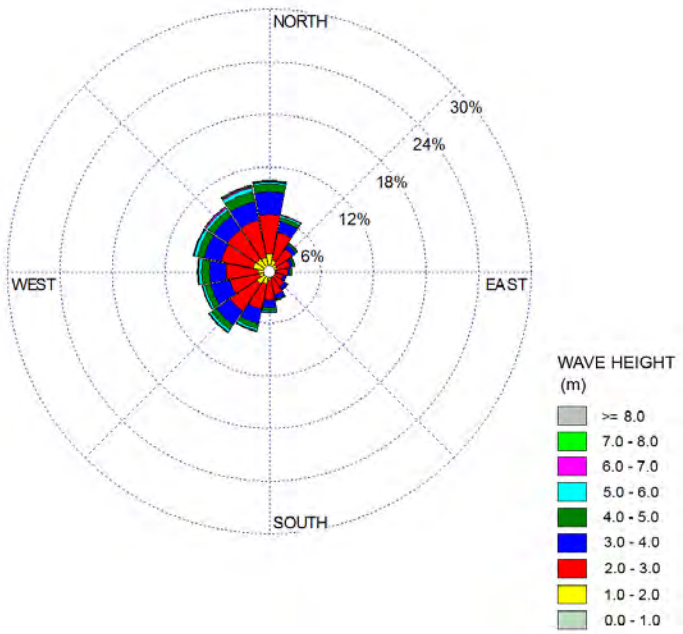

Wave Height Percentage Occurrence
Grid Point 10537
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

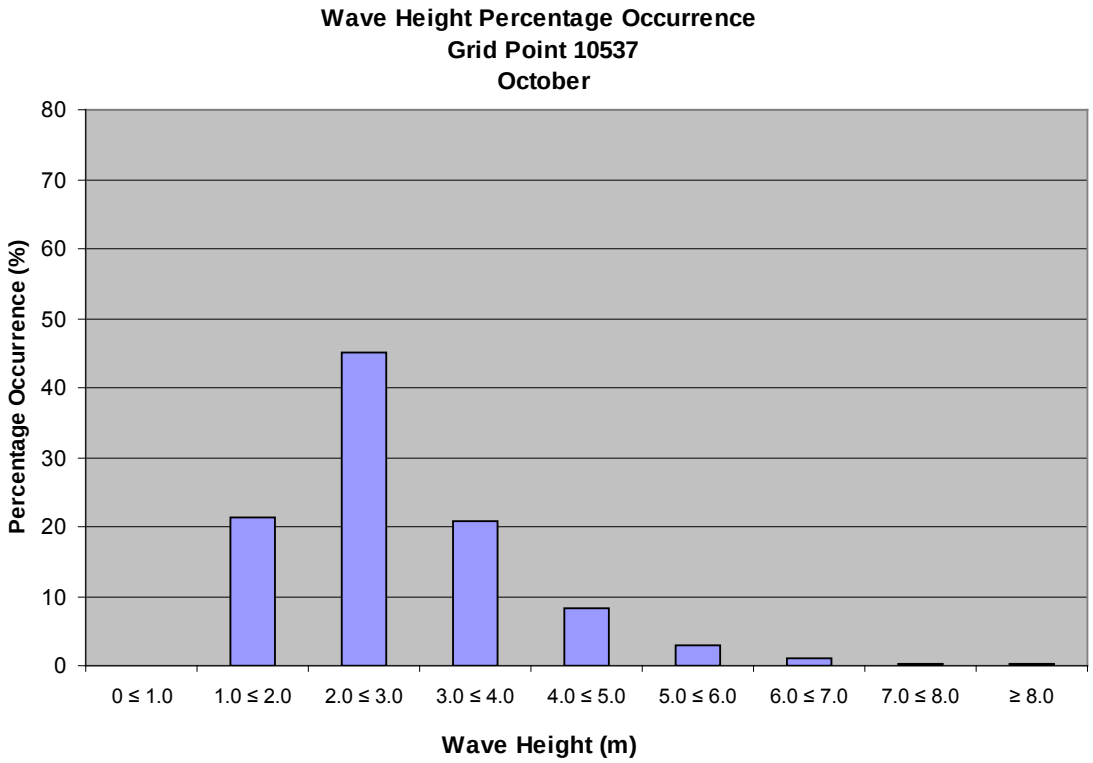
September


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

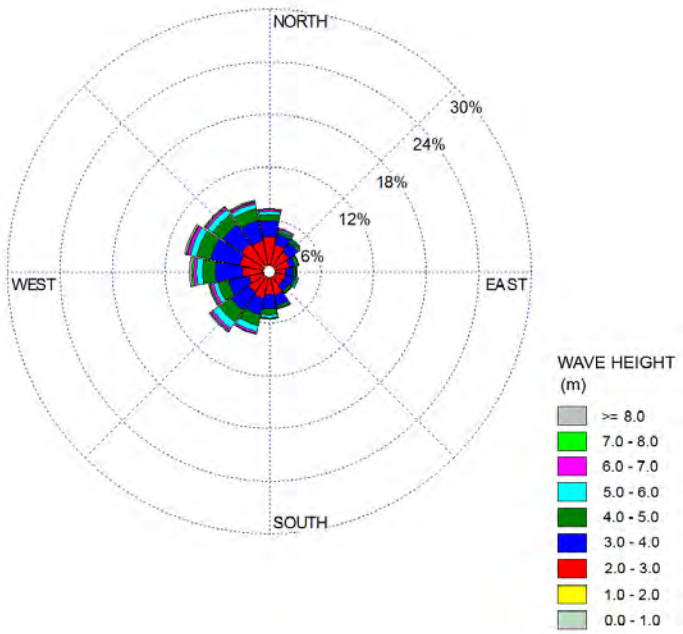

Wave Height Percentage Occurrence
Grid Point 10537
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

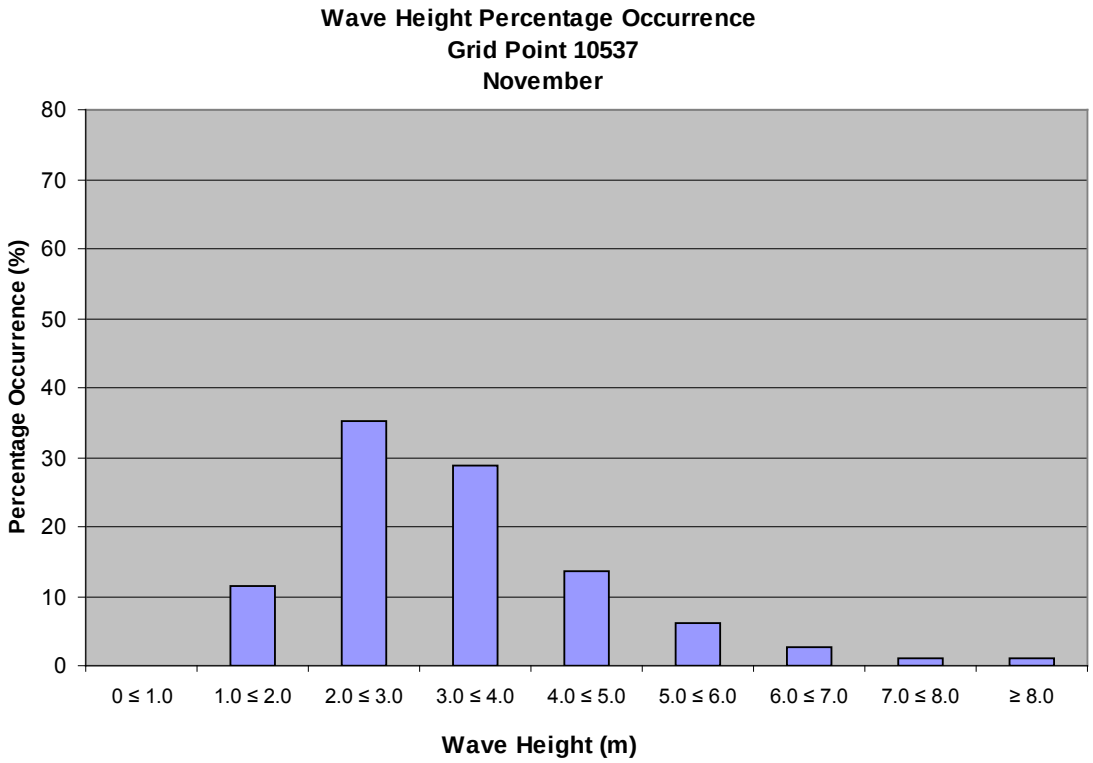
October


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

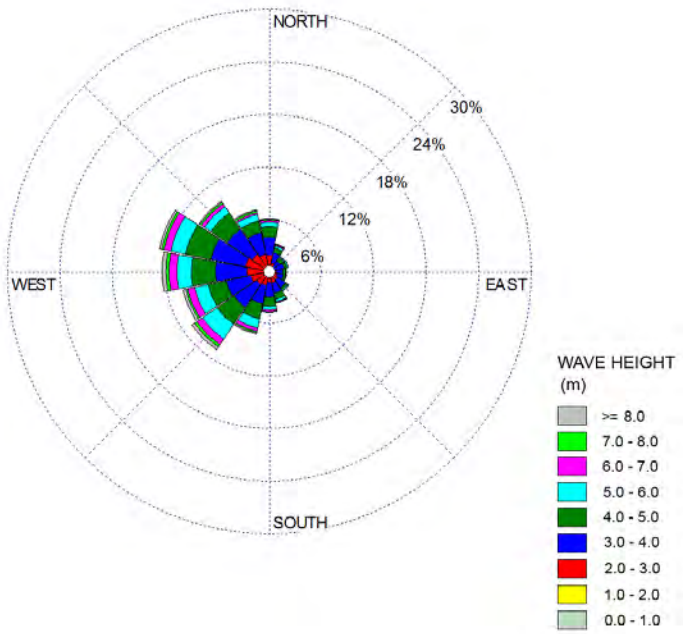

Wave Height Percentage Occurrence
Grid Point 10537
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

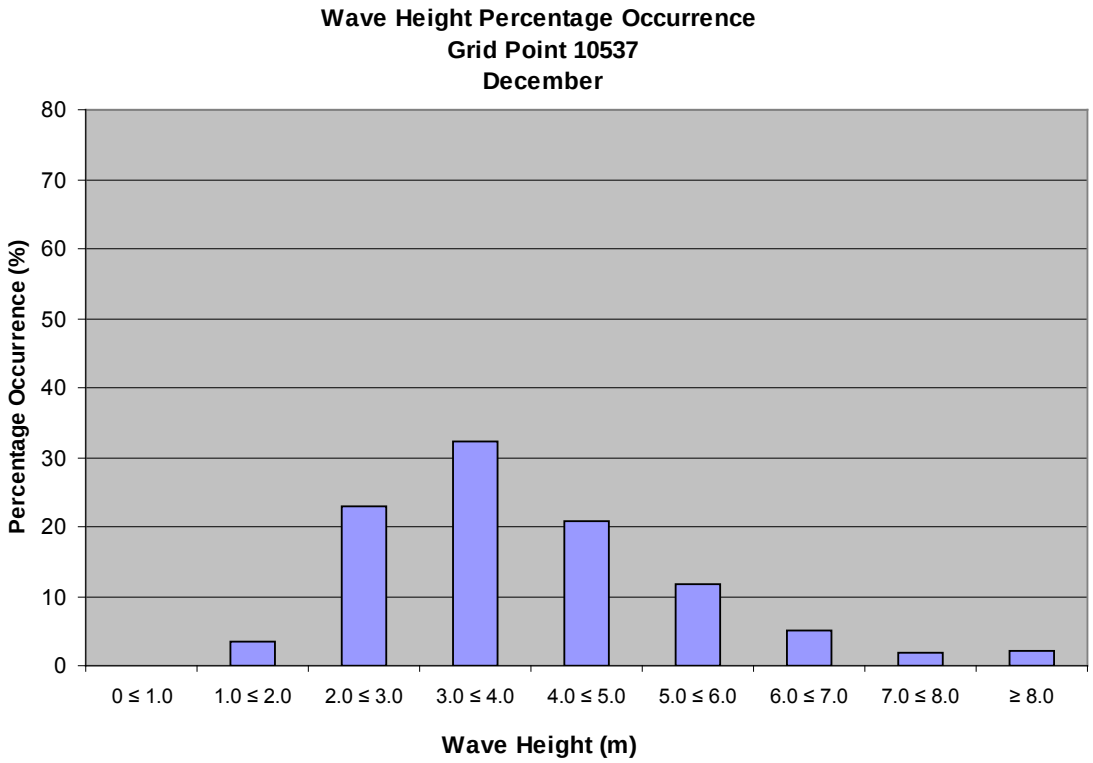
November


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 10537
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

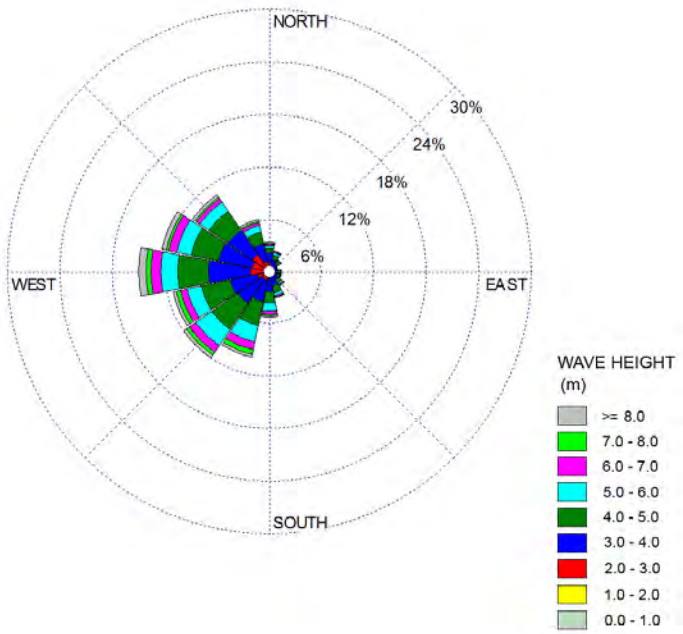
December

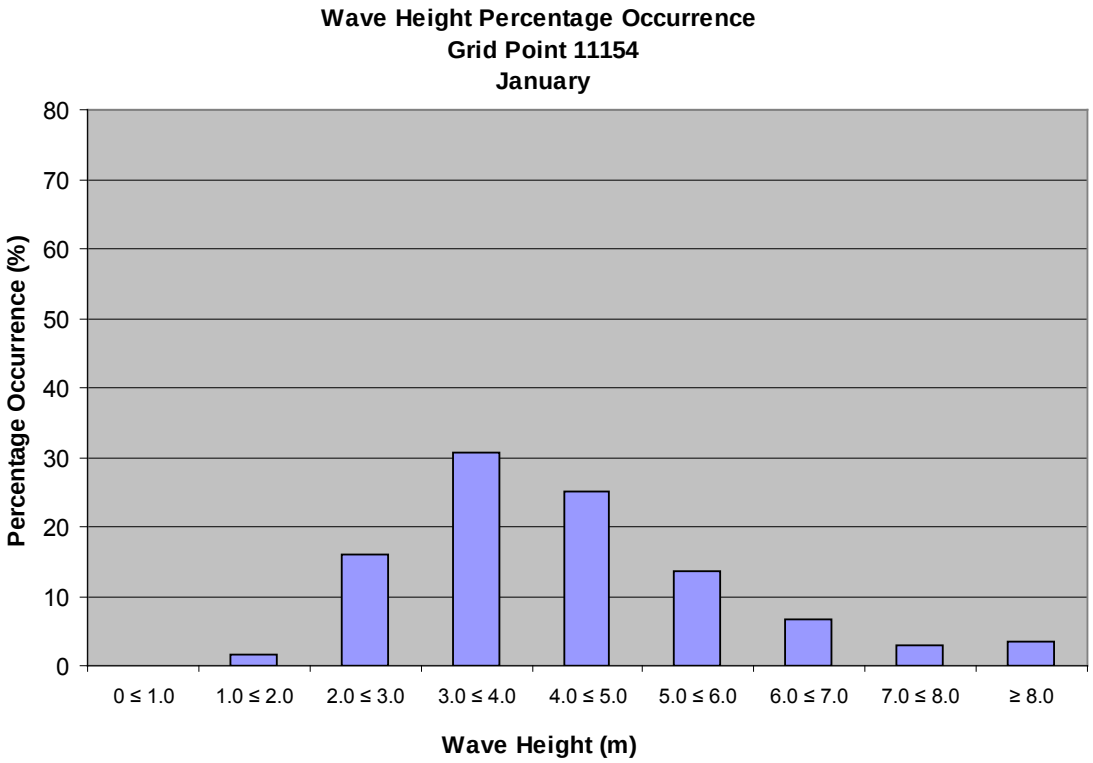

NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 10537
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

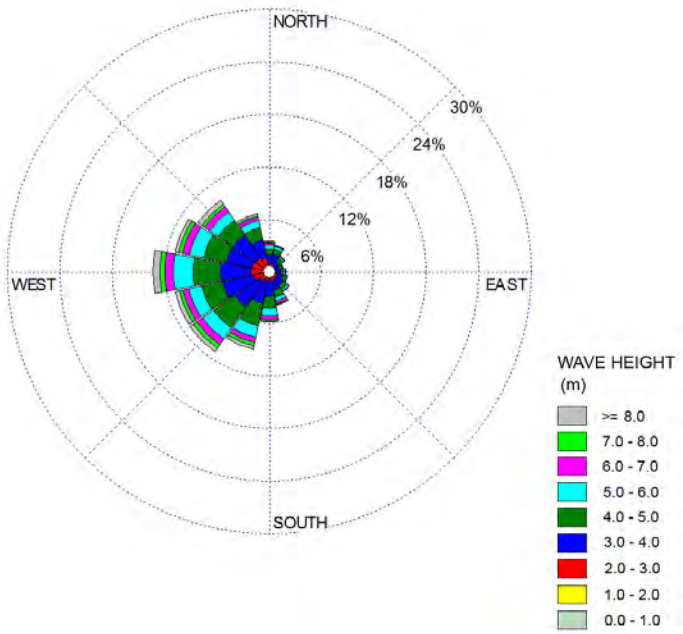
Appendix 8
Wave Roses
and
Wave Height Frequency Distributions
for MSC50 Grid Point 11154

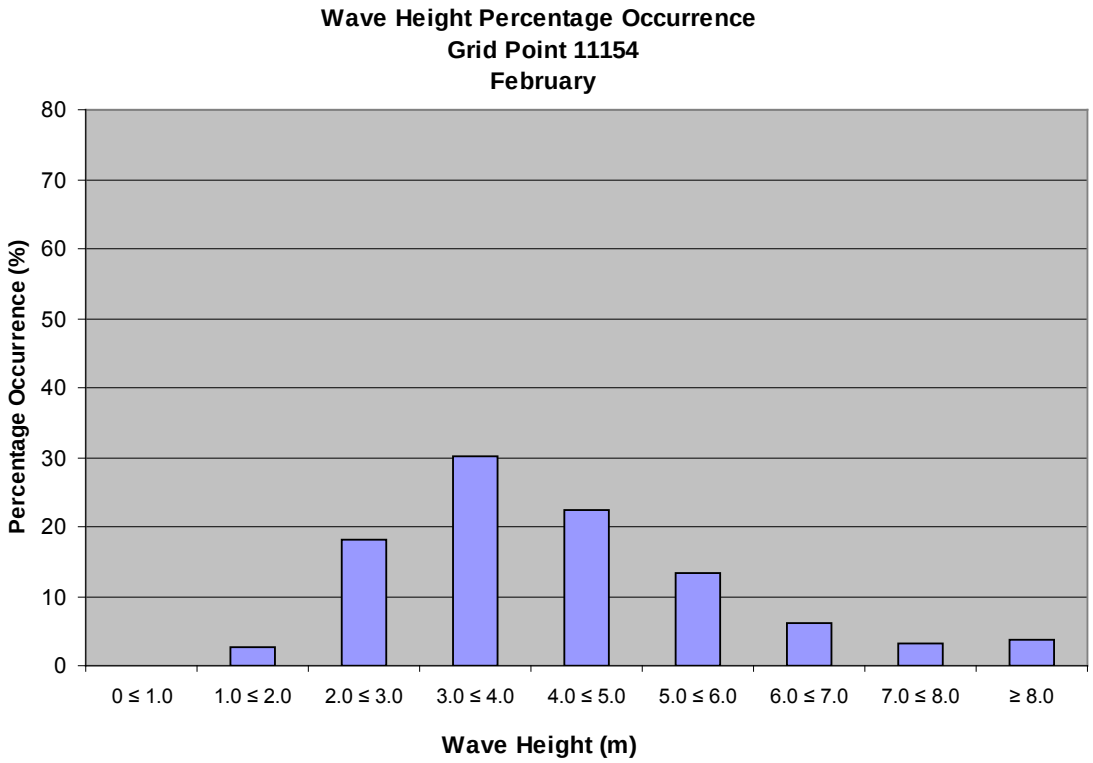
January


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

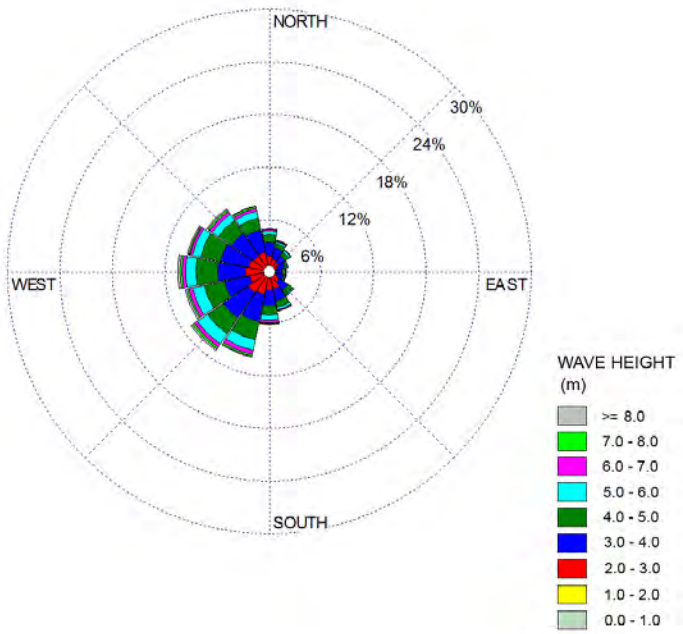

Wave Height Percentage Occurrence
Grid Point 11154
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

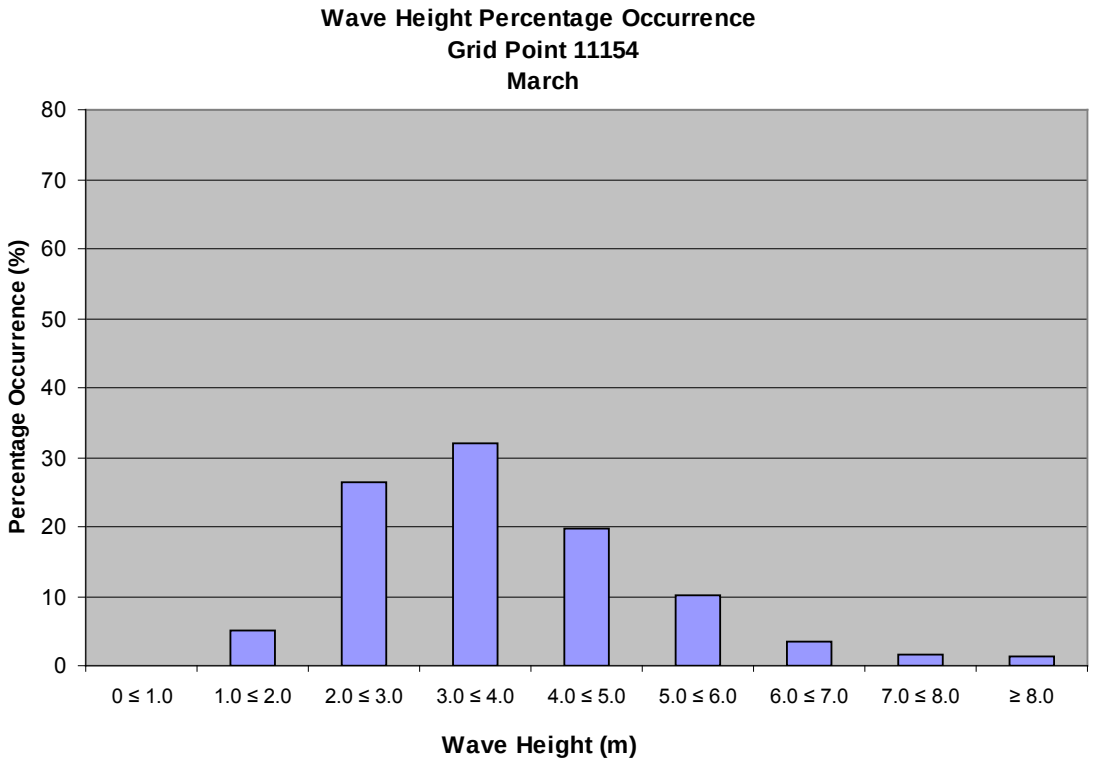
February


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

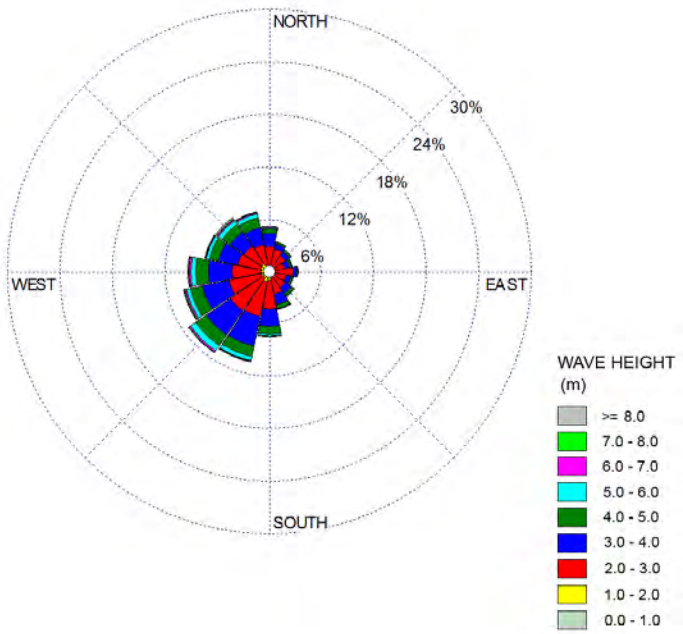

Wave Height Percentage Occurrence
Grid Point 11154
February
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

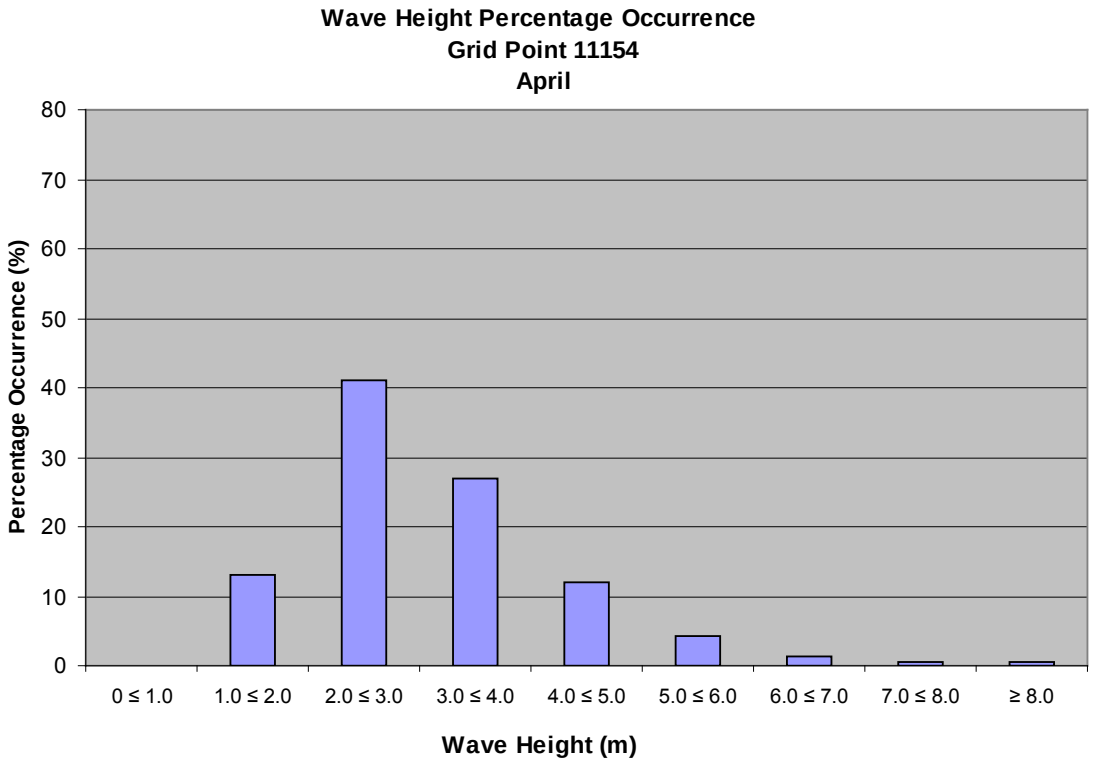
March


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

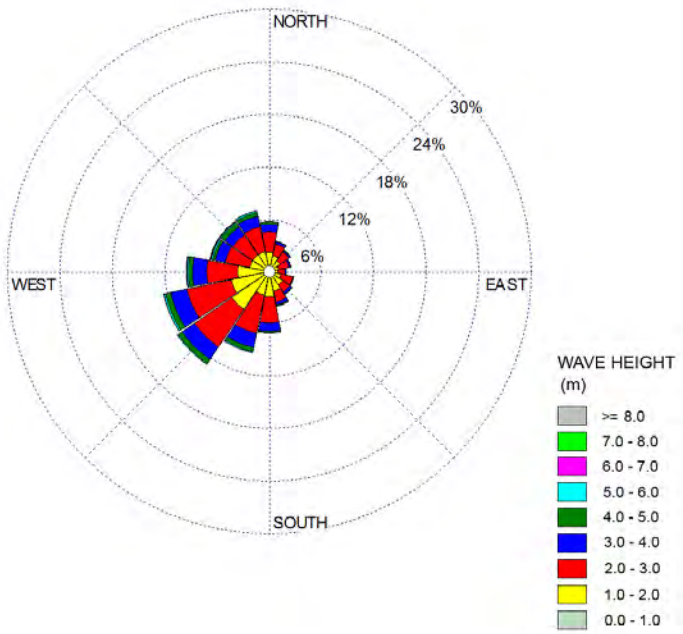

Wave Height Percentage Occurrence
Grid Point 11154
March
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

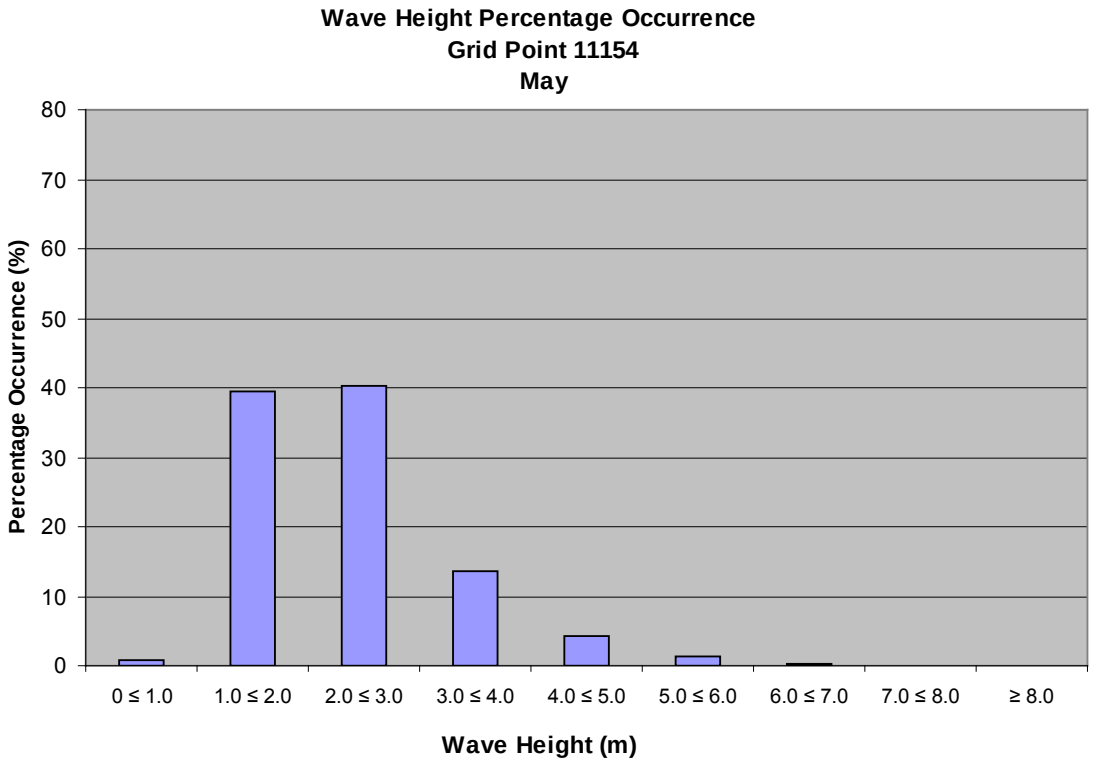
April


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

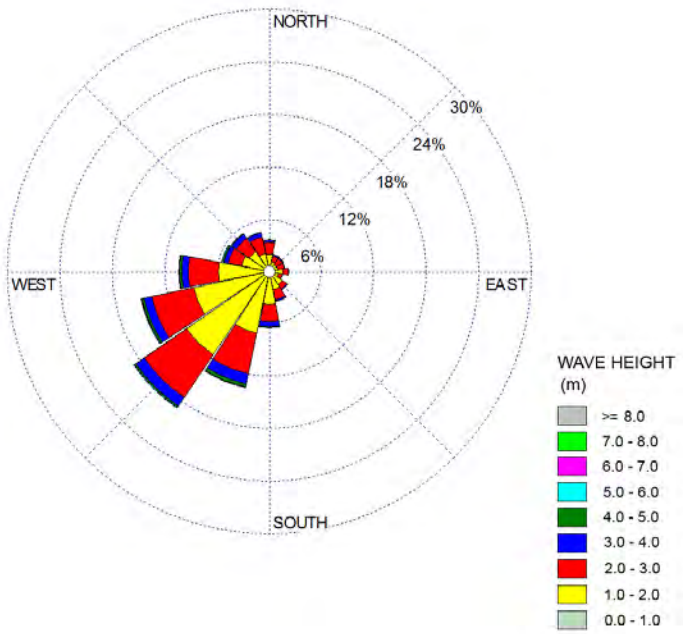

Wave Height Percentage Occurrence
Grid Point 11154
April
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

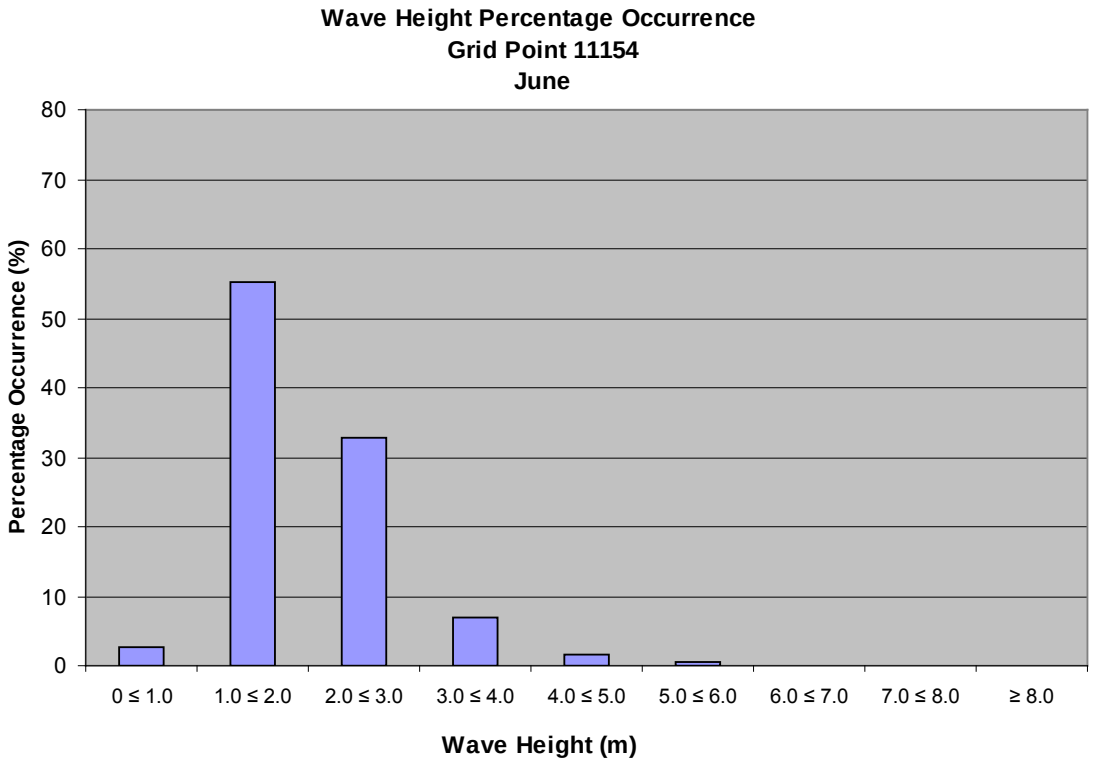
May


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

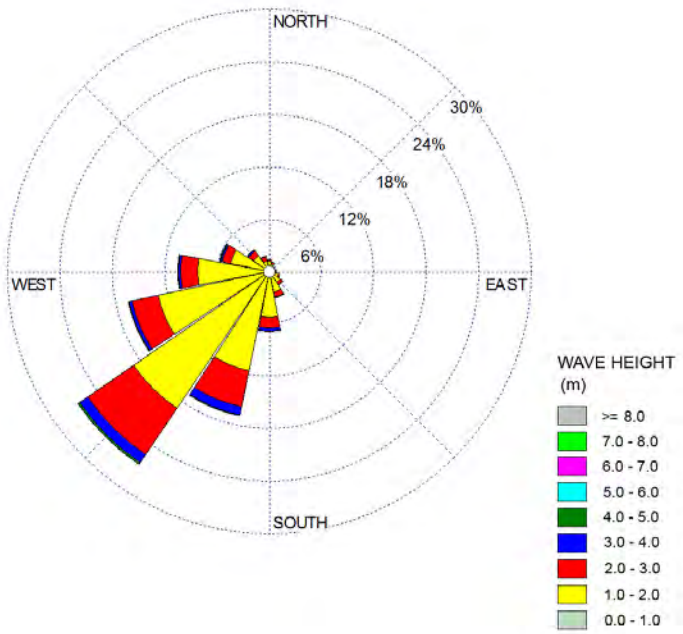

Wave Height Percentage Occurrence
Grid Point 11154
May
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

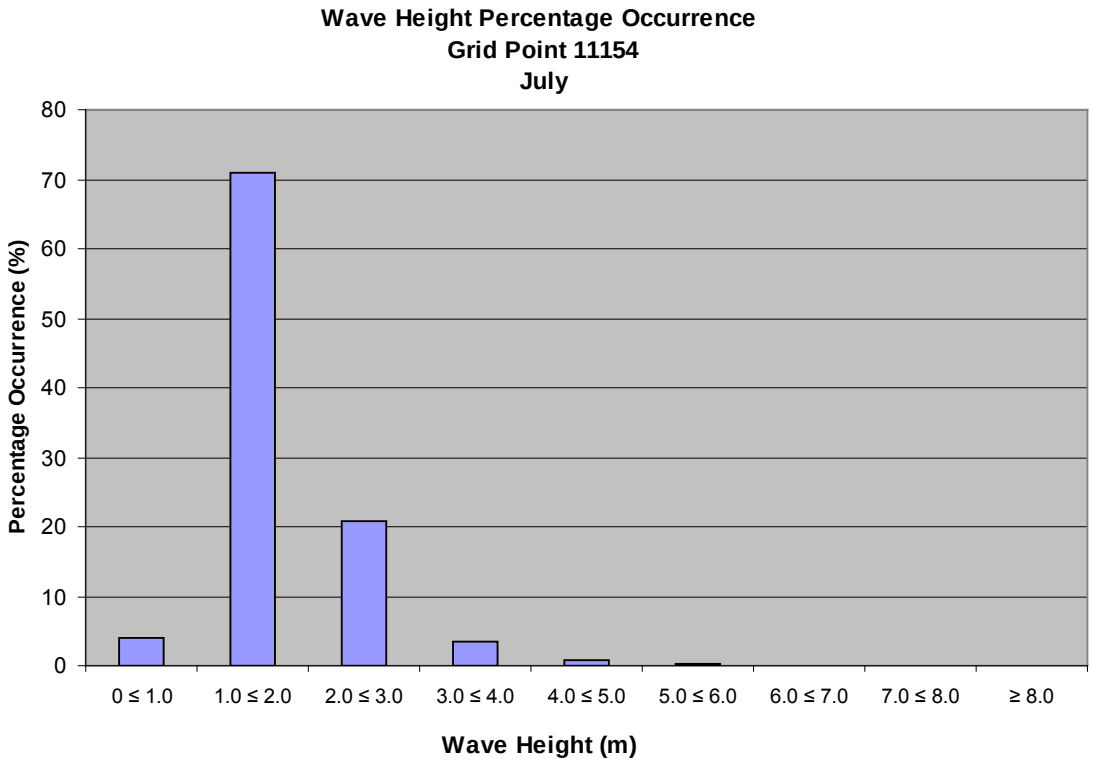
June


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

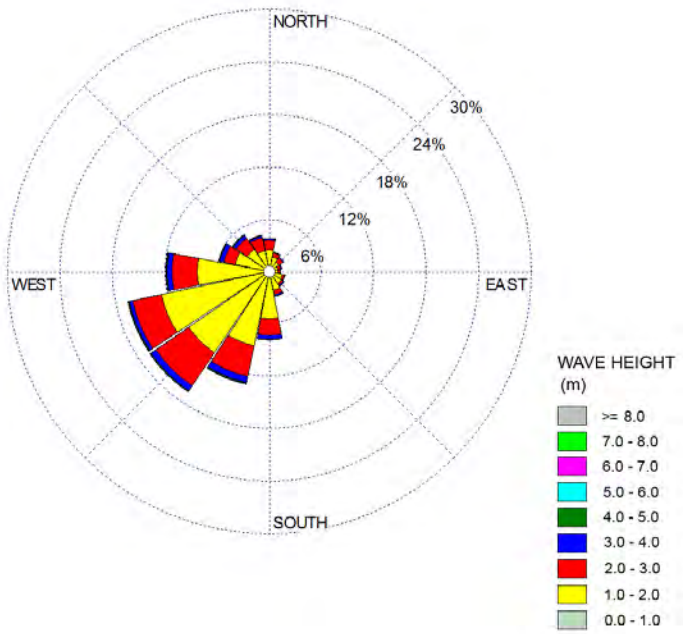

Wave Height Percentage Occurrence
Grid Point 11154
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

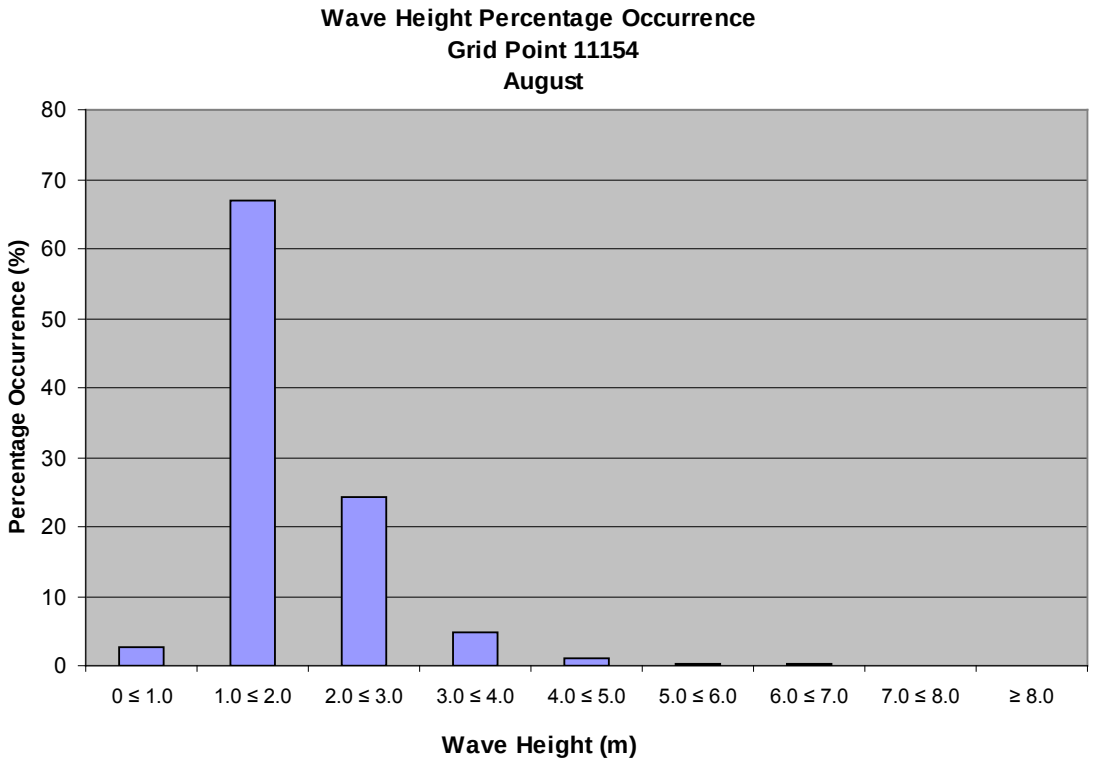
July


NORTH
30%
24%
18%
12%
6%
WEST
EAST
SOUTH
WAVE HEIGHT
(m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

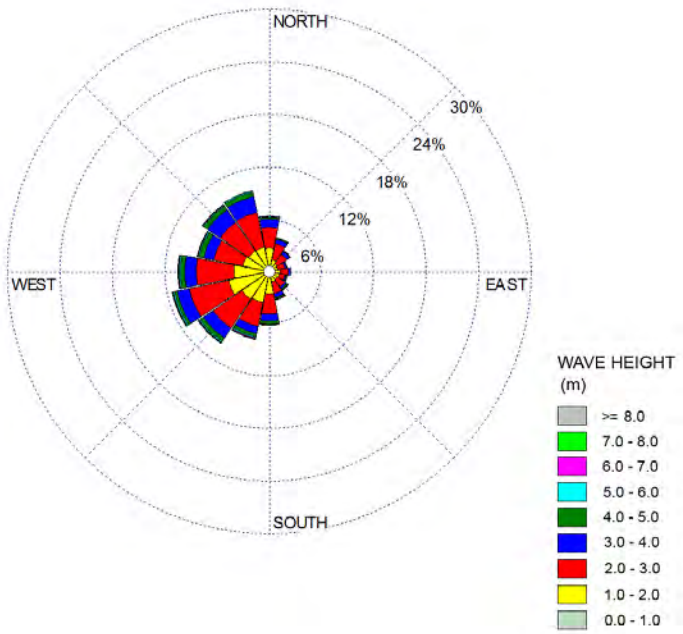

Wave Height Percentage Occurrence
Grid Point 11154
July
Percentage Occurrence (%)
80
70
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

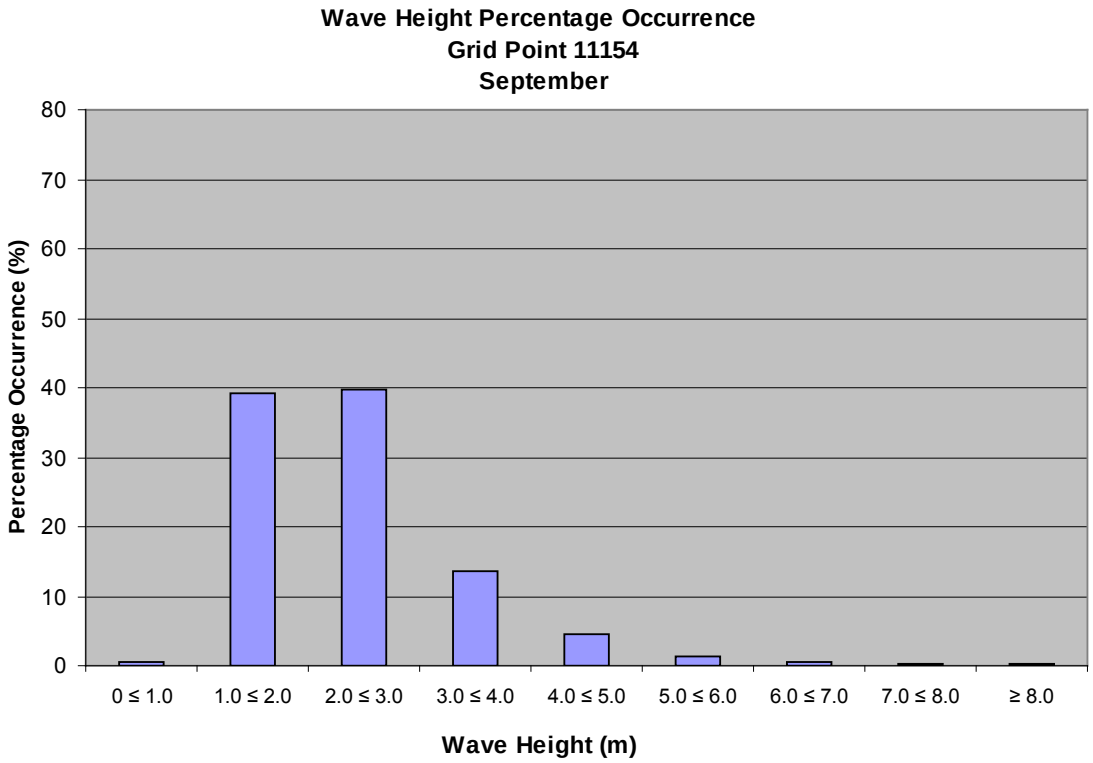
August


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

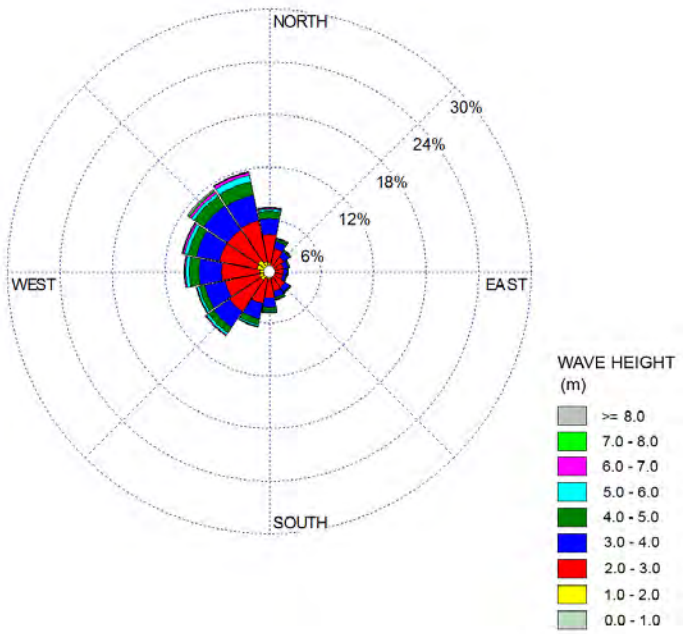

Wave Height Percentage Occurrence
Grid Point 11154
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

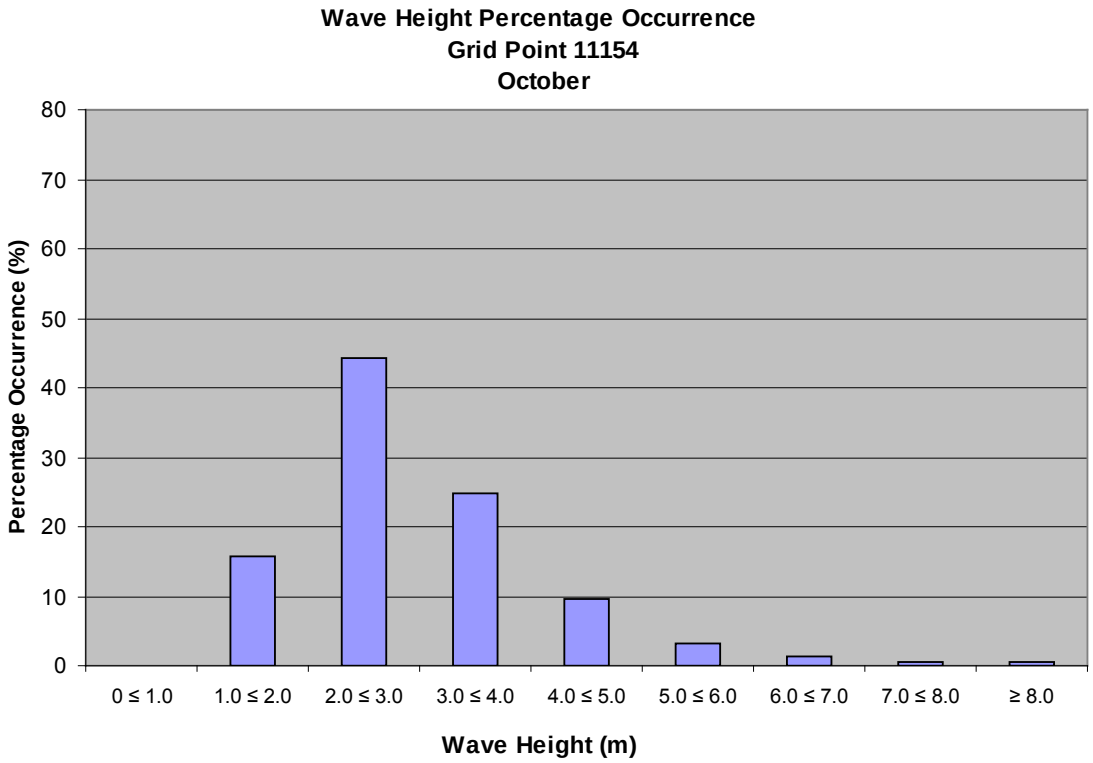
September


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

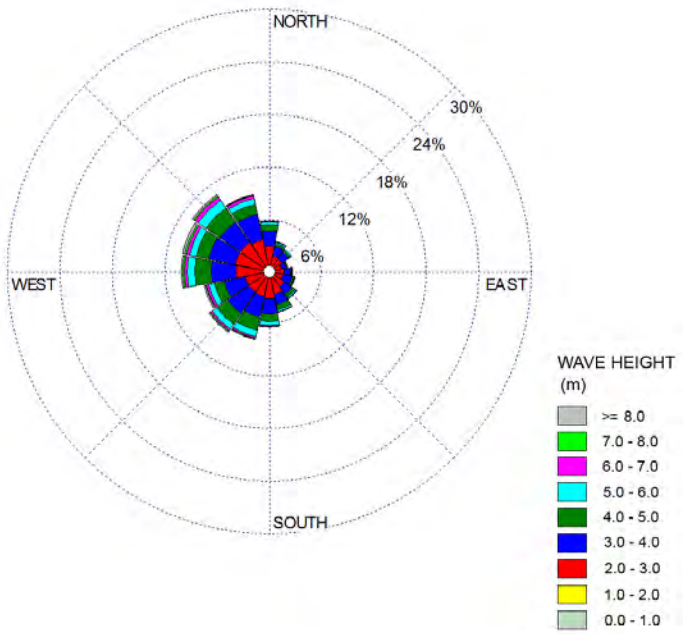

Wave Height Percentage Occurrence
Grid Point 11154
September
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

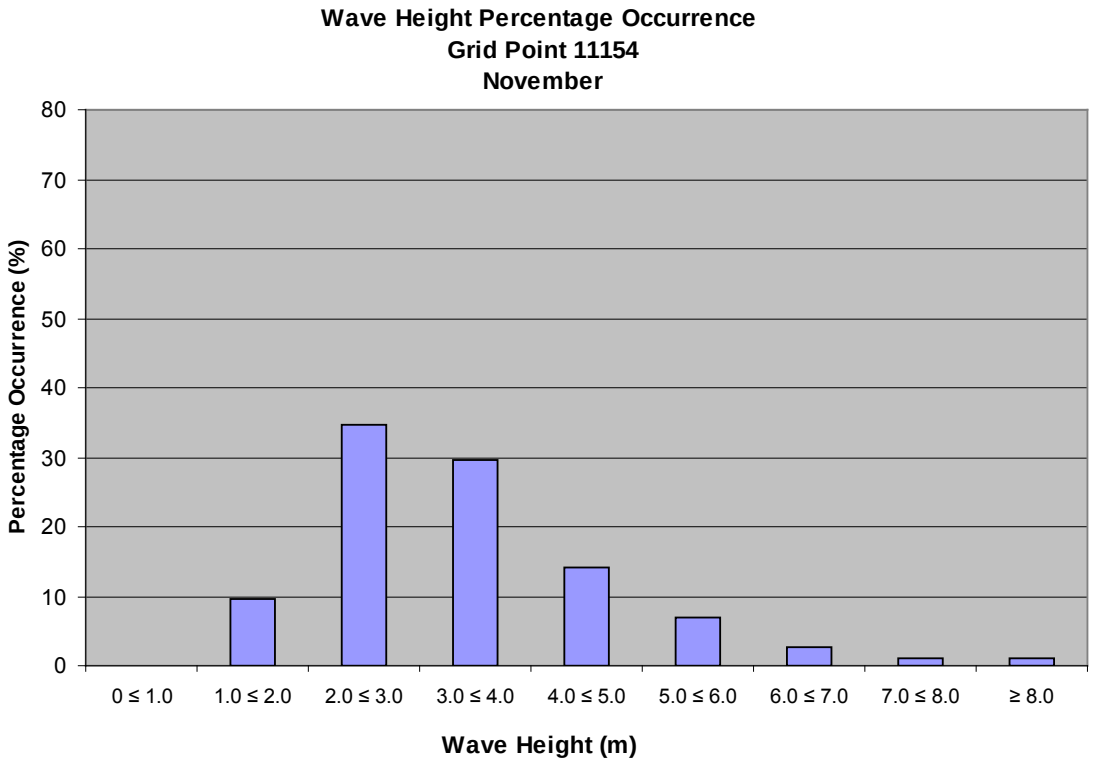
October


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0

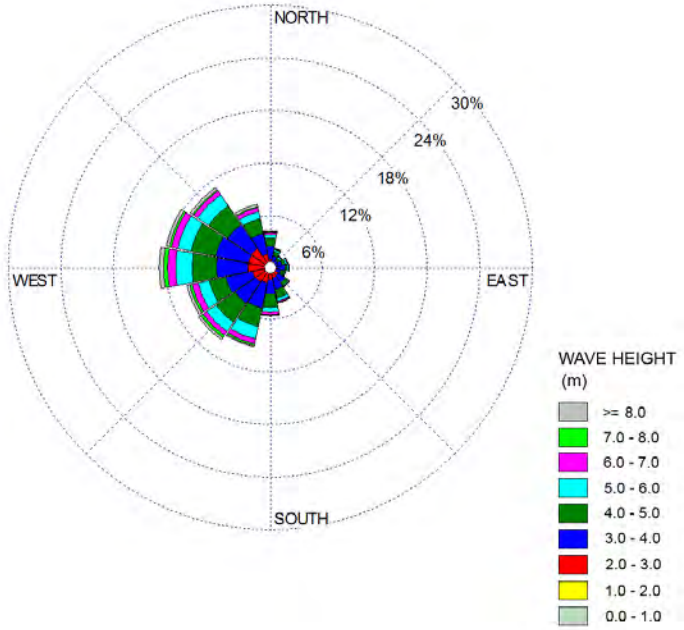

Wave Height Percentage Occurrence
Grid Point 11154
October
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

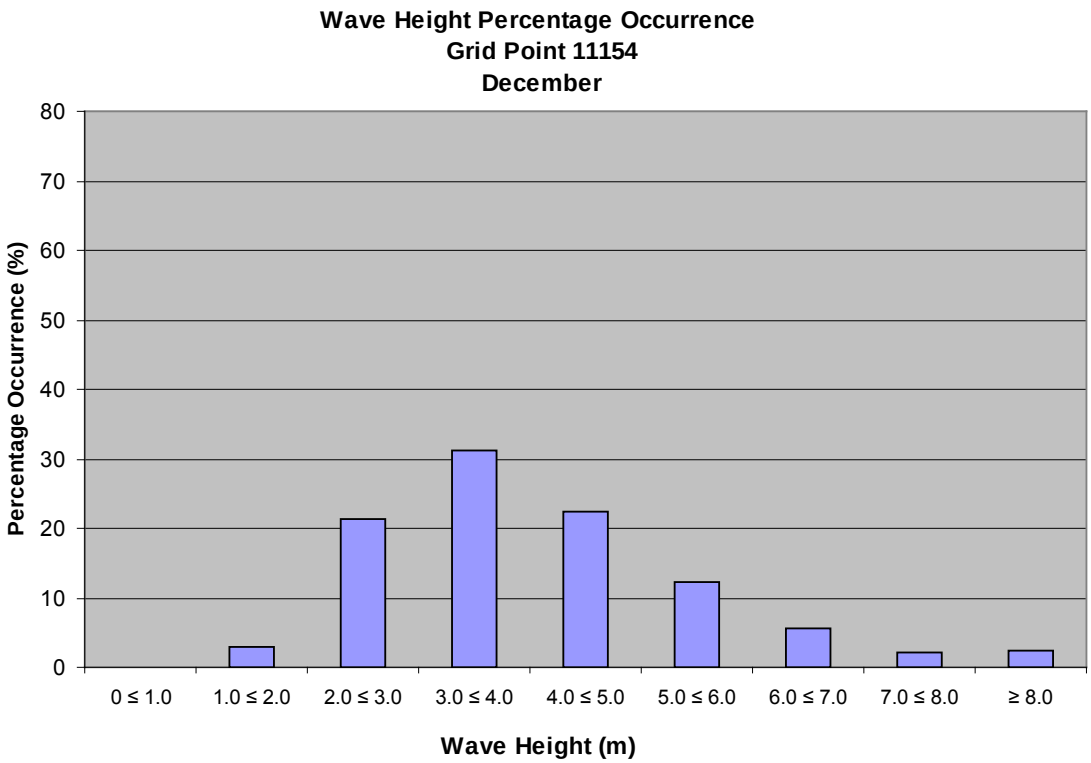
November


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT (m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 11154
November
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

December


NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
WAVE HEIGHT
(m)
>= 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0


Wave Height Percentage Occurrence
Grid Point 11154
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)