Physical Environment Jeanne d'Arc Basin / Central Ridge/Flemish Pass Basins Seismic Program for Statoil Canada

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1.0 Introduction

The purpose of this report is to provide a description of the physical environment of the Jeanne d'Arc Basin and Central Ridge/ Flemish Pass Basin to support seismic and geohazard surveys to be carried out by Statoil Canada. The Jeanne d'Arc Basin is located on the Northeast Grand Banks, Grand Banks. The most prominent features in the study area are the Grand Banks, the Sackville Spur, and Flemish Pass. The study area is shown in Figure 1.1.

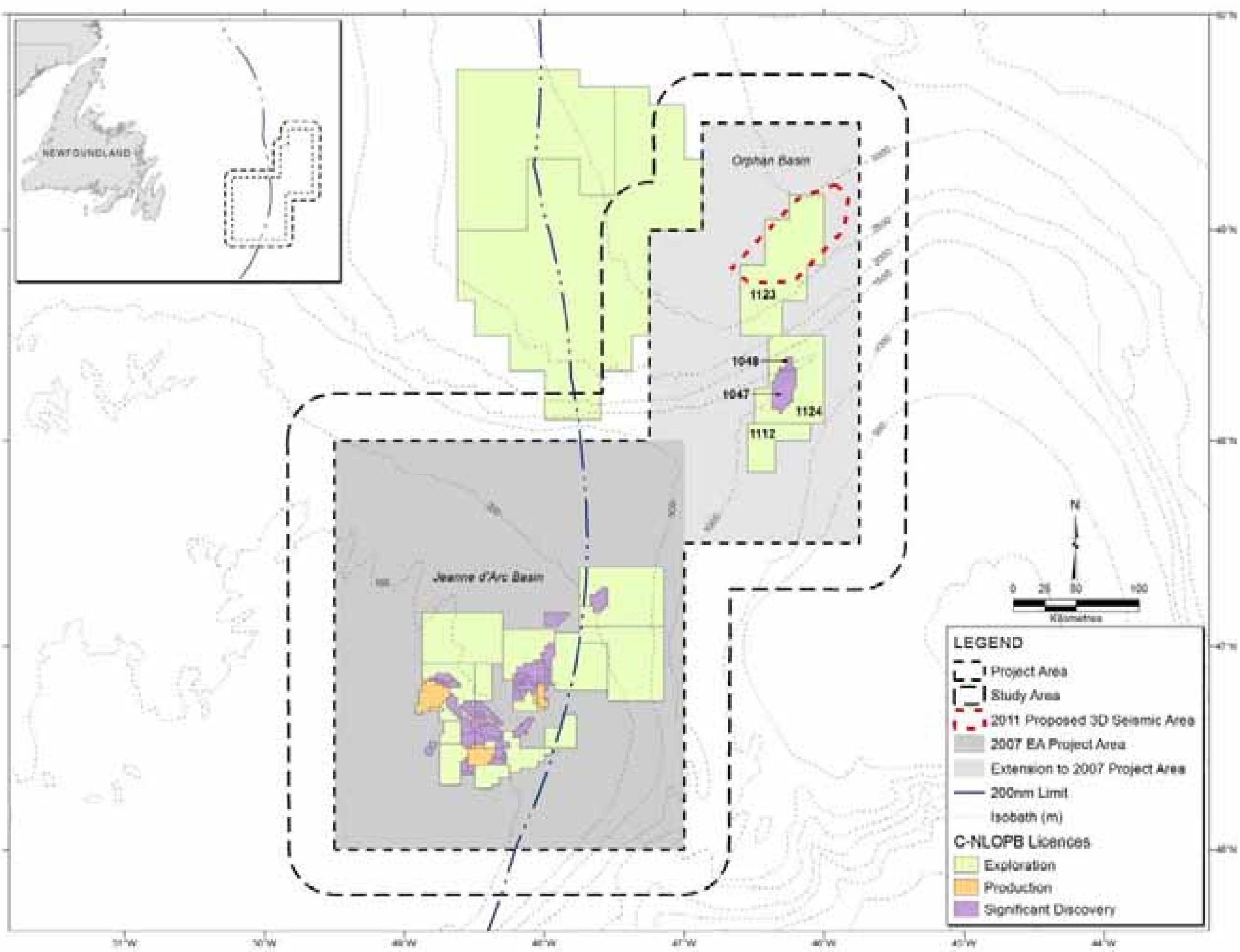


Figure 1.1 The study area for the environmental assessment off the coast of Newfoundland

The wind and wave climatology of the project area was prepared from the MCS50 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 10255 at 46.3°N; 48.4°W, Grid Point 11820 at 47.1°N: 47.3°W, Grid Point 13428 at 48.0°N; 46.3°W and Grid Point 14697 at 48.8°N: 46.3°W. One grid point was selected in Southern Orphan Basin, one on the Grand Banks south of Terra Nova, and two in Flemish Pass. The International Comprehensive Ocean-Atmosphere Data Set (ICOADS) was used for information on air temperature, sea surface temperature, and visibility.

The physical oceanography section consists of a description of the currents and the water properties in the area. The current data base consists of moored current data from Terra Nova and White Rose and data from the Bedford Institute of Oceanography archive. A general description of currents is presented for the area using information from published literature and models 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 Climatology

2.1 General Description of Weather Systems

The project area including the Northeast Grand Banks, Flemish Pass and the southern Orphan Basin 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 the project area is very dynamic, being largely governed by the passage of high and low pressure circulation systems. These circulation systems are embedded in, and steered by, the prevailing westerly flow that typifies the upper levels of the atmosphere in the mid-latitudes, 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.]

At any given time, the upper level flow is a wave-like pattern of large and small amplitude ridges and troughs. These ridges and troughs tend to act as a steering mechanism for surface features and therefore their positions in the upper atmosphere determine the weather at the earth's surface. Upper ridges tend to support areas of high pressure at the surface, while upper troughs lend support to low pressure developments. The amplitude of the upper flow pattern tends to be higher in winter than summer, which is conducive to the development of more intense storm systems.

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.

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 area.

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

2.2 Data Sources

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. The MSC50 database consists of continuous wind and wave hindcast data in 1-hour time steps from January 1954 to December 2005, on a 0.1° latitude by 0.1° longitude grid. Winds from the MSC50 data set are 1-hour averages of the effective neutral wind at a height of 10 metres (Harris, 2007).). In this project, four grid points were chosen to represent conditions within the project area. These points are listed below in Table 2.1 and presented in Figure 2.1.

Table 2.1 Grid Point Locations

Grid Point	Position
10255	46.3°N; 48.4°W
11820	47.1°N; 47.3°W
13428	48.0°N; 46.3°W
14697	48.8°N; 46.3°W

Grid Point 10255 and Grid Point 11820 were chosen to represent the conditions in the Jean d'Arc Basin region and the western side of Flemish Pass in project area (Region 1), while Grid Point 13428 and Grid Point 14697 were chosen to represent conditions in Flemish Pass and the Orphan Basin (Region 2). Wave heights and periods in the MSC50 data base are computed using a Pierson Moskowitz spectrum.

Air temperature, sea surface temperature and visibility 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 bounded on all sides by the project area and covering the period from January 1980 to January 2011 was used in this report. This data was sub-divided into two regions representing the Jean d'Arc Basin and the Orphan Basin. 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 speed, and 3.5 standard deviations for air temperature 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 however 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.

It should also be noted that wind speeds from the MSC50 and ICOADS data sets are not directly comparable to each other due to their sampling period and the heights at which they were measured. Wind speed is dependent on height since the wind speed increases at increasing heights above sea level. Methods to reduce wind speeds from anemometer level to 10 metres have proven ineffective due to atmospheric stability issues. Winds in the ICOADS data set were either estimated or measured by anemometers at various heights above sea level.

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

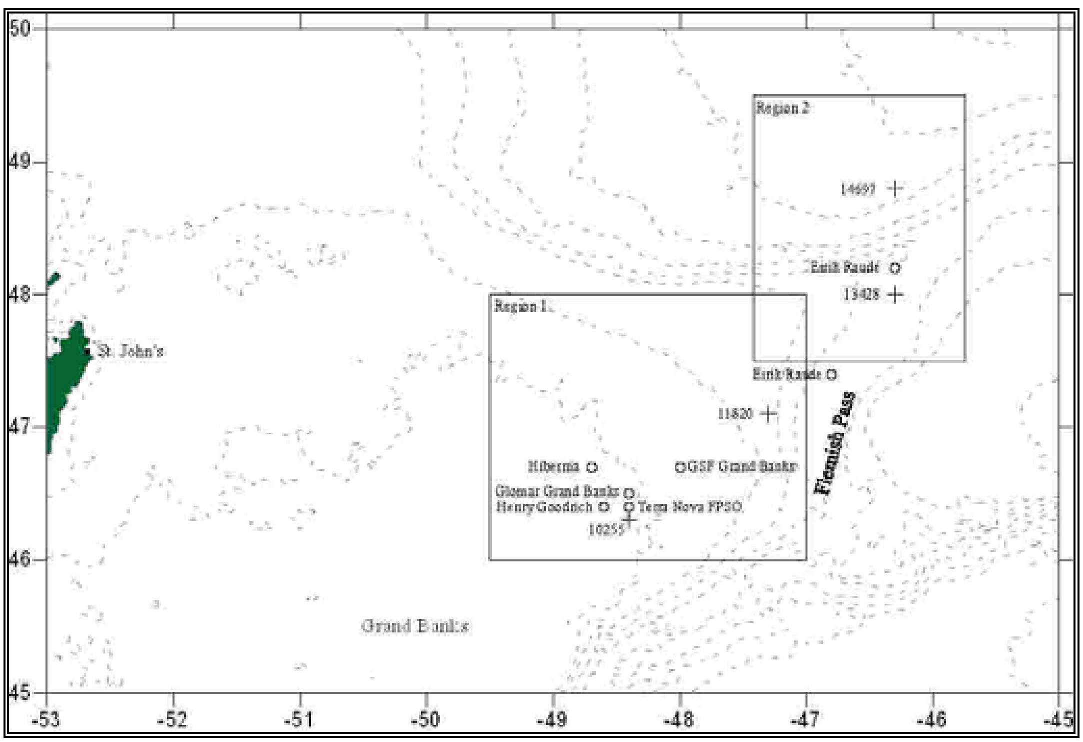


Figure 2.1 Locations of the Climate Data Sources

In addition, wind statistics were also compiled using MANMAR data from several offshore platforms located in Region 1 of the project area. The location, period of observation and anemometer height for each of these stations is presented in Table 2.2. Note that the Glomar Grand Banks and the GSF Grand Banks are the same platform under different names at the time of the observations.

Table 2.2 Locations of MANMAR observations

	Latitude	Longitude	Anemometer Height	Period
Terra Nova FPSO	46.4°N	48.4°W	50	August 12, 2007 - December 31, 2010
Glomar Grand Banks	46.5°N	48.4°W	82.5	December 31, 1998 - July 02, 2000
GSF Grand Banks	46.7°N	48.0°W	82.5	August 01, 2007 - June 28, 2009
Henry Goodrich	46.4°N	48.6°W	95	February 23, 2000 - June 30, 2009
Hibernia	46.7°N	48.7°W	139	January 01, 1999 - July 31, 2009
Eirik Raude (Mizzen L-11)	48.2°N	46.3°W	109	February 08, 2003 – April 27, 2003
Eirik Raude (Tuckamore B-27)	47.4°N	46.8°W	109	April 28, 2003 – June 10, 2003

Wave statistics were also compiled from wave data measured in and near the project area. The Hibernia wave data set has been divided into two periods due to changes in the sampling period. The sampling period changed from a 60-minute average updated every 20 minutes, to a 60-minute average updated every 2.5 minutes. The location and observation period of these stations is presented in Table 2.3.

Table 2.3 Locations of wave observations

	Latitude	Longitude	Period
Terra Nova	46.4°N	48.4°W	July 13, 1999 – September 30, 2009
Whiterose	46.8°N	48.0°W	October 06, 2003 – August 18, 2007
Ocean Ranger	46.5°N	48.4°W	December 04, 1980 – February 09, 1982
Buoy 44153	46.7°N	48.8°W	July 02, 1994 – March 11, 1998
Hibernia	46.7°N	48.7°W	January 01, 1998 - December 08, 2004
Hibernia	46.7°N	48.7°W	January 01, 2004 - December 31, 2010
Eirik Raude (Mizzen L-11)	48.2°N	46.3°W	February 08, 2003 – April 27, 2003
Eirik Raude (Tuckamore B-27)	47.4°N	46.8°W	April 28, 2003 – June 10, 2003

2.3 Wind

The project area experiences predominately southwest to west flow throughout the year. West to northwest winds which are prevalent during the winter months begin to shift counter-clockwise during March and April resulting in a predominant southwest wind by the summer months. As autumn approaches, the tropical-to-polar temperature gradient strengthens and the winds shift slightly, becoming predominately westerly again by late fall and into winter. 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.

In addition to mid-latitude low pressure systems crossing the Grand Banks, tropical cyclones often move northward out of the influence of the warm waters south of the Gulf Stream, passing near the Island of Newfoundland. Once the cyclones move over colder waters they lose their source of latent heat energy and often begin to transform into a fast-moving and rapidly developing extratropical cyclone producing large waves and sometimes hurricane force winds. Since 1950, 46% of Atlantic Tropical cyclones transitioned into the extratropical stage. This extratropical transition occurs in the lower latitudes in the early and late hurricane season and at higher latitudes during the peak of the season (Hart, 2001).

Region 1

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 for all datasets peak during the month of January (Table 2.4).

Wind speed typically increases with increasing heights above sea level. Statistics provided in Table 2.1 are presented in order of increasing height, with the MSC50 data set being the lowest and the Hibernia Platform being the highest. The anemometer heights for each platform are found in Table 2.2. Statistics for each anemometer level are presented to give a better idea of winds at varying levels above sea level.

Table 2.4 Mean Wind Speed Statistics

	MSC50 Grid Point 10255	MSC50 Grid Point 11820	ICOADS Region 1	Terra Nova FPSO	Glomar Grand Banks	GSF Grand Banks	Henry Goodrich	Hibernia
January	11.5	11.8	14.2	14.3	12.9	13.5	15.4	16.9
February	11.4	11.7	13.6	13.3	11.9	12.6	15.3	16.0
March	10.4	10.6	12.5	12.3	11.9	12.3	14.0	14.6
April	8.8	8.9	11.7	11.5	11.4	11.7	12.7	13.7
May	7.3	7.5	10.6	11.0	9.7	11.6	11.8	12.8
June	6.8	6.9	10.5	10.0	9.4	9.0	11.6	12.1
July	6.3	6.4	10.2	9.4	9.5	9.2	11.1	11.5
August	6.7	6.7	9.4	9.4	8.4	8.8	9.8	10.8
September	7.8	8.0	10.4	10.6	10.3	9.5	10.4	11.9
October	9.2	9.5	11.7	11.8	12.8	10.2	12.2	13.6
November	10.0	10.2	12.3	12.3	11.0	11.5	12.7	14.5
December	11.1	11.4	14.0	14.5	12.6	13.4	14.4	16.1

Wind roses of the annual wind speed for Grid Points 10255 and 11820 are presented in Figure 2.2 and Figure 2.3 and their associated histograms of the wind speed frequency in Figure 2.4 and Figure 2.5. Monthly wind roses along with histograms of the frequency distributions of wind speeds can be found in Appendices 1 and 2. There is a marked increase in the occurrence of winds from the west to northwest in the winter months as opposed to the summer months, which is consistent with the wind climatology of the area. The percentage exceedance of wind speeds at grid points 10255 and 11820 is presented in Figure 2.6 to Figure 2.7.

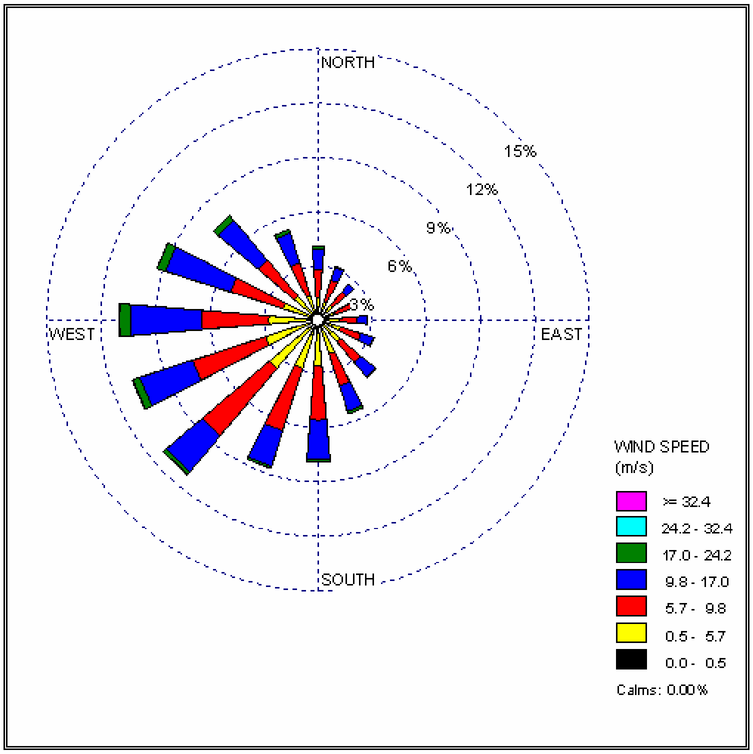


Figure 2.2 Annual Wind Rose for MSC50 Grid Point 10255 located near 46.3°N; 48.4°W. 1954 – 2005

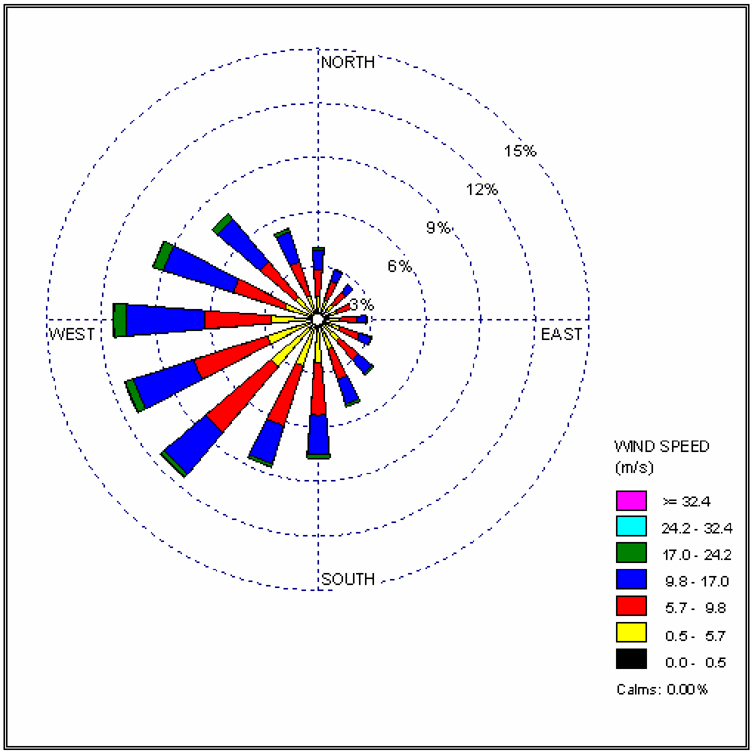


Figure 2.3 Annual Wind Rose for MSC50 Grid Point 11280 located 47.1°N; 47.3°W. 1954 – 2005

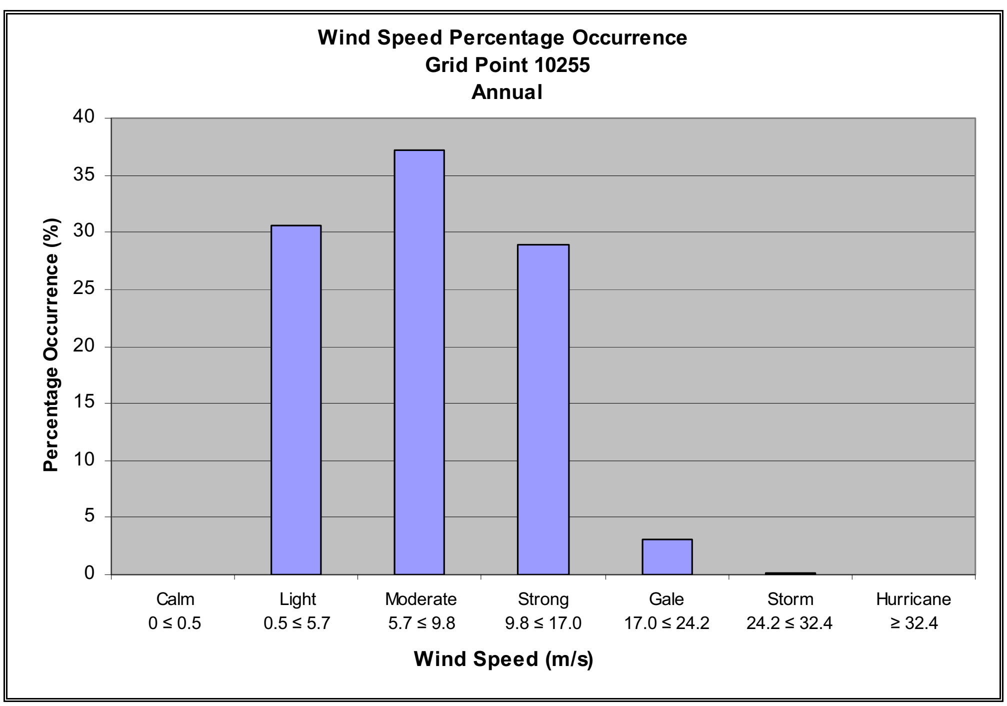


Figure 2.4 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 10255 located near 46.3°N; 48.4°W. 1954 – 2005

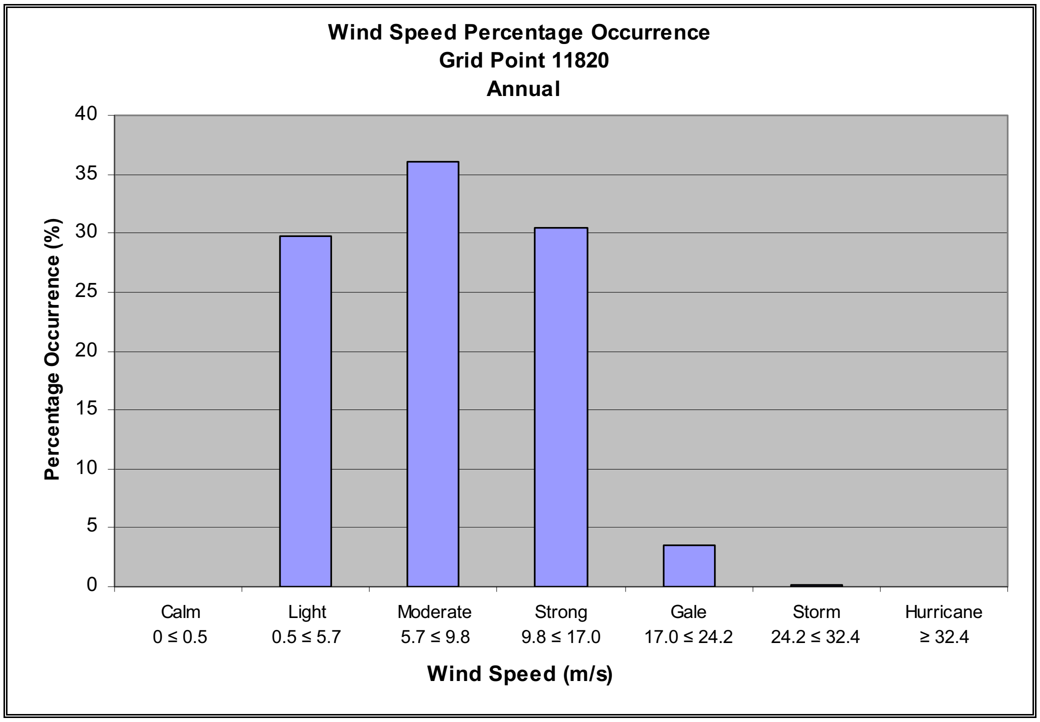


Figure 2.5 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 11280 located near 47.1°N; 47.3°W. 1954 – 2005

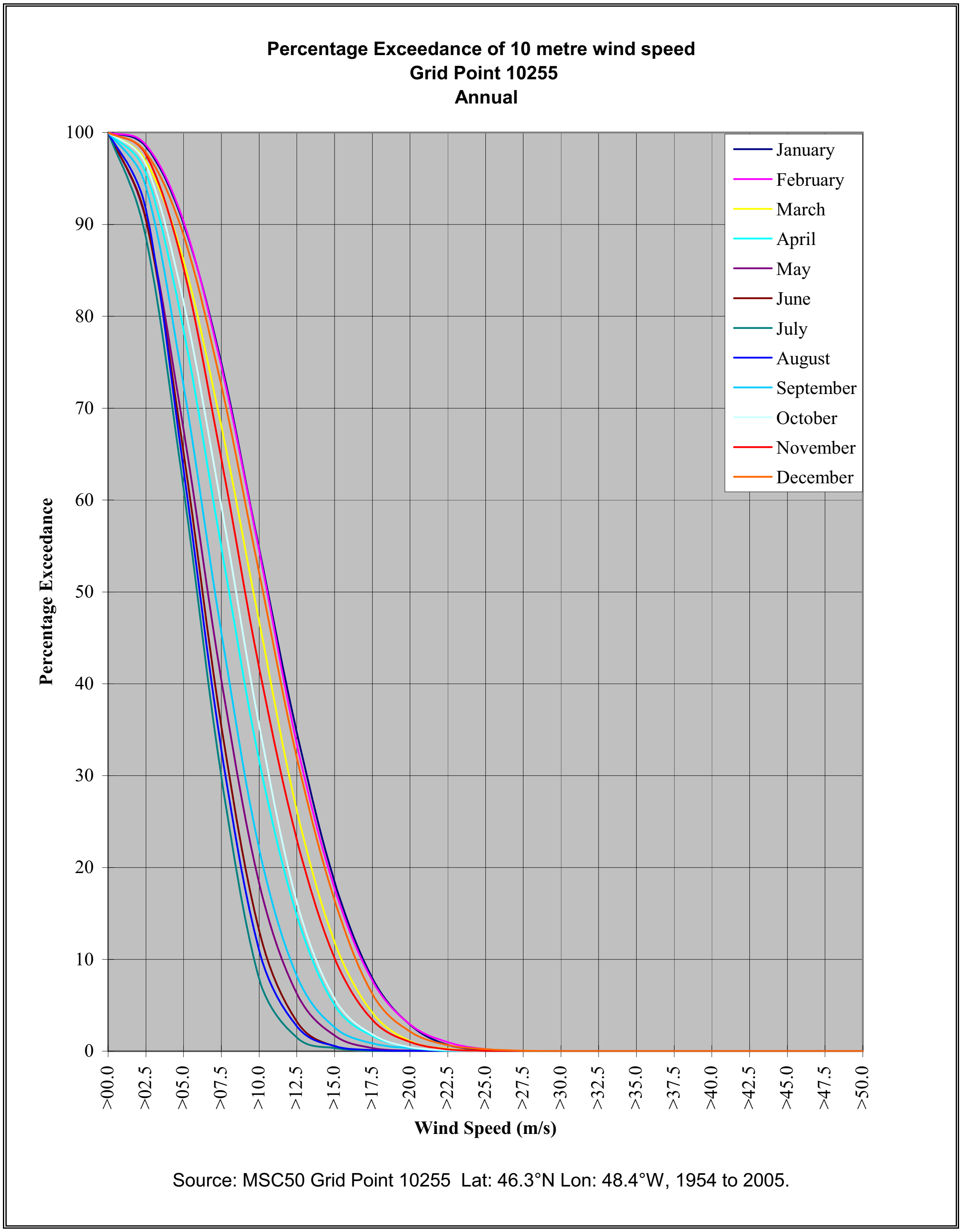


Figure 2.6 Percentage Exceedance of 10 metre wind speed at Grid Point 10255 located near 46.3°N; 48.4°W . 1954 to 2005

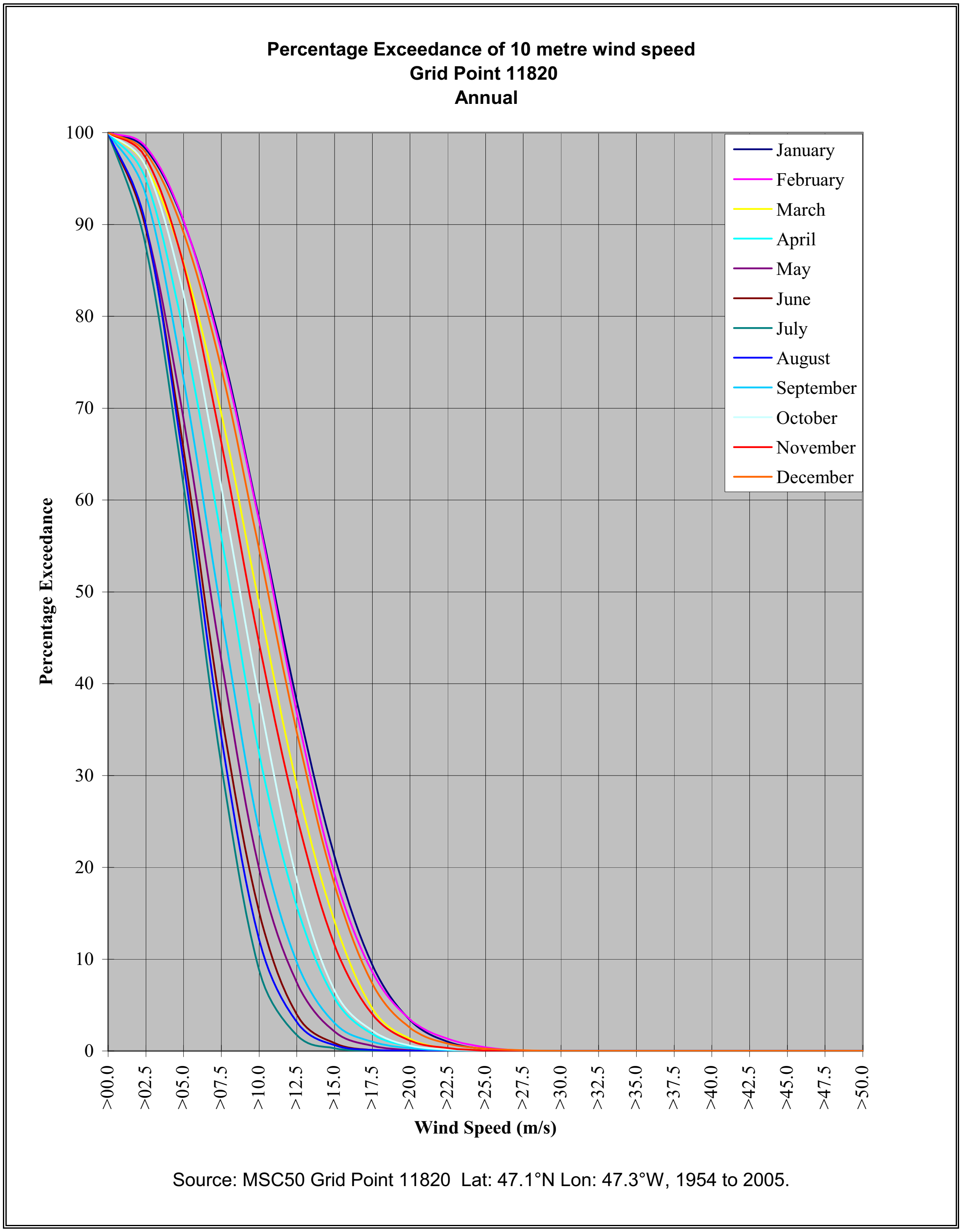


Figure 2.7 Percentage Exceedance of 10 metre wind speed at Grid Point 11820 located near 47.1°N; 47.3°W . 1954 to 2005

A table of monthly maximum wind speeds for each of the data sets is presented in Table 2.5. Rapidly deepening storm systems known as weather bombs frequently cross the Grand Banks. These storm systems typically develop in the warm waters of Cape Hatteras and move northeast across the Grand Banks. Wind speeds of 49.4 m/s and 50.9 m/s from the southwest were recorded by the Hibernia Platform and the Henry Goodrich anemometers, respectively as this system passed. During this storm, a low pressure developing off Cape Hatteras on February 10^{th} rapidly deepened to 949 mb as it tracked northeast across the Avalon Peninsula around 18Z on February 11^{th}.

Table 2.5 Maximum Wind Speed (m/s) Statistics

	MSC50 Grid Point 10255	MSC50 Grid Point 11820	ICOADS Region 1	Terra Nova FPSO	Glomar Grand Banks	GSF Grand Banks	Henry Goodrich	Hibernia
January	29.0	28.9	43.7	31.9	30.9	37.6	44.2	43.2
February	31.7	32.6	46.3	31.4	26.8	27.8	50.9	49.4
March	28.6	32.5	38.0	29.8	23.7	28.8	32.9	37.6
April	26.5	27.1	37.0	23.2	26.8	24.2	30.9	31.9
May	22.8	25.1	33.9	25.2	22.1	25.7	32.9	32.4
June	24.1	25.1	35.5	24.2	21.1	27.3	28.3	35.5
July	22.4	21.8	31.9	23.2	20.1	25.2	26.2	31.9
August	31.8	30.1	36.0	29.8	25.7	26.2	28.8	41.2
September	25.0	25.7	37.6	34.5	29.3	21.6	28.3	43.2
October	29.3	29.5	41.1	31.9	32.9	30.9	27.8	44.8
November	29.1	29.8	41.2	28.3	25.7	25.2	32.4	38.1
December	31.7	30.8	47.8	37.6	27.3	29.3	38.1	39.1

Region 2

Mean wind speeds at grid points 13428 and 14697 and the ICOADS data set peak during the month of January (Table 2.6). The highest mean wind speed for both grid points occurred in January with a speed of 11.7 m/s for 13428 and 12.1 m/s for 14697, while the ICOADS dataset recorded the highest mean wind speed of 12.6 m/s for January. Wind speed statistics are also presented from the Eirik Raude platform while at Mizzen L-11 and Tuckamore B-27

Table 2.6 Mean Wind Speed (m/s) Statistics

Month	Grid Point 13428	Grid Point 14697	ICOADS Region 2	Mizzen L-11	Tuckamore B-27
January	12.4	12.8	12.6		
February	12.2	12.5	12.0	17.5	
March	11.0	11.4	10.9	13.1	
April	9.2	9.5	8.4	12.0	9.1
May	7.9	8.3	7.9		9.1
June	7.2	7.5	7.8		9.6
July	6.6	6.9	7.3		
August	7.0	7.3	7.5		
September	8.4	8.8	8.4		
October	9.9	10.3	9.0		
November	10.8	11.2	10.8		
December	11.9	12.3	11.1		

Wind roses of the annual wind speed and histograms of the wind speed frequency from grid points 13428 and 14697 are presented in Figures 2.8 to 2.11. Monthly wind roses along with histograms of the frequency distributions of wind speeds for Grid Point 13428 and 14697 can be found in Appendices 5 and 6.

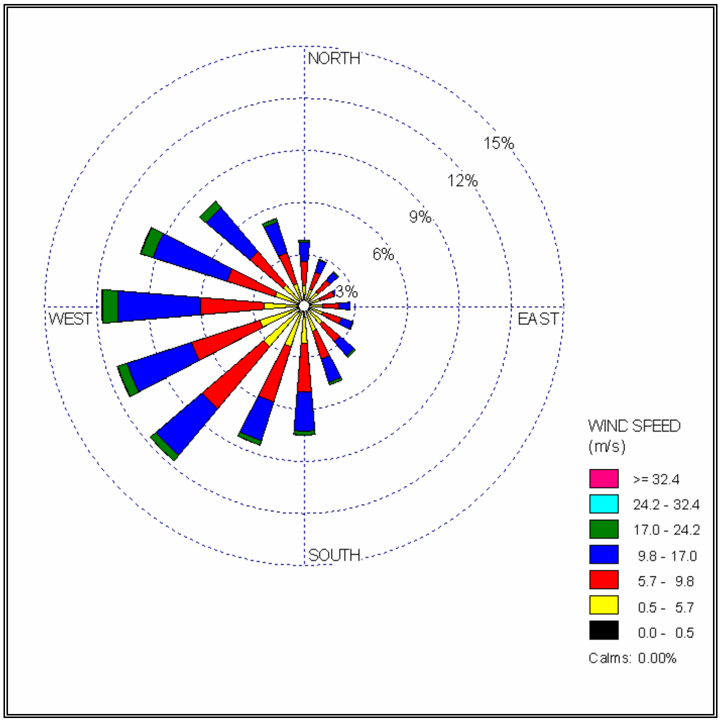


Figure 2.8 Annual Wind Rose for MSC50 Grid Point 13428 located near 48.0°N; 46.3°W. 1954 – 2005

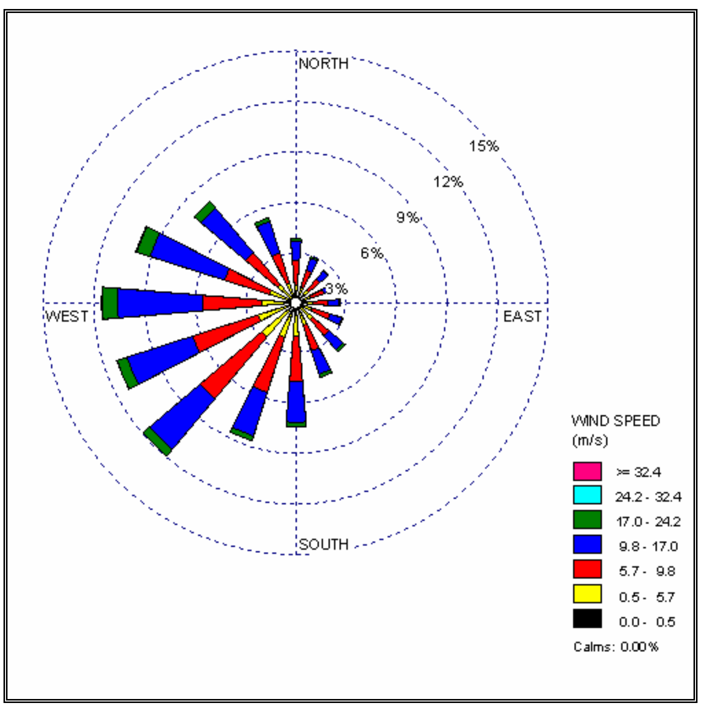


Figure 2.9 Annual Wind Rose for MSC50 Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

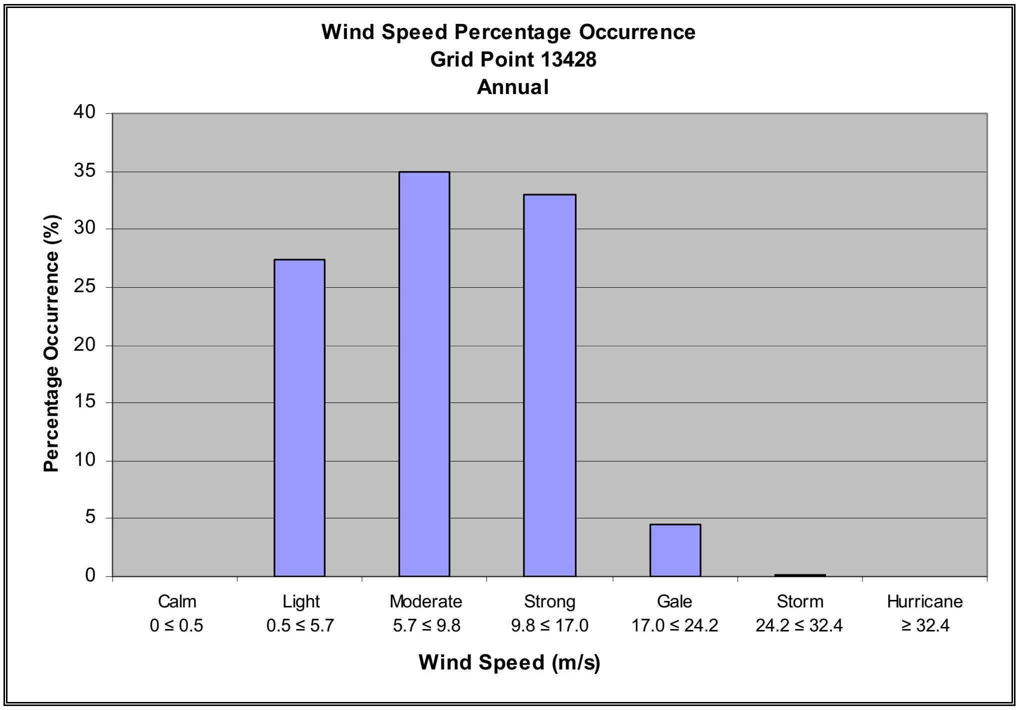


Figure 2.10 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 13428 located near 48.0°N; 46.3°W. 1954 – 2005

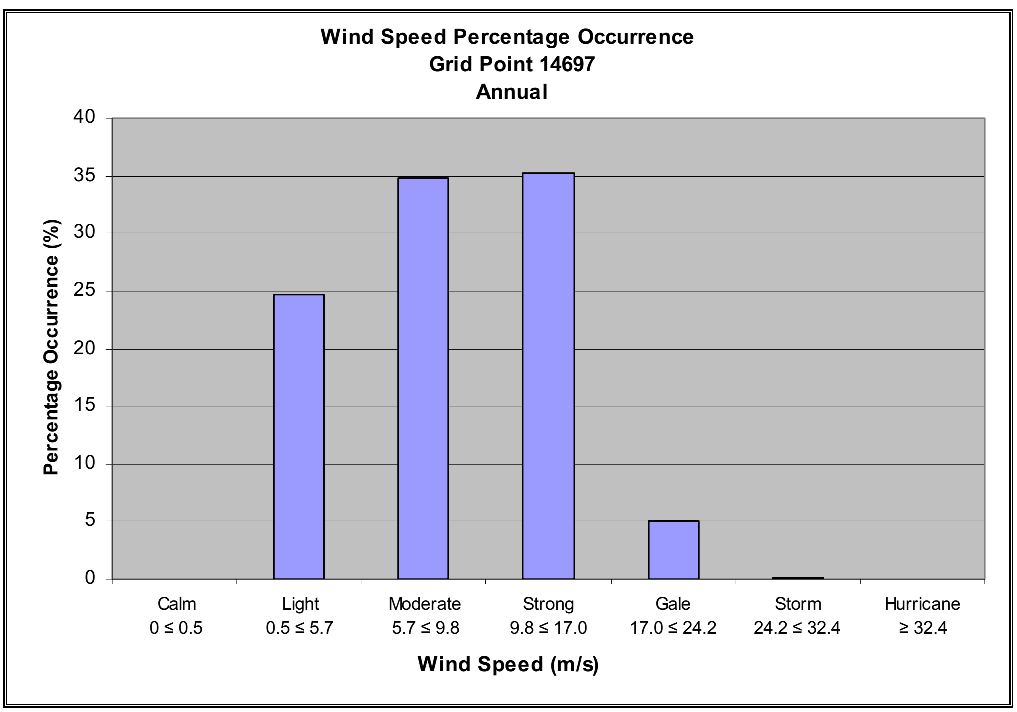


Figure 2.11 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

The Eirik Raude platform was located at Mizzen L-11 during an extreme wind event which occurred on February 11, 2003. During this event, the platform recorded a mean 10-minute wind speed of 43.2 m/s (Table 2.7). A similar, although somewhat weaker system passed through the project area March 08, 2003. Mean wind speeds recorded by the Eirik Raude during this event peaked at 33.4 m/s.

Table 2.7 Maximum Wind Speed (m/s) Statistics

Month	Grid Point 13428	Grid Point 14697	ICOADS Region 2	Mizzen L-11	Tuckamore B-27
January	30.9	30.1	37.0		
February	33.6	33.7	40.1	43.2	
March	32.3	33.4	33.4	33.4	
April	27.6	27.1	28.3	23.2	18.5
May	27.1	26.9	27.8		25.2
June	24.7	24.4	28.3		22.6
July	20.5	21.1	30.9		
August	28.6	30.5	26.8		
September	29.8	28.1	28.8		
October	29.5	30.2	26.8		
November	29.3	29.4	37.0		
December	32.5	33.8	30.9		

Figures 2.12 and 2.13 show percentage exceedance curves of mean 10-metre wind speed for Grid Points 13428 and 14697.

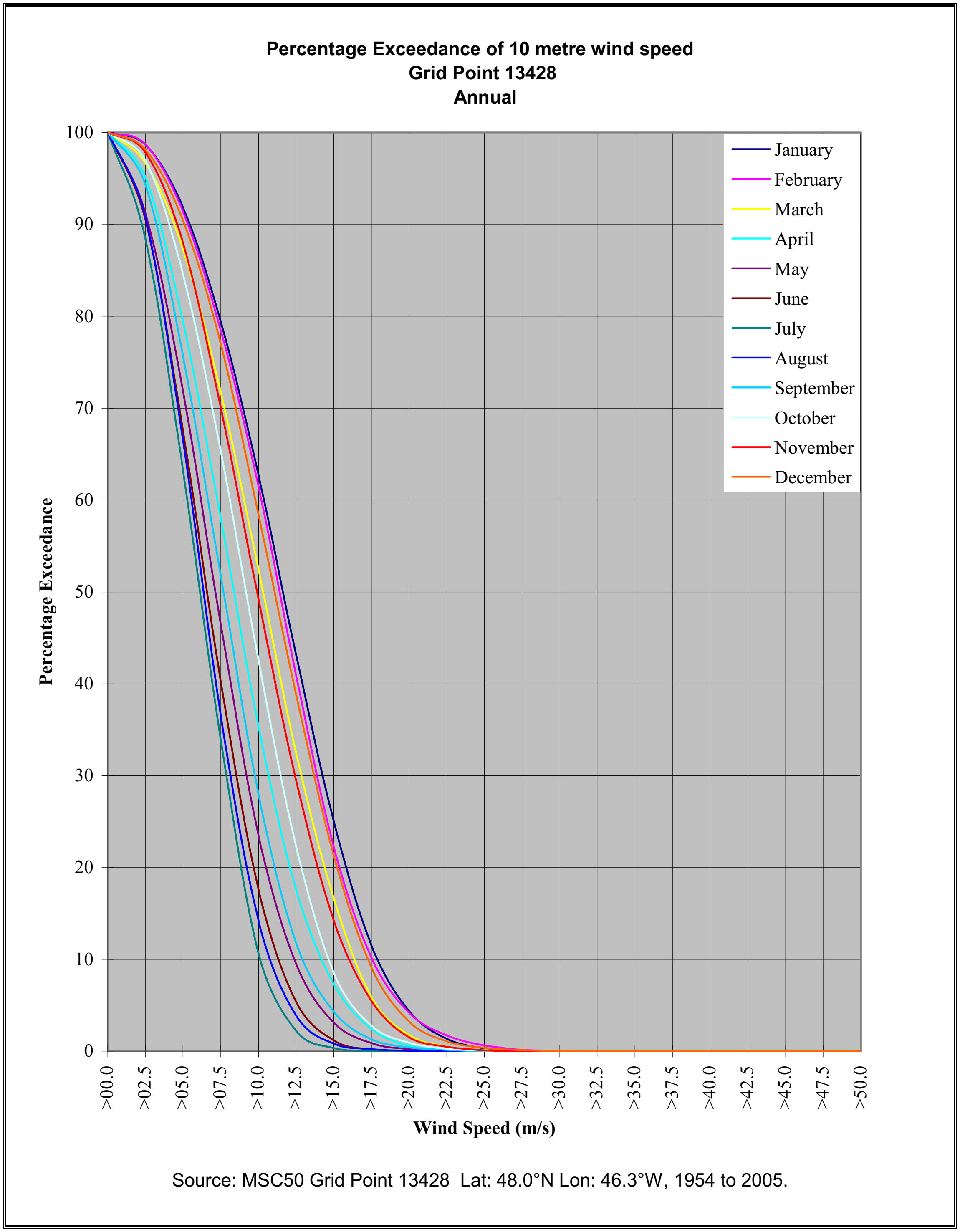


Figure 2.12 Percentage Exceedance of 10 metre wind speed at Grid Point 13428 located near 48.0°N; 46.3°W . 1954 to 2005

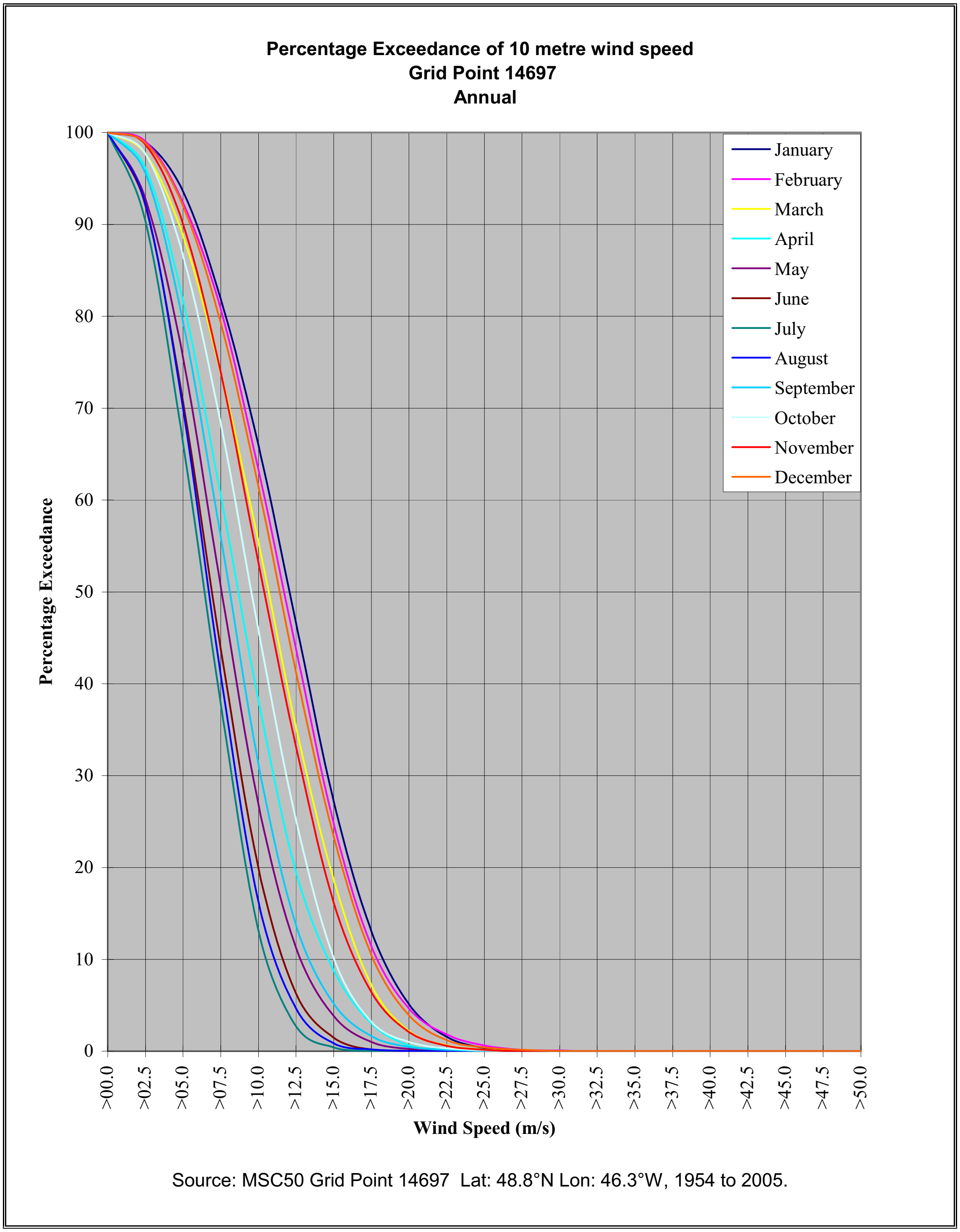


Figure 2.13 Percentage Exceedance of 10 metre wind speed at Grid Point 14697 located near 48.8°N; 46.3°W. 1954 to 2005

2.4 Waves

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

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

During autumn and winter, the dominate direction of the combined significant wave height is from the west. This corresponds with a higher frequency of occurrence of the wind wave during these months, suggesting that during the late fall and winter, the wind wave is the main contributor to the combined significant wave height. During the months of March and April, the wind wave remains predominately westerly, while the swell begins to back to southerly, resulting in the vector mean direction of the combined significant wave heights backing to southwesterly. A mean southwesterly direction for the combined significant wave heights during the summer months is a result of a mainly southwesterly wind wave and a southwesterly swell. As winter approaches during the months of September and October, the wind wave will veer to the westerly and become the more dominant component of the combined significant wave height. This will result in the frequency of occurrence of the combined significant wave heights veering to westerly once again.

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).

Region 1

The annual wave rose from the MSC50 data for each of the grid points in Region 1 are presented in Figure 2.14 and Figure 2.15. The wave roses show that the majority of wave energy comes from the west-southwest to south-southwest, and accounts for 35.9% of the wave energy at grid point 10255 and 36% of the wave energy at Grid Point 11820. Waves were "iced out" for 0.98% of the time at grid point 10255 and 2.12% of the time at grid point 11421 over the 50-year record.

The annual percentage frequency of significant wave heights is presented in Figure 2.16 and Figure 2.17. These figures show that the majority of significant wave heights in Region 2 lie between 1.0 and 4.0 metres. There is a gradual decrease in frequency of wave heights above 4.0 m and only a small percentage of the wave heights exceeding 7.0 m can be found. Monthly wave roses histograms of frequency distributions of wave heights can be found in Appendices 3 and 4.

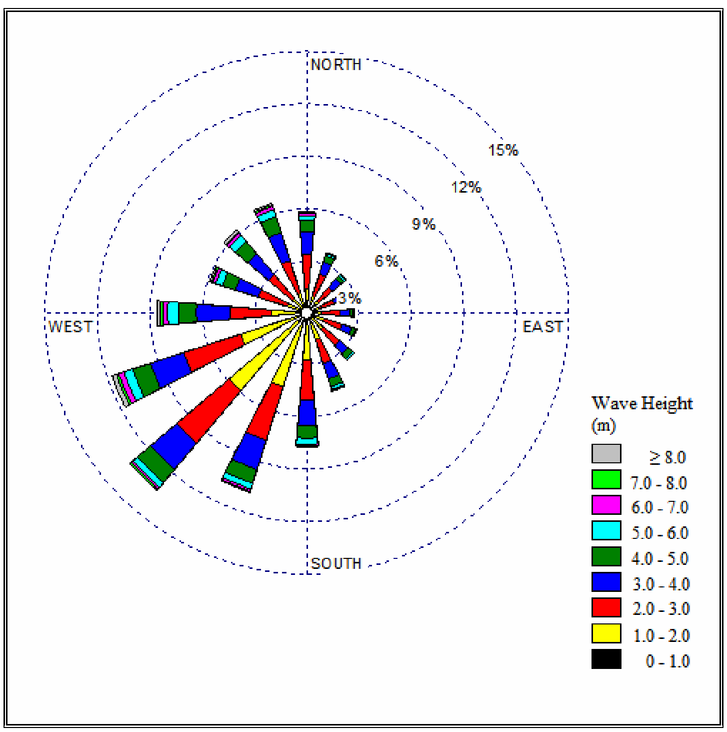


Figure 2.14 Annual Wave Rose for MSC50 Grid Point 10255 located near 46.3°N; 48.4°W, 1954 to 2005

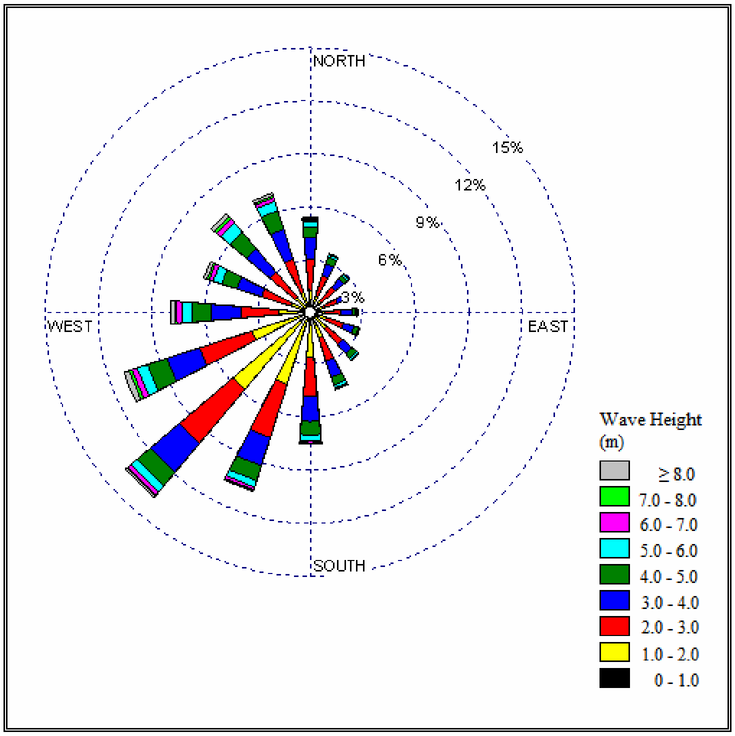


Figure 2.15 Annual Wave Rose for MSC50 Grid Point 11820 located near 47.3°N; 47.3°W, 1954 to 2005

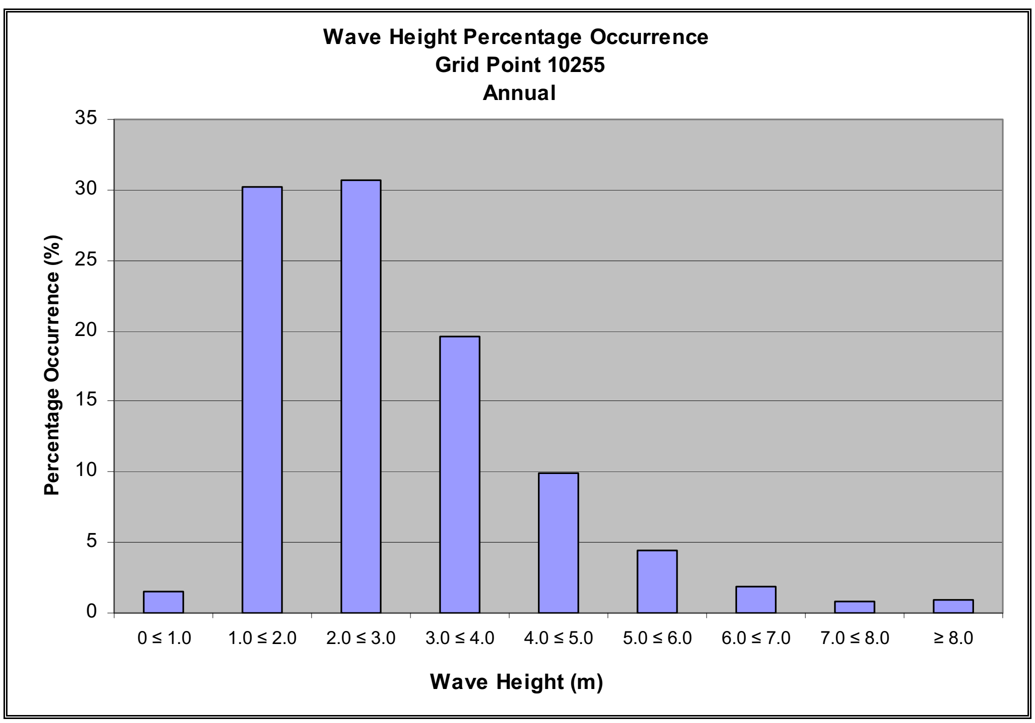


Figure 2.16 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 10255 located near 46.3°N; 48.4°W. 1954 to 2005

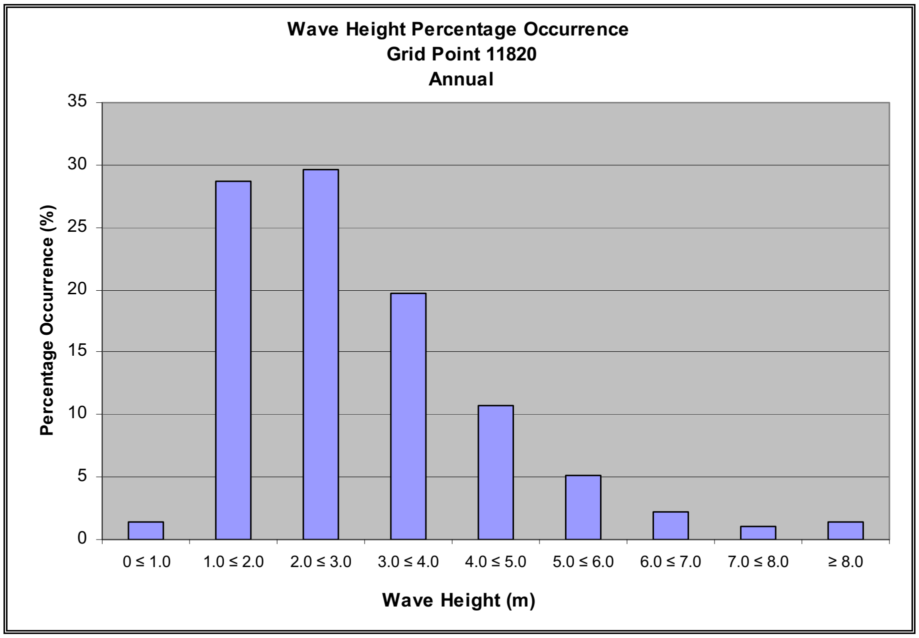


Figure 2.17 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 11820 located near 47.3°N; 47.3°W. 1954 to 2005

Significant wave heights on the Grand Banks peak during the winter months with Grid Points 10255 and 11820 having a mean monthly significant wave height of 4.0 and 4.2 metres respectively in January. The lowest significant wave heights occur in the summer with July month having a mean monthly significant wave height of only 1.7 m (Table 2.8).

Table 2.8 Combined Significant Wave Height Statistics (m)

	MSC50 Grid Point 10255	MSC50 Grid Point 11820	Terra Nova	White Rose	Hibernia (1998-2004)	Hibernia (2005-2008)	Ocean Ranger	Buoy 44153
January	4.0	4.2	4.1	4.2	4.0	3.9	5.2	N/A
February	3.7	3.7	3.8	3.5	3.7	3.4	4.4	0.2
March	3.2	3.1	3.3	3.5	3.6	3.1	4.7	N/A
April	2.7	2.8	2.6	2.6	2.8	2.3	3.7	N/A
May	2.2	2.3	2.2	2.2	2.3	1.8	1.7	0.7
June	1.9	1.9	1.8	1.8	2.0	1.8	1.5	0.6
July	1.7	1.7	1.5	1.4	1.6	1.6	1.8	0.7
August	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.0
September	2.4	2.4	2.3	2.4	2.3	2.4	3.8	1.0
October	2.9	3.1	3.0	3.0	2.6	3.2	3.0	1.3
November	3.3	3.5	3.1	3.2	3.2	2.9	4.8	1.6
December	3.9	4.1	3.8	3.4	3.8	3.6	4.6	2.1

Combined significant wave heights of 10.5 metres or more occurred in each month between September and April in the MSC50 data, with the highest waves occurring during the month of February (Table 2.9). The highest combined significant wave heights of 14.6 m and 13.8 m in the Terra Nova and Hibernia datasets, respectively, occurred during the February 11, 2003 storm event 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.

Table 2.9 Maximum Combined Significant Wave Height Statistics (m)

	MSC50 Grid Point 10255	MSC50 Grid Point 11280	Terra Nova	Hibernia (1998 - 2004)	Hibernia (2005 - 2008)	Ocean Ranger	Buoy 44153
January	13.3	13.6	12.5	12.2	11.5	10.6	N/A
February	13.9	14.6	14.6	13.8	9.4	8.3	2.1
March	11.9	11.5	9.4	9.7	9.3	7.2	N/A
April	10.8	10.8	7.1	9.4	7.5	7.8	N/A
May	9.9	11.1	6.3	7.4	6.8	3.8	1.5
June	9.6	10.6	6.5	7.2	8.4	3.0	2.6
July	6.2	7.0	4.1	6.4	9.1	4.2	2.1
August	8.1	8.6	8.0	18.2	8.2	3.3	5.2
September	10.9	11.4	10.4	9.9	9.8	8.4	5.0
October	11.8	12.7	10.4	9.0	10.2	5.8	5.1
November	11.3	12.3	10.2	10.5	9.3	7.0	6.0
December	13.7	14.2	11.7	10.8	9.3	8.1	5.9

Figures 2.18 and 2.19 shows percentage exceedance curves of significant wave heights for Grid Points 11250 and 11280. Percentage exceedance curves for the months of January through April show that the curves do not reach 100% because of the presence of ice during these months.

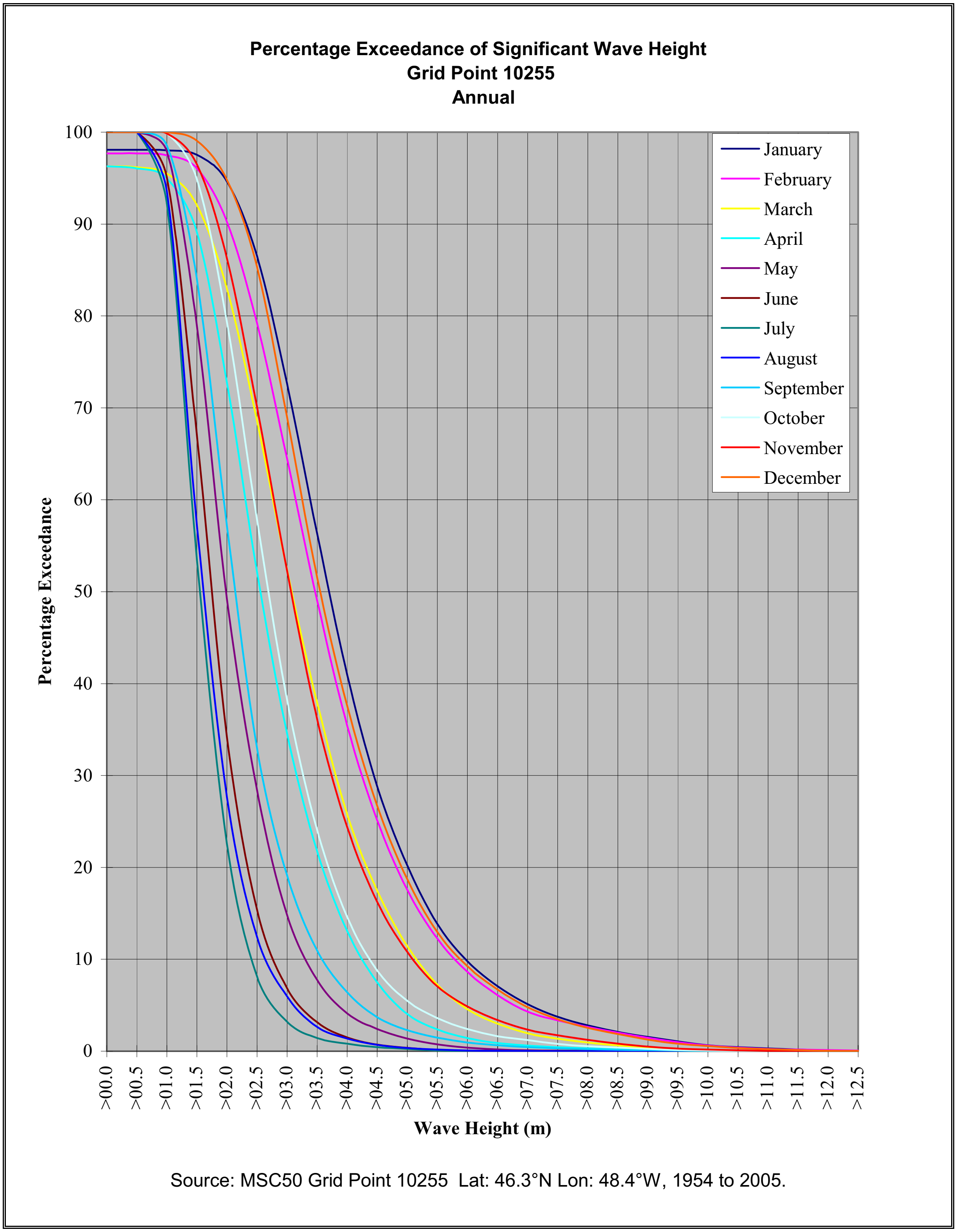


Figure 2.18 Percentage Exceedance of Significant Wave Height at Grid Point 10255 located near 46.3°N; 48.4°W. 1954 to 2005

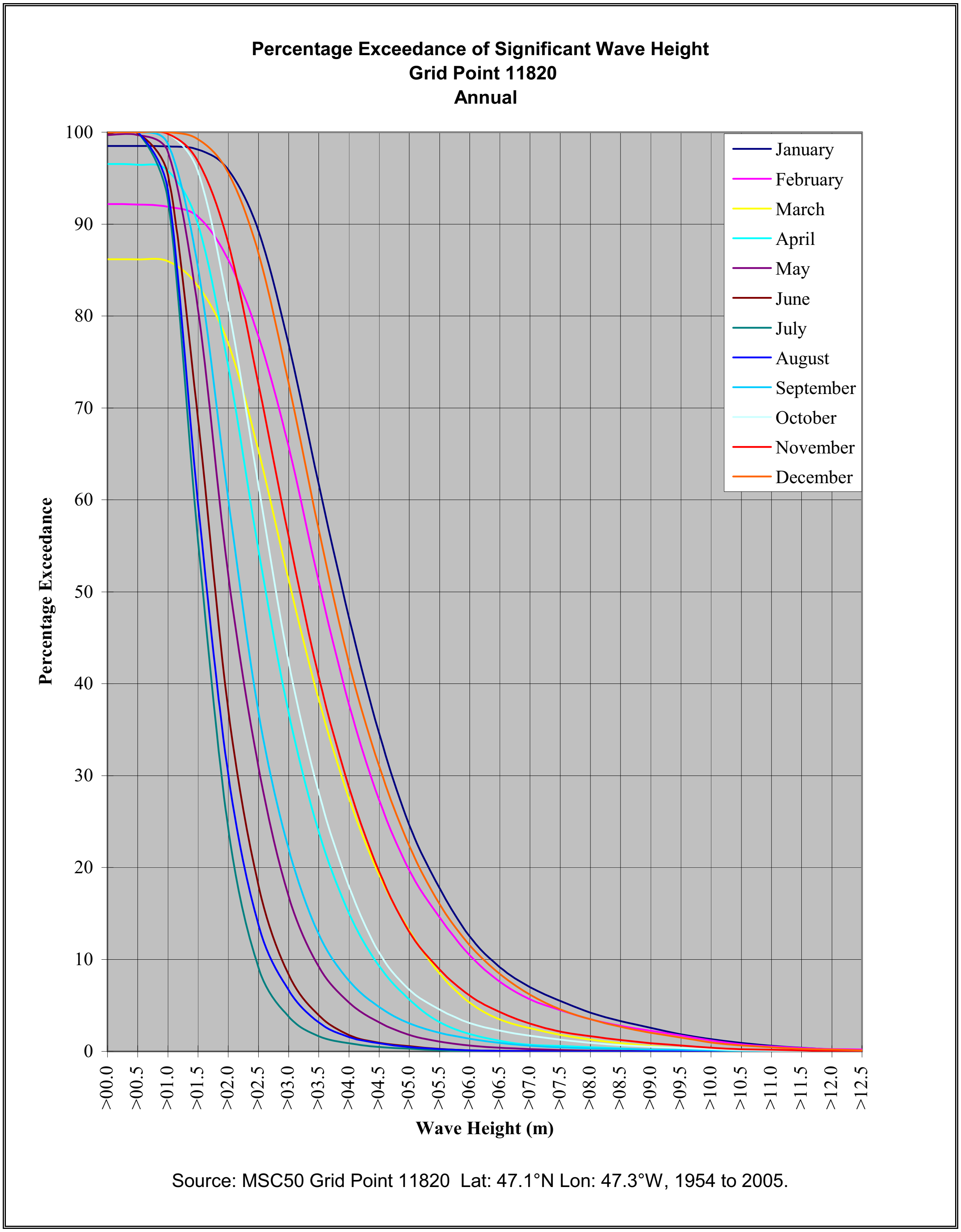


Figure 2.19 Percentage Exceedance of Significant Wave Height Grid Point 11820 located near 47.3°N; 47.3°W. 1954 to 2005

The spectral peak period of waves vary with season with the most common period varying from 7 seconds during summer to 11 seconds in winter. Annually, the most common peak spectral period is 9 seconds, occurring 19.0% of the time at Grid Point 10255 and 17.9% of the time at Grid Point 11820. The percentage occurrence of spectral peak period for each month at both grid points is shown in Tables 2.10 and 2.11 and in Figures 2.20 and 2.21.

Table 2.10 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 10255 located near 46.3°N; 48.4°W. 1954 to 2005

	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	0.2	1.4	5.0	8.5	15.6	18.8	22.4	11.8	10.9	4.7	0.6	0.1
February	0.0	0.0	0.0	0.1	0.8	2.5	7.1	10.1	16.5	18.3	20.2	11.7	8.0	3.8	0.6	0.2
March	0.0	0.0	0.0	0.4	1.1	3.5	8.9	11.7	18.0	19.0	17.5	9.8	6.1	3.6	0.2	0.3
April	0.0	0.0	0.0	0.4	1.2	4.1	8.8	15.1	24.6	19.7	14.1	7.0	3.2	1.6	0.2	0.1
May	0.0	0.0	0.0	0.1	1.7	6.8	16.3	25.7	23.4	14.0	6.2	3.8	1.5	0.4	0.0	0.0
June	0.0	0.0	0.0	0.2	3.5	11.0	24.9	27.4	20.0	7.8	2.2	1.4	1.5	0.1	0.0	0.0
July	0.0	0.0	0.0	0.3	4.7	14.1	30.5	27.5	13.7	5.6	1.2	0.4	1.4	0.2	0.1	0.2
August	0.0	0.0	0.0	0.4	5.2	12.9	30.0	26.1	14.1	5.0	2.5	1.9	1.4	0.4	0.0	0.0
September	0.0	0.0	0.0	0.1	2.0	6.8	17.3	21.4	20.6	10.2	8.5	7.0	4.2	1.3	0.3	0.2
October	0.0	0.0	0.0	0.1	0.9	3.8	11.1	17.6	23.1	16.1	12.0	8.0	4.9	1.9	0.2	0.2
November	0.0	0.0	0.0	0.0	0.5	2.8	7.8	11.6	20.9	20.5	16.4	9.0	7.3	2.6	0.2	0.2
December	0.0	0.0	0.0	0.0	0.3	1.3	5.1	9.0	17.0	21.7	20.5	11.5	9.5	3.4	0.5	0.2
Winter	0.0	0.0	0.0	0.1	0.4	1.7	5.7	9.2	16.4	19.6	21.0	11.7	9.5	4.0	0.5	0.2
Spring	0.0	0.0	0.0	0.3	1.3	4.8	11.3	17.5	22.0	17.5	12.6	6.9	3.6	1.9	0.1	0.1
Summer	0.0	0.0	0.0	0.3	4.5	12.7	28.5	27.0	15.9	6.2	2.0	1.2	1.4	0.2	0.1	0.1
Autumn	0.0	0.0	0.0	0.1	1.1	4.5	12.1	16.9	21.5	15.6	12.3	8.0	5.5	2.0	0.2	0.2
Annual	0.0	0.0	0.0	0.2	1.8	5.9	14.4	17.7	19.0	14.7	12.0	6.9	5.0	2.0	0.2	0.1

Table 2.11 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 11820 located near 47.3°N; 47.3°W. 1954 to 2005

	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	0.2	1.1	4.4	8.5	13.5	19.4	21.7	13.2	10.6	6.1	1.1	0.2
February	0.0	0.0	0.0	0.2	0.4	1.9	5.4	10.2	15.6	18.0	20.0	13.3	8.1	5.4	1.0	0.5
March	0.0	0.0	0.0	0.1	0.7	2.2	7.0	11.1	17.7	19.2	17.9	12.3	6.2	4.7	0.5	0.3
April	0.0	0.0	0.0	0.2	0.9	3.0	8.2	14.6	22.9	20.7	15.3	8.0	3.3	2.5	0.4	0.1
May	0.0	0.0	0.0	0.1	1.4	6.7	16.0	25.2	22.9	15.4	6.2	4.1	1.4	0.5	0.0	0.0
June	0.0	0.0	0.0	0.3	3.1	9.9	24.7	28.0	19.8	8.6	2.2	1.6	1.4	0.3	0.0	0.0
July	0.0	0.0	0.0	0.3	4.1	14.7	30.2	27.3	13.4	6.1	1.2	0.4	1.7	0.2	0.2	0.3
August	0.0	0.0	0.0	0.5	4.5	12.8	29.5	25.9	14.0	5.6	2.6	2.1	1.7	0.4	0.1	0.1
September	0.0	0.0	0.0	0.1	1.7	5.8	16.9	22.2	19.6	10.7	8.8	7.2	4.2	1.9	0.5	0.3
October	0.0	0.0	0.0	0.0	0.8	3.2	10.2	18.4	22.0	16.9	12.2	9.0	4.0	2.7	0.5	0.3
November	0.0	0.0	0.0	0.1	0.5	2.2	7.1	12.9	18.9	21.2	16.5	9.7	6.4	3.8	0.3	0.2

December	0.0	0.0	0.0	0.0	0.2	1.3	4.6	9.1	15.0	21.4	20.3	13.4	8.6	5.1	0.7	0.4
Winter	0.0	0.0	0.0	0.1	0.2	1.4	4.8	9.3	14.7	19.6	20.6	13.3	9.1	5.5	0.9	0.3
Spring	0.0	0.0	0.0	0.1	1.0	4.0	10.4	17.0	21.2	18.4	13.1	8.1	3.6	2.6	0.3	0.1
Summer	0.0	0.0	0.0	0.4	3.9	12.5	28.1	27.1	15.7	6.8	2.0	1.4	1.6	0.3	0.1	0.1
Autumn	0.0	0.0	0.0	0.1	1.0	3.8	11.4	17.8	20.2	16.3	12.5	8.6	4.8	2.8	0.4	0.3
Annual	0.0	0.0	0.0	0.2	1.5	5.4	13.7	17.8	17.9	15.3	12.1	7.9	4.8	2.8	0.4	0.2

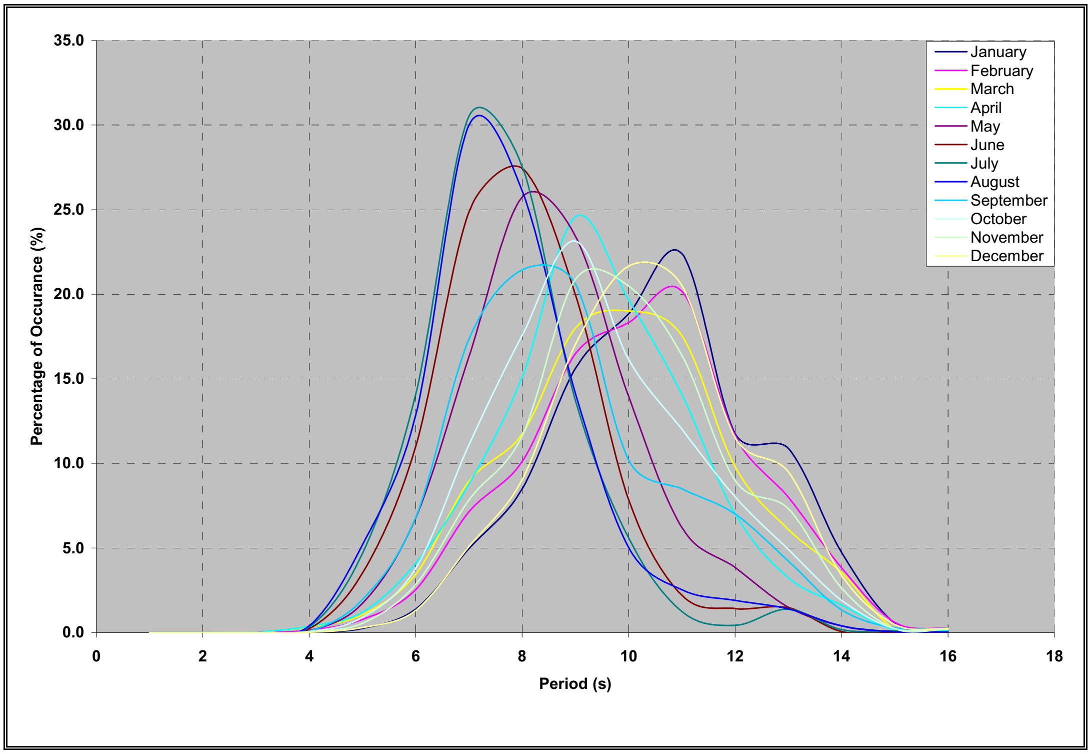


Figure 2.20 Percentage of Occurrence of Peak Wave Period at Spectrum at Grid Point 10255 located near 46.3°N; 48.4°W. 1954 to 2005

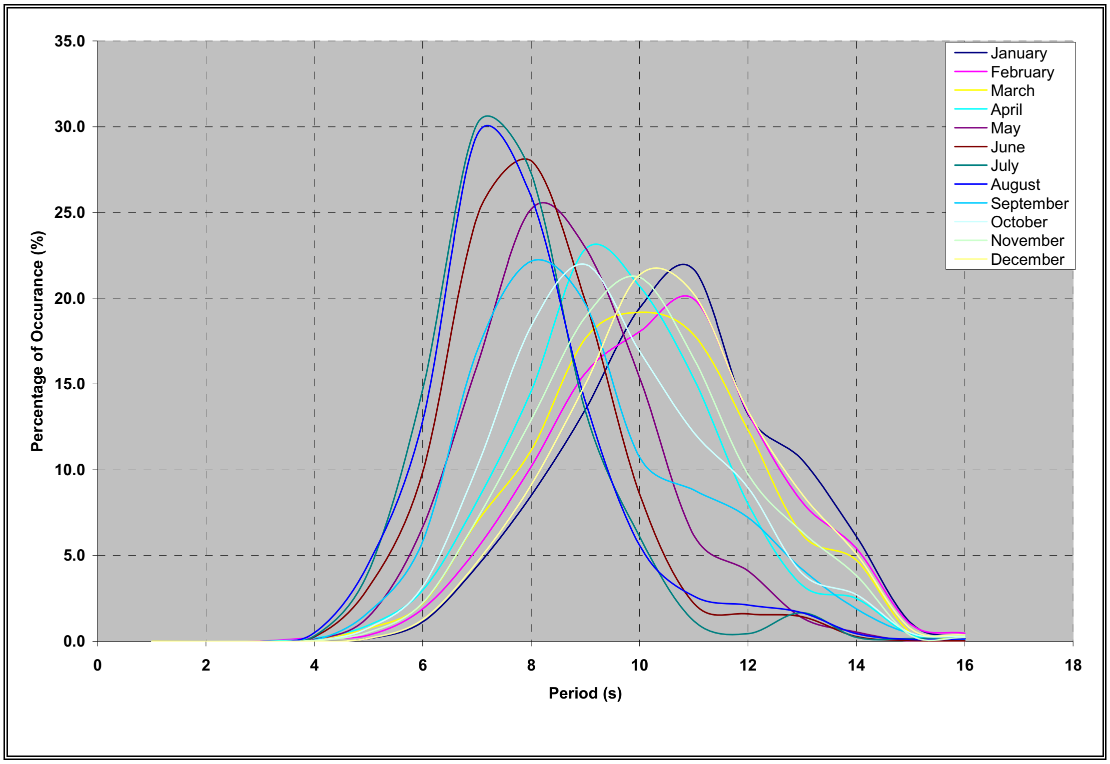


Figure 2.21 Percentage of Occurrence of Peak Wave Period at Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

Scatter diagrams of the significant wave height versus spectral peak period are presented in Table 2.12 and 2.13. From this table it can be seen that the most common wave at grid points 10255 and 11820 is 2 metres with a peak spectral period of 9 seconds. Note that wave heights in these tables have been rounded to the nearest whole number. Therefore, the 1 metre wave bin would include all waves from 0.51 metres to 1.50 metres.

Table 2.12 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 10255

		Wave Height (m)														Total
		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	
Period (s)	0	0.96														0.96
	1	0.00														0.00
	2															0.00
	3	0.00	0.00													0.00
	4	0.00	0.14	0.03	0.00											0.17
	5	0.00	1.06	0.74	0.04	0.00										1.84
	6	0.00	1.63	3.85	0.40	0.02										5.90
	7		4.81	5.86	3.43	0.28	0.01									14.38
	8	0.01	4.66	6.47	4.34	1.97	0.14	0.00								17.59

		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	9	0.00	1.65	8.41	4.13	3.44	1.05	0.06	0.00	0.00						18.76
	10	0.01	0.58	4.37	4.35	2.41	2.16	0.59	0.04	0.00						14.52
	11	0.00	0.22	2.10	4.15	2.33	1.34	1.12	0.43	0.06	0.01					11.76
	12	0.00	0.21	1.34	1.99	1.32	0.61	0.46	0.45	0.31	0.14	0.01				6.83
	13	0.00	0.23	0.74	1.14	1.20	0.63	0.28	0.19	0.17	0.19	0.12	0.02	0.00		4.91
	14	0.00	0.04	0.14	0.45	0.59	0.35	0.13	0.07	0.03	0.04	0.06	0.05	0.02	0.00	1.96
	15		0.01	0.01	0.04	0.06	0.06	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.24
	16		0.02	0.02	0.03	0.04	0.01	0.01	0.00	0.00	0.00				0.00	0.14
	17		0.01	0.01	0.01	0.00	0.00	0.00								0.03
	18		0.00				0.00									0.00

Table 2.13 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 11820

		Wave Height (m)														**Total**
		<1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
Period (s)	**0**	2.23														2.23
	1	0.00														0.00
	2															0.00
	3		0.00													0.00
	4		0.13	0.03												0.15
	5	0.00	0.88	0.63	0.03											1.54
	6	0.00	1.60	3.39	0.37	0.02	0.00									5.38
	7		4.28	5.87	3.13	0.29	0.01									13.57
	8	0.01	4.39	6.60	4.46	1.95	0.14	0.00								17.56
	9	0.00	1.49	7.44	3.99	3.47	1.07	0.07	0.00							17.54
	10	0.00	0.67	4.40	4.19	2.61	2.25	0.65	0.04	0.00						14.82
	11	0.00	0.20	1.77	4.07	2.35	1.47	1.27	0.42	0.06	0.00					11.61
	12	0.00	0.19	1.33	1.99	1.60	0.80	0.62	0.54	0.36	0.14	0.02	0.00			7.58
	13	0.00	0.23	0.62	0.88	0.97	0.65	0.37	0.25	0.21	0.22	0.19	0.03	0.00		4.62
	14	0.00	0.06	0.18	0.51	0.70	0.51	0.22	0.12	0.08	0.08	0.11	0.10	0.04	0.00	2.70
	15	0.00	0.02	0.03	0.04	0.08	0.12	0.05	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.42
	16		0.03	0.03	0.04	0.05	0.03	0.02	0.00	0.00	0.00	0.00		0.00	0.01	0.21
	17	0.00	0.01	0.01	0.01	0.00	0.00	0.00								0.05
	18	0.00	0.00	0.00	0.00		0.00	0.00								0.00

<u>Region 2</u>

The annual wave rose from the MSC50 data for Grid Points 13428 and 14697 is presented in Figures 2.22 and 2.23. The wave rose show that the majority of wave energy comes from the southwest, and accounts for 33.9% of the wave energy at grid point 13428. Waves were "iced out" for 0.4791 % of the time over the 52-year record. At Grid Point 14697 the majority of wave energy is from the southwest, accounting for 32.9% of the wave energy. Waves were "iced out" for 0.0% of the time at grid point 14697 over the 52-year record. Monthly wave roses along with histograms of the frequency distributions of wave heights for Grid Point 13428 and 14697 can be found in Appendices 7 and 8.

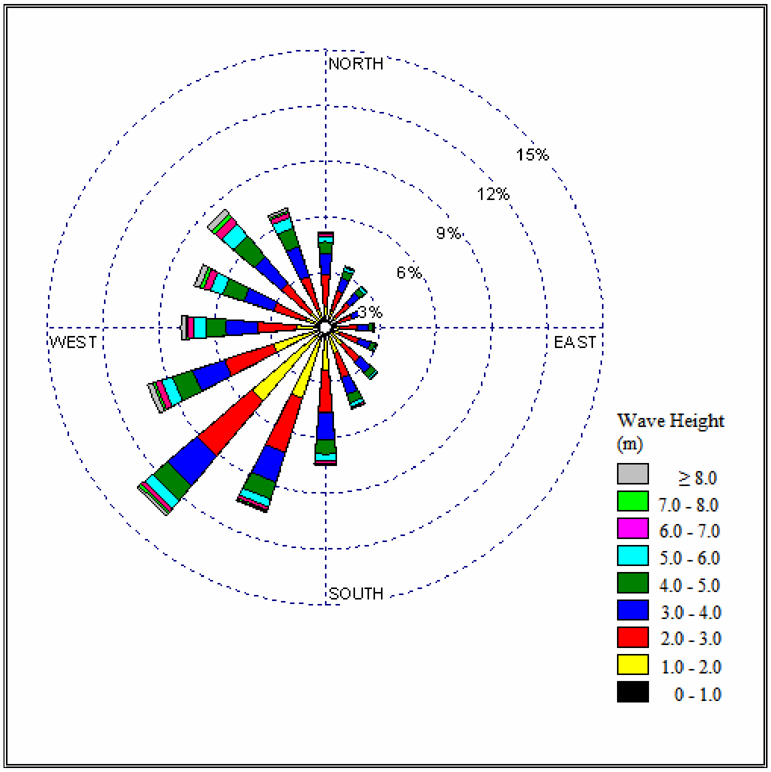


Figure 2.22 Annual Wave Rose for MSC50 Grid Point 13428 located near 48.0°N; 46.3°W. 1954 to 2005

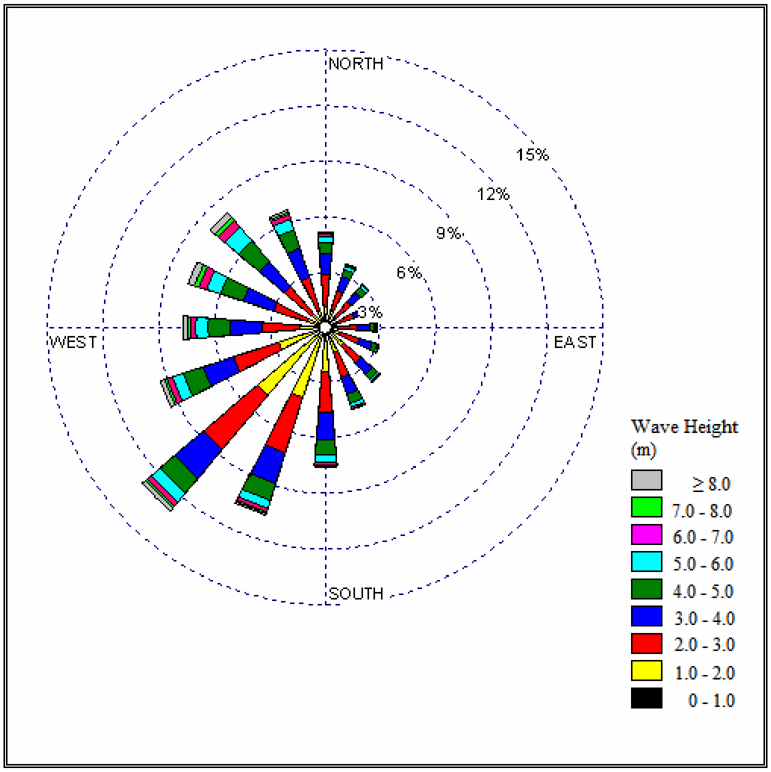


Figure 2.23 Annual Wave Rose for MSC50 Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

Histograms depicting the percentage occurrence of significant wave heights (Figures 2.24 and 2.25) show that the dominate wave height is between 1.0 and 3.0 metres at both grid points. There is a gradual decrease in frequency of wave heights above 3.0 m and only a small percentage of the wave heights exceeding 8.0 m can be found.

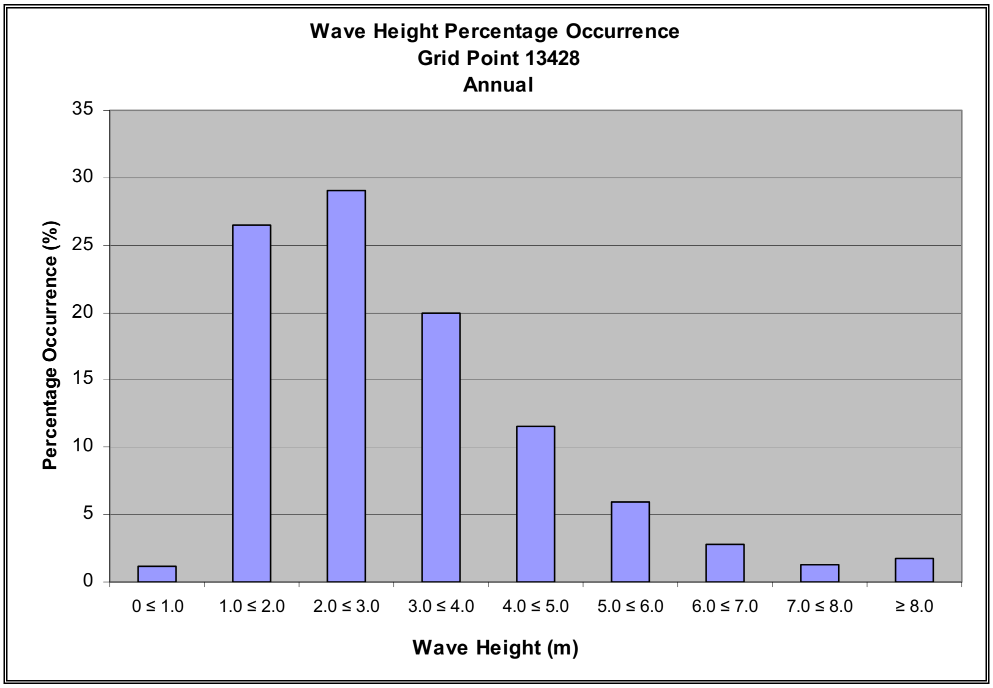


Figure 2.24 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 13428 located near 48.0°N; 46.3°W. 1954 – 2005

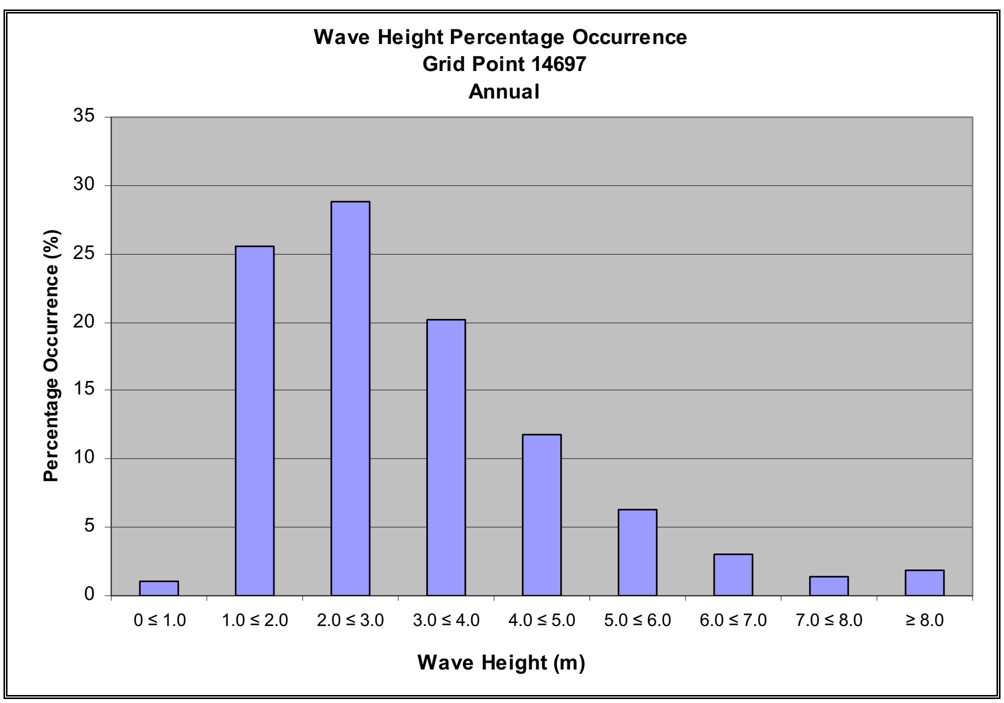


Figure 2.25 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 14697 located near 48.8°N; 46.3°W. 1954 to 2005

Significant wave heights in the project area peak during the winter months with Grid Points 13428 and 14697 having a mean monthly significant wave height of 4.5 and 4.6 metres respectively in January. The lowest significant wave heights occur in the summer with July month having a mean monthly significant wave height of only 1.7 m (Table 2.14). Wave height statistics from the Eirik Raude at Mizzen L-11 and Tuckamore B-27 are presented for comparison purposes. This data is not considered to be of sufficient length for climatological purposes.

Table 2.14 Combined Significant Wave Height Statistics (m)

Month	Grid Point 13428	Grid Point 14697	Mizzen L-11	Tuckamore B-27
January	4.5	4.6		
February	4.1	4.3		
March	3.5	3.7	4.2	
April	3.0	3.0	3.3	2.5
May	2.3	2.4		2.3
June	2.0	2.0		2.2
July	1.7	1.8		
August	1.9	1.9		
September	2.5	2.6		
October	3.2	3.2		
November	3.6	3.7		
December	4.2	4.3		

Combined significant wave heights of 10 metres or more occurred in each month between September and June, with the highest waves occurring during the month of February at Grid Point 13428 and December at Grid Point 14697 (Table 2.15). The combined significant wave height of 13.6 m measured at Mizzen occurred during an intense storm which developed in the project area. 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.

Table 2.15 Maximum Combined Significant Wave Height Statistics (m)

Month	Grid Point 13428	Grid Point 14697	Mizzen L-11	Tuckamore B-27
January	13.5	13.5		
February	15.3	15.1		
March	13.0	13.2	13.6	
April	11.0	11.1	7.1	3.5
May	11.7	11.6		4.2
June	10.7	10.2		2.6
July	7.0	6.8		
August	8.7	7.2		
September	12.0	12.9		
October	12.5	12.9		
November	13.3	13.9		
December	15.1	15.4		

Figures 2.26 and 2.27 shows percentage exceedance curves of significant wave heights for Grid Points 13428 and 14697. Percentage exceedance curves for the months of January through April show that the curves do not reach 100% for Grid Point 13428 because of the presence of ice on the during these months.

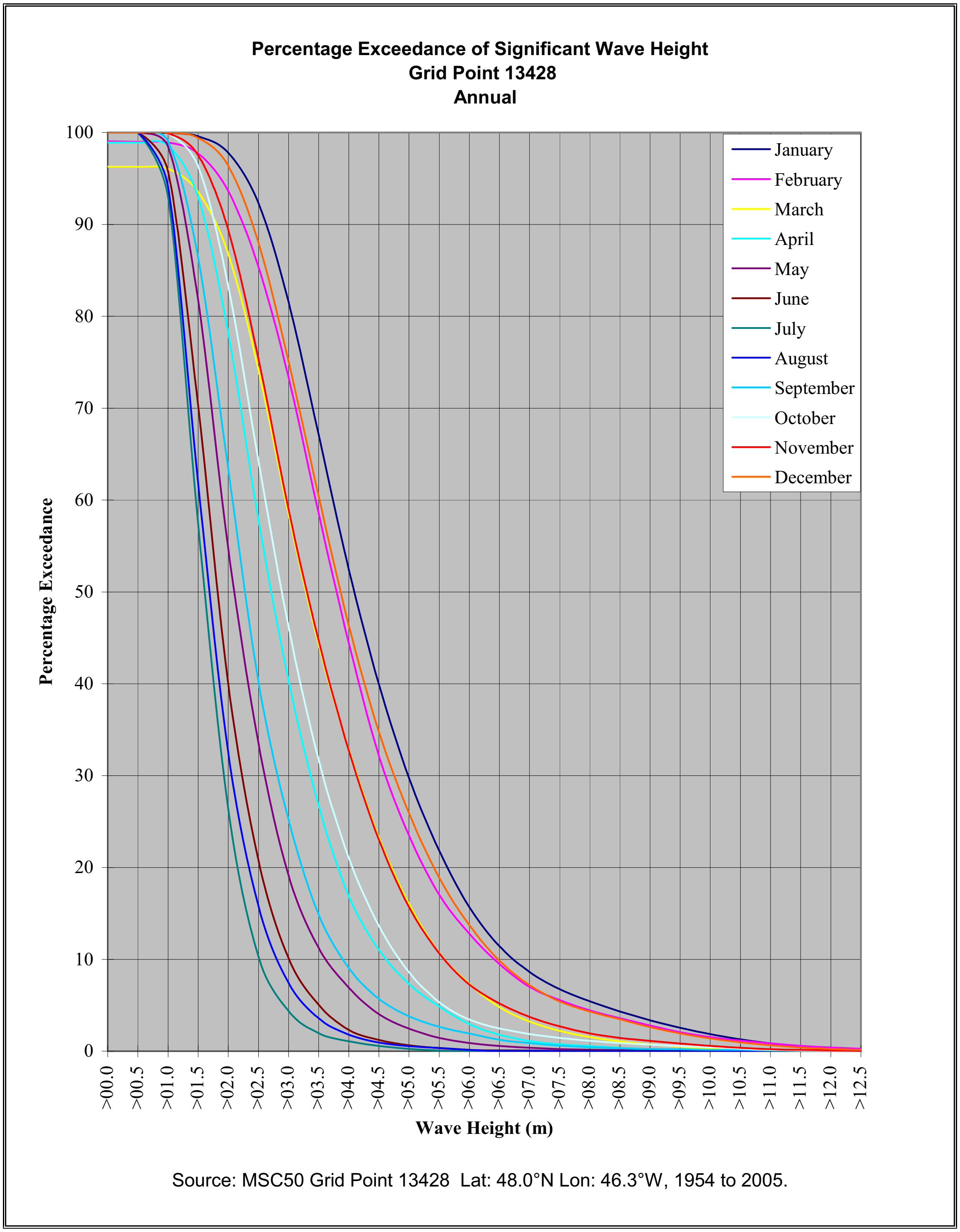


Figure 2.26 Percentage Exceedance of Significant Wave Height at Grid Point 13428 located near 48.0°N; 46.3°W. 1954 to 2005

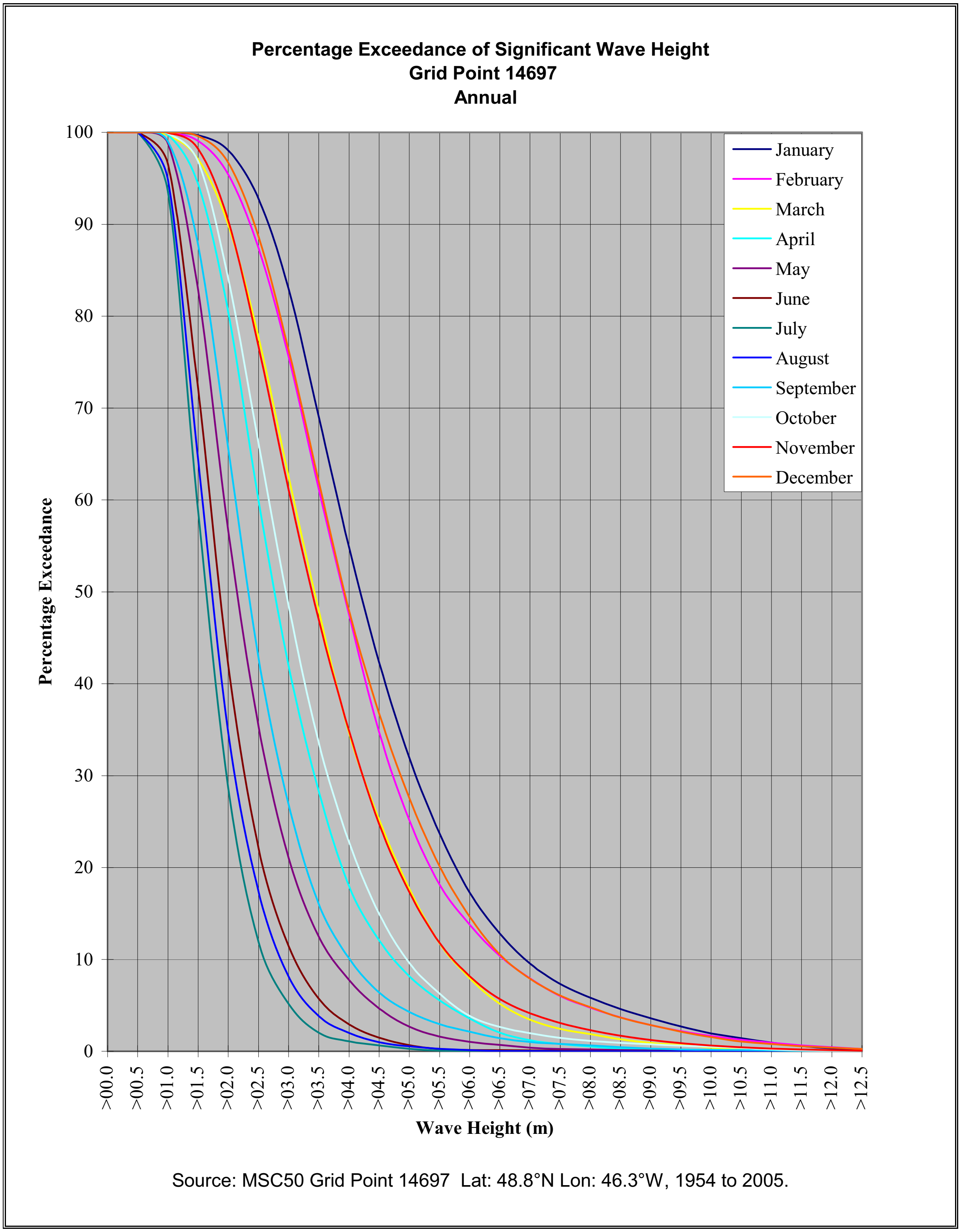


Figure 2.27 Percentage Exceedance of Significant Wave Height at Grid Point 14697 located near 48.8°N; 46.3°W. 1954 to 2005

The spectral peak period of waves vary with season with the most common period varying from 7 seconds during summer to 11 seconds in winter. Annually, the most common peak spectral period is 9 seconds, occurring 18.4% of the time at Grid Point 13428 and 18.3% of the time at Grid Point 14697. The percentage occurrence of spectral peak period for each month at both grid points is shown in Tables 2.16 and 2.17 and in Figures 2.28 and 2.29.

Table 2.16 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 13428 located near 48.0°N; 46.3°W . 1954 – 2005

	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	0.7	3.7	7.8	14.1	20.0	21.4	13.2	12.1	5.8	0.9	0.3
February	0.0	0.0	0.0	0.1	0.5	2.0	5.4	9.9	15.8	17.8	20.3	12.2	9.1	5.6	1.0	0.4
March	0.0	0.0	0.0	0.1	1.0	2.6	7.8	11.0	16.7	17.8	18.9	11.4	7.0	4.9	0.4	0.4
April	0.0	0.0	0.0	0.1	0.8	3.3	9.7	13.8	22.6	19.8	16.0	7.4	3.8	2.4	0.3	0.1
May	0.0	0.0	0.0	0.1	1.9	6.1	18.4	21.3	24.6	15.4	6.6	3.6	1.5	0.5	0.0	0.0
June	0.0	0.0	0.0	0.4	3.5	9.6	25.6	25.0	20.9	9.1	2.6	1.5	1.5	0.3	0.1	0.0
July	0.0	0.0	0.0	0.3	4.2	14.5	32.3	22.6	15.2	6.7	1.2	0.4	1.8	0.3	0.2	0.3
August	0.0	0.0	0.0	0.4	4.4	12.7	32.0	22.5	15.1	5.7	2.7	2.2	1.7	0.5	0.1	0.1
September	0.0	0.0	0.0	0.1	1.5	5.5	18.2	20.8	20.1	10.6	9.2	7.2	4.4	1.9	0.3	0.3
October	0.0	0.0	0.0	0.0	0.7	3.0	10.3	17.1	22.8	17.4	12.8	7.9	5.0	2.4	0.4	0.2
November	0.0	0.0	0.0	0.0	0.4	2.1	7.2	13.3	18.7	20.6	16.6	9.5	7.6	3.3	0.4	0.2
December	0.0	0.0	0.0	0.0	0.1	1.0	4.6	8.9	14.8	21.3	20.1	13.3	9.8	4.9	0.7	0.3
Winter	0.0	0.0	0.0	0.0	0.2	1.2	4.6	8.9	14.9	19.7	20.6	12.9	10.3	5.4	0.9	0.3
Spring	0.0	0.0	0.0	0.1	1.2	4.0	12.0	15.4	21.3	17.7	13.8	7.5	4.1	2.6	0.2	0.2
Summer	0.0	0.0	0.0	0.4	4.0	12.3	30.0	23.4	17.1	7.2	2.2	1.4	1.6	0.3	0.1	0.1
Autumn	0.0	0.0	0.0	0.0	0.9	3.5	11.9	17.1	20.5	16.2	12.9	8.2	5.7	2.5	0.4	0.3
Annual	0.0	0.0	0.0	0.1	1.6	5.3	14.6	16.2	18.4	15.2	12.4	7.5	5.4	2.7	0.4	0.2

Table 2.17 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

	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	0.7	3.7	8.1	14.9	19.6	21.3	13.2	11.8	5.5	0.8	0.2
February	0.0	0.0	0.0	0.0	0.3	1.7	6.3	10.6	16.7	18.4	19.0	11.7	9.0	5.1	0.9	0.3
March	0.0	0.0	0.0	0.1	0.8	2.8	9.0	12.2	16.5	17.4	18.2	11.2	7.0	4.2	0.4	0.3
April	0.0	0.0	0.0	0.1	0.8	4.0	10.9	14.0	21.9	18.8	16.1	7.4	3.6	2.3	0.2	0.1
May	0.0	0.0	0.0	0.1	2.2	6.7	19.4	21.0	24.2	14.7	6.5	3.4	1.4	0.3	0.0	0.0
June	0.0	0.0	0.0	0.3	3.9	10.0	26.3	23.9	20.0	9.8	2.6	1.4	1.5	0.3	0.0	0.0
July	0.0	0.0	0.0	0.4	4.6	14.5	34.2	21.3	14.5	6.5	1.2	0.3	1.6	0.3	0.2	0.3
August	0.0	0.0	0.0	0.4	5.0	13.5	32.6	21.5	14.5	5.4	2.5	2.1	1.8	0.4	0.1	0.1
September	0.0	0.0	0.0	0.1	1.5	5.8	19.0	20.6	19.8	10.5	9.2	7.1	4.1	1.7	0.4	0.3
October	0.0	0.0	0.0	0.0	0.6	3.3	11.0	16.8	22.8	17.5	12.6	7.8	4.8	2.2	0.4	0.2
November	0.0	0.0	0.0	0.0	0.4	2.3	8.0	13.8	18.4	20.2	16.3	9.7	7.2	3.0	0.4	0.2

December	0.0	0.0	0.0	0.0	0.1	1.0	5.0	9.2	14.9	21.8	19.7	13.0	9.3	5.0	0.7	0.3
Winter	0.0	0.0	0.0	0.0	0.2	1.1	5.0	9.3	15.5	19.9	20.0	12.7	10.0	5.2	0.8	0.2
Spring	0.0	0.0	0.0	0.1	1.3	4.5	13.1	15.7	20.9	17.0	13.6	7.3	4.0	2.3	0.2	0.1
Summer	0.0	0.0	0.0	0.4	4.5	12.7	31.0	22.3	16.4	7.2	2.1	1.3	1.6	0.4	0.1	0.1
Autumn	0.0	0.0	0.0	0.0	0.8	3.8	12.6	17.1	20.3	16.1	12.7	8.2	5.4	2.3	0.4	0.2
Annual	0.0	0.0	0.0	0.1	1.7	5.5	15.4	16.1	18.3	15.0	12.1	7.4	5.3	2.5	0.4	0.2

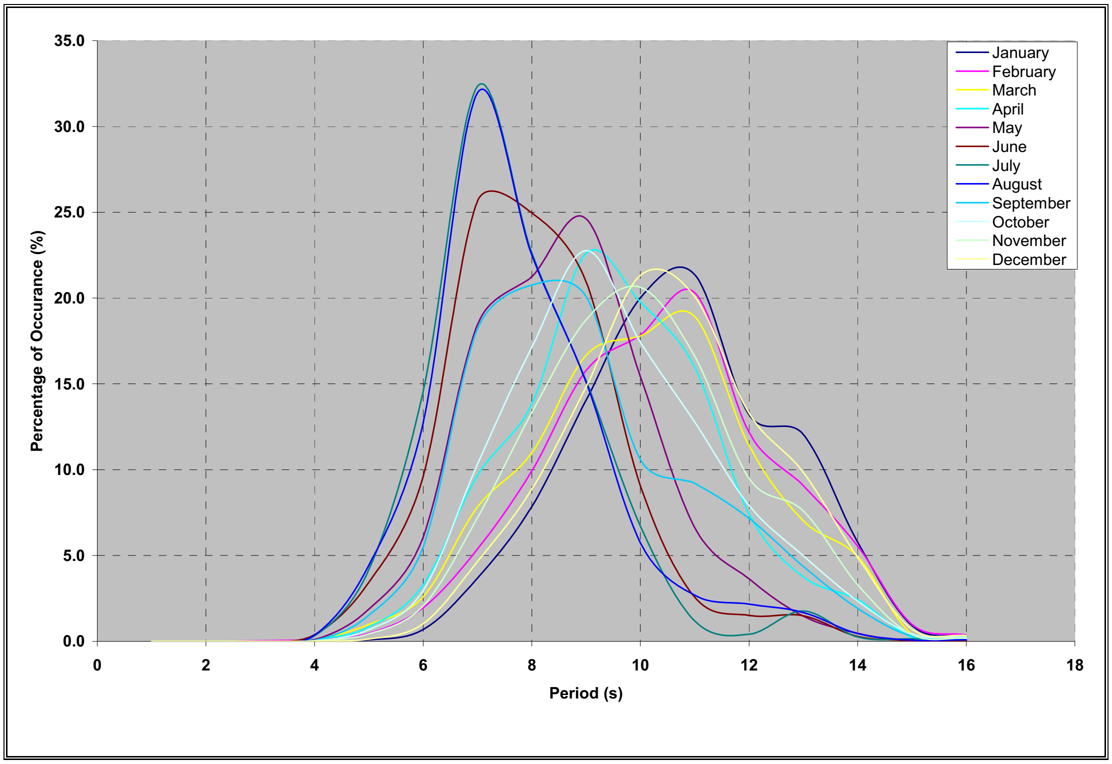


Figure 2.28 Percentage of Occurrence of Peak Wave Period at Grid Point 13428 located near 48.0°N; 46.3°W. 1954 – 2005

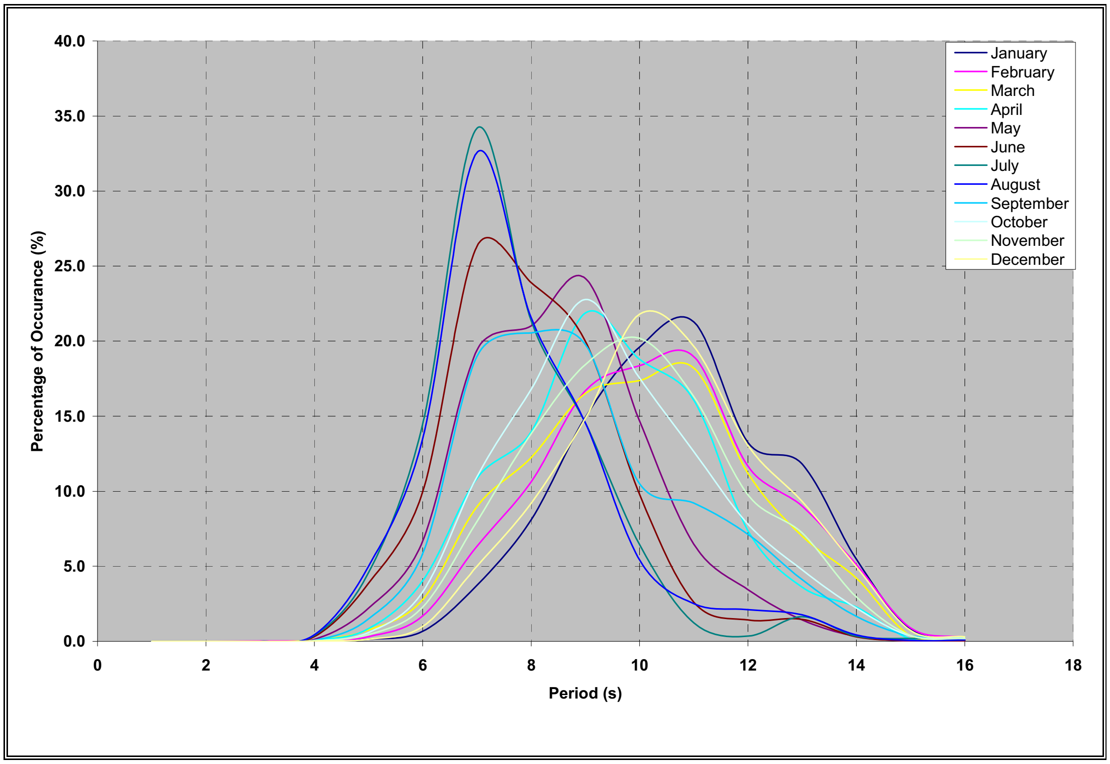


Figure 2.29 Percentage of Occurrence of Peak Wave Period at Grid Point 14697 located near 48.8°N; 46.3°W. 1954 – 2005

Scatter diagrams of the significant wave height versus spectral peak period is presented in Table 2.18 and 2.19. From this table it can be seen that the most common wave at grid point 13428 is 2 metres with a peak spectral period of 9 seconds. The most common wave at grid point 14697 is 2 metres and a peak spectral period of 9 seconds. Note that wave heights in these tables have been rounded to the nearest whole number. Therefore, the 1 metre wave bin would include all waves from 0.51 metres to 1.49 metres.

Table 2.18 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 13428

		Wave Height (m)														Total
		<1	1	2	3	4	5	6	7	8	9	10	11	12	13	
Period (s)	0	0.48														0.48
	1															0.00
	2															0.00
	3	0.00	0.00													0.00
	4	0.00	0.11	0.02												0.13
	5		0.88	0.69	0.03											1.60
	6	0.00	1.49	3.39	0.36	0.02	0.00									5.26
	7	0.00	4.56	6.26	3.49	0.31	0.01									14.62

	8		3.28	5.82	4.70	2.19	0.15	0.00								16.13
	9	0.00	1.68	7.17	4.14	3.97	1.31	0.09	0.00							18.35
	10	0.00	0.68	4.08	4.06	2.74	2.61	0.84	0.05	0.00						15.08
	11	0.00	0.19	1.92	3.88	2.42	1.68	1.50	0.55	0.08	0.00	0.00				12.22
	12	0.00	0.17	1.28	1.72	1.42	0.85	0.66	0.69	0.42	0.17	0.02	0.00			7.41
	13		0.23	0.64	1.04	1.09	0.73	0.47	0.31	0.26	0.30	0.23	0.06	0.00		5.38
	14		0.05	0.12	0.41	0.71	0.54	0.27	0.13	0.07	0.08	0.12	0.13	0.06	0.01	2.69
	15		0.01	0.03	0.03	0.04	0.09	0.06	0.02	0.01	0.00	0.01	0.01	0.03	0.03	0.39
	16		0.03	0.03	0.04	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.21
	17		0.01	0.01	0.01	0.00	0.01	0.00								0.04
	18				0.00											0.00
		0.49	13.35	31.48	23.90	14.96	8.00	3.91	1.77	0.84	0.56	0.38	0.21	0.10	0.05	99.99

Table 2.19 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 14697

		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	0.00													0.00
	4	0.00	0.12	0.02												0.14
	5		0.93	0.75	0.03	0.00										1.71
	6		1.40	3.77	0.36	0.01	0.00									5.54
	7		4.33	6.80	4.02	0.34	0.01	0.00								15.50
	8		2.86	5.27	5.13	2.67	0.18	0.00								16.11
	9		1.57	6.61	3.98	4.26	1.70	0.12	0.00							18.24
	10		0.70	3.95	3.70	2.69	2.89	1.00	0.08	0.00	0.00					15.02
	11		0.15	1.86	3.73	2.25	1.59	1.66	0.70	0.11	0.01	0.00				12.05
	12		0.14	1.28	1.78	1.33	0.79	0.62	0.70	0.49	0.20	0.03	0.00			7.35
	13		0.23	0.58	0.98	1.04	0.70	0.46	0.28	0.27	0.31	0.28	0.09	0.01	0.00	5.24
	14		0.05	0.11	0.31	0.66	0.53	0.30	0.13	0.07	0.06	0.07	0.13	0.07	0.02	2.51
	15		0.01	0.03	0.03	0.04	0.07	0.06	0.03	0.01	0.01	0.00	0.01	0.03	0.04	0.36
	16		0.03	0.03	0.03	0.03	0.03	0.01	0.00	0.00	0.00			0.00	0.00	0.18
	17		0.01	0.01	0.01	0.01	0.01									0.04
	18			0.00												0.00
		0.00	12.53	31.07	24.08	15.31	8.51	4.23	1.93	0.95	0.59	0.39	0.23	0.11	0.05	99.99

2.5 Weather Variables

2.5.1 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.

Region 1

Air and sea surface temperatures for Region 1 were extracted from the ICOADS data set. A monthly plot of air temperature versus sea surface temperature is presented in Figure 2.30. Temperature statistics presented in Table 2.20 show that the atmosphere is coldest in February with a mean temperature of -0.4°C, and warmest in August with a mean temperature of 14.3°C. The sea surface temperature is warmest in August with a mean temperature of 13.7°C and coldest in February and March with a mean temperature of 0.3°C. The mean sea surface temperature is colder than the mean air temperature from April to August, with the greatest difference occurring in the month of July. The colder sea surface temperatures from April to August have a cooling effect on the atmosphere, while relatively warmer sea surface temperatures from September to April tends to warm the overlying atmosphere.

Table 2.20 Air and Sea Surface Temperature Statistics for ICOADS Region 1

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	0.1	10.3	-11.0	1.0	7.0	-2.0
February	-0.4	10.4	-12.0	0.3	6.0	-2.0
March	0.3	9.8	-10.0	0.3	6.0	-2.0
April	1.9	10.0	-7.3	1.0	7.5	-2.0
May	4.1	12.7	-3.2	3.0	9.6	-2.0
June	7.1	16.8	-1.2	5.9	14.0	-2.0
July	11.9	21.3	2.8	10.5	19.0	2.3
August	14.3	22.5	5.5	13.7	20.5	6.0
September	12.6	20.5	4.2	12.7	20.0	4.0
October	8.8	18.4	-1.0	9.1	17.0	1.0
November	5.1	15.3	-4.6	5.5	13.0	-1.9
December	2.1	12.8	-10.0	2.7	10.2	-2.0

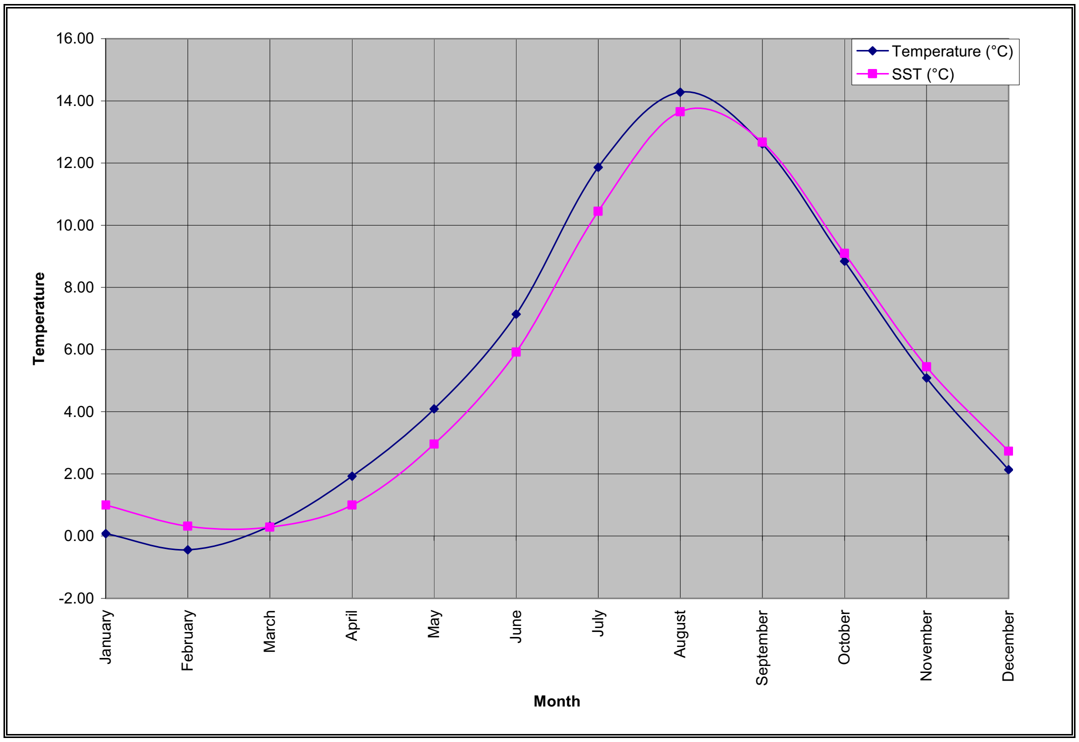


Figure 2.30 Monthly Mean Air and Sea Surface Temperature for ICOADS Region 1

Region 2

Air and sea surface temperatures for Region 2 were extracted from the ICOADS data set. A monthly plot of air temperature versus sea surface temperature is presented in Figure 2.31. Temperature statistics presented in Table 2.21 show that the atmosphere is coldest in February with a mean temperature of 0.1°C, and warmest in August with a mean temperature of 12.6°C. The sea surface temperature is warmest in August with a mean temperature of 12.3°C and coldest in February and March with a mean temperature of 1.6°C. The mean sea surface temperature is colder than the mean air temperature from May to August, with the greatest difference occurring in the month of July. The colder sea surface temperatures from May to August have a cooling effect on the atmosphere, while relatively warmer sea surface temperatures from September to April tends to warm the overlying atmosphere.

Table 2.21 Air and Sea Surface Temperature Statistics for ICOADS Region 2

	Air Temperature (°C)			Sea Surface Temperature (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	0.3	13.5	-13.0	2.8	12.0	-2.0
February	0.1	13.8	-13.5	1.6	12.0	-2.0
March	1.3	14.0	-10.8	2.2	11.2	-2.0
April	2.6	15.0	-6.0	2.8	13.0	-2.0
May	4.6	18.0	-6.9	4.4	17.0	-2.0
June	6.6	16.0	-0.1	6.7	14.0	-1.0

July	10.1	23.3	0.5	9.7	22.0	0.6
August	12.6	20.5	4.2	12.3	20.0	5.0
September	11.5	23.0	-0.2	11.6	19.0	1.0
October	8.3	20.0	-1.0	9.1	18.0	-1.0
November	5.5	18.0	-4.5	6.6	16.7	0.3
December	3.2	17.0	-7.0	4.7	14.0	-1.7

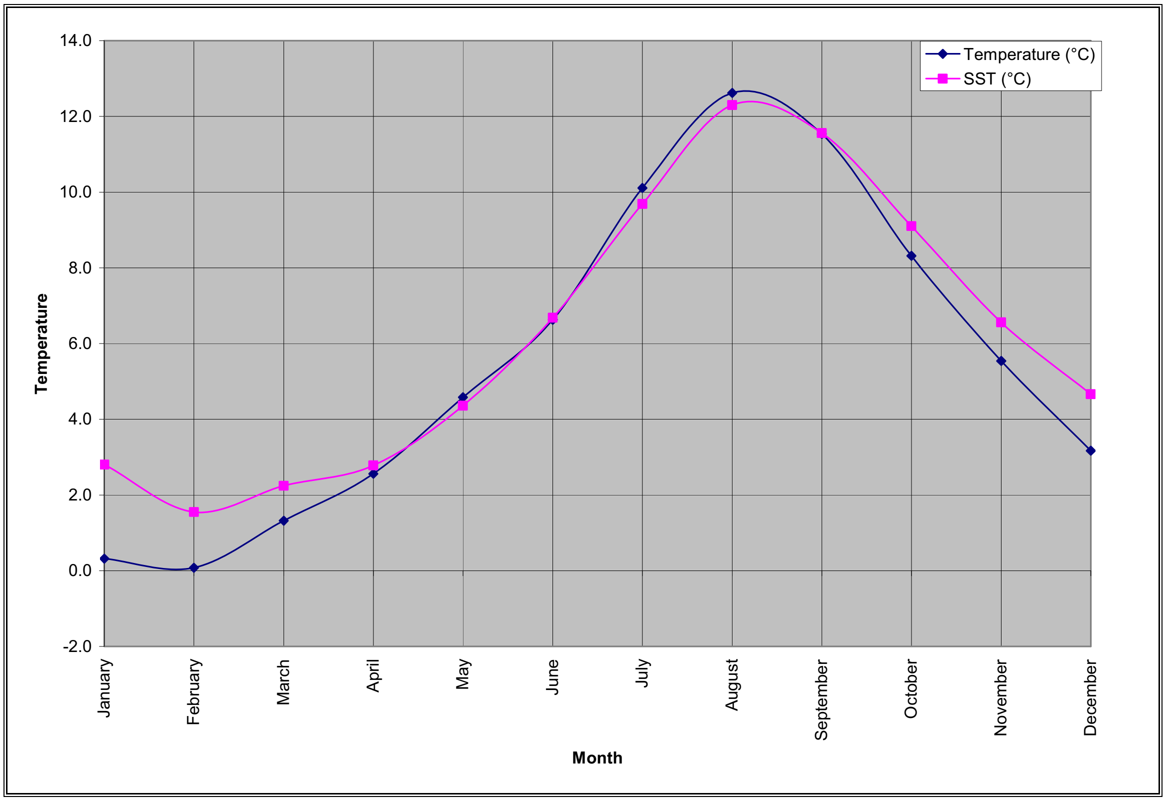


Figure 2.31 Monthly Mean Air and Sea Surface Temperature for ICOADS Region 2

2.5.2 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 project 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 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

The frequency of precipitation type (Table 2.22) shows that annually, precipitation occurs 22.1% of the time. Winter has the highest frequency of precipitation with 34.6 % of the observations reporting precipitation. Snow accounts for the majority of precipitation during the winter months, accounting for 59.0% of the occurrences of winter precipitation. Summer has the lowest frequency of precipitation with a total frequency of occurrence of only 12.9%. Snow has been reported in each month however this is probably due to coding error rather than the actual presence of snow.

Thunderstorms occur relatively infrequently over the project 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 during the months of November to January. 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.

Table 2.22 Percentage Frequency (%) Distribution of Precipitation for ICOADS Region 1

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	12.7	0.5	0.6	23.3	0.0	0.2	37.3
February	10.1	0.8	0.4	22.5	0.0	0.0	33.9
March	11.8	0.9	0.3	14.5	0.0	0.0	27.6
April	13.2	0.2	0.2	5.0	0.0	0.0	18.7
May	14.1	0.0	0.1	1.1	0.0	0.0	15.3
June	13.1	0.0	0.0	0.1	0.1	0.0	13.3

July	10.9	0.0	0.0	0.0	0.1	0.0	11.0
August	14.2	0.0	0.0	0.1	0.2	0.0	14.5
September	15.5	0.0	0.0	0.1	0.1	0.0	15.7
October	20.2	0.0	0.1	1.1	0.1	0.1	21.6
November	19.3	0.0	0.4	5.9	0.0	0.2	25.8
December	15.9	0.1	0.6	15.4	0.1	0.3	32.4
Winter	13.0	0.5	0.5	20.4	0.0	0.2	34.6
Spring	13.1	0.4	0.2	6.6	0.0	0.0	20.2
Summer	12.7	0.0	0.0	0.1	0.1	0.0	12.9
Autumn	18.3	0.0	0.2	2.4	0.1	0.1	21.1
Total	14.3	0.2	0.2	7.3	0.1	0.1	22.1

Region 2

The frequency of precipitation type (Table 2.23) shows that annually, precipitation occurs 21.8% of the time. Winter has the highest frequency of precipitation with 33.6 % of the observations reporting precipitation. Snow accounts for the majority of precipitation during the winter months, accounting for 55.4% of the occurrences of winter precipitation. Summer has the lowest frequency of precipitation with a total frequency of occurrence of 13.5%. Snow has been reported in each month with the exception of August however this is probably due to coding error rather than the actual presence of snow.

Thunderstorms occur relatively infrequently over the project 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 during the months of November to April. 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.

Table 2.23 Percentage Frequency (%) Distribution of Precipitation for ICOADS Region 2

	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Thunder storm	Hail	Total
January	12.4	0.4	2.2	21.1	0.1	0.2	36.3
February	12.1	0.3	1.4	20.2	0.1	0.0	34.1
March	10.7	0.2	1.1	15.2	0.0	0.1	27.3
April	9.5	0.1	0.4	6.3	0.1	0.2	16.5
May	11.8	0.0	0.4	2.6	0.1	0.0	14.9
June	14.9	0.0	0.1	0.2	0.1	0.0	15.4
July	10.7	0.0	0.0	0.3	0.4	0.0	11.4
August	13.5	0.0	0.1	0.0	0.3	0.1	14.1
September	17.2	0.0	0.1	0.7	0.1	0.0	18.2
October	16.9	0.0	0.0	1.2	0.1	0.0	18.2
November	16.9	0.0	1.4	4.9	0.0	0.3	23.5

December	13.0	0.1	2.7	12.3	0.1	0.5	28.8
Winter	12.4	0.3	2.0	18.6	0.1	0.2	33.6
Spring	10.5	0.1	0.6	8.1	0.1	0.1	19.5
Summer	13.0	0.0	0.1	0.2	0.3	0.0	13.5
Autumn	17.0	0.0	0.5	2.2	0.1	0.1	19.9
Total	12.6	0.1	0.8	8.0	0.1	0.1	21.8

2.5.3 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

During the winter months, 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. September and October have 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.

Region 1

A plot of the frequency distribution of visibility from the ICOADS data set is presented in Figure 2.32. This figure shows that obstructions to vision can occur in any month. Annually, 47.8% of the observations had reduced visibilities.

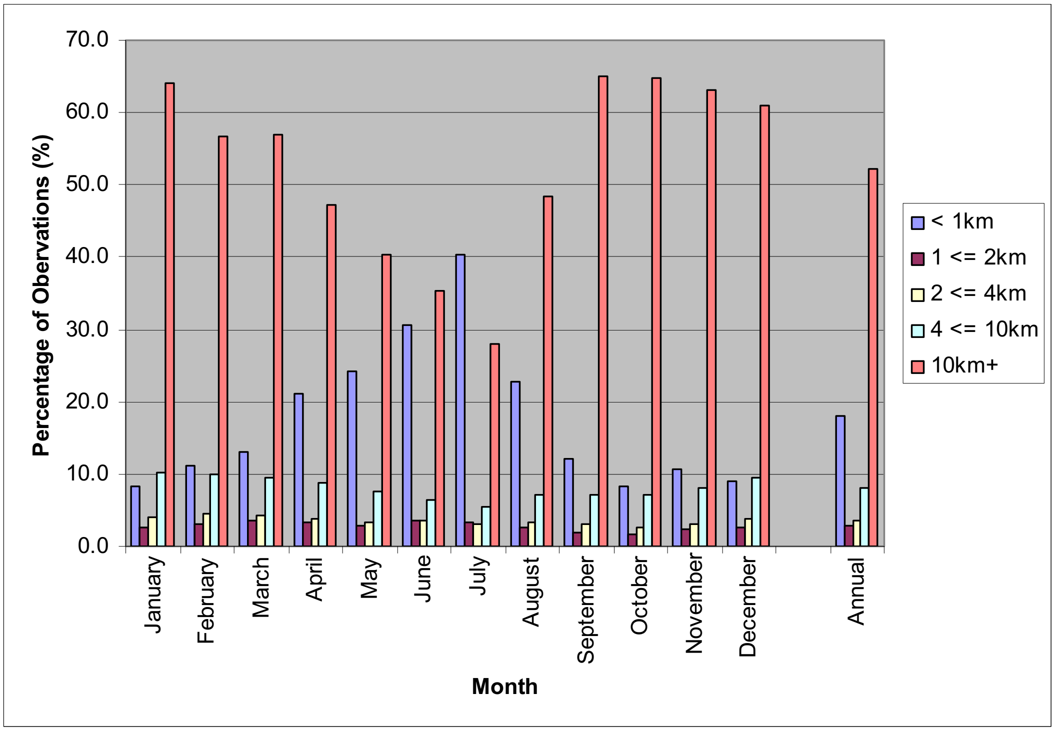


Figure 2.32 Monthly and Annual Percentage Occurrence of Visibility in Region 1

(Source: ICOADS Data set (1950-2010))

Region 2

A plot of the frequency distribution of visibility from the ICOADS data set is presented in Figure 2.33. This figure shows that obstructions to vision can occur in any month. Annually, 39.0% of the observations had reduced visibilities.

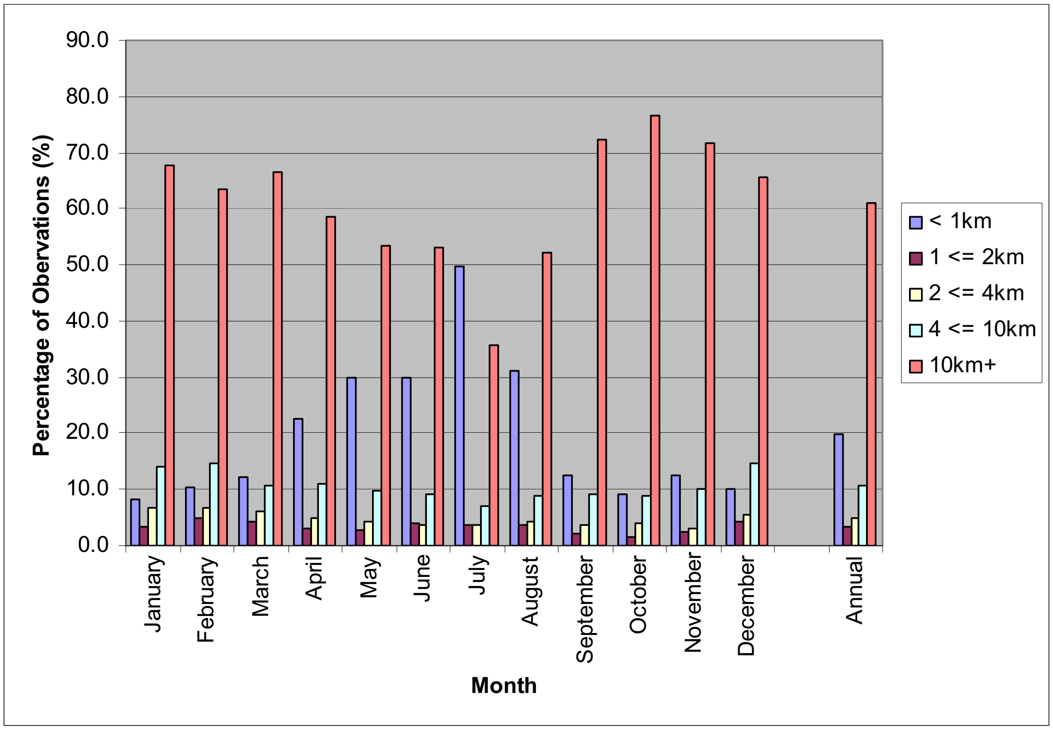


Figure 2.33 Monthly and Annual Percentage Occurrence of Visibility in Region 2

Source: ICOADS Data set (1950-2010)

2.6 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 Newfoundland and the project area. 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 within the last 15 years. Figure 2.34 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 (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 Response zone. There is little change in the 5-year trend for hurricanes coming within the project area. It should be noted that the unusually high number of tropical storms in 2005 may be skewing the results for the 2000 – 2005 season.

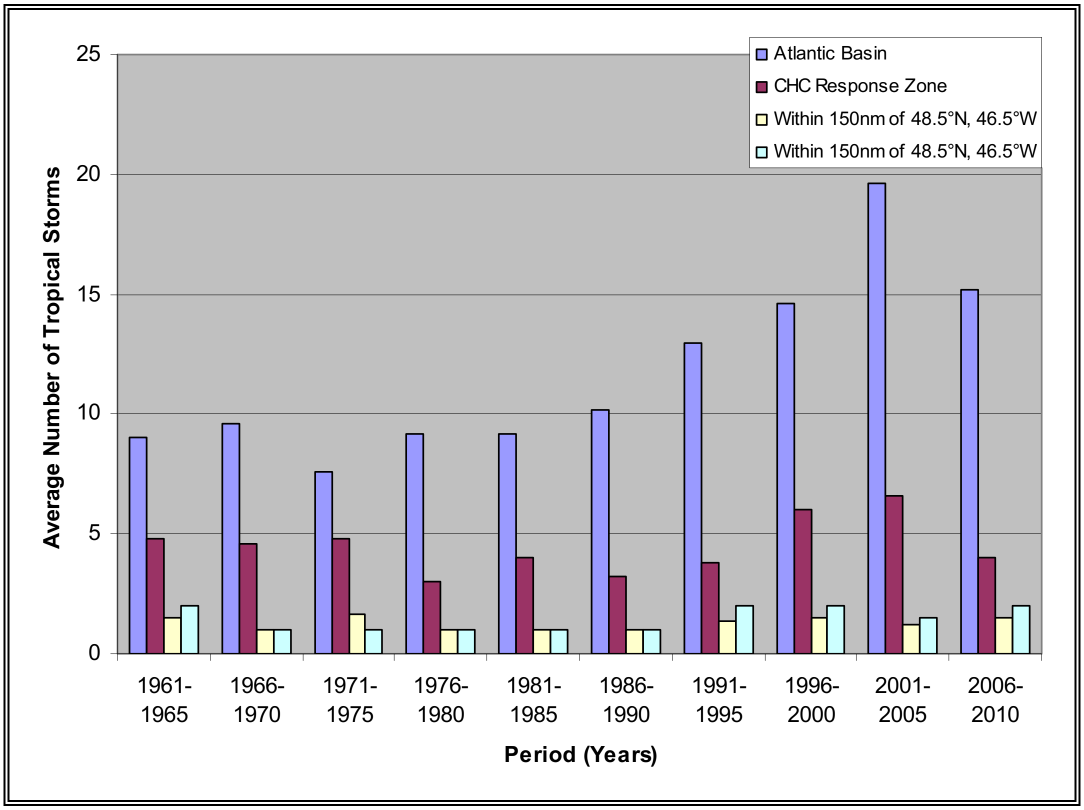


Figure 2.34 5-Year Average of the number of Tropical Storms which formed in the Atlantic Basin since 1961

A significant number of tropical cyclones which move into the midlatitudes transition into extratropical cyclones. On average, 46% of tropical cyclones which formed in the Atlantic transition into extratropical cyclones. During this transformation, the system loses tropical characteristics and becomes more extratropical in nature resulting in an increase in the area which produces large waves, gale to hurricane force winds and intense rainfall. The likelihood that a tropical cyclone will 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 latitudes in the early and late hurricane season and at higher latitudes during the peak of the season (Hart and Evans, 2001).

On occasion, these systems still maintain their tropical characteristics when they reach Newfoundland. Eight Category 1 and one Category 2 hurricane crossed Region 1 during this time period, while 4 crossed Region 2. The most intense of these storms was Hurricane Gladys which crossed Region 12Z October 03, 1975 with maximum sustained wind speeds of 43.7 m/s and a central pressure of 960 mb. Hurricane Gladys underwent extratropical transition over the next several hours and crossed Region 2 as an extratropical storm with wind speeds of 38.6m/s.

Region 1

Since 1958, 26 tropical systems have passed within 278 nm of 47.0ºN; 48.4ºW. The names are given in Table 2.24 and the tracks over the project area are shown in Figure 2.35. 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 within 278 nm of the location.

Table 2.24 Tropical Systems Passing within 278 km of 47.0ºN, 48.4ºW (1958 to 2008)

Year	Month	Day	Hour	Name	Latitude	Longitude	Wind (m/s)	Pressure	Category
1963	8	28	0000	Beulah	45.8	-48.3	36.0		Category 1
1963	10	12	1800	Flora	45.2	-47.5	38.6		Extratropical
1964	9	4	1800	Cleo	46.9	-49.8	36.0		Category 1
1967	9	4	0600	Arlene	45.8	-48.6	30.9		Tropical Storm
1969	8	13	0000	Blanche	47.1	-49.0	25.7		Extratropical
1971	7	7	1800	Arlene	46.5	-53.0	23.1		Extratropical
1971	8	6	1200	Unnamed	55.7	-43.8	36.0	974	Category 1
1974	7	20	0600	Subtrop 2	46.7	-48.0	20.6		Extratropical
1975	7	4	0600	Amy	44.5	-51.6	25.7	986	Tropical Storm
1975	10	3	1975	Gladys	46.6	-50.6	38.6	960	Category 2
1976	8	24	1976	Candice	45.9	-48.7	33.4		Category 1
1977	9	30	0000	Dorothy	47.0	-51.0	25.7	995	Extratropical
1978	9	5	0600	Ella	47.2	-50.2	41.2	975	Category 1
1979	8	6	0600	Unnamed	48.2	-50.6	12.9		Tropcial Depression
1980	9	8	1200	Georges	45.6	-51.1	34.5	993	Category 1
1982	9	19	0600	Debby	47.0	-50.5	38.6	979	Category 1
1984	9	2	1984	Cesar	46.0	-50.4	25.7	994	Tropical Storm
1990	9	3	0000	Gustav	46.0	-46.5	28.3	993	Tropical Storm
1992	10	26	1800	Frances	46.0	-46.9	28.3	988	Tropcail Storm
1993	9	10	0600	Floyd	45.4	-48.3	33.4	990	Category 1
1995	7	20	1200	Chantal	45.4	-48.8	25.7	1000	Extratropical
1995	8	22	1200	Felix	46.8	-50.8	25.7	985	Tropical Storm
1999	10	19	1200	Irene	48.0	-48.0	41.2	968	Extratropical
2000	9	25	1200	Helene	44.0	-55.5	28.3	988	Tropical Storm
2001	8	29	0000	Dean	47.0	-48.5	23.1	999	Extratropical
2001	9	20	0000	Gabrielle	48.5	-48.5	30.9	988	Extratropical
2003	10	7	1800	Kate	47.5	-47.2	30.9	980	Tropical Storm
2004	9	2	0000	Gaston	47.0	-50.0	23.1	997	Extratropical
2005	7	30	1800	Franklin	46.4	-48.8	20.6	1006	Extratropical
2006	9	10	0600	Florence	48.6	48.3	30.9	967	Extratropical
2006	10	3	0600	Isaac	48.6	49.0	23.1	998	Extratropical
2008	10	1	1800	Laura	47.5	-46.3	20.6	995	Extratropical

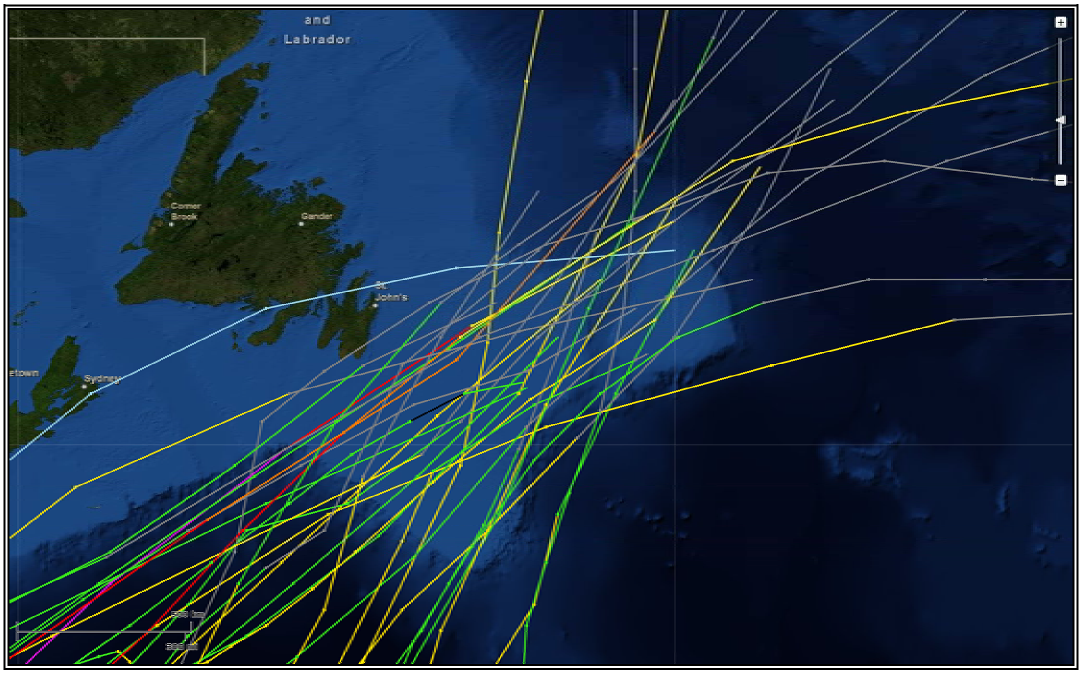


Figure 2.35 Storm Tracks of Tropical Systems Passing within 278 nm of 47.0ºN, 48.4ºW (1958 to 2008)

Region 2

Since 1958, 26 tropical systems have passed within 150 nm of 48.5ºN; 46.5ºW. The names are given in Table 2.25 and the tracks over the project area are shown in Figure 2.36. 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 within 278 nm of the location.

Table 2.25 Tropical Systems Passing within 278 km of 48.5ºN, 46.5ºW (1958 to 2008)

Year	Month	Day	Hour	Name	Latitude	Longitude	Wind (m/s)	Pressure	Category
1963	8	20	6	Beulah	49.4	44.9	33.4	N/A	Extratropical
1963	10	13	6	Flora	49.2	42.8	36.0	N/A	Extratropical
1969	8	13	0	Blanche	47.1	49	25.7	N/A	Extratropical
1971	8	6	18	Unnamed	50	46	36.0	N/A	Category 1
1974	7	20	6	SubTrop2	46.7	48	20.6	N/A	Extratropical
1975	10	3	18	Gladys	50.5	45.5	38.6	975	Extratropical
1976	5	24	6	Candice	47.3	45.5	33.4	N/A	Category 1
1978	9	5	6	Ella	47.2	50.2	41.2	975	Category 1
1979	8	2	0	Unnamed	48.2	50.6	12.9	N/A	Tropical Depression
1980	9	8	12	Georges	45.6	51.1	34.5	993	Category 1
1982	9	19	12	Debby	48.5	47.1	25.7	996	Tropical Storm
1990	9	3	0	Gustav	46	46.5	28.3	993	Tropical Storm
1995	7	13	0	Chantal	47.7	45.2	25.7	1001	Extratropical

1995	8	22	18	Felix	49	46	25.7	985	Extratropical
1999	9	19	6	Floyd	48.5	52.5	18.0	994	Extratropical
1999	10	19	12	Irene	48	48	41.2	968	Extratropical
2001	8	29	6	Dean	49	45	23.1	999	Extratropical
2001	9	20	0	Gabrielle	48.5	48.5	30.9	988	Extratropical
2003	10	7	18	Kate	47.5	47.2	30.9	980	Tropical Storm
2004	9	2	6	Gaston	48.5	44	23.1	996	Extratropical
2005	7	30	18	Franklin	46.4	48.8	20.6	1006	Extratropical
2005	9	19	12	Ophelia	49.5	45.7	23.1	1000	Extratropical
2006	9	14	6	Florence	48.6	48.3	30.9	967	Extratropical
2006	10	3	6	Isaac	48.6	49	23.1	998	Extratropical
2006	7	19	6	Unnamed	49.2	49.4	12.9	1012	Subtropical
2008	10	1	18	Laura	47.5	46.3	20.6	995	Subtropical

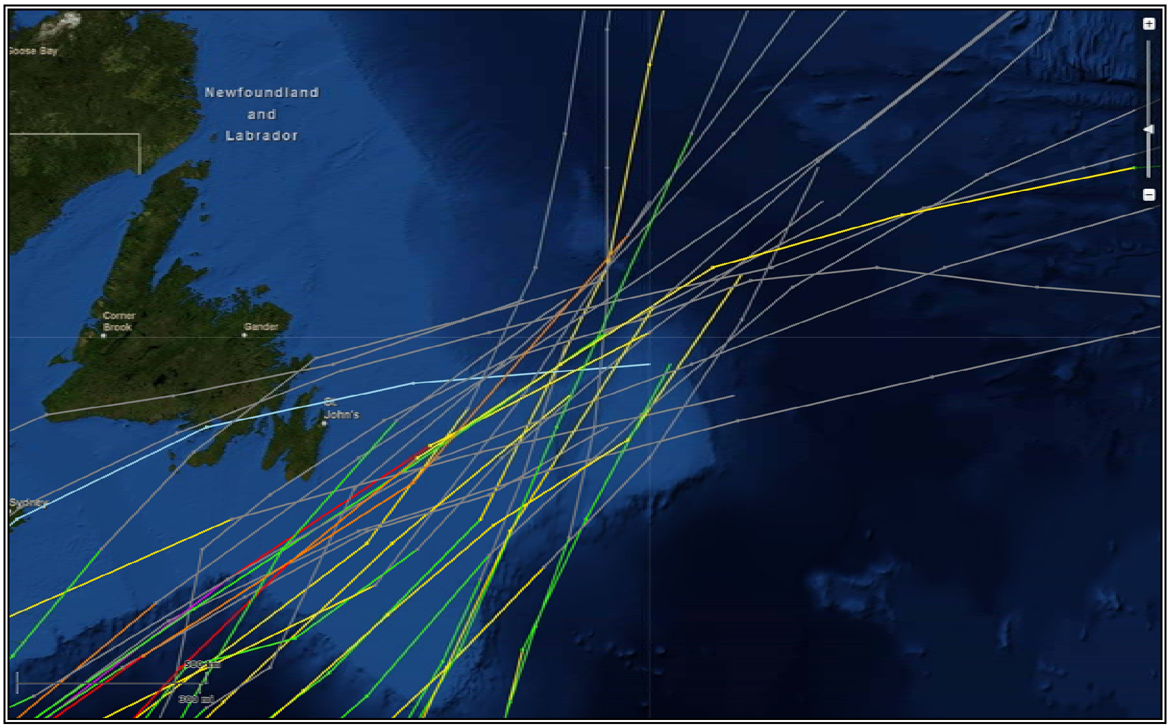


Figure 2.36 Storm Tracks of Tropical Systems Passing within 278 nm of 48.5ºN, 46.5ºW (1958 to 2008)

3.0 Extreme Analysis

An analysis of extreme wind and waves was performed for each region using the MSC50 data set. This data set was determined to be the most representative of the available data sets, as it provides a continuous 52-year period of 1 hourly data for the project area. The extreme value analysis for wind speeds was carried out using the peak-over-threshold method. For the extreme wave analysis, two methods were used; the peak-over-threshold method and the joint probability method.

After considering four different distributions, the Gumbel distribution was chosen to be the most representative for the peak-over-threshold method as it provided the best fit to the data. Since extreme values can vary, depending on how well the data fits the distribution, a sensitivity analysis was carried out to determine how many storms to use in the analysis.

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 are presented in Table 3.1.

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

			Annually	Monthly
Region 1	Grid Point 10255	Wind	314	71
		Wave	323	73
	Grid Point 11820	Wind	232	56
		Wave	234	56
Region 2	Grid Point 13428	Wind	284	66
		Wave	227	55
	Grid Point 14697	Wind	265	62
		Wave	247	60

3.1 Extreme Value Estimates 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 analysis used hourly wind values for the reference height of 10-meters above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ration of 1.06 and 1.22 respectively (U.S. Geological Survey, 1979).

A comparison of these values, with actual values measured by platforms in the project area was not possible. Logarithmic profiles for adjusting wind speeds from anemometer height to the surface are valid only in neutral or unstable conditions. Observations from platforms on the Grand Banks over the past ten years frequently show stable conditions in which the surface layer wind speed profiles are not valid. Using a logarithmic profile to adjust wind speeds between the

10-meter and anemometer level would therefore introduce an unnecessary source of error in the results.

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):

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

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.

Region 1

The calculated annual and monthly values for 1-hour, 10-minutes and 1-minute are presented in Table 3.2 to Table 3.4. The annual 100-year extreme 1-hour wind speed was determined to be 31.5m/s at Grid Point 10255 and 32.2m/s at Grid Point 11820. Monthly, the highest extreme winds occur during February at Grid Point 10255 and 11820 with extreme wind estimates of 30.7m/s and 31.2m/s respectively.

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

	GridPoint #10255					GridPoint #11820				
Period	1	10	25	50	100	1	10	25	50	100
January	22.1	25.6	26.7	27.6	28.5	22.6	26.4	27.4	28.6	29.1
February	21.9	26.8	28.3	29.5	30.7	21.7	27.3	28.9	30.1	31.2
March	20.0	24.5	25.9	27.0	28.1	19.6	25.4	27.0	28.3	29.5
April	18.0	22.1	23.5	24.5	25.5	17.8	22.7	24.0	25.1	26.1
May	15.3	19.2	20.5	21.4	22.4	15.2	20.3	21.7	22.8	23.8
June	14.1	17.6	18.8	19.7	20.5	13.9	18.2	19.5	20.4	21.3
July	13.0	17.1	18.4	19.4	20.4	12.6	17.0	18.2	19.1	20.0
August	13.7	20.6	22.9	24.6	26.3	12.4	20.7	23.0	24.8	26.5
September	16.7	22.0	23.8	25.1	26.3	16.5	22.3	24.0	25.2	26.4
October	17.9	23.3	25.1	26.4	27.7	17.7	23.8	25.6	26.9	28.2
November	19.6	24.4	26.0	27.1	28.3	18.9	24.8	26.5	27.7	29.0
December	21.4	26.2	27.8	29.0	30.1	21.4	26.8	28.3	29.5	30.6
Annual	24.7	28.1	29.5	30.5	31.5	25.4	28.8	30.2	31.2	32.2

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

	GridPoint #10255					GridPoint #11820				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	23.4	27.1	28.3	29.3	30.2	23.9	27.9	29.1	30.3	30.8
February	23.2	28.4	30.0	31.3	32.6	23.0	28.9	30.6	31.9	33.1
March	21.2	25.9	27.5	28.7	29.8	20.7	26.9	28.6	29.9	31.2
April	19.1	23.5	24.9	26.0	27.1	18.9	24.0	25.5	26.6	27.7
May	16.2	20.3	21.7	22.7	23.7	16.1	21.5	23.0	24.1	25.2
June	14.9	18.7	19.9	20.9	21.8	14.7	19.3	20.6	21.6	22.6
July	13.7	18.1	19.5	20.6	21.6	13.4	18.0	19.3	20.3	21.2
August	14.5	21.8	24.3	26.1	27.9	13.1	21.9	24.4	26.3	28.1
September	17.7	23.3	25.2	26.6	27.9	17.4	23.6	25.4	26.7	28.0
October	18.9	24.7	26.6	28.0	29.4	18.8	25.3	27.1	28.5	29.9
November	20.7	25.8	27.5	28.8	30.0	20.1	26.3	28.1	29.4	30.7
December	22.7	27.8	29.4	30.7	31.9	22.7	28.4	30.0	31.3	32.5
Annual	26.2	29.8	31.2	32.3	33.4	26.9	30.5	32.0	33.0	34.1

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

	GridPoint #10255					GridPoint #11820				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	26.9	31.2	32.6	33.7	34.7	27.5	32.2	33.5	34.8	35.5
February	26.7	32.6	34.6	36.0	37.5	26.5	33.3	35.2	36.7	38.1
March	24.4	29.9	31.6	33.0	34.3	23.9	30.9	33.0	34.5	36.0
April	22.0	27.0	28.7	29.9	31.1	21.8	27.6	29.3	30.6	31.8
May	18.7	23.4	25.0	26.1	27.3	18.6	24.7	26.5	27.8	29.1
June	17.2	21.5	22.9	24.0	25.1	16.9	22.2	23.7	24.9	26.0
July	15.8	20.8	22.4	23.7	24.9	15.4	20.7	22.2	23.3	24.4
August	16.7	25.1	27.9	30.0	32.1	15.1	25.2	28.1	30.2	32.4
September	20.4	26.9	29.0	30.6	32.1	20.1	27.2	29.2	30.7	32.2
October	21.8	28.4	30.6	32.2	33.8	21.6	29.1	31.2	32.8	34.4
November	23.9	29.7	31.7	33.1	34.6	23.1	30.3	32.3	33.8	35.3
December	26.2	32.0	33.9	35.3	36.7	26.1	32.7	34.6	36.0	37.4
Annual	30.1	34.3	36.0	37.2	38.4	30.9	35.2	36.8	38.0	39.2

Region 2

The calculated annual and monthly values for 1-hour, 10-minutes and 1-minute are presented in Table 3.5 to Table 3.7. The annual 100-year extreme 1-hour wind speed was determined to be 33.2m/s at Grid Point 13428 and 33.4m/s at Grid Point 14697. Monthly, the highest extreme winds occur during February at Grid Point 13428 with extreme wind estimates of 32.7m/s. For Grid Point 14697, December has the highest 1-hour extreme wind estimates of 32.8m/s.

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

	GridPoint #13428					GridPoint #14697				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	23.1	27.0	28.2	29.2	30.1	23.2	26.8	27.9	28.8	29.6
February	22.8	28.3	30.0	31.4	32.7	23.0	28.3	30.0	31.2	32.5
March	20.7	25.8	27.4	28.6	29.9	20.8	26.4	28.1	29.4	30.7
April	18.7	22.8	24.2	25.2	26.2	18.9	22.9	24.2	25.1	26.1
May	16.4	21.2	22.7	23.9	25.0	16.5	21.3	22.8	23.9	25.1
June	14.8	18.8	20.0	21.0	21.9	15.1	18.9	20.0	20.9	21.7
July	13.5	16.7	17.8	18.5	19.3	13.4	17.1	18.3	19.1	20.0
August	13.7	20.5	22.7	24.4	26.0	13.7	20.2	22.2	23.7	25.2
September	17.5	23.6	25.6	27.1	28.5	17.8	23.0	24.6	25.8	27.0
October	18.8	24.3	26.0	27.3	28.6	18.9	24.8	26.8	28.2	29.6
November	20.4	25.2	26.7	27.8	29.0	20.7	25.3	26.7	27.7	28.7
December	22.5	27.9	29.7	31.0	32.3	22.3	28.3	30.1	31.5	32.8
Annual	26.0	29.7	31.1	32.2	33.2	26.2	29.9	31.3	32.3	33.4

Table 3.6 10-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #13428					GridPoint #14697				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	24.5	28.6	29.9	30.9	31.9	24.6	28.4	29.6	30.5	31.4
February	24.2	30.0	31.8	33.2	34.6	24.3	30.0	31.8	33.1	34.4
March	21.9	27.3	29.1	30.4	31.6	22.0	28.0	29.8	31.2	32.5
April	19.8	24.2	25.6	26.7	27.7	20.0	24.3	25.6	26.6	27.7
May	17.4	22.4	24.1	25.3	26.5	17.5	22.6	24.2	25.4	26.6
June	15.7	19.9	21.2	22.2	23.2	16.0	20.0	21.2	22.1	23.0
July	14.4	17.7	18.8	19.6	20.4	14.2	18.1	19.3	20.3	21.1
August	14.5	21.8	24.1	25.8	27.5	14.5	21.4	23.5	25.1	26.7
September	18.5	25.0	27.1	28.7	30.2	18.8	24.4	26.1	27.3	28.6
October	19.9	25.7	27.6	29.0	30.3	20.1	26.3	28.4	29.9	31.4
November	21.6	26.7	28.3	29.5	30.7	22.0	26.8	28.2	29.4	30.5
December	23.8	29.6	31.4	32.8	34.2	23.6	29.9	31.9	33.3	34.8
Annual	27.5	31.4	32.9	34.1	35.2	27.7	31.6	33.1	34.3	35.4

Table 3.7 1-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #13428					GridPoint #14697				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	28.2	32.9	34.4	35.6	36.7	28.3	32.7	34.1	35.1	36.1
February	27.8	34.5	36.6	38.2	39.8	28.0	34.6	36.6	38.1	39.6
March	25.2	31.5	33.5	34.9	36.4	25.3	32.2	34.3	35.9	37.4
April	22.8	27.9	29.5	30.7	31.9	23.0	27.9	29.5	30.7	31.8
May	20.0	25.8	27.7	29.1	30.5	20.1	26.0	27.9	29.2	30.6
June	18.1	22.9	24.4	25.6	26.7	18.5	23.0	24.4	25.5	26.5
July	16.5	20.4	21.7	22.6	23.5	16.4	20.9	22.3	23.3	24.3
August	16.7	25.0	27.7	29.7	31.7	16.7	24.6	27.1	28.9	30.8
September	21.3	28.8	31.2	33.0	34.8	21.7	28.0	30.0	31.5	32.9
October	22.9	29.6	31.7	33.3	34.9	23.1	30.3	32.6	34.4	36.1
November	24.8	30.7	32.6	34.0	35.3	25.3	30.8	32.5	33.8	35.1
December	27.4	34.0	36.2	37.8	39.4	27.2	34.5	36.7	38.4	40.0
Annual	31.7	36.2	37.9	39.2	40.5	31.9	36.4	38.1	39.5	40.8

3.2 Extreme Value Estimates for Waves from a Gumbel Distribution

Region 1

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 3.8. The annual 100-year extreme significant wave height is 15.2m for Grid Point 10255 and 15.8m for Grid Point 11820. Monthly, the highest extreme significant wave height occurs during the month of February with an extreme height of 14.9 metres at Grid Pont 10255 and 15.8 metres at Grid Point 11820.

During a storm event on January 08, 2007 a maximum individual wave height of 22.63 metres was recorded by a waverider in the Terra Nova field. This is greater than the January maximum 10-year return period estimate of 21.8 metres for grid point 10255, which is the closest grid point to the Terra Nova waverider, however less than the 25-year return period estimate of 23.7 metres. The significant wave height during this event was 9.72 metres.

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

	GridPoint #10255					GridPoint #11820				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	8.8	11.9	12.9	13.7	14.4	9.4	12.5	13.4	14.1	14.8
February	8.3	11.9	13.1	14.0	14.9	8.5	12.8	14.0	14.9	15.8
March	7.1	10.1	11.1	11.8	12.6	7.1	10.4	11.4	12.1	12.8
April	5.8	8.6	9.5	10.2	10.9	5.5	9.1	10.2	10.9	11.7
May	4.6	6.9	7.7	8.3	8.9	4.4	7.7	8.6	9.3	10.0
June	3.7	5.8	6.5	7.0	7.6	3.4	6.3	7.2	7.8	8.4

July	3.4	5.3	6.0	6.4	6.9	3.1	5.5	6.2	6.7	7.2
August	3.8	6.2	7.0	7.6	8.2	3.4	6.4	7.2	7.9	8.5
September	5.3	8.5	9.6	10.4	11.2	5.1	9.2	10.4	11.3	12.2
October	6.2	9.6	10.7	11.6	12.4	5.9	10.5	11.8	12.8	13.7
November	7.4	10.3	11.2	11.9	12.7	7.6	11.1	12.2	13.0	13.8
December	8.6	11.6	12.5	13.2	14.0	9.0	12.4	13.4	14.1	14.8
Annual	10.5	12.9	13.8	14.5	15.2	11.3	13.6	14.5	15.1	15.8

The maximum individual wave heights and extreme associated peak periods are presented Table 3.9 and Table 3.10, respectively. Maximum individual wave heights and the extreme associated peak periods peak during the month of February for both points.

Table 3.9 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #10255					**GridPoint #11820**				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	16.4	21.8	23.7	25.0	26.4	17.3	23.0	24.6	25.8	27.0
February	15.5	22.1	24.3	25.9	27.5	15.9	23.7	25.9	27.5	29.2
March	13.5	19.3	21.2	22.6	24.0	13.1	19.2	20.9	22.2	23.5
April	11.0	15.9	17.5	18.7	19.9	10.3	16.9	18.8	20.1	21.5
May	8.6	13.9	15.7	17.0	18.3	8.2	14.9	16.9	18.3	19.7
June	7.1	11.0	12.3	13.3	14.3	6.6	11.7	13.1	14.2	15.3
July	6.4	9.9	11.1	12.0	12.8	5.9	10.3	11.5	12.4	13.3
August	7.2	11.6	13.0	14.1	15.2	6.7	11.6	13.0	14.1	15.1
September	10.3	16.0	17.9	19.4	20.8	9.4	16.8	18.9	20.5	22.0
October	11.7	17.8	19.8	21.3	22.8	11.0	19.2	21.5	23.3	25.0
November	13.9	19.1	20.7	22.0	23.3	14.0	20.4	22.3	23.8	25.2
December	16.4	21.7	23.5	24.8	26.1	16.8	22.9	24.7	26.0	27.3
Annual	19.5	23.8	25.5	26.7	28.0	20.9	25.1	26.7	27.9	29.2

Table 3.10 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #10255					**GridPoint #11820**				
Period	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	12.6	14.3	14.8	15.1	15.4	12.9	14.7	15.2	15.5	15.9
February	12.2	14.4	15.0	15.5	15.9	12.2	14.9	15.6	16.1	16.5
March	11.4	13.3	13.8	14.2	14.6	11.9	13.5	13.9	14.1	14.4
April	11.1	12.5	12.9	13.2	13.5	10.8	12.6	13.1	13.4	13.7
May	10.0	11.4	11.8	12.0	12.3	9.6	12.2	12.8	13.2	13.6
June	9.4	11.0	11.4	11.8	12.1	8.3	11.1	11.8	12.3	12.7
July	8.5	10.2	10.7	11.1	11.4	8.2	10.8	11.4	11.8	12.2
August	8.9	11.5	12.2	12.8	13.3	8.9	11.3	11.9	12.3	12.7

September	10.6	13.1	13.8	14.3	14.8	10.7	13.5	14.1	14.6	15.0
October	11.4	13.6	14.2	14.6	15.0	11.4	13.7	14.2	14.5	14.9
November	11.9	13.4	13.8	14.1	14.4	12.4	13.8	14.1	14.3	14.6
December	12.8	14.0	14.4	14.6	14.9	13.0	14.7	15.2	15.5	15.8
Annual	13.6	14.8	15.2	15.5	15.8	14.1	15.4	15.9	16.2	16.5

Region 2

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 3.11. The annual 100-year extreme significant wave height for Grid Point 13428 and Grid Point 14697 is 16.3 metres and 16.4 metres respectively. Monthly, the highest extreme significant wave height occurs during the winter months with an extreme height of 16.2 metres in February at Grid Point 13428 and 15.9 metres in December at Grid Point 14697.

A significant wave height of 13.6 m was measured by a buoy located at the Mizzen L-11 field on March 08, 2003. This height is slightly higher than the 50-year annual significant wave height for both Grid points.

Table 3.11 Extreme Significant Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #13428					**GridPoint #14697**				
Period	1	10	25	50	100	1	10	25	50	100
January	9.8	12.8	13.6	14.2	14.8	10.1	12.8	13.6	14.3	14.9
February	8.7	13.1	14.4	15.3	16.2	9.4	13.0	14.1	14.9	15.7
March	7.3	10.6	11.6	12.2	12.9	7.7	10.8	11.8	12.5	13.1
April	5.9	9.3	10.3	11.0	11.7	6.4	9.3	10.3	10.9	11.6
May	4.6	8.3	9.3	10.1	10.8	4.9	8.4	9.5	10.3	11.1
June	3.5	6.6	7.5	8.1	8.7	3.9	6.5	7.3	7.9	8.5
July	3.3	5.5	6.1	6.5	7.0	3.5	5.5	6.1	6.5	6.9
August	3.5	6.4	7.3	7.9	8.5	3.9	6.1	6.8	7.2	7.7
September	5.2	9.9	11.2	12.2	13.1	5.6	10.2	11.5	12.6	13.6
October	6.6	10.9	12.3	13.4	14.4	6.4	11.1	12.6	13.6	14.7
November	7.6	11.6	12.7	13.5	14.3	8.1	11.8	12.9	13.7	14.5
December	9.4	13.0	14.0	14.8	15.5	9.7	13.3	14.3	15.1	15.9
Annual	11.8	14.1	14.9	15.6	16.3	11.9	14.2	15.1	15.8	16.4

The maximum individual wave heights and extreme associated peak periods are presented Table 3.12 and Table 3.13, respectively. Maximum individual wave heights and the extreme associated peak periods peak during the month of February for both points.

Table 3.12 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #13428					GridPoint #14697				
Period	1	10	25	50	100	1	10	25	50	100
January	18.3	23.6	25.1	26.3	27.4	18.7	24.0	25.6	26.8	28.0
February	16.4	24.3	26.6	28.2	29.9	17.4	24.3	26.4	28.0	29.5
March	13.8	19.7	21.4	22.6	23.9	14.4	20.1	21.9	23.2	24.5
April	11.1	17.1	18.8	20.1	21.3	11.9	17.5	19.3	20.5	21.8
May	8.5	15.9	18.0	19.5	21.1	9.2	16.0	18.1	19.7	21.2
June	6.8	12.2	13.7	14.9	16.0	7.5	12.2	13.6	14.6	15.6
July	6.3	10.1	11.2	12.0	12.8	6.6	10.1	11.2	12.0	12.8
August	6.8	12.2	13.7	14.8	15.9	7.4	11.5	12.8	13.7	14.6
September	9.7	17.8	20.3	22.0	23.7	10.6	18.7	21.1	23.0	24.8
October	12.3	20.2	22.7	24.6	26.5	12.0	20.6	23.2	25.1	27.0
November	14.0	21.3	23.3	24.8	26.3	15.0	21.7	23.7	25.2	26.7
December	17.3	24.0	25.9	27.3	28.6	17.9	24.5	26.4	27.9	29.4
Annual	21.7	26.0	27.7	28.9	30.2	22.0	26.4	28.1	29.3	30.6

Table 3.13 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	GridPoint #13428					GridPoint #14697				
Period	1	10	25	50	100	1	10	25	50	100
January	13.2	14.9	15.3	15.6	15.9	13.3	14.9	15.3	15.6	15.9
February	12.3	15.1	15.8	16.3	16.8	12.7	14.8	15.4	15.8	16.3
March	11.9	13.4	13.8	14.1	14.3	11.9	13.4	13.8	14.1	14.4
April	11.2	12.8	13.2	13.4	13.7	11.5	12.9	13.2	13.5	13.7
May	9.7	12.4	13.0	13.4	13.8	10.0	12.4	13.0	13.5	13.9
June	8.3	11.3	12.0	12.5	13.0	9.1	11.0	11.5	11.9	12.2
July	8.4	10.7	11.3	11.7	12.1	8.6	10.5	11.0	11.4	11.7
August	8.7	11.3	11.8	12.2	12.6	9.2	11.0	11.5	11.8	12.1
September	10.8	13.7	14.4	14.8	15.3	10.9	13.6	14.2	14.7	15.1
October	12.0	13.8	14.3	14.7	15.0	11.5	13.8	14.4	14.8	15.2
November	12.1	14.1	14.5	14.9	15.2	12.1	14.1	14.6	15.0	15.4
December	13.0	15.0	15.5	15.8	16.2	13.2	14.8	15.3	15.6	15.9
Annual	14.3	15.5	16.0	16.3	16.6	14.2	15.5	15.9	16.3	16.6

3.3 Joint Probability of Extreme wave Heights and Spectral Peak Period

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). Since the equations involved in this methodology were originally developed for 3-hourly data, a 3-hour subset of the

MSC50 data was used in the analysis. 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 metre 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 metres were modeled separately in a Weibull Distribution. The two Weibull curves were combined near 2 metres, 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 the calculated. Using the coefficients and the two distribution functions, the joint wave height and period combinations were calculated for the various return periods.

Region 1

A contour plot depicting these values for return periods of 1-year, 10-years, 25-years, 50-years and 100-years for both Grid Points are presented in Figure 3.1 and 3.2. The annual values for the significant wave height estimates and the associated spectral peak periods are given in Table 3.14. The extreme wave height for all return periods was higher using the Weibull Distribution when compared to the Gumbel Distribution.

Table 3.14 Annual Extreme Significant Wave Estimates and Spectral Peak Periods for Return Periods of 1, 10, 25, 50 and 100 Years

	Combined Significant Wave Height (m)		Spectral Peak Period Median Value (s)	
Return Period	**Grid Point 10255**	**Grid Point 11820**	**Grid Point 10255**	**Grid Point 11820**
1	11.5	12.1	14.2	14.6
10	13.8	14.4	15.5	15.8
25	14.7	15.3	16.0	16.3
50	15.4	15.9	16.3	16.6
100	16.1	16.6	16.7	17.0

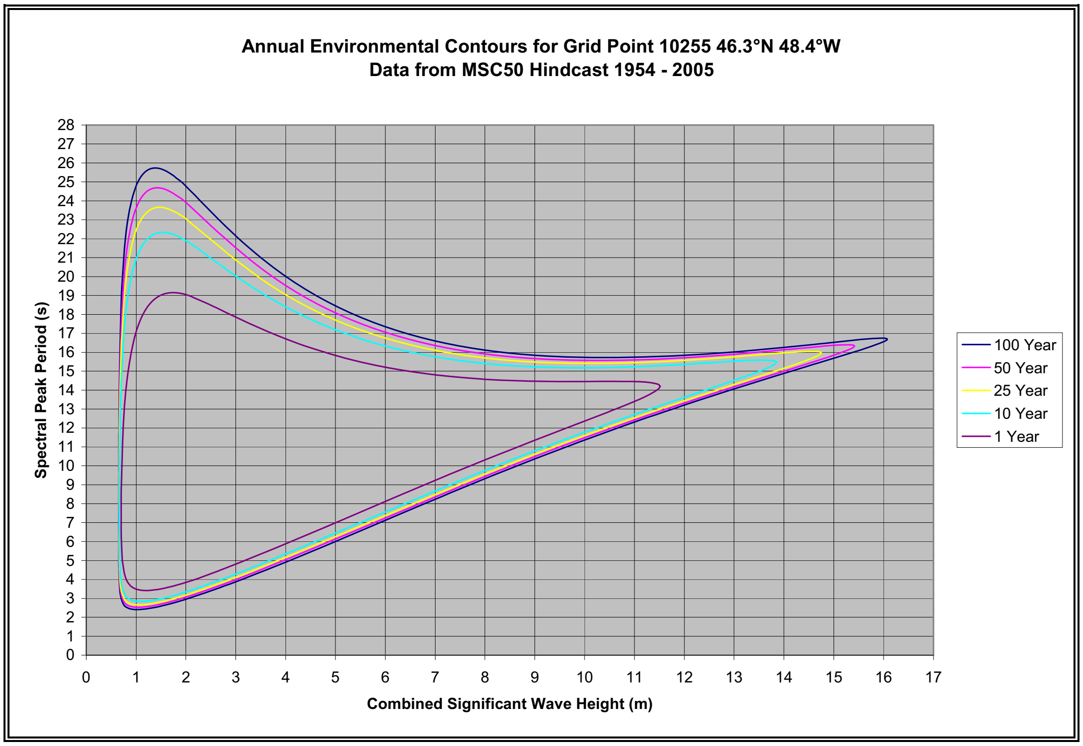


Figure 3.1 Environmental Contour Plot for Grid Point 10255 located near 46.3°N; 48.0°W

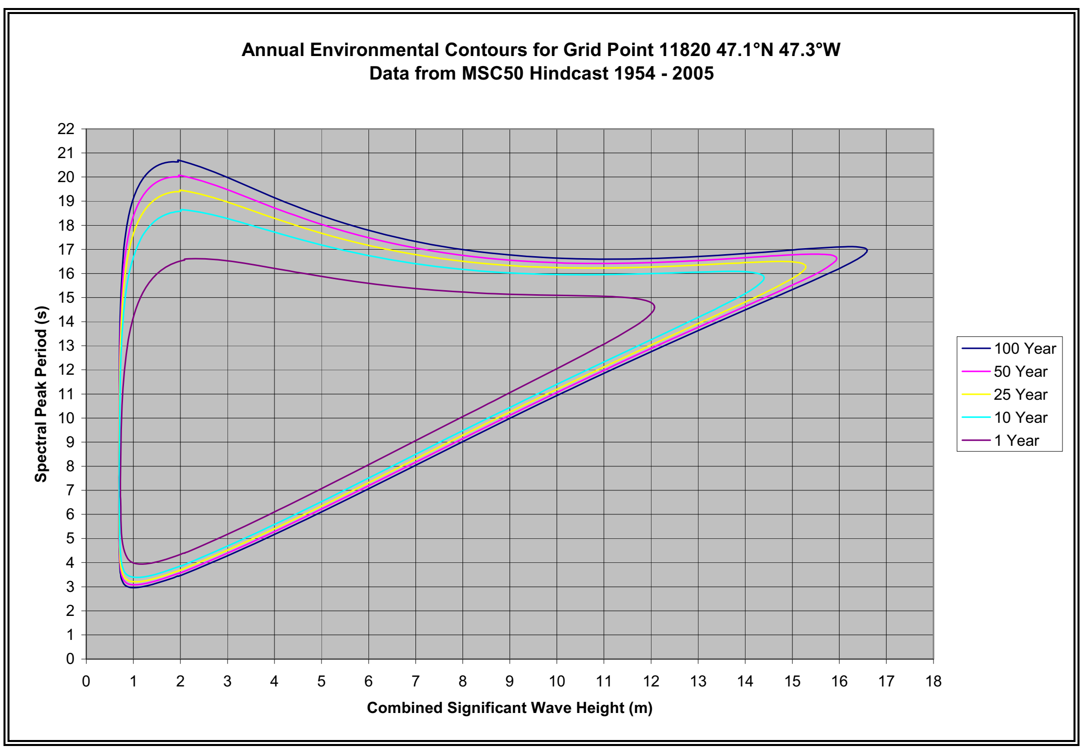


Figure 3.2 Environmental Contour Plot for Grid Point 11820 located near 47.1°N; 47.3°W

Region 2

A contour plot depicting these values for return periods of 1-year, 10-years, 25-years, 50-years and 100-years for both Grid Points are presented in Figure 3.3 and 3.4. The annual values for the significant wave height estimates and the associated spectral peak periods are given in Table 3.15. The extreme wave height for all return periods was higher using the Weibull Distribution when compared to the Gumbel Distribution.

Table 3.15 Annual Extreme Significant Wave Estimates and Spectral Peak Periods for Return Periods of 1, 10, 25, 50 and 100 Years

	Combined Significant Wave Height (m)		Spectral Peak Period Median Value (s)	
Return Period	Grid Point 13428	Grid Point 14697	Grid Point 13428	Grid Point 14697
1	12.5	12.8	14.8	14.7
10	14.8	15.4	16.1	16.0
25	15.7	16.4	16.5	16.5
50	16.4	17.1	16.9	16.9
100	17.1	17.9	17.2	17.3

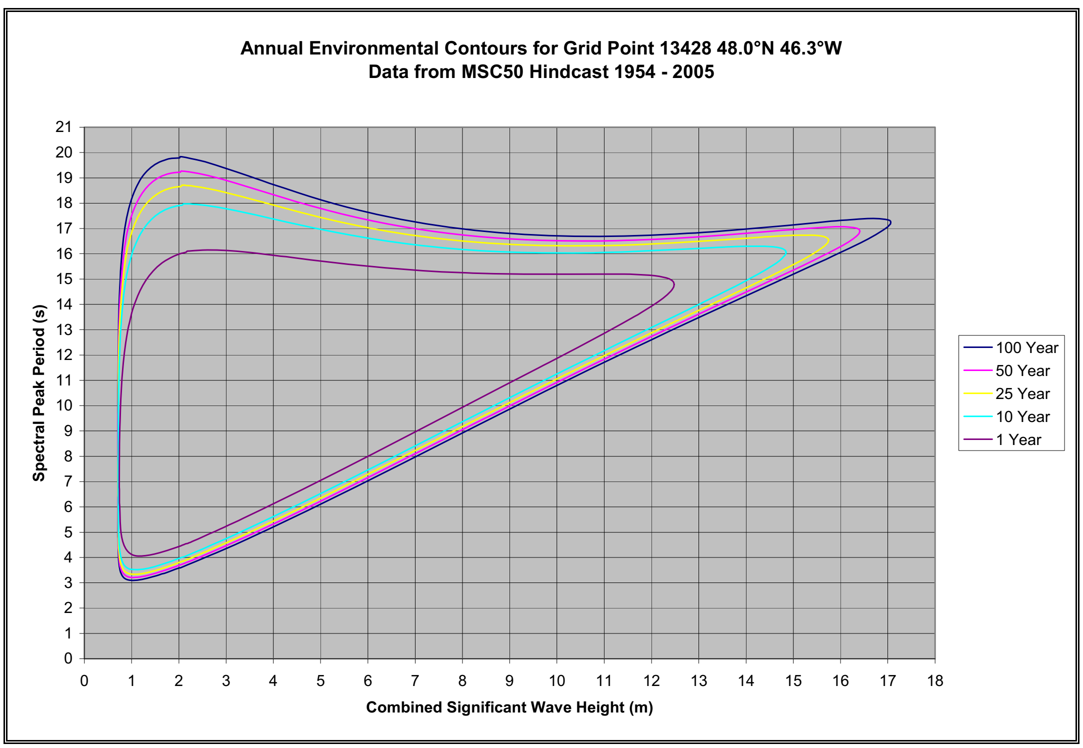


Figure 3.3 Environmental Contour Plot for Grid Point 13428 located near 48.0°N; 46.3°W

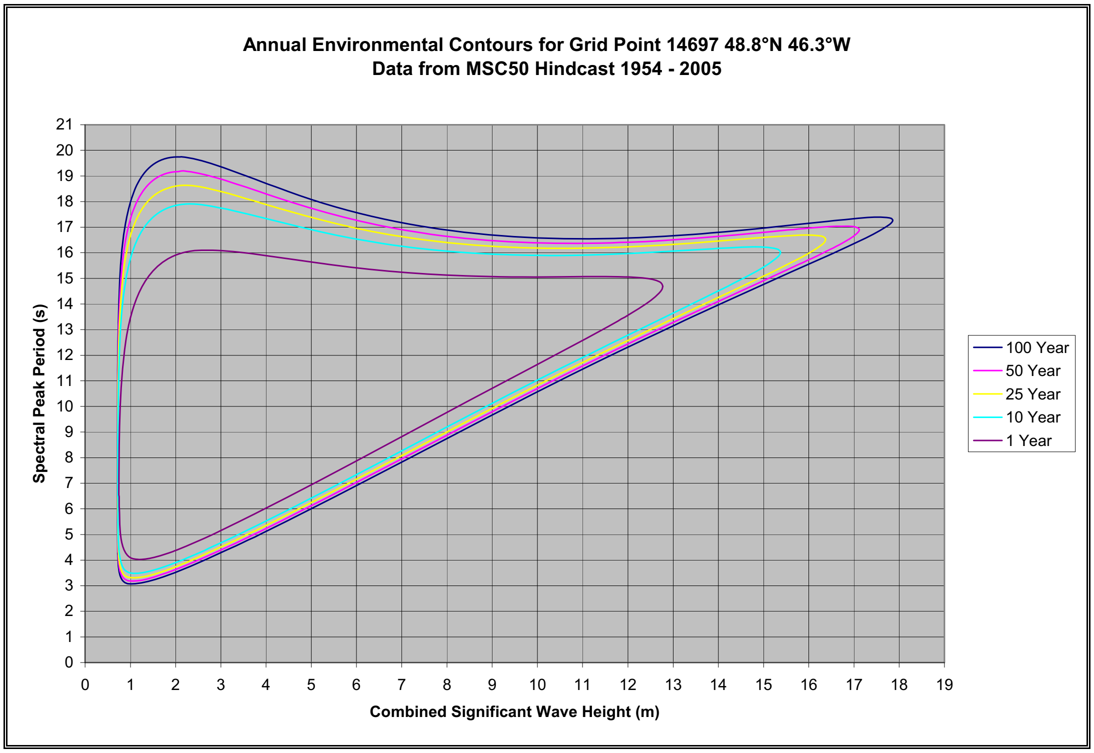


Figure 3.4 Environmental Contour Plot for Grid Point 14697 located near 48.8°N; 46.3°W

4.0 Physical Oceanography

4.1 Major Currents in the Study Area

The study area is the southern part of Orphan Basin, the Sackville Spur, the Northeast Newfoundland Slope, northern Flemish Pass, and the Jeanne d'Arc Basin. The large scale circulation off the coast of Newfoundland and Labrador is dominated by well established currents that flow along the margins of the Continental Shelf. The two major current systems in the area are the Labrador Current and the North Atlantic Current (Colbourne & Foote, 2000). The Labrador Current is the main current in the study area and it transports sub-polar water to lower latitudes along the Continental Shelf of eastern Canada. Oceanographic studies show that this strong western boundary current follows the shelf break with relatively low variability compared to the mean flow. Over the Grand Banks a weaker current system is observed where the variability often exceeds that of the mean flow. Figure 4.1 shows the major currents off the coast of Newfoundland and Labrador.

The Labrador Current consists of two major branches. The inshore branch of the Labrador Current is approximately 100 km wide (Stein, 2007) and is steered by the local underwater topography through the Avalon Channel. The stronger offshore branch flows along the shelf break over the upper portion of the Continental Slope. The offshore branch passes between the 400 m and 1200 m isobaths (Lazier and Wright, 1993). This branch of the Labrador Current divides east of 48°W, resulting in part of the branch flowing to the east around Flemish Cap and the other flowing south around the eastern edge of the Grand Banks and through Flemish Pass. Within Flemish Pass the width of the Labrador Current is reduced to 50 km with speeds of about 30 cm/s (Stein, 2007). This flow transports cold, relatively low salinity Labrador Slope water into the region. To the southeast of the Flemish Cap the North Atlantic Current transports warmer, high salinity water to the northeast along the southeast slope of Grand Bank and the Flemish Cap (Figure 4.2).

The volume transport of the Labrador Current is variable from year to year. Han et al. (2010) found that the transport decreased by 6.3 Sv from the early to late 1990's and increased by 3.2 Sv from the late 1990's to the early 2000's. They found that the multi-year changes in the Labrador Current transport appeared to be primarily barotopic and positively correlated with the North Atlantic Oscillation at zero lag implying a fast response of the regional circulation to the atmospheric forcing variability.

The outer branch of the Labrador Current exhibits a distinct seasonal variation in flow speeds (Lazier and Wright, 1993), in which mean flows are a maximum in October and a minimum in March and April. This annual cycle is reported to be the result of the large annual variation in the steric height over the continental shelf in relation to the much less variable internal density characteristic of the adjoining deep waters. The additional freshwater in spring and summer is largely confined to the waters over the shelf. In summer, the difference in sea level between the shelf and open ocean is 0.09 m greater than in winter (Lazier and Wright, 1993). This difference produces a greater horizontal surface pressure gradient and hence, stronger mean flows.

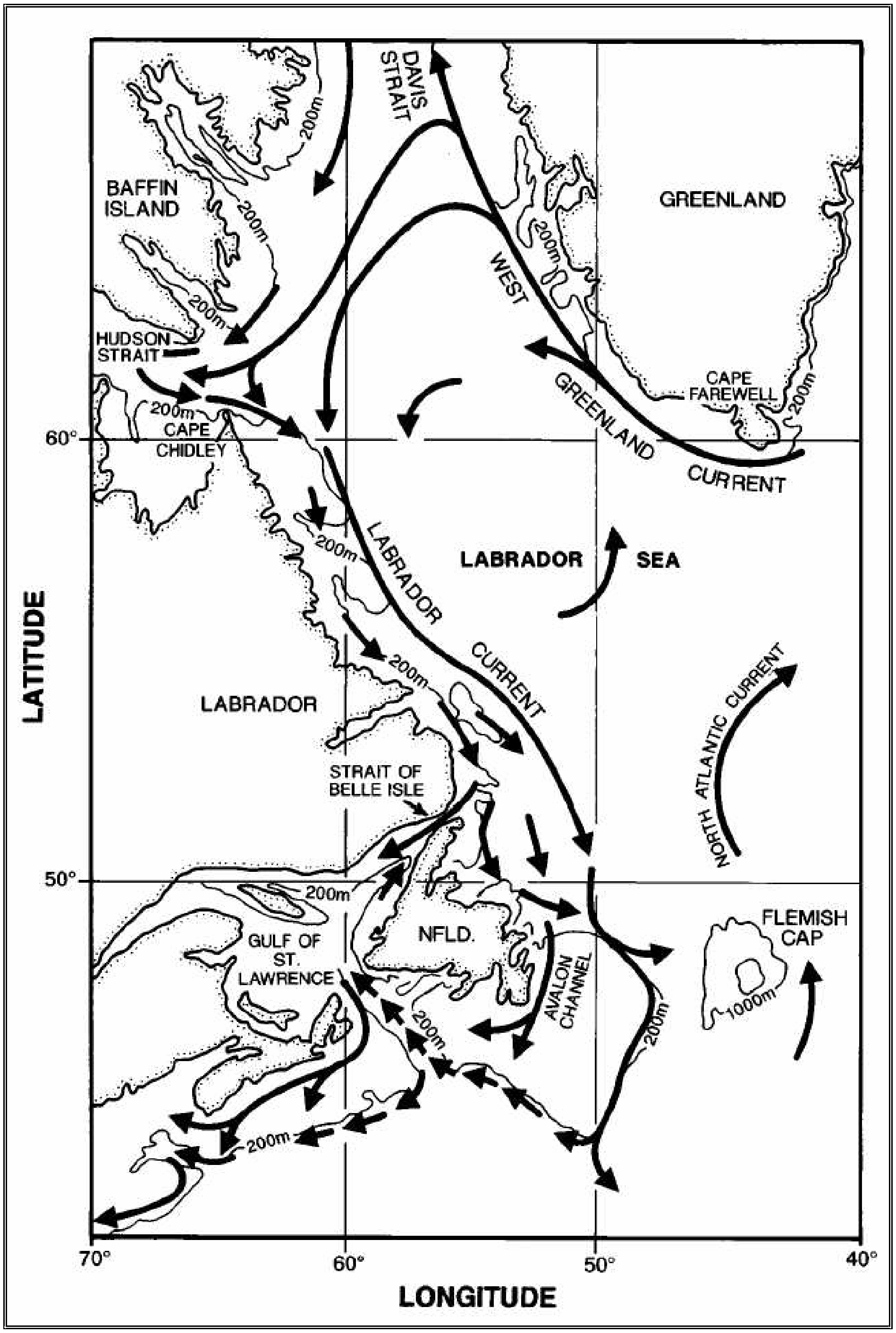


Figure 4.1 Major ocean circulation features in the Northeast Atlantic (Colbourne et al., 1997)

Source: Colbourne et al., 1977

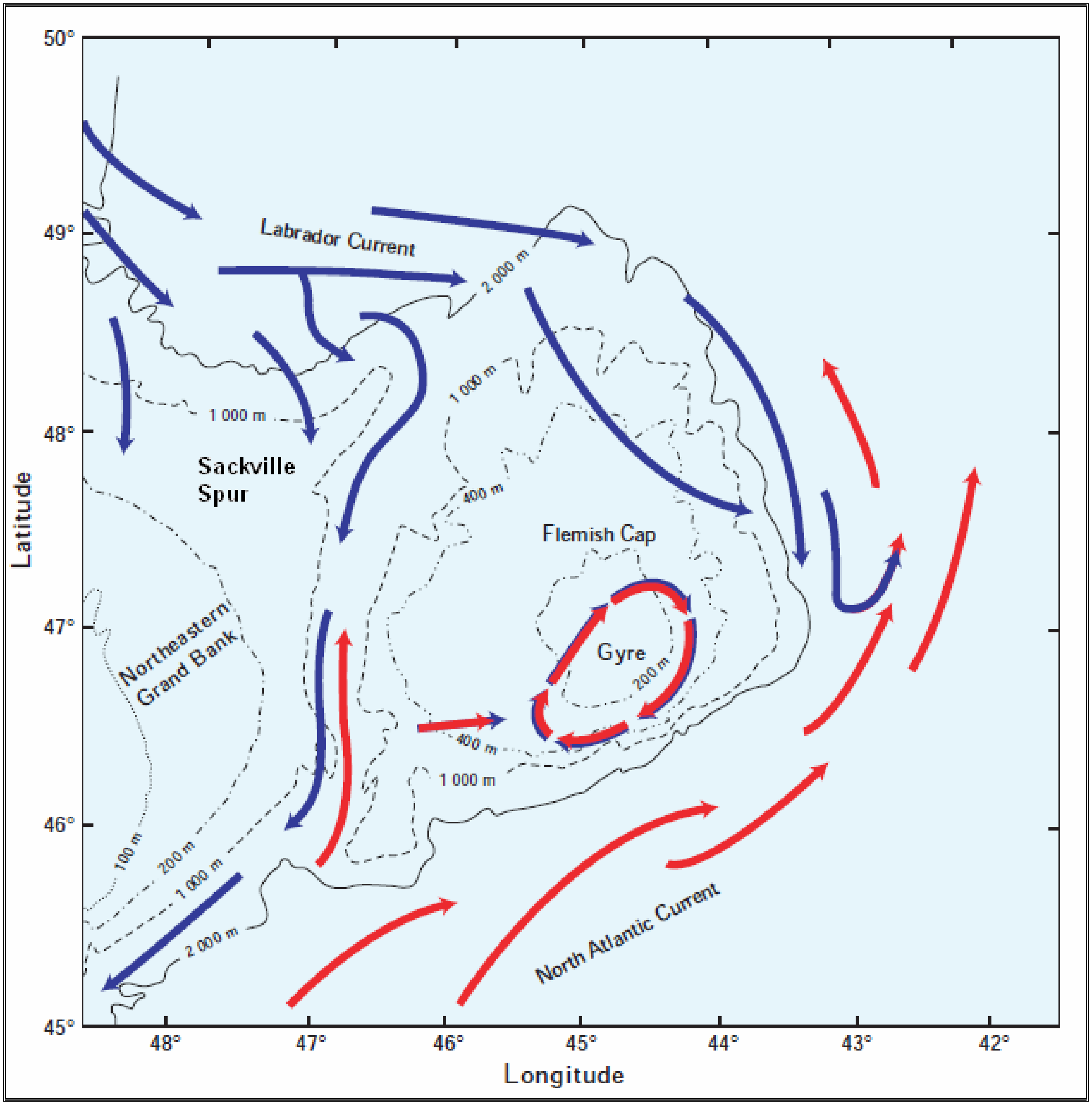


Figure 4.2 The major circulation features around the Flemish Cap and Sackville Spur

Source: (modified from Colbourne & Foote, 2000)

4.2 Currents in the Project Area

The project study area was divided into three sub-areas (Figure 4.3). The first sub-area is Orphan Basin, the second is Flemish Pass and Sackville Spur, and the third is the northeast Grand Banks.

Figure 4.3 Map showing the three sub areas within the project study area

The data used for the following descriptions came from data collections for White Rose and Terra Nova (sub-area 3) and moored current data obtained from the Bedford Institute of Oceanography. There is little current information available for sub-area 1 and sub-area 2. There was one mooring in sub-area 1 in the southern Orphan Basin, and four moorings in sub-area 2 for the Sackville Spur and Flemish Pass and 24 moorings in sub-area 3 on the Grand Banks. Location of the moorings in sub-area 1 and 2 are shown in Table 4.1. The data for the Northeast Grand Banks were from moored current meters at White Rose and Terra Nova. On several of the moorings, there was more than one instrument which allowed data to be collected at different depths in the water column.

Table 4.1 Current Meter Data for the Area

Mooring #	Location	Date	Depth (m)	Latitude	Longitude
1	Southern Orphan Basin	Jul 16-19, 1979	2738	49.50°N	47.08°W
2	Sackville Spur	Apr 11 – Jul 17, 1976	467	48.00°N	47.11°W
2	Sackville Spur	Apr 11 – Jul 17, 1976	767	48.00°N	47.11°W
3	NE NL Slope	Dec 1991- May 1992	143	47.85°N	48.02°W
3	NE NL Slope	Dec 1991- May 1992	293	47.85°N	48.02°W
4	Flemish Pass	Apr 23 – Jul 23, 1986	346	47.35°N	47.08°W
4	Flemish Pass	Apr 23 – Jul 23, 1986	589	47.35°N	47.08°W
4	Flemish Pass	July 25 – Oct 31, 1986	67	47.35°N	47.16°W
4	Flemish Pass	July 25 – Oct 31, 1986	334	47.35°N	47.16°W
4	Flemish Pass	July 25 – Oct 31, 1986	592	47.35°N	47.16°W

4.2.1 Sub-area 1: Orphan Basin

There is only one data set available for the southern section of Orphan Basin. This record is for only three days in July 1979. For this short record, the mean speed was 6.9 cm/s and the maximum speed was 18.3 cm/s. The flow was in a south southeast direction as shown by the progressive vector diagram in Figure 4.4.

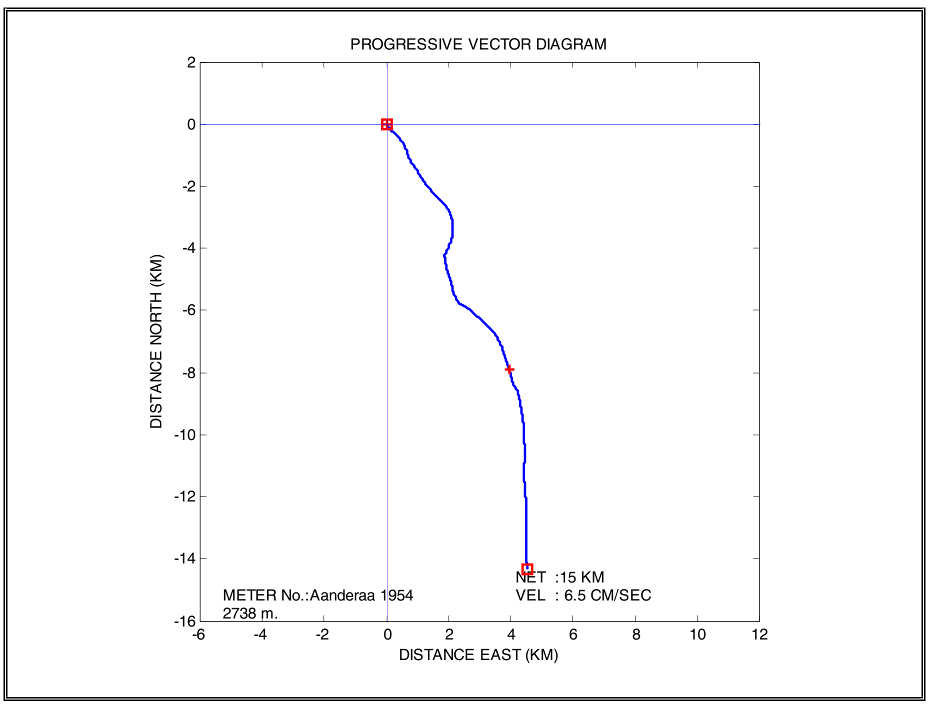


Figure 4.4 Progressive vector diagram for the currents in southern Orphan Basin

4.2.2 Sub-area 2: Sackville Spur &Flemish Pass

The current meter mooring on the Sackville Spur was located in a water depth of approximately 800 m. The currents were measured at depths of 467 m and 767 m. Statistics for the mean and maximum current speeds and average velocity for each month are presented in Tables 4.2 and 4.3. At a depth of 467 m, the mean current speed was 8.1 cm/s and the maximum speed was 27.2 cm/s. At a depth of 767 m, the mean current speed was 8.3 cm/s and the maximum speed was 37.3 cm/s. The velocity was 5.9 cm/s in a southerly direction at a depth of 467 m and 6.7 cm/s in a south southwest direction at a depth of 767 m. During April the current flowed in a northeast direction at both depths whereas during the following months the current flowed towards the south (Figure 4.5 and 4.6). This is the area where the offshore branch of the Labrador splits into two streams, one stream flowing northeast around the top of Flemish Cap and the other stream flowing south through Flemish Pass.

Table 4.2 Current statistics for a water depth of 467 m on the Sackville Spur

Month	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
April	10.7	27.2	3.4
May	5.7	17.7	4.3
June	9.2	19.8	8.8
July	7.3	14.9	6.9
Overall	8.1	27.2	5.9

Table 4.3 Current Statistics for a water depth of 767 m on the Sackville Spur

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
April	12.2	37.3	7.1
May	6.1	18.1	4.9
June	8.9	21.4	8.6
July	6.7	19.4	6.4
Overall	8.3	37.3	6.7

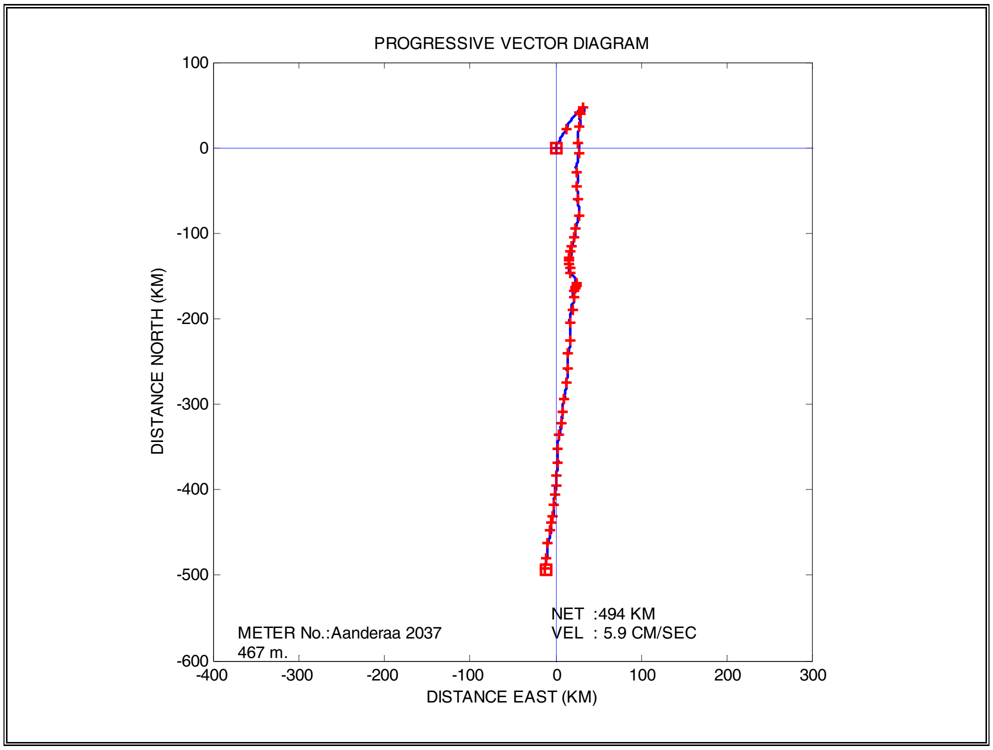


Figure 4.5 Progressive vector diagram for the currents on the Sackville Spur at 457 m

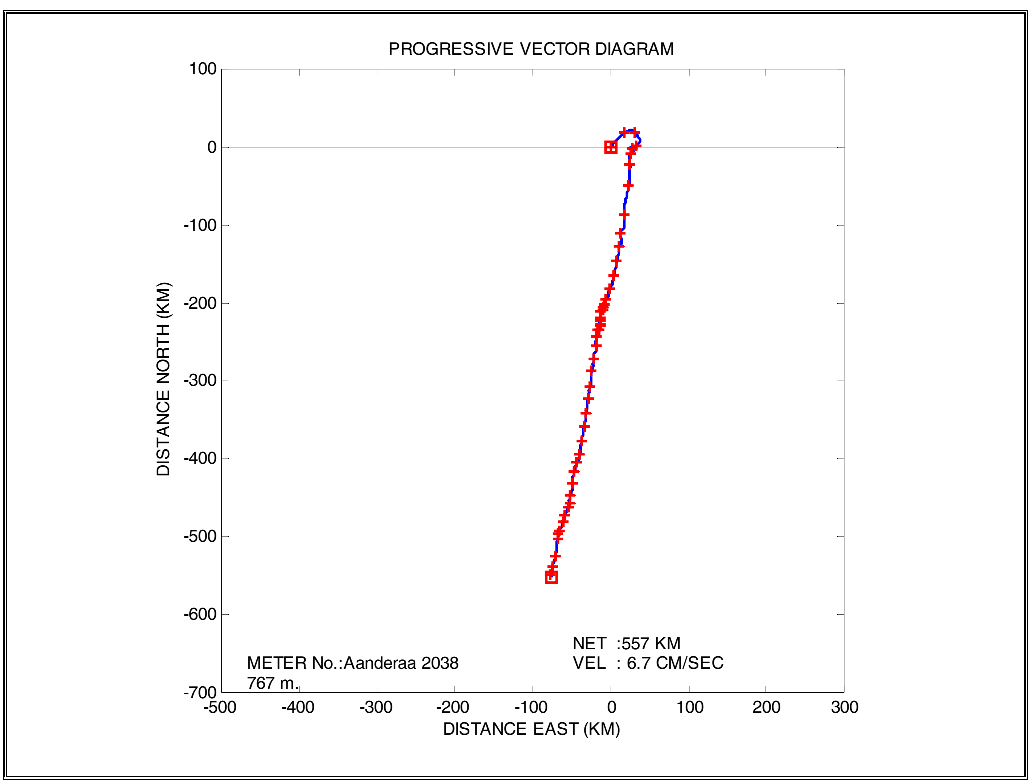


Figure 4.6 Progressive vector diagram for the currents on the Sackville Spur at 767 m

Mooring No. 3 was on the northeast Newfoundland Slope in the area before the Labrador Current splits into two streams. At this location the current speeds were higher than on the Sackville Spur or in Flemish Pass. Statistics on the current speeds are presented in Table 4.4 and Table 4.5 for water depths of 143 m and 293 m, respectively. At a depth of 143 m, the mean current speed was 26.9 cm/s and the maximum speed was 77.5 cm/s. At a depth of 293 m, the mean current speed was 17.7 cm/s and the maximum speed was 54.2 cm/s for depths of 143 m and 293 m, respectively. At a depth of 143 m, the mean velocity was in a southeast direction (Figure 4.7) and at a depth of 293 m; the current flowed in a east southeast direction (Figure 4.8).

Table 4.4 Current statistics for a water depth of 143 m on the northeast Newfoundland Slope

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
December	24.8	77.5	24.5
January	32.2	76.2	30.4
February	30.6	72.5	28.0
March	25.2	70.4	22.7
April	23.3	52.9	22.2
May	20.3	40.4	18.3
Overall	26.9	77.5	24.5

Table 4.5 Current statistics for a water depth of 293 m on the northeast Newfoundland Slope

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
December	18.2	47.2	11.1
January	19.6	54.2	12.7
February	18.5	46.5	11.0
March	18.4	53.3	11.8
April	15.4	37.4	15.4
May	13.6	34.8	7.4
Overall	17.7	54.2	11.3

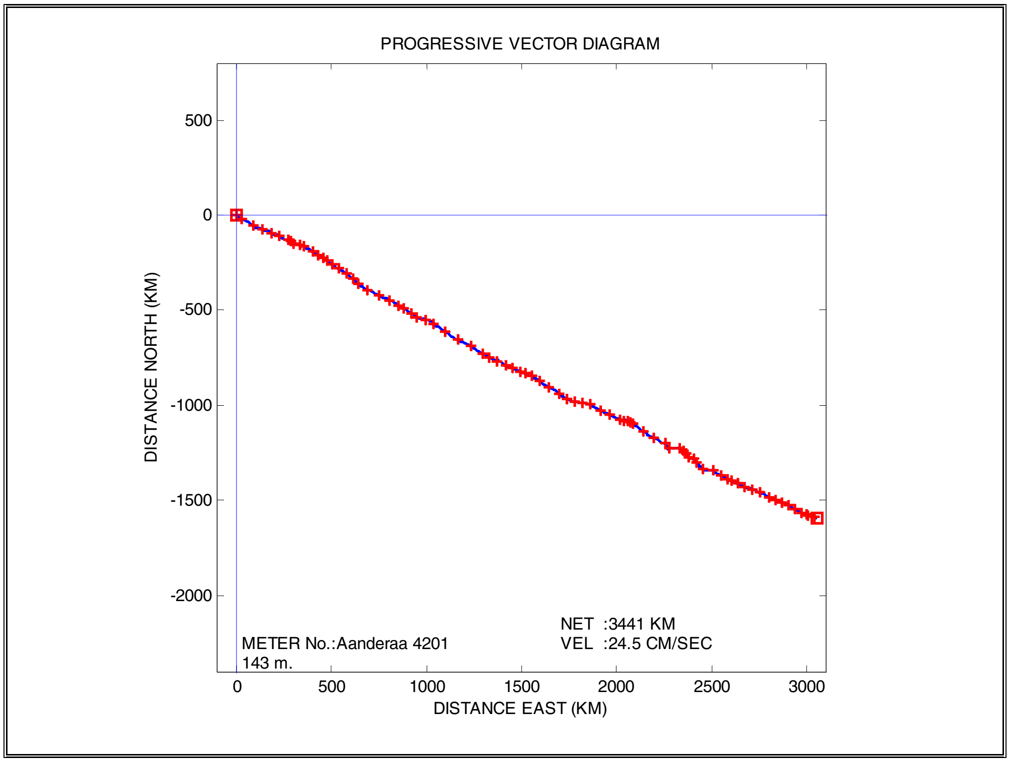


Figure 4.7 Progressive vector diagrams for the currents on the northeast Newfoundland Shelf at 143 m

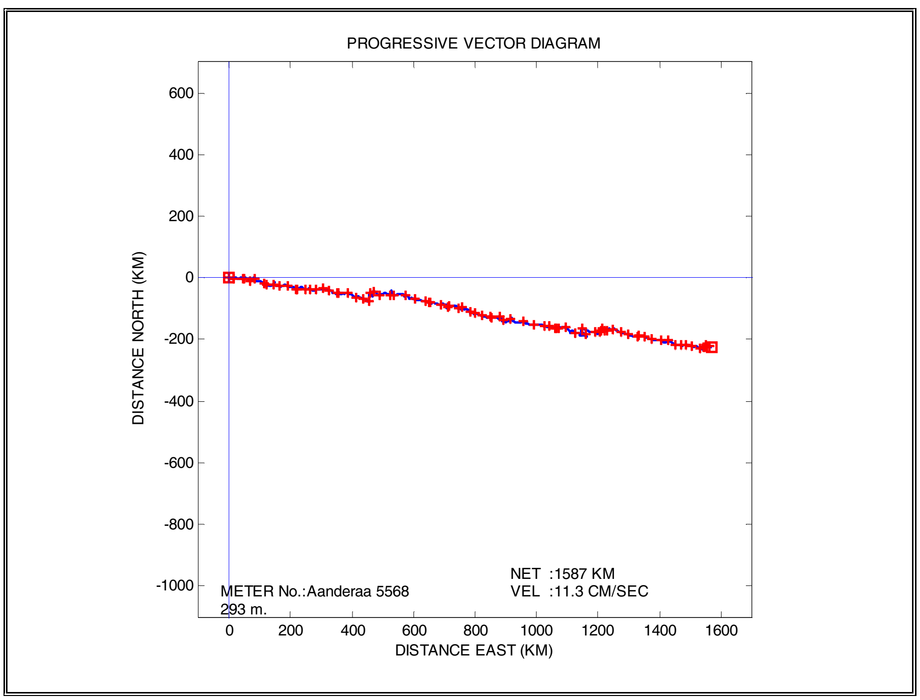


Figure 4.8 Progressive vector diagrams for the currents on the northeast Newfoundland Shelf at 293 m

Currents were measured near the 700 m contour on the western side of Flemish Pass at the Lancaster F-70 exploration well in 1986. Currents were measured at depths of 347 m and 589 m between April and July and at depths of 67 m, 334 m, and 592 m between July and October, 1986. Current statistics on the mean and maximum speeds and mean velocities are presented in Tables 4.6 to 4.10. The mean current speed varied between 30.7 cm/s at a depth of 67 m to 10.2 cm/s at a depth of 589 m. The highest current speed was 63.5 cm/s at a depth 67 m. At this depth, the mean velocity was 29.7 cm/s in a south southwest direction. The progressive vector diagrams for the five depths are shown in Figures 4.9 to 4.13. The progressive vector diagrams show that during April the current flowed towards the northeast while during the period of May to October the current flowed in a southwest direction.

Table 4.6 Current statistics for a water depth of 346 m in Flemish Pass

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
April	13.6	28.4	6.3
May	10.1	22.4	3.7
June	11.9	27.5	11.2
July	11.9	31.9	11.4
Overall	11.4	31.9	7.0

Table 4.7 Current statistics for a water depth of 589 m in Flemish Pass

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
April	13.8	34.3	3.3
May	9.8	29.5	7.0
June	9.6	28.3	8.8
July	10.1	33.4	9.7
Overall	10.2	34.3	7.3

Table 4.8 Current statistics for a water depth of 67 m in Flemish Pass

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
July	19.9	34.4	19.2
August	21.5	40.7	20.5
September	32.3	53.2	31.4
October	40.7	63.5	39.6
Overall	30.7	63.5	29.7

Table 4.9 Current statistics for a water depth of 334 m in Flemish Pass

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
July	16.0	22.6	15.8
August	12.1	22.1	11.9
September	16.2	29.1	15.9
October	25.5	43.1	25.1
Overall	17.8	43.1	17.5

Table 4.10 Current statistics for a water depth of 592 m in Flemish Pass

	Mean Speed (cm/s)	Maximum Speed (cm/s)	Mean Velocity (cm/s)
July	14.9	22.2	14.9
August	8.6	20.8	8.4
September	12.4	28.2	12.0
October	18.7	40.6	18.4
Overall	13.4	40.6	13.0

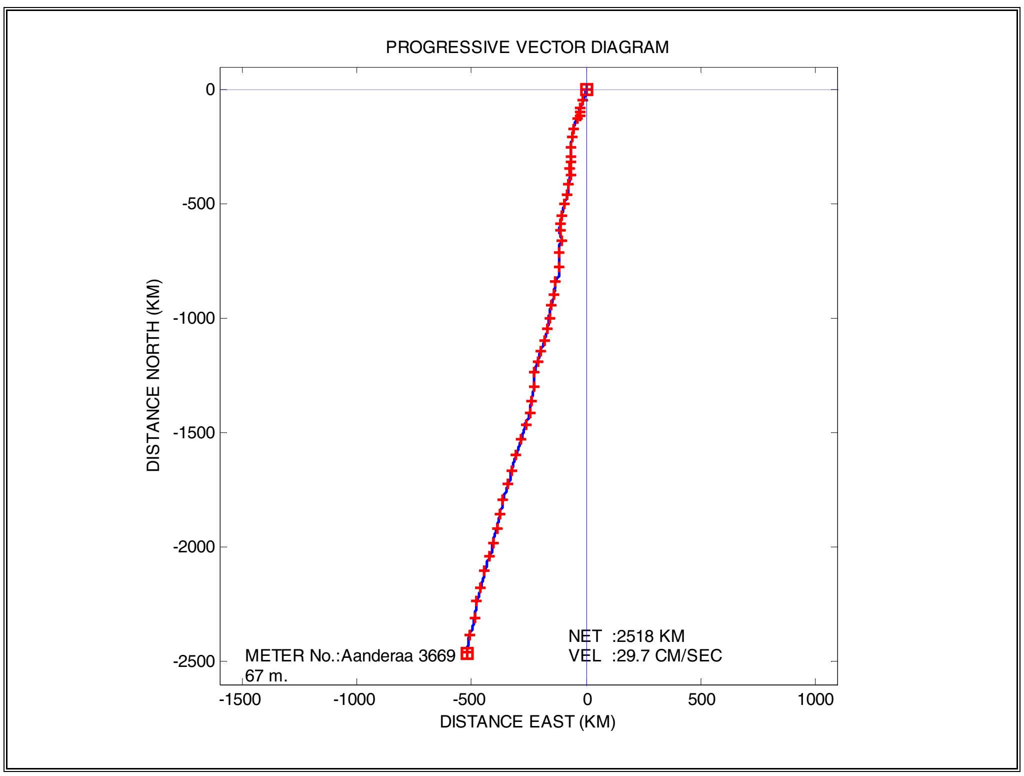


Figure 4.9 Progressive vector diagrams for the currents in Flemish Pass at 67 m

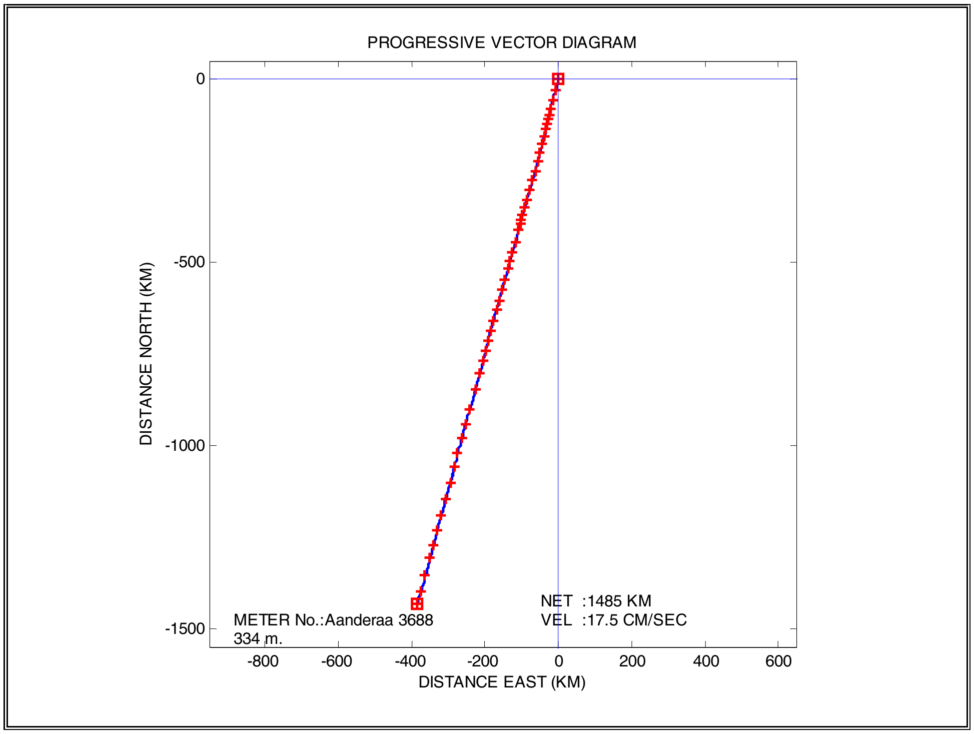


Figure 4.10 Progressive vector diagrams for the currents in Flemish Pass at 334 m

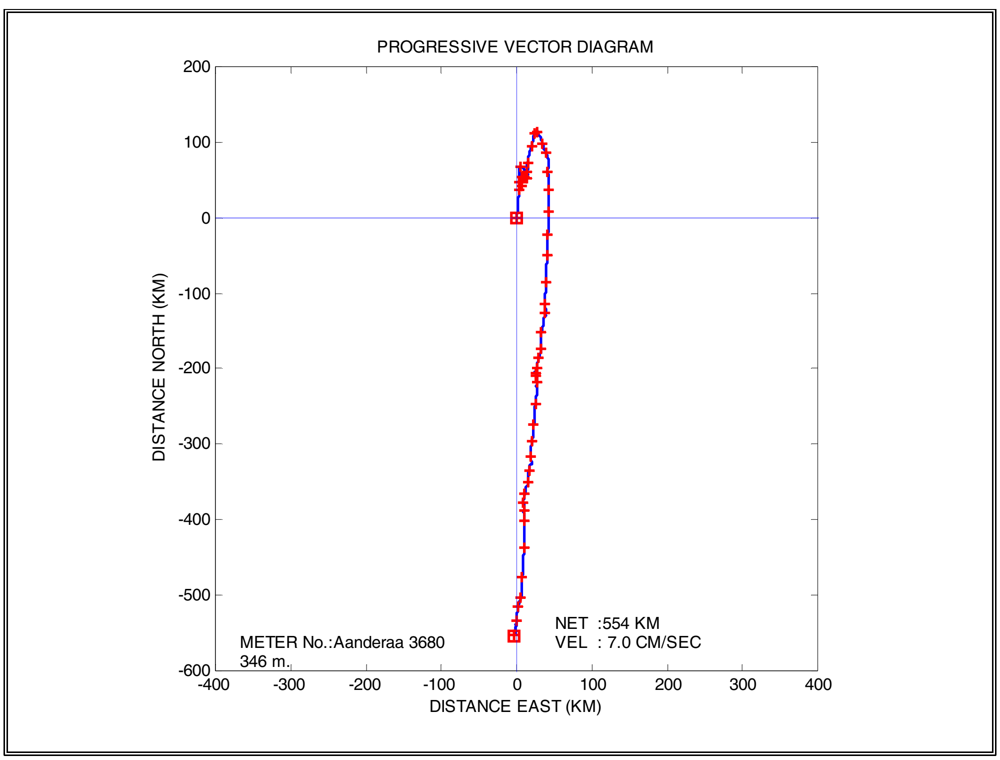


Figure 4.11 Progressive vector diagrams for the currents in Flemish Pass at 346 m

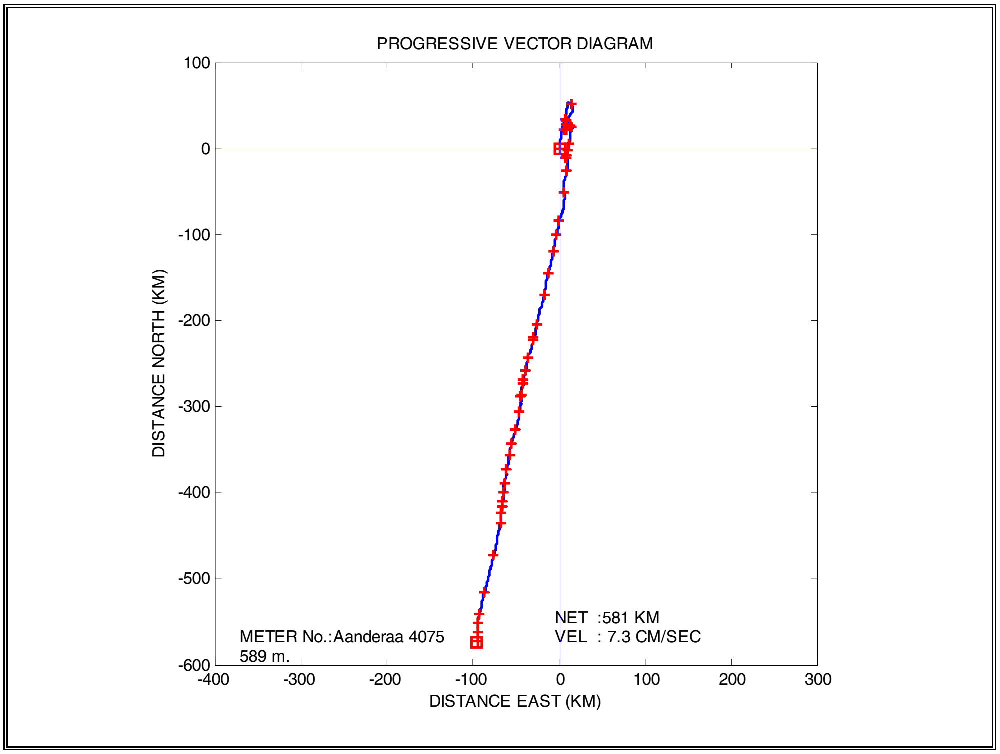


Figure 4.12 Progressive vector diagrams for the currents in Flemish Pass at 589 m

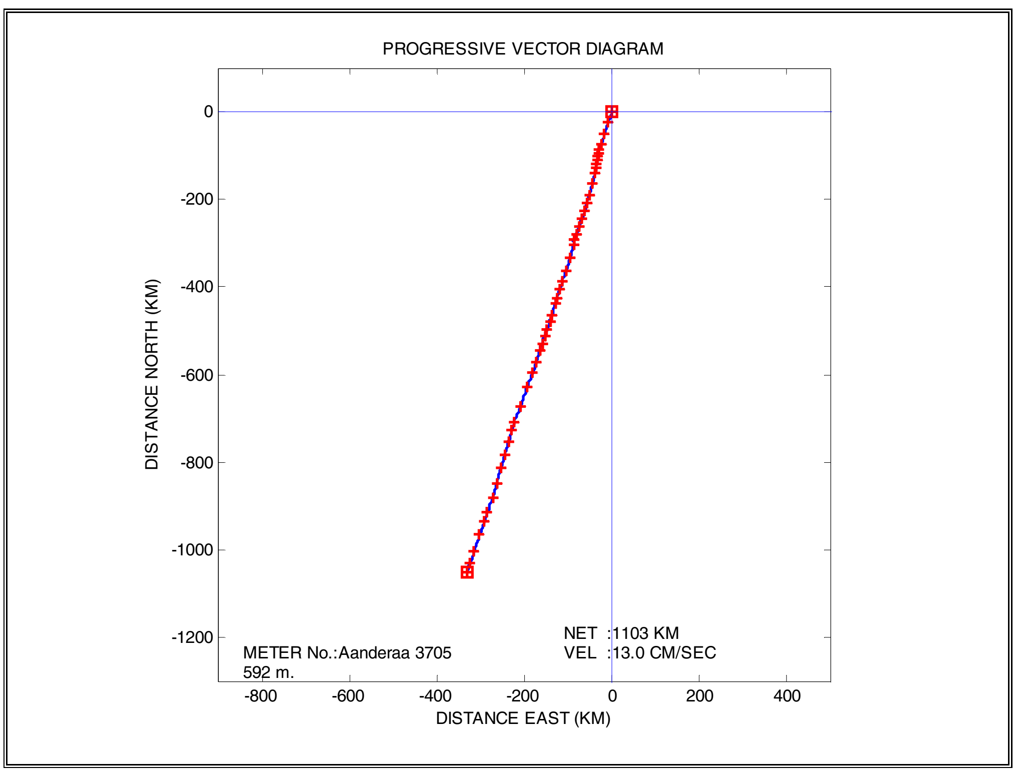


Figure 4.13 Progressive vector diagrams for the currents in Flemish Pass at 592 m

4.2.3 Northeast Grand Banks

Tables 4.11 to 4.13 present current values at Terra Nova measured near the surface in a water depth of 20 m, mid-depth in 45 m to 50 m, and at 10 m above the seabed. Tables 4.11 to 4.13 show typical maximum speeds and directions, mean velocities, and mean speeds for each month. The identifier in the table is to identify the data set from which the values for the maximum speeds and directions were extracted. The mean speeds and velocities have been averaged from different data sets covering a few years for each month and depth. It is important to note that because the degree of variability at Terra Nova is high, different data sets will have the maximum currents in different directions and the mean velocities may also be different in both magnitude and direction.

The current at Terra Nova can be divided into its main components consisting of a residual or mean velocity, tidal currents, and low frequency components. The residual flow or mean velocity tends to be small as seen from the values in Tables 4.11 to 4.13 and range between 0.2 cm/sec to 5.6 cm/sec. The maximum speeds were 77 cm/s, 42 cm/s and 42 cm/s for near surface, mid-depth, and near bottom, respectively.

The tidal currents are a significant portion of the flow on the Grand Banks. In the near surface waters, M_2, S_2, O_1, and K_1 can have values which range from 6 to 9 cm/se, 2 to 4 cm/sec, 2 to 6 cm/sec and 2 to 6 cm/sec, respectively. At mid-depth, the tidal constituents of M_2, S_2, O_1, and K_1, have values of 6 to 7 cm/sec, 1 to 3 cm/sec, 2 to 3 cm/sec, 2 to 4 cm/sec. At 10 m above bottom the constituents of M_2, S_2, O_1, and K_1 have values of 0 to 7 cm/sec, 0 to 3 cm/sec, 0 to 4 cm/sec and 0 to 4 cm/sec. The individual constituents have low values, but the combination of all the tidal constituents contribute significantly to the overall flow.

The semi-diurnal tidal currents rotate through 360° twice per day in a clockwise direction. The diurnal tidal ellipses at Terra Nova are almost circular showing no preferred direction, and the semidiurnal tidal ellipses are slightly elongated in a northwest/southeast direction. Overall, the tidal currents at Terra Nova are responsible for about 30% of the variability near the surface and at mid-depth, and for 20% of the variability near the bottom.

The low frequency components are the most important contributor to the overall flow. The strongest currents have been observed to always occur during the passage of low pressure systems. Some of the flow can be attributed to direct effects of wind stress upon the sea surface as indicated by an inertial period signal in a spectral analysis of the data. The barotropic component appears to be the largest component of the strong flows. Spectral analysis shows that the low frequency components are in the period range of 4 to 7 days.

The low frequency components are also associated with transport of warmer water onto the Grand Banks. For instance, on February 9, 2002 during the passage of a low pressure system, temperature measurements at both 1 m and 10 m above bottom showed a 0.5°C sudden increase in temperature. This event was measured at two locations at 1 m above bottom, separated by a distance of 4 nautical miles. The current flow which was in a northwest direction registered the temperature increase on the eastern side of the Terra Nova field a few hours before it was recorded on the western side. The event appears to have been an advection of warmer water onto the Banks from the southwest. This event signifies that the low frequency barotropic components are probably a major contributor to the advection and mixing of warm water from the Slope to the more shallow regions on the Grand Banks.

Wind stress is also an important driving force for the surface currents on the Continental Shelf, with a distinct annual cycle of comparatively strong winds in winter and weaker more variable winds in summer. An analysis of an array of current meter data collected from January to May 1992 by De Tracey et al. (1996) on the north-eastern section of the Grand Banks showed that the near-surface currents and local wind are highly coherent in the shallow region of the Grand Banks, suggesting that the currents on the Grand Banks have a strong wind driven component.

Table 4.11 Near-surface currents at Terra Nova

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)
January	TN9904	48	E	13	5.6	183
February	TN0301	59	ENE	13	3.6	178
March	TH0201	45	SE,E	12	4.7	171
April	TN0101	41	N	12	1.6	170
May	TN0302	57	N	13	2.0	211
June	TN0102	52	W	12	1.7	127
July	TN0102	39	E	12	0.9	198
August	TN0003	60	NW	13	0.8	265
September	TN0003	77	SSW	18	2.0	213
October	TN0203	57	N	18	2.7	196
November	TN9904	48	E,S	14	4.3	357
December	TN9904	59	S	13	1.4	28

Table 4.12 Mid-depth currents at Terra Nova

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)
January	TNC09	19	S	11	3.5	287
February	TNC09	30	W,SE,E	11	1.1	286
March	TN0201	42	SSW	10	3.0	183
April	TN0201	36	SSW	10	1.3	194
May	TN0002	31	NE	9	0.8	174
June	TN0002	34	NE,NW	10	1.7	208
July	TN0002	30	E	9	1.8	308
August	TN0102	25	E,NW	10	2.4	324
September	TN0202	25	SE,SW,W	11	1.2	177
October	TN0103	29	SW	12	1.1	305
November	TN0004	41	W	11	0.6	334
December	TN0004	37	SW	11	0.7	232

Table 4.13 Near-bottom currents at Terra Nova

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)
January	TN0104	36	N	12	4.2	193
February	TN0301	42	E,SE	12	2.6	167
March	TN0201	32	SE,S,SW	11	2.5	177
April	TNC009	27	N	9	3.0	205
May	TN0002	28	E	8	1.3	159
June	TN0002	26	NE	8	0.7	169
July	TN0002	20	NE	8	0.5	296
August	TN0002	24	NW	10	2.0	310
September	TN0002	30	NE	10	0.2	135
October	TN0003	41	E	10	0.4	296
November	TN0303	29	NE,SE,SW,N	11	0.6	89
December	TN0303	32	NW,N	11	0.4	283

Table 4.14 to 4.16 show typical maximum current speeds and directions, mean velocities, and mean speeds for each month from data archived in the Bedford Institute of Oceanography. The maximum current speeds have been selected from particular data sets while the mean speeds and velocities have been averaged over the available data.

There are some fundamental differences in the circulation regime at White Rose as compared with Terra Nova. At Terra Nova, the currents are characterized by a very weak residual flow because the main flow is overshadowed by the magnitude of the variabilities. At White Rose there are less variabilities overall, but near surface (20 m) the currents are more likely to be flowing in unexpected directions for a long period of time. For instance, near surface, the currents may flow towards the northeast for months at a time before reversing to flow south again.

The percentage of the variability of the flow attributable to the tidal currents is similar at White Rose and Terra Nova. At both locations the tidal currents are responsible for about 30% of the flow at mid-depth and for about 20% near bottom. Near the surface the tidal currents account for about 30% of the variability at Terra Nova and for 20% of the variability at White Rose.

Near surface the magnitude of the tidal constituents for M_2, S_2, K_1, and O_1 vary from 0.9 to 7.0 cm/sec, 0.4 to 1.9 cm/sec, 1.5 to 5 .1 cm/sec and 0.8 to 3.1 cm/sec, respectively (Oceans Ltd, 2001). At mid-depth, the values of M_2, S_2, K_1, and O_1 vary from 0.2 to 5.8 cm/sec, 0.2 to 2.8 cm/sec, 1.0 to 5.3 cm/sec, and 0.4 to 3.8 cm/sec, respectively. At 10 m above the sea bed the values of M_2, S_2, K_1, and O_1 vary from 0.2 to 6.1 cm/sec, 0.1 to 2.3 cm/sec, 1.0 to 5.1 cm/sec and 0.3 to 3.6 cm/sec, respectively.

The currents at White Rose will be influenced by the same driving forces as at Terra Nova. The low frequency oscillations on a synoptic scale due to the passage of low pressure systems should be as prevalent at White Rose as at Terra Nova. Since White Rose is located closer to the Continental Shelf break, there is bound to be some influence from the interactions between the

Labrador Current and the branch of the North Atlantic Current which enters Flemish Pass (Figure 4.2).

Table 4.14 Near-surface currents at White Rose

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°126T)
January	WRB07	51	SE	15	2.7	126
February	TRE87	38	SSE	15	9.2	127
March	TRE87	40	E	19	6.2	130
April	WRL08	40	S	11	4.0	333
May	WRH20	50	E	12	3.3	153
June	WRH20	67	SW	15	2.2	78
July	WRB07	46	WSW	13	0.8	177
August	WRB07	61	NE	16	1.6	197
September	WRN30	90	N	21	8.3	202
October	WRB07	81	SE	20	7.9	211
November	WRN02	70	S	17	3.4	172
December	TRE87	47	W,S	14	3.7	47

Table 4.15 Mid-depth currents at White Rose

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)
January	WRB07	39	S,W	13	3.5	196
February	WRE09	35	ESE	12	6.4	162
March	TRE87	26	SSE	12	1.6	93
April	WRL08	29	SSE	14	6.0	180
May	WRB07	37	S,N	11	3.9	158
June	WRB07	45	S	11	1.9	151
July	WRB07	36	S	9	2.5	171
August	WRB07	62	NE	11	1.5	117
September	WRB07	57	NW	12	0.7	111
October	WRB07	75	W	13	2.1	186
November	WRB07	54	N	13	1.5	100
December	TRE87	46	S	13	1.3	48

Table 4.16 Near bottom currents at White Rose

Month	Identifier	Max Speed (cm/sec)	Direction	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)

January	TRE87	35	E	14	2.5	183
February	WRE09	35	SE,S,SW	12	6.0	150
March	TRE87	29	SSE,S,SSW	9	2.9	108
April	WR110	32	W	10	2.7	161
May	WRB07	41	S,N	10	2.7	162
June	WRB07	51	SW	10	1.6	142
July	WRB07	47	NE,S,W	9	1.9	196
August	WRB07	65	E	8	1.4	203
September	WRB07	72	NNW	10	1.9	221
October	WRB07	65	N	11	2.7	189
November	WRB07	58	N	12	0.9	247
December	TRE87	39	SSE	12	1.6	124

Data was processed from six current meter moorings located outside the White Rose field in the Labrador Current flowing along the upper edge of the Continental Slope. The currents showed similar characteristics at all locations. Only 2 instruments collected data in the near-surface waters. The data is summarized in Tables 4.17 to 4.19.

In this area there is less variability in the currents than at either Terra Nova or White Rose. The flow tends to be directed towards the south or southeast with higher velocities than found at White Rose or Terra Nova.

In the near-surface waters the maximum speed was 77.8 cm/sec. This value may be too low because there was only a total of 9 months of data collected in the near-surface waters. Table 4.18 shows that the maximum speed at mid-depth occurred in December with a value of 86.5 cm/sec. The maximum near-bottom current speed was 61.7 cm/sec (Table 4.19), which occurred at the same time and location as the maximum speed at mid-depth.

Table 4.17 Near surface currents in sub-area 3

Month	No. of months	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)	Max Speed (cm/sec)	Direction (°T)	Identifier
Jan	1	28.1	19.0	SSE	47.8	SE	8301
Feb	1	21.3	14.4	SSW	62.3	SW	8301
July	1	18.6	13.7	SSE	57.7	SE	8301
August	1	28.5	3.3	NW	67.5	SE	8301
Oct	1	14.6	14.5	SW	26.3	SW	8604
Nov	2	26.4	22.8	S	77.8	SSE	8301
Dec	1	18.3	18.1	SW	44.6	SW	8604

Table 4.18 Mid-depth currents in sub-area 3

Month	No. of month	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)	Max Speed (cm/sec)	Direction (°T)	Identifier
Jan	6	31.1	23.6	S	79.3	S	8504
July	2	11.6	10.9	SSE	34.3	SSW	8301
August	2	13.0	12.0	S	47.2	SSE	8301
Sept	2	16.1	15.3	S	40.4	SSE	8301
Oct	3	29.2	24.2	S	59.8	SSE	8301
Nov	5	32.3	28.1	SSE	79.1	S	8504
Dec	6	31.5	26.6	S	86.5	S	C100

Table 4.19 Near bottom current in sub-area 3

Month	No. of month	Mean Speed (cm/sec)	Mean Velocity (cm/sec)	Direction (°T)	Max Speed (cm/sec)	Direction (°T)	Identifier
Jan	5	24.3	21.5	S	54.1	E,NE	F293
Feb	2	17.1	11.8	S	46.5	NE	F293
March	2	16.8	12.0	S	54.7	S	60F2934
April	2	13.1	9.7	S	37.4	NE	F293
May	2	11.6	7.9	S	34.8	E,SE	8602
June	1	7.2	5.7	S	19.5	S	8602
July	1	8.5	6.7	S	22.8	S	8602
August	1	8.4	6.7	S	21.3	S	8602
Sept	1	9.8	8.7	S	22.9	S	8602
Oct	5	19.3	18.8	S	38.7	S	C300
Nov	4	25.4	24.2	S	56.1	S	C300
Dec	4	24.8	23.4	S	61.7	S	C300

4.3 Water Mass Structure

There are three major water masses in the study area; the Labrador Current Water between the surface and approximately 400 m, the Labrador Sea Water with a depth range between 200 m and 1500 m, and the North Atlantic Deep water with a depth range between 1500 m and 4000 m. The Labrador Sea Water and the North Atlantic Deep water are nearly homogeneous with little or no seasonal variability in water properties. The Labrador Sea Water is an intermediate layer water mass with temperatures between 2°C and 4°C and salinities between 34.86% and 35%. The North Atlantic Deep Water is characterized by its high salinity (34.9 to 34.97 psu) and low temperatures (2°C to 3.5°C).

In the study area, the North Atlantic Deep Water will be found only in the southern section of Orphan Basin whereas the Labrador Sea Water will be found in Flemish Pass and on the northeast Newfoundland Slope as well as in Orphan Basin.

On the northeastern edge of the Grand Banks the water structure is characterized by three identifiable features. The first feature is the surface layer which is exposed to interaction with the atmosphere. The surface layer experiences temperature variations from sub zero values in January to above 15°C in the summer and early fall. The salinity of the surface layer is strongly affected by wave action and local precipitation. During the summer the stratified surface layer extends to a depth of 40 m or more. During the winter the surface stratification disappears and the water column becomes well mixed due to atmospheric cooling and mixing processes from wave action.

The second feature of the water structure is the Cold Intermediate Layer (Petrie et al., 1988). In areas where the water is deep enough, this layer of cold water is trapped during summer between the seasonally heated upper layer and warmer slope water near the seabed (Colbourne, 2002). Its temperatures range from less than -1.5°C to 0°C (Petrie et al., 1988; Colbourne et al., 1996) and salinities vary within 32 and 33 psu. It can reach a maximum vertical extent of over 200 m (Colbourne, 2004). The Cold Intermediate Layer is the residual cold layer that occurs from late spring to fall and is composed of cold waters formed during the previous winter season. It becomes isolated from the sea surface by the formation of the warm surface layer during summer, and disappears again during late fall and winter due to the intense mixing processes that take place in the surface layer from strong winds due to the intense mixing processes that take place in the surface layer from strong winds, high waves, and atmospheric cooling.

Figure 4.17 shows average bottom temperature during the decade from 1991 to 2000. The figure shows that positive bottom temperatures are found south of 46°N. The blue area to the north of 46°N in Figure 4.17 corresponds to the average spread of the Cold Intermediate Layer. The variabilities in temperature and salinity in the area have been the subject of systematic research (Colbourne, 2004; Colbourne et al., 1997; Colbourne and Foote, 2000). These studies suggest that the water properties on the Grand Banks experience notable temporal variability. Colbourne (2004) explains that bottom temperatures ranged from near record lows during 1991 to very high values in the late 90's. The areal coverage of the Cold Intermediate Layer was highest on the Newfoundland Shelf during years 1972, 1984 and 1991 (Colbourne, 2004).

Bottom temperature and salinity maps were produced by Colbourne et al. (2007) by trawl-mounted CTD data from approximately 700 fishing tows during the fall of 2005. These maps are presented in Figure 4.18. Both Figures 4.17 and 4.18 shows that the Cold Intermediate Layer is still present near the bottom over much of the Grand Banks.

During the last 50 years there have been three warming periods in the Labrador Sea; 1960 to 1971, 1977 to 1983, and 1994 to present. In 1994, the Labrador Sea water filled the entire central part of the Labrador Sea basin within the depth range of 500 to 2400 m (Yashayaev and Clarke, 2006). The warming trend since 1994 has caused the water to become warmer, saltier, and more stratified; thus making it more difficult for winter renewal of Labrador Sea Water to take place. Unusual warming took place in 2004 believed to have originated from waters transported north and west by the North Atlantic Current and the Irminger Current (Yashayaev and Clarke, 2006).

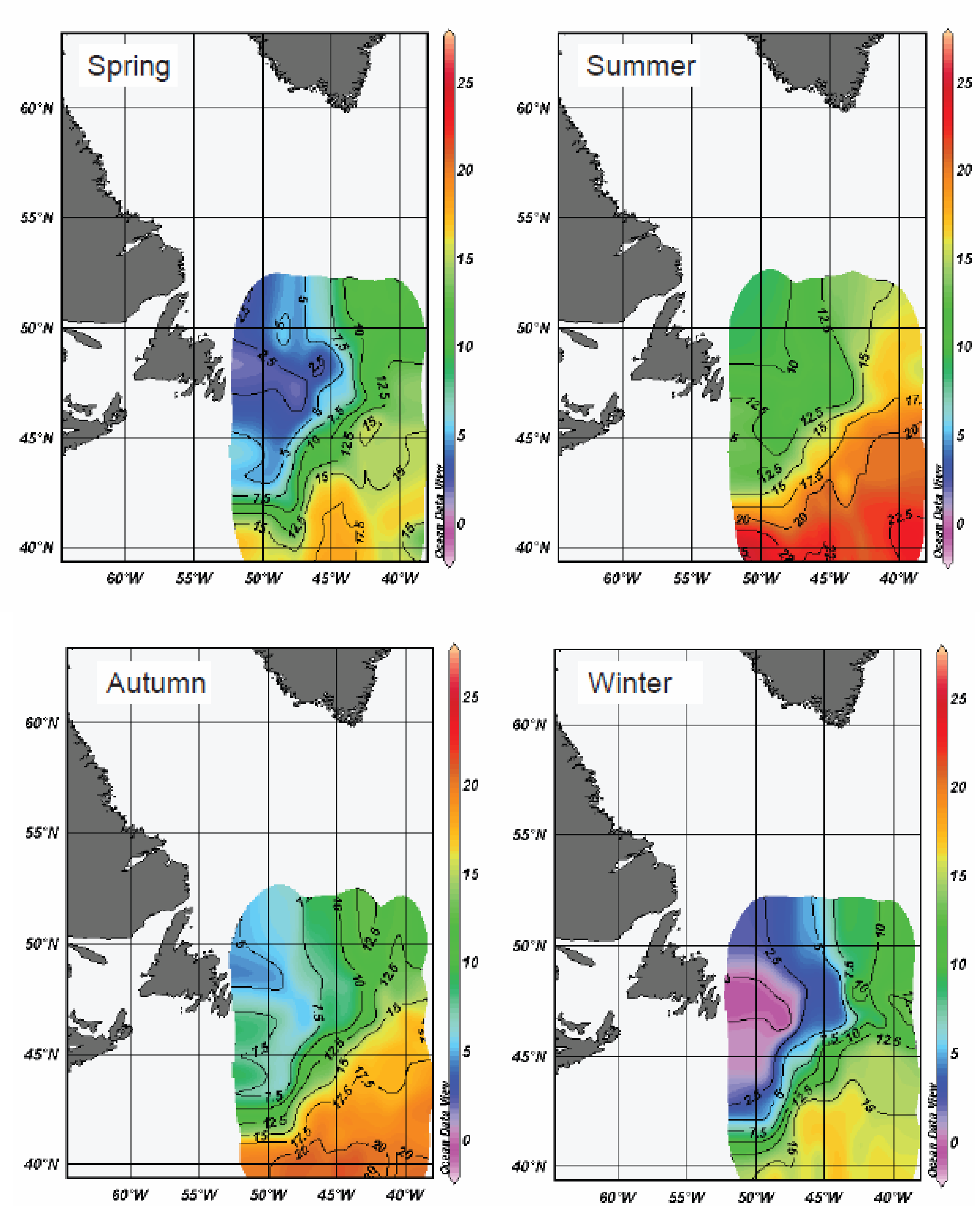


Figure 4.14 Sea surface temperature (°C) over the Grand Banks of Newfoundland. Spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

Source: From Stein (2007) data from World Ocean Database 2001.

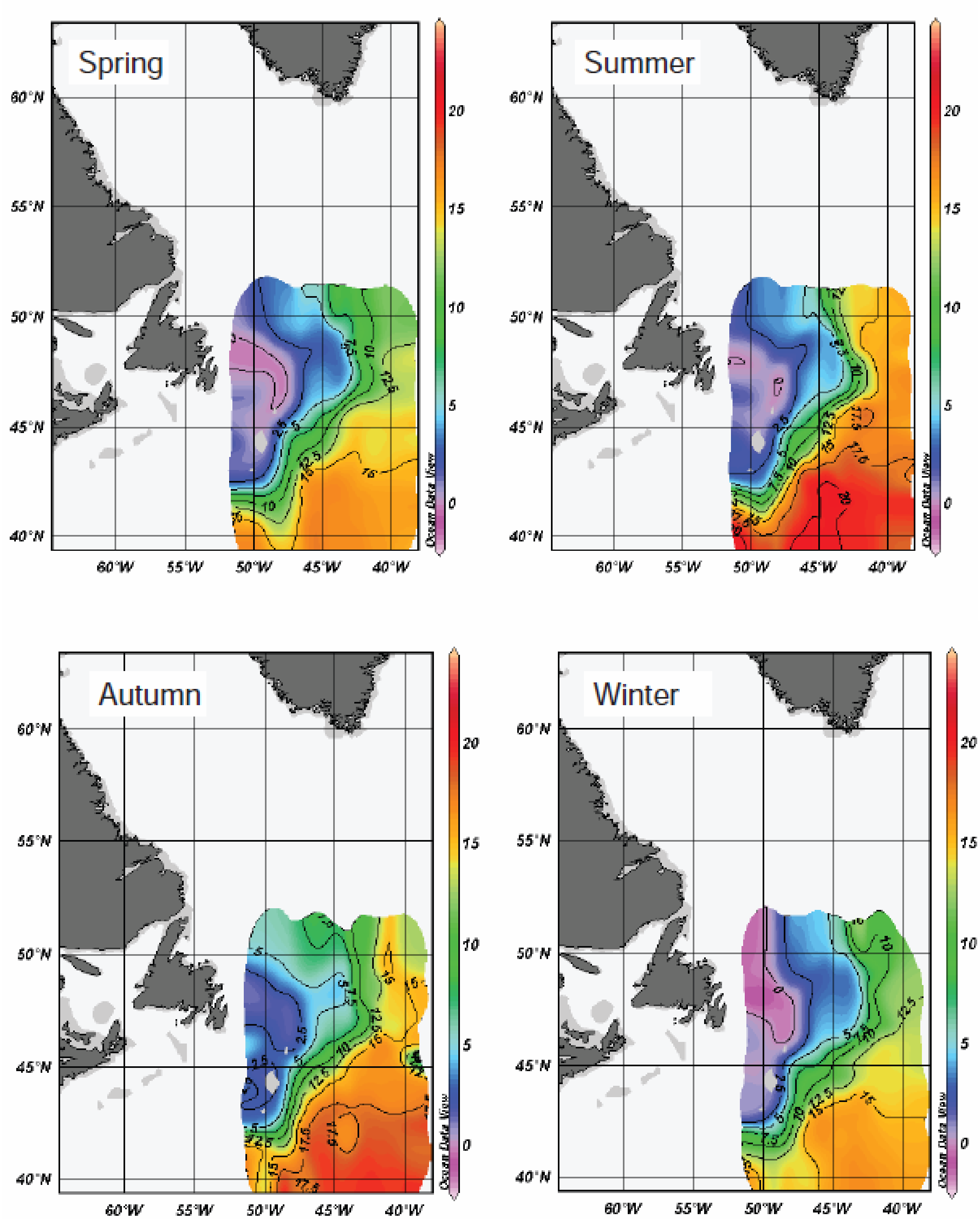


Figure 4.15 Temperature (°C) at 50 m depth over the Grand Banks of Newfoundland. Spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

Source: From Stein (2007) data from World Ocean Database 2001

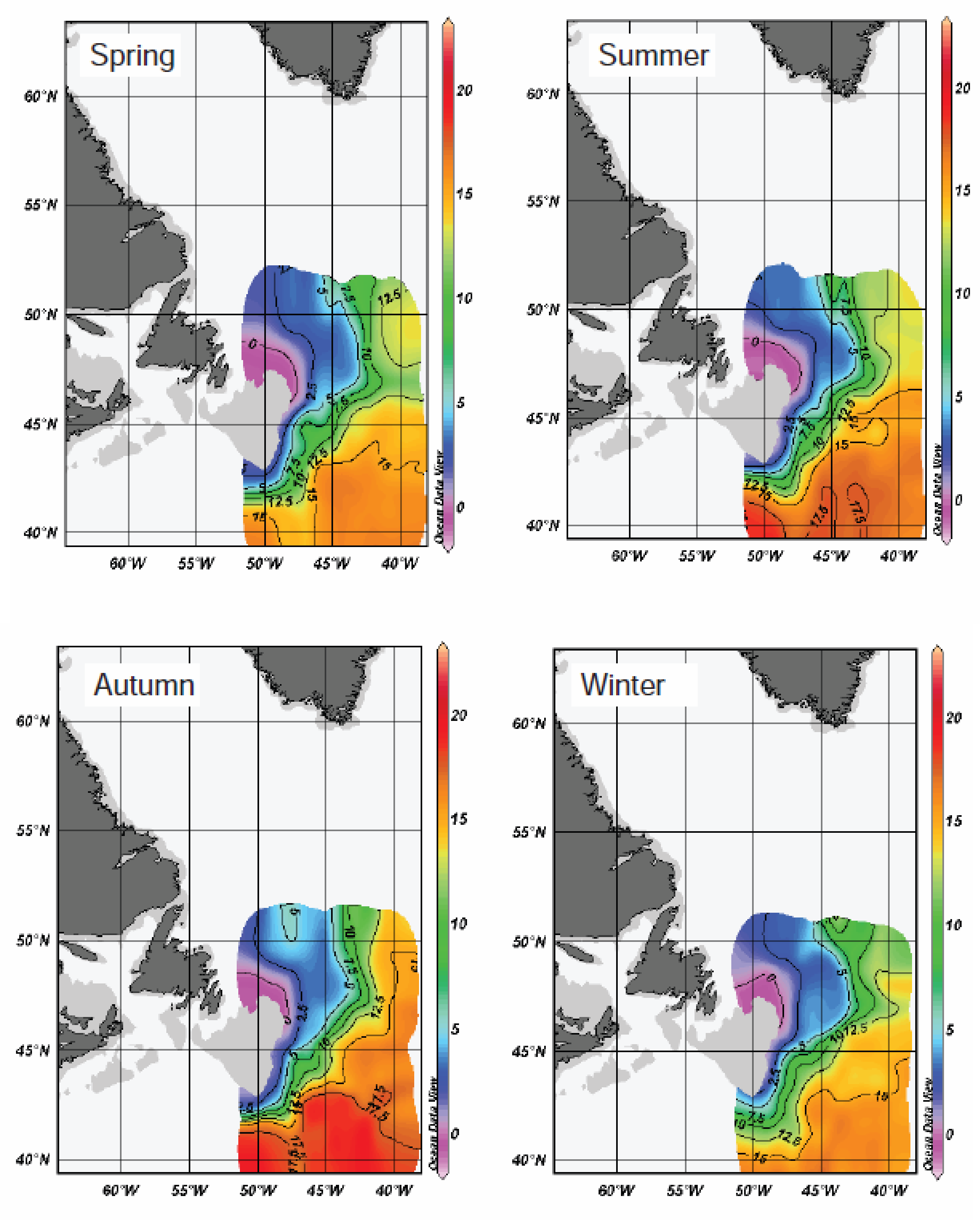


Figure 4.16 Temperature (°C) at 100 m depth over the Grand Banks of Newfoundland. Spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

Source: From Stein (2007) data from World Ocean Database 2001

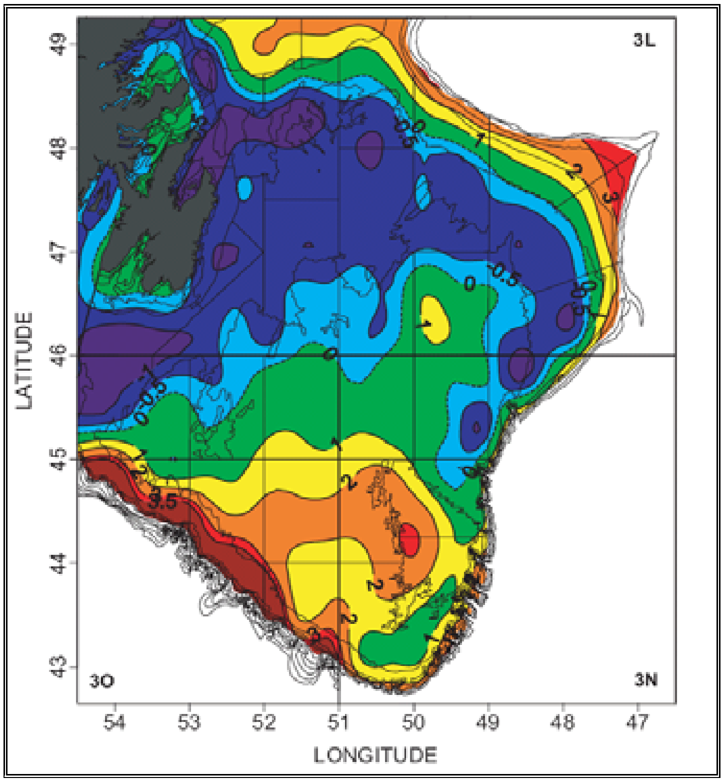


Figure 4.17 Average near bottom temperature during spring from all available data for the decade 1991-2000

Source: adapted from Colbourne, 2004

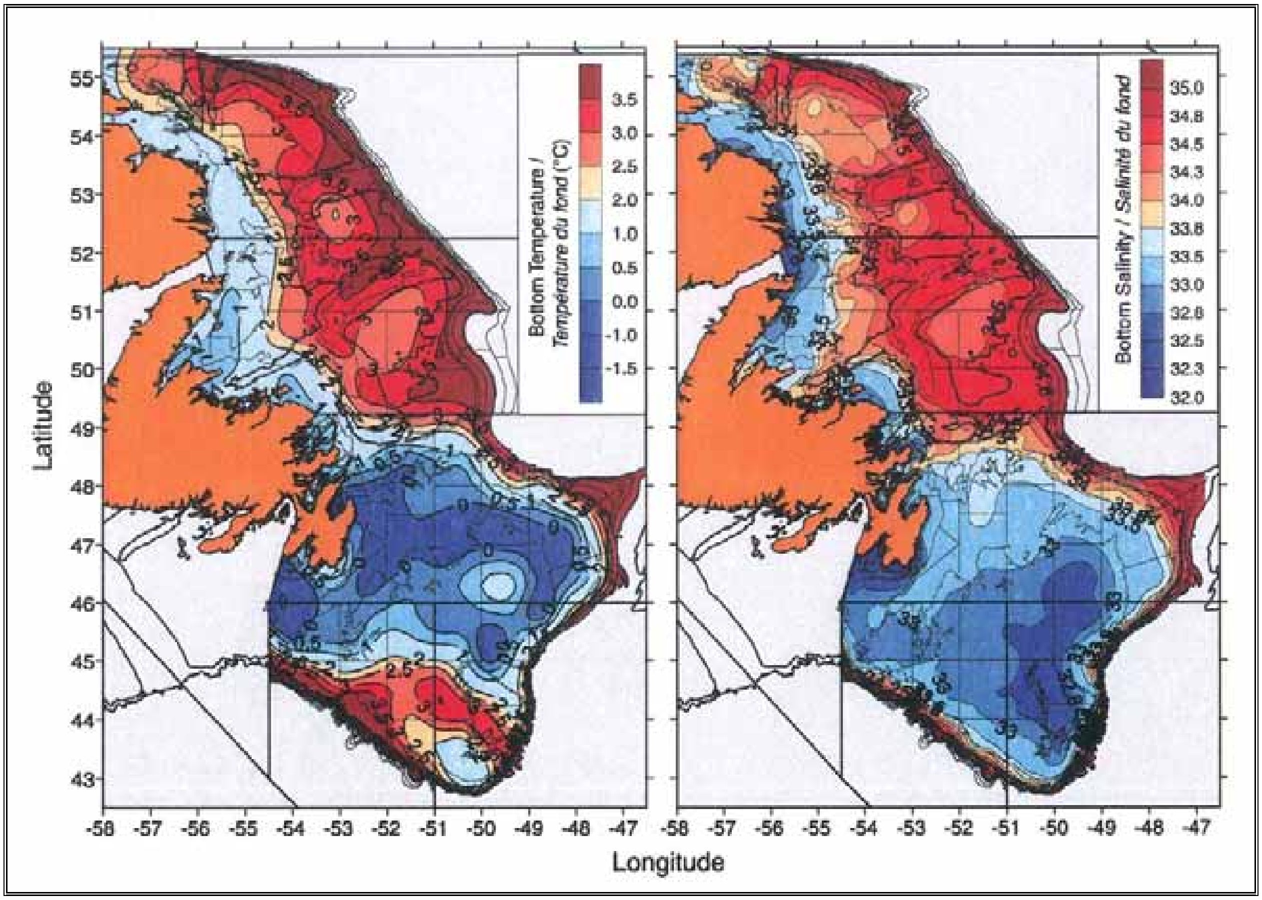


Figure 4.18 Bottom temperature and salinity maps derived for the trawl-mounted CTD data

Source: from Colbourne et al. 2007

CTD transects for the Flemish Cap and Bonavista transects are collected by Fisheries and Oceans Canada on a yearly basis. The temperature and salinity data for 2009 and 2010 are shown in Figures 4.19 through 4.26.

The temperature and salinity boundary between the water on the Shelf and the water in Flemish Pass is shown in Figures 4.19 through 4.23 from CTD data collected during 2009 and 2010 along the Flemish Cap transect. The offshore branch of the Labrador Current flows along the Shelf break in the region of this strong density gradient. A stratified surface layer is shown in the temperature plots from July 2009 and 2010, while the other monthly plots from April 2009, November 2009, and December 2010 show a well mixed surface layer. Figure 4.24 to 4.26 show temperature and salinity plots from the Bonavista transect. During all seasons the water is slightly colder across the Bonavista transect. In summer the salinities are similar across both transects while during the winter season the salinity is higher across the Bonavista transect.

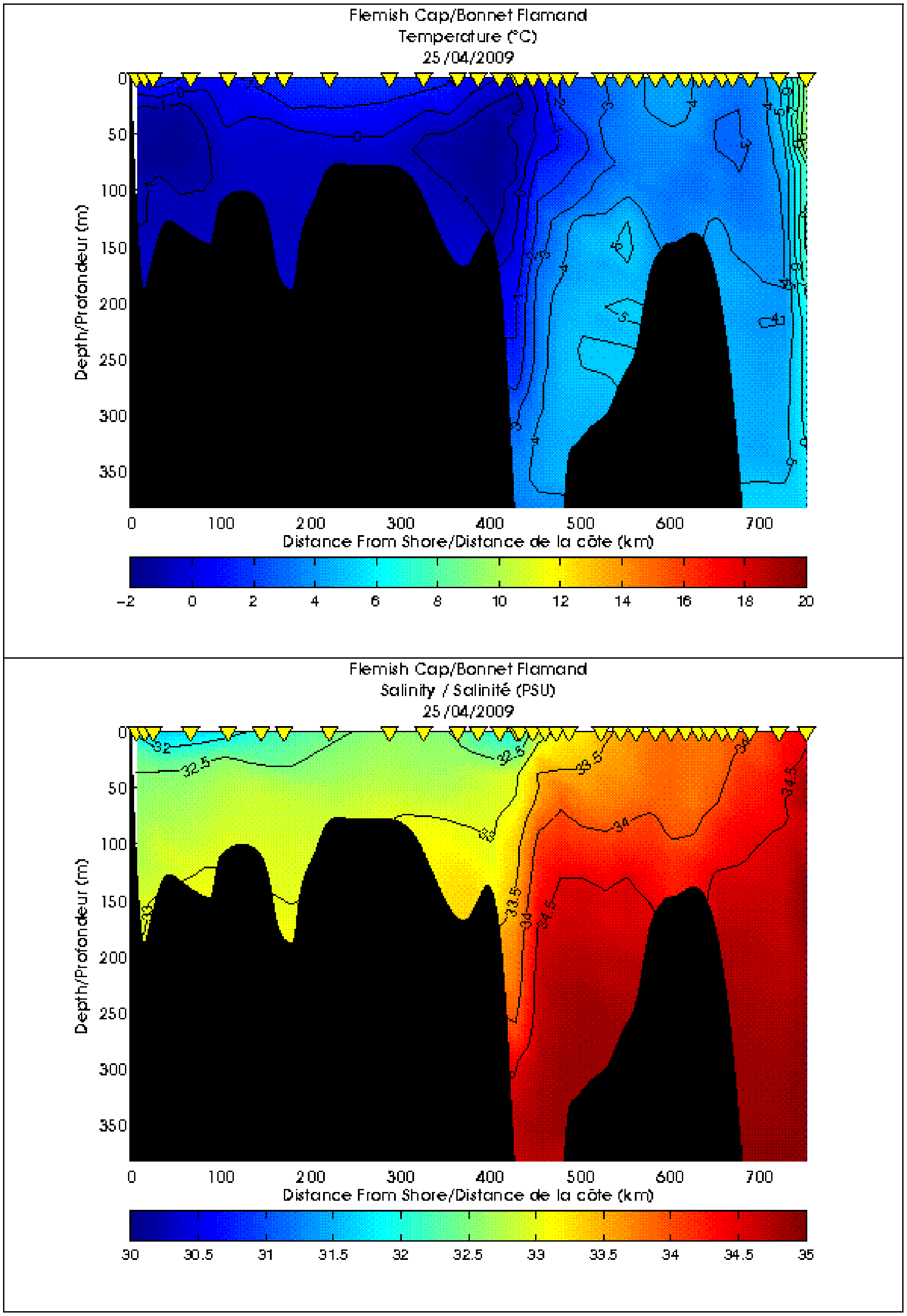


Figure 4.19 Hydrographic contours in the Flemish Cap section during April, 2009 (from DFO Marine Environmental Data Service website)

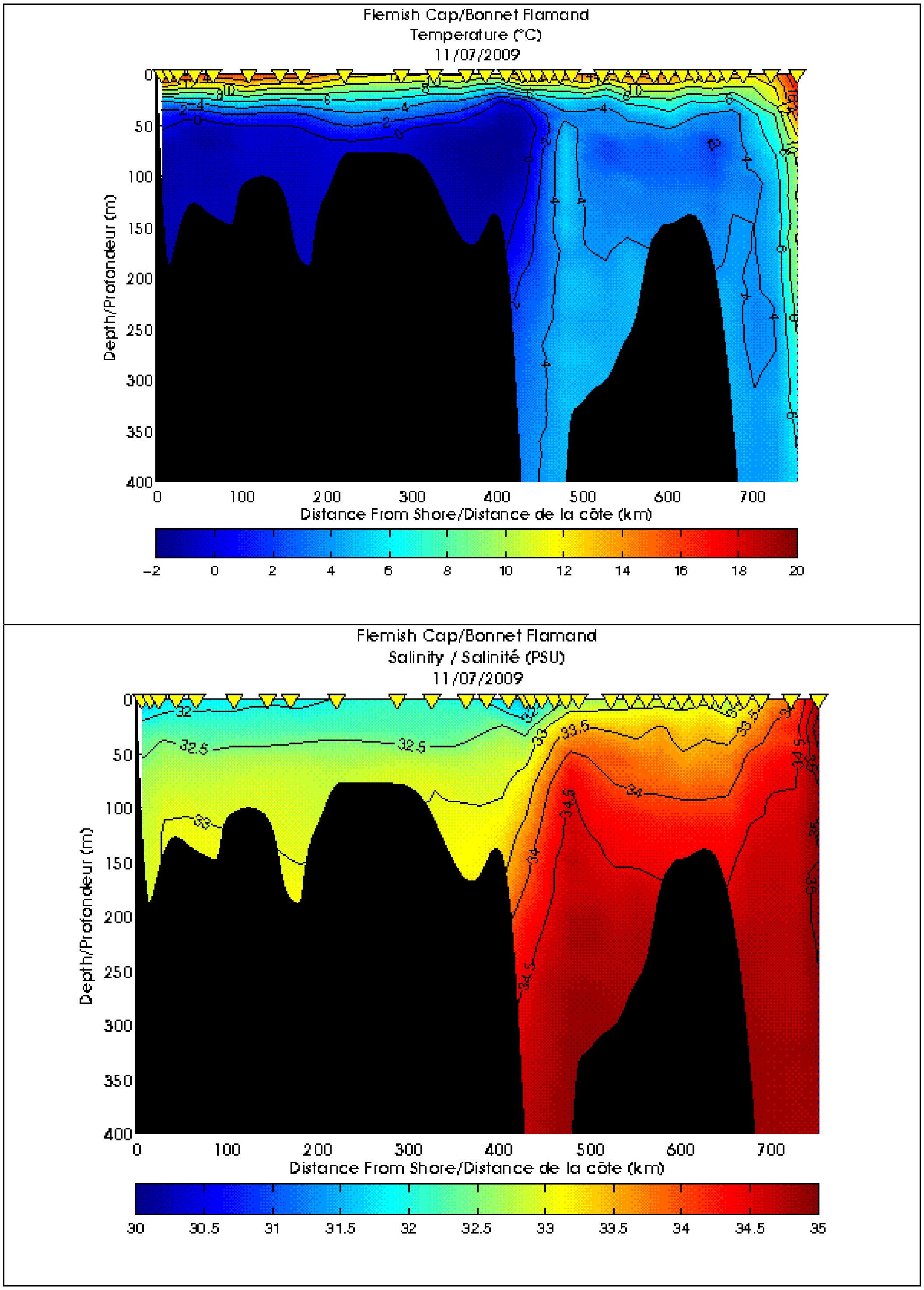


Figure 4.20 Hydrographic contours in the Flemish Cap section during July, 2009 (from DFO Marine Environmental Data Service website)

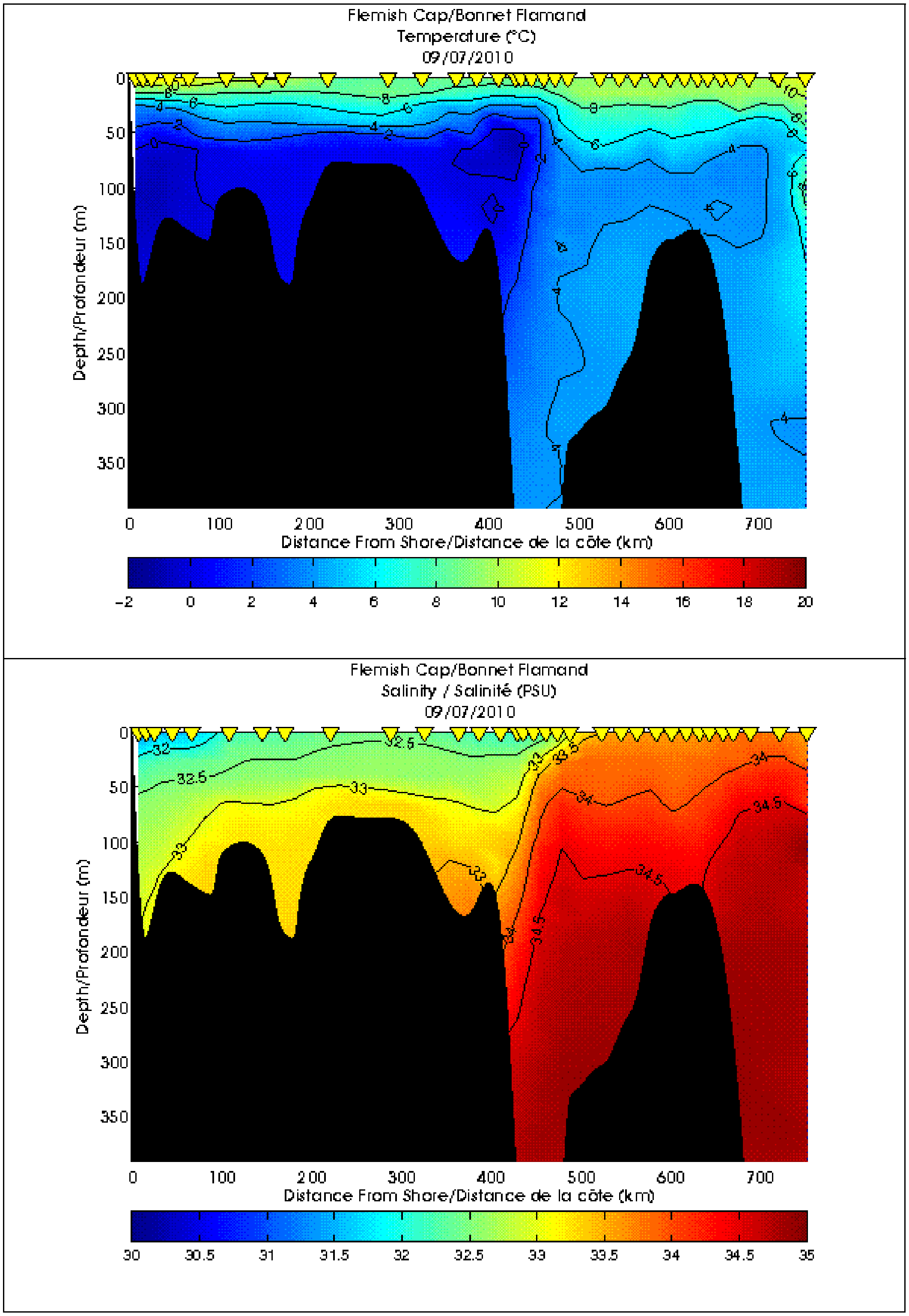
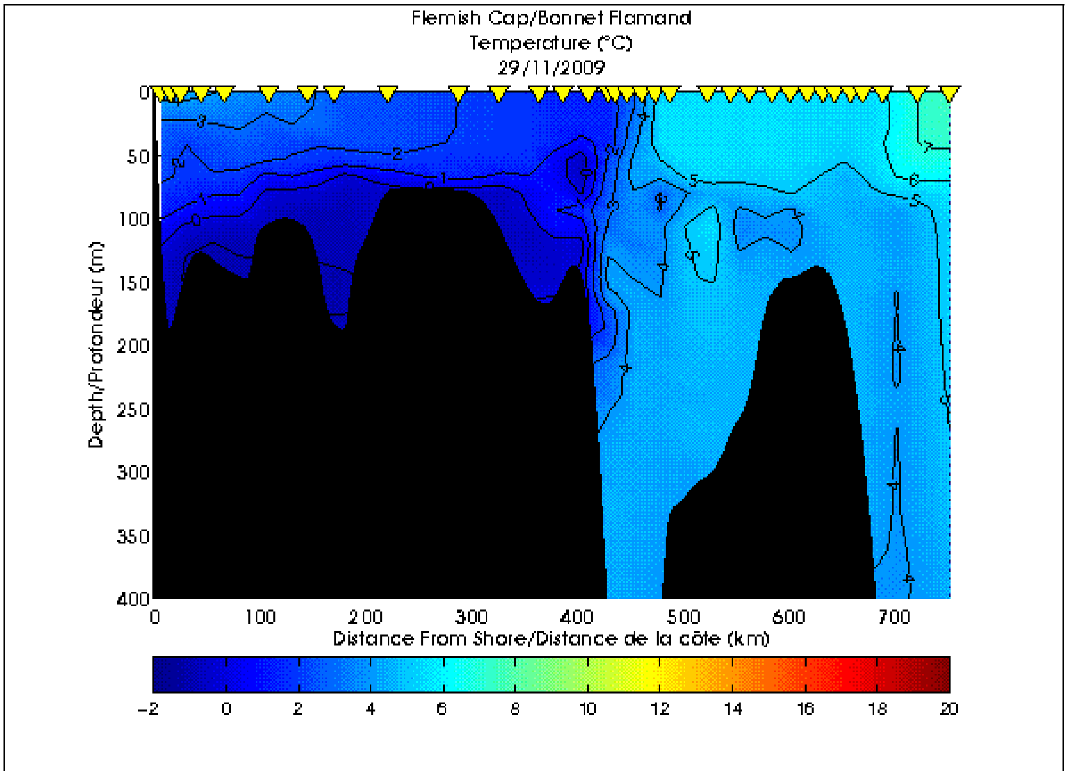


Figure 4.21 Hydrographic contours in the Flemish Cap section during July, 2010 (from DFO Marine Environmental Data Service website)



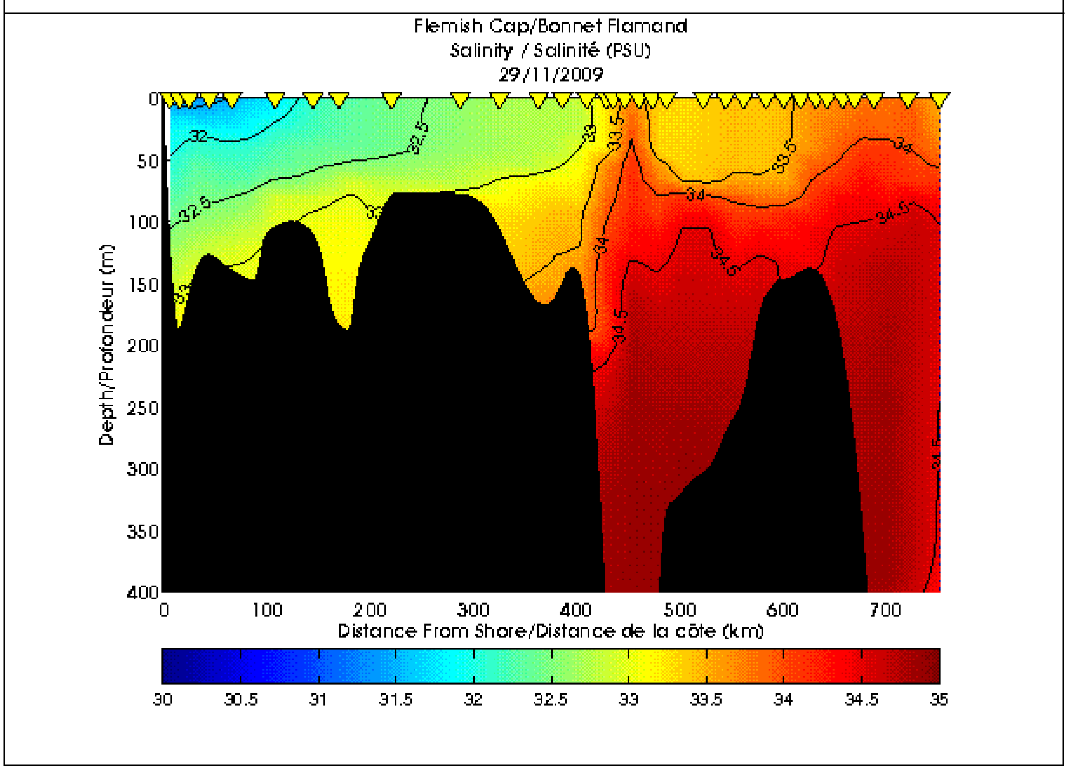


Figure 4.22 Hydrographic contours in the Flemish Cap section during November, 2009 (from DFO Marine Environmental Data Service website)

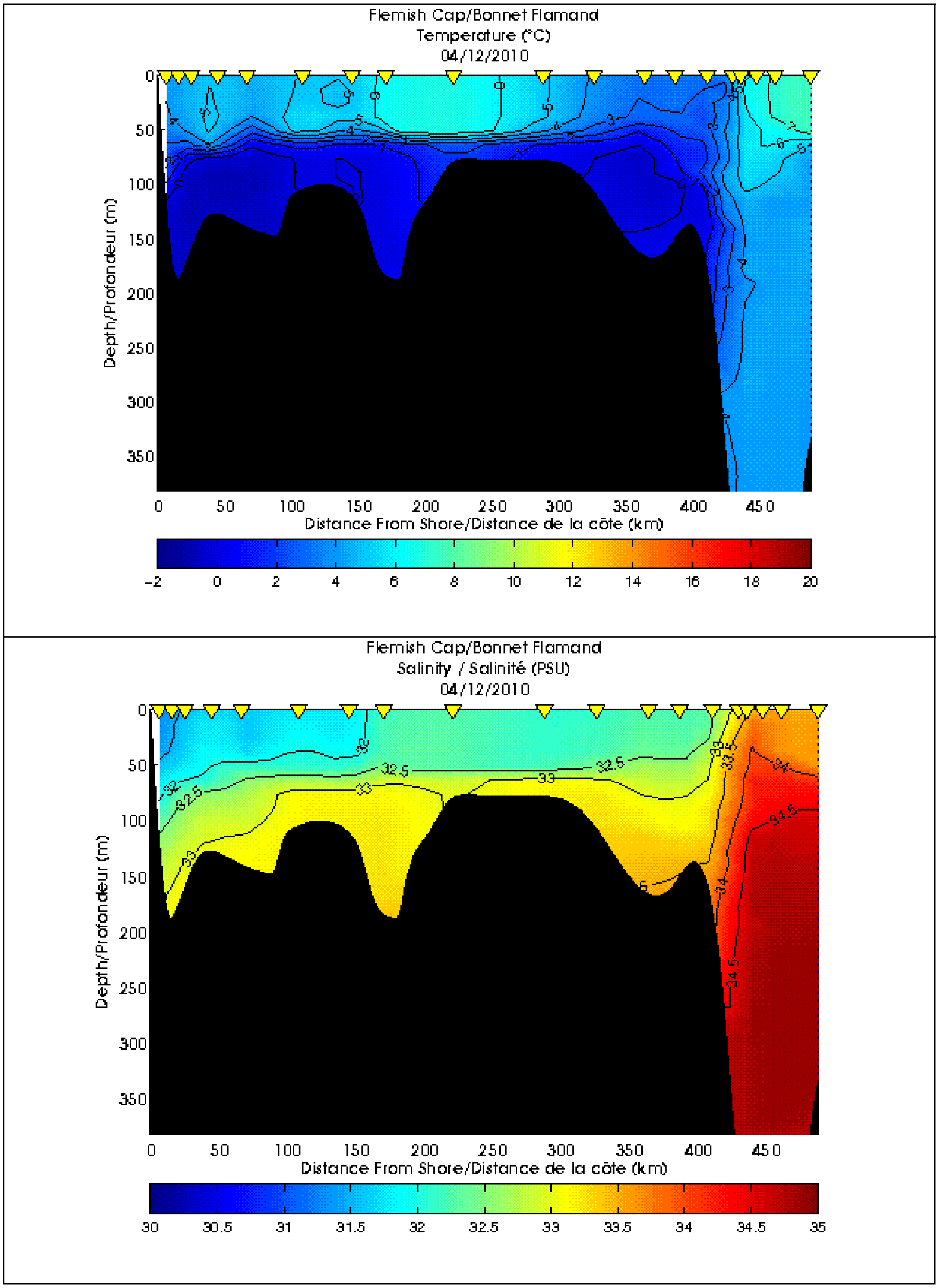


Figure 4.23 Hydrographic contours in the Flemish Cap section during December, 2010 (from DFO Marine Environmental Data Service website)

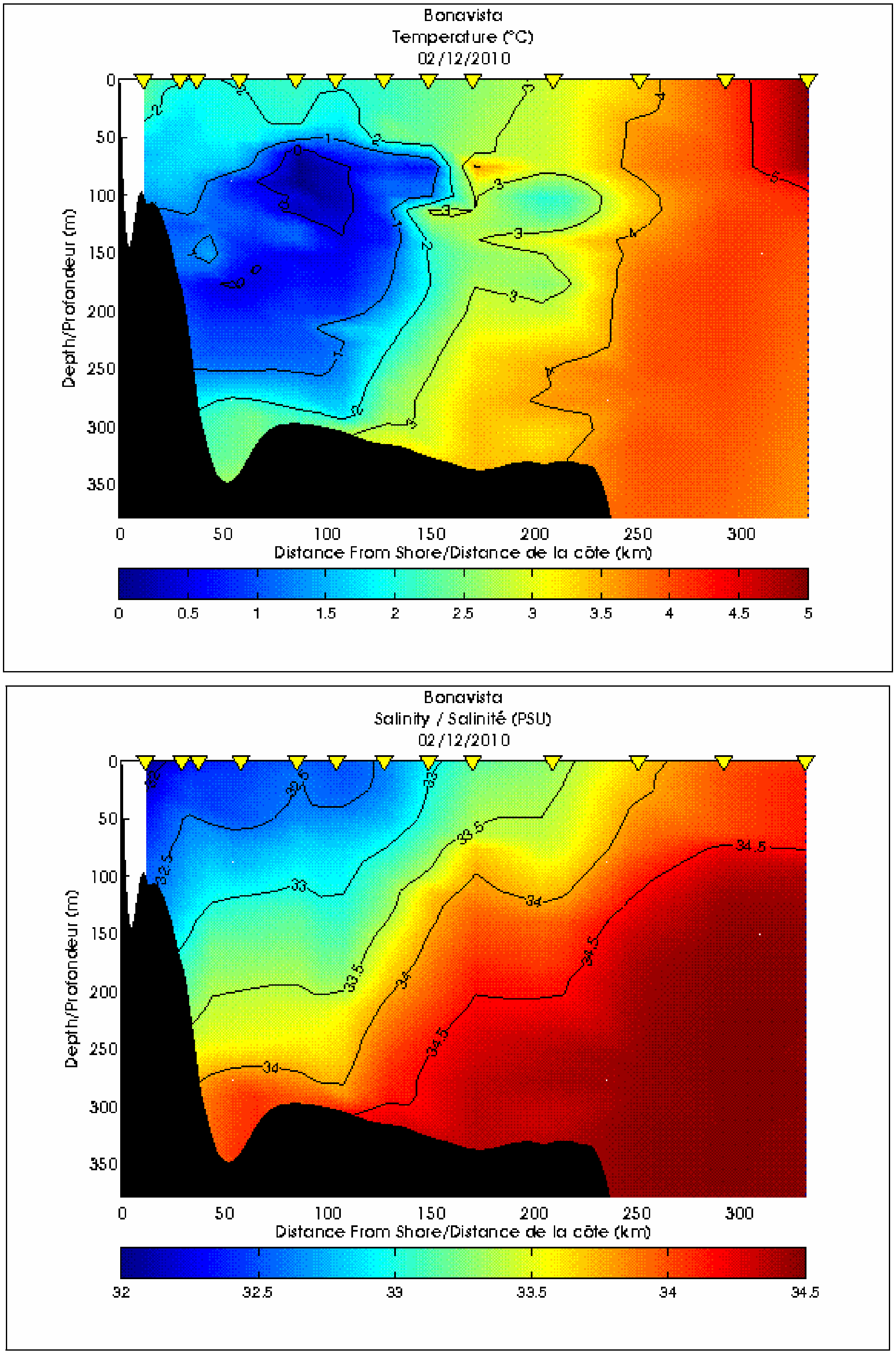
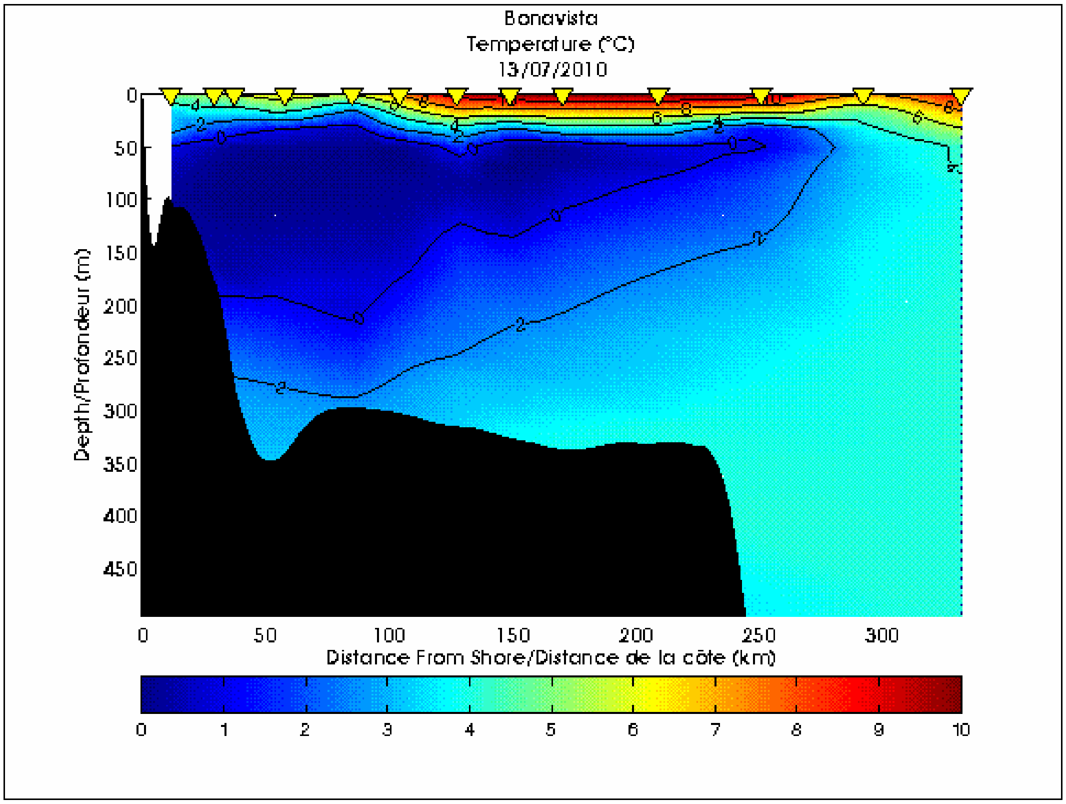


Figure 4.24 Hydrographic contours in the Bonavista transect during December 2010



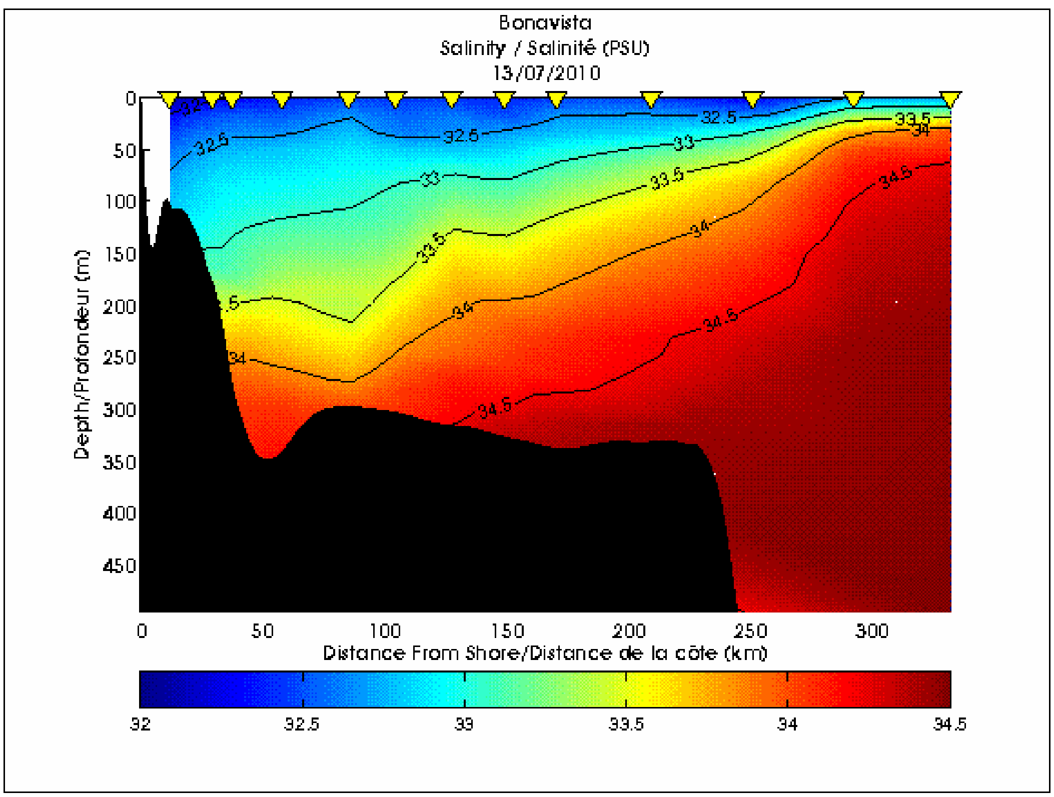


Figure 4.25 Hydrographic contours in the Bonavista transect during July 2010

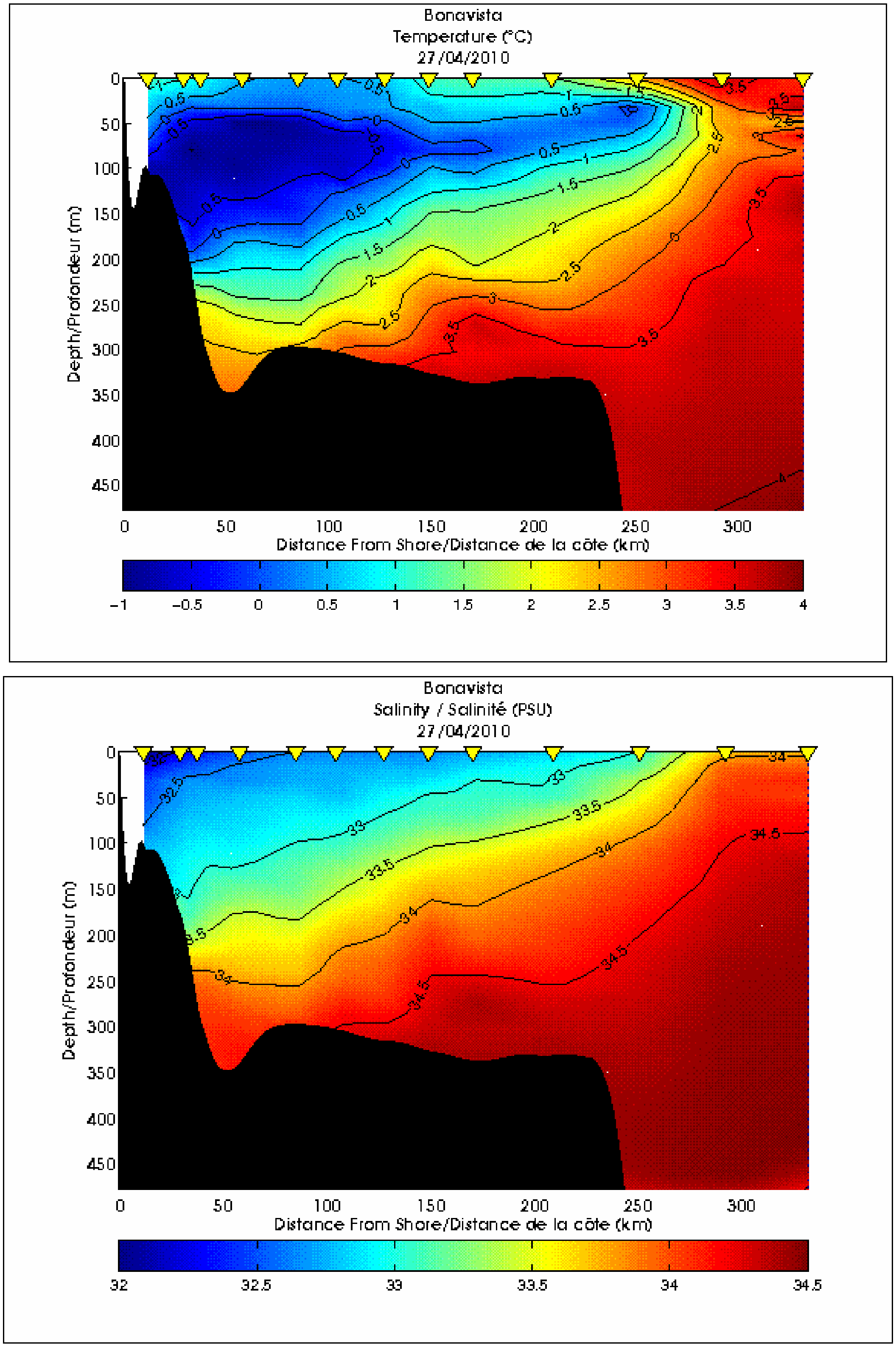


Figure 4.26 Hydrographic contours in the Bonavista transect during April 2010

4.4 Water Properties in the Project Area

Temperature and salinity data from historical measurements was extracted from the Bedford Institute of Oceanography (BIO) archive. The area covered by the CTD measurements is shown in Figure 4.27. The CTD data is presented as monthly statistics in each sub-area at the surface, at depths of 50 m, 100 m, 200 m, and at depth ranges of 300 to 900 m and 1000 to 3000 m.

Figure 4.27. Area where bottle and CTD data was collected

Source: Data is from the Bedford Institute of Oceanography archive

4.4.1 Sub-area: 1 Orphan Basin

Sub-area 1 is in the southern section of Orphan Basin. The water depth varies between the 1500 m and 3000 m isobaths. Tables 4.20 to 4.25 present the temperature and salinity data by month at the surface, 50 m, 100 m, 200 m, 300 to 900 m, and 1000 to 3000 m.

The surface waters were warmest during the months of July to September with mean temperatures ranging from 9.68°C to 11.67°C. The coldest temperatures were in February and March with mean temperatures of 2.27°C and 2.26°C, respectively. The mean salinities ranged between 33.33 psu in September and 34.37 psu in January. At a depth of 50 m, the mean temperatures ranged between 2.68°C in February to 6.69°C in November. The mean salinities ranged between33.33 psu in October and 34.47 psu in June. At a depth of 100 m, the mean temperatures ranged between 2.86°C in February and 4.74°C in December. The salinity had a standard deviation of less than 0.2 and mean salinity values that ranged from 34.51 psu in December and January to 34.70 psu in September. At a depth of 200 m, the mean temperatures ranged between 3.42°C in March to 4.04°C in December. The salinity had a standard deviation of less than 0.11 and mean salinity values that ranged from 34.73 psu in March and 34.82 psu in September. At a depth of 300 to 900 m, the mean temperatures ranged between 3.50°C in August to 3.78°C in February. The salinity had a standard deviation of less than 0.1 and mean salinity values that ranged from 34.84 psu during the summer and 34.88 psu during February. At a depth of 1000 to 3000 m, the mean temperatures ranged between 3.26°C in December to 3.42°C in February. The salinity had a standard deviation of less than 0.05 and mean salinity values that ranged between 34.88 psu and 34.90 psu.

The data is also presented in seasonal T-S plots in Figure 4.28. 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 fall the water is stratified to a depth between 50 m and 100 m. The T-S diagrams show that the core of the Labrador Current water is around 100 m and the core of the Labrador Sea water is around 500 m. The Atlantic Deep Water is present at 2000 m.

Table 4.20 Monthly temperature and salinity statistics for the surface water in sub-area 1 from historical CTD data

Surface Temperature (0 m) in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	22	3.39	1.00	4.85	0.97
February	12	2.27	1.26	3.53	0.65
March	14	2.26	-0.48	4.96	1.58
April	84	3.23	-0.60	5.43	1.49
May	100	4.51	0.76	8.07	1.31
June	65	6.73	3.60	10.23	1.59
July	22	9.68	6.18	12.02	1.63
August	26	11.42	9.11	13.98	1.53
September	9	11.67	9.32	14.16	1.49
October	33	8.92	7.36	11.04	1.21
November	28	6.89	4.50	9.23	1.20

December	15	5.50	3.58	7.26	1.01

Surface salinity (0 m) in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	22	34.37	33.64	34.58	0.23
February	12	34.23	33.76	34.40	0.18
March	14	34.24	33.42	34.74	0.43
April	84	34.29	32.85	34.76	0.39
May	100	34.22	33.13	34.91	0.39
June	65	34.26	33.58	34.81	0.31
July	22	33.69	32.70	34.50	0.65
August	26	33.68	32.89	34.45	0.44
September	9	33.67	32.61	34.20	0.55
October	33	33.90	33.32	34.31	0.24
November	28	33.96	33.03	34.26	0.33
December	15	34.21	33.85	34.37	0.15

Table 4.21 Monthly temperature and salinity data for a depth of 50 m in sub-area 1 from historical CTD data

Temperature 50 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	25	3.76	2.26	5.50	0.78
February	12	2.68	1.41	4.15	0.82
March	18	2.77	0.80	4.94	1.25
April	75	2.95	-1.20	5.40	1.35
May	96	3.63	0.04	7.83	1.30
June	60	4.37	1.10	8.22	1.33
July	22	3.84	0.53	6.73	1.65
August	29	3.88	0.50	6.30	1.57
September	12	4.50	2.16	7.76	1.50
October	35	5.94	2.26	10.02	1.97
November	30	6.69	4.50	8.64	1.22
December	20	5.63	4.44	7.36	0.88

Salinity 50 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	25	34.42	33.77	34.59	0.17
February	12	34.33	33.86	34.64	0.19
March	18	34.37	33.43	34.76	0.35
April	75	34.41	33.55	34.77	0.27
May	96	34.38	33.44	34.91	0.21
June	60	34.47	33.98	34.89	0.17

July	22	34.36	33.96	34.66	0.22
August	29	34.41	33.95	34.70	0.22
September	12	34.39	34.10	34.61	0.17
October	35	34.20	33.33	34.68	0.31
November	30	34.10	33.47	34.31	0.18
December	20	34.31	34.05	34.56	0.14

Table 4.22 Monthly temperature and salinity data for a depth of 100 m in sub-area 1 from historical CTD data

Temperature 100 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	24	3.65	2.65	5.31	0.72
February	10	2.86	1.48	4.17	0.79
March	14	3.08	1.84	4.86	0.93
April	73	3.01	-0.41	5.41	0.79
May	80	3.07	0.88	7.52	0.86
June	56	3.57	2.19	8.03	1.01
July	21	3.34	2.13	4.92	0.80
August	30	3.28	1.66	4.66	0.76
September	11	3.91	3.17	4.73	0.58
October	35	3.57	2.10	4.59	0.58
November	32	4.22	2.41	7.20	0.78
December	20	4.74	3.96	6.61	0.58

Salinity 100 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	24	34.51	34.27	34.73	0.11
February	10	34.45	34.25	34.65	0.15
March	14	34.54	34.15	34.75	0.16
April	73	34.57	33.99	34.85	0.15
May	80	34.57	34.15	34.94	0.13
June	56	34.62	34.37	34.97	0.11
July	21	34.60	34.32	34.79	0.13
August	30	34.62	34.30	34.77	0.13
September	11	34.70	34.60	34.82	0.07
October	35	34.64	34.01	34.81	0.16
November	32	34.63	34.12	34.80	0.15
December	20	34.51	34.25	34.75	0.17

Table 4.23 Monthly temperature and salinity data for a depth of 200 m in sub-area 1 from historical data

Temperature 200 m Depth in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	23	4.01	3.48	4.57	0.28
February	10	3.88	3.33	4.39	0.32
March	16	3.42	2.23	4.42	0.65
April	73	3.47	2.46	5.11	0.49
May	81	3.45	1.40	4.84	0.51
June	60	3.56	2.77	6.02	0.61
July	20	3.54	2.97	4.06	0.36
August	29	3.49	3.04	4.28	0.32
September	10	3.79	3.22	4.14	0.26
October	33	3.64	3.25	4.13	0.25
November	31	3.92	3.30	4.56	0.34
December	19	4.04	3.60	4.60	0.30

Salinity 200 m Depth in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	23	34.79	34.66	34.85	0.06
February	10	34.80	34.67	34.88	0.08
March	16	34.73	34.58	34.85	0.08
April	73	34.77	34.48	34.93	0.08
May	81	34.76	34.40	34.90	0.08
June	60	34.77	34.66	34.95	0.05
July	20	34.77	34.63	34.87	0.06
August	29	34.78	34.62	34.83	0.04
September	10	34.82	34.76	34.87	0.04
October	33	34.79	34.33	34.88	0.11
November	31	34.79	34.47	34.90	0.09
December	19	34.81	34.76	34.90	0.04

Table 4.24 Monthly temperature and salinity data for a depth of 300 to 900 m in sub-area 1 from historical CTD data

Temperature 300 to 900 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	115	3.68	3.36	4.34	0.22
February	68	3.78	3.30	4.39	0.29
March	76	3.75	2.79	4.40	0.32
April	307	3.66	2.47	4.50	0.29
May	352	3.62	3.02	4.38	0.26
June	194	3.58	3.09	4.48	0.26
July	114	3.57	3.13	4.11	0.22

August	144	3.50	3.12	4.01	0.22
September	50	3.60	3.18	4.16	0.25
October	186	3.54	3.20	4.07	0.19
November	159	3.71	3.10	4.39	0.24
December	117	3.55	3.13	4.29	0.22

Salinity 300 to 900 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	115	34.85	34.73	34.92	0.03
February	68	34.88	34.80	34.95	0.03
March	76	34.87	34.80	34.94	0.03
April	307	34.87	34.66	35.02	0.05
May	352	34.86	34.67	34.94	0.04
June	194	34.84	34.74	34.96	0.04
July	114	34.84	34.73	34.92	0.04
August	144	34.84	34.74	34.90	0.03
September	50	34.86	34.81	34.92	0.03
October	186	34.84	34.39	35.01	0.09
November	159	34.85	34.63	34.93	0.06
December	117	34.85	34.77	34.90	0.02

Table 4.25 Monthly temperature and salinity data for a depth of 1000 to 3000 m in sub-area 1 from historical CTD data

Temperature 1000 to 3000 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	38	3.31	2.91	3.54	0.15
February	17	3.42	2.90	3.80	0.26
March	22	3.35	2.97	3.70	0.23
April	100	3.35	2.00	3.90	0.29
May	126	3.38	2.27	3.74	0.22
June	97	3.35	2.70	3.72	0.17
July	36	3.35	2.89	3.65	0.21
August	43	3.31	2.83	3.64	0.22
September	18	3.30	2.85	3.67	0.22
October	48	3.33	2.84	3.61	0.19
November	39	3.36	2.90	3.66	0.24
December	25	3.26	3.00	3.64	0.14

Salinity 1000 to 3000 m in sub-area 1

MONTH	# Observations	Mean	Min	Max	STD
January	38	34.90	34.82	34.99	0.04
February	17	34.89	34.84	34.94	0.02

March	22	34.89	34.84	34.95	0.03
April	100	34.90	34.82	35.01	0.03
May	126	34.90	34.81	34.96	0.03
June	97	34.89	34.77	34.96	0.03
July	36	34.89	34.84	34.93	0.02
August	43	34.90	34.86	34.96	0.03
September	18	34.88	34.84	34.91	0.02
October	48	34.89	34.84	35.01	0.03
November	39	34.89	34.74	34.95	0.04
December	25	34.88	34.84	34.92	0.02

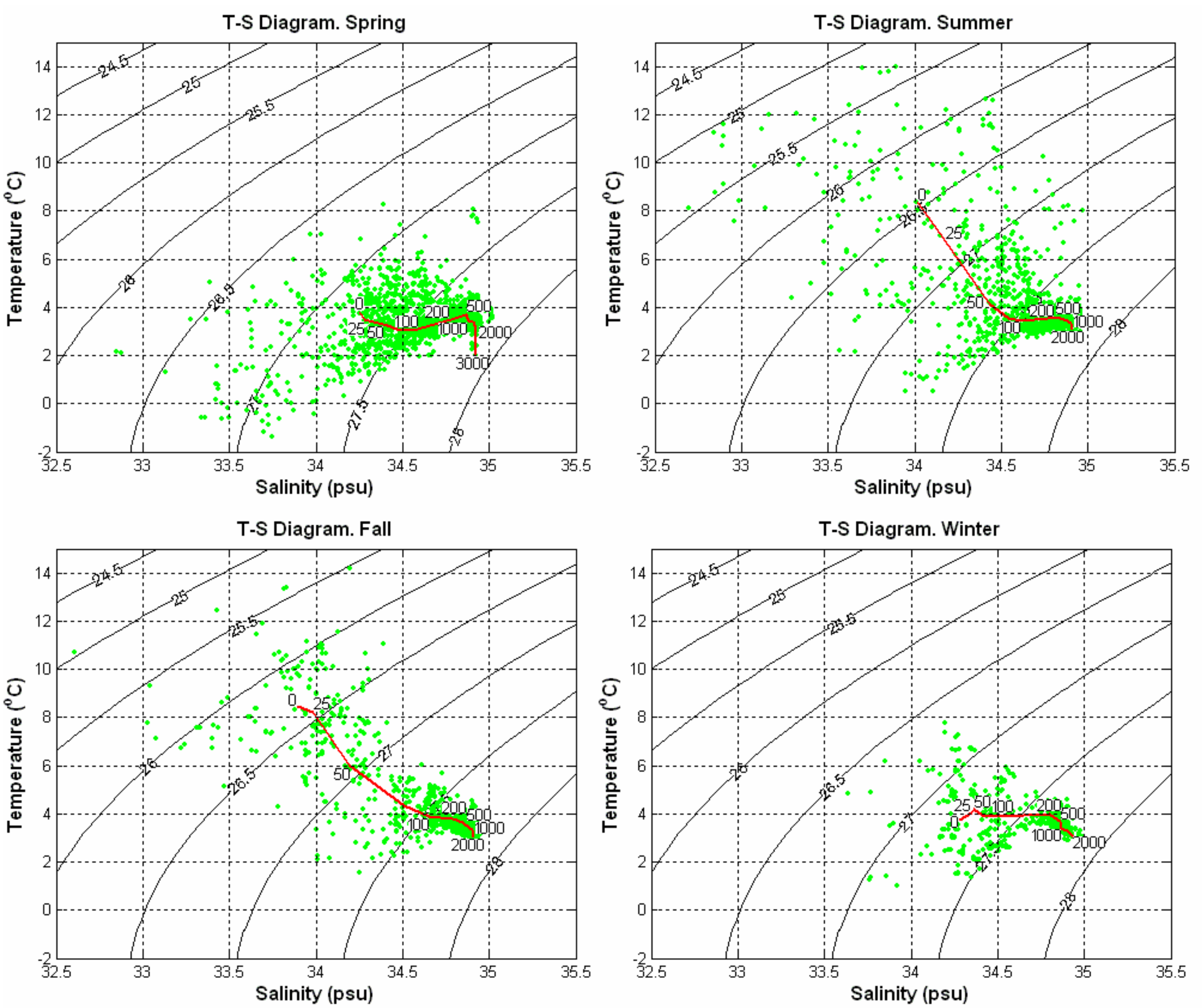


Figure 4.28 Seasonal T-S plots for sub-area 1

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

4.4.2 Sub-area 2: Sackville Spur and Flemish Pass

Sub-area 2 contains Sackville Spur and Flemish Pass. The water depth varies between the 500 m and 3000 m. Tables 4.26 to 4.31 present the temperature and salinity data by month, at the surface, 50 m, 100 m, 200 m, 300 to 900 m, and 1000 to 3000 m.

The surface waters were warmest during the months July to September with mean temperatures ranging from 10.70°C to 12.05°C. The coldest temperatures were in March and April with mean temperatures of 2.72°C and 2.88°C, respectively. The mean salinities ranged between 32.71 psu in September and 33.98 psu in February. At a depth of 50 m, the mean temperatures ranged between 2.46°C in April to 5.92°C in November. The mean salinities ranged between 33.85 psu in December and 34.10 psu in January. At a depth of 100 m, the mean temperatures ranged between 2.54°C in April to 3.94°C in December. The mean salinities ranged between 34.24 psu in April and 34.49 psu in October and November. At a depth of 200 m, the mean temperatures ranged between 3.36°C in June to 4.04°C in December. The salinity had a standard deviation of less than 0.15 and mean salinity values ranged between 34.65 psu in April and 34.76 psu in October to December. At a depth of 300 to 900 m, the mean temperatures ranged between 3.54°C in September to 3.77°C in March. The salinity had a standard deviation of less than 0.1 and mean salinity values ranged between 34.82 psu in June and September and 34.85 psu in October, November, February and March. At a depth of 1000 to 3000 m, the mean temperatures ranged between 3.34°C in December to 3.48°C in May. The salinity had a standard deviation of less than 0.06 and mean salinity values ranged between 34.84 psu and 34.89 psu.

The data is also presented in seasonal T-S plots in Figure 4.29. 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 season throughout the water column. In summer and fall the water is stratified between 50 m and 100 m. The T-S diagrams show that the core of the Labrador Current water is around 100 m and the core of the Labrador Sea Water is around 500 m.

Table 4.26 Monthly temperature and salinity statistics for the surface water in Sub-area 2 from historical CTD data

Surface temperature (0 m) in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	156	3.86	-1.00	6.45	1.33
February	106	3.14	-0.44	5.80	1.16
March	162	2.72	-1.30	5.07	1.48
April	614	2.88	-1.31	8.99	1.88
May	421	4.59	-1.00	8.40	1.77
June	356	6.61	1.10	12.25	2.13
July	596	10.70	4.65	15.90	1.92
August	171	12.05	7.20	16.25	1.67
September	70	12.04	8.26	14.66	1.67
October	119	8.82	5.39	12.02	1.40
November	144	7.04	2.37	11.58	1.75
December	86	5.93	3.08	11.00	1.95

Surface salinity (0 m) in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	156	33.95	32.36	34.59	0.35
February	106	33.98	33.15	34.48	0.25
March	162	33.93	33.08	34.71	0.31
April	614	33.79	32.03	34.93	0.41
May	421	33.76	32.70	34.65	0.40
June	356	33.57	31.93	34.39	0.39
July	596	33.29	31.36	34.37	0.45
August	171	32.80	31.31	34.06	0.48
September	70	32.71	31.46	34.02	0.49
October	119	33.52	32.38	34.35	0.48
November	144	33.58	32.68	34.49	0.47
December	86	33.70	32.84	34.36	0.42

Table 4.27 Monthly temperature and salinity data for a depth of 50 m in sub-area 2 from historical CTD data

Temperature 50 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	115	3.42	-0.60	6.39	1.25
February	96	3.02	-0.11	5.12	1.05
March	153	2.64	-1.56	5.40	1.30
April	588	2.46	-1.62	7.80	1.65
May	403	3.00	-1.44	8.60	1.62
June	370	3.25	-1.30	7.54	1.78
July	628	3.95	-1.20	9.81	1.68
August	159	3.28	-1.60	8.30	2.21
September	68	3.52	-0.81	10.76	2.34
October	119	5.21	0.09	10.89	2.42
November	146	5.92	0.90	9.92	1.74
December	87	5.28	1.96	9.30	1.32

Salinity 50 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	115	34.10	33.22	34.60	0.31
February	96	34.06	33.46	34.75	0.24
March	153	34.01	33.28	34.70	0.26
April	588	33.96	32.97	34.70	0.32
May	403	33.98	32.82	34.65	0.32
June	370	34.00	33.10	34.58	0.28
July	628	34.02	33.11	34.68	0.28
August	159	33.93	32.54	34.65	0.33
September	68	34.00	33.06	34.54	0.27

October	119	33.97	32.95	34.86	0.34
November	146	33.87	32.94	34.56	0.35
December	87	33.85	33.01	34.36	0.34

Table 4.28 Monthly temperature and salinity data for a depth of 100 m in sub-area 2 from historical CTD data

Temperature 100 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	116	3.36	-0.20	4.79	0.90
February	86	3.22	0.41	5.68	0.93
March	139	2.85	-0.16	4.56	0.94
April	608	2.54	-1.40	8.10	1.08
May	356	2.82	-0.18	8.50	1.15
June	353	2.84	-0.80	7.40	1.08
July	606	3.32	-0.70	6.84	1.00
August	151	3.17	-0.79	6.37	1.52
September	66	3.13	1.18	5.47	0.90
October	110	3.25	1.12	6.26	0.87
November	146	3.88	0.98	7.31	1.10
December	90	3.94	1.35	6.28	1.06

Salinity 100 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	116	34.33	33.23	34.66	0.20
February	86	34.27	33.63	34.84	0.24
March	139	34.30	33.75	34.79	0.21
April	608	34.24	33.42	34.89	0.24
May	356	34.31	33.45	34.81	0.22
June	353	34.33	33.47	34.72	0.20
July	606	34.36	33.66	34.82	0.19
August	151	34.35	33.65	34.79	0.25
September	66	34.40	33.69	34.75	0.18
October	110	34.49	34.08	34.77	0.20
November	146	34.49	33.93	34.93	0.20
December	90	34.39	33.84	34.82	0.23

Table 4.29 Monthly temperature and salinity data for a depth of 200 m in sub-area 2 from historical CTD data

Temperature 200 m Depth in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	119	3.88	1.20	5.09	0.55
February	94	3.92	1.92	5.60	0.46

March	121	3.58	0.69	5.17	0.78
April	562	3.43	0.94	5.70	0.78
May	376	3.49	0.70	6.90	0.78
June	401	3.36	0.39	5.48	0.74
July	522	3.80	1.22	5.68	0.54
August	141	3.73	1.41	5.60	0.74
September	67	3.66	2.80	4.86	0.49
October	129	3.61	1.56	5.62	0.53
November	169	3.93	2.04	5.28	0.52
December	93	4.04	2.16	5.85	0.48

Salinity 200 m Depth in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	119	34.72	34.05	34.97	0.12
February	94	34.73	34.21	34.93	0.12
March	121	34.67	34.12	34.88	0.13
April	562	34.65	33.53	34.94	0.14
May	376	34.68	34.07	34.92	0.13
June	401	34.66	33.91	34.91	0.14
July	522	34.72	34.11	35.08	0.10
August	141	34.69	34.25	35.05	0.12
September	67	34.71	34.22	34.89	0.11
October	129	34.76	34.27	34.90	0.10
November	169	34.76	34.41	34.97	0.09
December	93	34.76	34.28	34.93	0.09

Table 4.30 Monthly temperature and salinity data for a depth of 300 to 900 m in sub-area 2 from historical CTD data

Temperature 300 to 900 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	360	3.75	2.20	4.35	0.27
February	170	3.76	3.01	4.87	0.28
March	305	3.77	1.92	4.73	0.39
April	1122	3.61	2.24	4.80	0.38
May	932	3.70	2.09	5.70	0.38
June	911	3.58	1.72	4.90	0.35
July	776	3.74	2.53	4.93	0.31
August	364	3.67	2.88	4.90	0.35
September	179	3.54	3.02	4.49	0.33
October	521	3.61	2.25	4.98	0.26
November	540	3.76	3.06	4.80	0.33
December	369	3.67	3.14	4.90	0.30

Salinity 300 to 900 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	360	34.83	34.49	35.01	0.05
February	170	34.85	34.59	34.97	0.06
March	305	34.85	34.41	34.98	0.08
April	1122	34.83	34.44	34.98	0.07
May	932	34.84	34.45	34.99	0.07
June	911	34.82	34.12	34.99	0.08
July	776	34.84	34.60	35.14	0.06
August	364	34.84	34.61	34.97	0.05
September	179	34.82	34.36	34.94	0.06
October	521	34.85	34.49	34.94	0.05
November	540	34.85	34.63	34.99	0.05
December	369	34.83	34.74	34.98	0.03

Table 4.31 Monthly temperature and salinity data for a depth of 1000 to 3000 m in sub-area 2 from historical CTD data

Temperature 1000 to 3000 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	53	3.41	3.05	3.71	0.12
February	11	3.44	3.28	3.64	0.12
March	42	3.42	2.97	4.20	0.27
April	130	3.44	3.10	3.90	0.14
May	153	3.48	2.89	3.95	0.19
June	119	3.44	3.00	3.90	0.16
July	57	3.39	1.67	3.91	0.39
August	56	3.42	2.98	3.87	0.23
September	27	3.38	3.04	3.94	0.20
October	66	3.44	2.98	3.85	0.19
November	54	3.41	3.05	3.85	0.19
December	48	3.34	3.09	3.81	0.18

Salinity 1000 to 3000 m in sub-area 2

MONTH	# Observations	Mean	Min	Max	STD
January	53	34.87	34.84	34.95	0.03
February	11	34.86	34.80	34.90	0.03
March	42	34.87	34.53	34.92	0.06
April	130	34.88	34.80	34.97	0.03
May	153	34.89	34.79	35.00	0.03
June	119	34.88	34.79	35.00	0.03
July	57	34.88	34.84	34.94	0.02
August	56	34.87	34.82	34.94	0.03
September	27	34.87	34.84	34.96	0.03
October	66	34.87	34.74	34.94	0.03

November	54	34.87	34.78	34.94	0.04
December	48	34.84	34.78	34.91	0.02

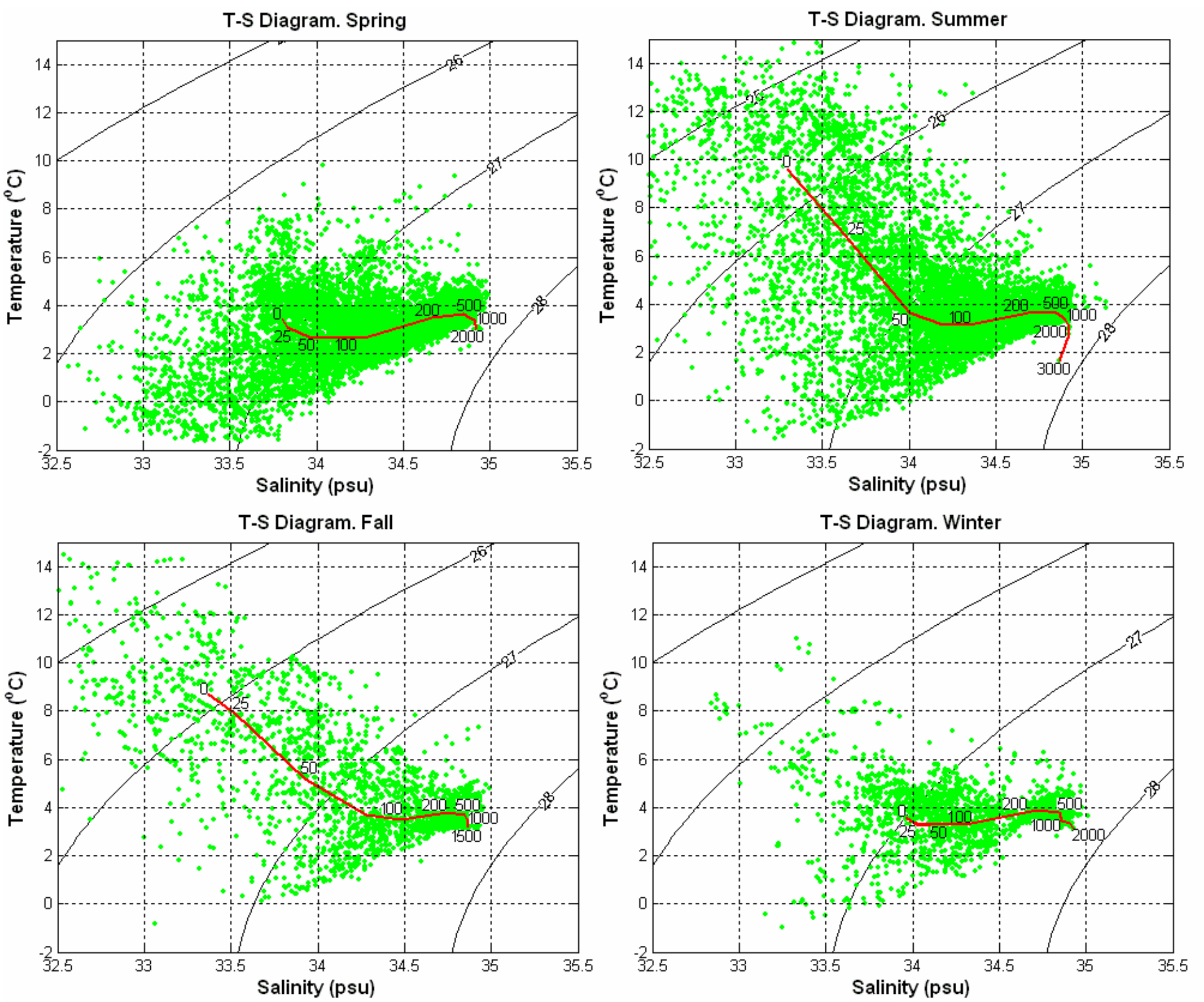


Figure 4.29 Seasonal T-S plots for sub-area 2

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

4.4.3 Sub-area 3: Northeast Grand Bank

Sub-area 3 is located on the Newfoundland shelf and upper Contiental Slope and reaches depths up to 500 metres. The analysis performed on this sub-area was further subdivided into three areas based on the water depth as shown in Figure 4.31

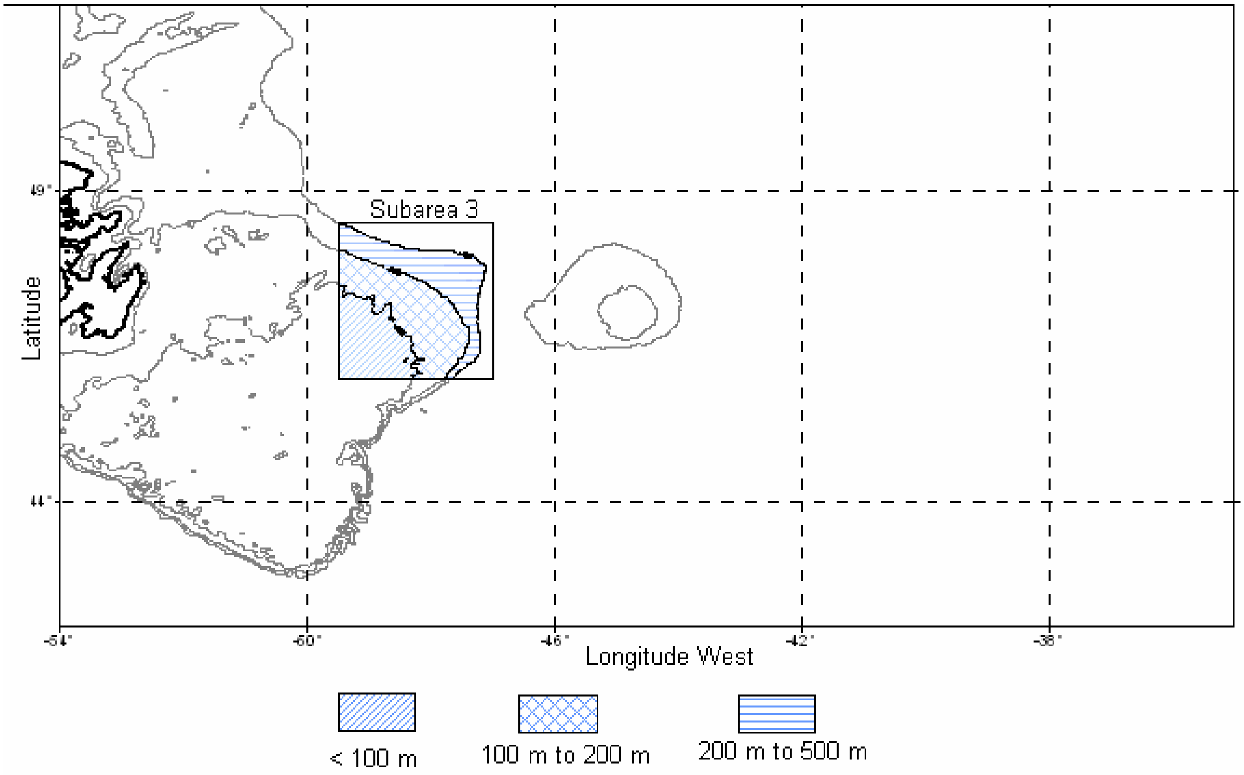


Figure 4.30 Sub-area 3 divided by water depth on the Newfoundland Shelf and Slope

Area 1: Water Depth less than 100 m

This section of sub-area 3 has a water depth less than 100 m. Hibernia and Terra Nova are located within this area. Tables 4.32 and 4.33 present CTD temperature and salinity data from the BIO database, collected at the surface and at a depth of 75 m. Table 4.32 shows that the surface water is warmest between July and September with mean temperatures ranging between 10.12°C and 12.81°C. The coldest temperatures are in February and March with a mean temperature of 0.01°C and -0.53°C, respectively. The mean salinities ranged between 32.04 psu in October to 32.97 psu in March.

At a depth of 75 m, the mean temperatures were always negative, ranging between -0.01 in January to -1.04 in March, consistent with temperatures in the Cold Intermediate Layer. The mean salinities ranged between 32.77 psu in February to 33.16 psu in December.

T-S diagrams in Figure 4.31 show how the water properties vary with season throughout the water column. In summer and fall the water is stratified to a depth of 50 m. Below 50 m the water is less stratified and shows negative temperature at 75 m and 100 m, within the core of the Cold Intermediate Layer.

In Winter and Spring, there is little to no distinction between the water properties at the surface and at 25 m because the surface layer is well mixed. However, below 75 m the water is more stratified than during summer, indicating an intrusion and mixing by the Labrador Slope water.

Table 4.32. Monthly temperature and salinity statistics for the surface water from historical CTD data for a water depth < 100 m on the Grand Banks

Surface temperature (0 m) on the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	14	0.90	-0.69	1.90	0.70
February	7	0.01	-1.69	0.64	0.83
March	17	-0.53	-1.75	0.96	1.05
April	177	0.48	-1.30	2.55	0.85
May	219	2.76	-0.39	6.52	1.66
June	489	5.32	1.61	14.36	1.40
July	140	10.12	5.30	13.50	1.79
August	19	12.81	10.30	16.45	1.56
September	38	11.97	6.12	18.20	2.67
October	114	9.33	5.20	12.96	2.34
November	122	6.33	2.53	10.69	1.78
December	59	2.93	0.66	6.94	1.82

Surface salinity (0 m) on the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	14	32.67	32.23	33.09	0.22
February	7	32.86	32.36	33.16	0.25
March	17	32.97	32.70	33.24	0.16
April	177	32.87	32.18	33.38	0.20
May	219	32.71	31.84	33.46	0.29
June	489	32.61	31.87	33.30	0.21
July	140	32.39	31.29	33.10	0.27
August	19	32.25	31.55	32.74	0.31
September	38	32.07	31.41	32.56	0.23
October	114	32.04	31.42	32.50	0.21
November	122	32.09	31.01	32.94	0.25
December	59	32.41	31.90	32.85	0.25

Table 4.33 Monthly temperatures and salinity statistics at 75 m depth from historical CTD data for a water depth of < 100 m on the Grand Banks

Temperature 75 m on the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	6	-0.01	-0.78	0.45	0.43
February	3	-0.83	-1.55	-0.33	0.64
March	11	-1.04	-1.73	0.09	0.83
April	130	-0.58	-1.72	2.71	0.66
May	160	-0.28	-1.57	1.26	0.75
June	284	-0.13	-1.62	1.68	0.64
July	137	-0.35	-1.54	1.05	0.55
August	20	-0.52	-1.35	0.88	0.54
September	26	-0.68	-1.47	0.72	0.53
October	111	-0.91	-1.34	1.36	0.44
November	73	-0.31	-1.35	1.82	0.74
December	51	-0.54	-1.26	1.30	0.59

Salinity 75 m on the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	6	32.98	32.76	33.19	0.20
February	3	32.77	32.57	32.90	0.18
March	11	33.04	32.85	33.26	0.13
April	130	33.01	32.56	34.27	0.26
May	160	33.06	32.72	33.57	0.17
June	284	33.04	32.56	34.01	0.17
July	137	33.08	32.73	33.43	0.16
August	20	33.08	32.82	33.40	0.16
September	26	33.08	32.77	33.33	0.16
October	111	33.05	32.77	33.20	0.10
November	73	33.07	32.52	33.70	0.21
December	51	33.16	32.78	33.34	0.14

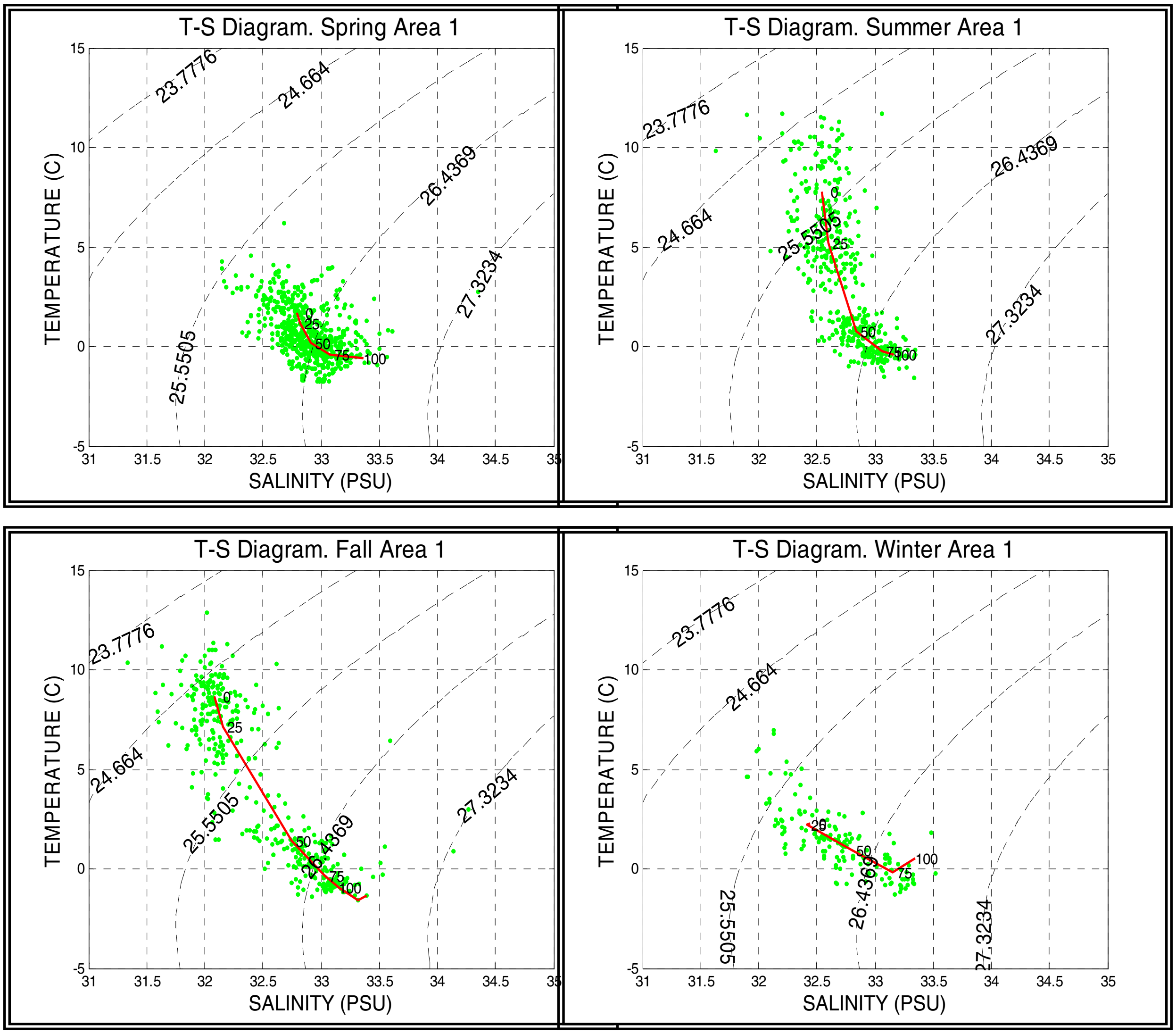


Figure 4.31 Seasonal T-S diagrams for sub-area 3 at depths less than 100 m

Note:The red lines correspond to the average T-S curve for each area. The numbers on these curves represent the depth in metres.

Area 2: Water depth between 100 m and 200 m.

This area has a water depth between 100 m and 200 m isobaths and contains the White Rose field. Tables 4.34 and 4.35 present the temperature and salinity data by month at the surface and at 75 m. The water properties in this section of sub-area 3 are similar to those where the water depth was less than 100 m. The exception is that the waters tend to be slightly colder in between the 100 m and 200 m isobaths than where the water depth is less than 100 m. The surface waters were warmest during the months of July to September with mean temperatures ranging from 9.08°C to 11.28°C. The coldest temperatures were in February and March with mean temperatures of –0.61°C and -0.75°C, respectively. The mean salinities ranged between 31.59 psu in August and 32.94 psu in February.

At a depth of 75 m, the mean temperatures were always negative, ranging between -1.50°C in August to -0.25°C in November. The mean salinities ranged between 32.94 psu in April and 33.18 psu in February.

The colder waters in this section indicate that the water in this area is experiencing advection from the north by the Labrador Current rather than by vertical mixing through local cooling.

The T-S diagrams in Figure 4.32 show two distinct water masses and the surface seasonally mixed layer. During summer and fall strong stratification occurs in the top 50 m which disappears to being a well mixed surface layer during winter and spring. The core of the Cold Intermediate Layer occurs between the 75 m and 100 m depths. Below 100 m the water is mixed with Labrador Sea water.

Table 4.34 Monthly temperature and salinity statistics for the surface water from historical CTD data for a water depth between 100 m and 200m

Temperature surface (0 m) on the outer edge of the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	15	0.10	-1.40	1.40	0.90
February	23	-0.61	-1.81	0.55	0.80
March	33	-0.75	-1.77	0.50	0.78
April	235	-0.16	-1.50	2.53	0.77
May	303	1.52	-1.10	5.08	1.33
June	422	4.15	0.64	10.34	1.70
July	249	9.08	4.15	13.7	1.86
August	72	11.28	6.37	16.08	2.08
September	87	9.98	4.23	17.1	2.61
October	60	7.13	3.54	11.54	1.97
November	184	4.19	0.83	9.74	1.72
December	53	2.44	-1.00	6.06	1.37

Salinity surface (0 m) on the outer edge of the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	15	32.77	32.19	33.30	0.31
February	23	32.94	32.61	33.29	0.21
March	33	32.91	32.41	33.37	0.18
April	235	32.86	32.23	33.33	0.19
May	303	32.72	31.82	33.19	0.22
June	422	32.56	31.62	33.50	0.24
July	249	32.23	31.08	32.77	0.27
August	72	31.59	30.62	32.65	0.53
September	87	31.87	31.16	32.68	0.32
October	60	32.10	31.32	33.21	0.44
November	184	32.39	31.45	33.77	0.36
December	53	32.51	31.91	33.08	0.27

Table 4.35 Monthly temperature and salinity statistic for 75 m depth from historical CTD data for water depth between 100 m and 200 m

Temperature 75 m on the outer edge of the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	16	-0.38	-1.40	0.55	0.54
February	19	-0.71	-1.73	0.96	0.79
March	29	-0.88	-1.76	0.57	0.76
April	384	-1.11	-1.78	1.62	0.55
May	285	-0.88	-1.76	1.48	0.71
June	391	-0.99	-1.80	1.49	0.55
July	244	-0.84	-1.81	5.90	0.79
August	130	-1.50	-1.70	-0.21	0.31
September	71	-1.25	-1.68	-0.05	0.37
October	133	-1.01	-1.65	0.05	0.33
November	178	-0.25	-1.50	3.30	1.10
December	55	-0.27	-1.44	2.13	0.98

Salinity 75 m on the outer edge of the Grand Banks

MONTH	# Observations	Mean	Min	Max	STD
January	16	33.03	32.69	33.33	0.20
February	19	33.18	32.66	33.55	0.22
March	29	33.11	32.77	33.68	0.23
April	384	32.94	32.53	33.8	0.29
May	285	33.09	32.65	34.11	0.19
June	391	33.06	32.53	33.66	0.18
July	244	33.05	32.56	34.00	0.15
August	130	33.08	32.75	33.52	0.11
September	71	33.16	32.79	33.79	0.25
October	133	33.16	32.81	33.69	0.19
November	178	33.17	32.48	33.98	0.24
December	55	33.14	32.75	33.69	0.20

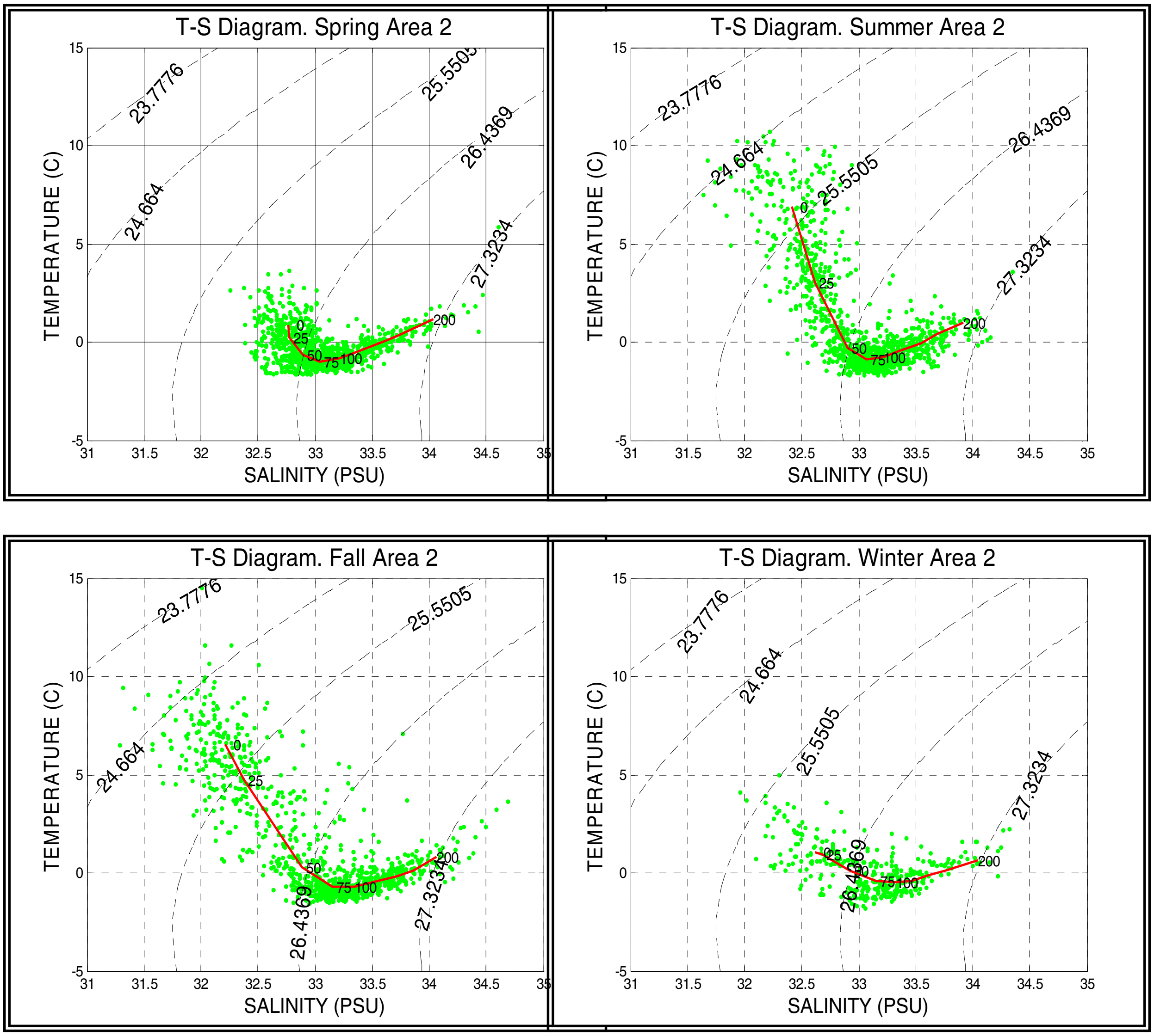


Figure 4.32 Seasonal T-S diagrams for sub-area 3 at depths from 100 m – 200 m

Note: The red lines correspond to the average T-S curve for each area. The numbers on these curves represent the depth in metres.

Area 3: Water depth between 200 m and 500 m.

This area is situated to the northeast of the White Rose field where the water depth is between 200 m and 500 m. Tables 4.36 and 4.37 present the temperature and salinity data by month. Similar to the two previous sections of sub-area 3, the warmest months are July to September and the coldest are February and March. The mean surface temperatures during the months of July to September ranged between 9.19°C and 10.24°C. During February and March the mean surface temperatures were -0.37°C and -0.57°C, respectively. The mean salinities ranged between 31.81 psu in August and 33.27 psu in December. Salinities above 33 psu occurred in the months of November to February. In both sub-areas 2 and 3, the lowest surface salinities are in August and the highest occur during the winter.

At a depth of 75 m, the mean temperatures are negative for most of the year, but positive during the months of November, December, and January. The temperatures range between -1.28°C in August to 2.02°C in December. The mean salinity ranges between 33.25 psu in July to 33.87 psu in December. In this area the Cold Intermediate Layer disappears in winter and is replaced by warmer, higher salinity Labrador Sea water.

The T-S diagrams in Figure 4.33 show two distinct water masses and the surface seasonally mixed layer in spring, summer and fall. The upper 50 m shows strong stratification in summer and fall and a weak stratification in spring and winter. The Cold Intermediate Layer is more pronounced in spring and summer than during the fall, and disappears in winter as mixing with the warmer and higher salinity water on the Slope intensifies.

Table 4.36. Monthly temperature and salinity statistics for the surface water from historical CTD data for water depth between 200 m and 500 m

Temperature surface (0 m) on the Continental Slope

MONTH	# Observations	Mean	Min	Max	STD
January	26	-0.14	-1.80	1.06	0.81
February	30	-0.37	-1.78	0.68	0.66
March	14	-0.57	-1.63	0.77	0.83
April	115	-0.25	-1.61	2.44	0.80
May	201	1.31	-0.99	5.52	1.41
June	308	4.03	0.57	9.55	1.66
July	82	9.22	3.42	13.7	2.14
August	56	10.24	5.55	13.8	1.92
September	22	9.19	6.63	14.13	1.75
October	41	5.84	2.32	8.24	1.61
November	141	3.47	-0.19	7.23	1.48
December	38	1.93	0.78	4.52	0.94

Salinity surface (0 m) on the Continental Slope

MONTH	# Observations	Mean	Min	Max	STD
January	26	33.15	32.36	34.01	0.35

February	30	33.26	32.75	34.58	0.37
March	14	32.98	32.76	33.42	0.18
April	115	32.94	32.24	33.87	0.27
May	201	32.82	31.81	33.79	0.30
June	308	32.59	31.36	33.97	0.35
July	82	32.10	30.95	33.02	0.35
August	56	31.81	30.29	33.04	0.56
September	22	32.02	30.77	33.46	0.56
October	41	32.71	31.50	33.86	0.61
November	141	33.03	31.24	34.37	0.56
December	38	33.27	32.38	34.04	0.45

Table 4.37.Monthly temperature and salinity statistics for 75 m depth from historical CTD data for water depth between 200 m and 500 m

Temperature 75 m on the Continental Slope

MONTH	# Observations	Mean	Min	Max	STD
January	34	0.01	-1.76	2.05	0.89
February	18	-0.10	-1.82	1.69	0.99
March	15	-0.40	-1.61	1.59	1.00
April	146	-0.73	-1.78	1.77	0.90
May	181	-0.53	-1.75	5.78	1.12
June	297	-0.61	-1.88	3.64	1.03
July	84	-1.13	-1.78	0.66	0.54
August	109	-1.28	-1.72	0.38	0.43
September	15	-0.69	-1.65	2.18	0.96
October	38	-0.09	-1.53	4.04	1.63
November	141	1.09	-1.38	5.90	1.73
December	32	2.02	-0.67	4.24	1.31

Salinity 75 m on the Continental Slope

MONTH	# Observations	Mean	Min	Max	STD
January	34	33.5	32.98	34.18	0.32
February	18	33.55	32.85	34.34	0.39
March	15	33.28	32.77	33.89	0.29
April	146	33.31	32.62	34.20	0.33
May	181	33.34	32.74	34.30	0.35
June	297	33.33	32.48	34.30	0.33
July	84	33.25	32.80	33.99	0.26
August	109	33.36	32.84	34.10	0.22
September	15	33.53	33.13	34.43	0.34
October	38	33.56	33.07	34.42	0.33

November	141	33.64	32.83	34.49	0.35
December	32	33.87	32.92	34.43	0.36

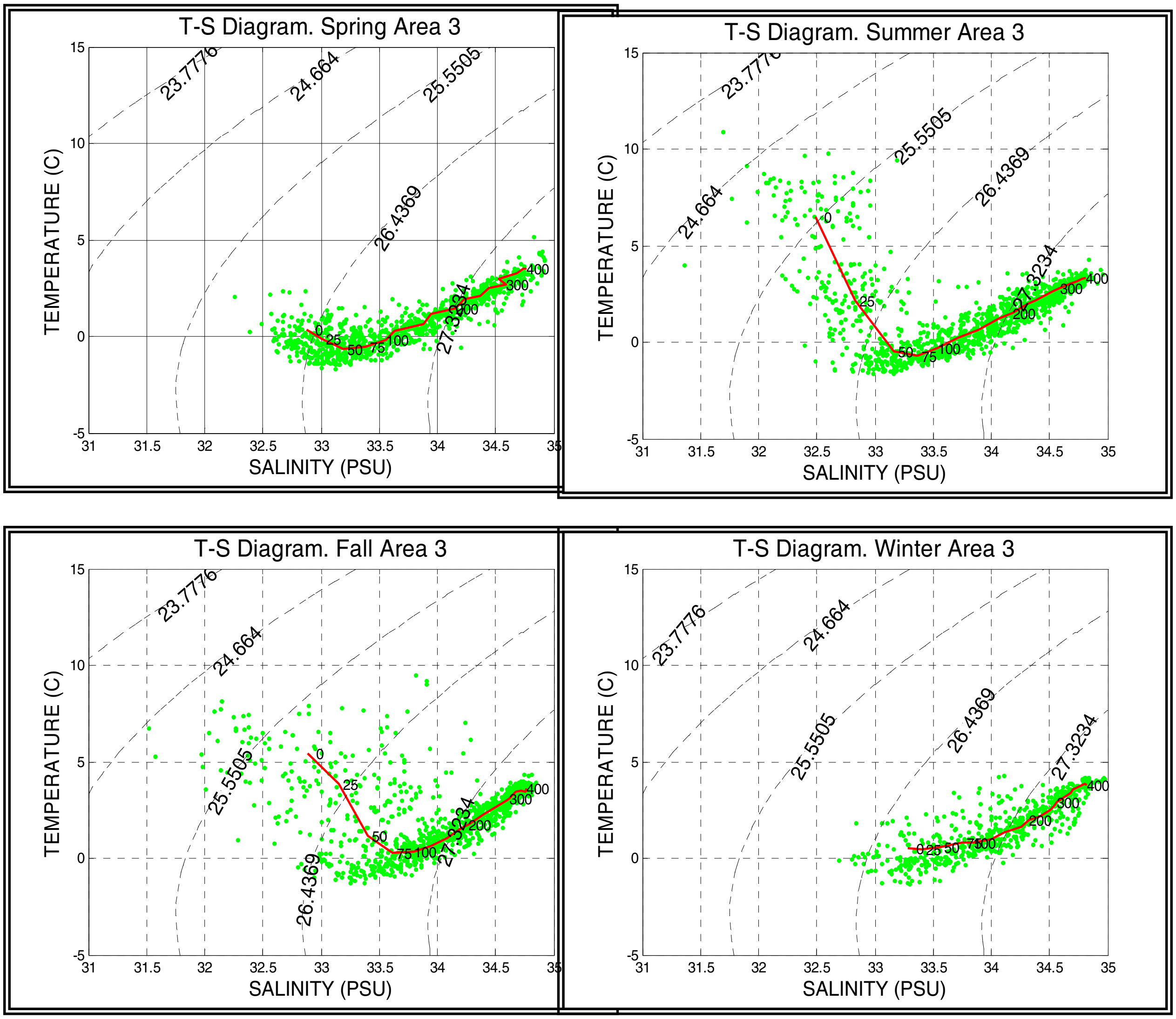


Figure 4.33. Seasonal T-S diagrams for sub-area 3 at water depths from 200 m to 500 m

Note: The red lines correspond to the average T-S curve for each area. The numbers on these curves represent the depth in metres.

5.0 Sea Ice and Icebergs

5.1 Sea Ice

A table defining the types of sea ice is presented below:

Table 5.1 Classifications of Sea Ice

Ice Type	Definition
New	Recently formed ice which includes frazil ice, grease ice, sluch 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 10cm. This includes ice rind, light nilas and dark nilas
Grey	Young ice 10 to 15 cm thick which is less elastic than nilas and breaks on swell. Usually rafts under pressure
Grey-White	Young ice 15 to 30 cm thick. Under pressure more likely to ridge than raft
First-Year	Sea ice of not more than one winter's growth, developing from young ice; thickness 30cm to 2m. May be subdivided into: Thin first year ice: 30-70 cm thick Medium first year ice: 70-120 cm thick Thick first year ice: over 120 cm thick
Old	Sea ice which has survived at least one summers melt. Most topographic features are smoother than on first year ice.
Fast	Sea ice which forms and remains fast along the coast where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. Fast ice may be forms in situ from sea water or by freezing of floating ice of any age to the shore and may extend a few metres or several hundred kilometers from the coast.

<u>Region 1</u>

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice in the over the area shows that the area is affected by sea ice beginning the week of January 08 and lasting until the week beginning May 28. Figure 5.1 shows the week of March 12, the time when the frequency of presence of sea ice is the greatest over the area. During this period, the whole region is covered with the greatest frequency of presence to the northwest with 51 - 66% coverage (green).

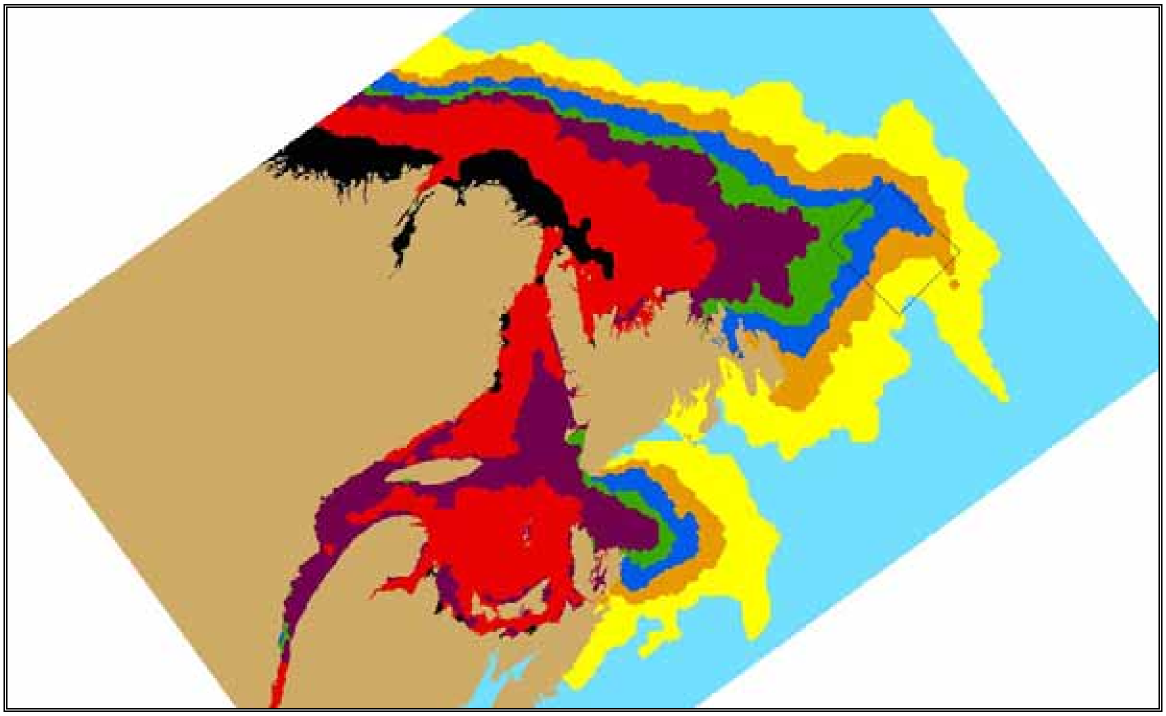


Figure 5.1 30-Year Frequency of Presence of Sea Ice within the study area (February 19)

The predominant ice type within the area from January 08th to the week of January 22nd is grey-white. By January 29th, there is a mixture of grey-white and first year ice. First-year ice is the predominate ice type from February 26 until the week of May 28

The 30-year median concentration of sea ice reaches its maximum extent within the area the week of March 12. This period is presented in Figure 5.2. During this period, the northernmost part of the area has 6/10ths coverage or less.

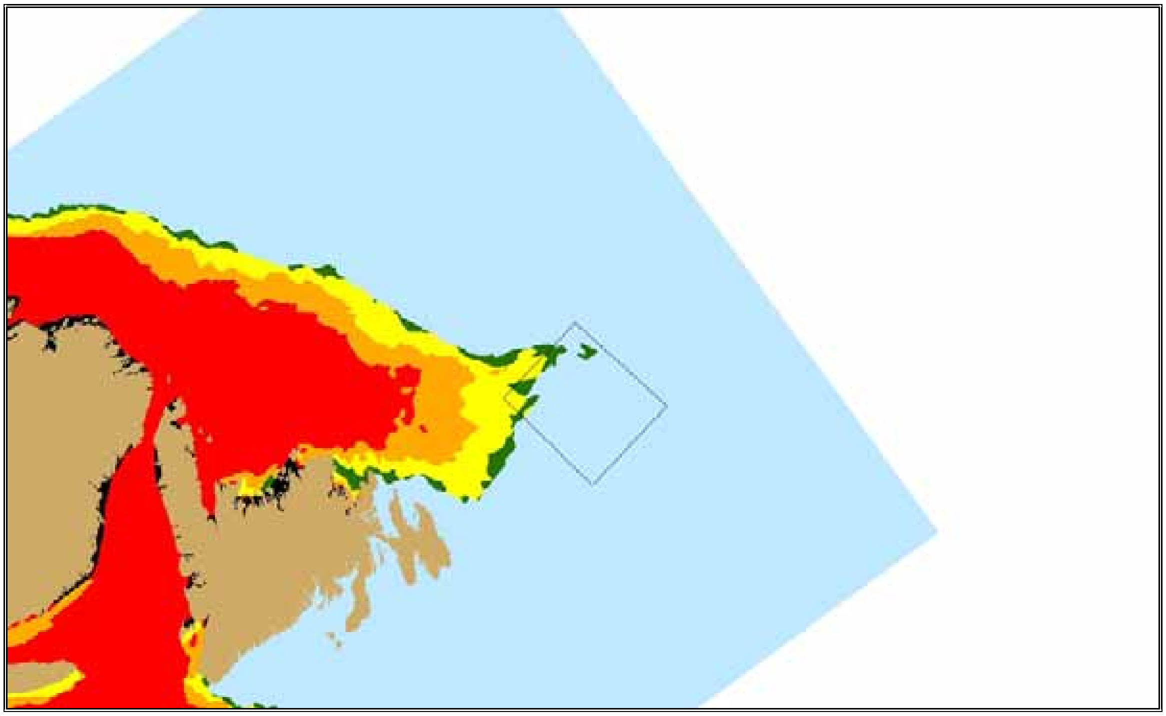


Figure 5.2 30-Year Median of Ice Concentration within the study area (March 12)

<u>Region 2</u>

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice in the over the area shows that the area is affected by sea ice beginning the week of January 15 and lasting until the week beginning May 7. Figure 5.3 shows the week of February 19, the time when the frequency of presence of sea ice is the greatest over the area. During this period, most of the area is covered by at least 1 – 15 % sea ice (yellow) while ice is present in the southeast corner 34 – 50% (blue) of the time.

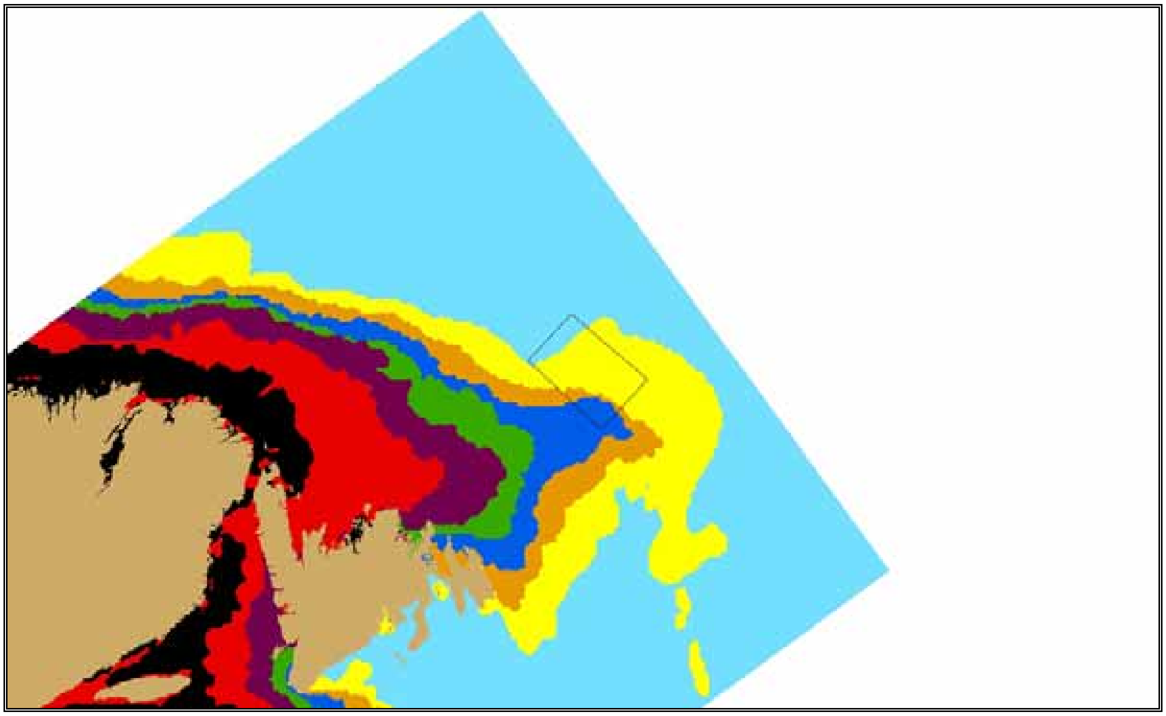


Figure 5.3 30-Year Frequency of Presence of Sea Ice within the study area (February 19)

The predominant ice types within the area from January 15th to the week of January 22nd is grey-white. By January 29th, first year ice is predominant and persists until the week of May 7th. A table defining the types of sea ice is presented below:

The 30-year median concentration of sea ice reaches its maximum extent within the area the week of March 12. This period is presented in Figure 5.4. During this period, the area has 3/10ths coverage or less. Concentrations of sea ice are 1/10ths or less for the remainder of the year.

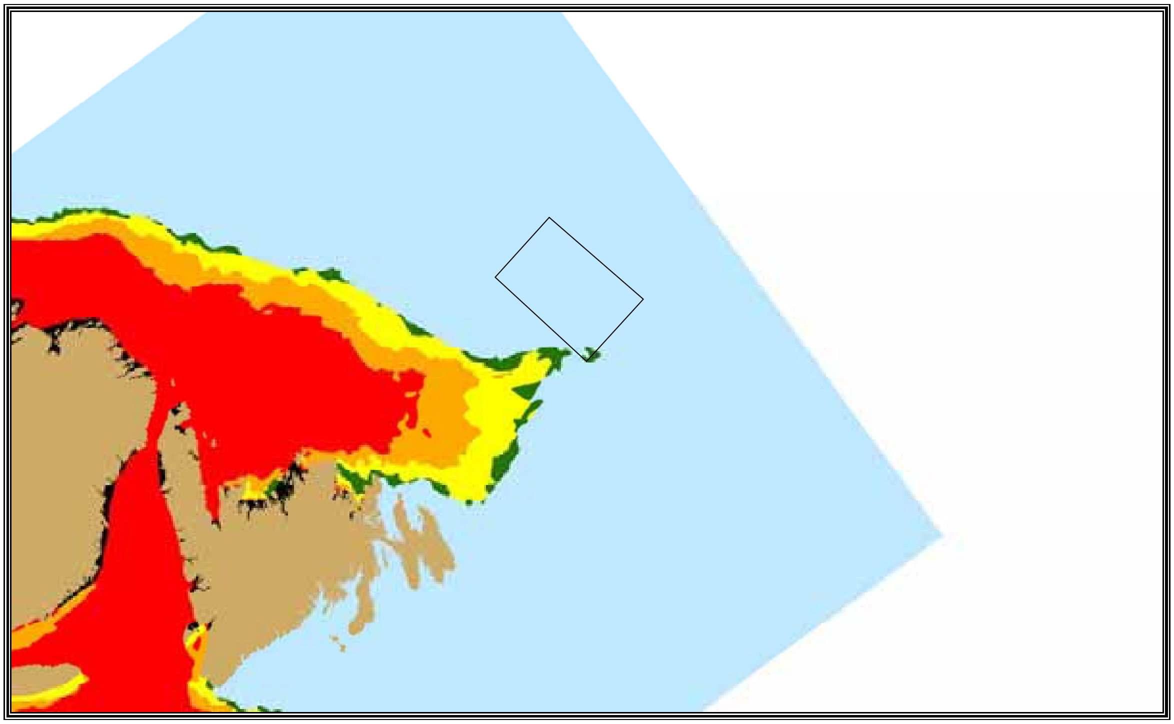


Figure 5.4 30-Year Median of Ice Concentration within the study area (March 12)

5.2 Icebergs

An analysis was performed to determine the threat posed by icebergs in the Orphan Basin. The International Ice Patrol Iceberg Sightings Database from 1974-2009 was used as the primary data source in this analysis, (NSIDC 1995). shows the number of iceberg sightings from 1974-2009.

Region 1

Overall there is a good distribution of iceberg sightings ranging from 987 in 1994 to only one in other years (Figure 5.5). Only iceberg sightings that occurred within the project 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.

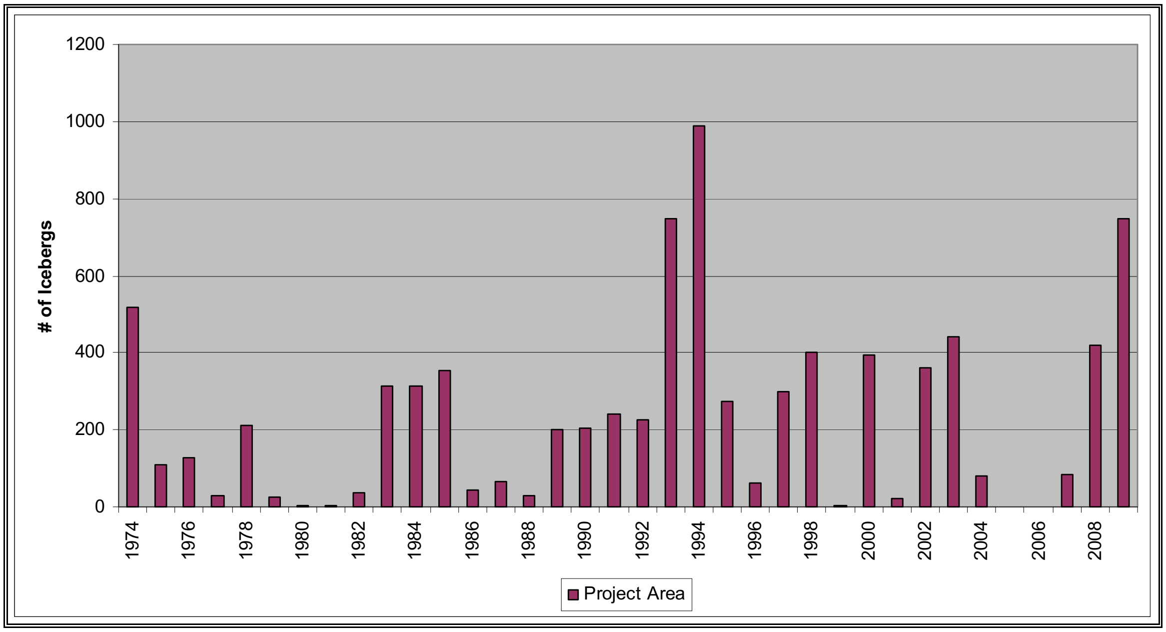


Figure 5.5 Iceberg Sightings in Region 1 (Source: IIP)

Figure 5.6 shows the positions of all icebergs within the region from 1974-2009. Over the 35 years studied, 10,083 out of 23,570 icebergs in total have been sighted inside the area. Environmental factors such as iceberg concentration, ocean currents and wind determine how icebergs drift through the area. Concentrations within the region appear less to the north.

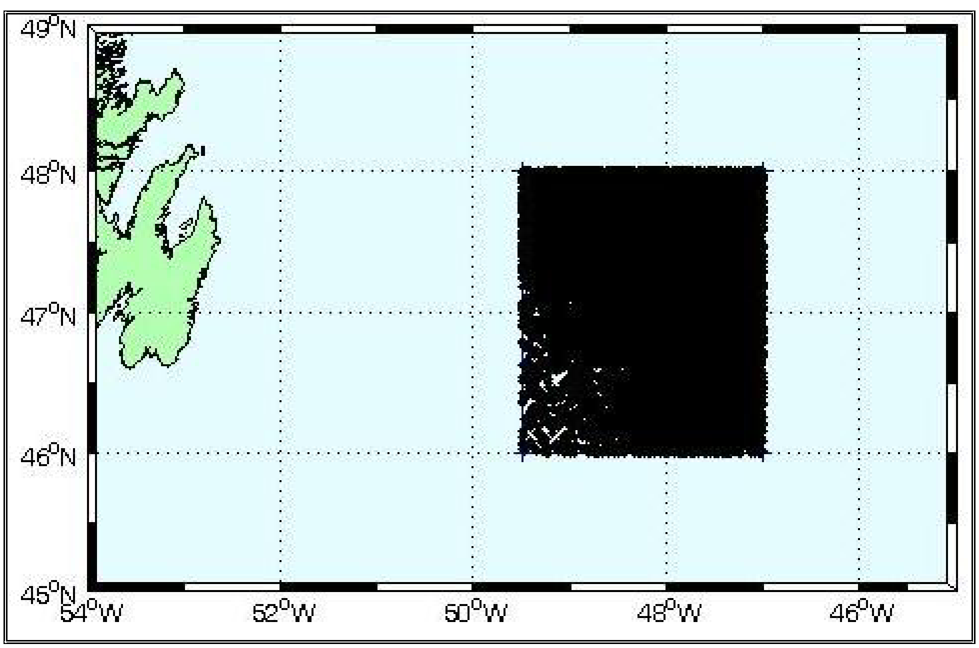


Figure 5.6 Iceberg sightings in Region 1 from 1974 - 2009

A monthly analysis shows that icebergs have been spotted within the region from December to August however they are most prominent during the month of April. With respect to size, the most prominent icebergs are small, accounting for 27.7% of observed icebergs within the region. Large icebergs occur 10.4% of the time.

Table 5.2 Iceberg Size by month in Region 1 (source:IIP)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
General	12	72	302	607	832	288	55	2	0	0	0	0	2170
Unidentified Target	11	85	114	24	63	29	7	2	0	2	0	2	339
Growler	1	12	78	155	187	34	25	0	0	0	0	0	492
Bergy Bit	5	4	66	110	77	23	5	0	0	0	0	0	290
Small	27	242	721	933	684	139	48	1	0	0	0	0	2795
Medium	12	112	596	886	752	240	62	2	0	0	0	1	2663
Large	2	22	202	370	280	151	20	0	0	0	0	0	1047
Very Large	0	1	18	34	15	3	3	0	0	0	0	0	74
Randomized	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Monthly	70	552	2125	3171	2993	924	236	7	0	2	0	3	10083

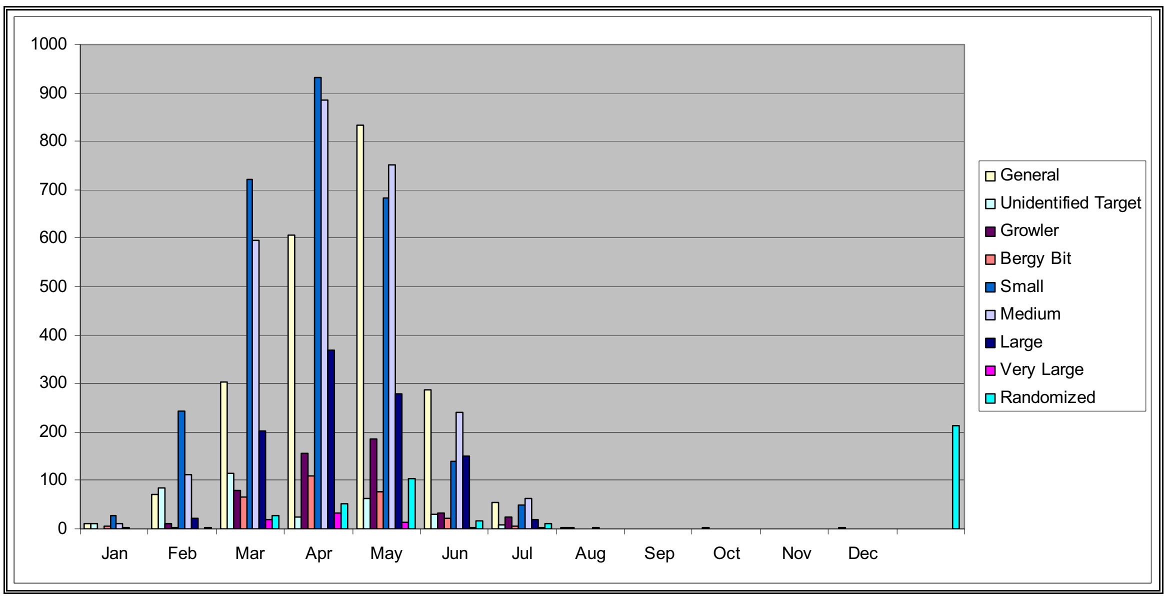


Figure 5.7 Iceberg Size by month in Region 1

<u>Region 2</u>

Overall there is a good distribution of iceberg sightings ranging from 676 in 1974 to none in other years (Figure 5.8). Only iceberg sightings that occurred within the project 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.

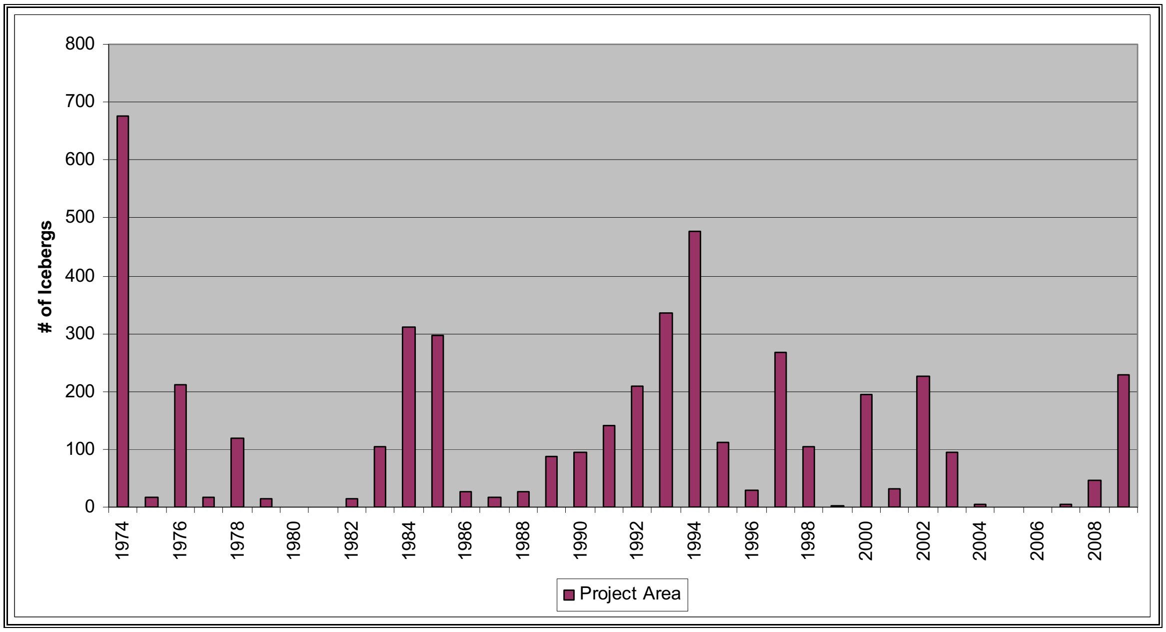


Figure 5.8 Iceberg Sightings (Source: IIP)

Figure 5.9 shows the positions of all icebergs within the region from 1974-2009. Over the 35 years studied, 2,880 out of 23,570 icebergs in total have been sighted inside the area. Environmental factors such as iceberg concentration, ocean currents and wind determine how icebergs drift through to area. Concentrations within the region appear less to the north. It should also be noted that the majority of these sightings occurred in the past 4 years. This does not infer however that icebergs were not present in other years, just that none were observed.

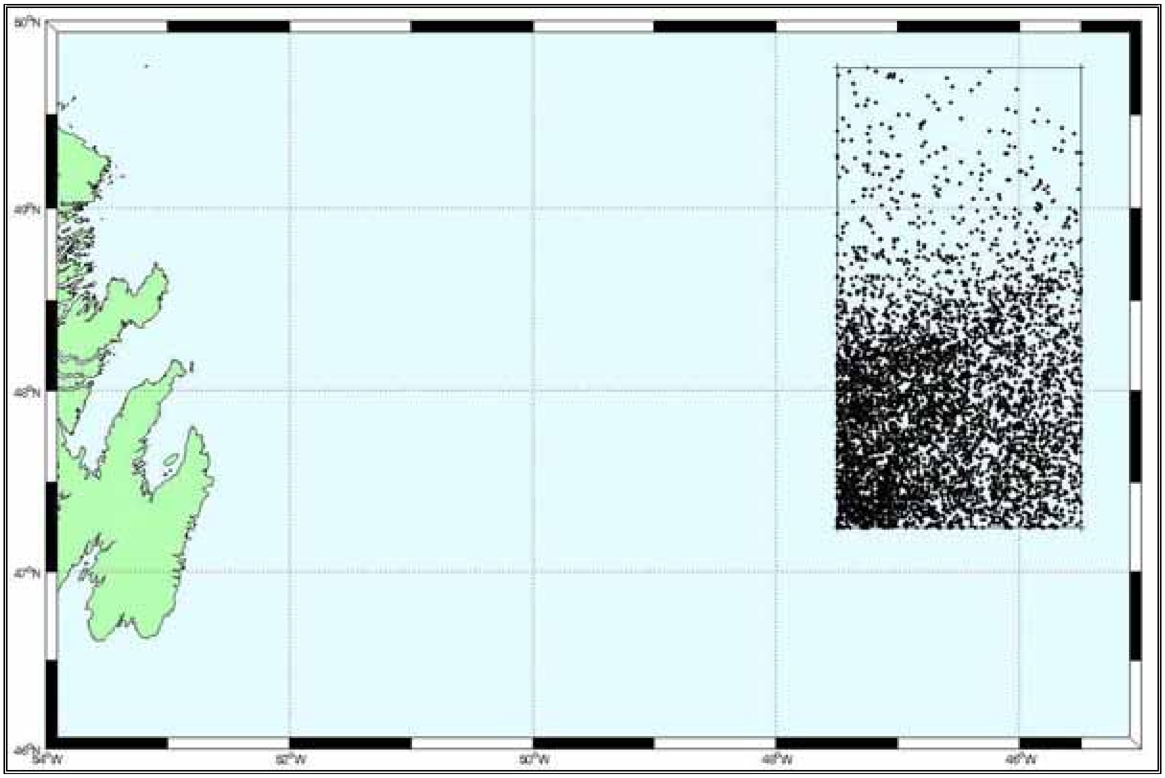


Figure 5.9 Iceberg sightings in Region 2 from 1974 - 2009

A monthly analysis (Table 5.3, Figure 5.10) shows that icebergs have been spotted within the region from December to August however they are most prominent during the month of March. With respect to size, the most prominent icebergs are medium sized, accounting for 26.3% of observed icebergs within the region. Large icebergs occur 8.2% of the time.

Table 5.3 Iceberg Size by month in Region 2 (source:IIP)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
General	0	10	176	185	271	100	57	1	0	0	0	0	800
Unidentified Target	25	30	39	14	53	26	6	0	0	1	0	1	195
Growler	0	5	38	21	40	2	3	0	0	2	0	0	111
Bergy Bit	3	5	16	17	19	2	0	0	0	0	0	0	62
Small	11	85	277	135	133	46	18	3	0	0	0	0	708
Medium	11	41	277	165	176	60	22	5	0	0	0	1	758
Large	1	4	73	44	65	40	7	2	0	0	0	0	236
Very Large	0	0	3	4	1	1	0	1	0	0	0	0	10
Randomized	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Monthly	51	180	899	585	758	277	113	12	0	3	0	2	2880

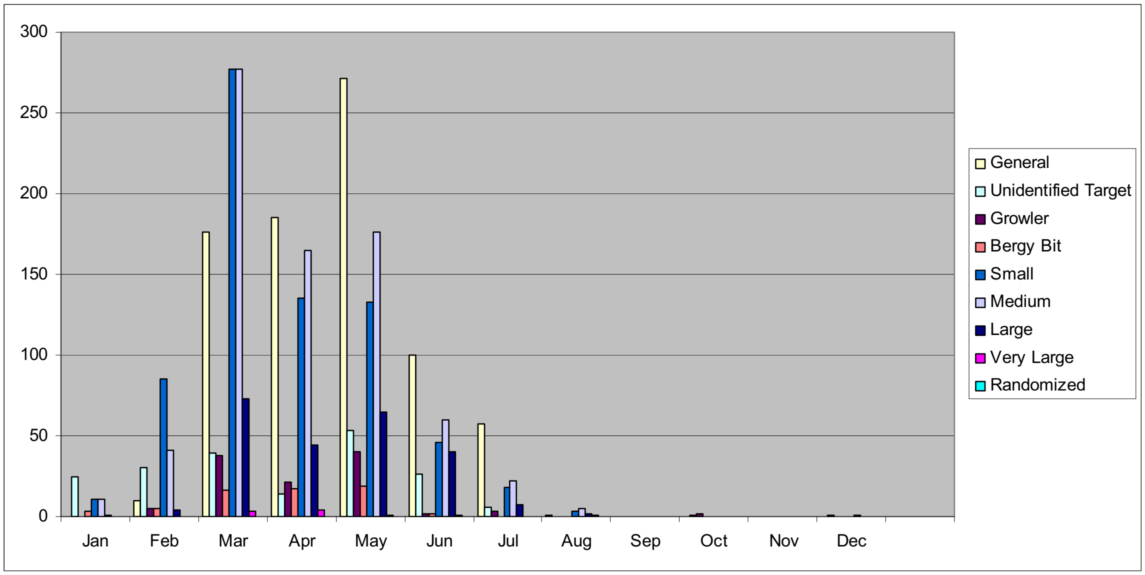


Figure 5.10 Iceberg Size by month in Region 2

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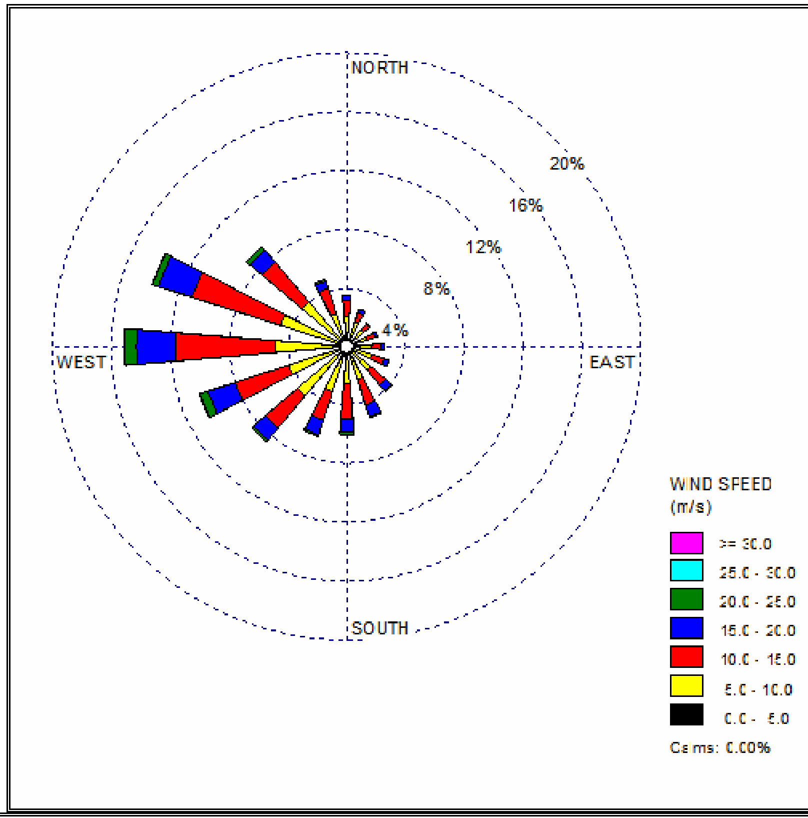
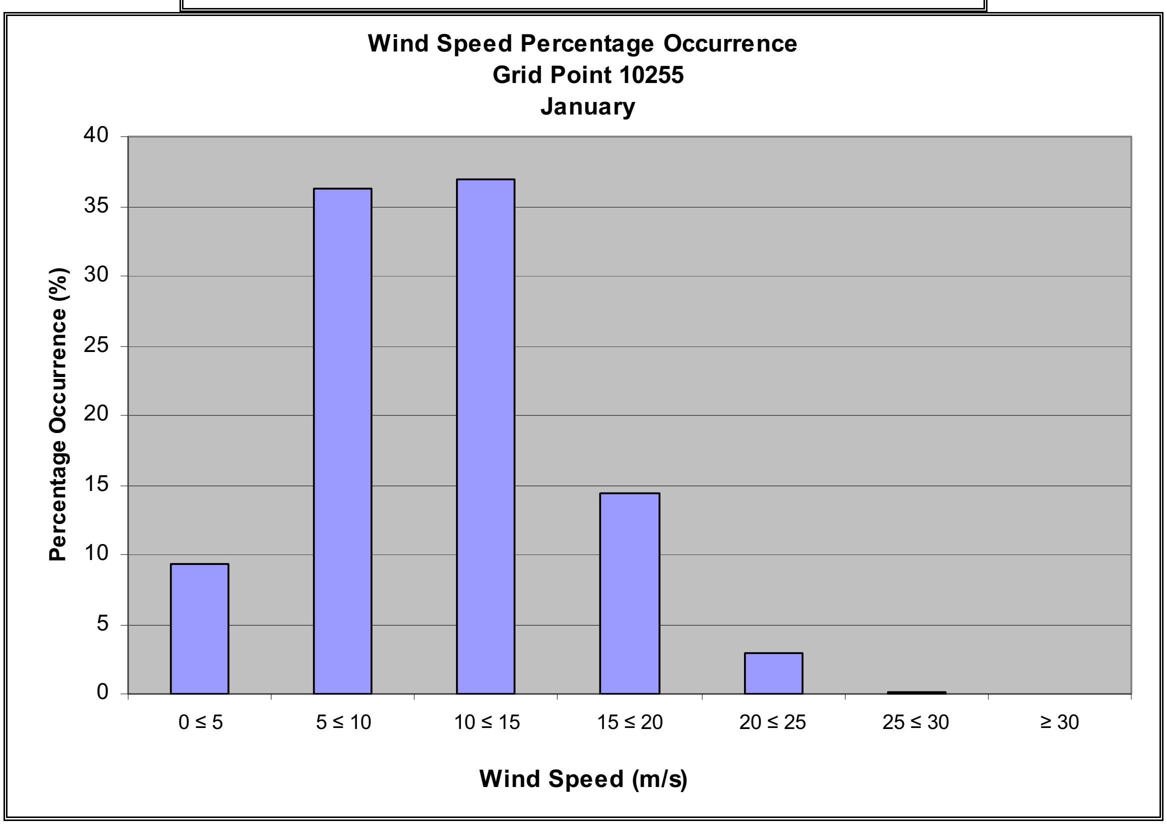
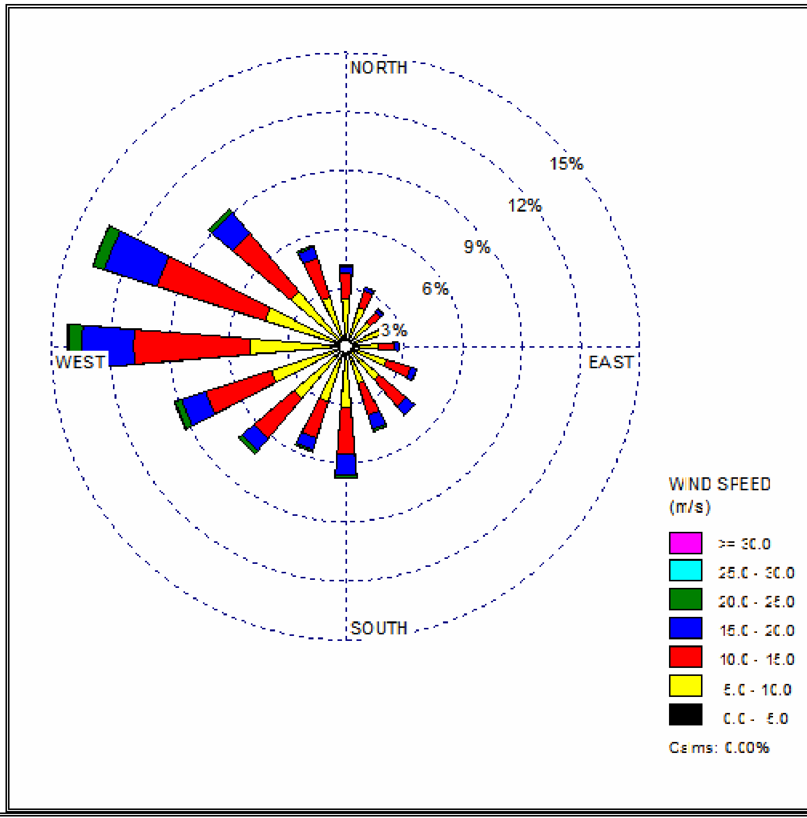
Appendix 1
Wind Roses and
Wind Speed Frequency Distributions
for MSC50 GridPoint 10255

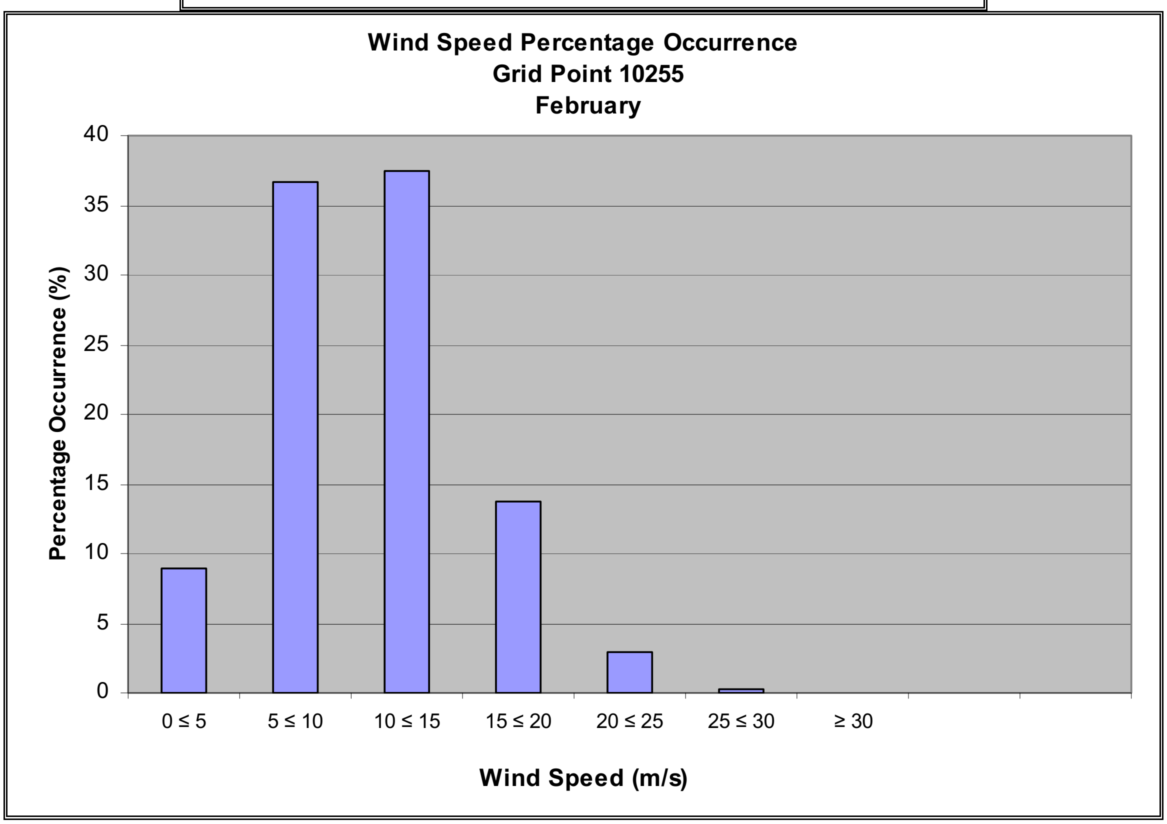
January


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

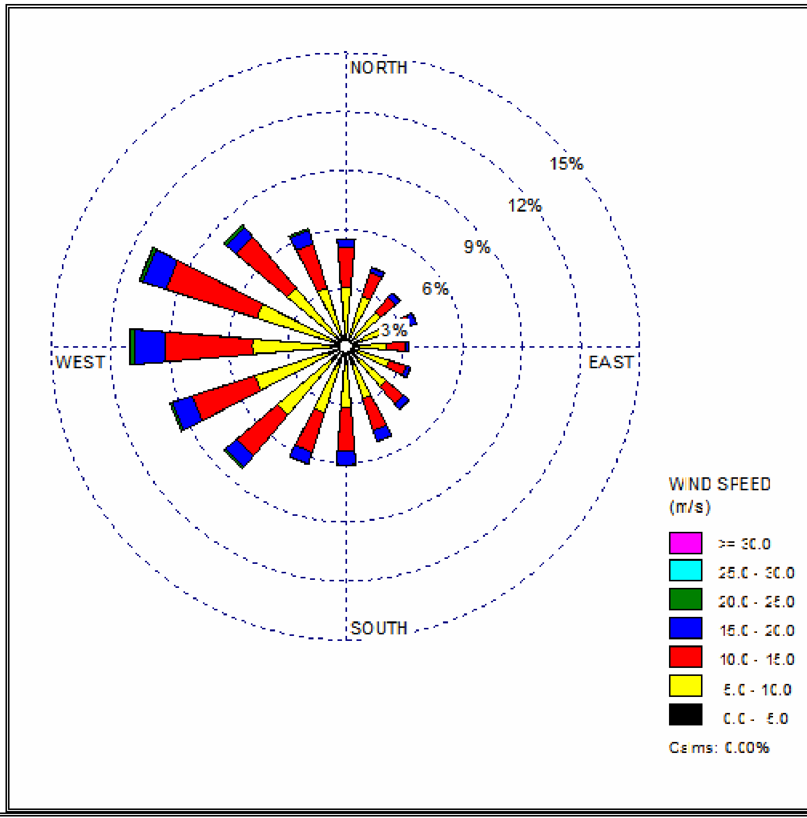

Wind Speed Percentage Occurrence
Grid Point 10255
January
Percentage Occurrence (%)
40
35
30
25
20
15
10
5
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

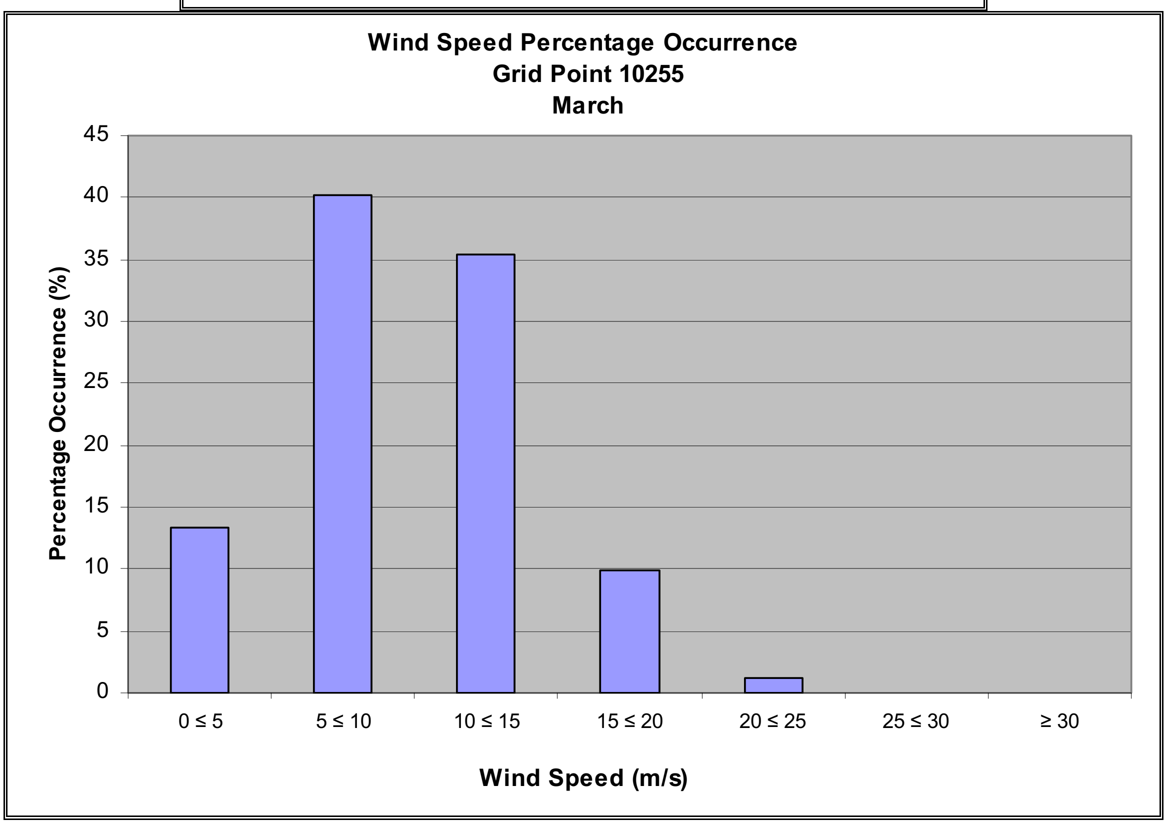
February


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

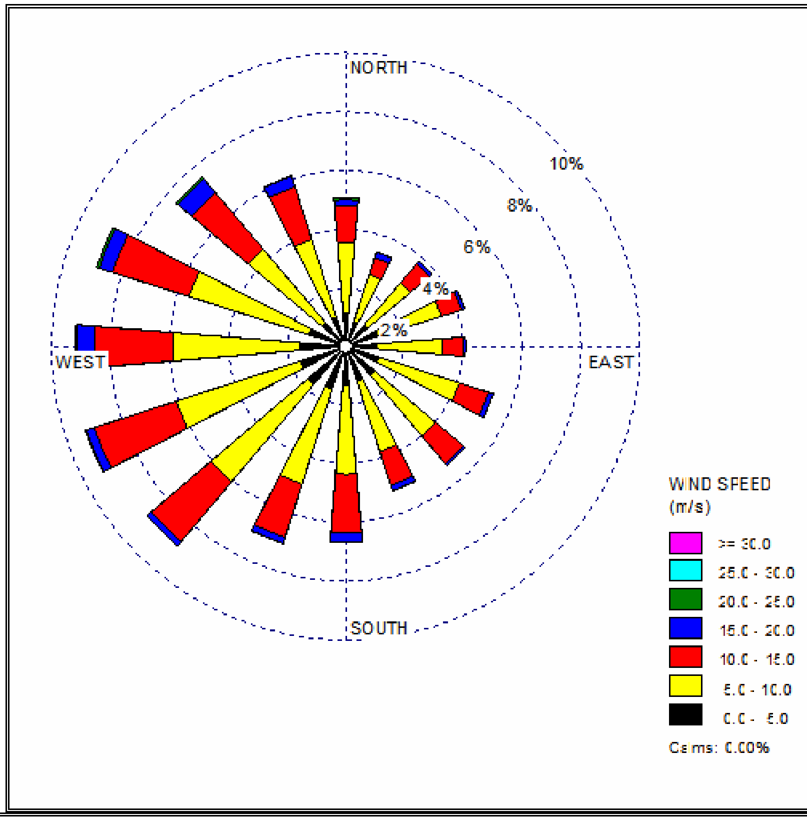

Wind Speed Percentage Occurrence
Grid Point 10255
February
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

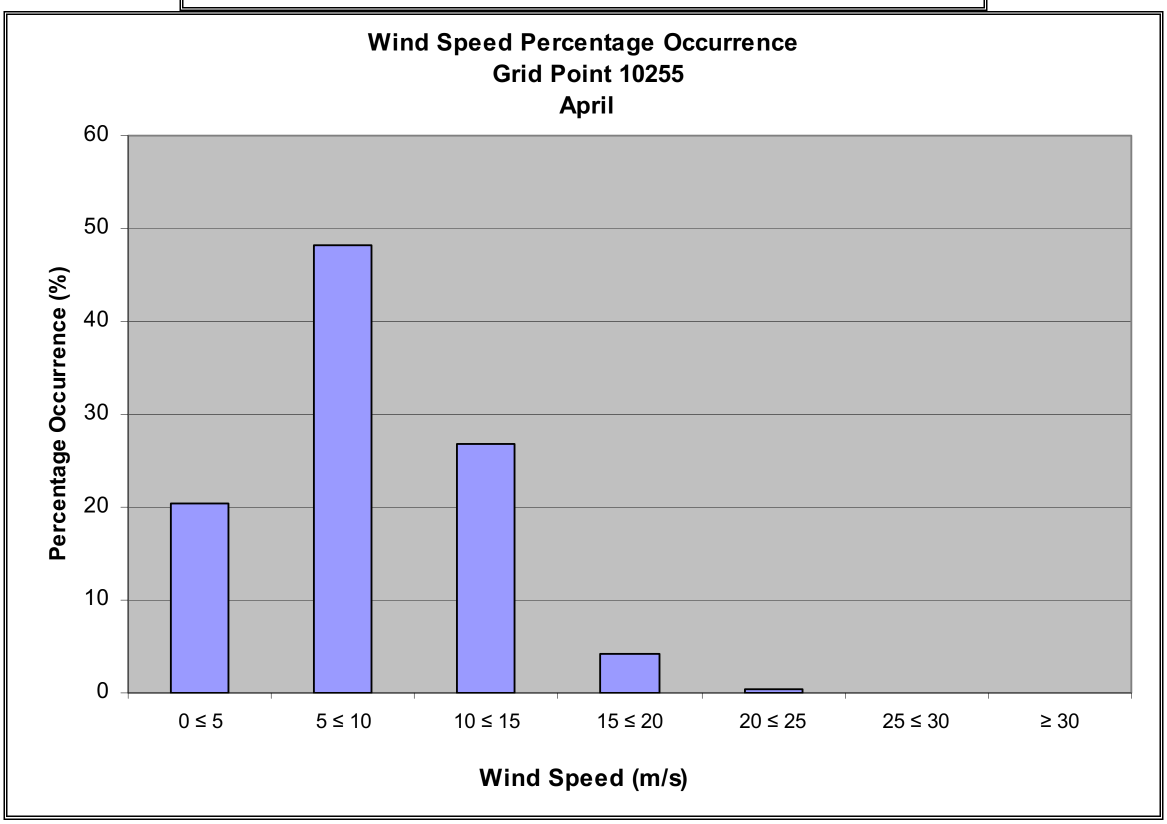
March


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

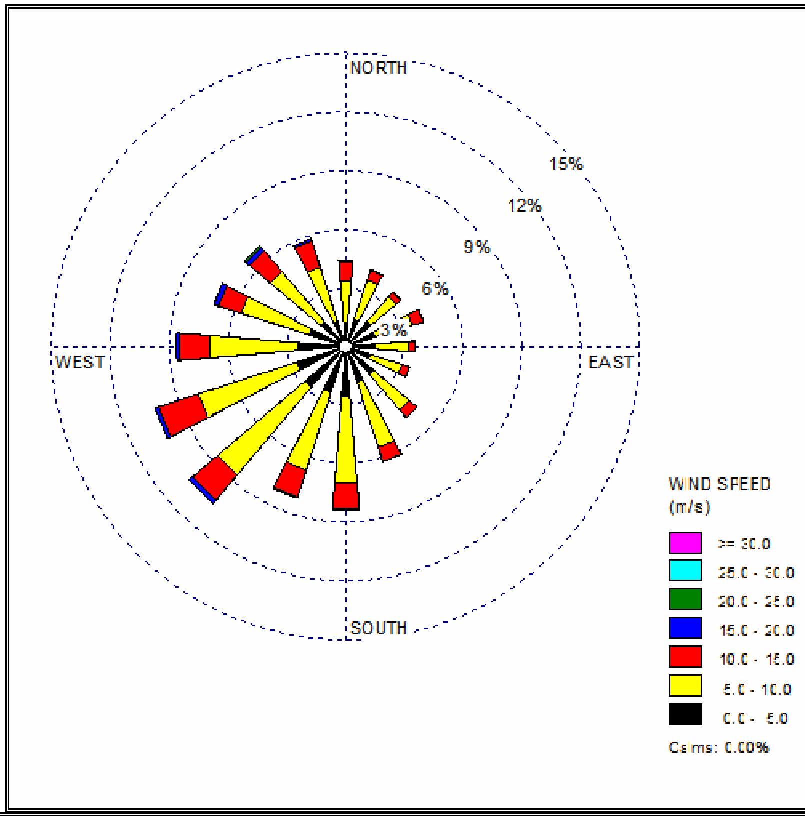

Wind Speed Percentage Occurrence
Grid Point 10255
March
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

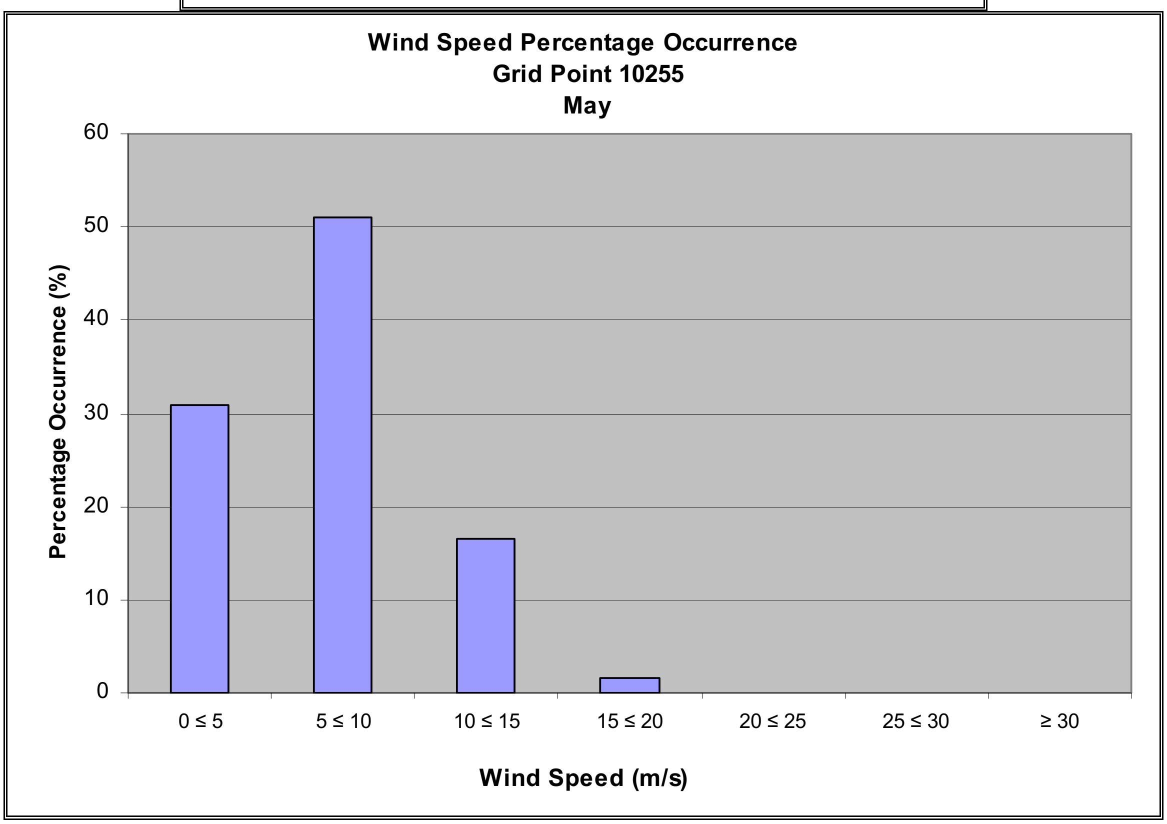
April


NORTH
SOUTH
WEST
EAST
2%
4%
6%
8%
10%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

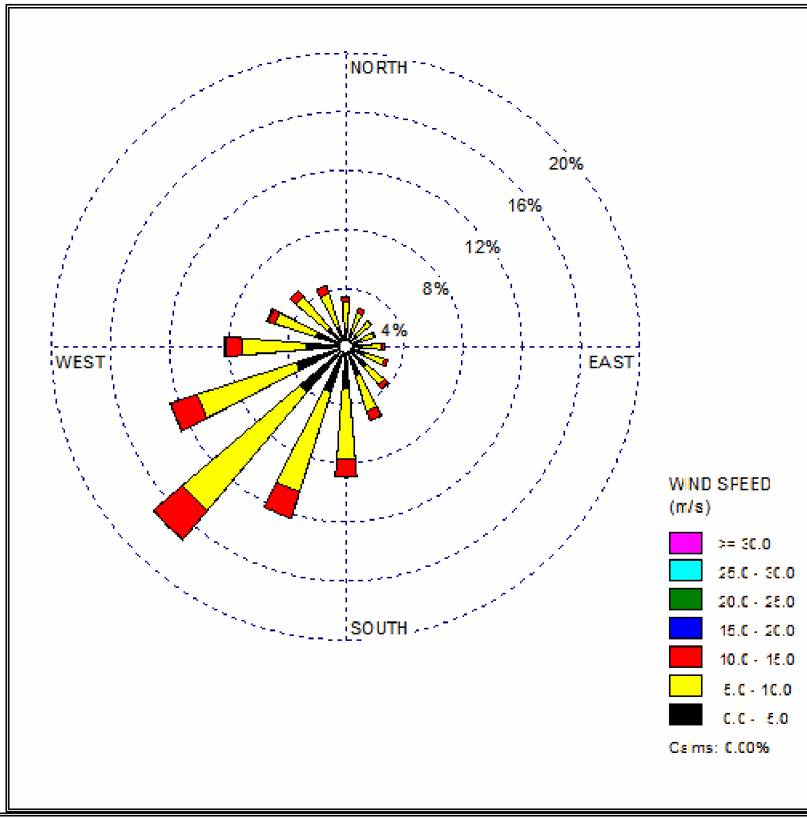

Wind Speed Percentage Occurrence
Grid Point 10255
April
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

May

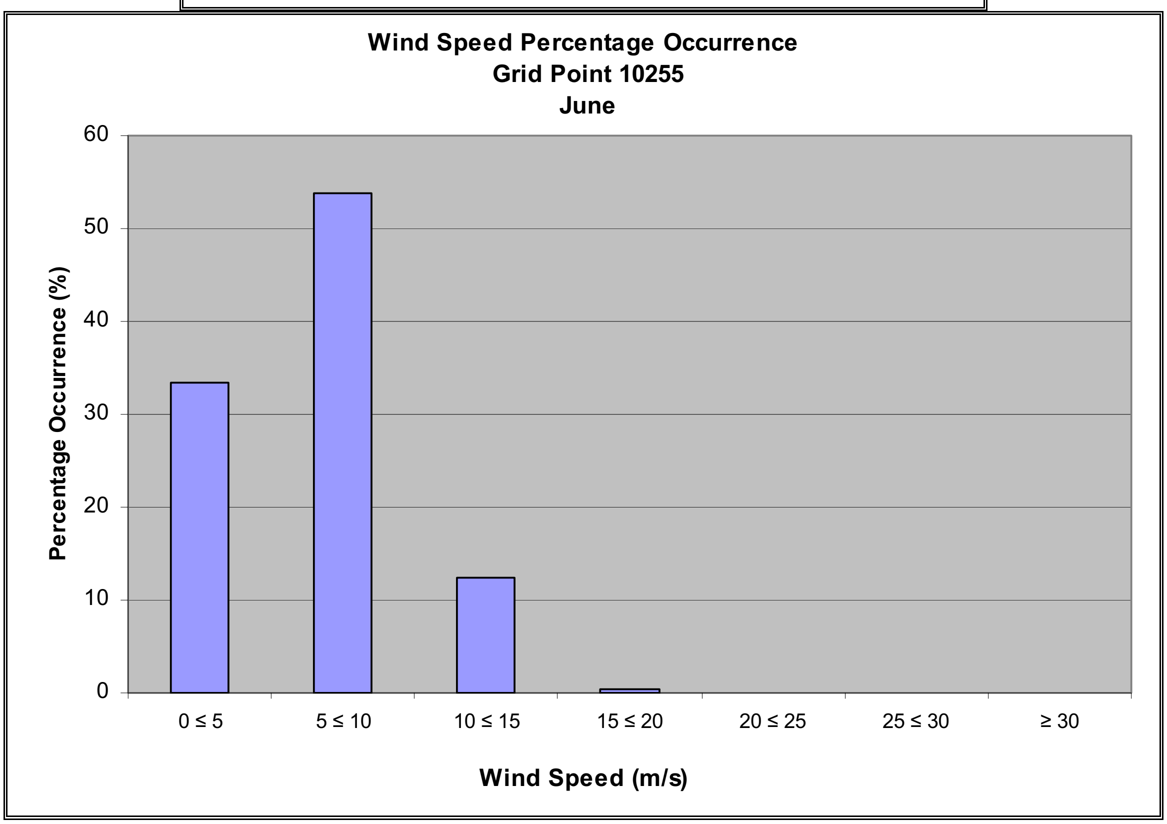

NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 10255
May
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

June

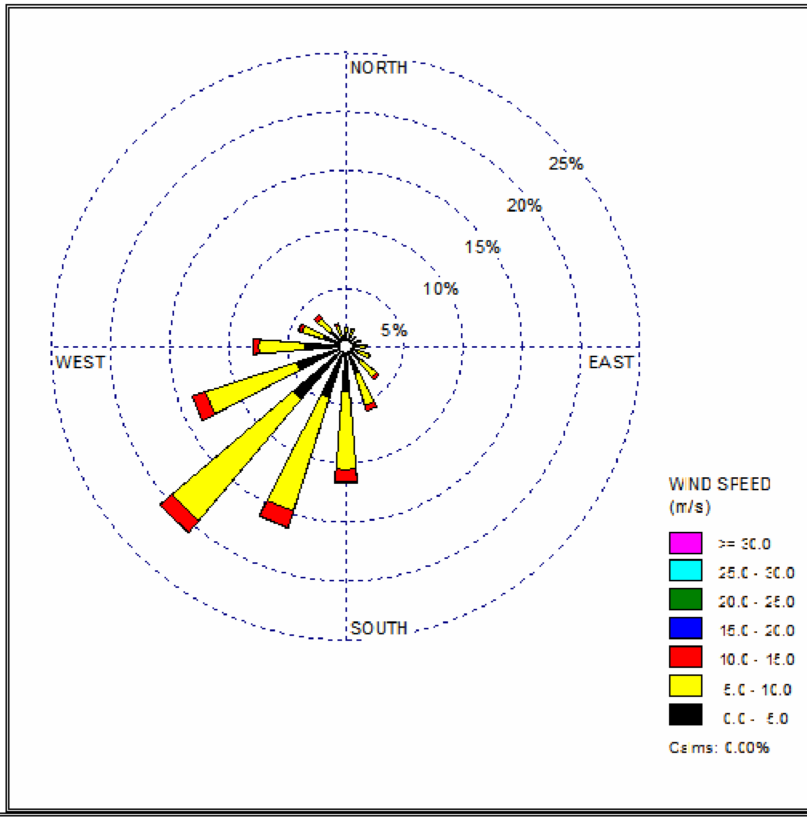


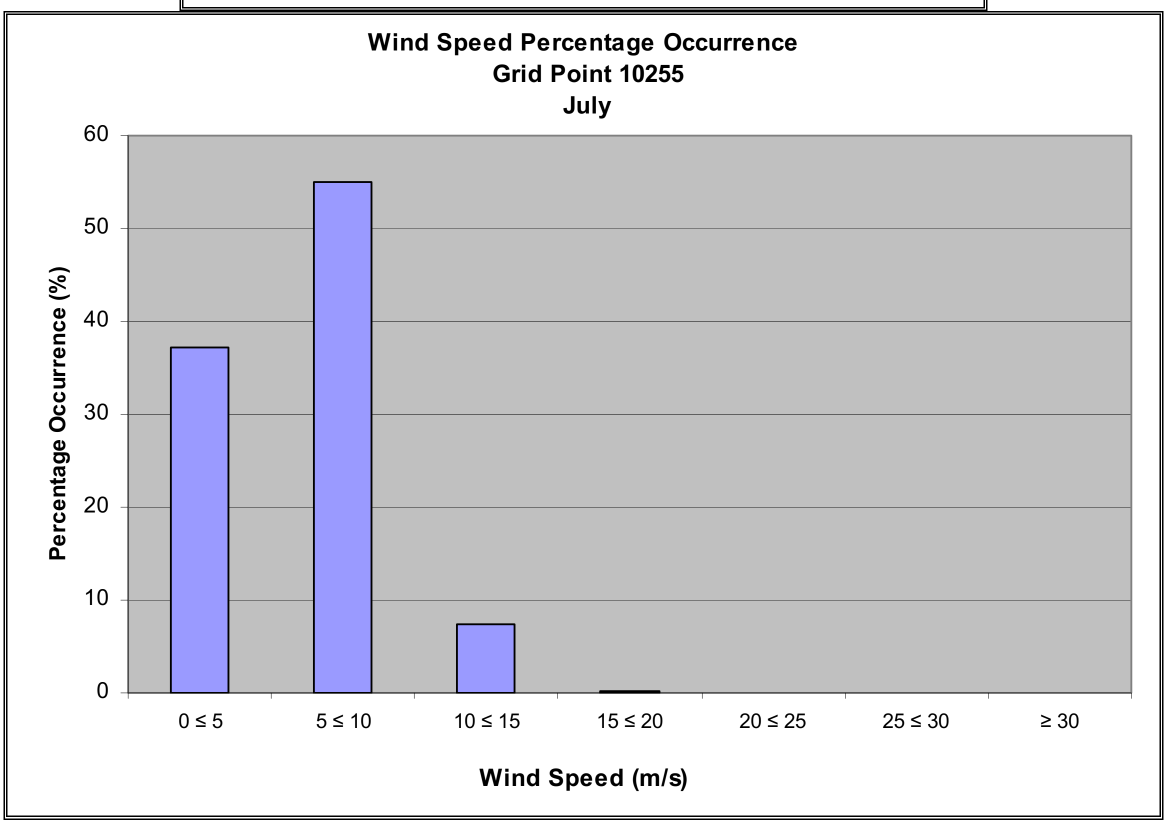
NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%



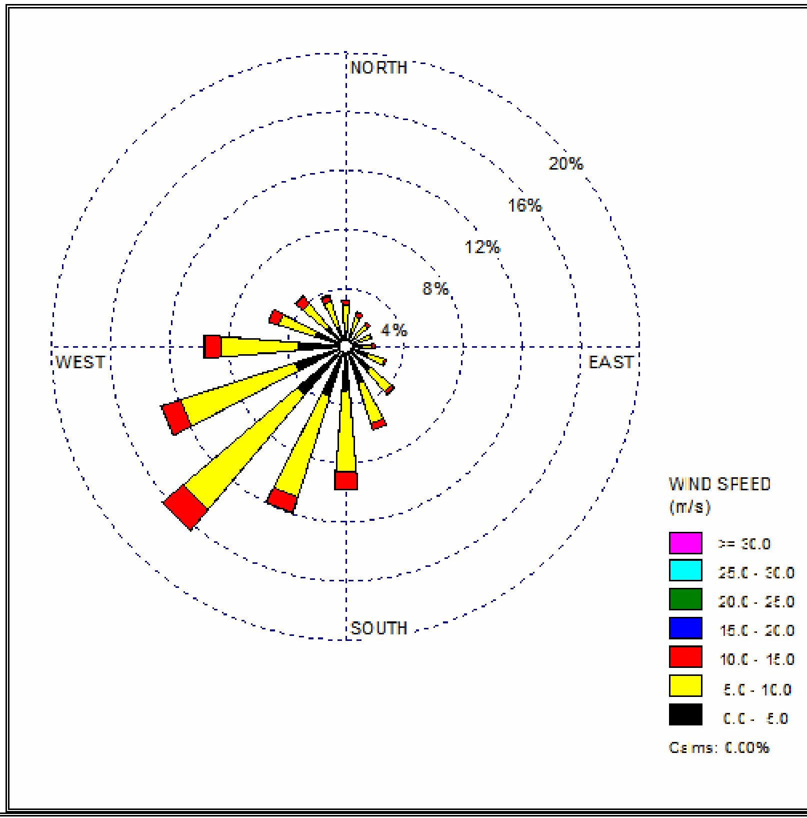
Wind Speed Percentage Occurrence
Grid Point 10255
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

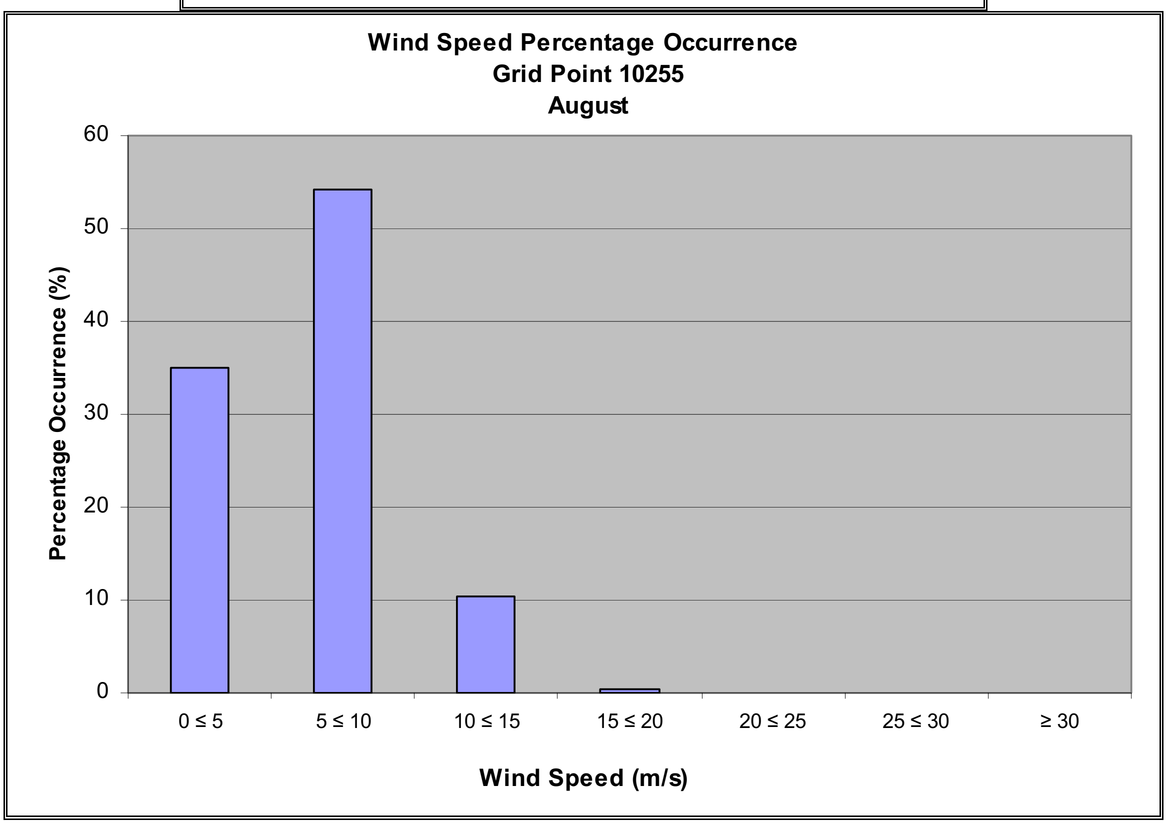
July


NORTH
SOUTH
EAST
WEST
5%
10%
15%
20%
25%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

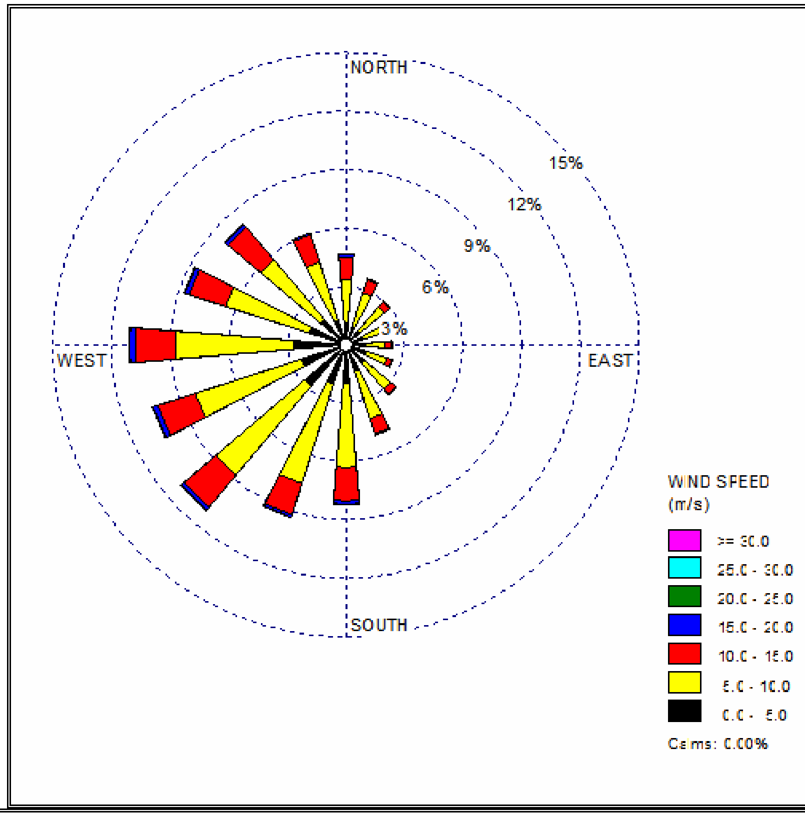

Wind Speed Percentage Occurrence
Grid Point 10255
July
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

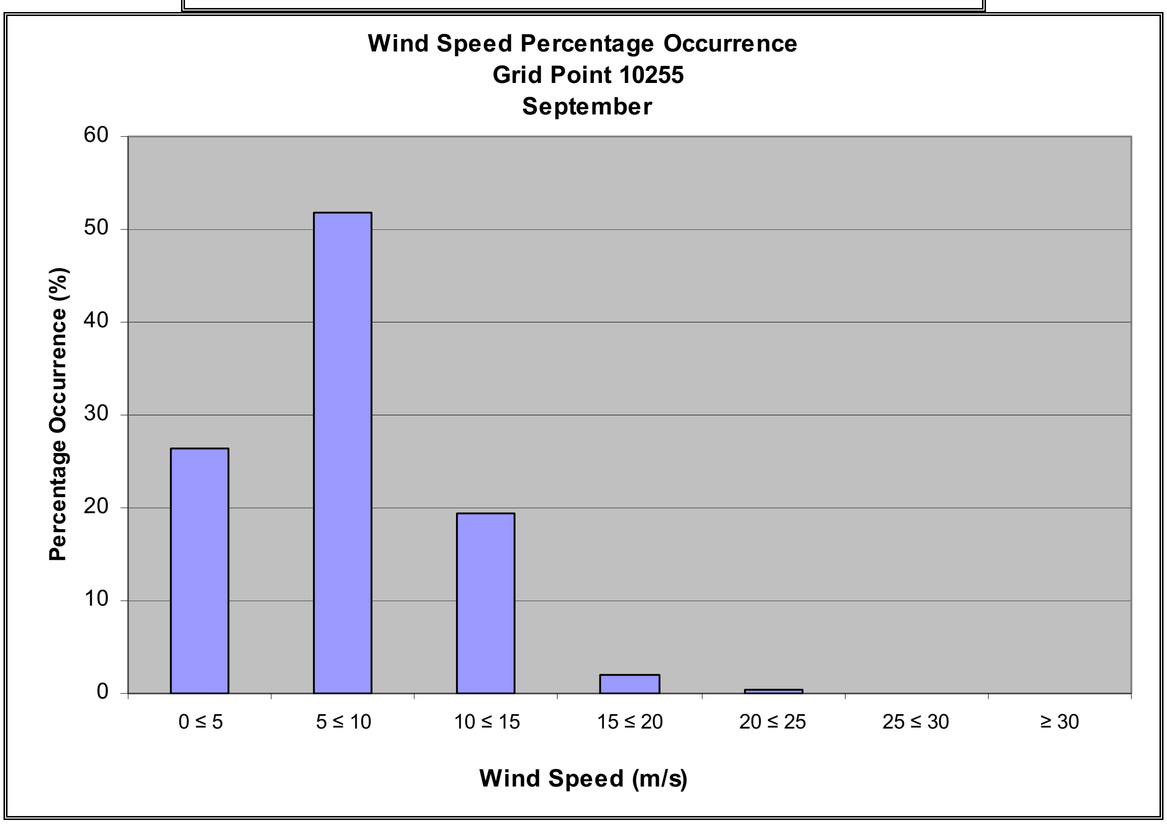
August


NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

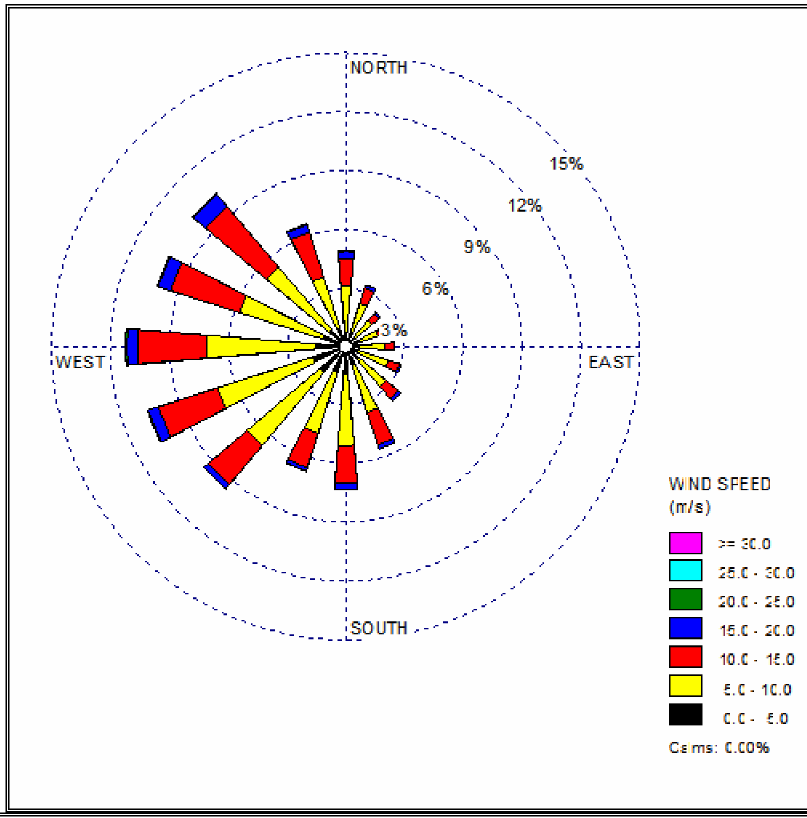

Wind Speed Percentage Occurrence
Grid Point 10255
August
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

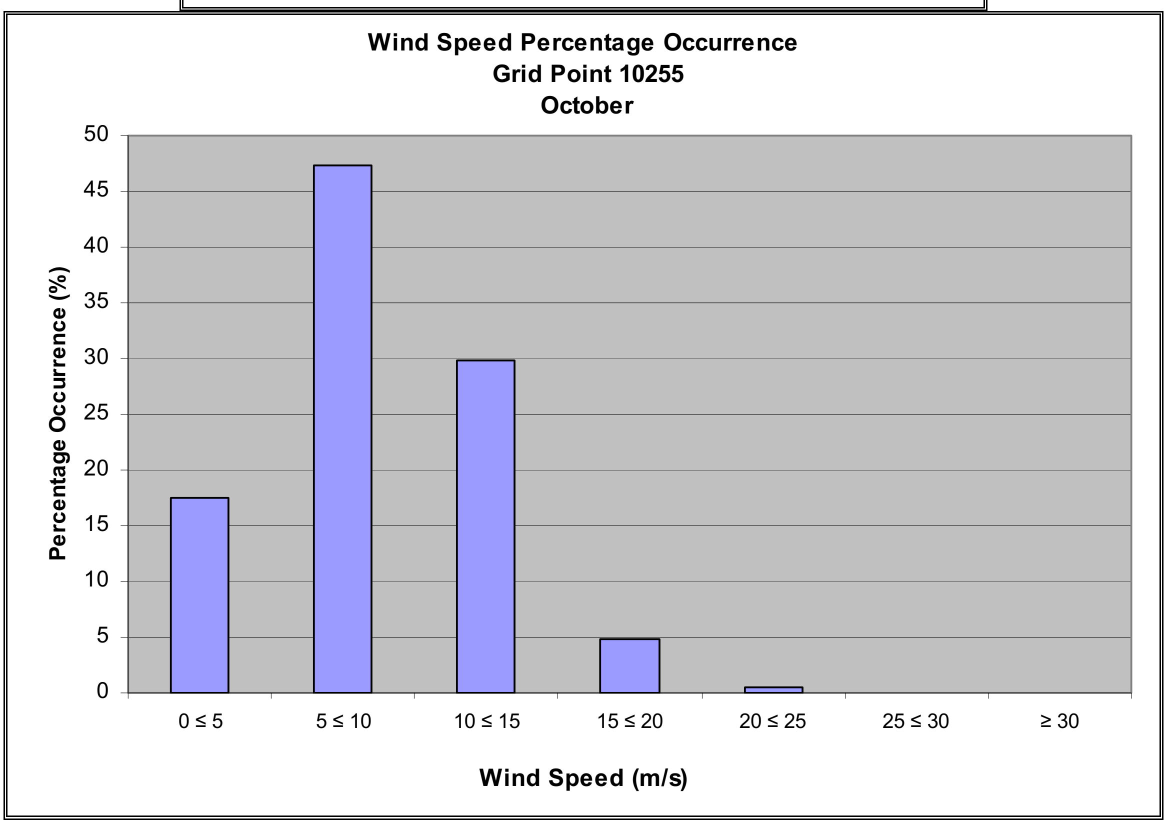
September


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%

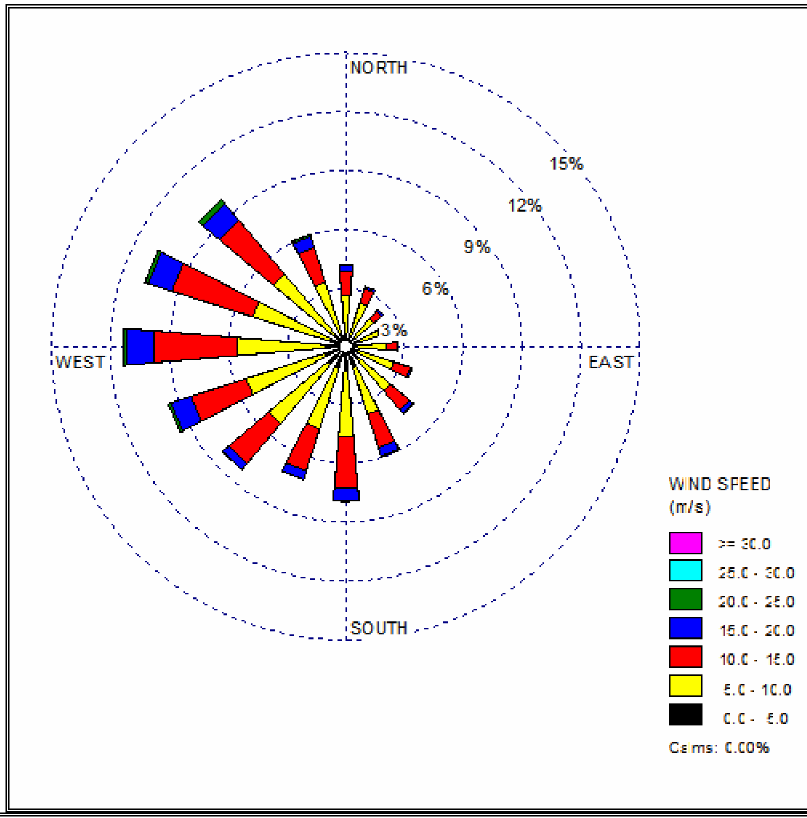

Wind Speed Percentage Occurrence
Grid Point 10255
September
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

October

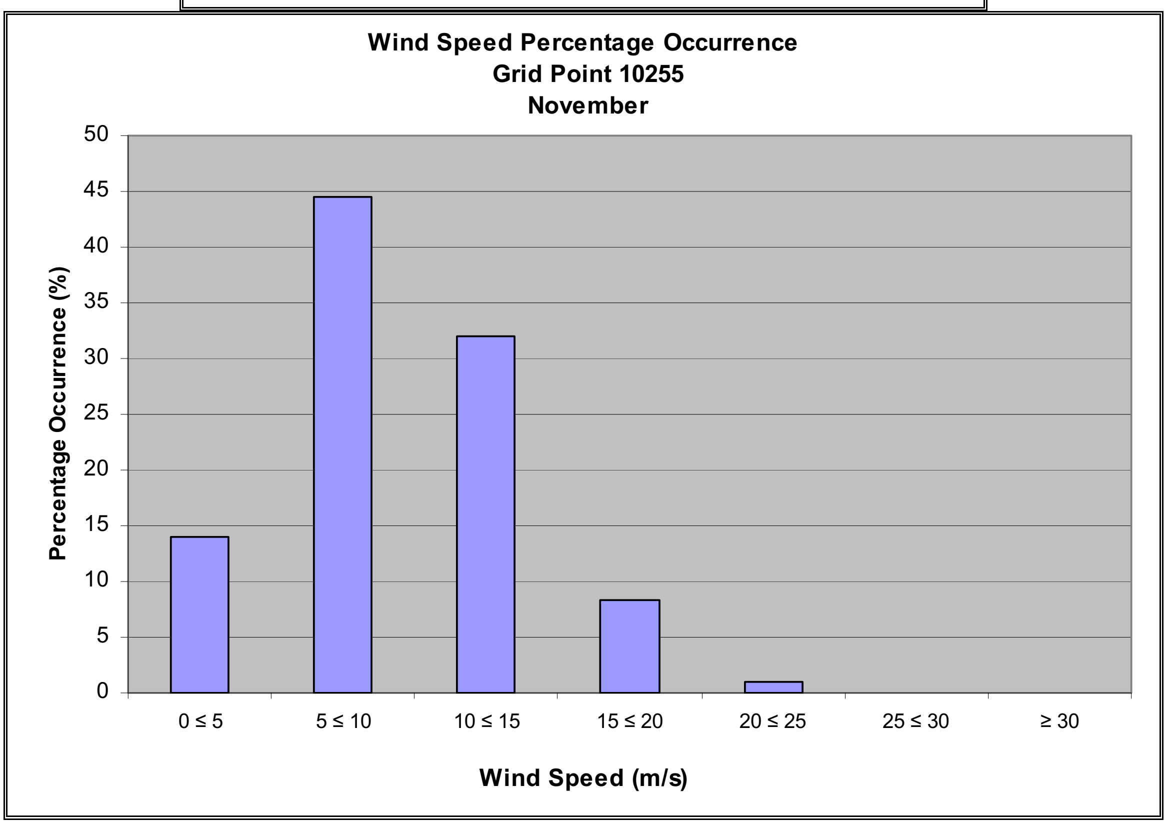

NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 10255
October
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

November

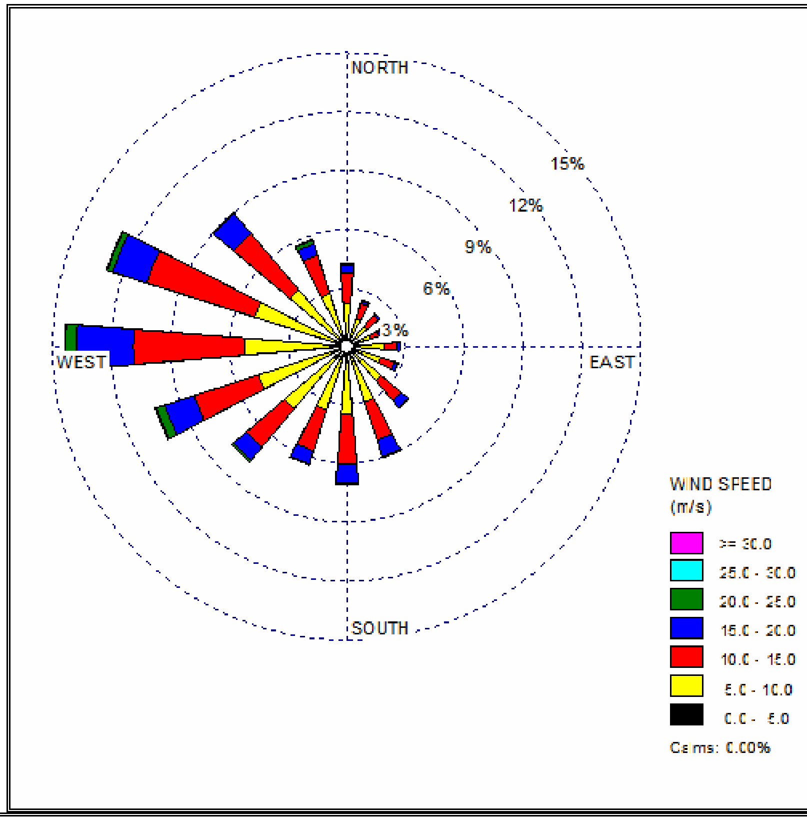


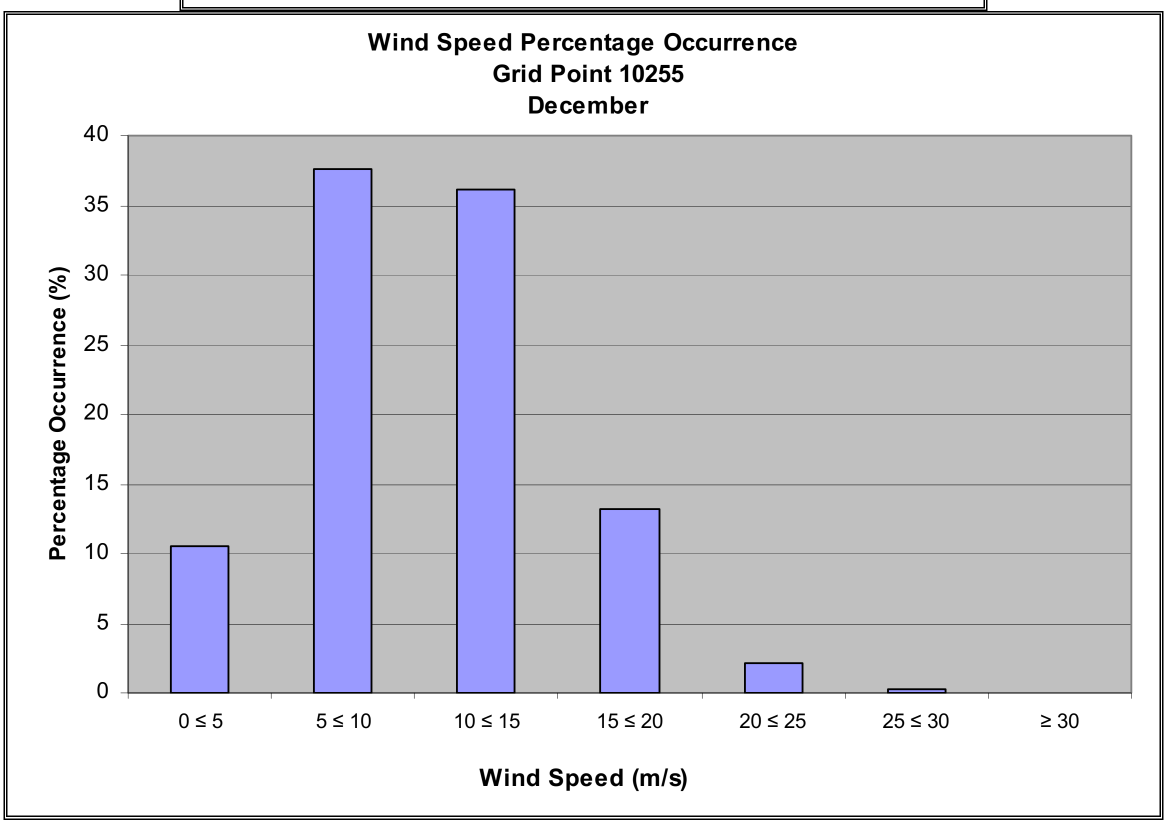
NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
WIND SPEED (m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%



Wind Speed Percentage Occurrence
Grid Point 10255
November
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

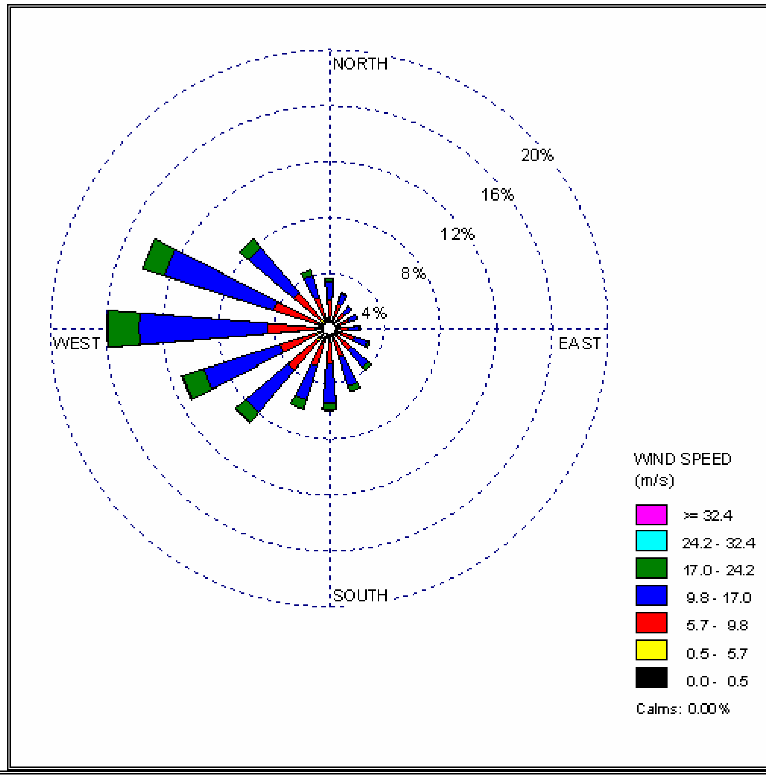
December

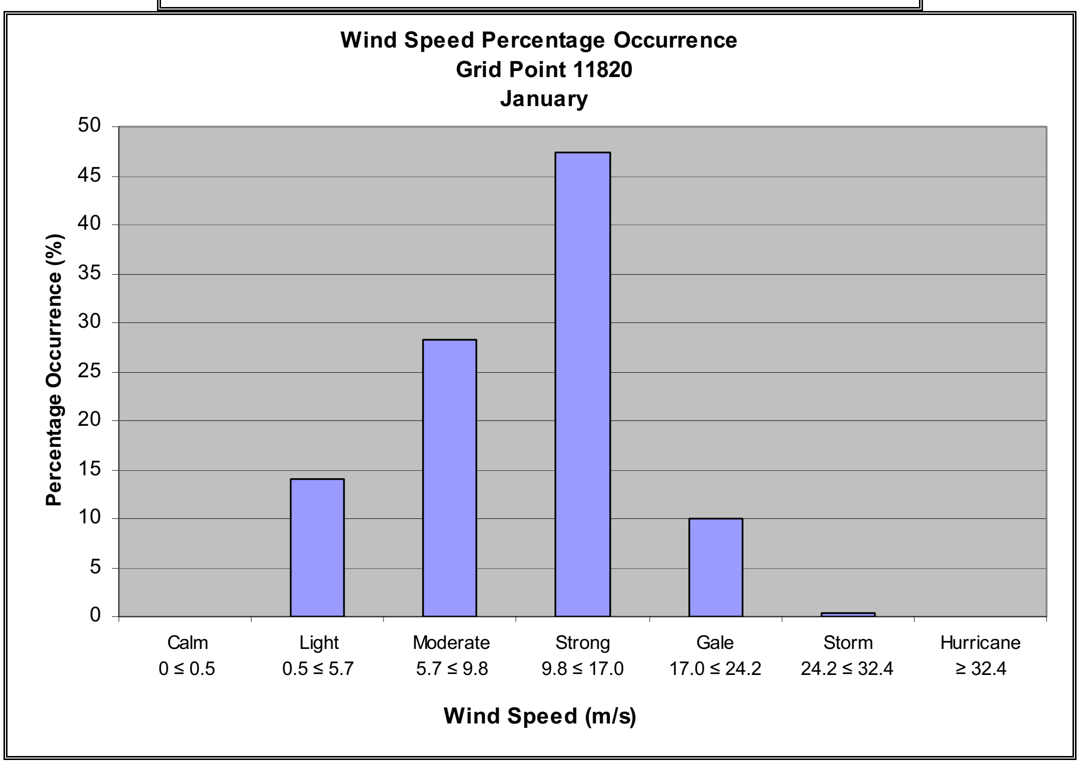

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED
(m/s)
>= 30.0
25.0 - 30.0
20.0 - 25.0
15.0 - 20.0
10.0 - 15.0
5.0 - 10.0
0.0 - 5.0
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 10255
December
Percentage Occurrence (%)
40
35
30
25
20
15
10
5
0
0 ≤ 5
5 ≤ 10
10 ≤ 15
15 ≤ 20
20 ≤ 25
25 ≤ 30
≥ 30
Wind Speed (m/s)

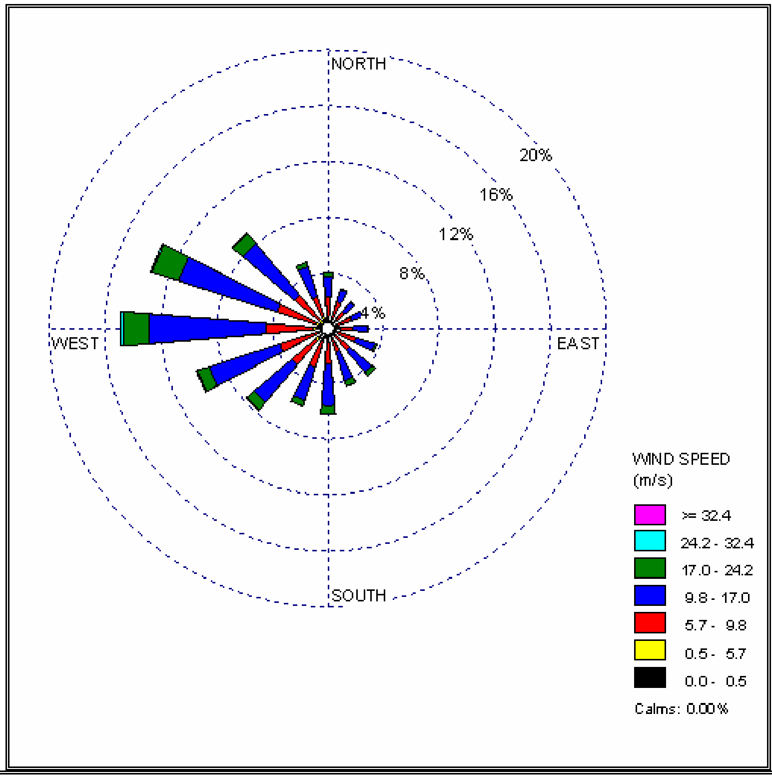
Appendix 2
Wind Roses and
Wind Speed Frequency Distributions
for MSC50 GridPoint 11820

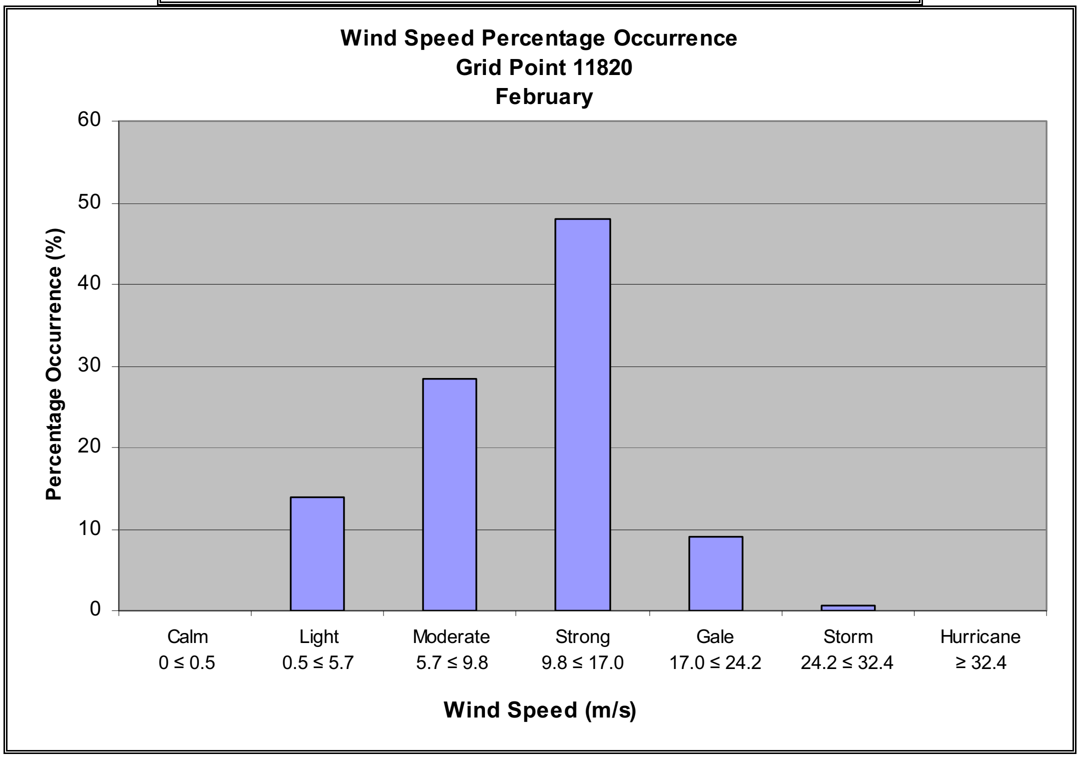
January


NORTH
SOUTH
WEST
EAST
20%
16%
12%
8%
4%
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%

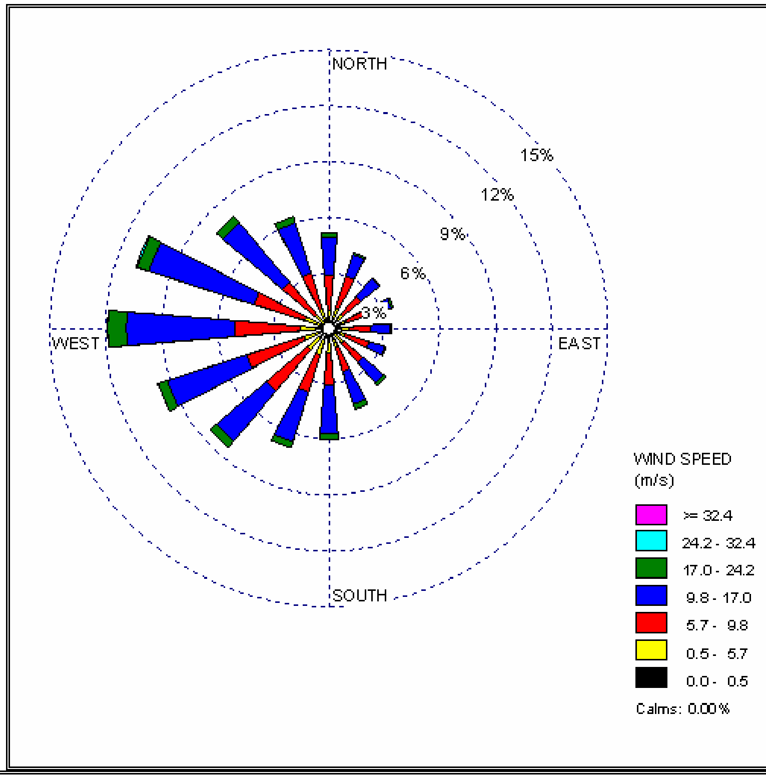

Wind Speed Percentage Occurrence
Grid Point 11820
January
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

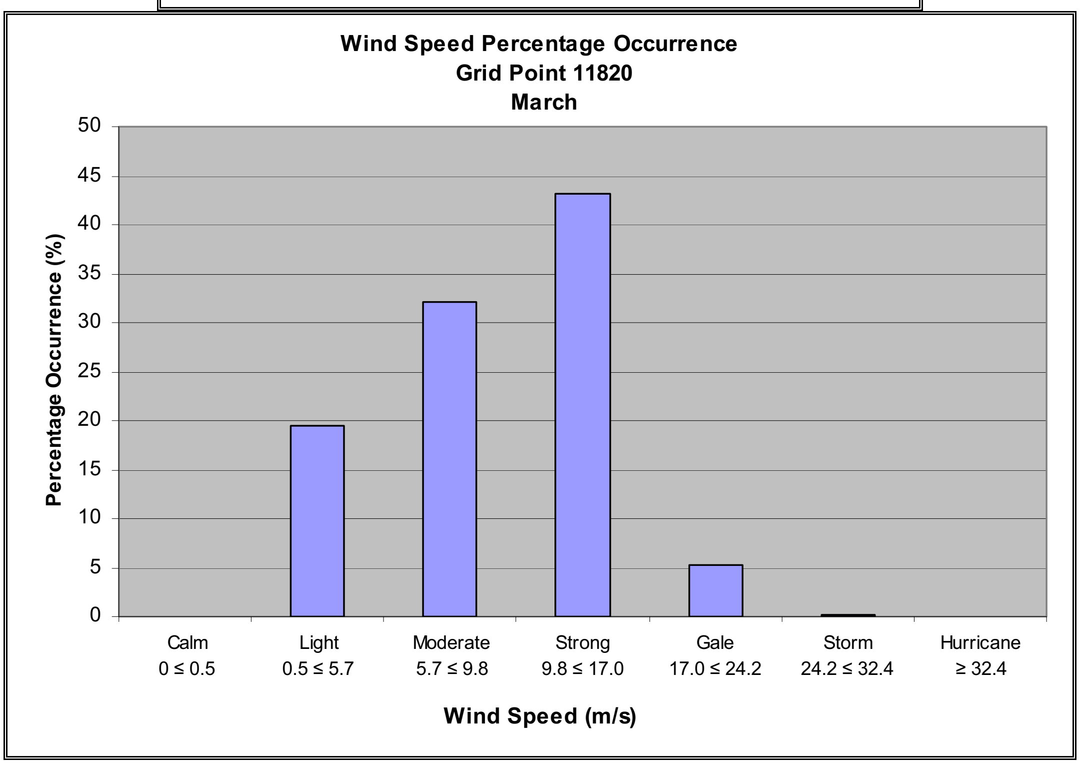
February


NORTH
SOUTH
WEST
EAST
20%
16%
12%
8%
4%
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%

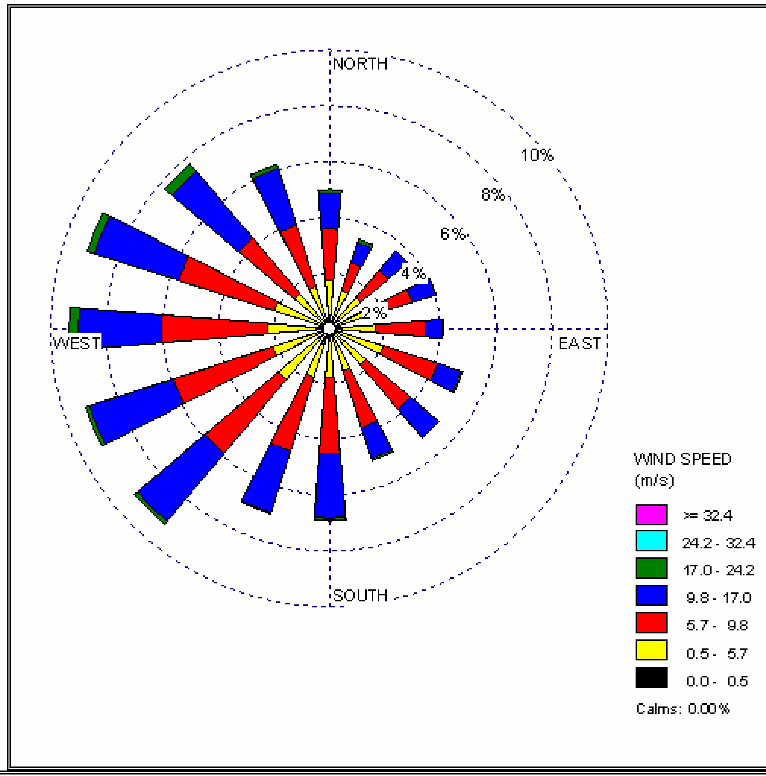

Wind Speed Percentage Occurrence
Grid Point 11820
February
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

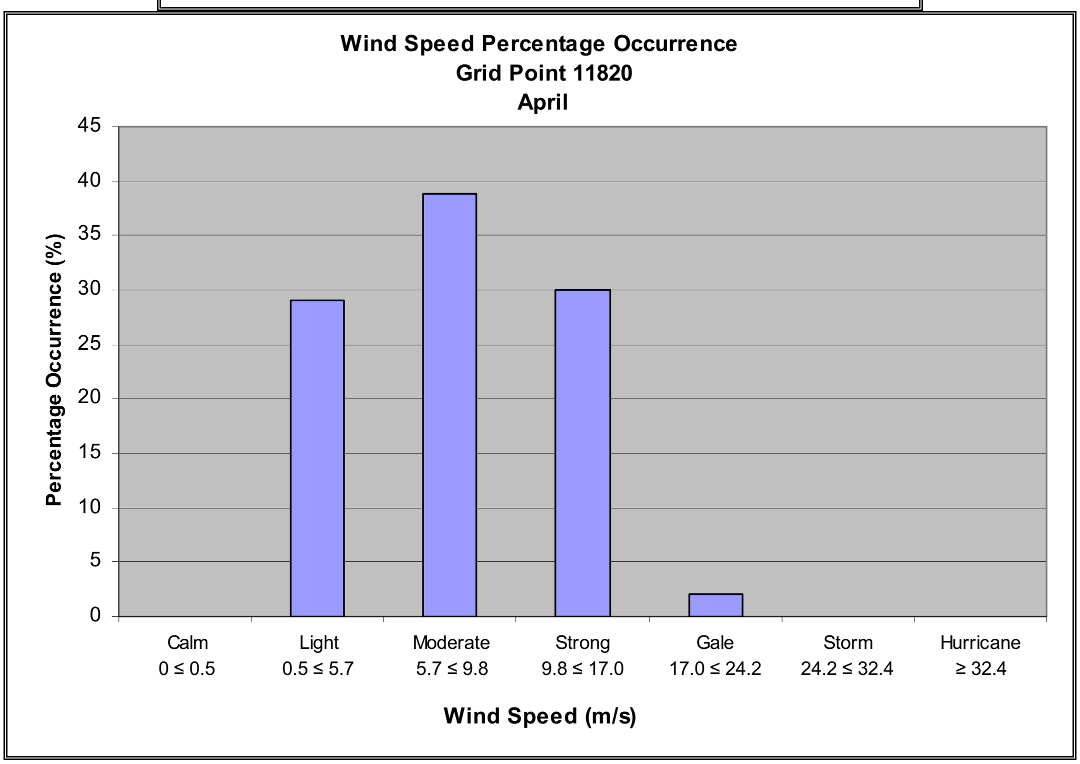
March


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
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%

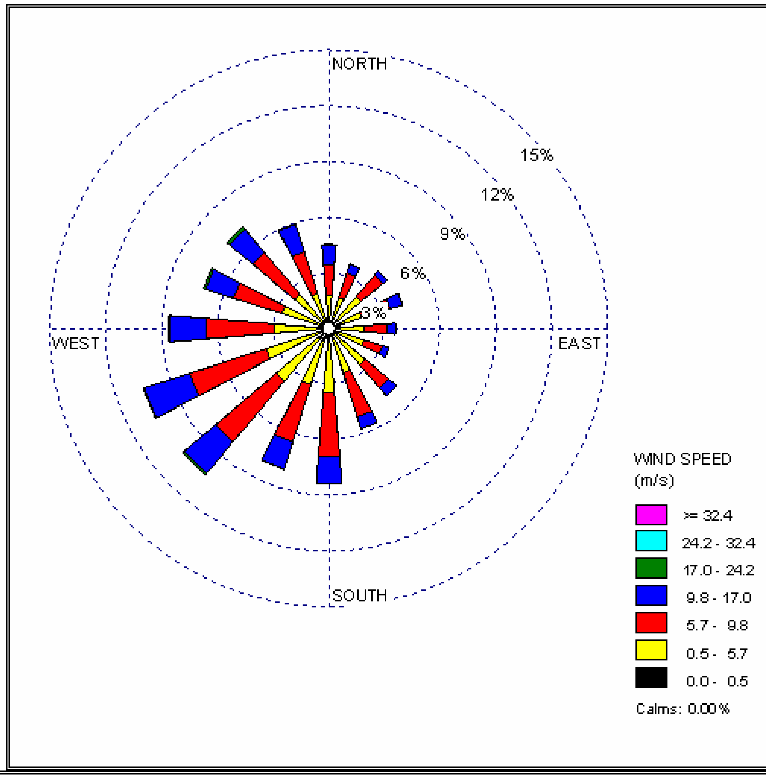

Wind Speed Percentage Occurrence
Grid Point 11820
March
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

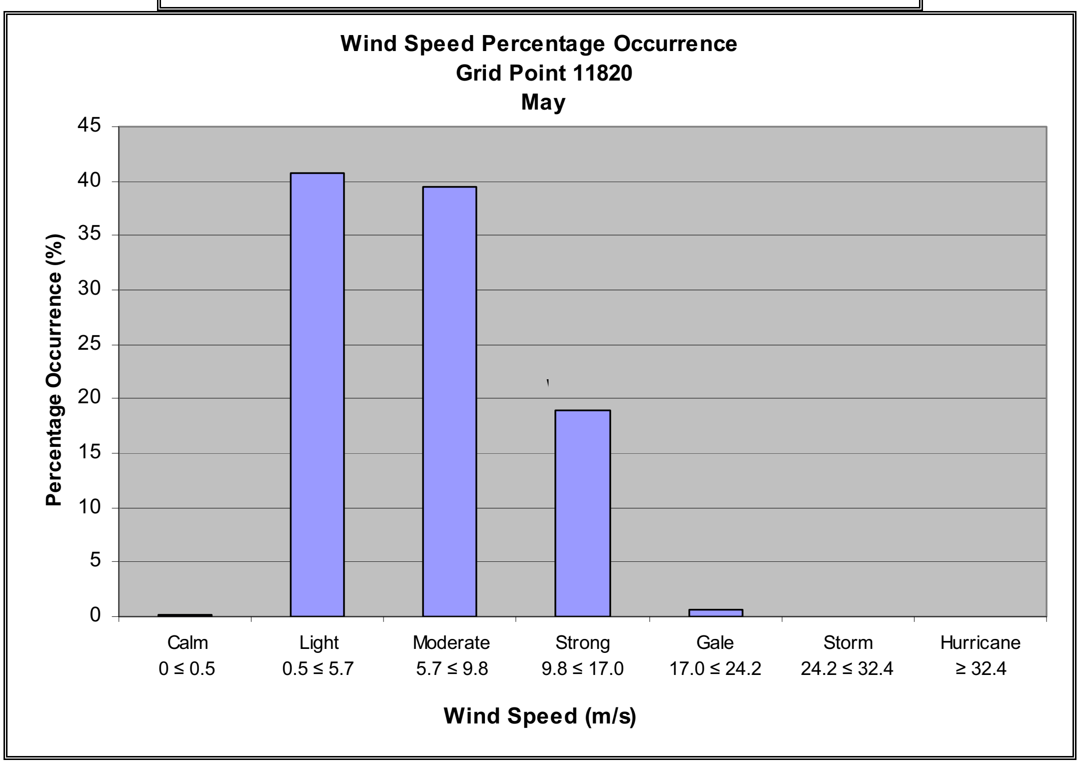
April


NORTH
SOUTH
WEST
EAST
10%
8%
6%
4%
2%
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%

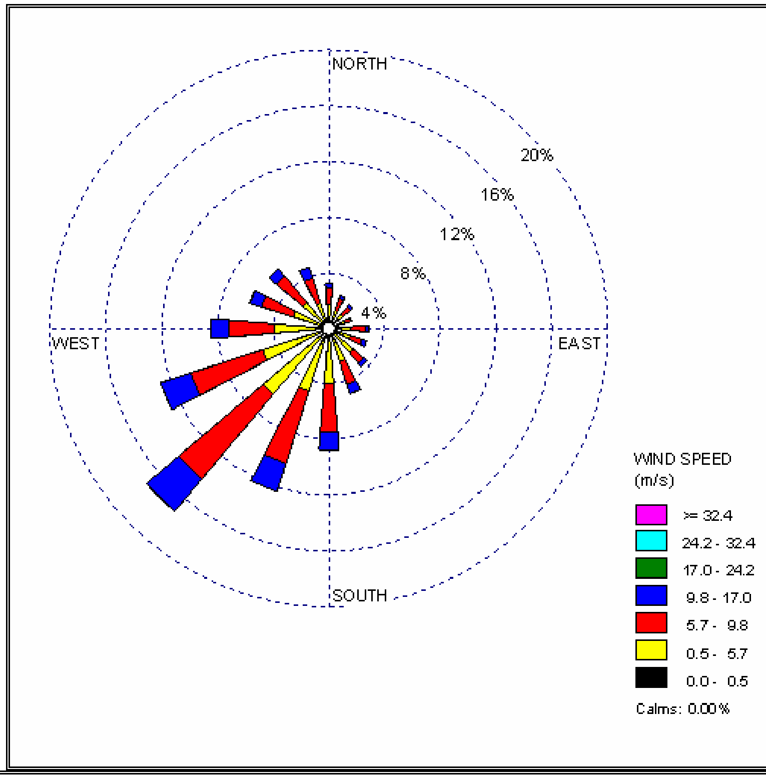

Wind Speed Percentage Occurrence
Grid Point 11820
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

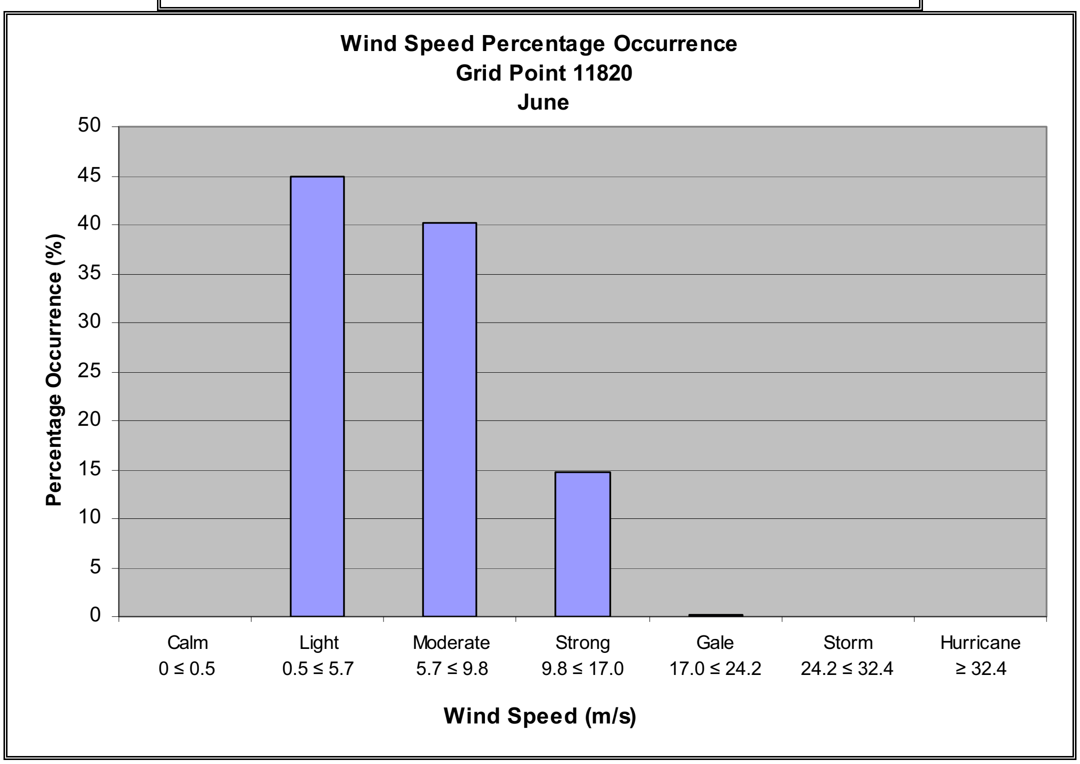
May


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
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%

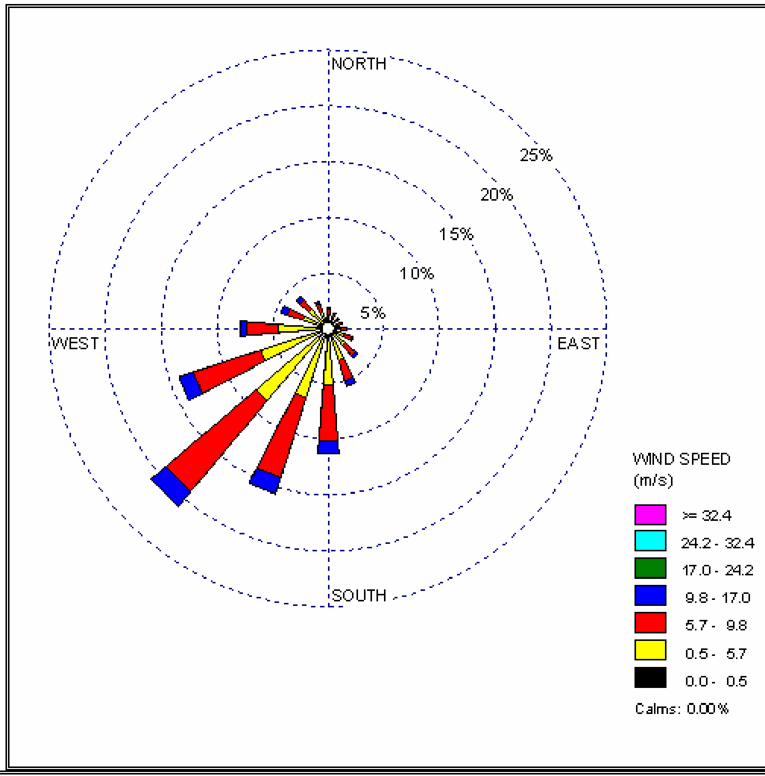

Wind Speed Percentage Occurrence
Grid Point 11820
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

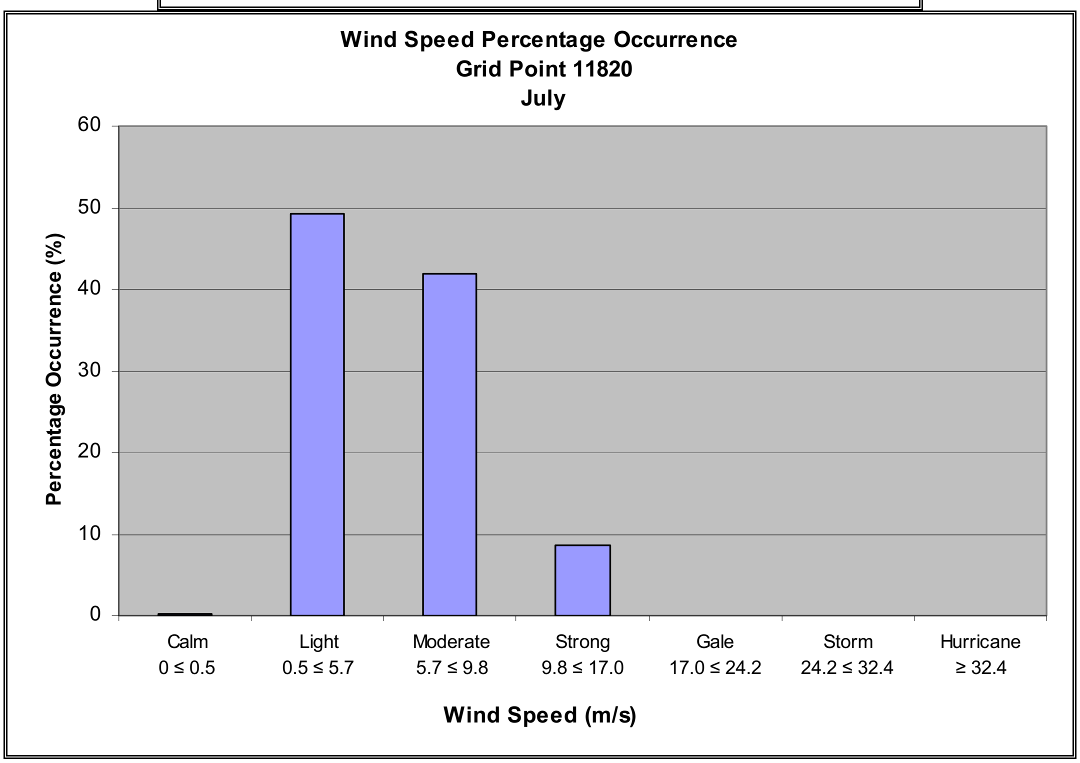
June


NORTH
20%
16%
12%
8%
4%
WEST
EAST
SOUTH
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%

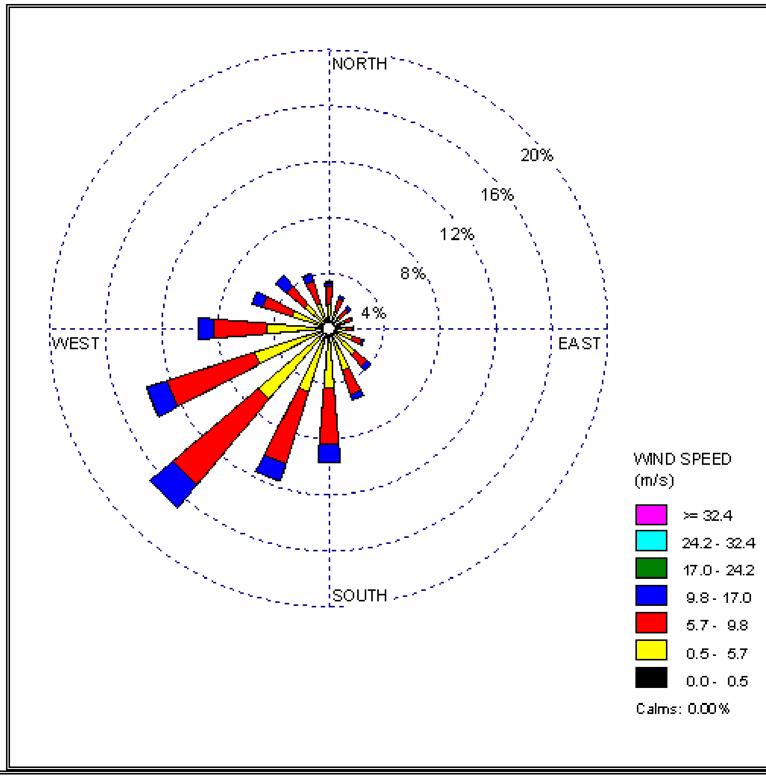

Wind Speed Percentage Occurrence
Grid Point 11820
June
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

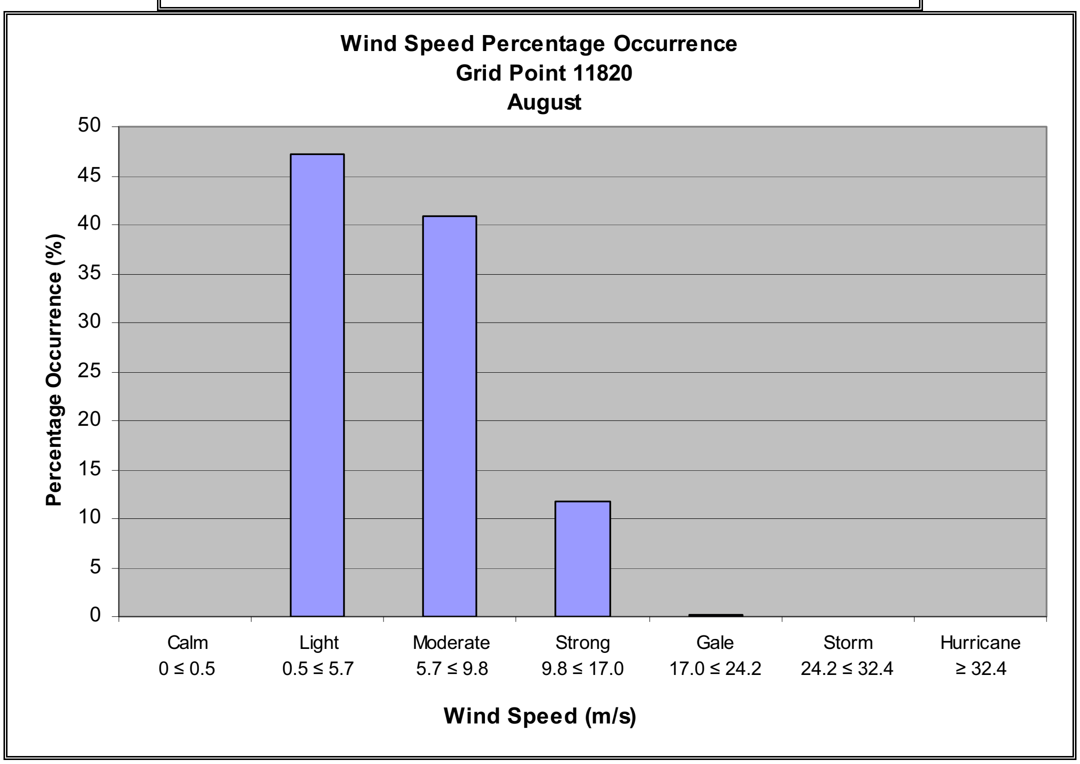
July


NORTH
25%
20%
15%
10%
5%
WEST
EAST
SOUTH
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%

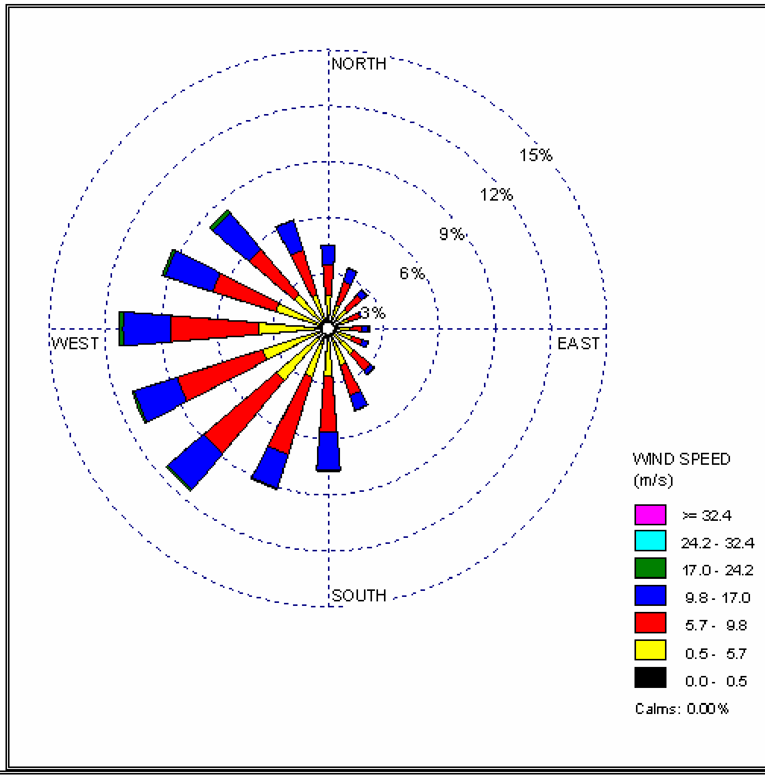

Wind Speed Percentage Occurrence
Grid Point 11820
July
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

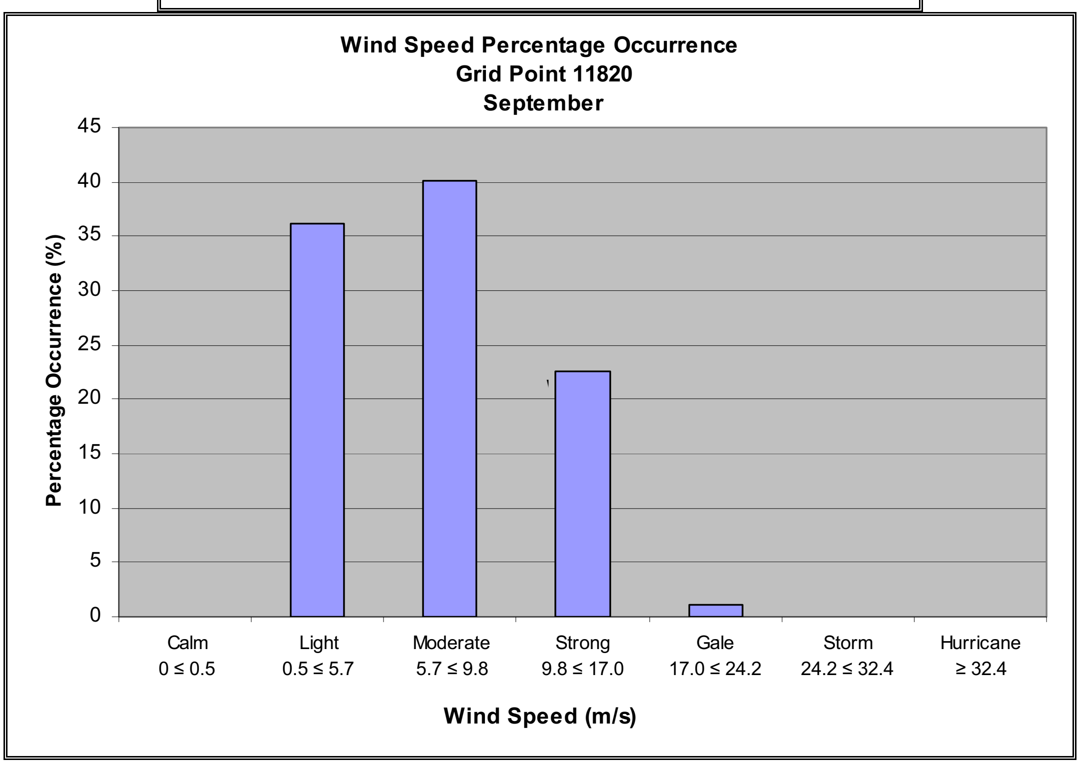
August


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%

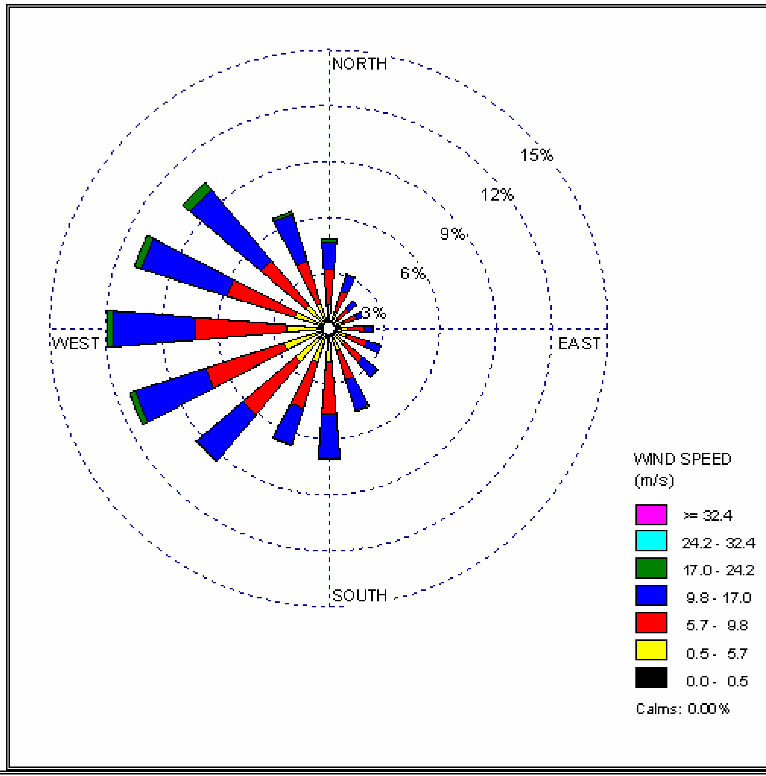

Wind Speed Percentage Occurrence
Grid Point 11820
August
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

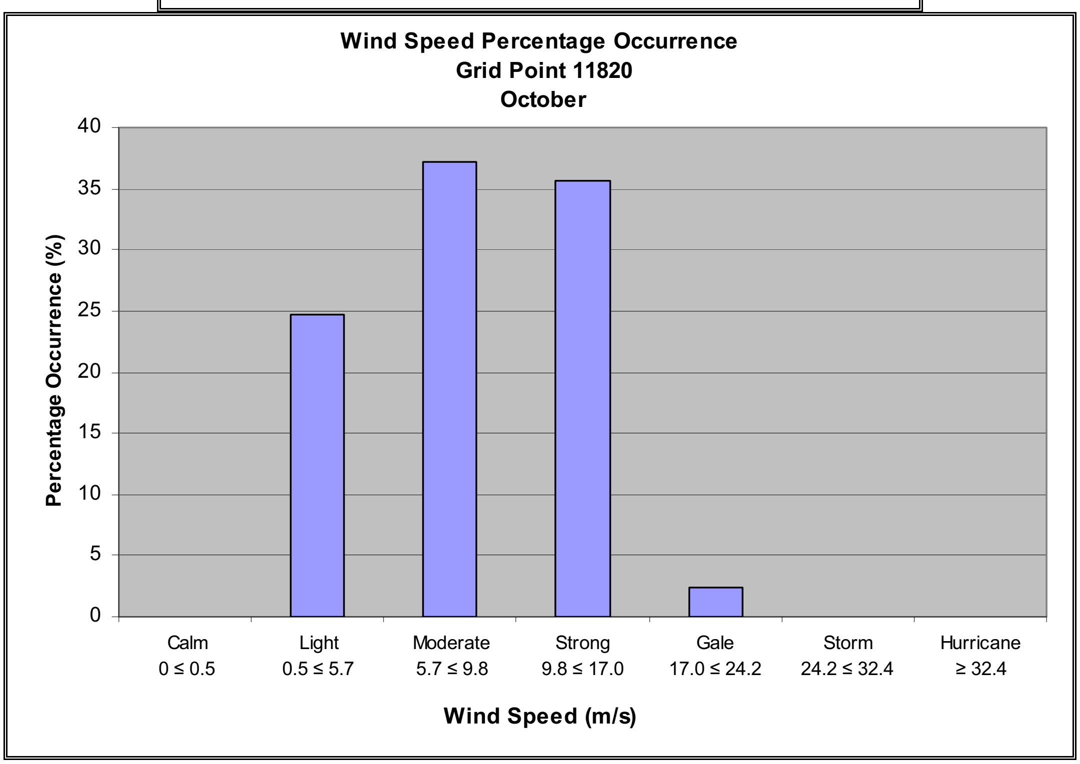
September


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
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%

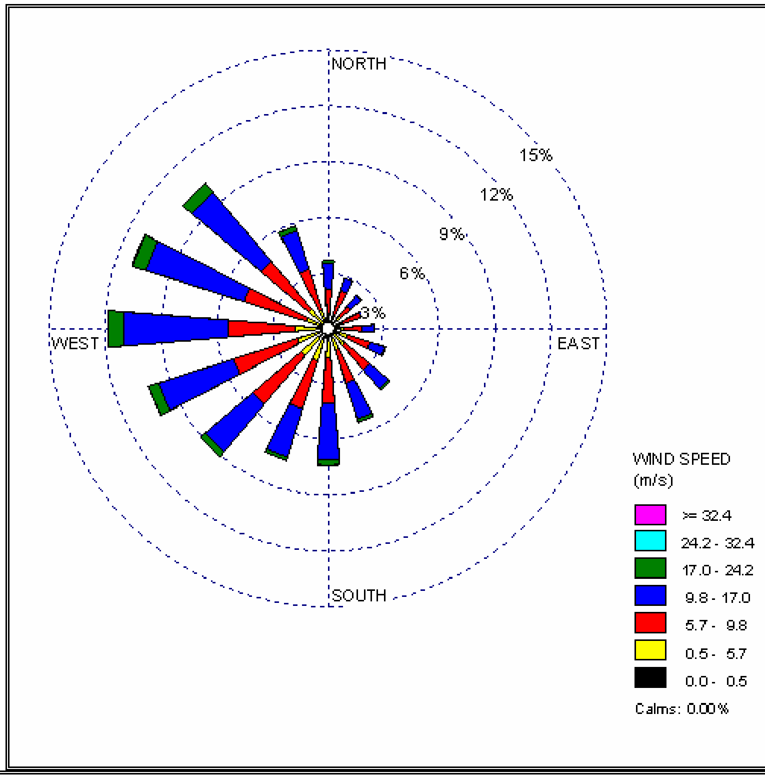

Wind Speed Percentage Occurrence
Grid Point 11820
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

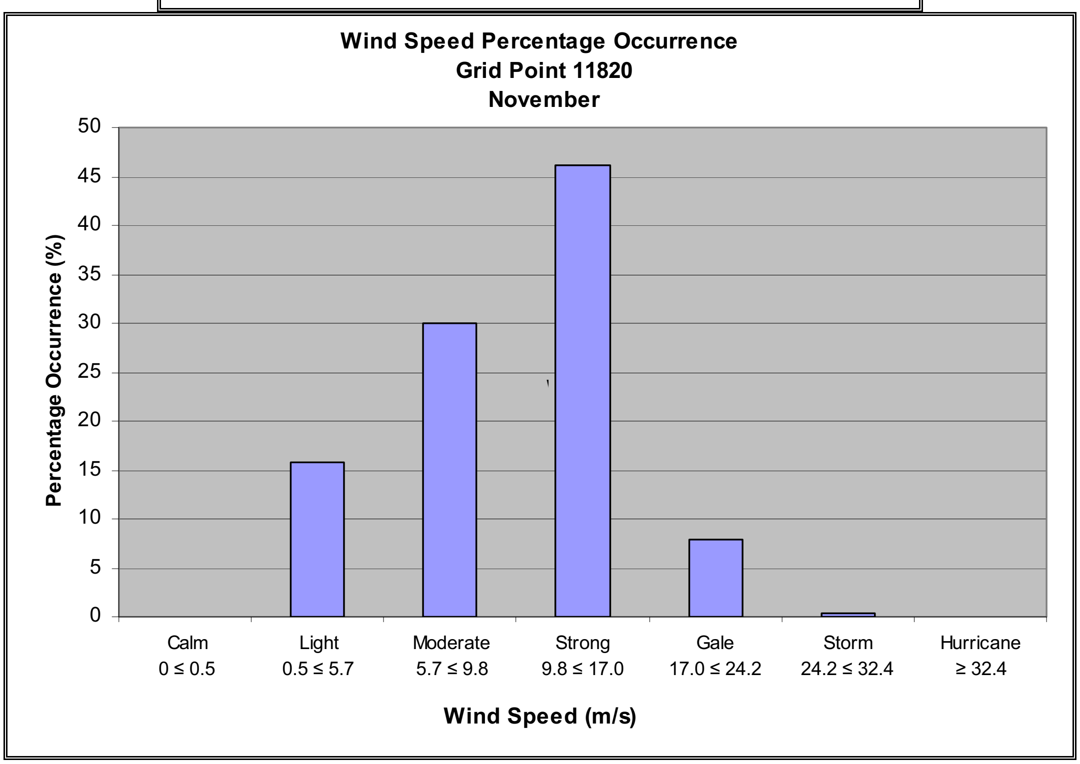
October


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
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%

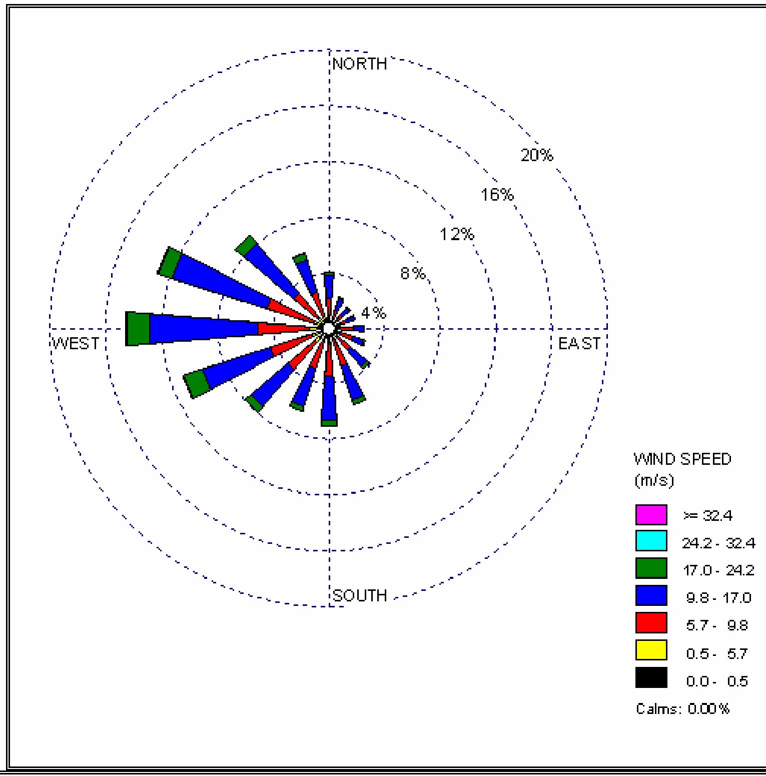

Wind Speed Percentage Occurrence
Grid Point 11820
October
Percentage Occurrence (%)
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

November

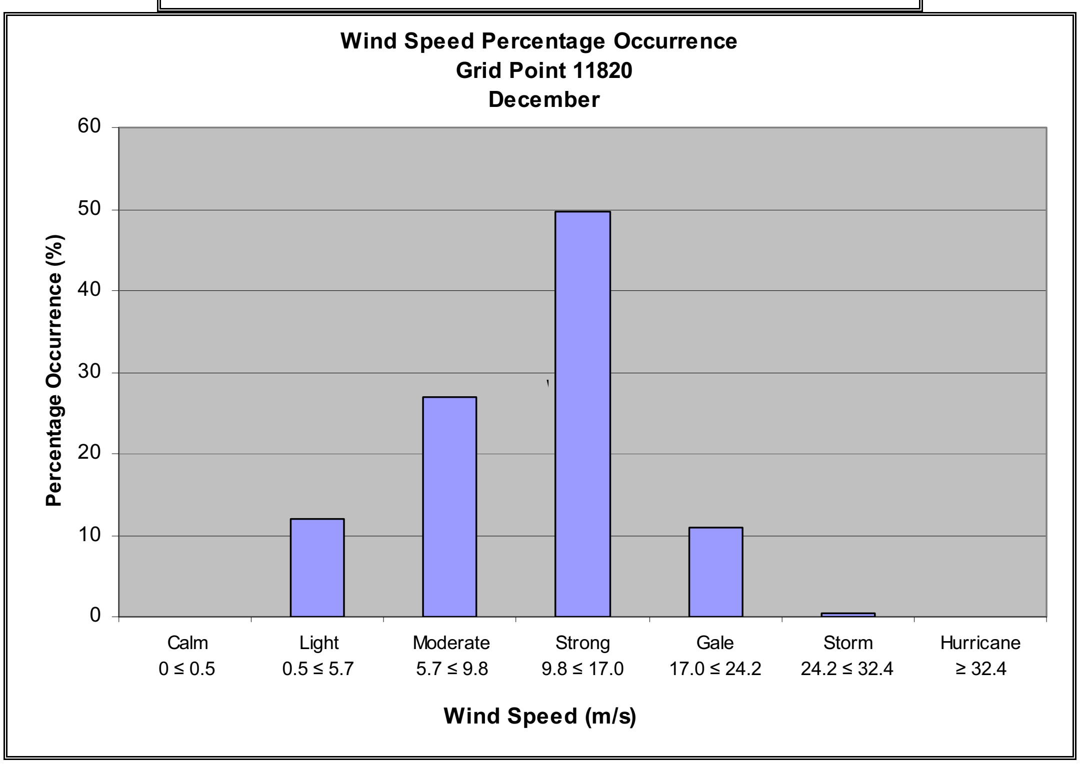

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 11820
November
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
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



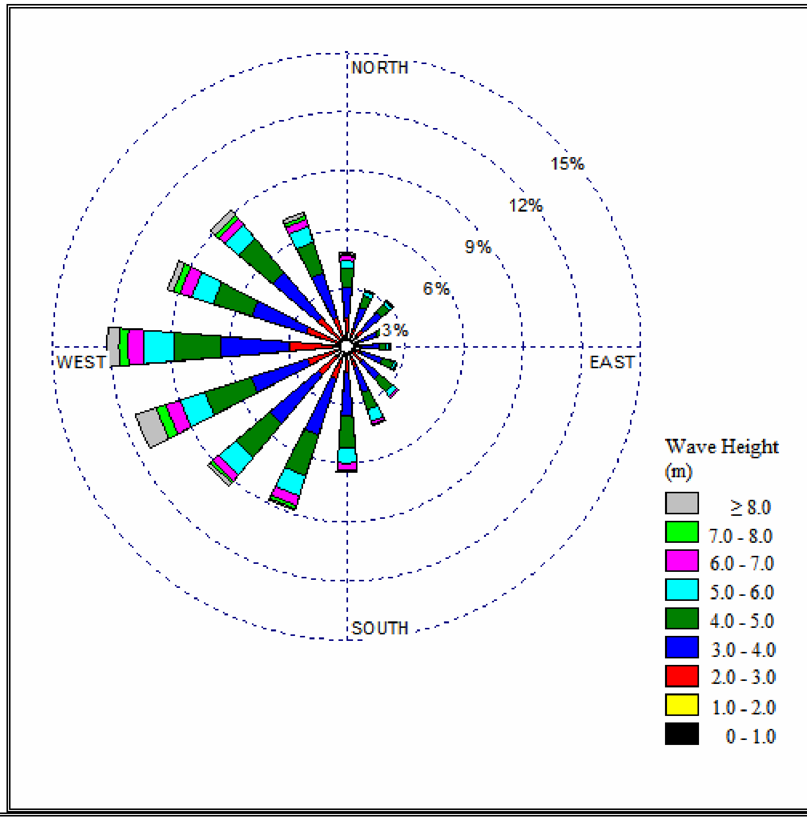
NORTH
SOUTH
EAST
WEST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

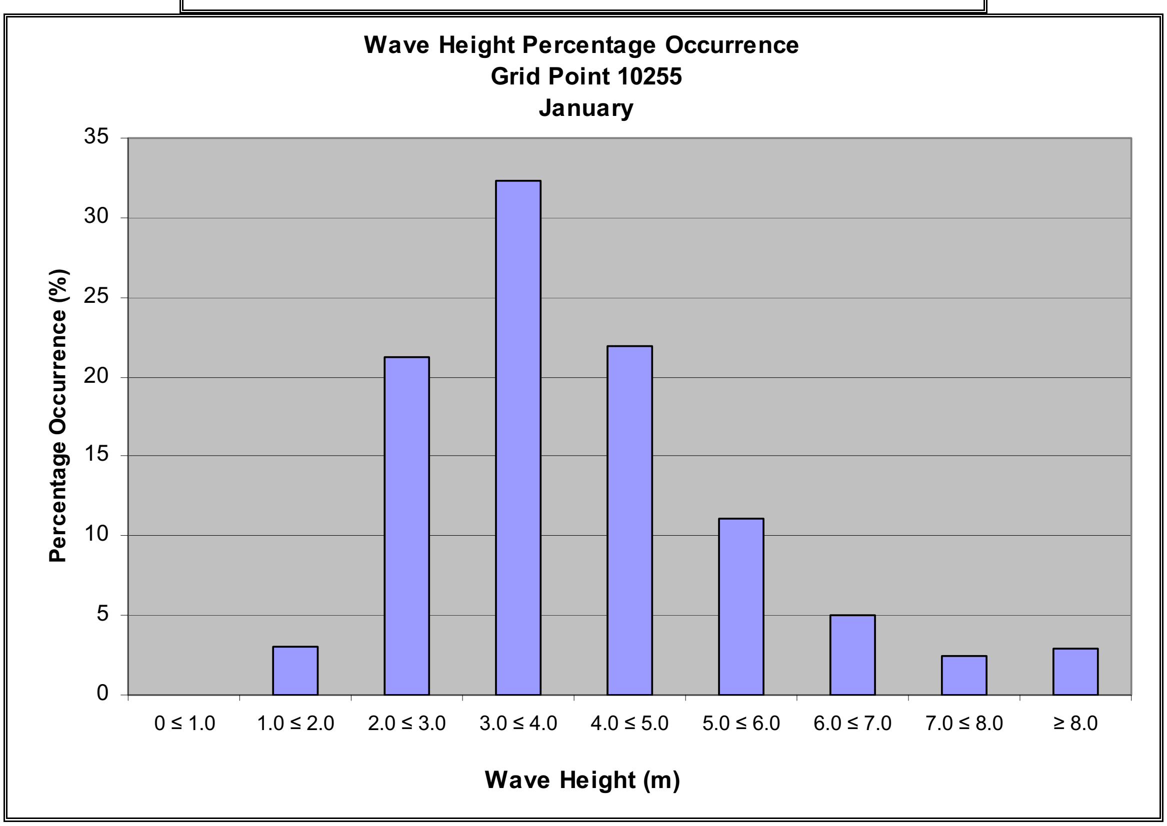


Wind Speed Percentage Occurrence
Grid Point 11820
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

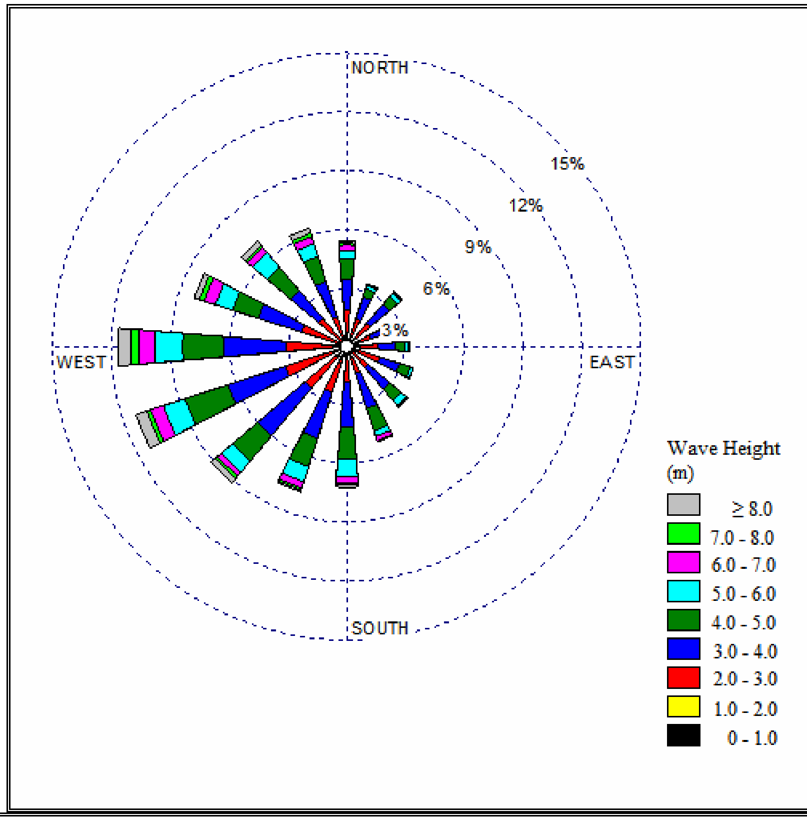
Appendix 3
Wave Roses and
Wave Height Frequency Distributions
for MSC50 GridPoint 10255

January

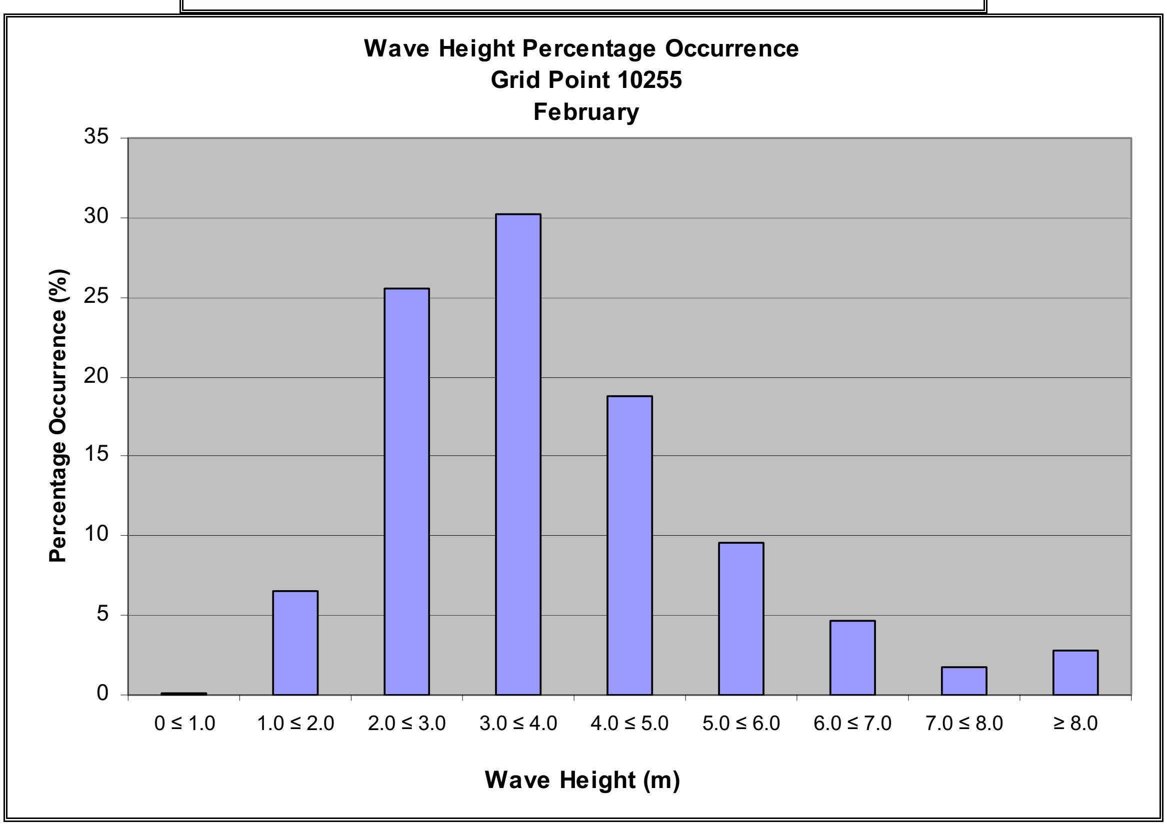

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 10255
January
Percentage Occurrence (%)
35
30
25
20
15
10
5
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)

February

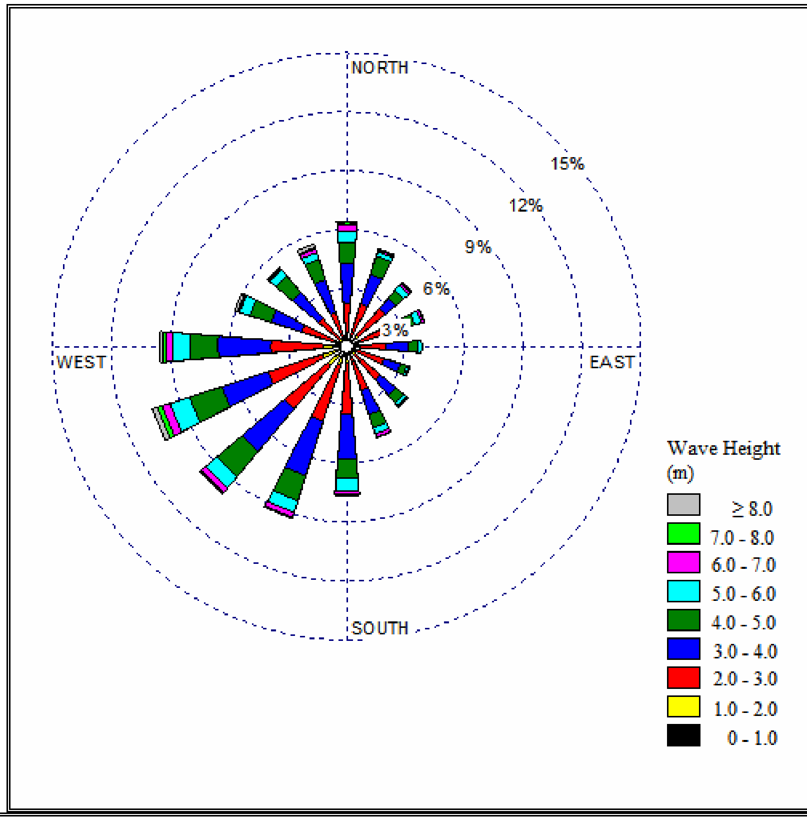


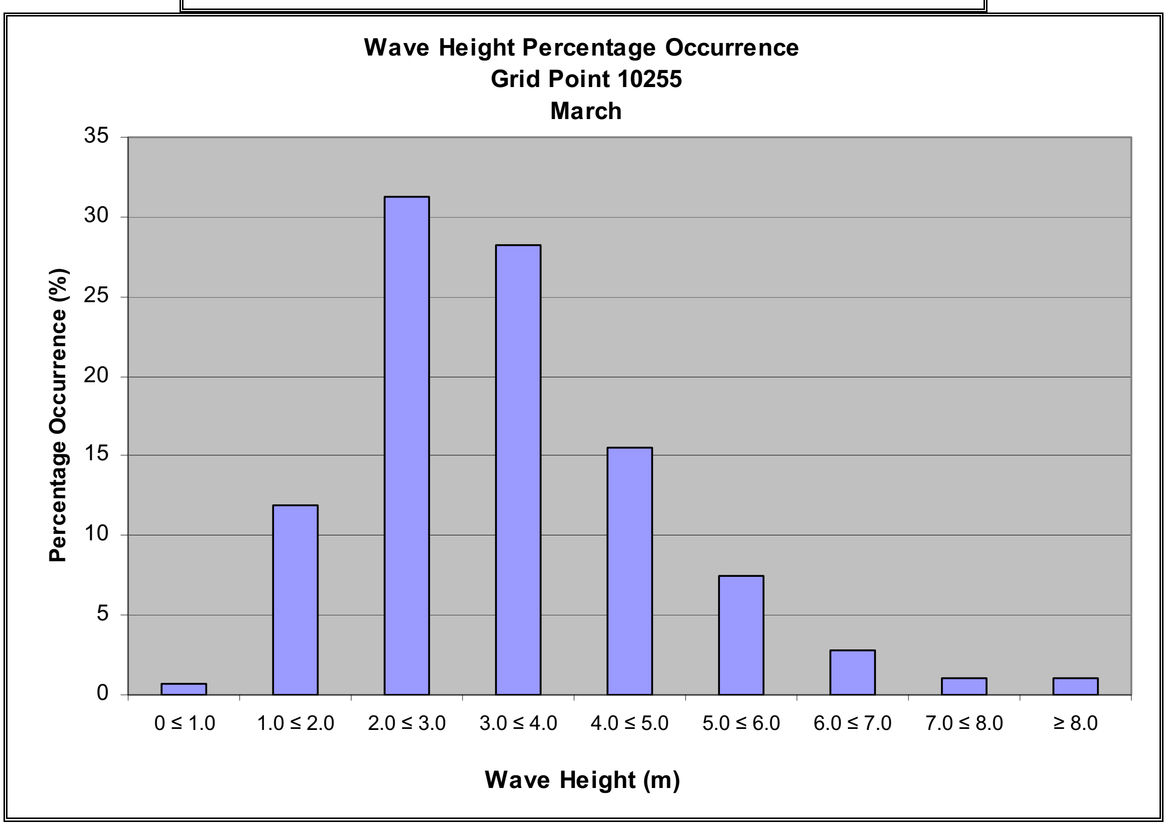
NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
Wave Height
(m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



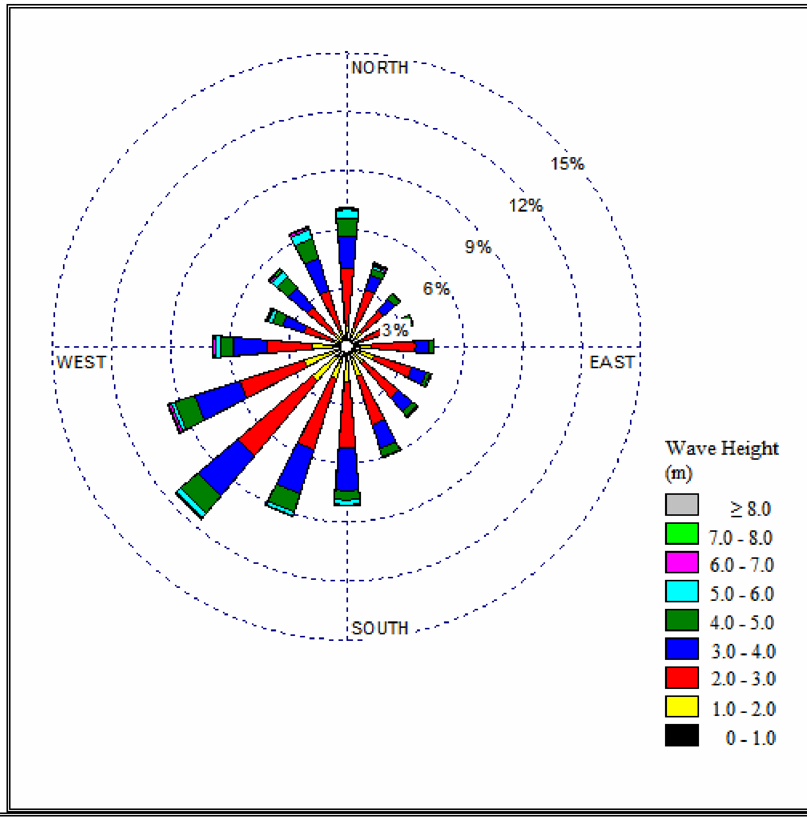
Wave Height Percentage Occurrence
Grid Point 10255
February
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

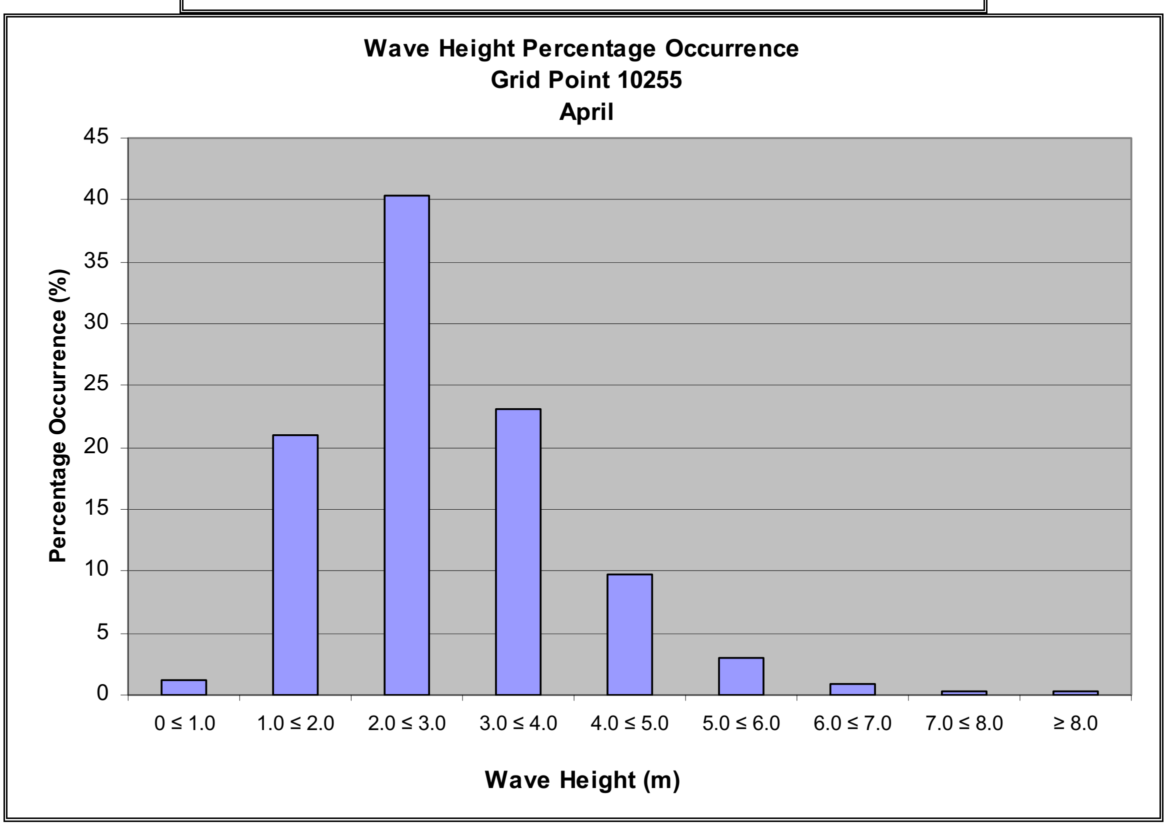
March


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
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 - 1.0

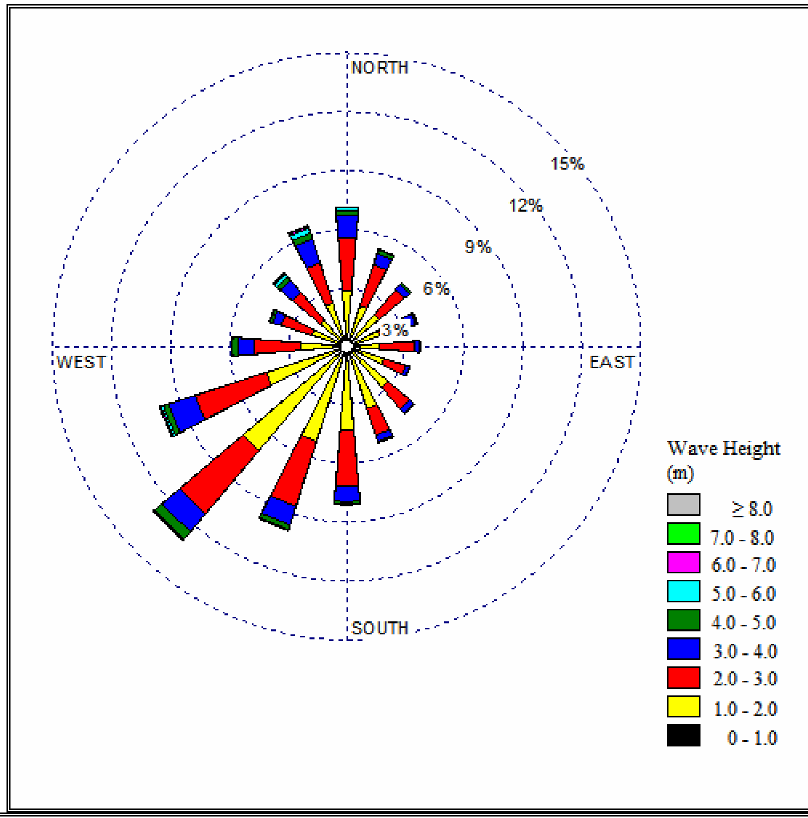

Wave Height Percentage Occurrence
Grid Point 10255
March
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

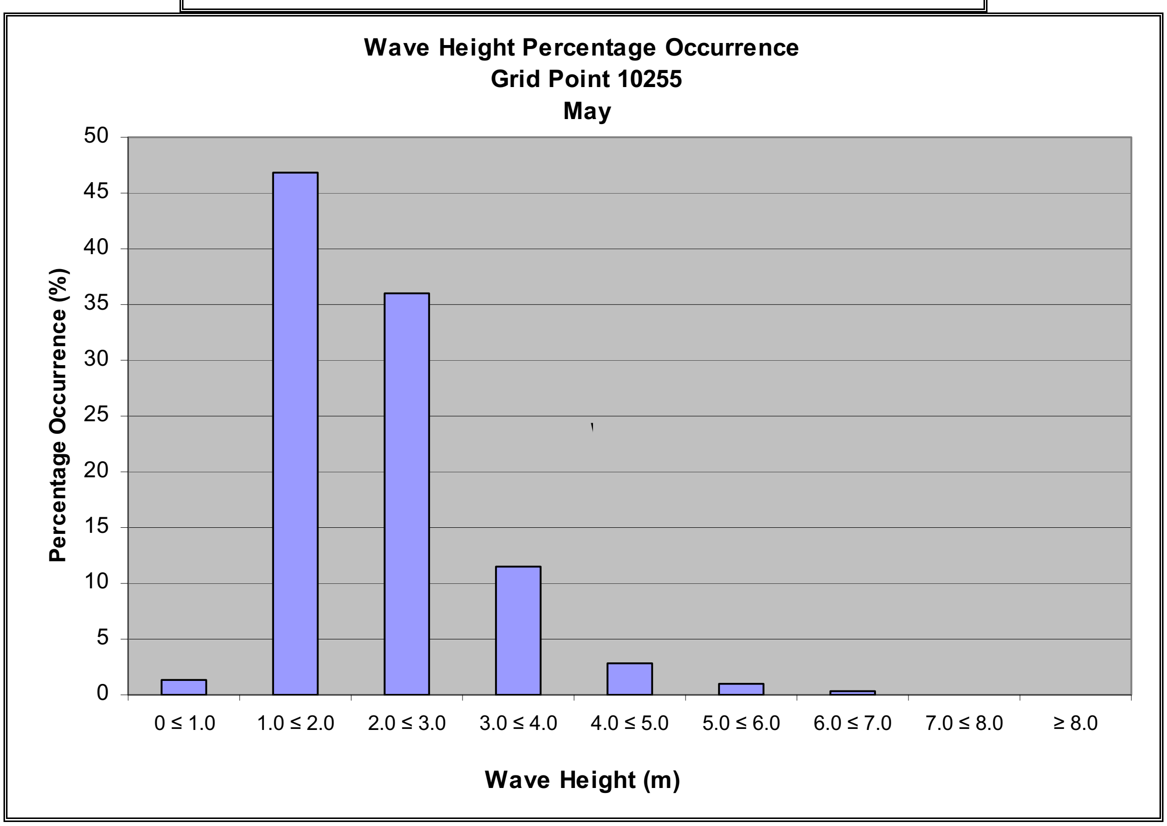
April


NORTH
15%
12%
9%
6%
3%
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 - 1.0

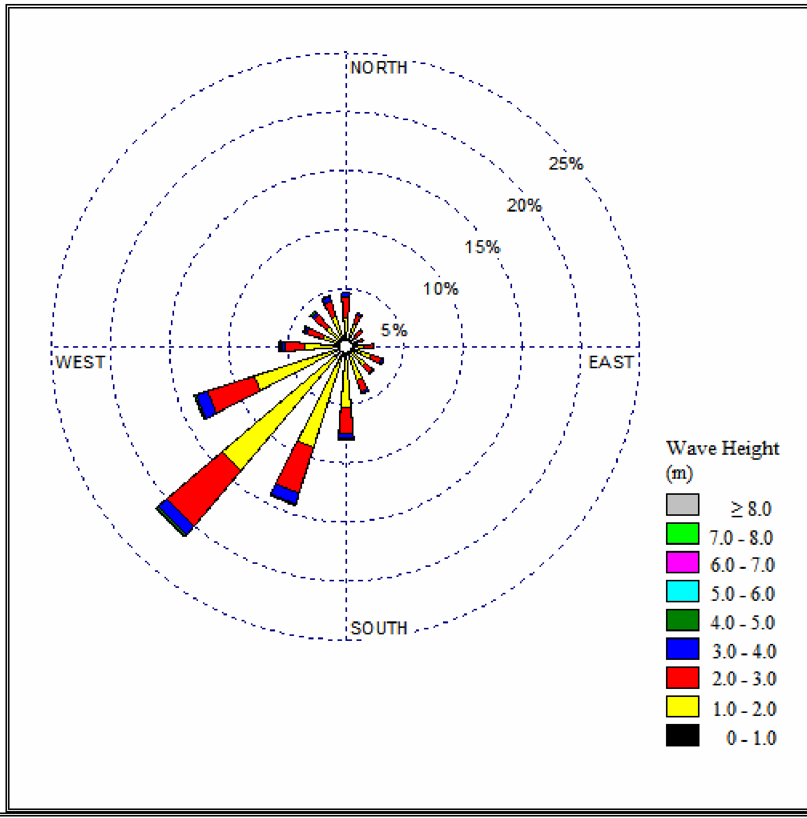

Wave Height Percentage Occurrence
Grid Point 10255
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

May

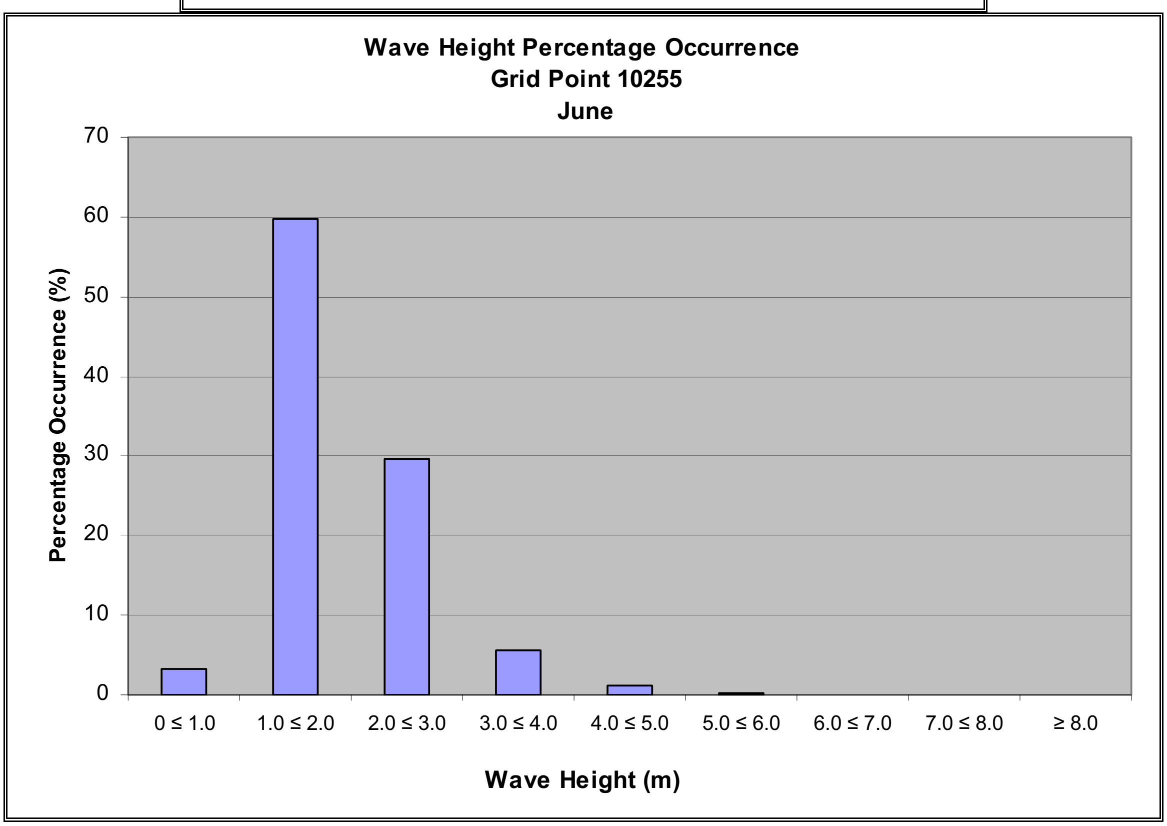

NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 10255
May
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
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

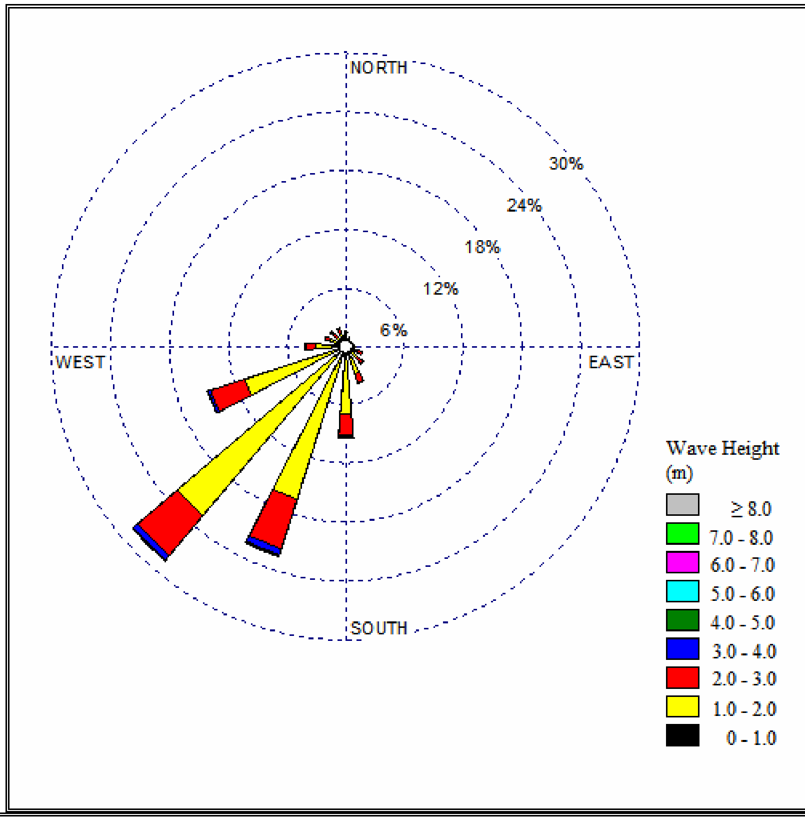


NORTH
25%
20%
15%
10%
5%
WEST
EAST
SOUTH
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

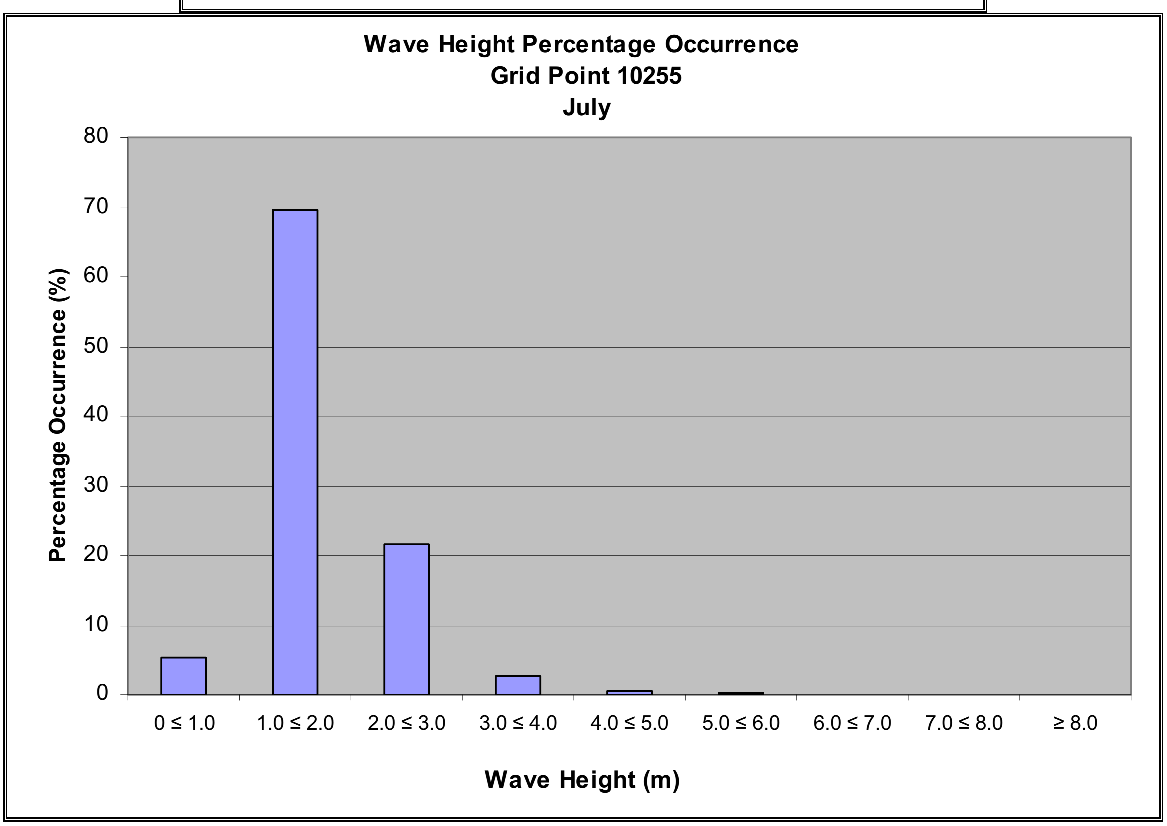


Wave Height Percentage Occurrence
Grid Point 10255
June
Percentage Occurrence (%)
70
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

July

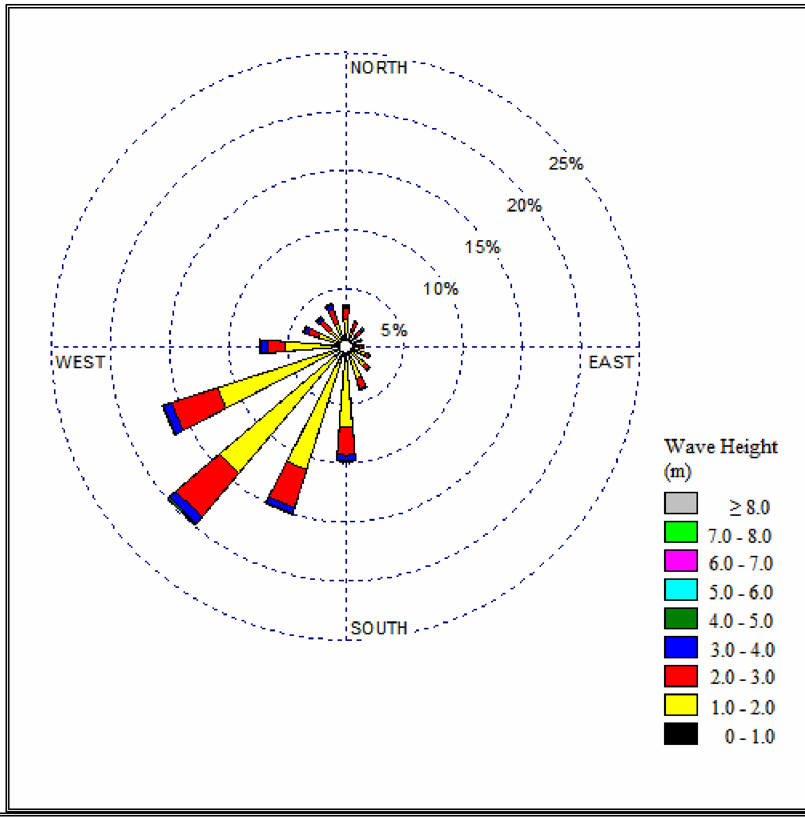


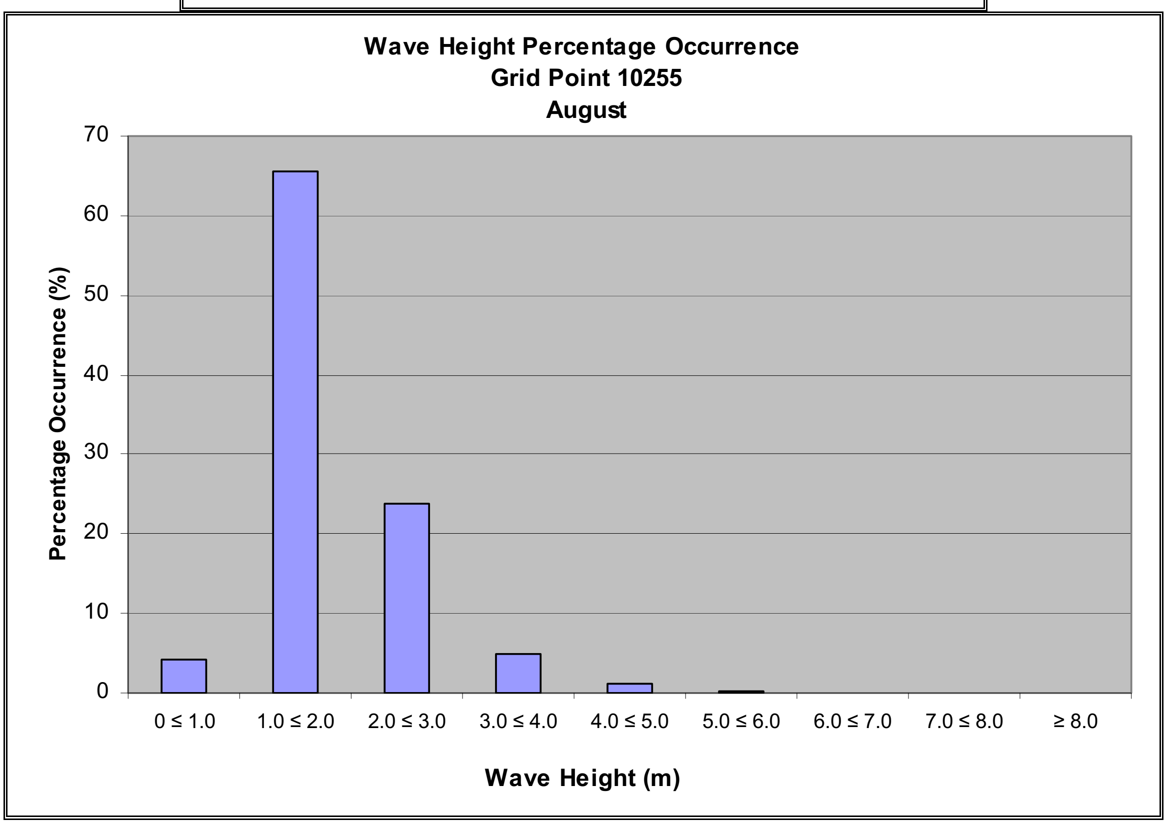
NORTH
SOUTH
WEST
EAST
6%
12%
18%
24%
30%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



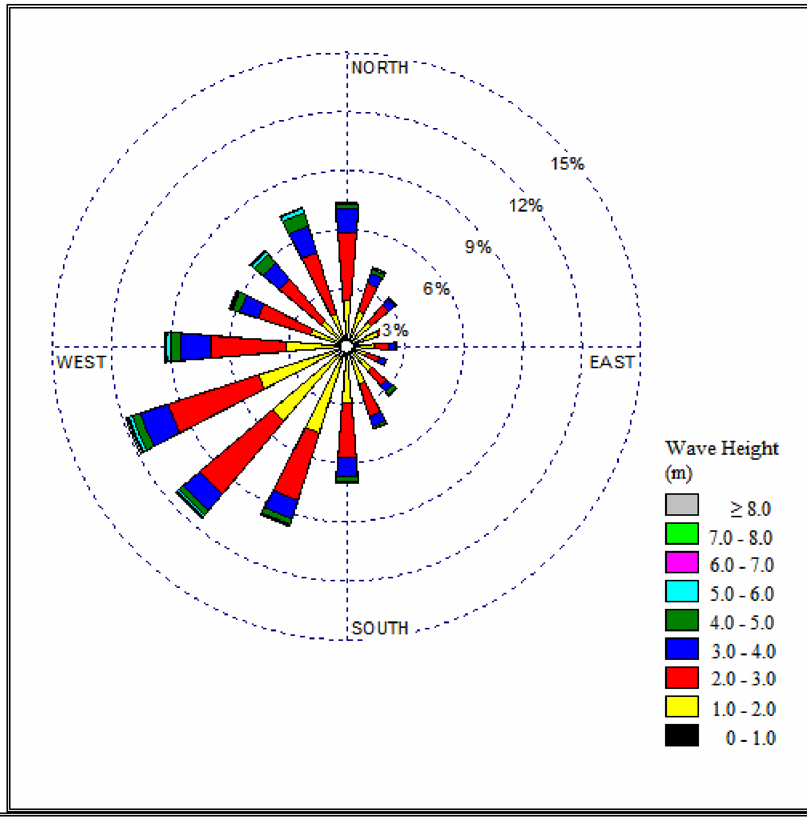
Wave Height Percentage Occurrence
Grid Point 10255
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
80
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

August

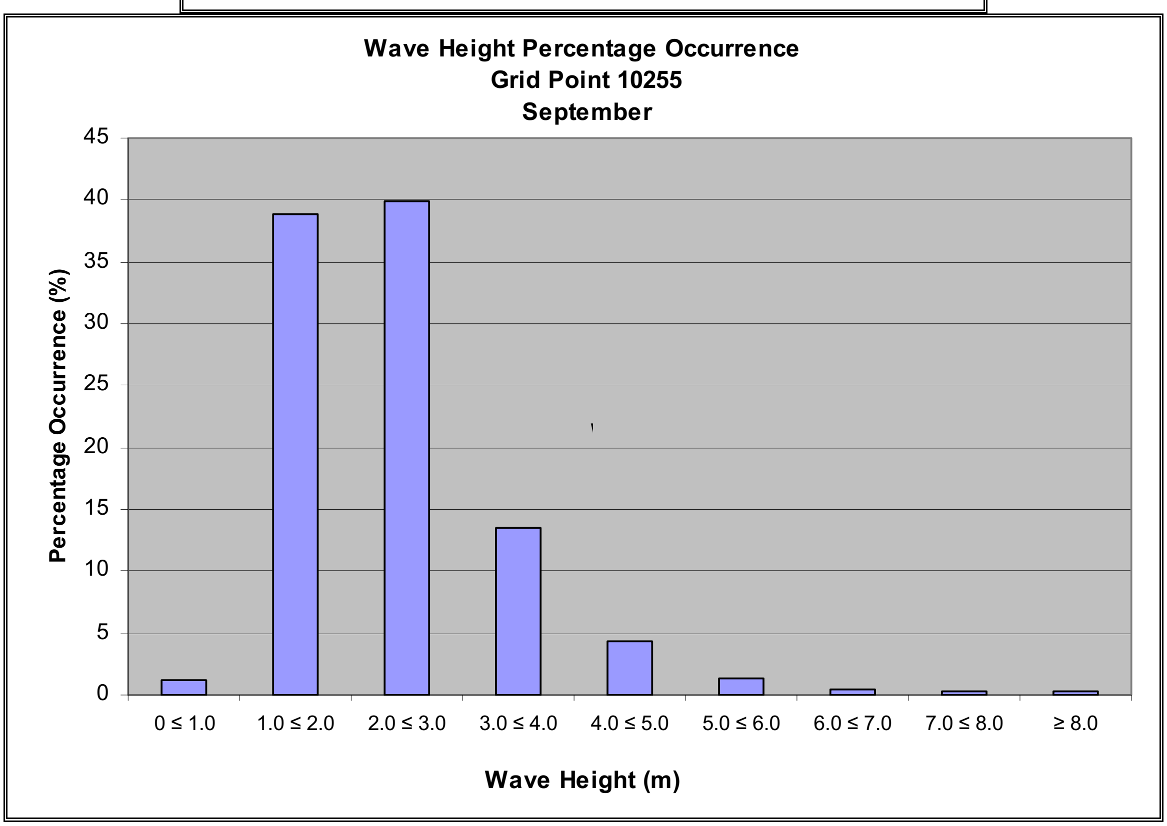

NORTH
SOUTH
WEST
EAST
5%
10%
15%
20%
25%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 10255
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
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

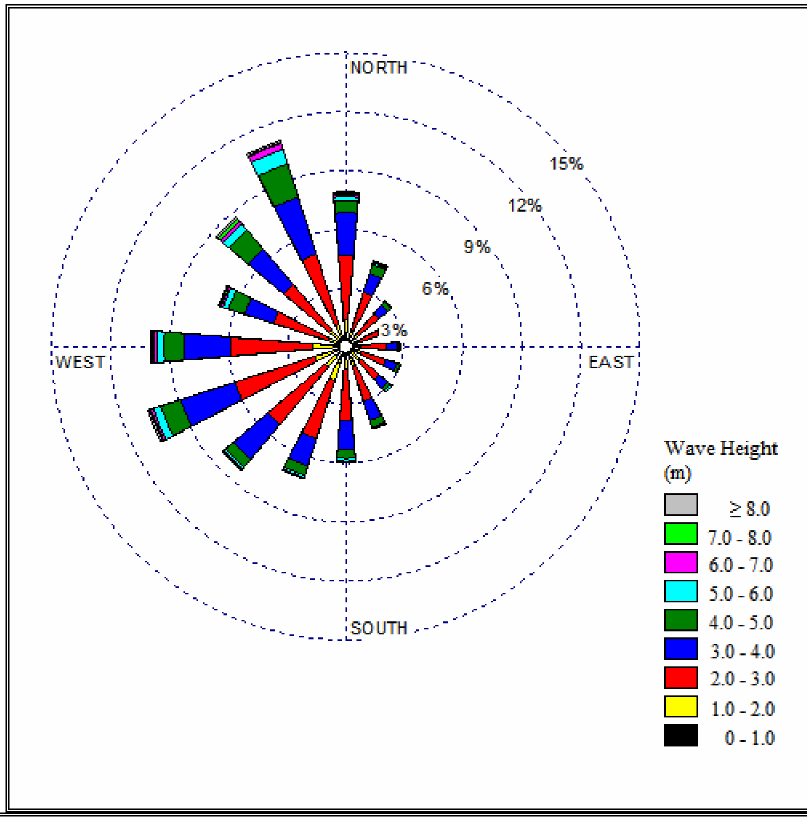


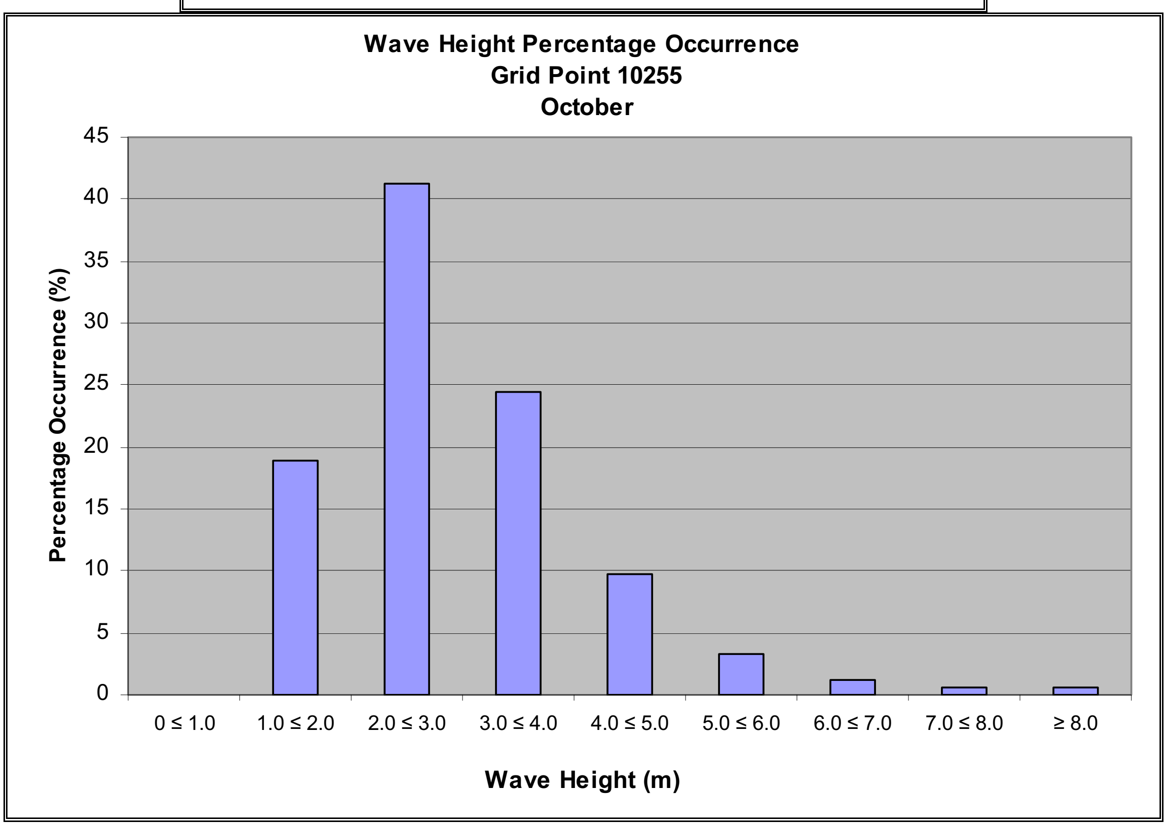
NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
Wave Height
(m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



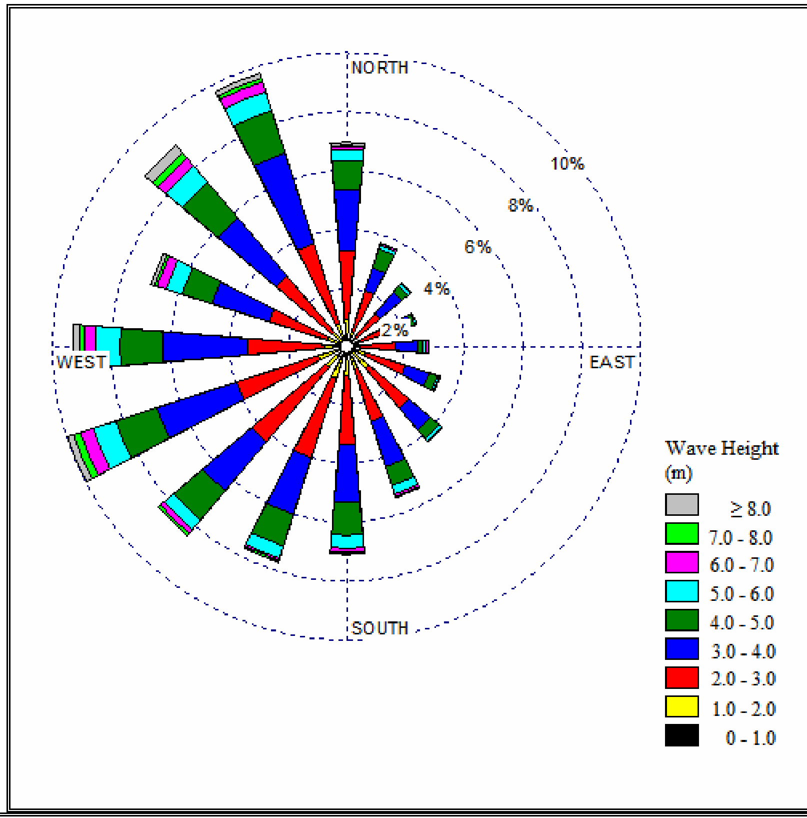
Wave Height Percentage Occurrence
Grid Point 10255
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

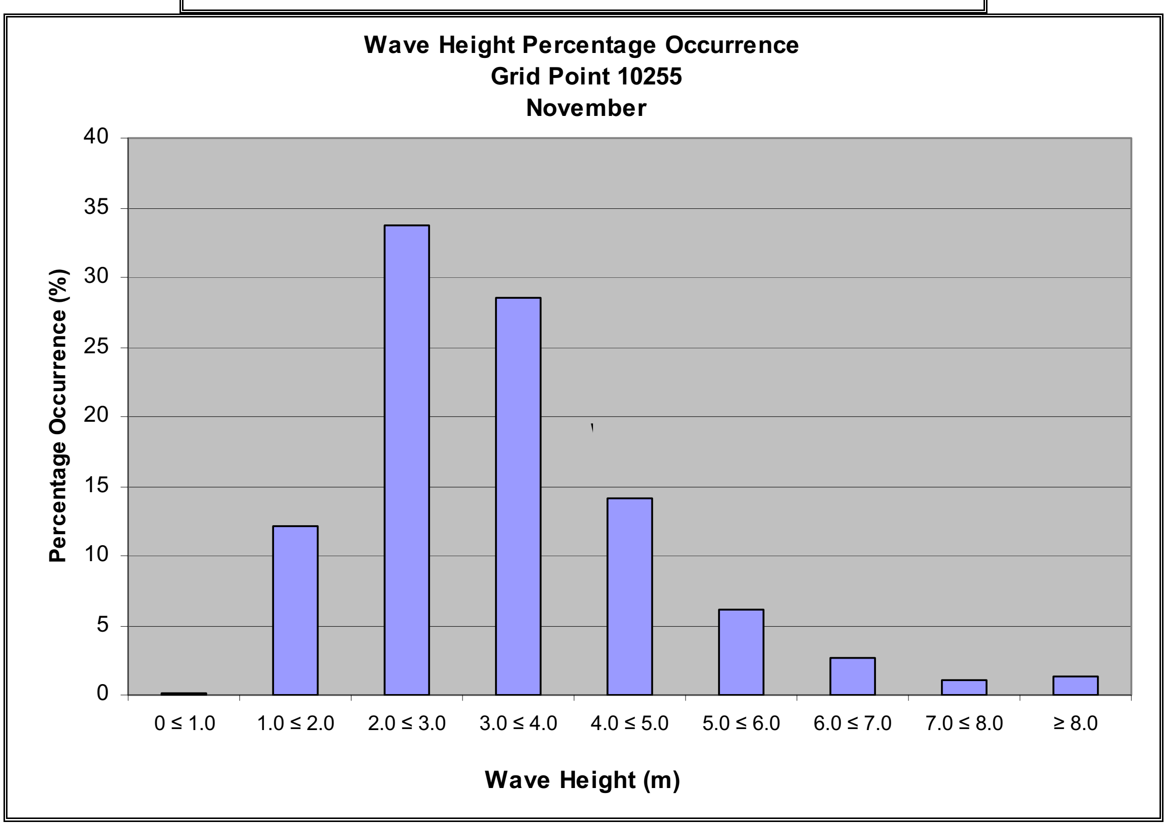
October


NORTH
15%
12%
9%
6%
3%
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 - 1.0

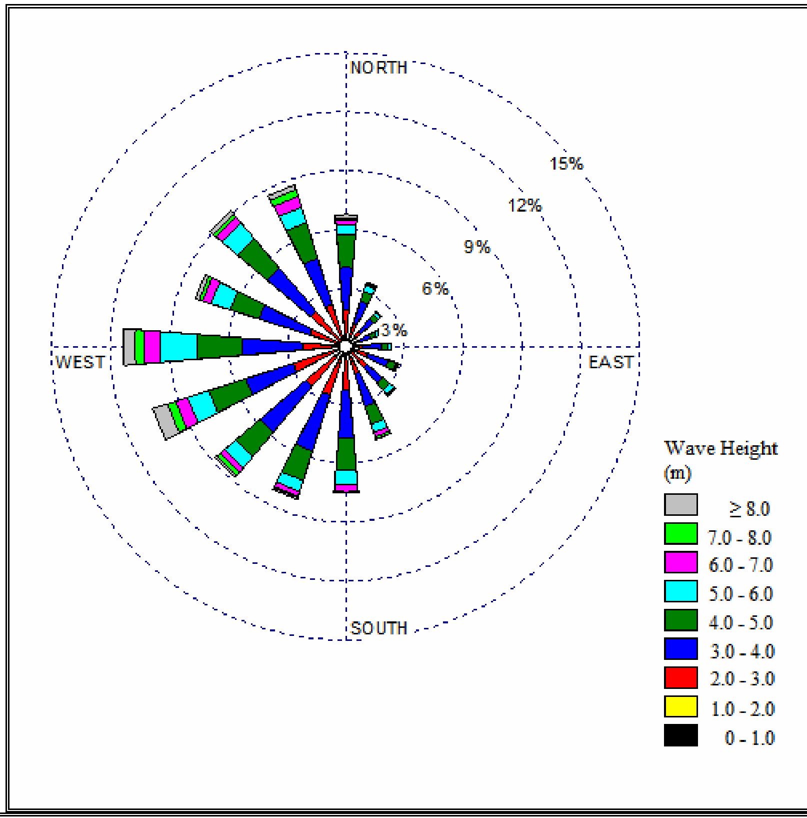

Wave Height Percentage Occurrence
Grid Point 10255
October
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

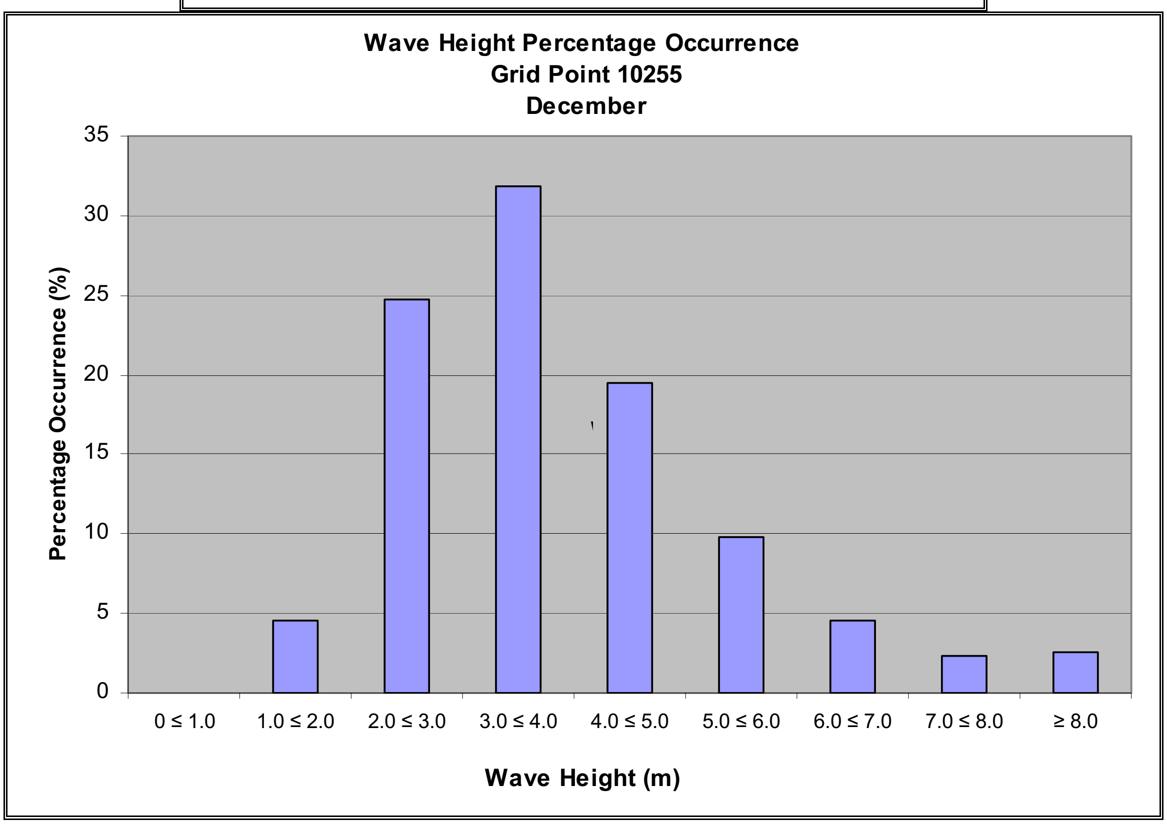
November


NORTH
SOUTH
EAST
WEST
2%
4%
6%
8%
10%
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 - 1.0


Wave Height Percentage Occurrence
Grid Point 10255
November
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
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)

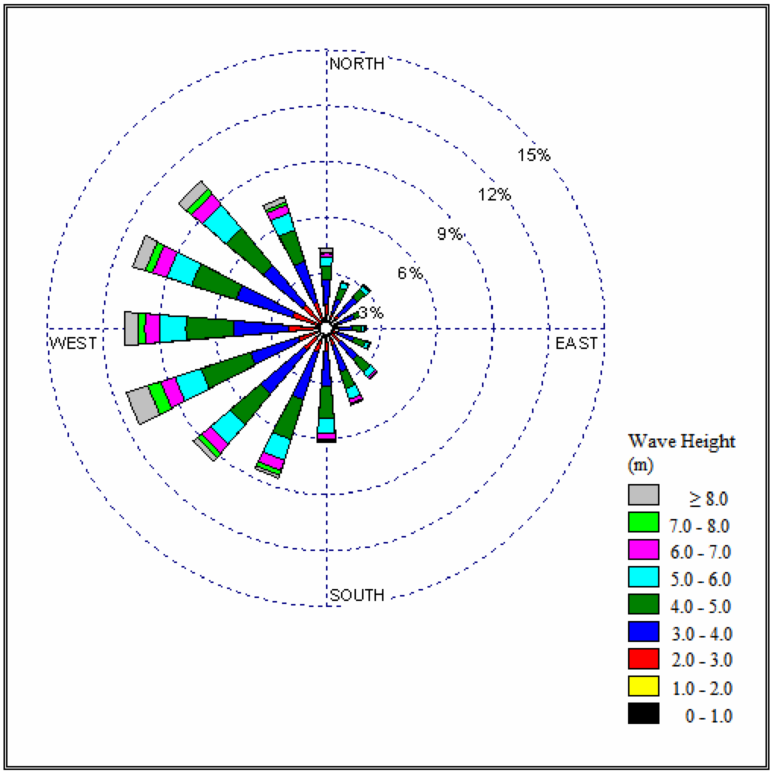
December


NORTH
15%
12%
9%
6%
3%
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 - 1.0

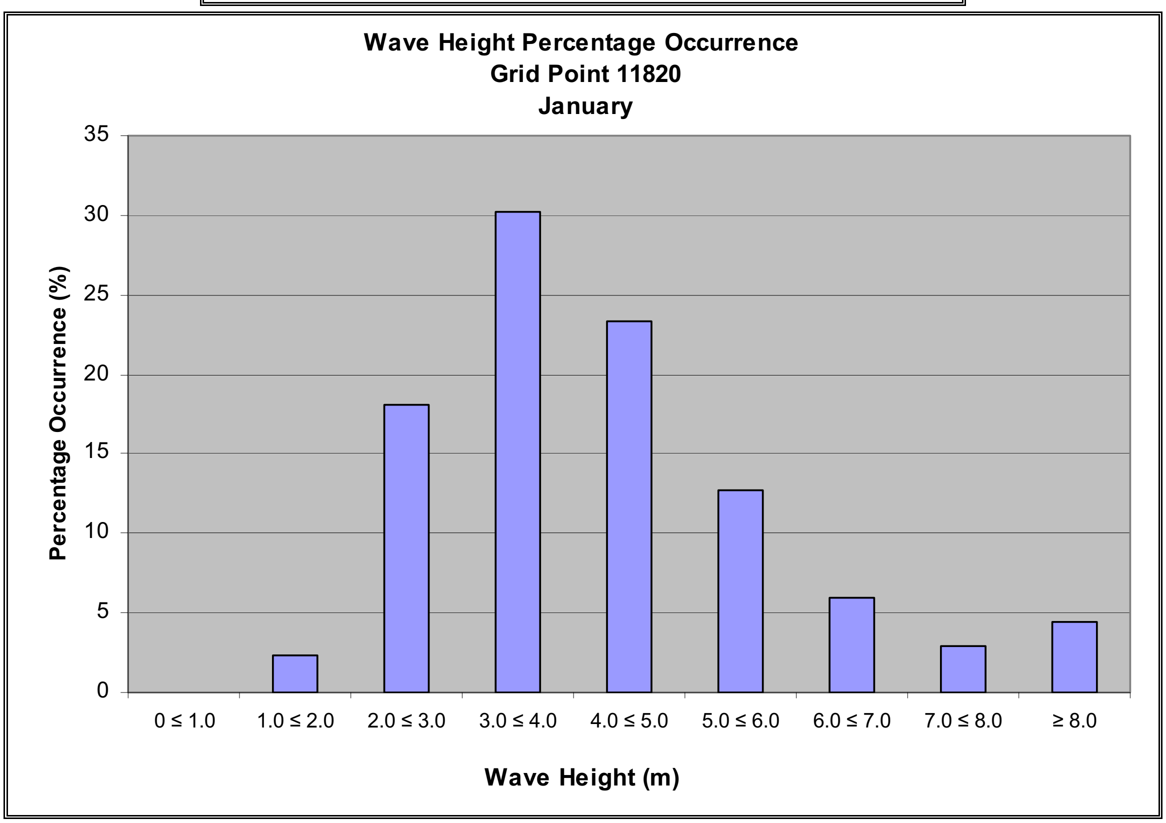

Wave Height Percentage Occurrence
Grid Point 10255
December
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

Appendix 4
Wave Roses and
Wave Height Frequency Distributions
for MSC50 GridPoint 11820

January

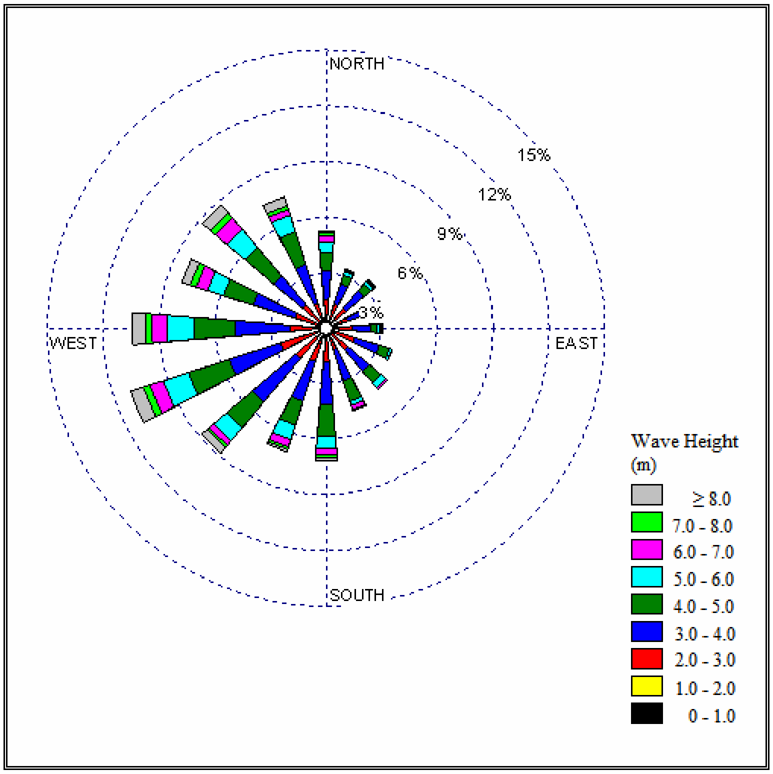


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

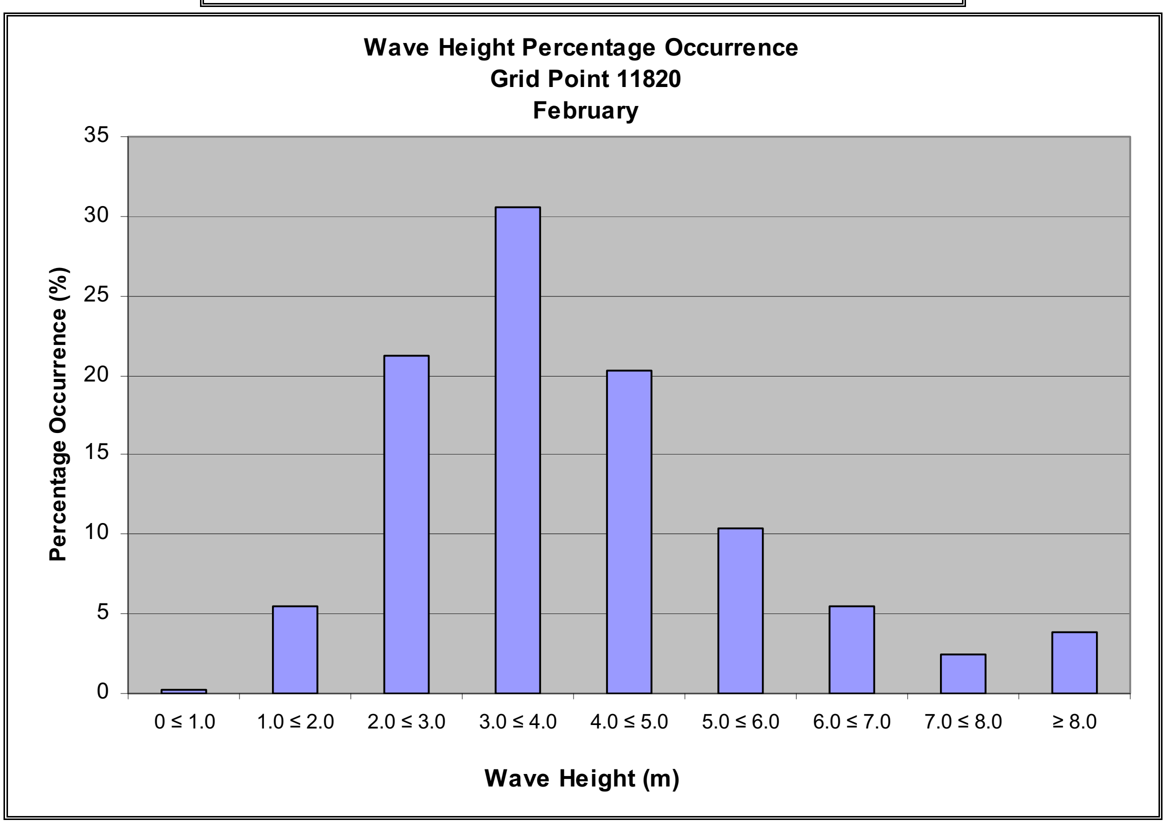


Wave Height Percentage Occurrence
Grid Point 11820
January
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

February

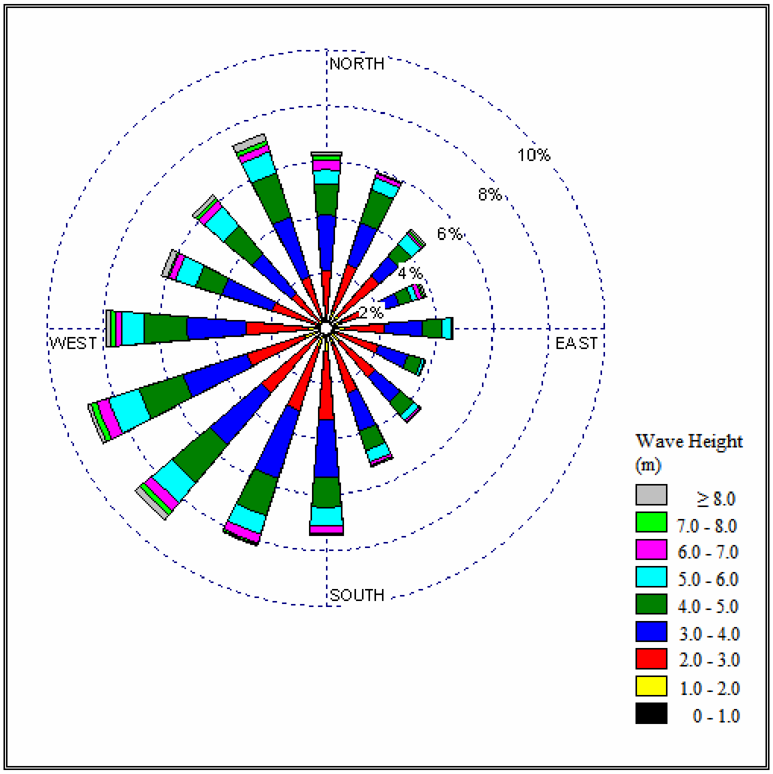


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

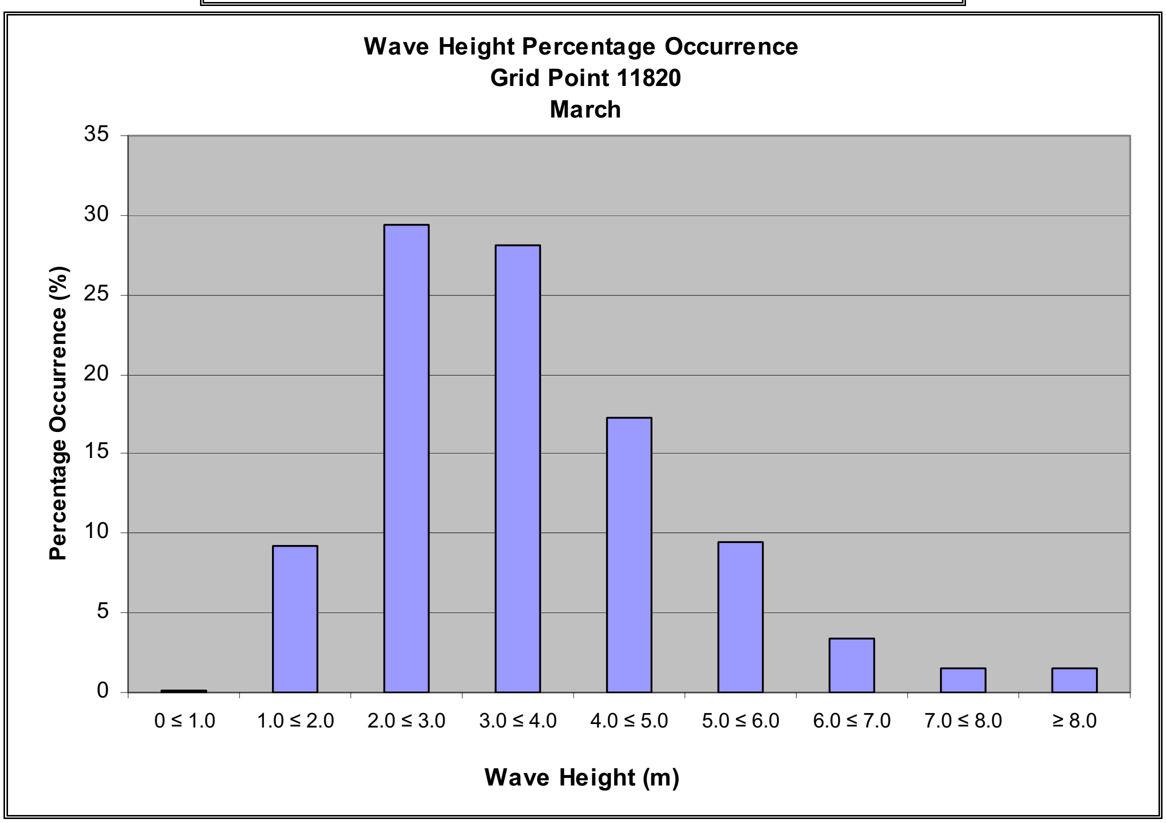


Wave Height Percentage Occurrence
Grid Point 11820
February
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

March

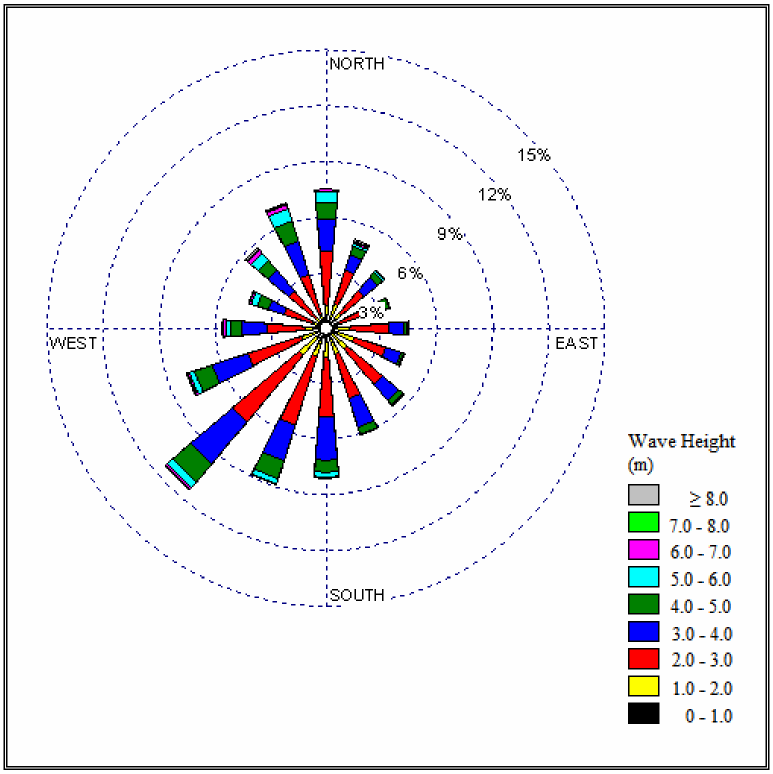


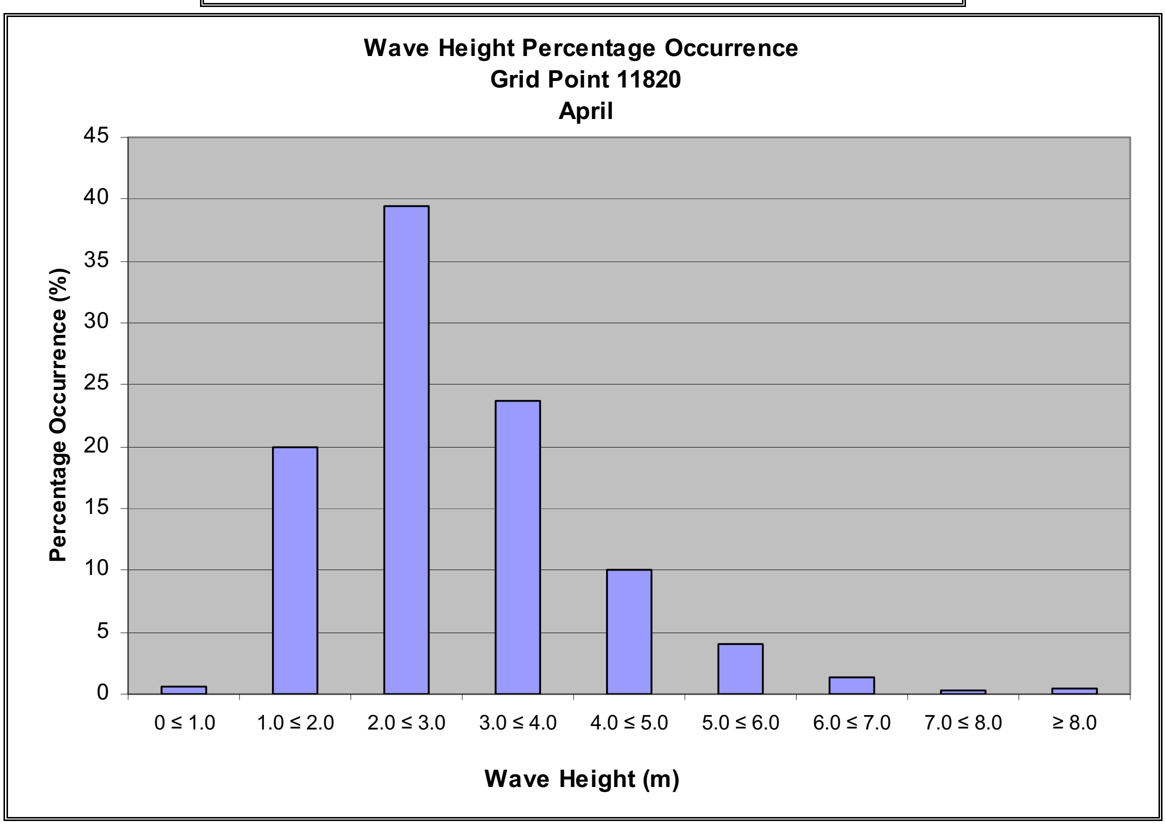
NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



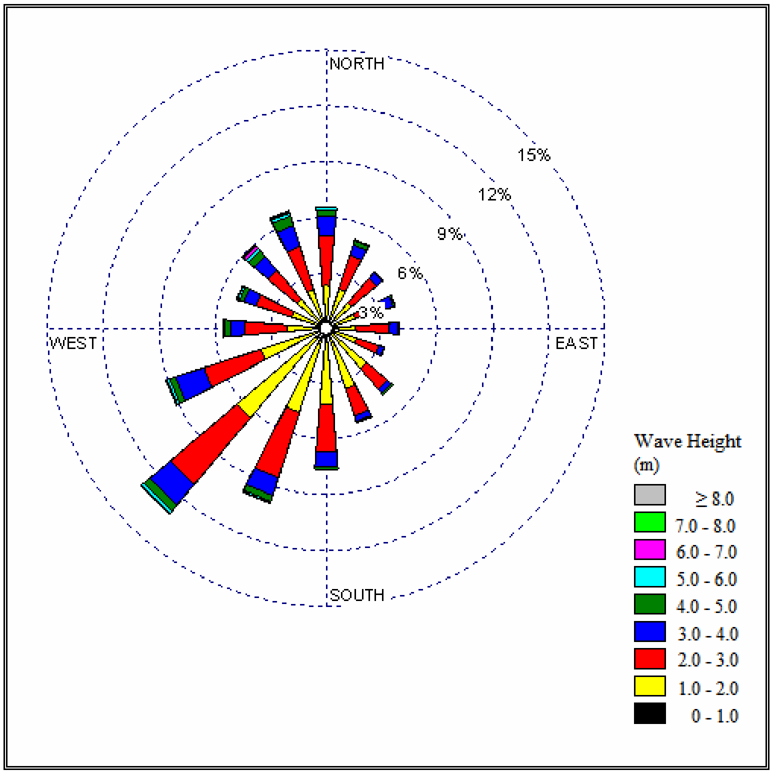
Wave Height Percentage Occurrence
Grid Point 11820
March
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

April

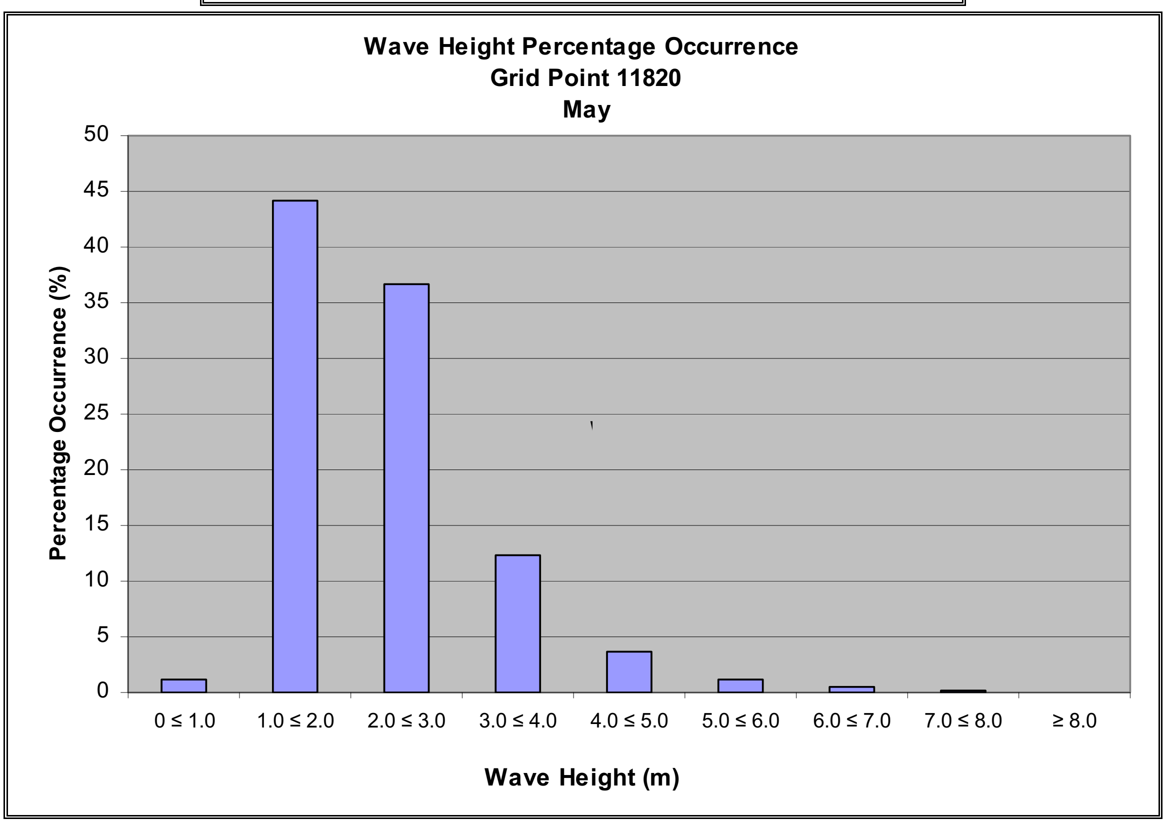

NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 11820
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
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)

May

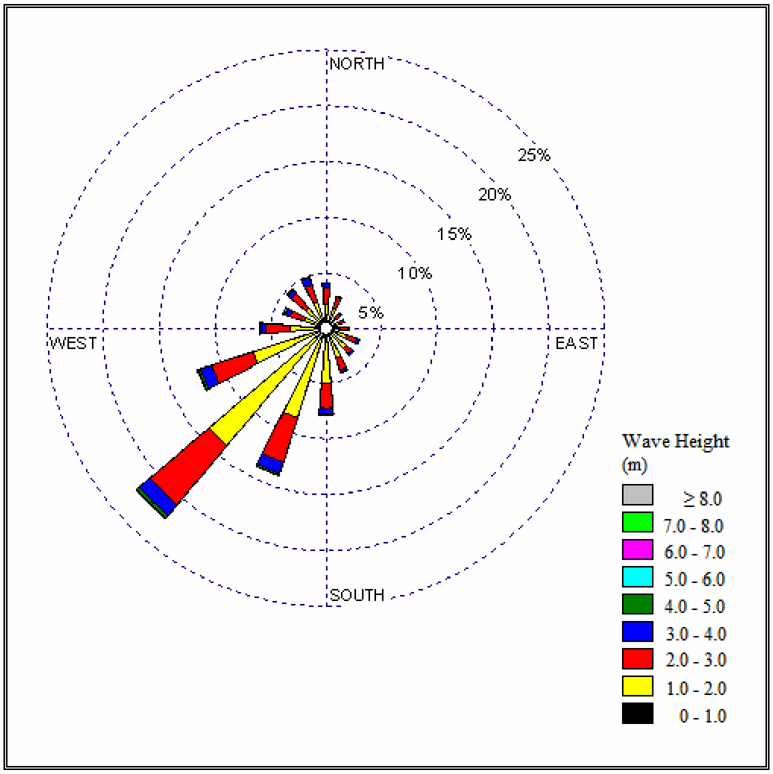


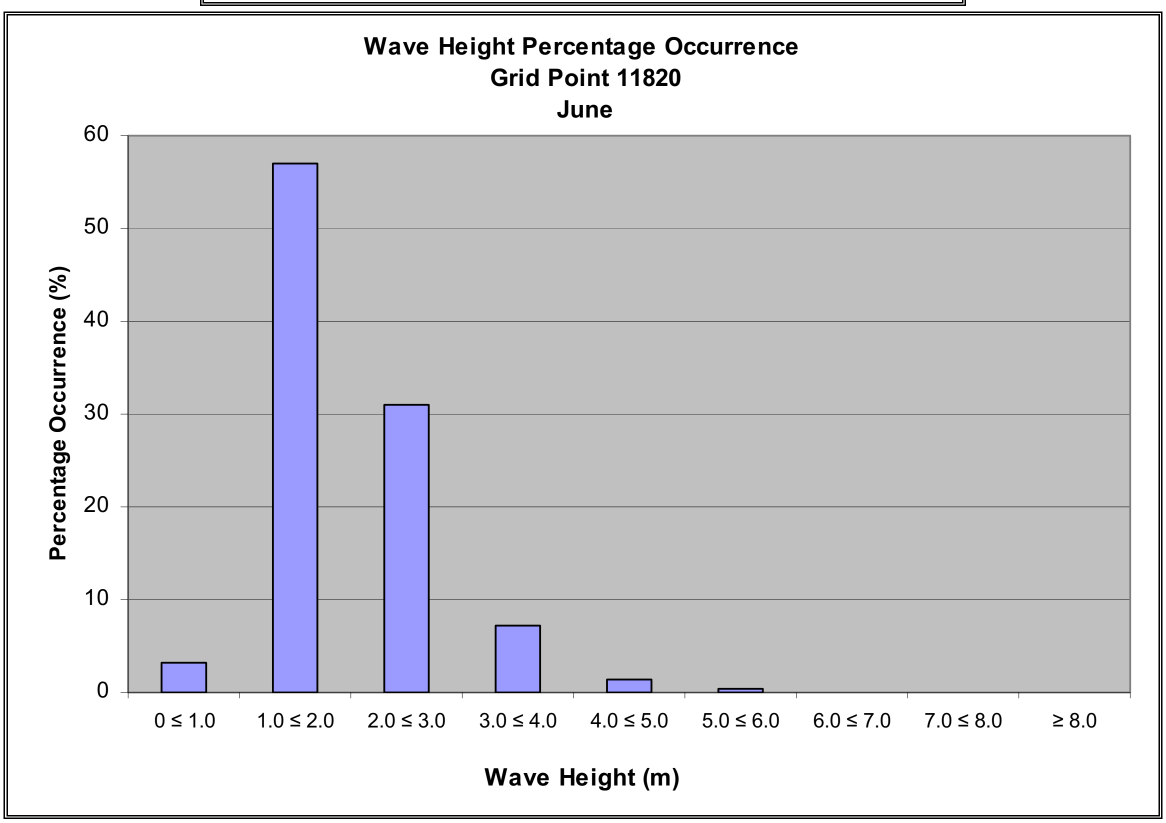
NORTH
SOUTH
WEST
EAST
15%
12%
9%
6%
3%
Wave Height
(m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



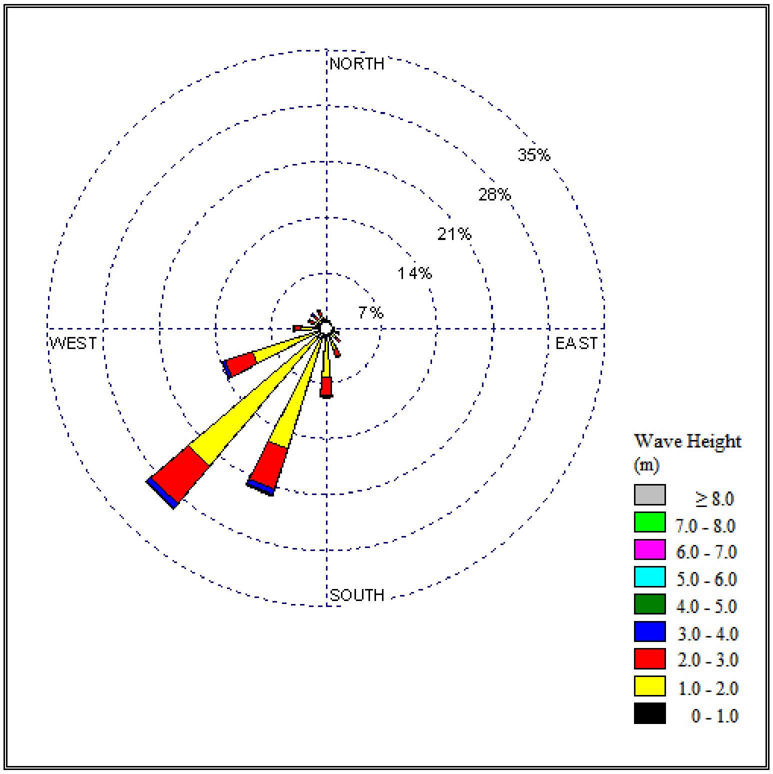
Wave Height Percentage Occurrence
Grid Point 11820
May
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

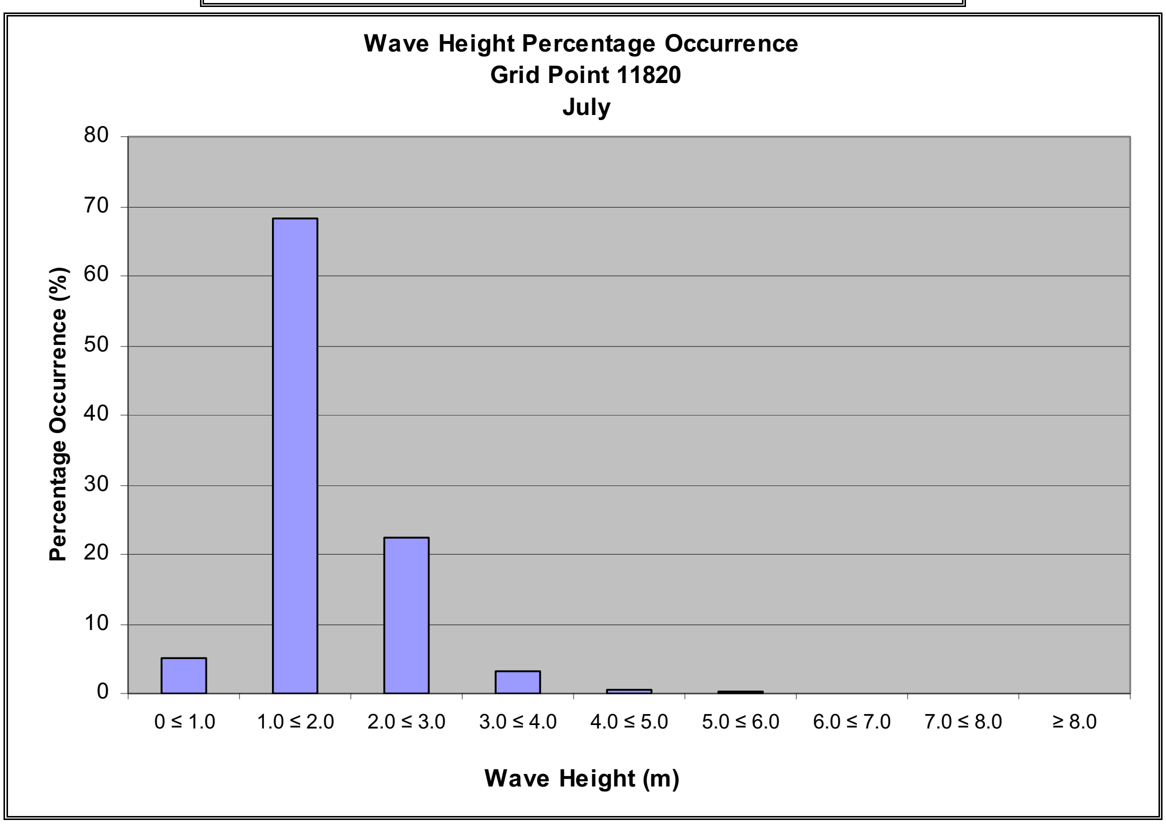
June


NORTH
SOUTH
EAST
WEST
25%
20%
15%
10%
5%
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 - 1.0

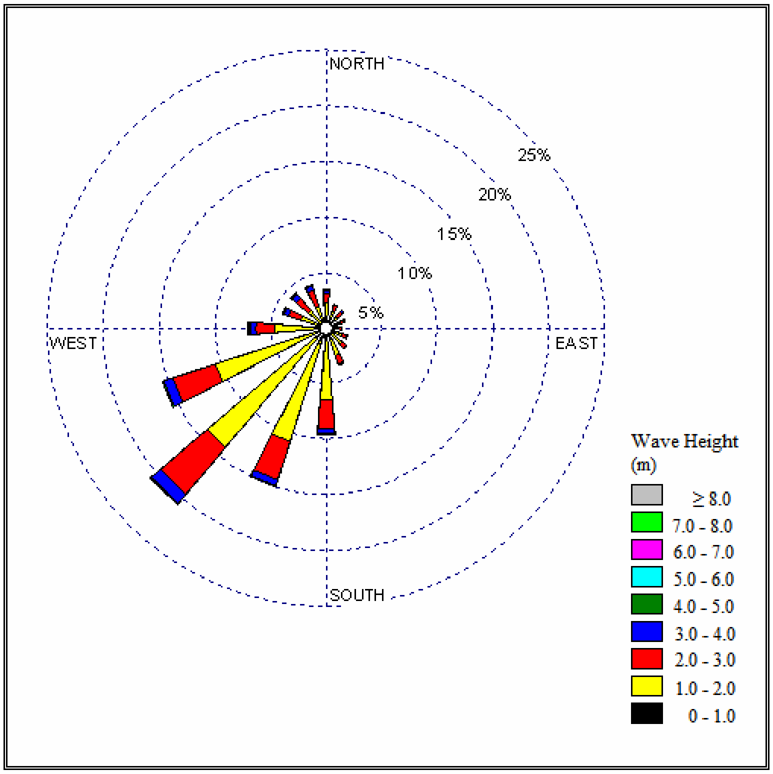

Wave Height Percentage Occurrence
Grid Point 11820
June
Percentage Occurrence (%)
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

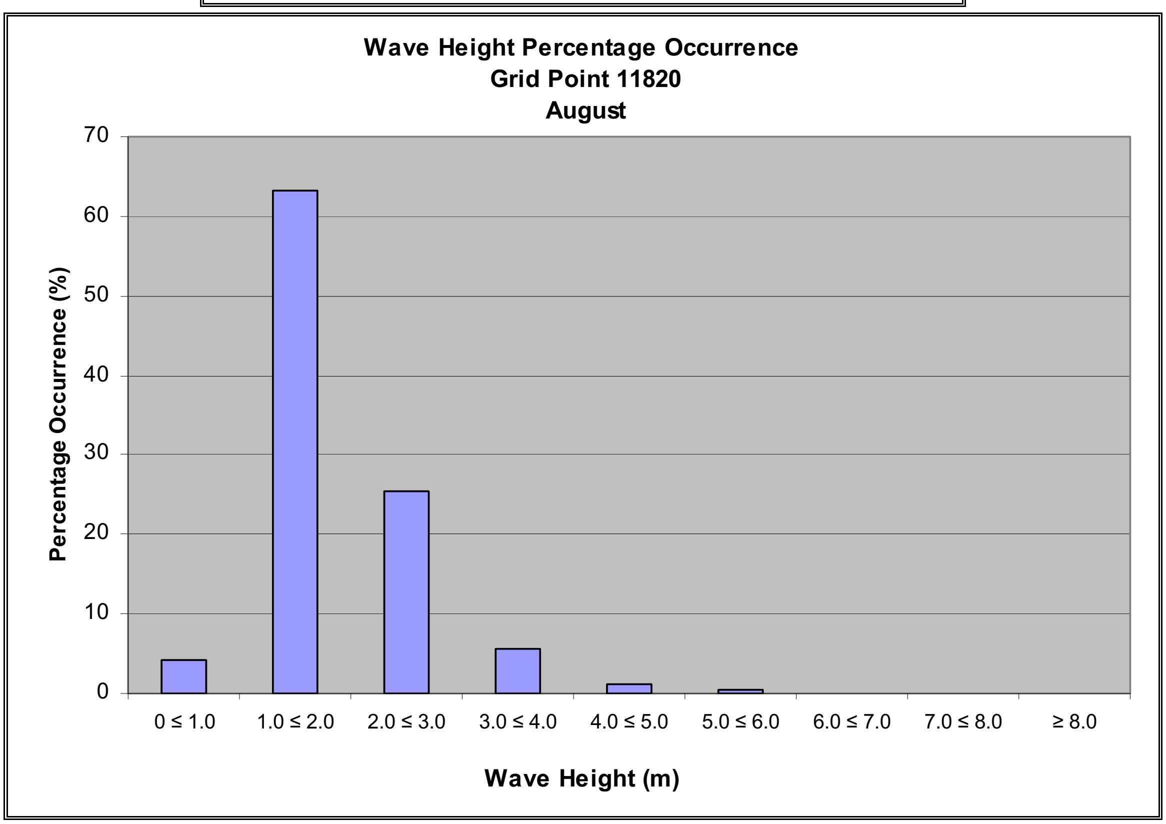
July


NORTH
35%
28%
21%
14%
7%
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 - 1.0

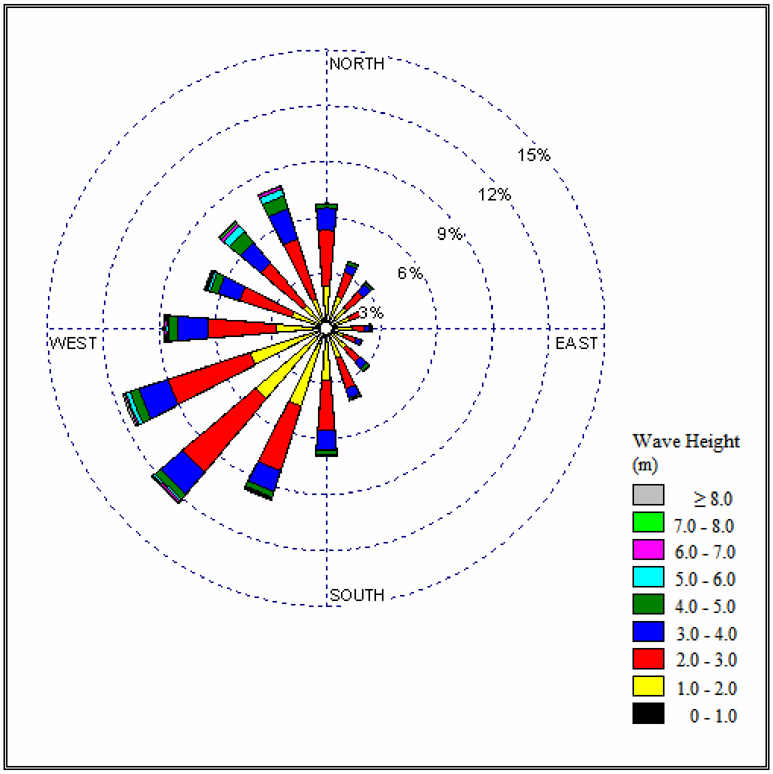

Wave Height Percentage Occurrence
Grid Point 11820
July
Percentage Occurrence (%)
80
70
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

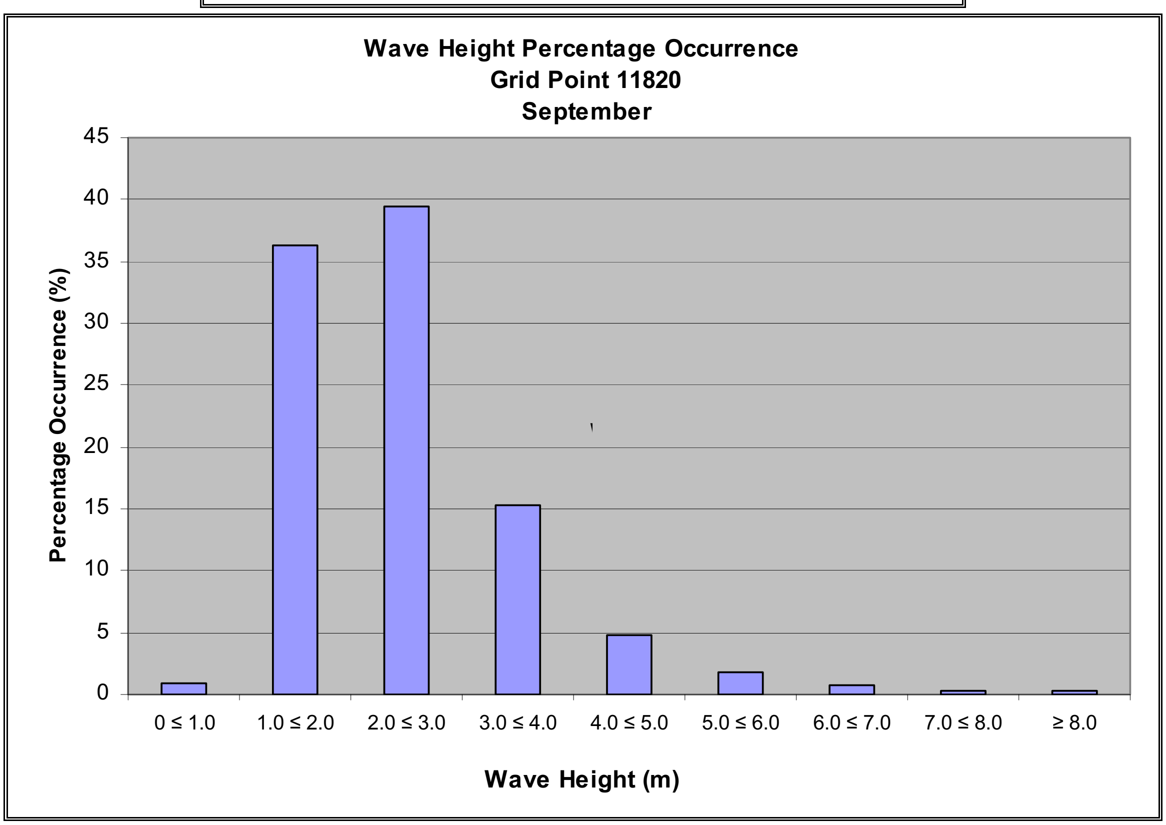
August


NORTH
SOUTH
WEST
EAST
5%
10%
15%
20%
25%
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 - 1.0

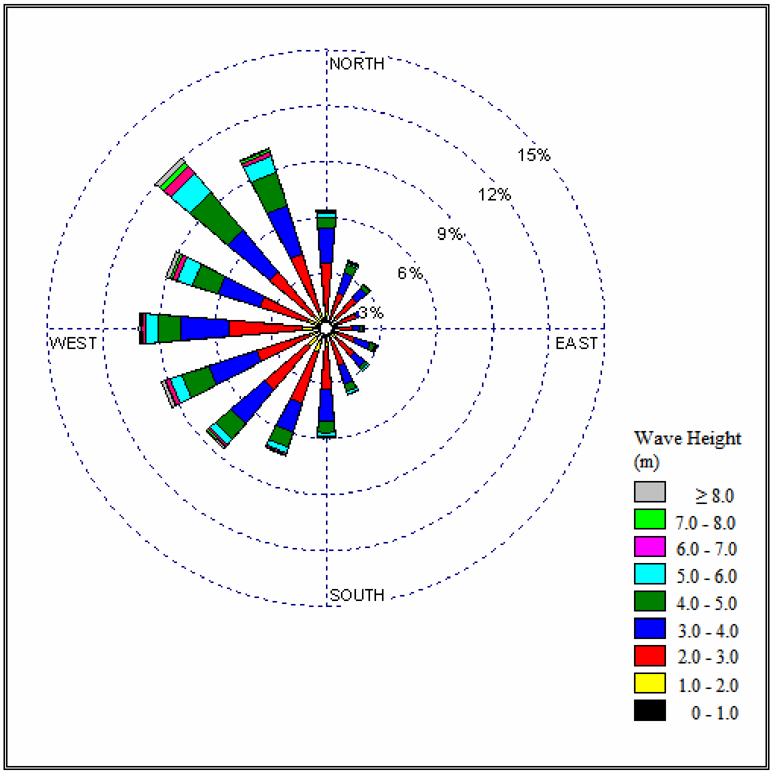

Wave Height Percentage Occurrence
Grid Point 11820
August
Percentage Occurrence (%)
70
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

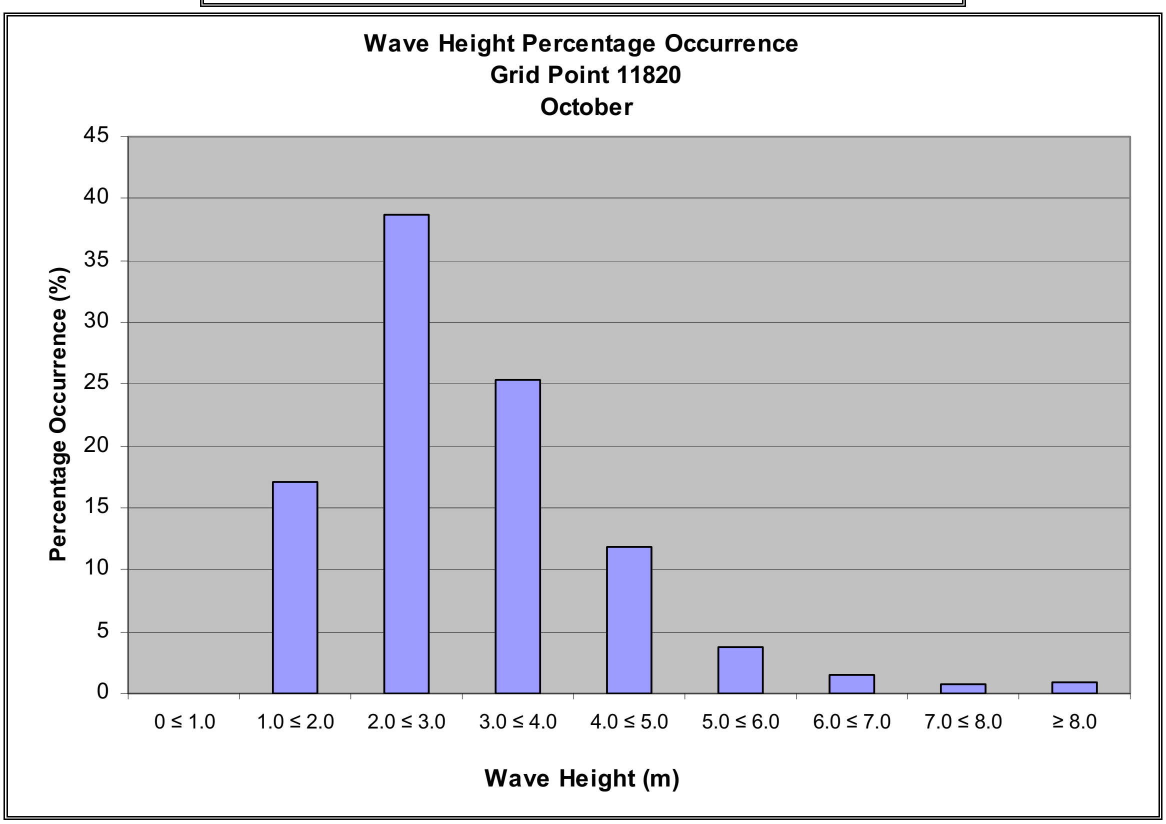
September


NORTH
15%
12%
9%
6%
3%
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 - 1.0

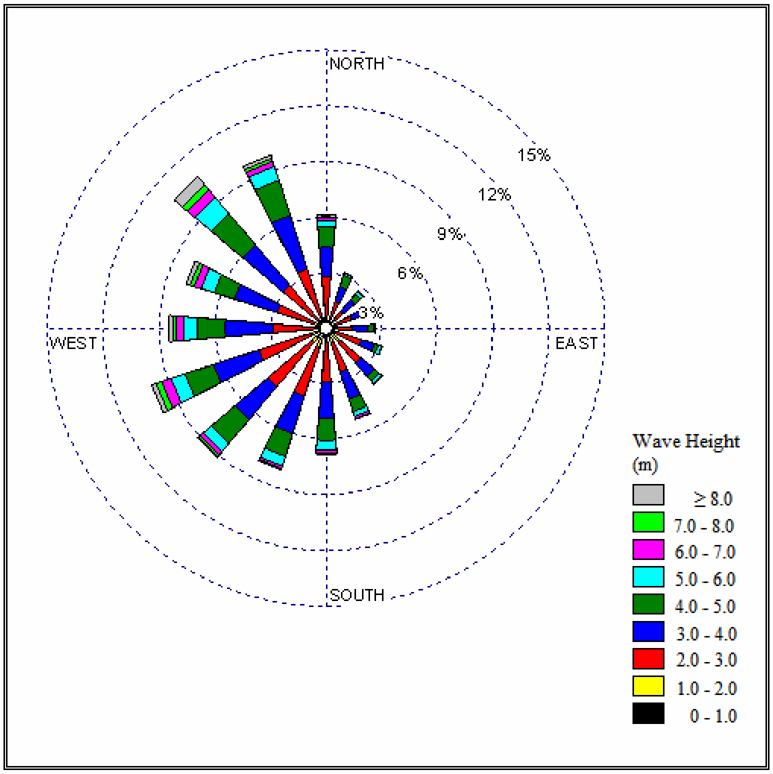

Wave Height Percentage Occurrence
Grid Point 11820
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

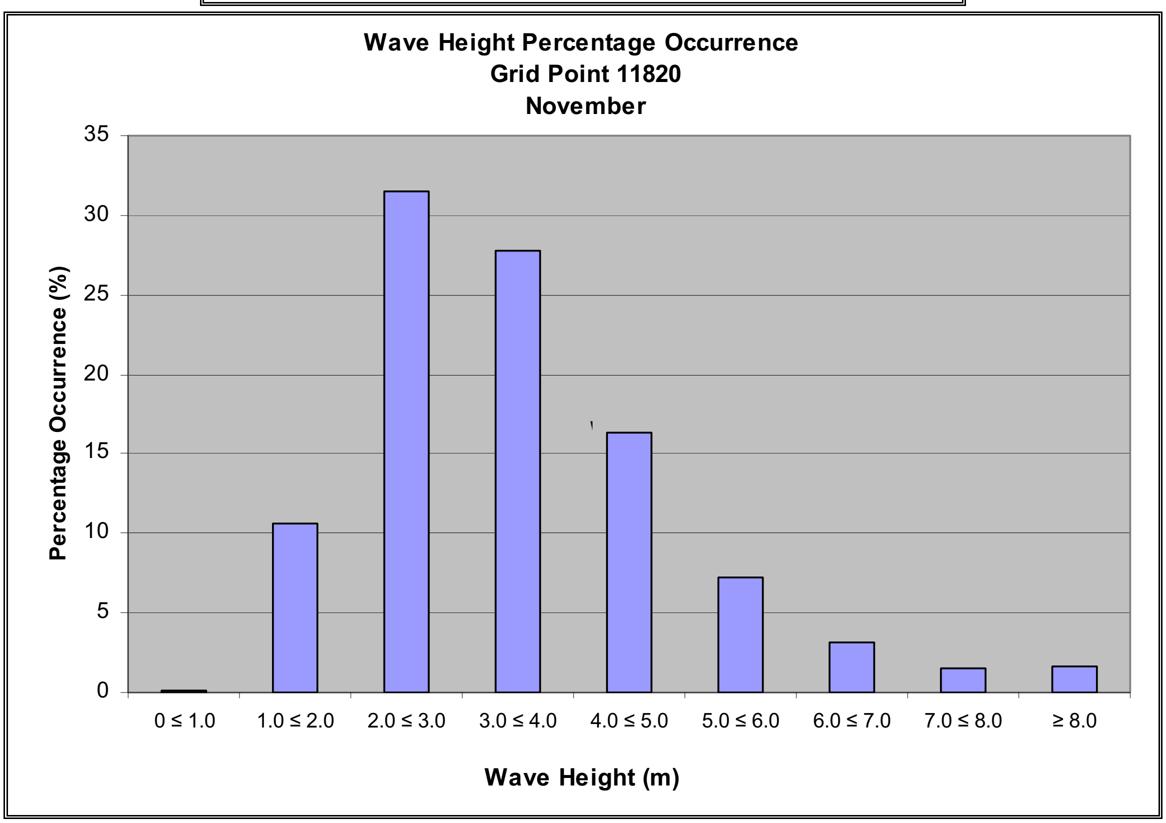
October


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
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 - 1.0

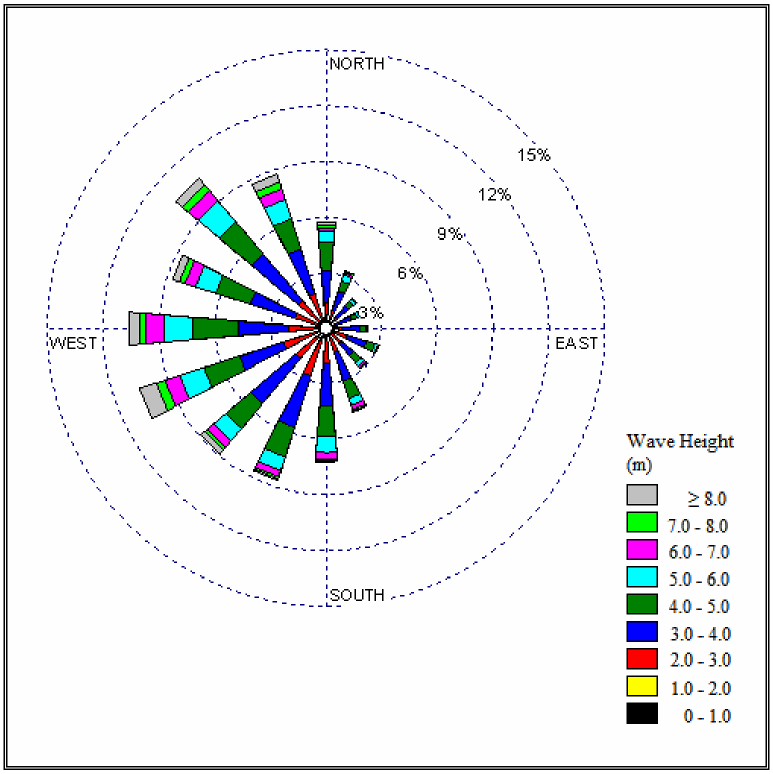

Wave Height Percentage Occurrence
Grid Point 11820
October
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

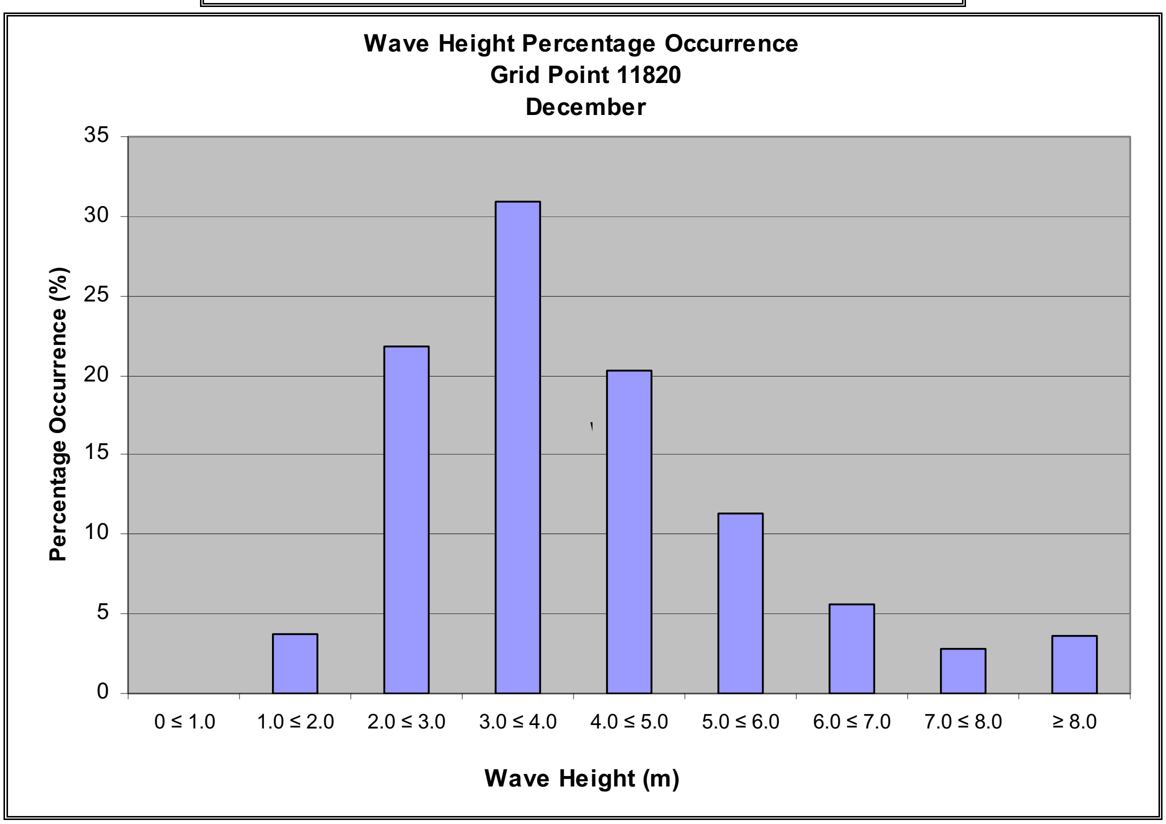
November


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
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 - 1.0


Wave Height Percentage Occurrence
Grid Point 11820
November
Percentage Occurrence (%)
35
30
25
20
15
10
5
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)

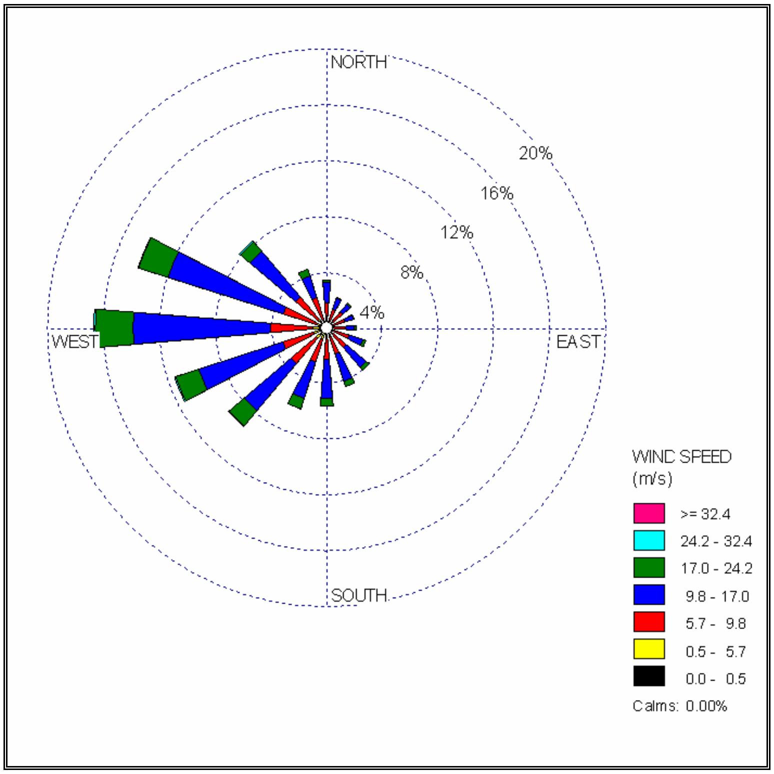
December


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
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 - 1.0

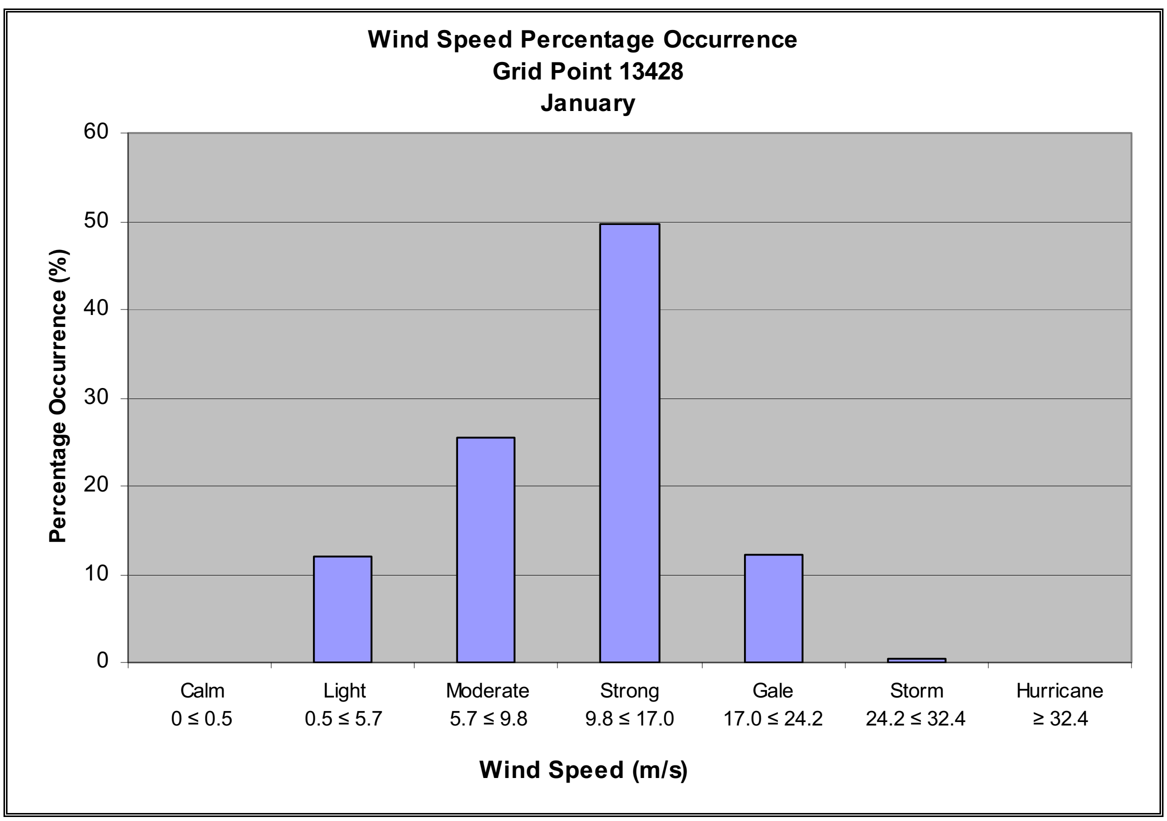

Wave Height Percentage Occurrence
Grid Point 11820
December
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

Appendix 5
Wind Roses and
Wind Speed Frequency Distributions
for MSC50 GridPoint 13428

January

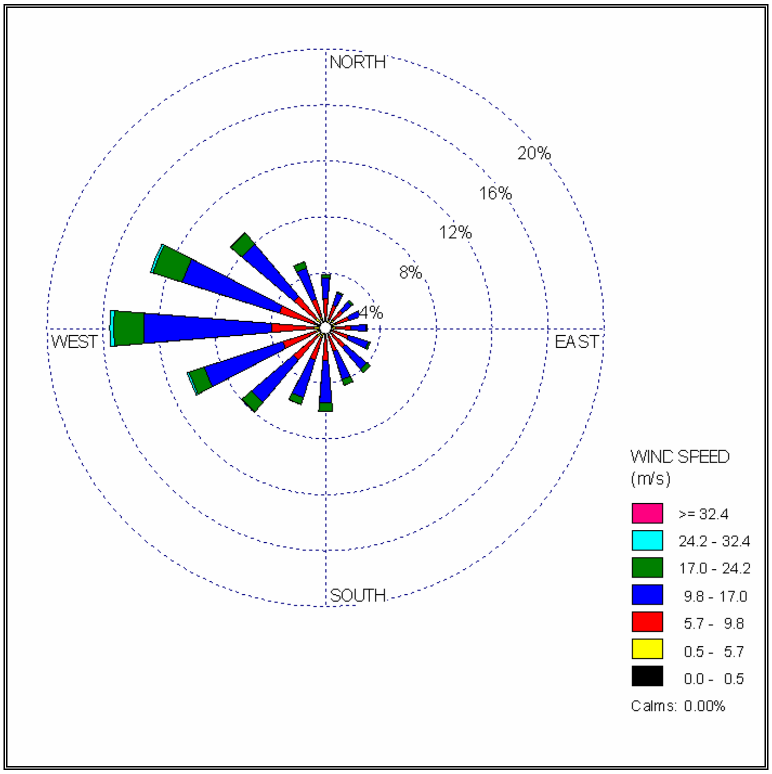


NORTH
SOUTH
EAST
WEST
4%
8%
12%
16%
20%
WIND SPEED (m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

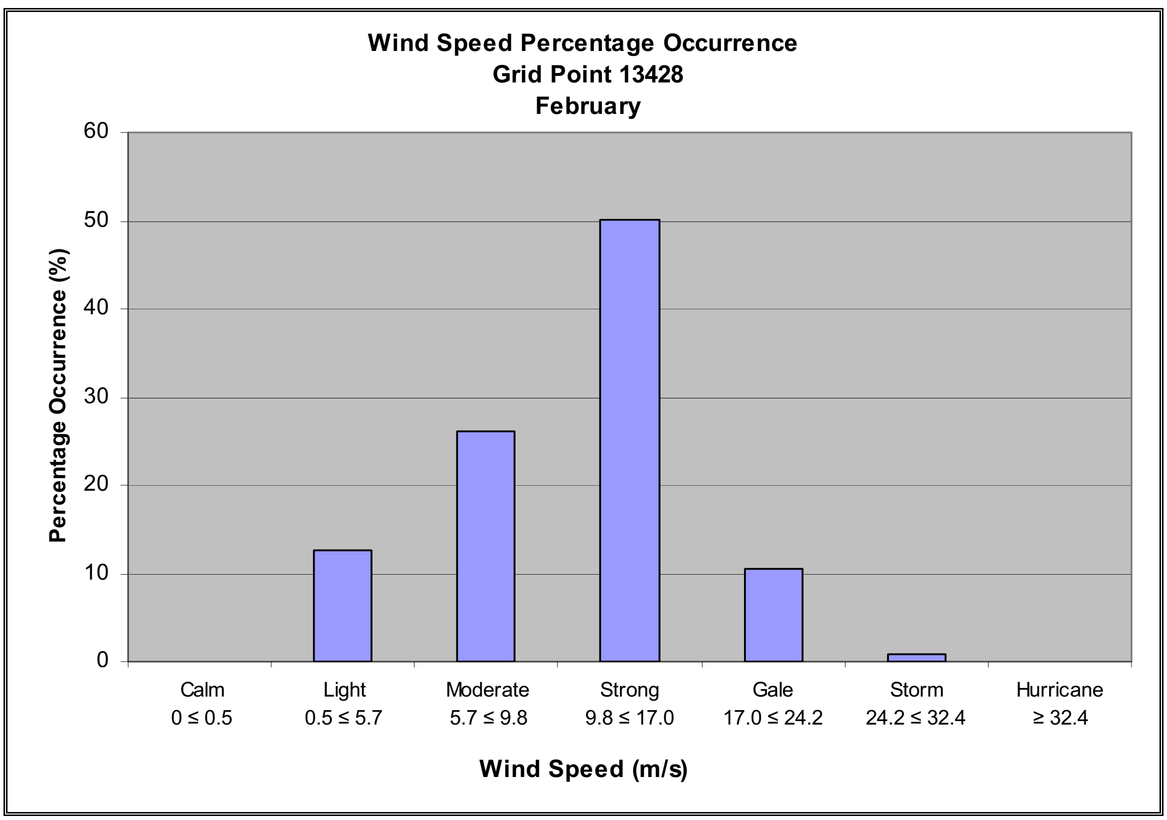


Wind Speed Percentage Occurrence
Grid Point 13428
January
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm 0 ≤ 0.5
Light 0.5 ≤ 5.7
Moderate 5.7 ≤ 9.8
Strong 9.8 ≤ 17.0
Gale 17.0 ≤ 24.2
Storm 24.2 ≤ 32.4
Hurricane ≥ 32.4
Wind Speed (m/s)

February

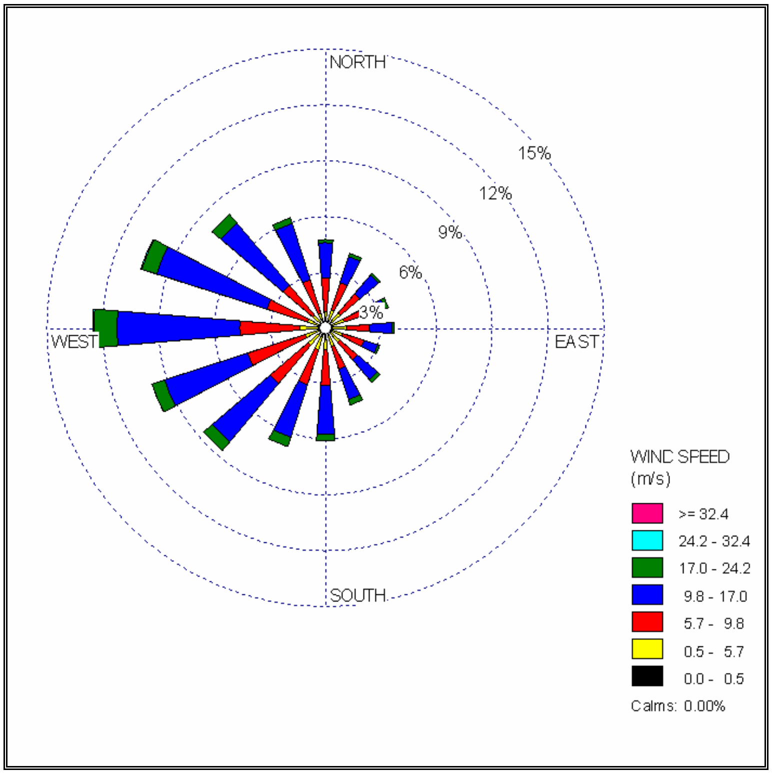


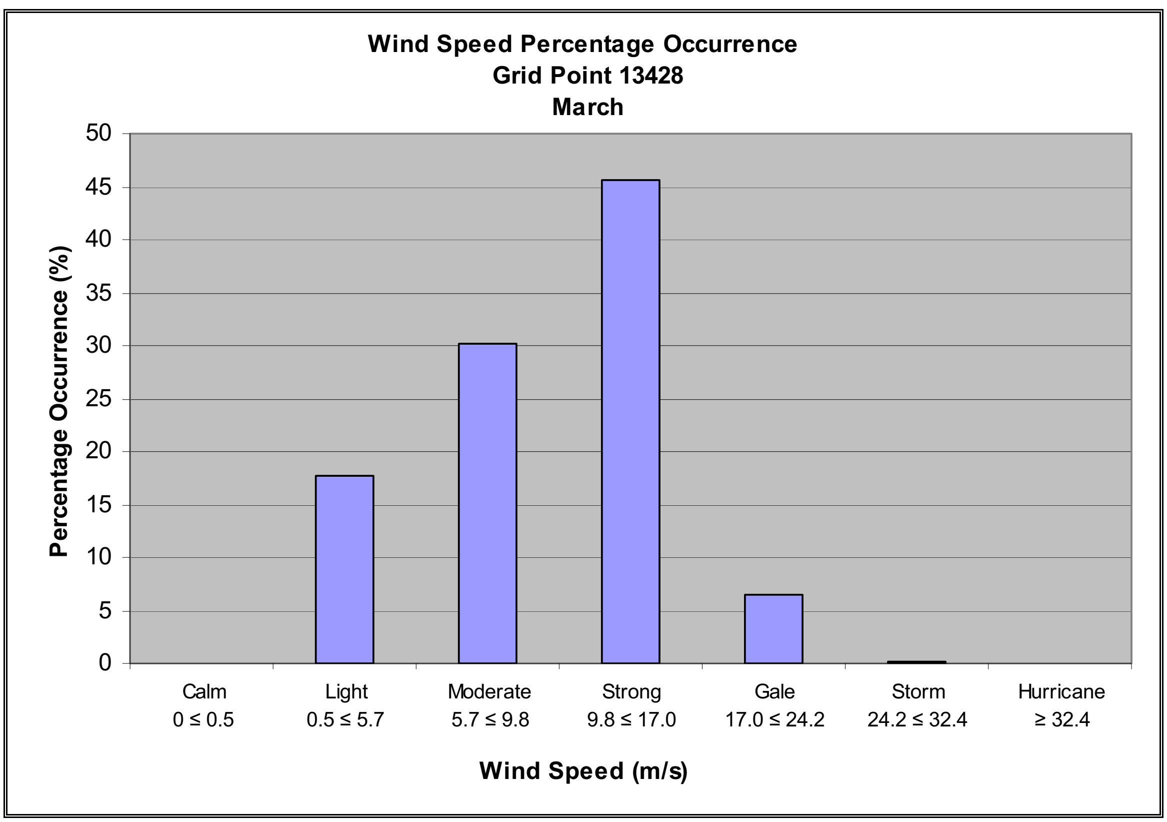
NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



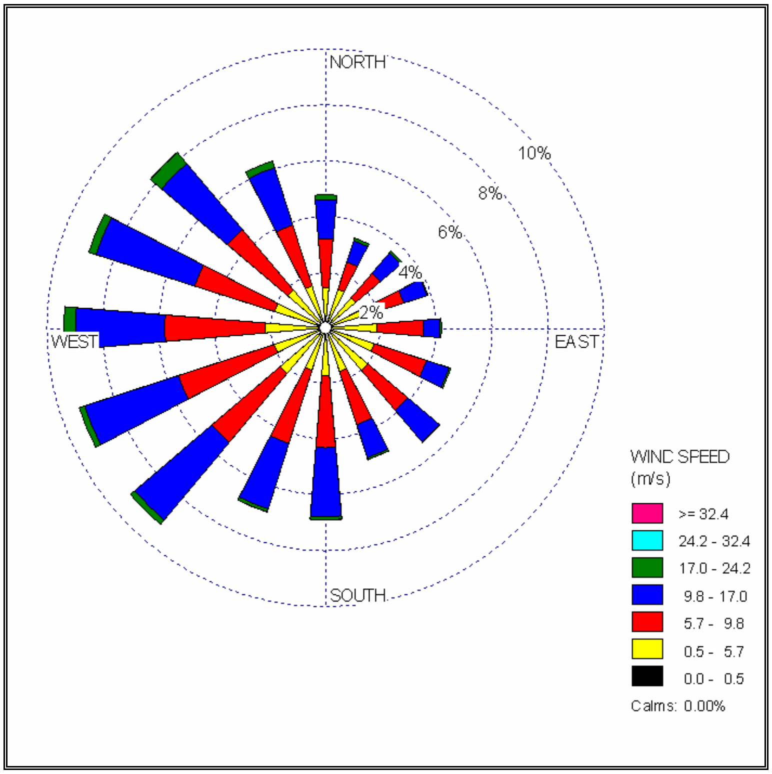
Wind Speed Percentage Occurrence
Grid Point 13428
February
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

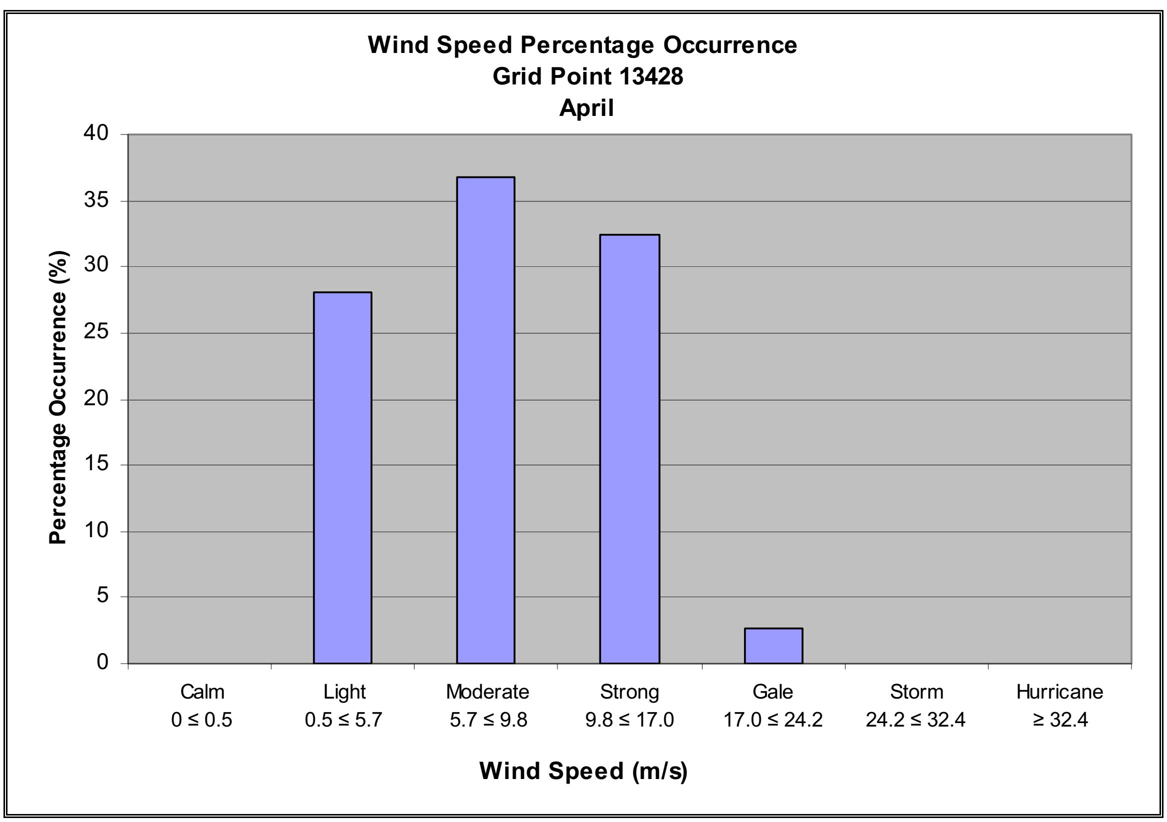
March


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
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%

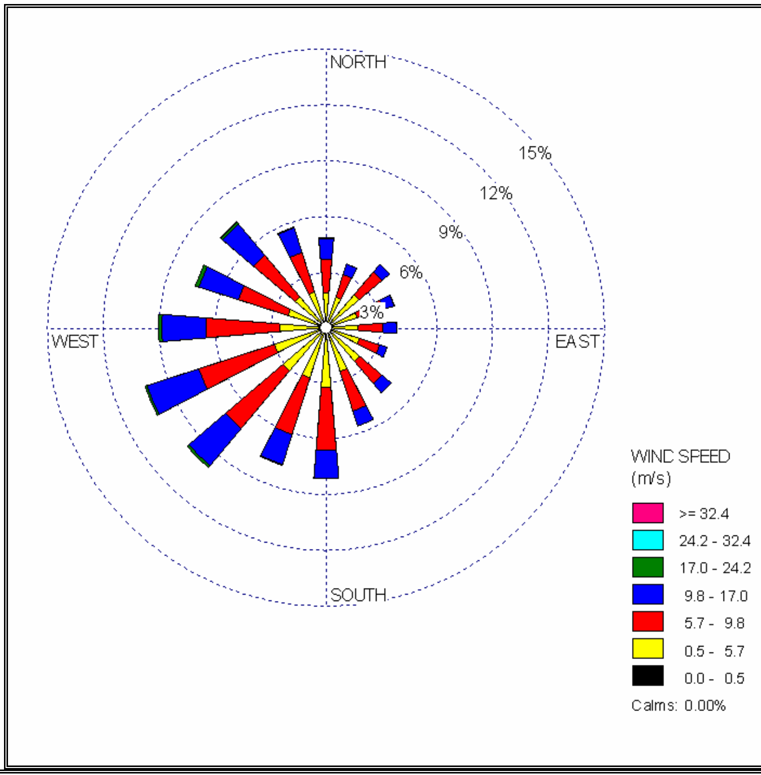

Wind Speed Percentage Occurrence
Grid Point 13428
March
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

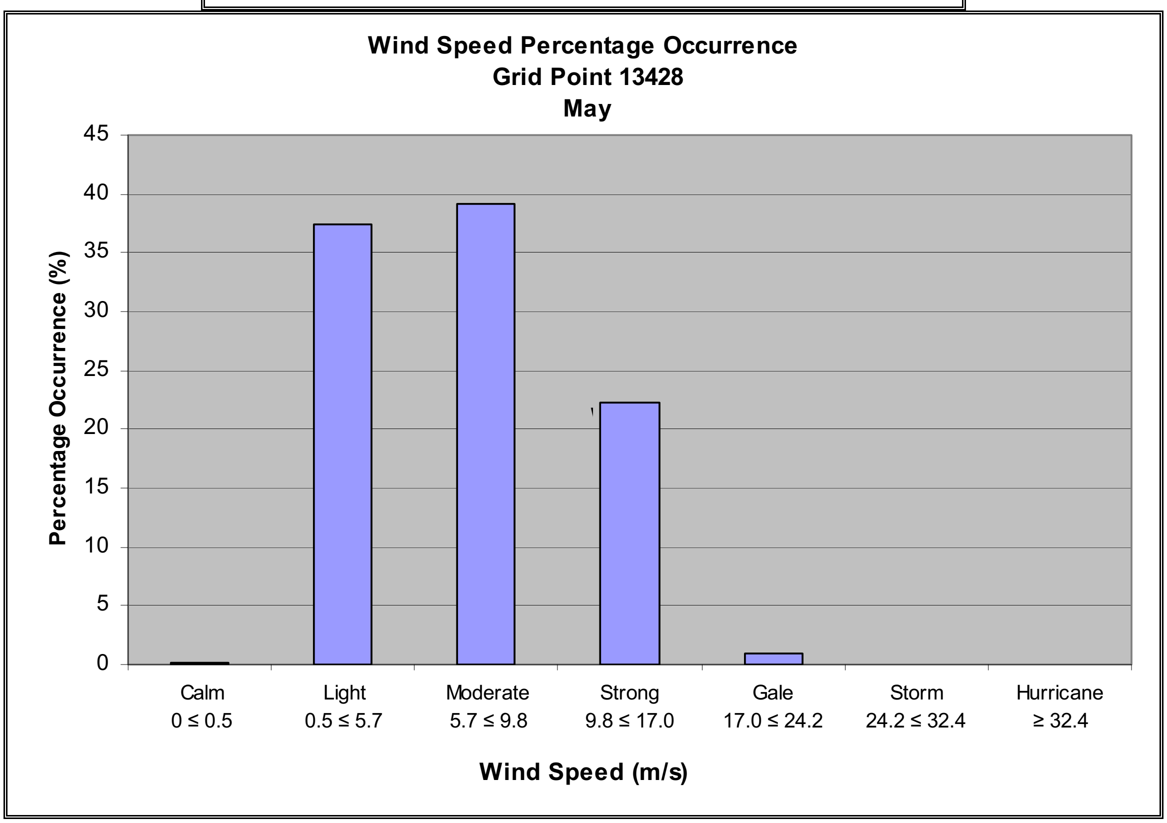
April


NORTH
SOUTH
EAST
WEST
2%
4%
6%
8%
10%
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%

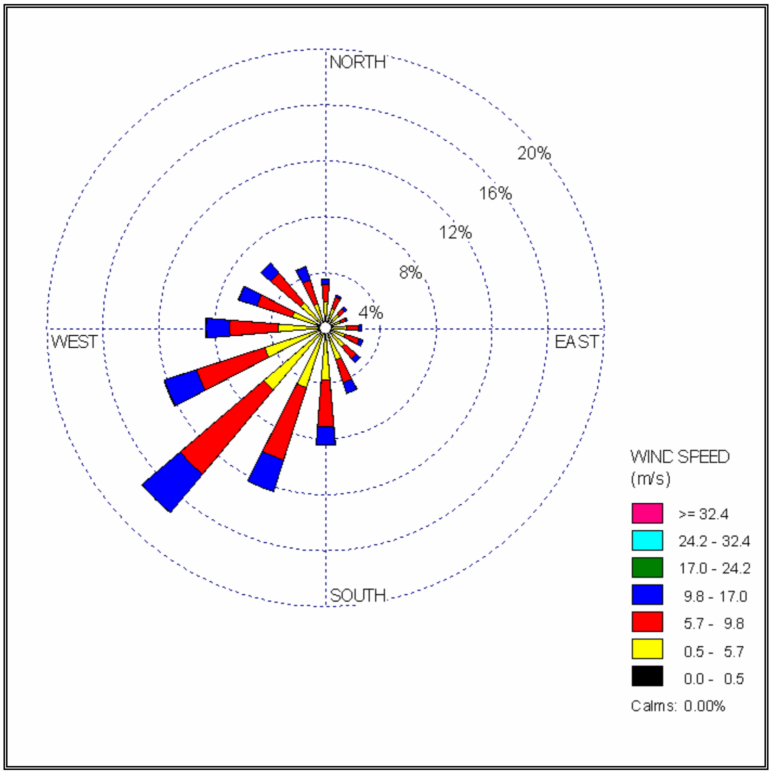

Wind Speed Percentage Occurrence
Grid Point 13428
April
Percentage Occurrence (%)
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

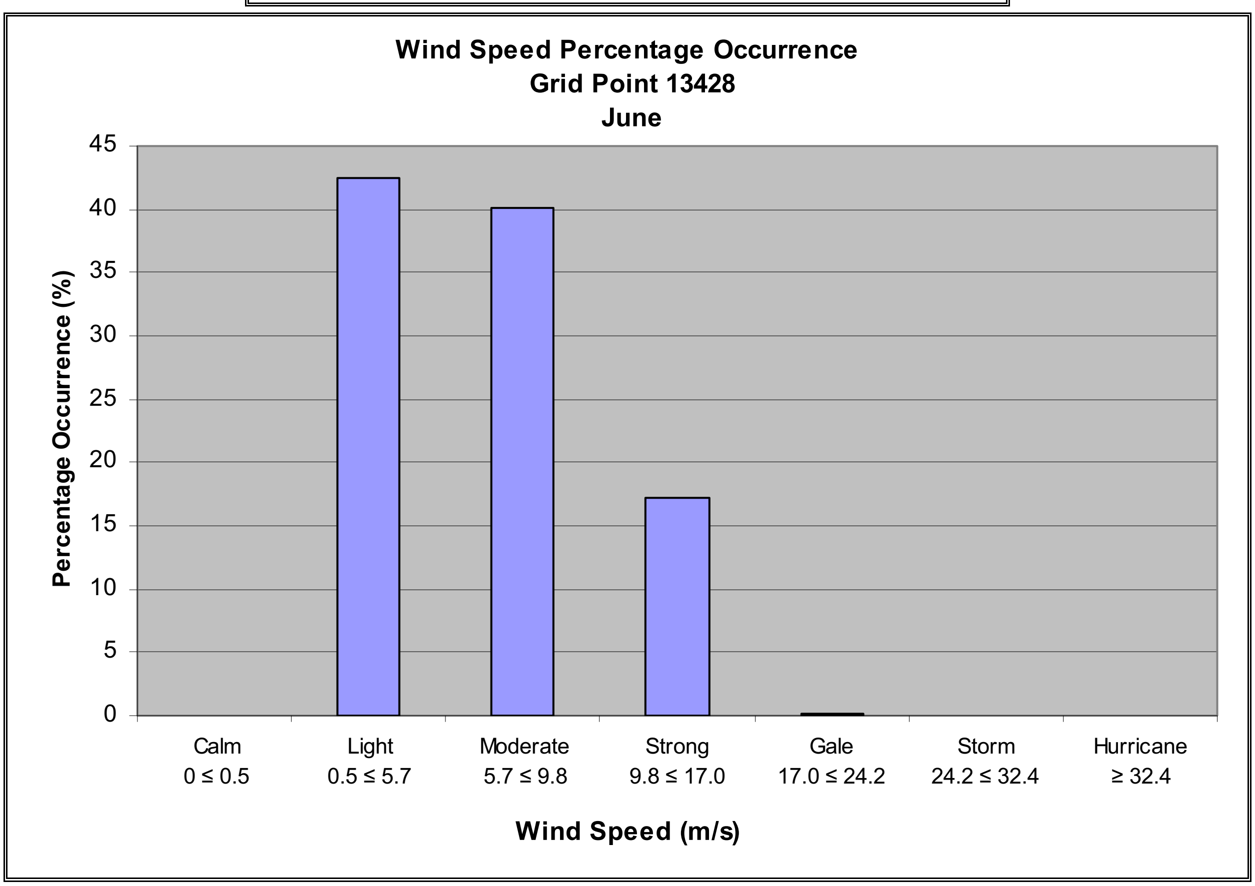
May


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
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%

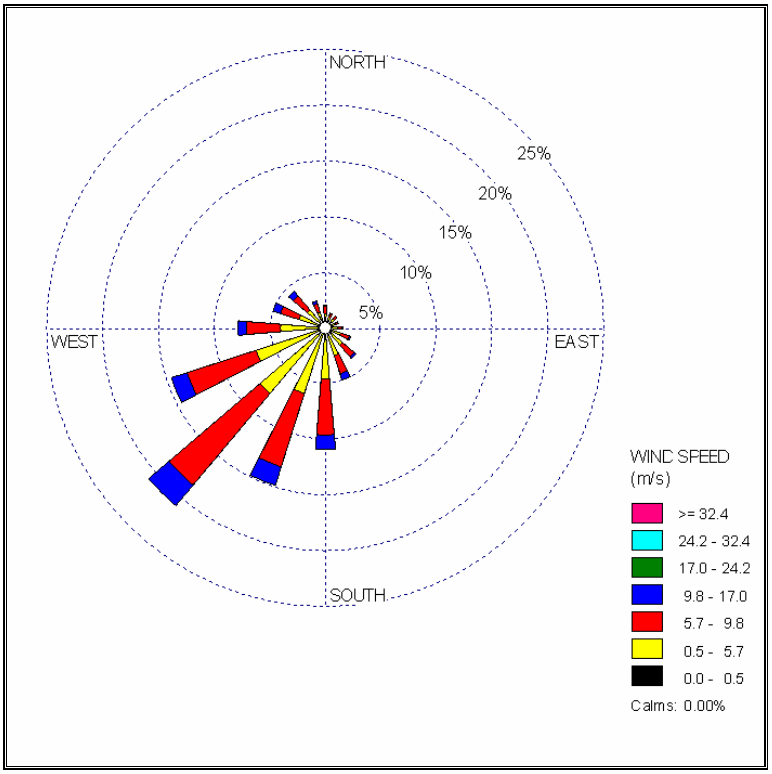

Wind Speed Percentage Occurrence
Grid Point 13428
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

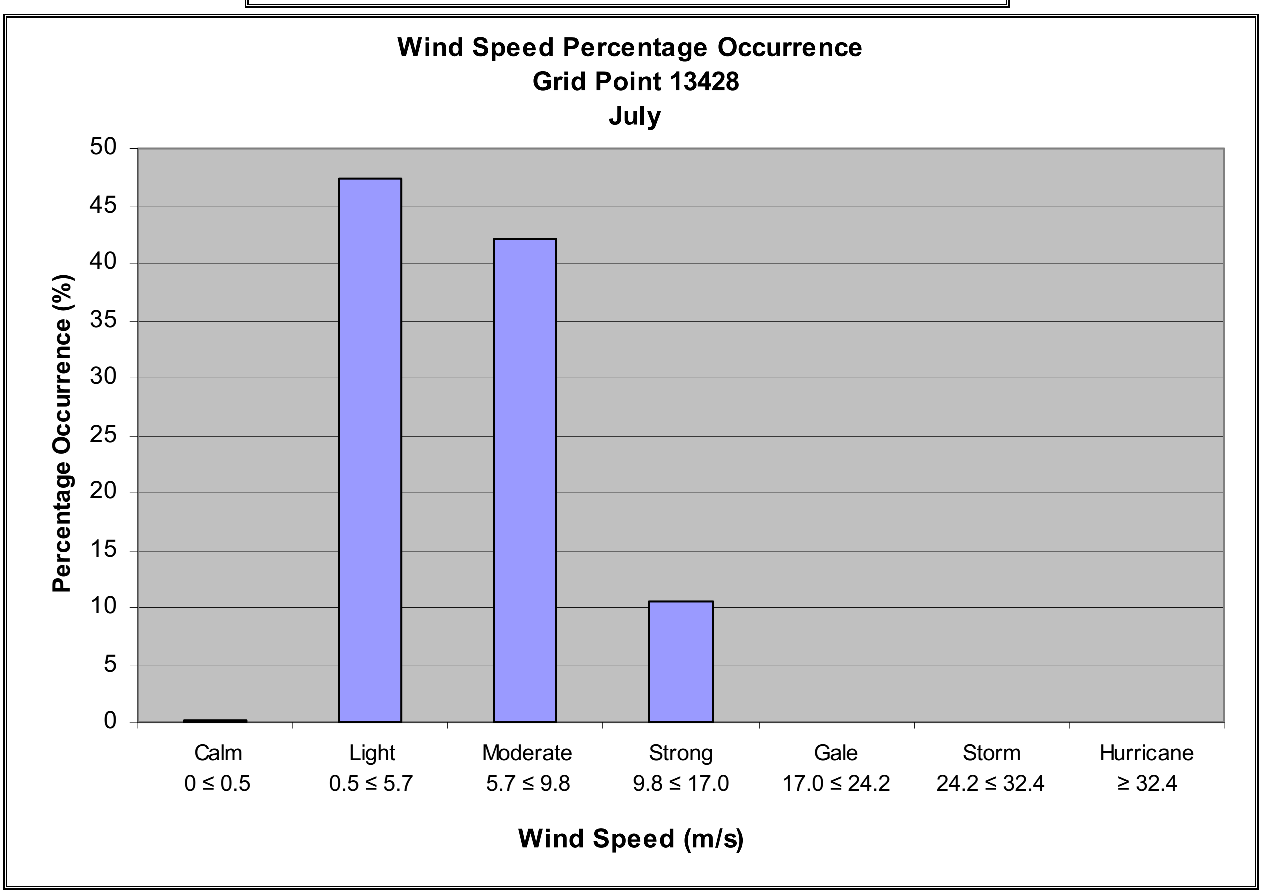
June


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%

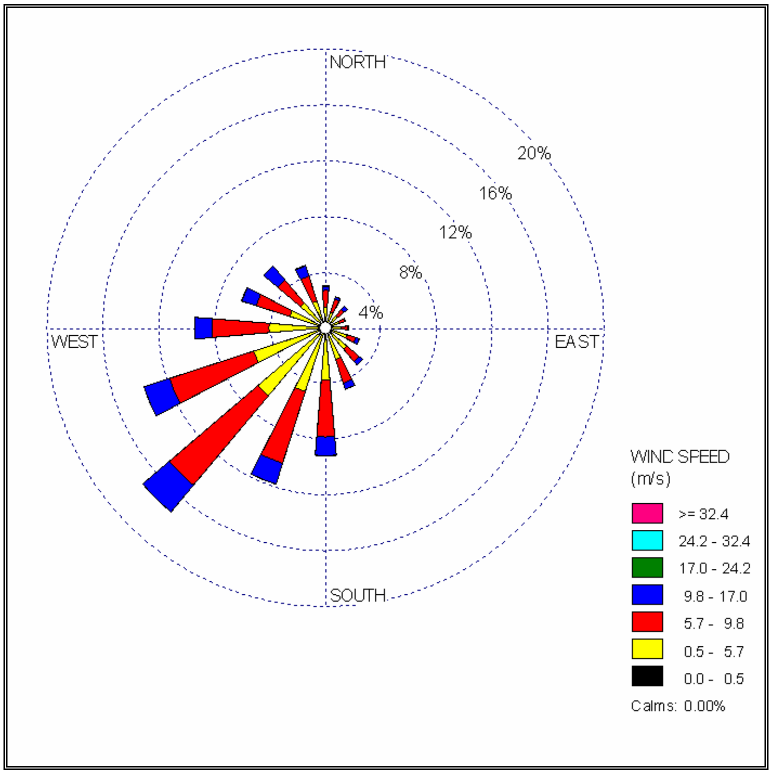

Wind Speed Percentage Occurrence
Grid Point 13428
June
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

July

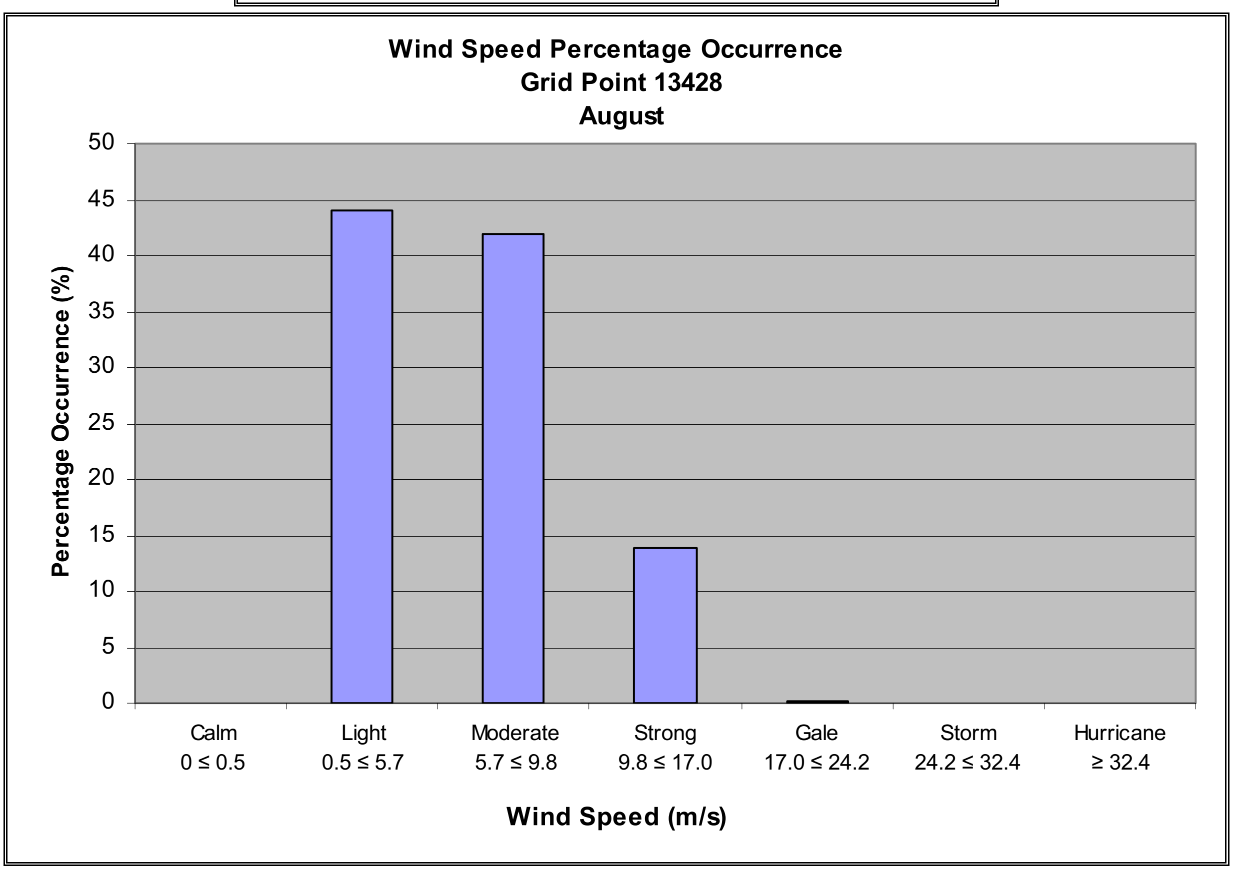

NORTH
SOUTH
WEST
EAST
5%
10%
15%
20%
25%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 13428
July
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
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

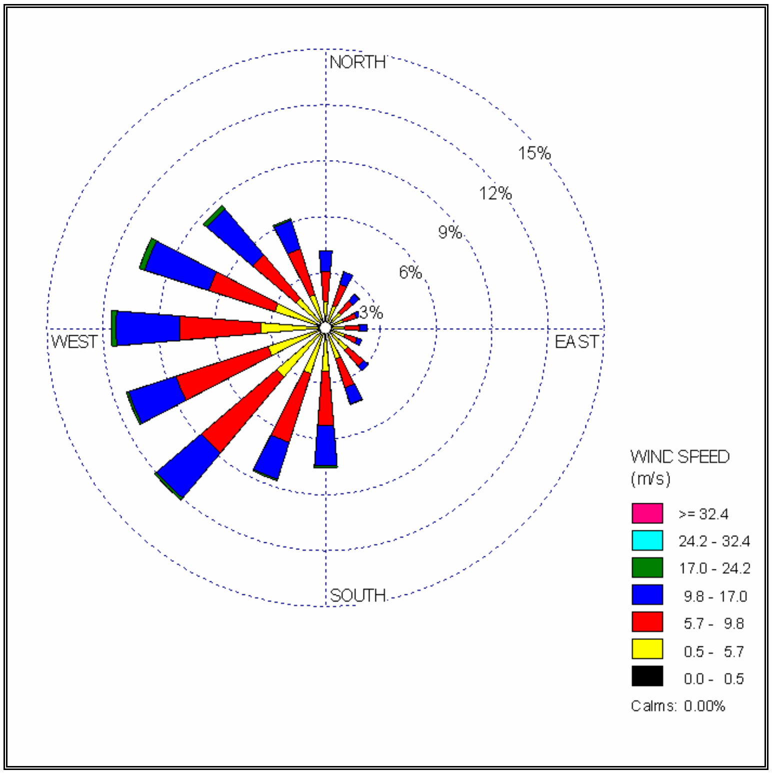


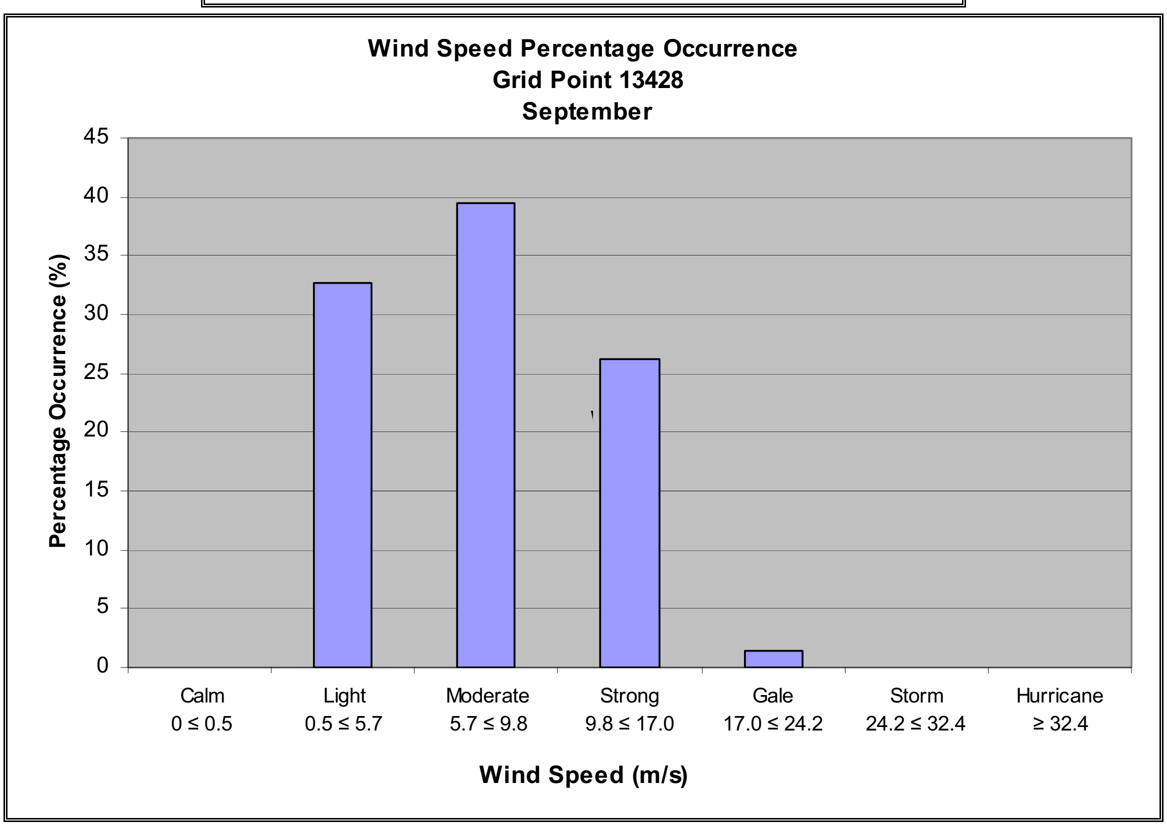
NORTH
SOUTH
WEST
EAST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



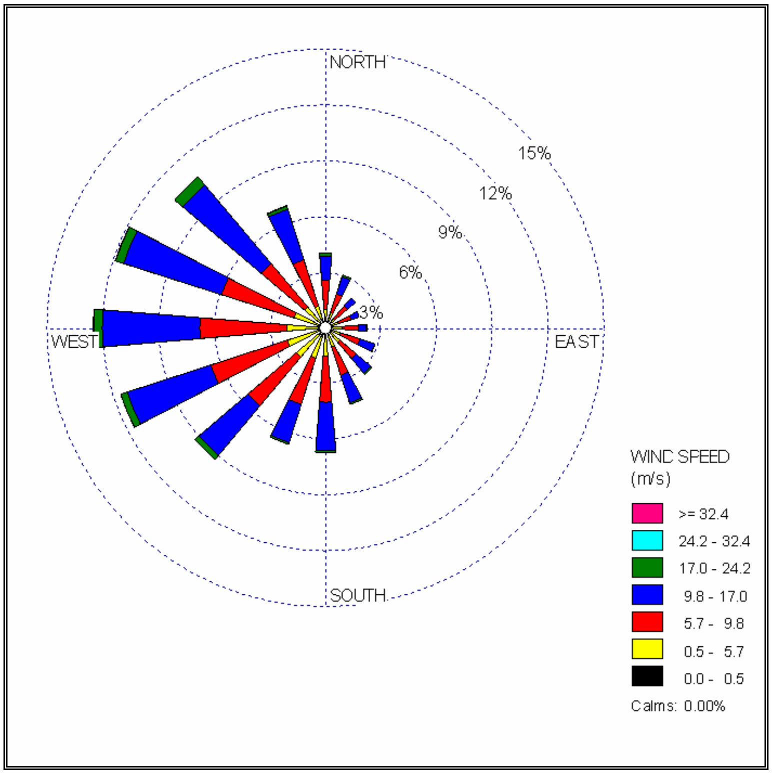
Wind Speed Percentage Occurrence
Grid Point 13428
August
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

September

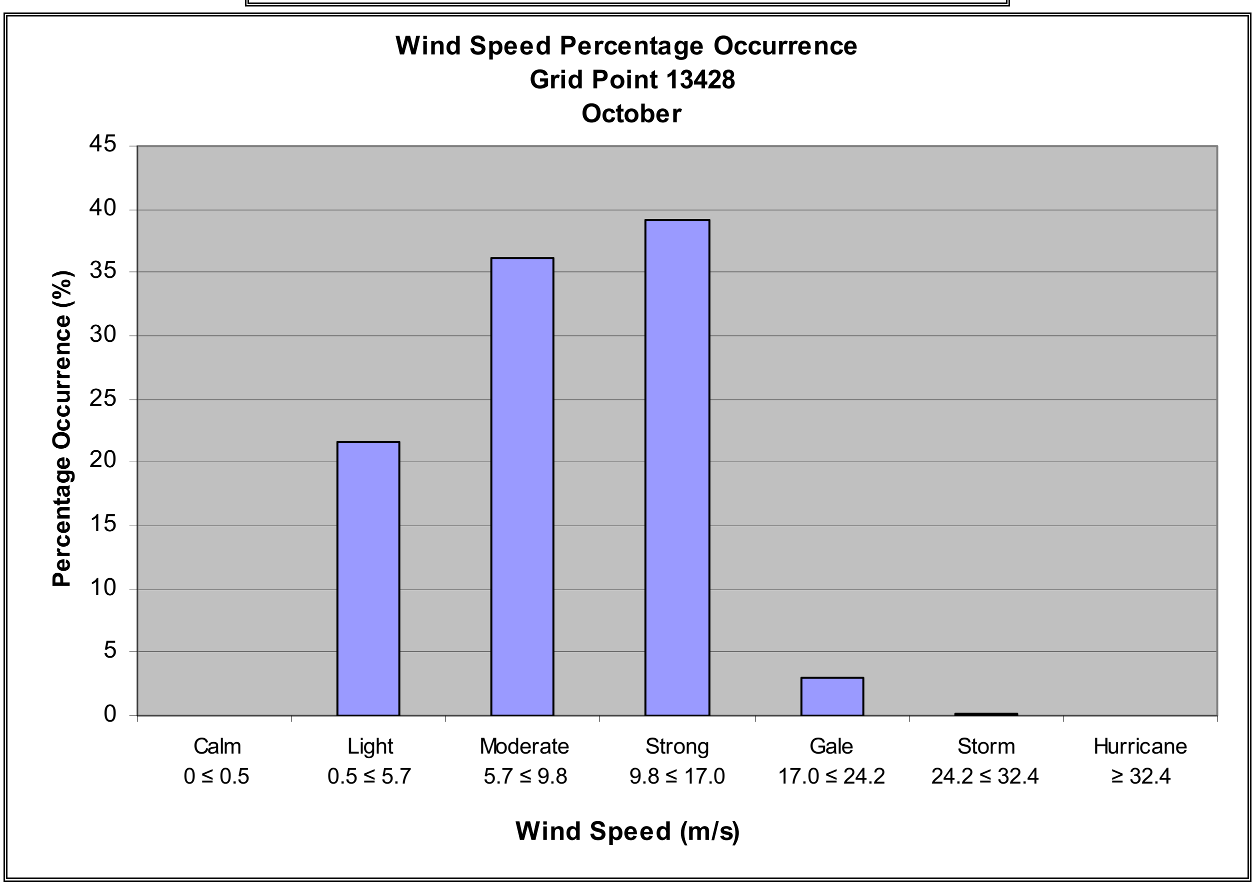

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED (m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 13428
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
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

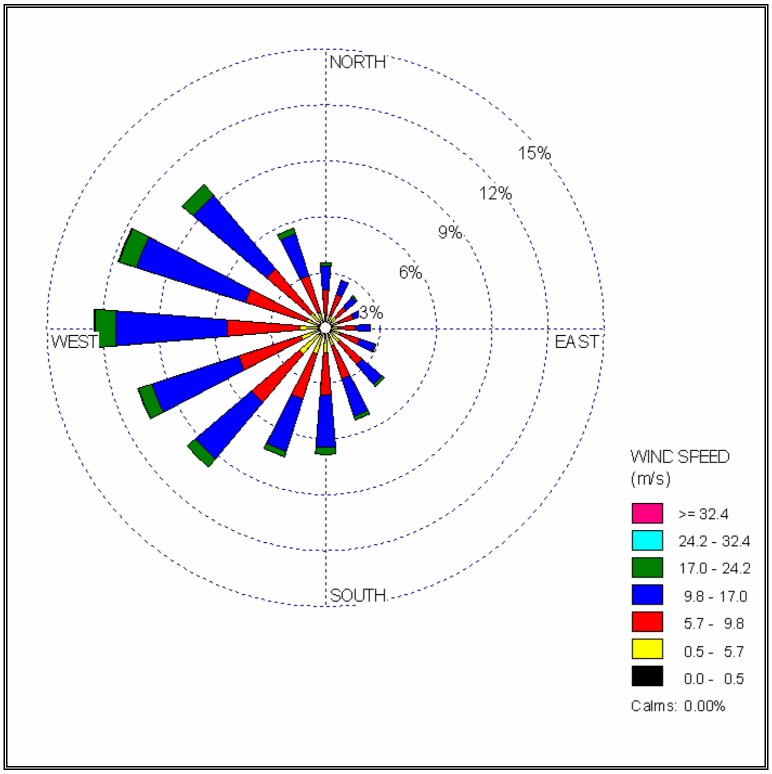


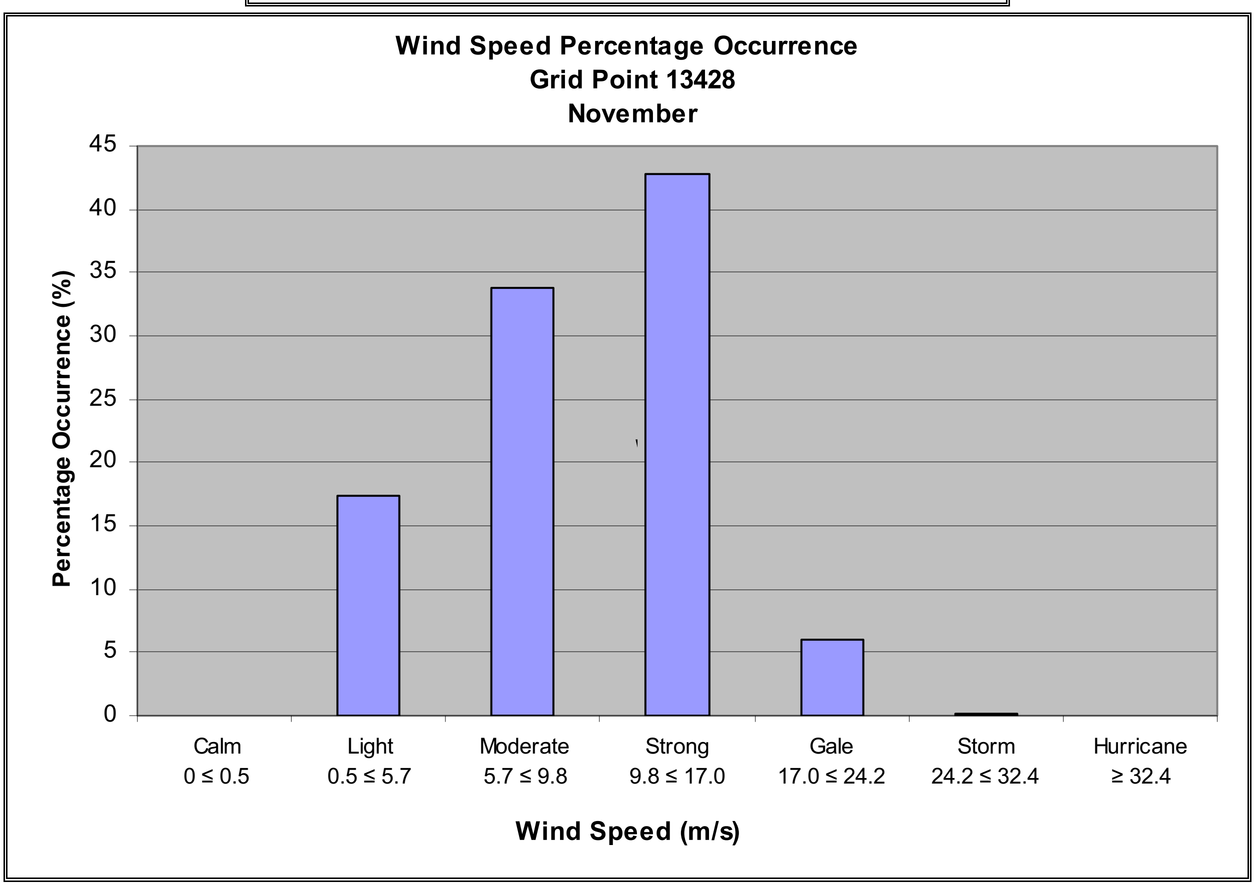
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



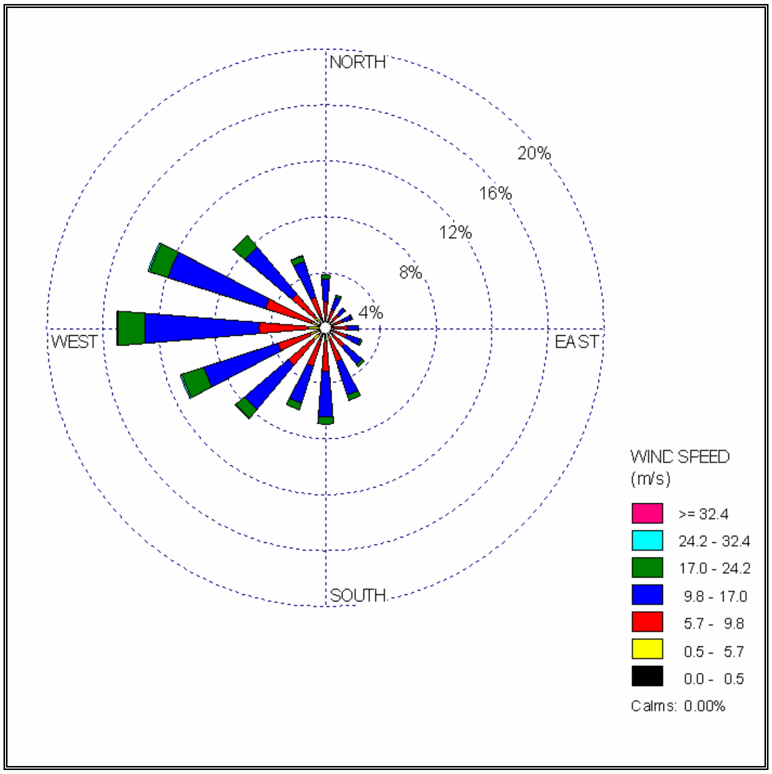
Wind Speed Percentage Occurrence
Grid Point 13428
October
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

November

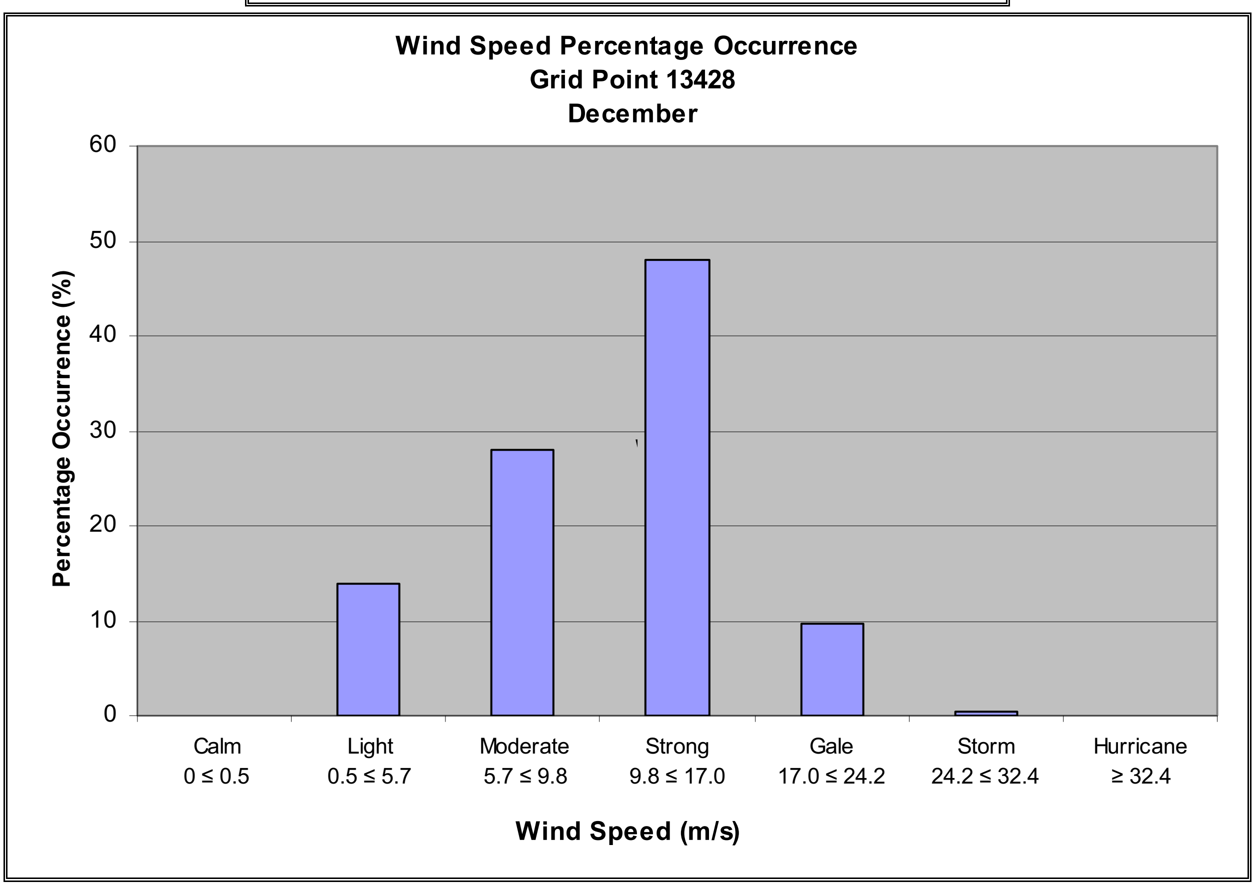

NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 13428
November
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
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



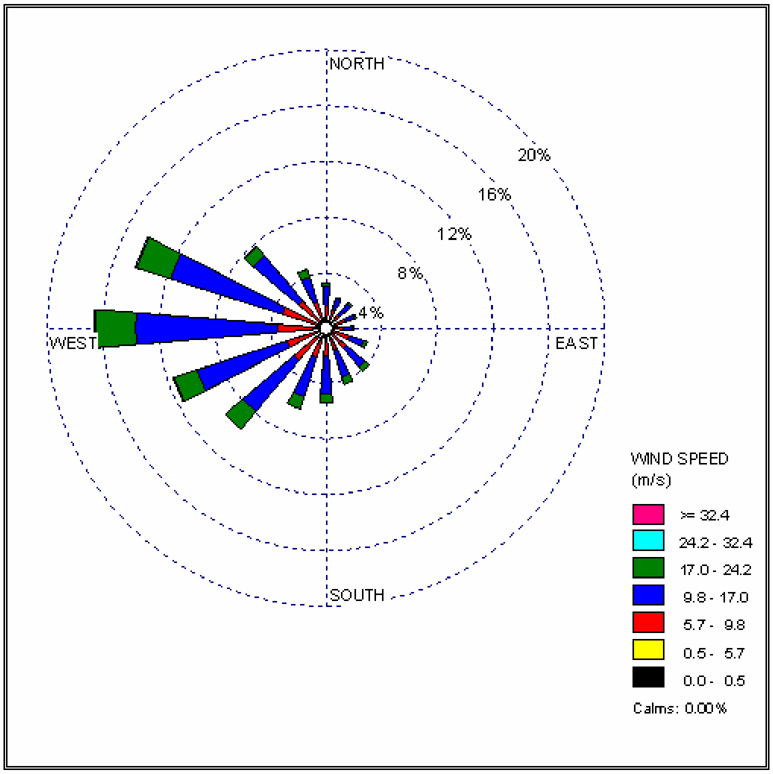
NORTH
SOUTH
EAST
WEST
4%
8%
12%
16%
20%
WIND SPEED (m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



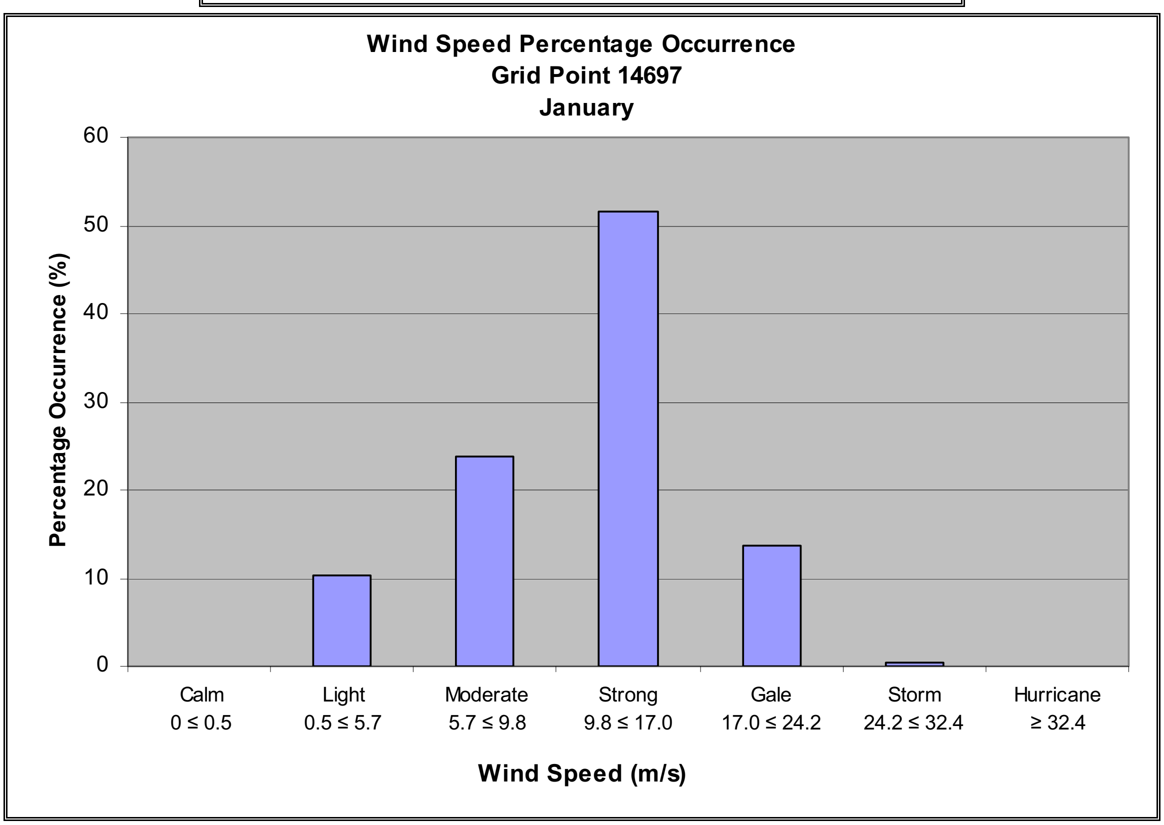
Wind Speed Percentage Occurrence
Grid Point 13428
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm 0 ≤ 0.5
Light 0.5 ≤ 5.7
Moderate 5.7 ≤ 9.8
Strong 9.8 ≤ 17.0
Gale 17.0 ≤ 24.2
Storm 24.2 ≤ 32.4
Hurricane ≥ 32.4
Wind Speed (m/s)

Appendix 6
Wind Roses and
Wind Speed Frequency Distributions
for MSC50 GridPoint 14697

January

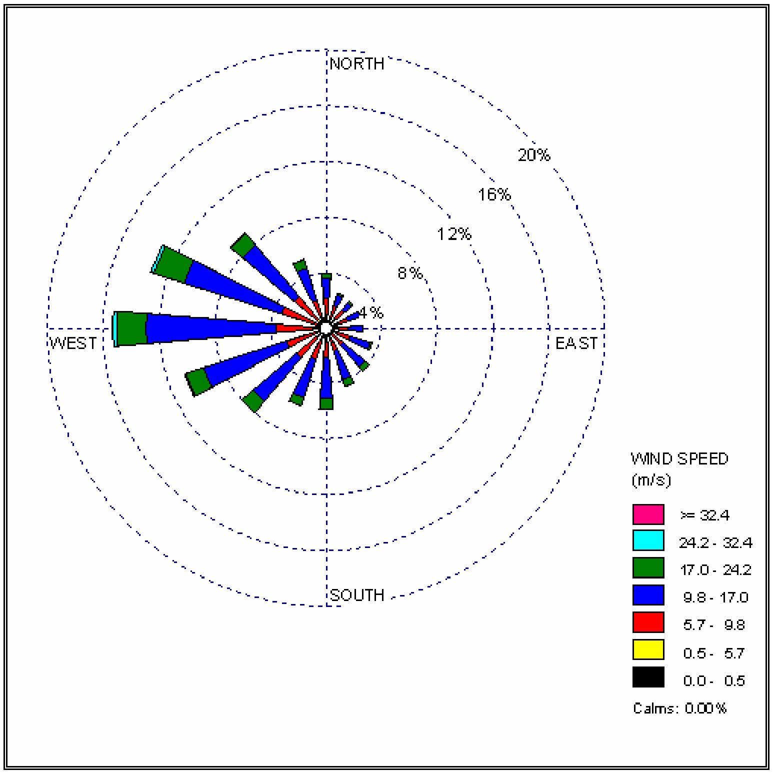


NORTH
SOUTH
EAST
WEST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

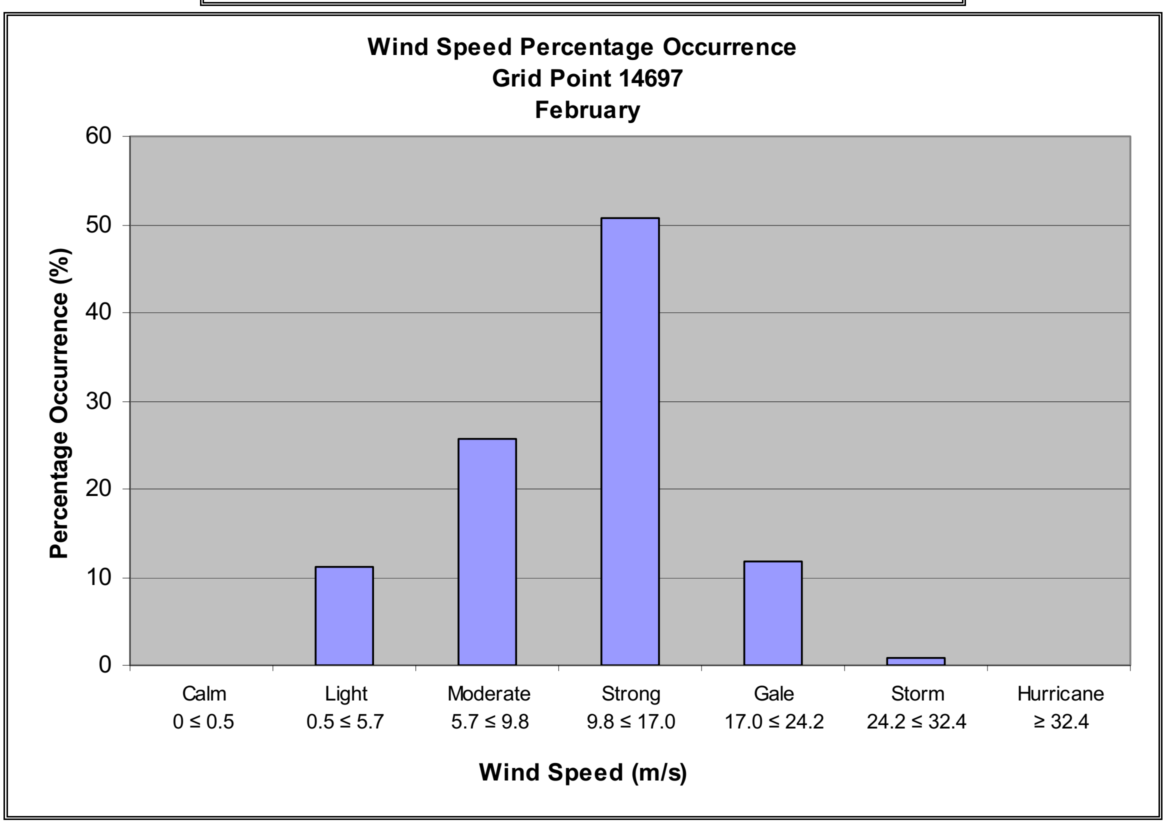


Wind Speed Percentage Occurrence
Grid Point 14697
January
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

February

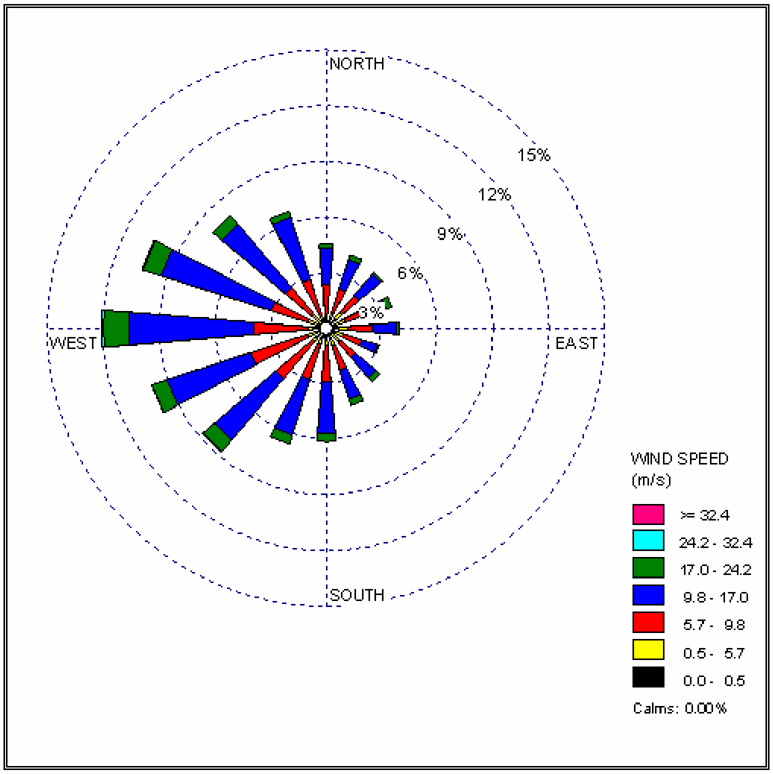


NORTH
SOUTH
EAST
WEST
4 %
8 %
12 %
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

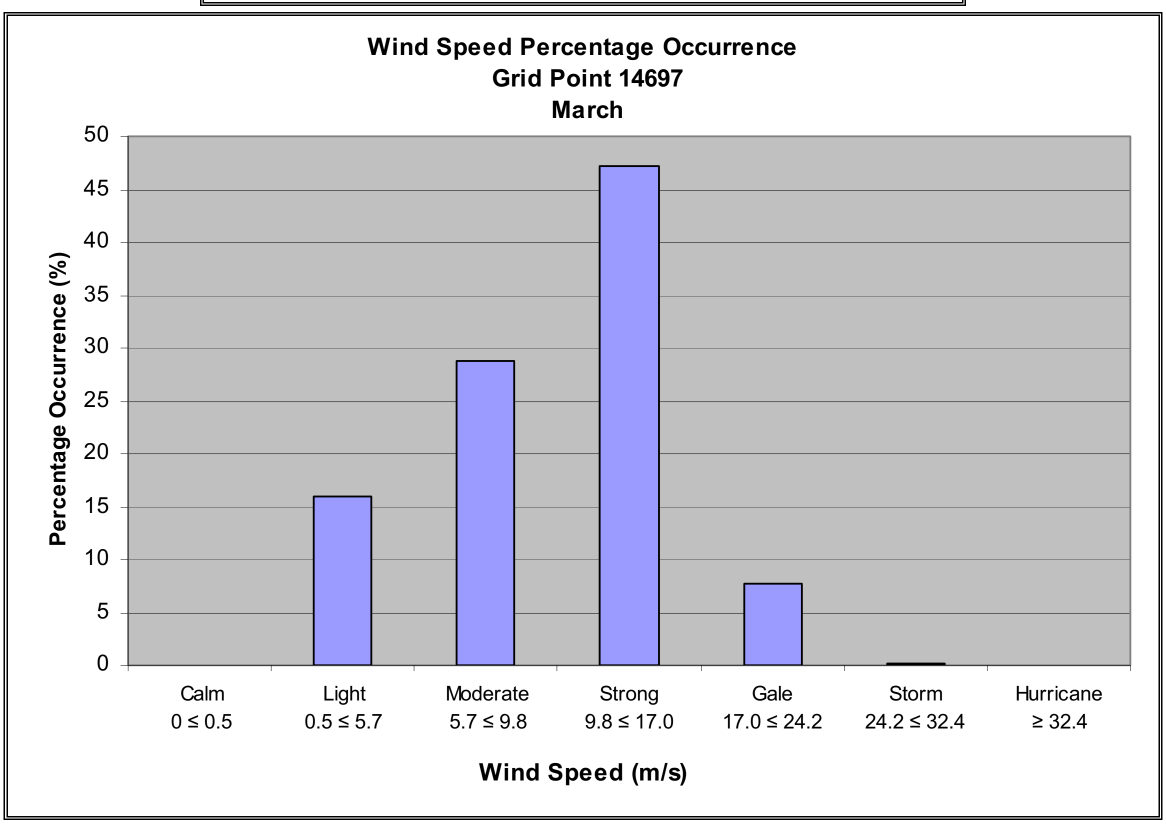


Wind Speed Percentage Occurrence
Grid Point 14697
February
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

March

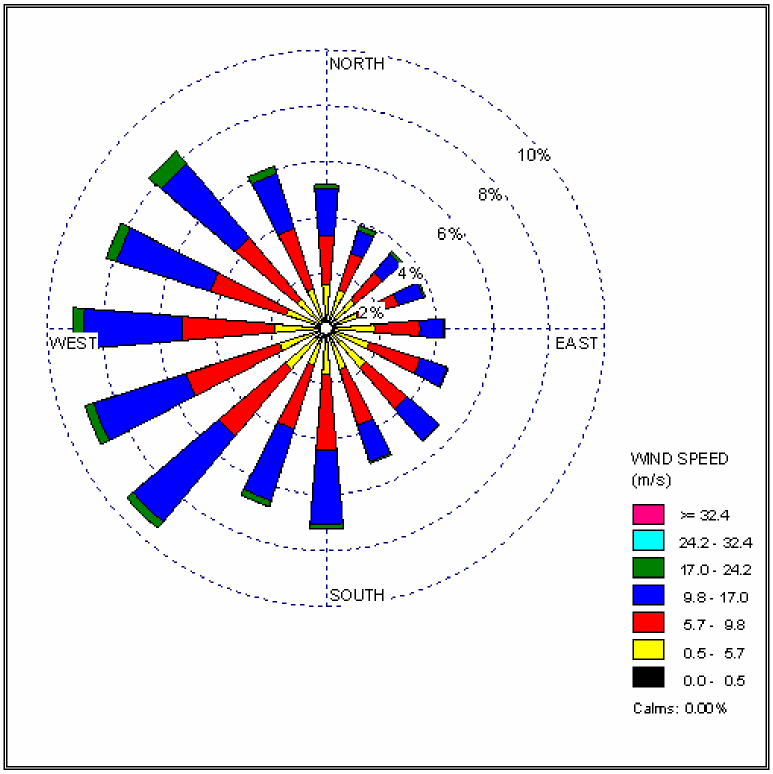


NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

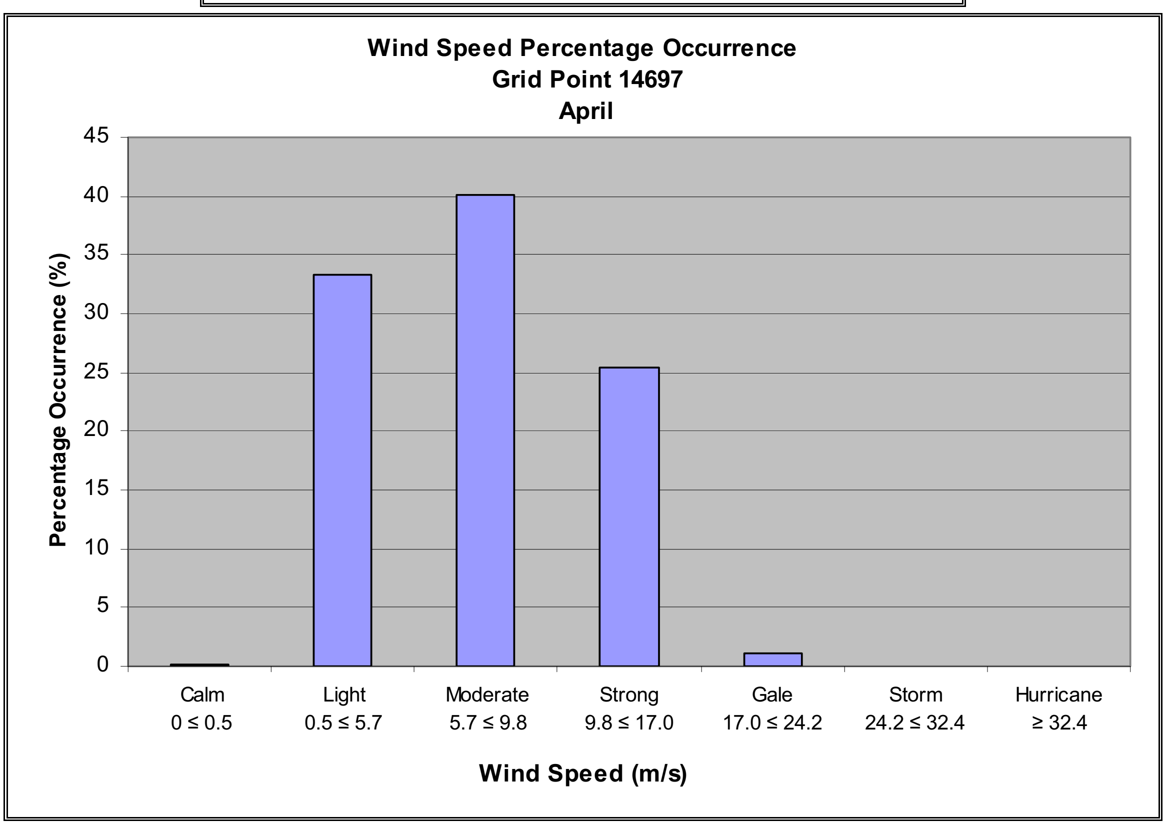


Wind Speed Percentage Occurrence
Grid Point 14697
March
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

April

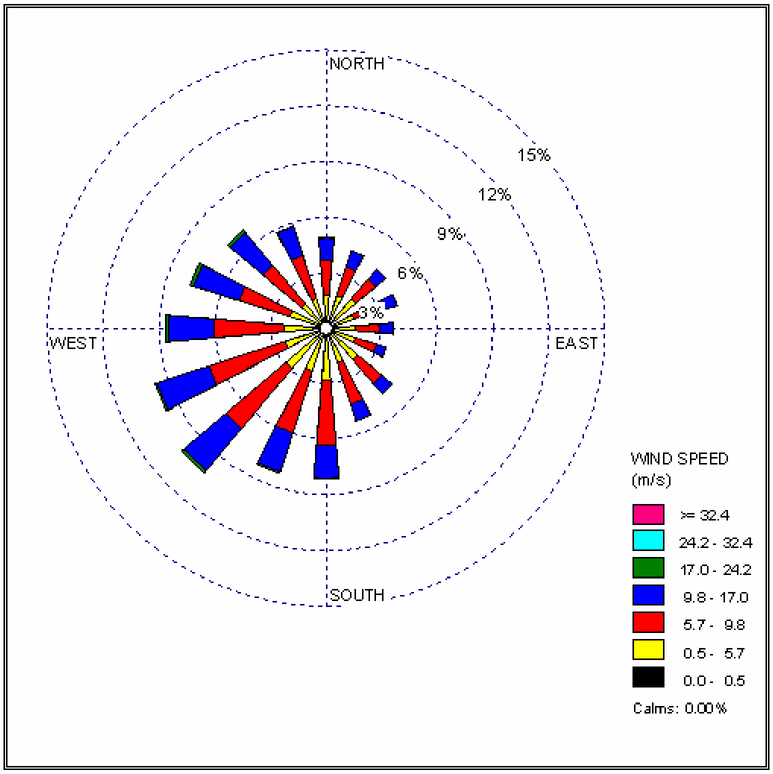


NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

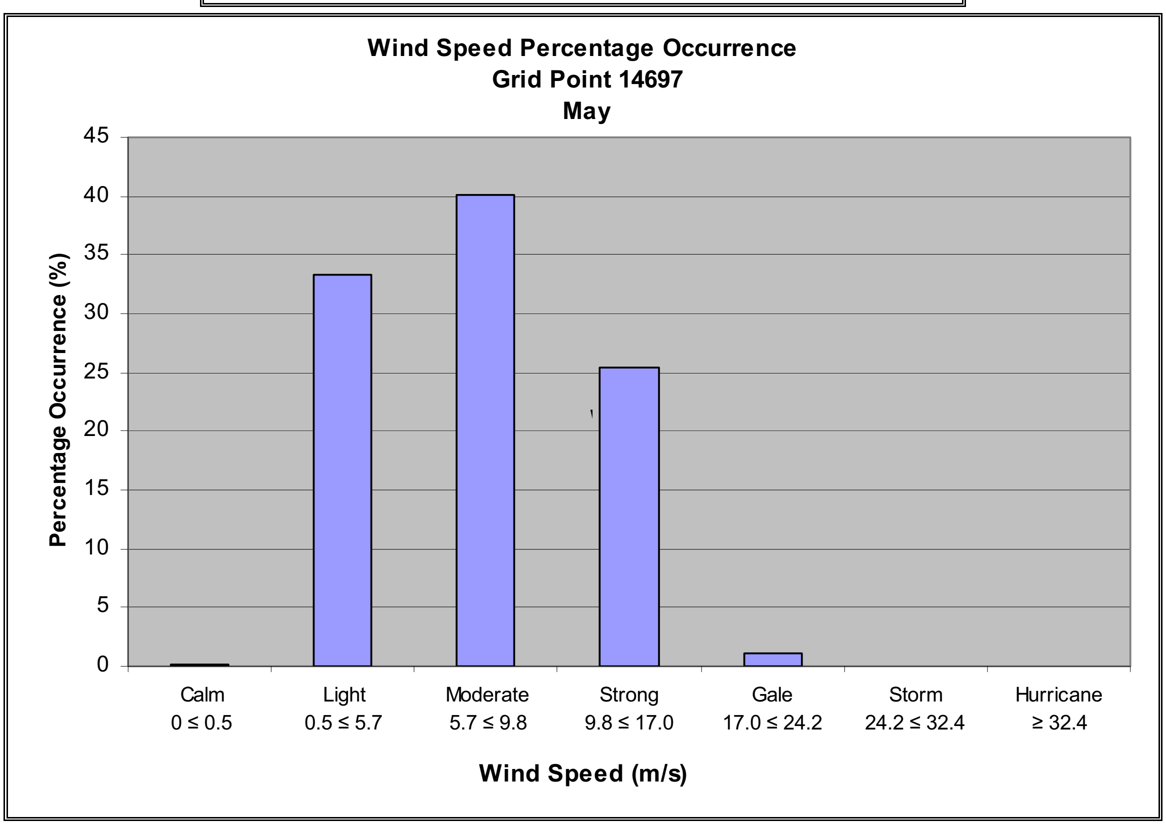


Wind Speed Percentage Occurrence
Grid Point 14697
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

May

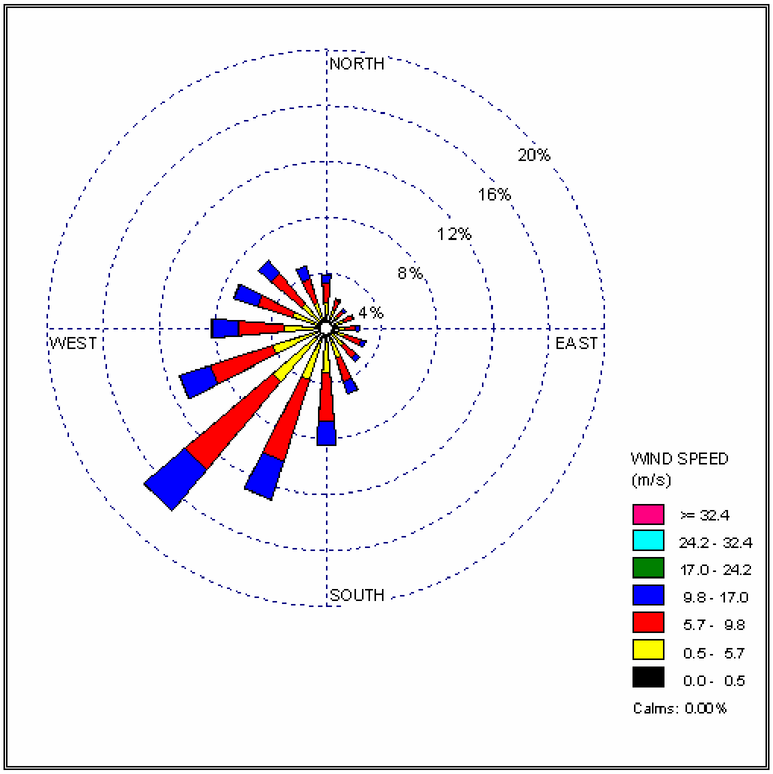


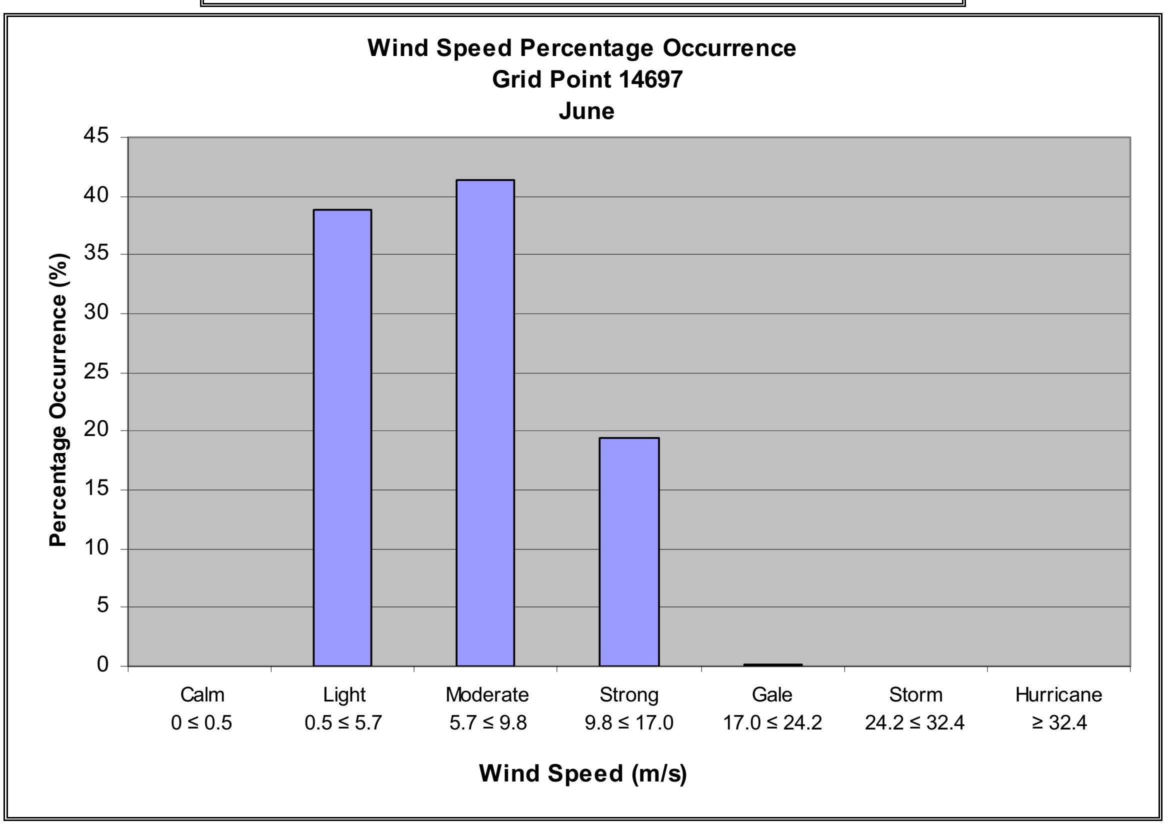
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



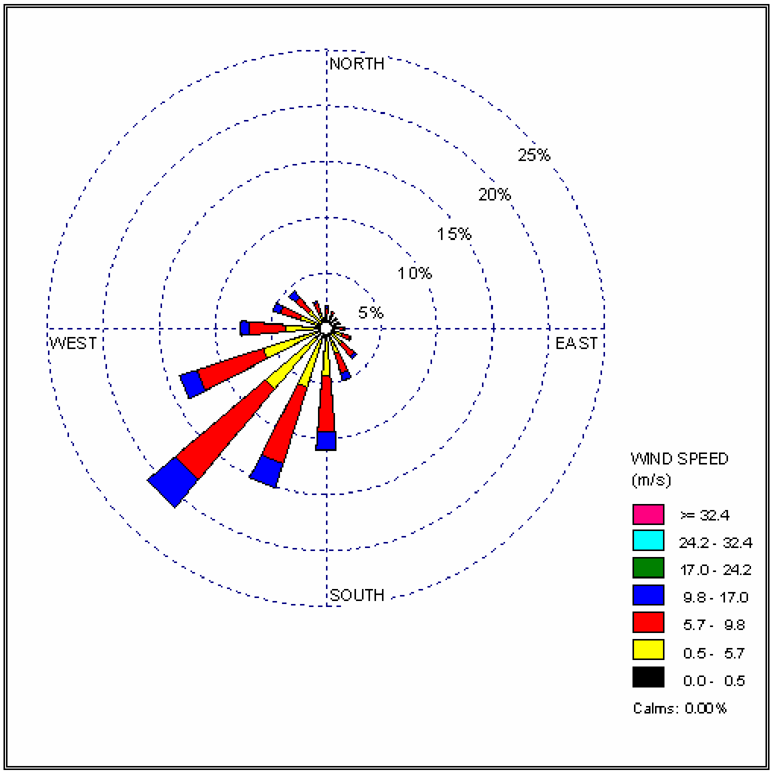
Wind Speed Percentage Occurrence
Grid Point 14697
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

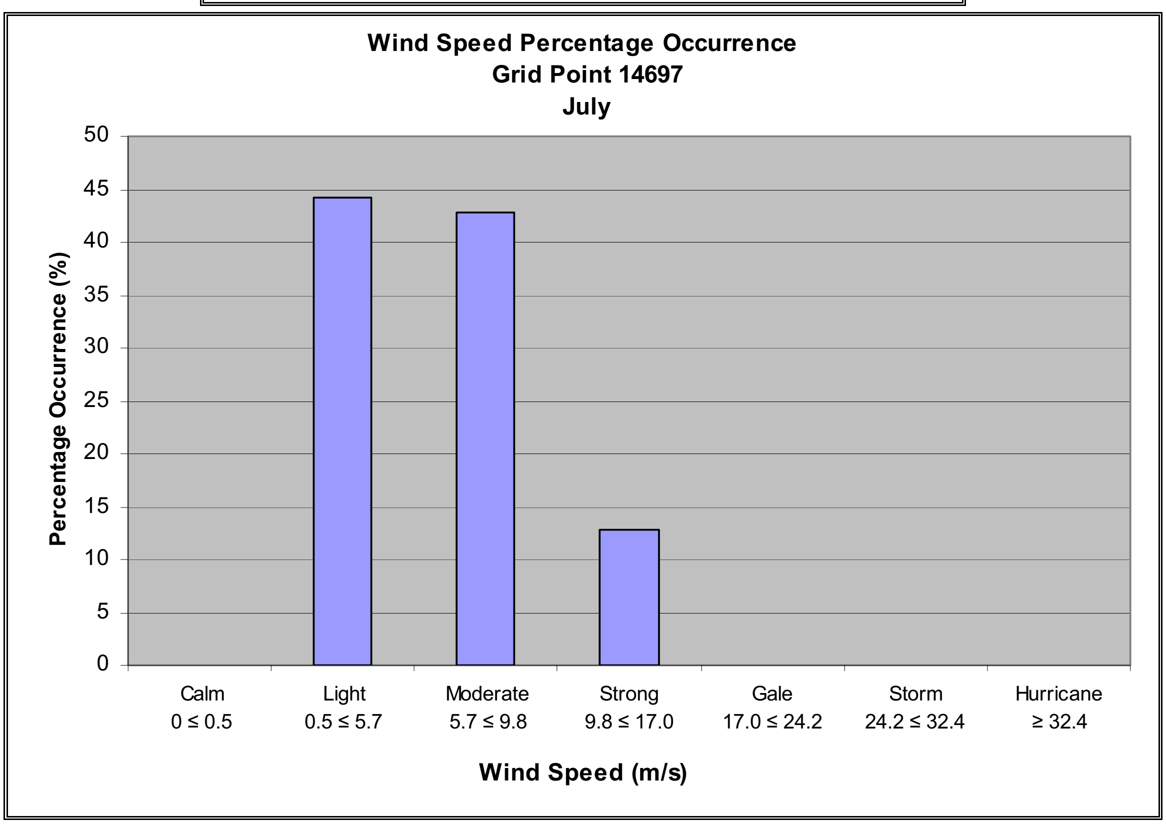
June


NORTH
SOUTH
EAST
WEST
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%

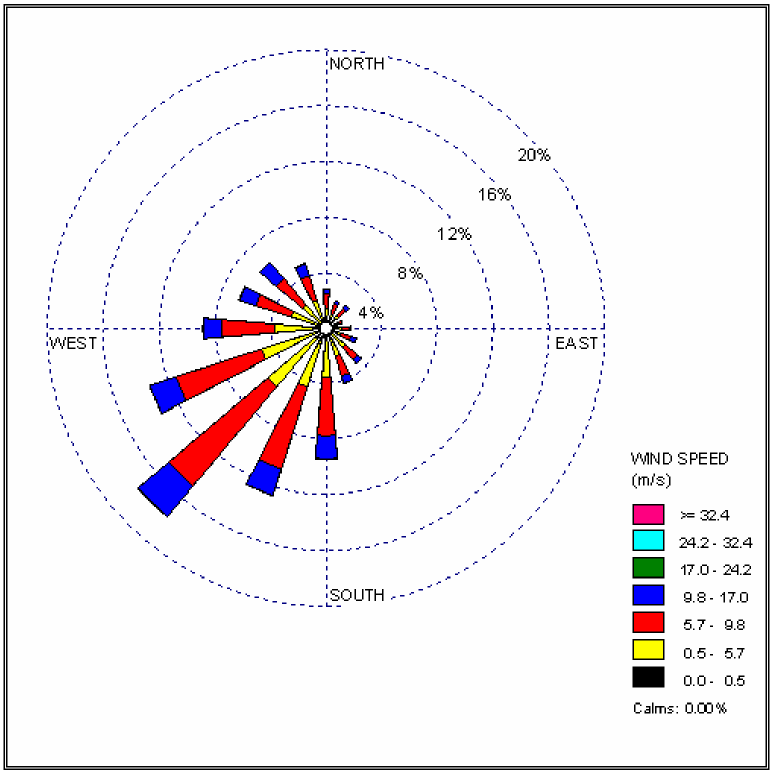

Wind Speed Percentage Occurrence
Grid Point 14697
June
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

July

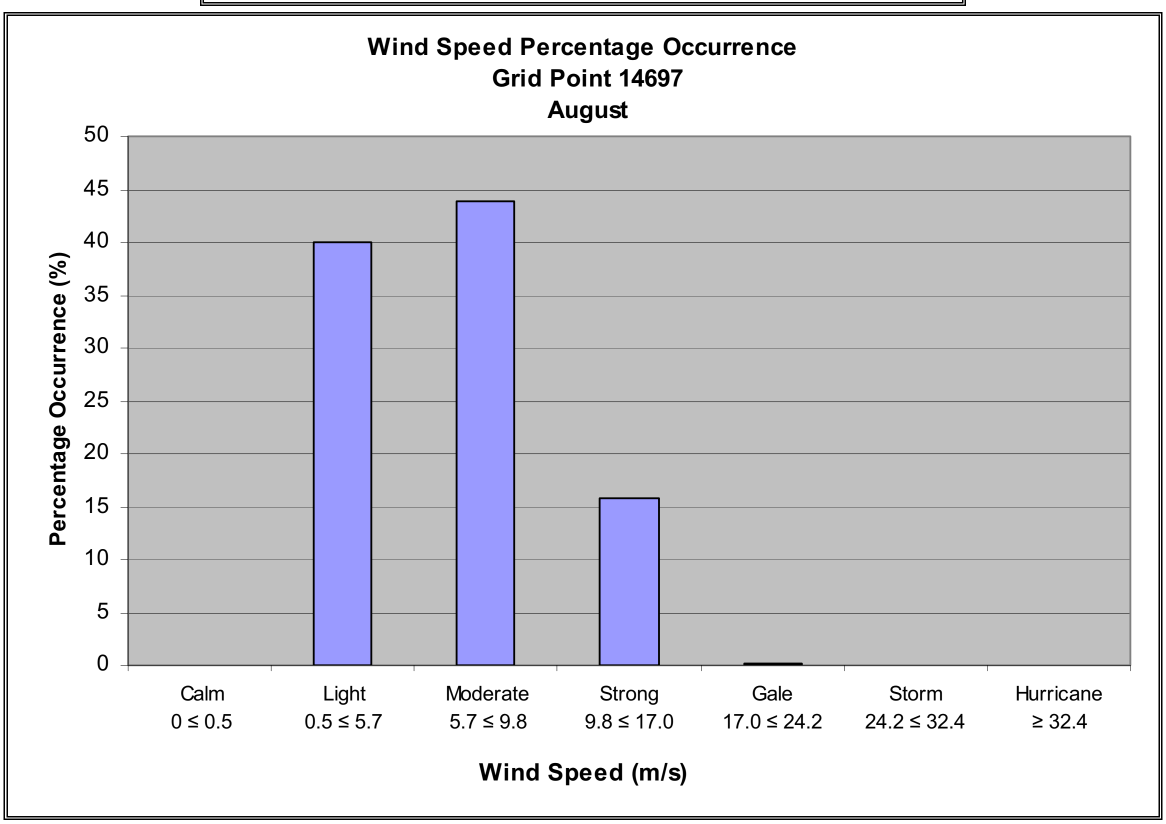

NORTH
WEST
EAST
SOUTH
5%
10%
15%
20%
25%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 14697
July
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
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

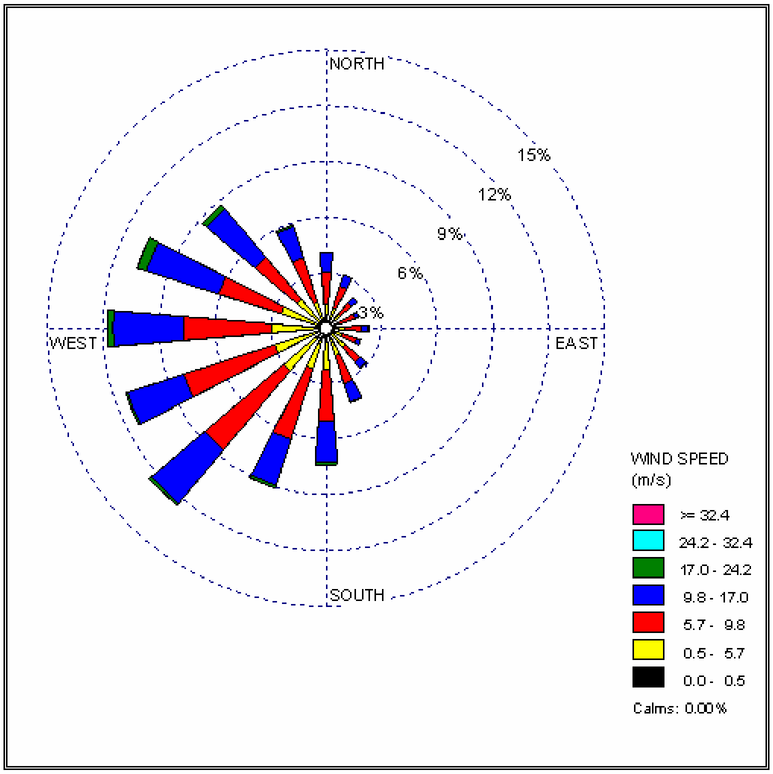


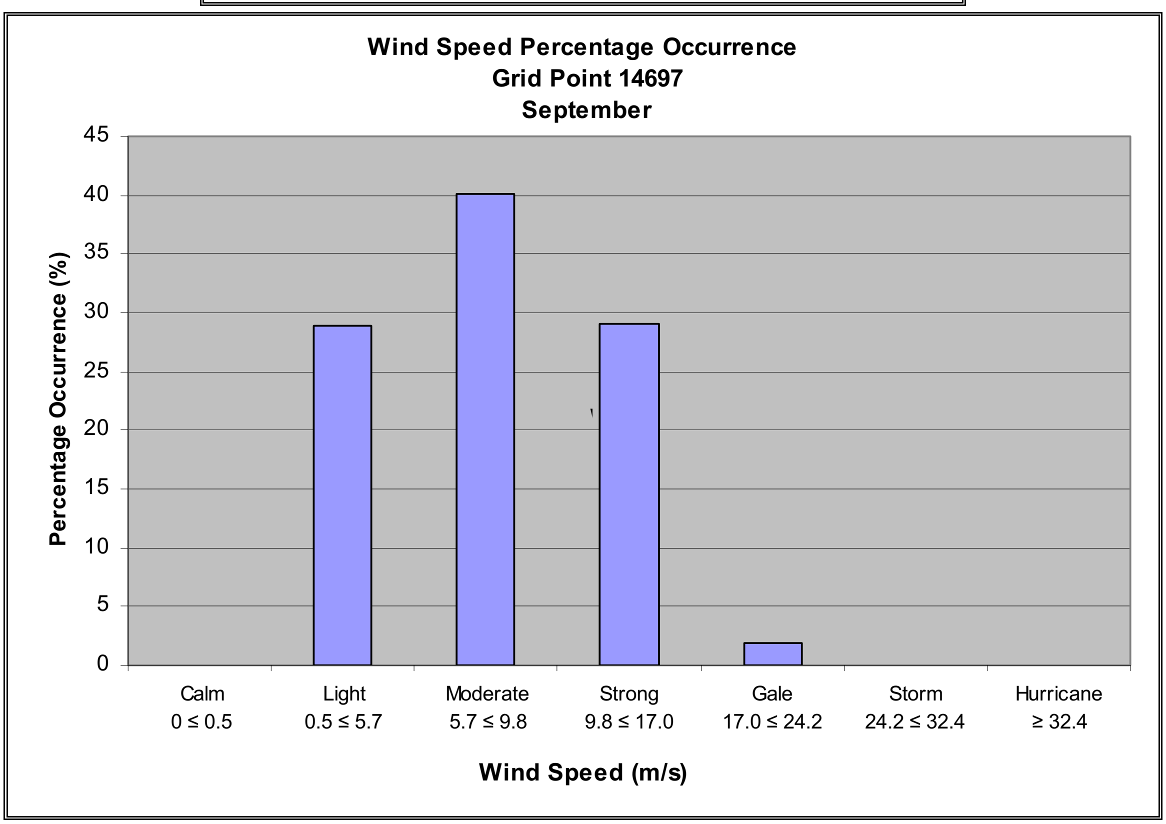
NORTH
WEST
EAST
SOUTH
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%



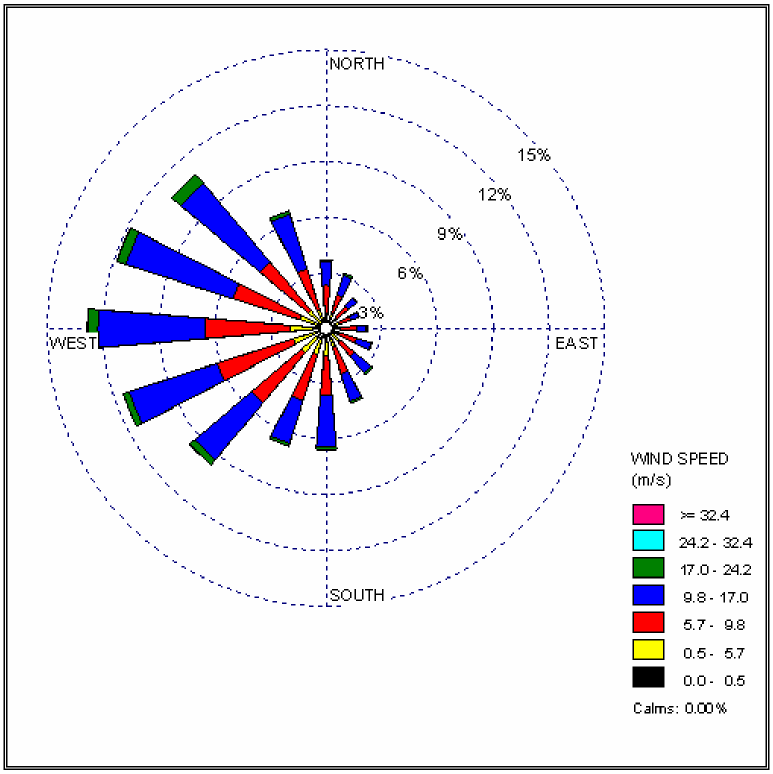
Wind Speed Percentage Occurrence
Grid Point 14697
August
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

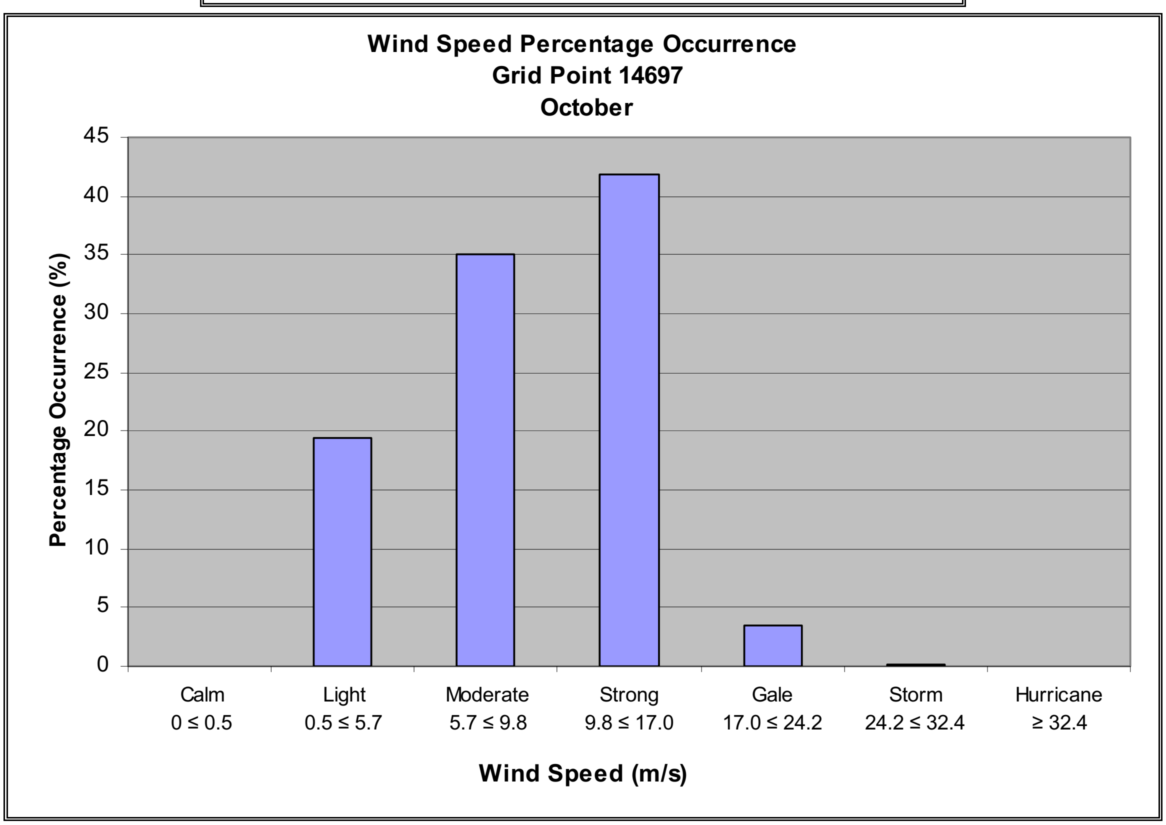
September


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
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%

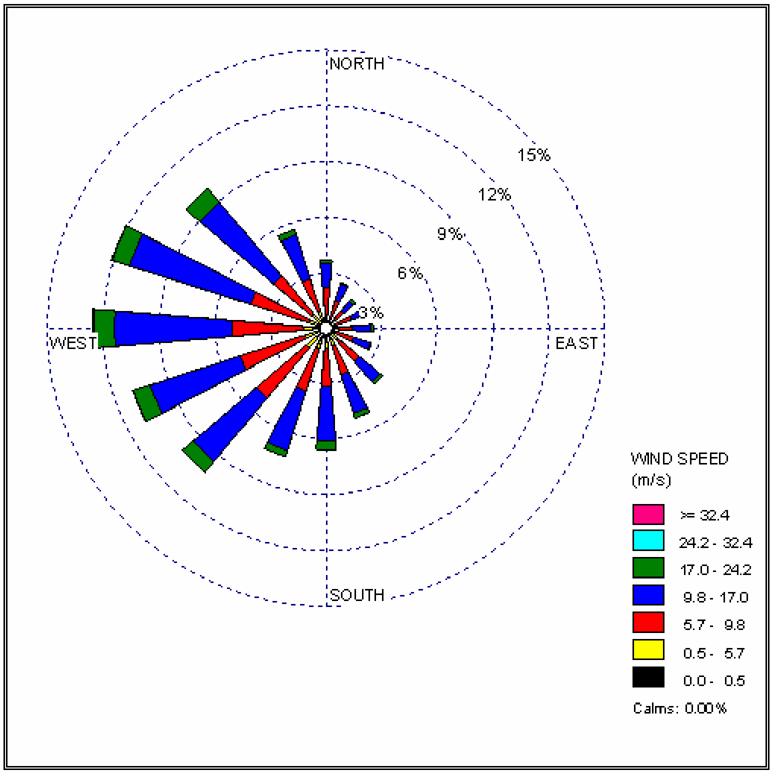

Wind Speed Percentage Occurrence
Grid Point 14697
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

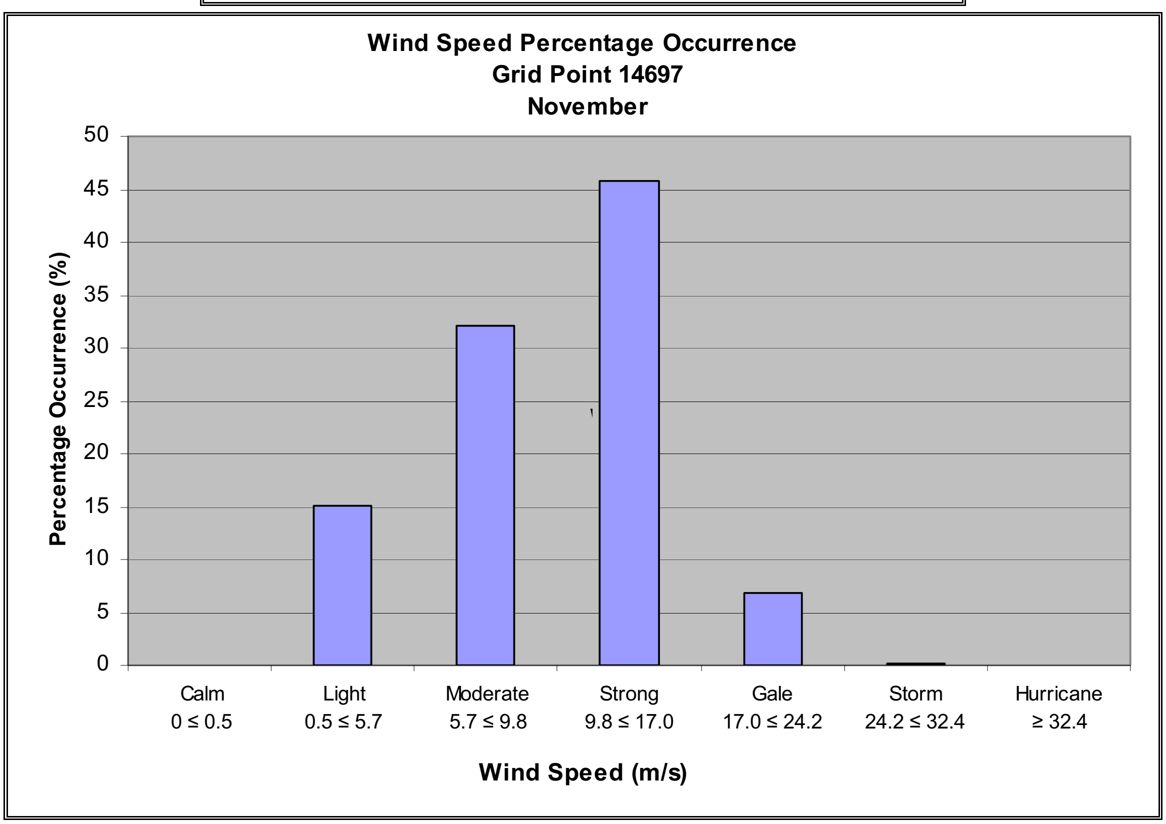
October


NORTH
WEST
EAST
SOUTH
3%
6%
9%
12%
15%
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%

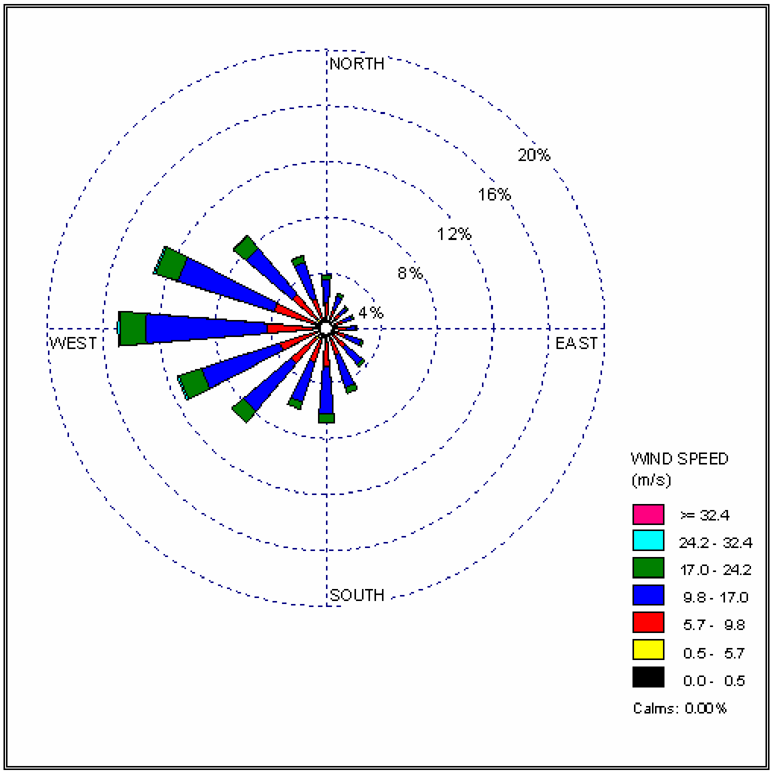

Wind Speed Percentage Occurrence
Grid Point 14697
October
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 ≤ 0.5
Light
0.5 ≤ 5.7
Moderate
5.7 ≤ 9.8
Strong
9.8 ≤ 17.0
Gale
17.0 ≤ 24.2
Storm
24.2 ≤ 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

November

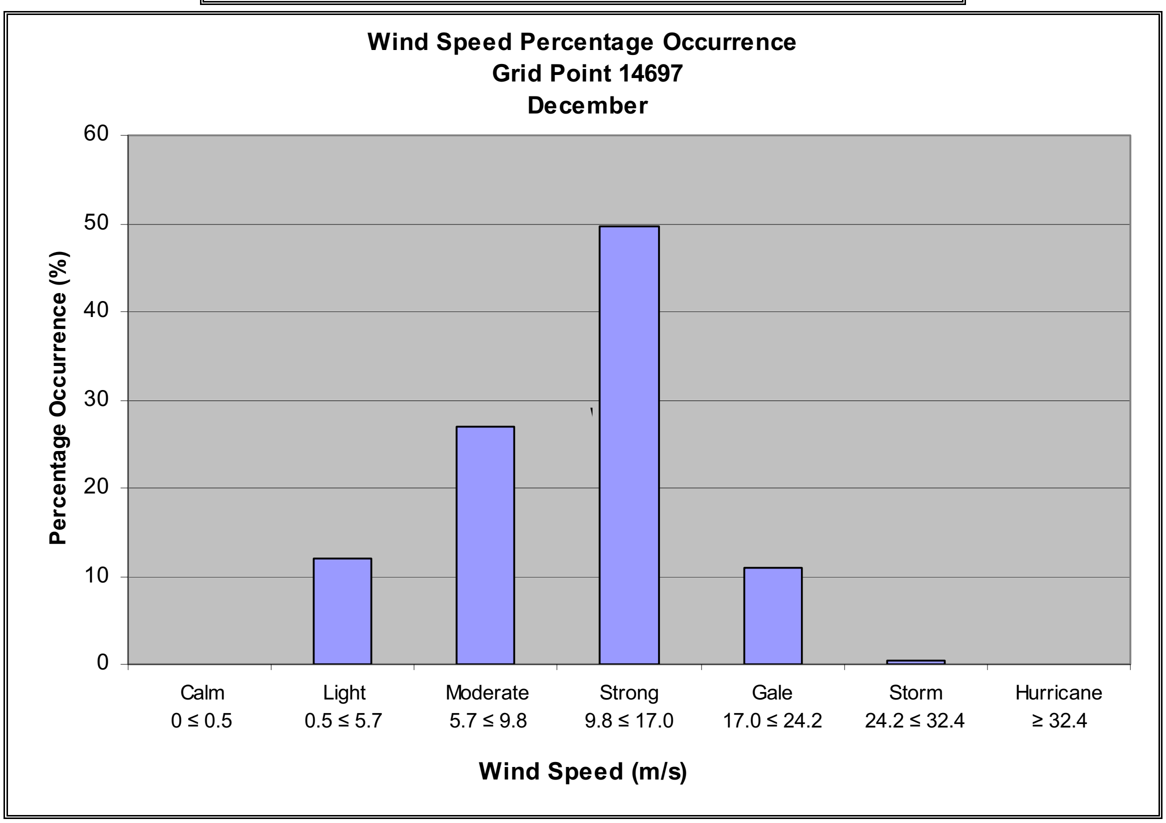

NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%


Wind Speed Percentage Occurrence
Grid Point 14697
November
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
50
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



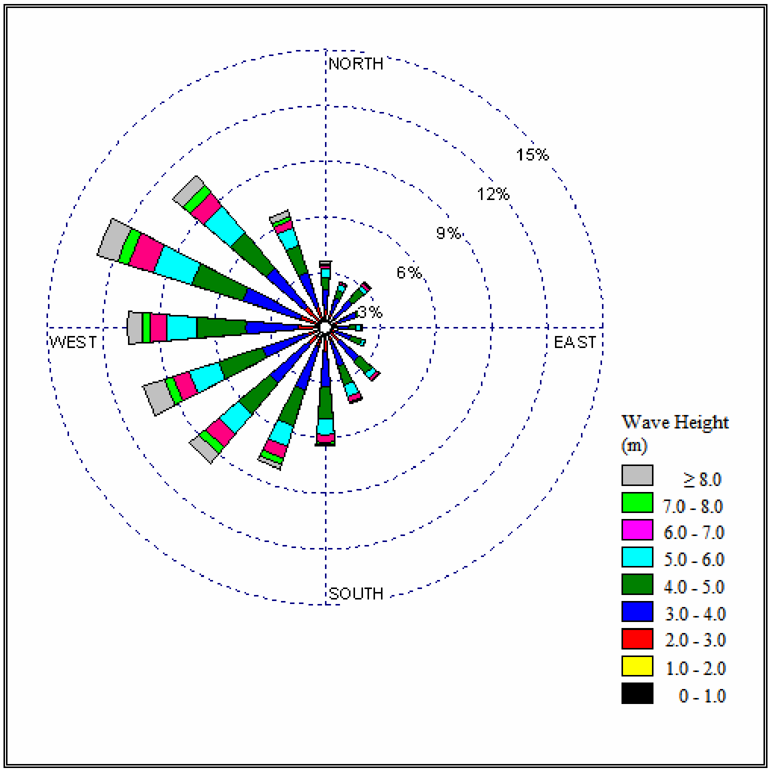
NORTH
SOUTH
EAST
WEST
4%
8%
12%
16%
20%
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

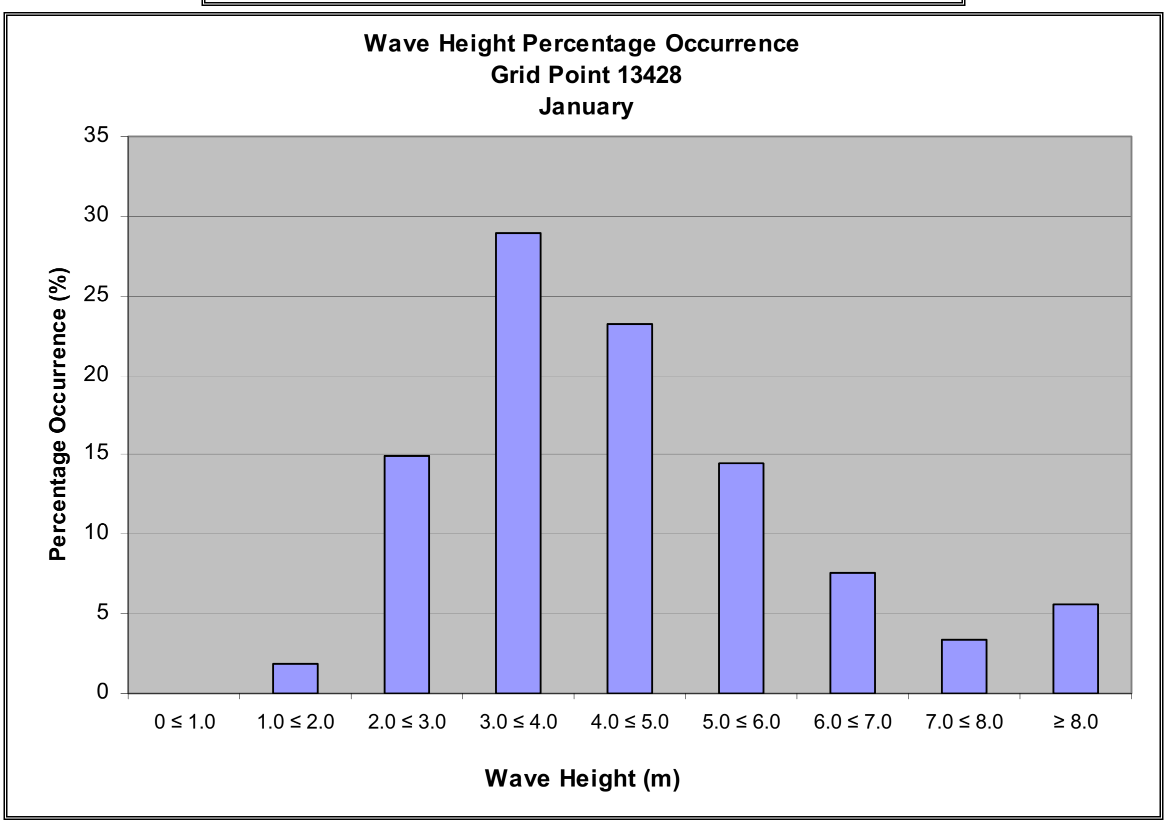


Wind Speed Percentage Occurrence
Grid Point 14697
December
Percentage Occurrence (%)
0
10
20
30
40
50
60
Calm 0 ≤ 0.5
Light 0.5 ≤ 5.7
Moderate 5.7 ≤ 9.8
Strong 9.8 ≤ 17.0
Gale 17.0 ≤ 24.2
Storm 24.2 ≤ 32.4
Hurricane ≥ 32.4
Wind Speed (m/s)

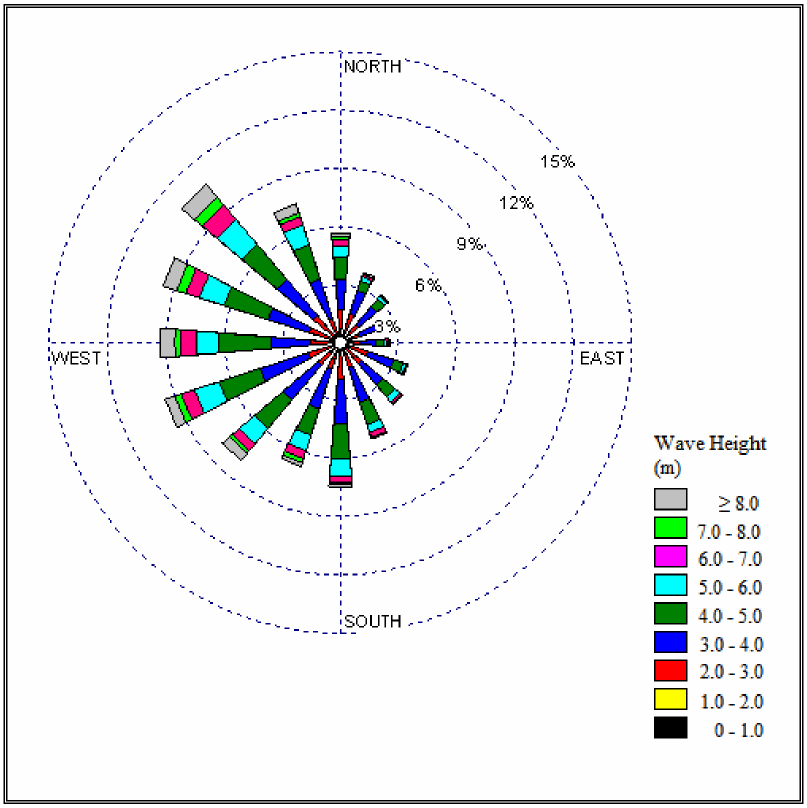
Appendix 7
Wave Roses and
Wave Height Frequency Distributions
for MSC50 GridPoint 13428

January

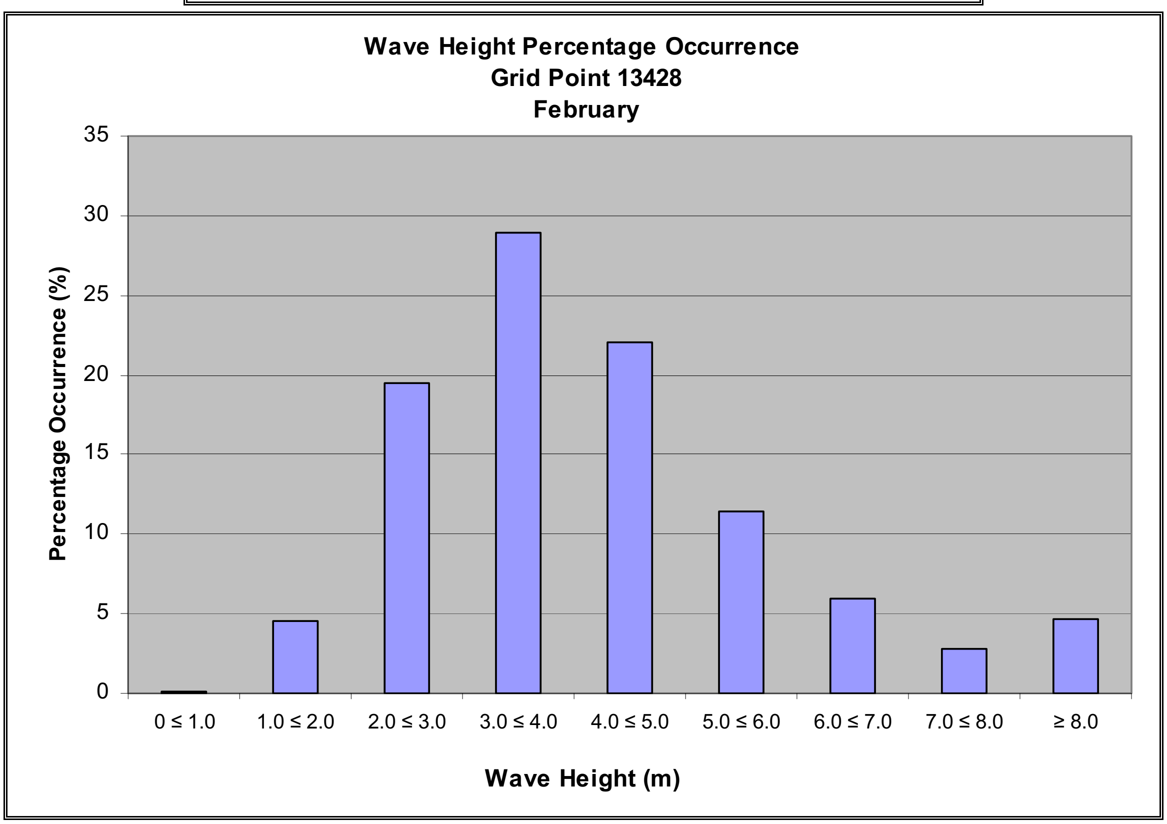

NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 13428
January
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
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

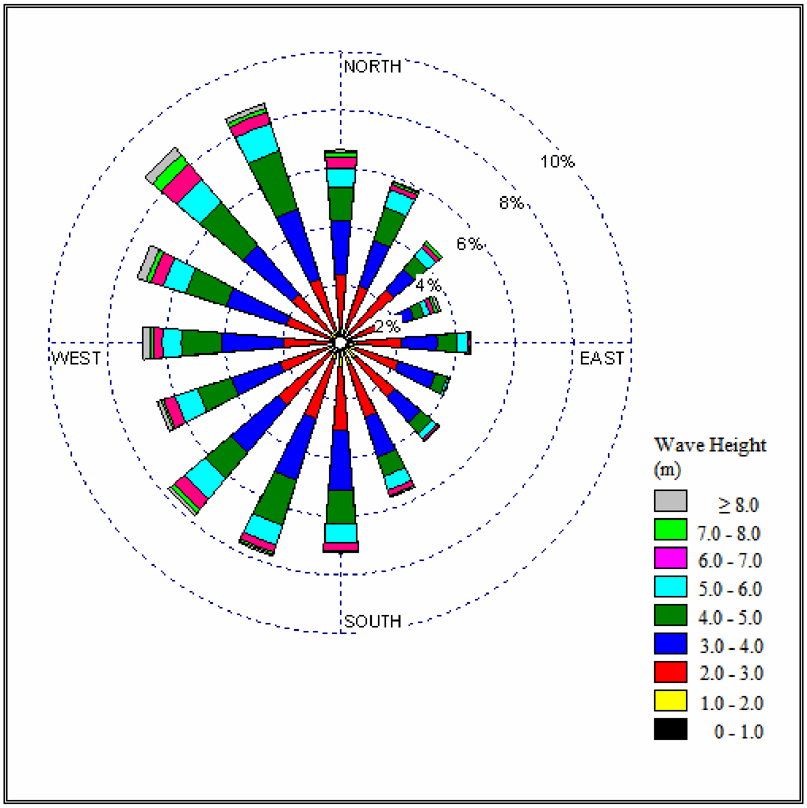


NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

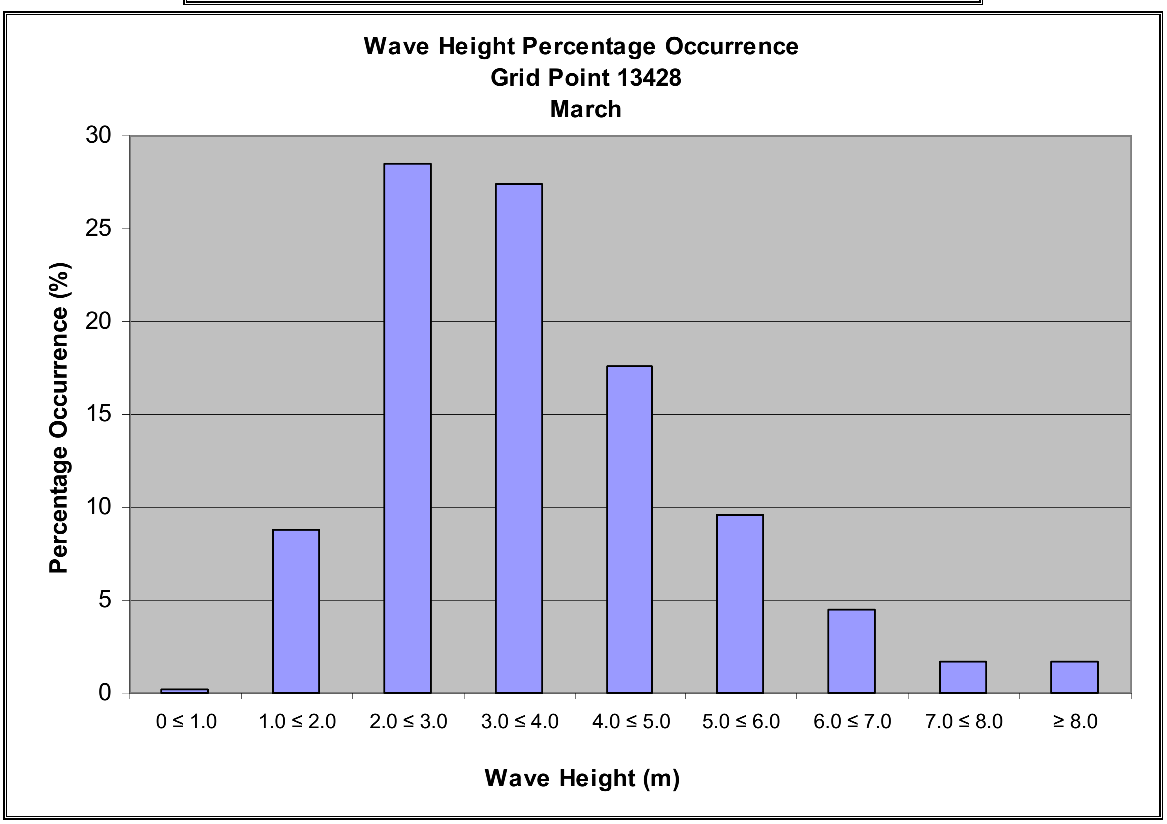


Wave Height Percentage Occurrence
Grid Point 13428
February
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

March

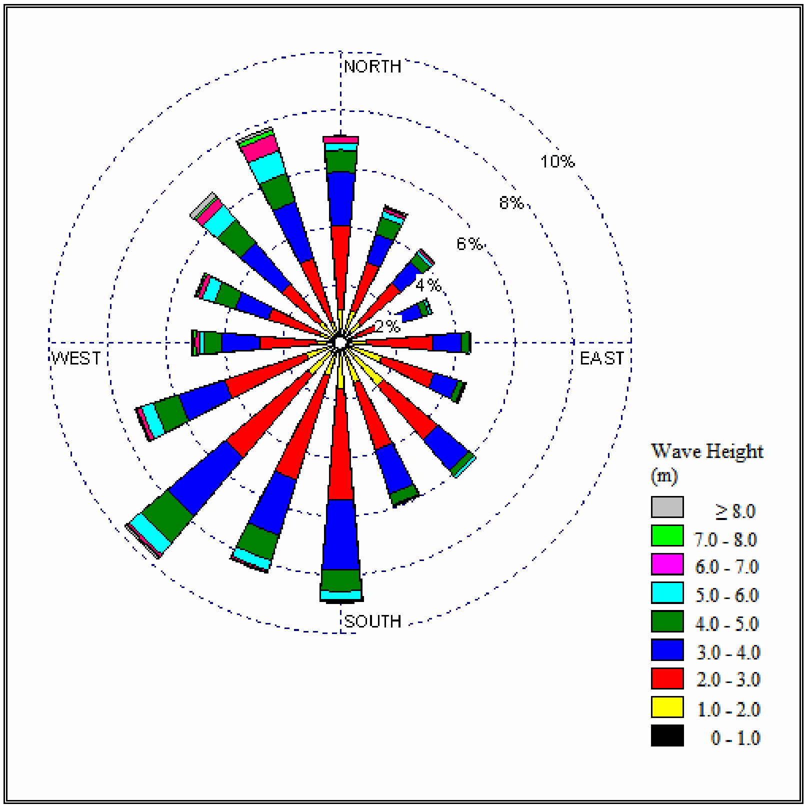


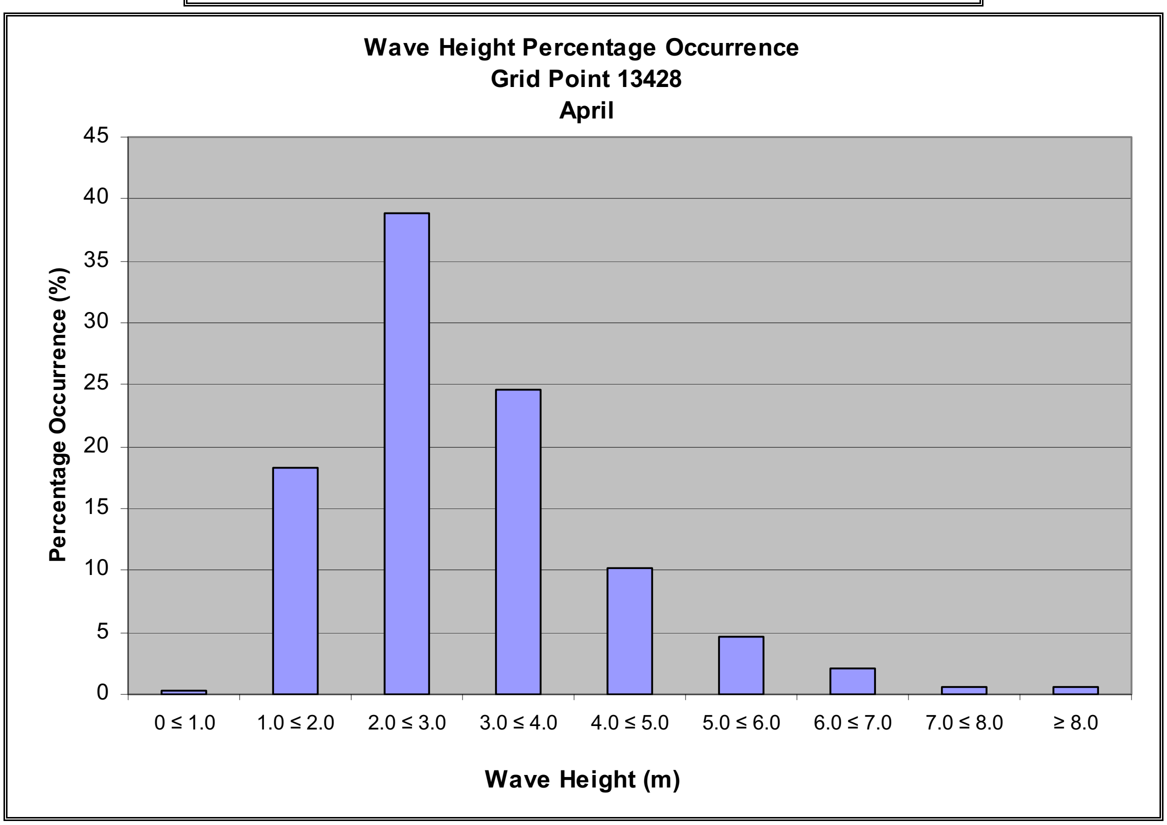
NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



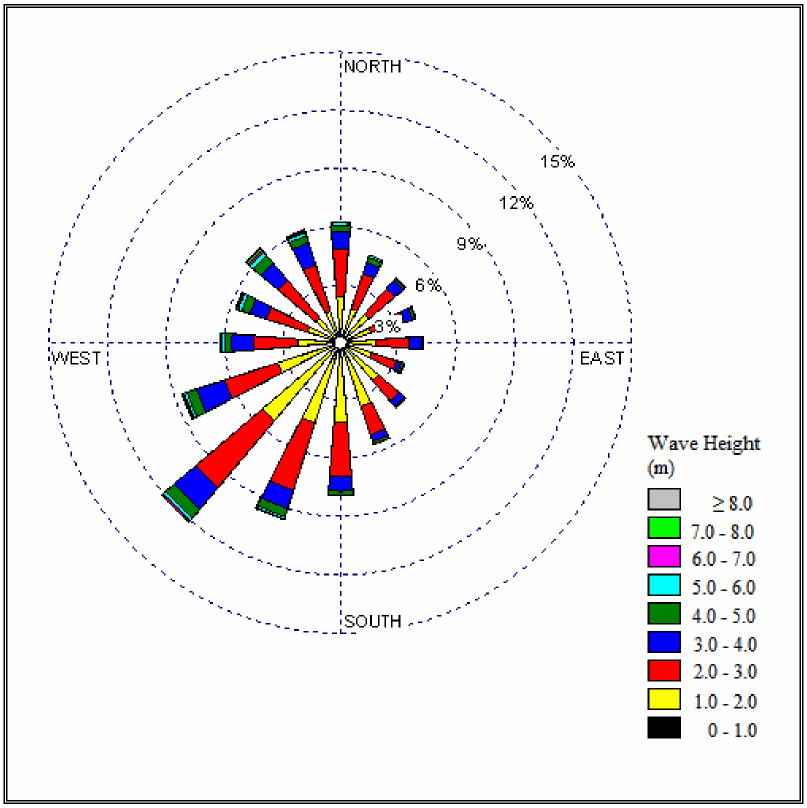
Wave Height Percentage Occurrence
Grid Point 13428
March
Percentage Occurrence (%)
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

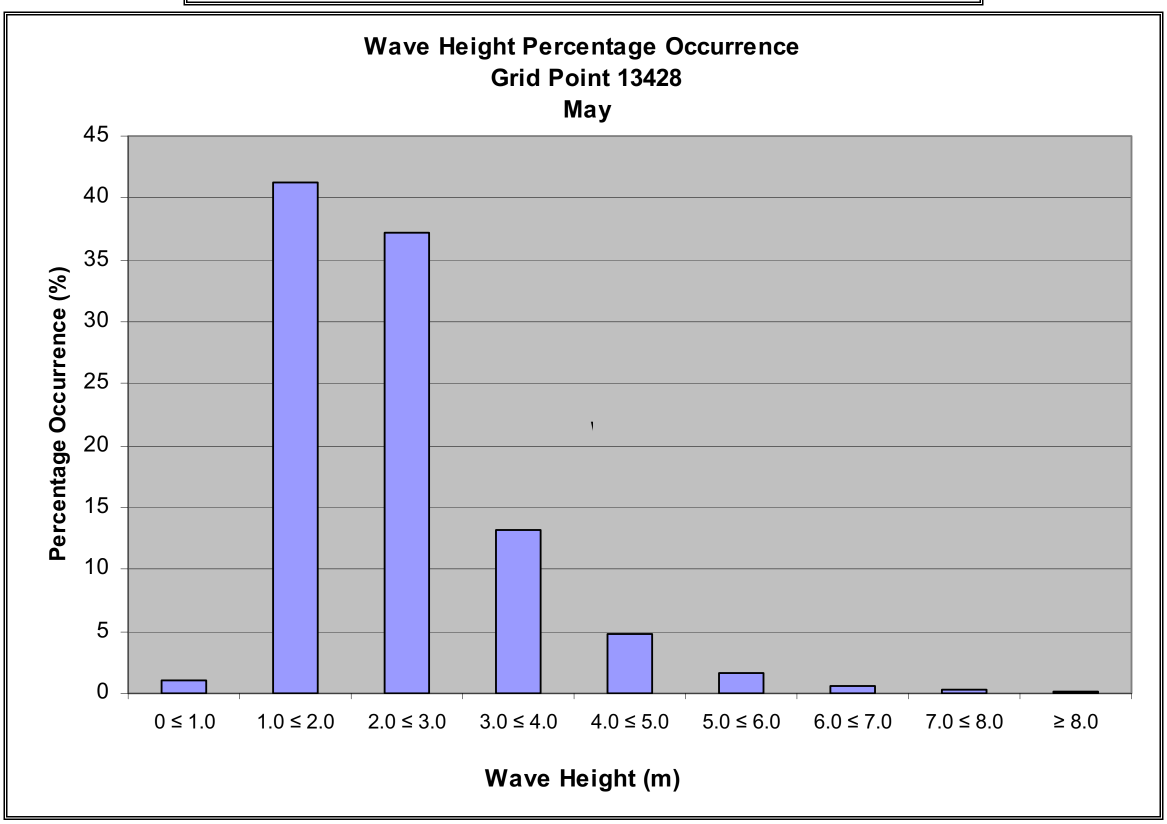
April


NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
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 - 1.0

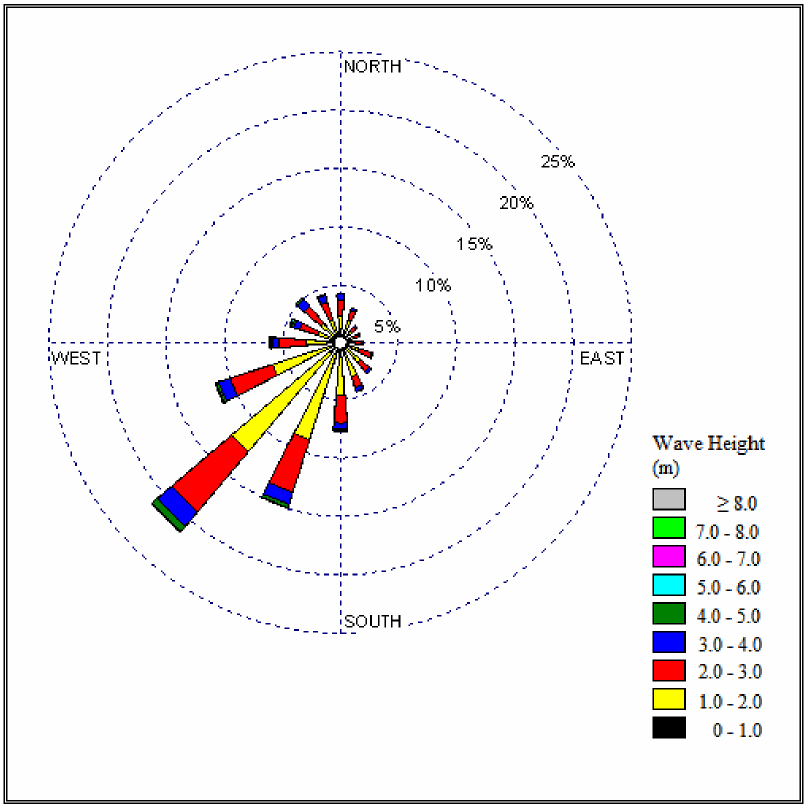

Wave Height Percentage Occurrence
Grid Point 13428
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

May

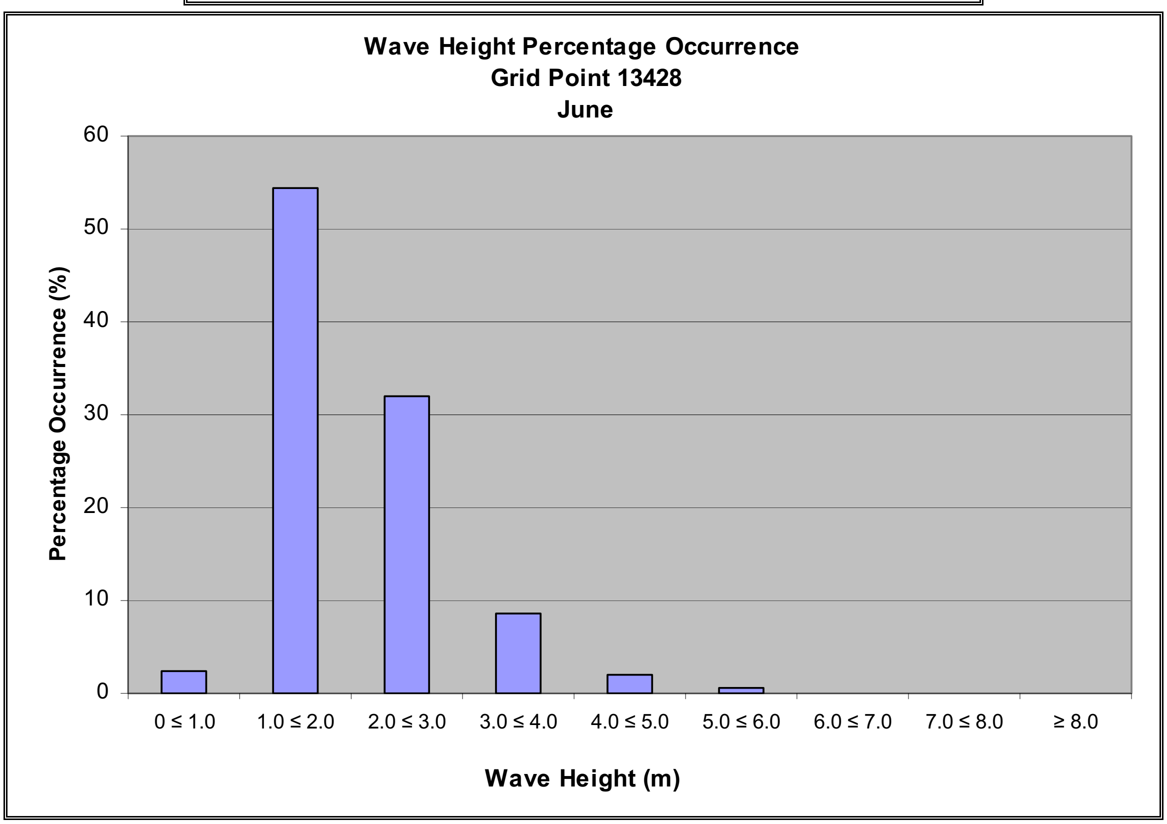

NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 13428
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
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)

June

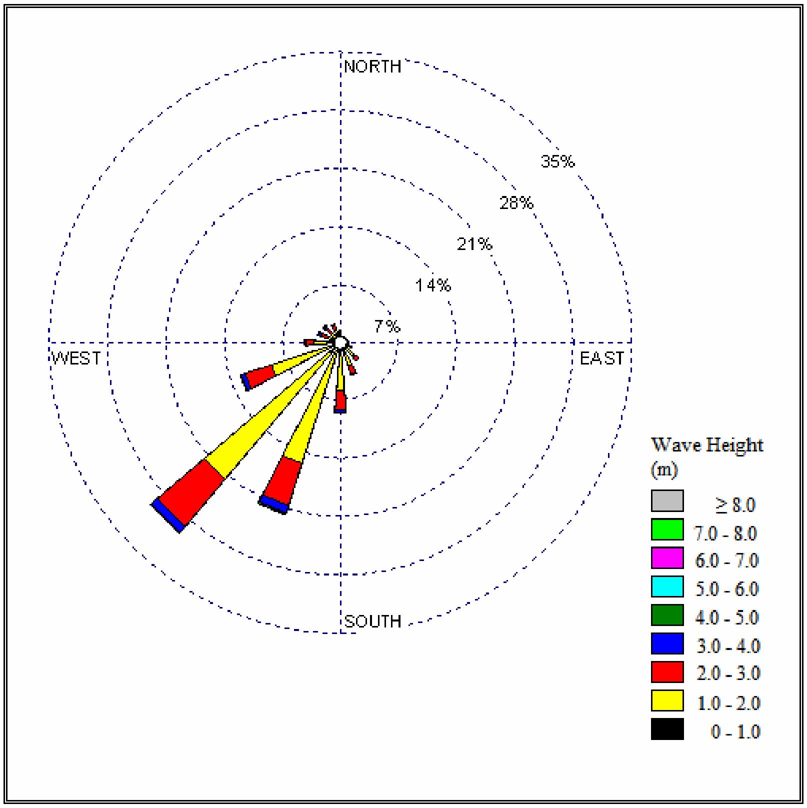


NORTH
SOUTH
EAST
WEST
5%
10%
15%
20%
25%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

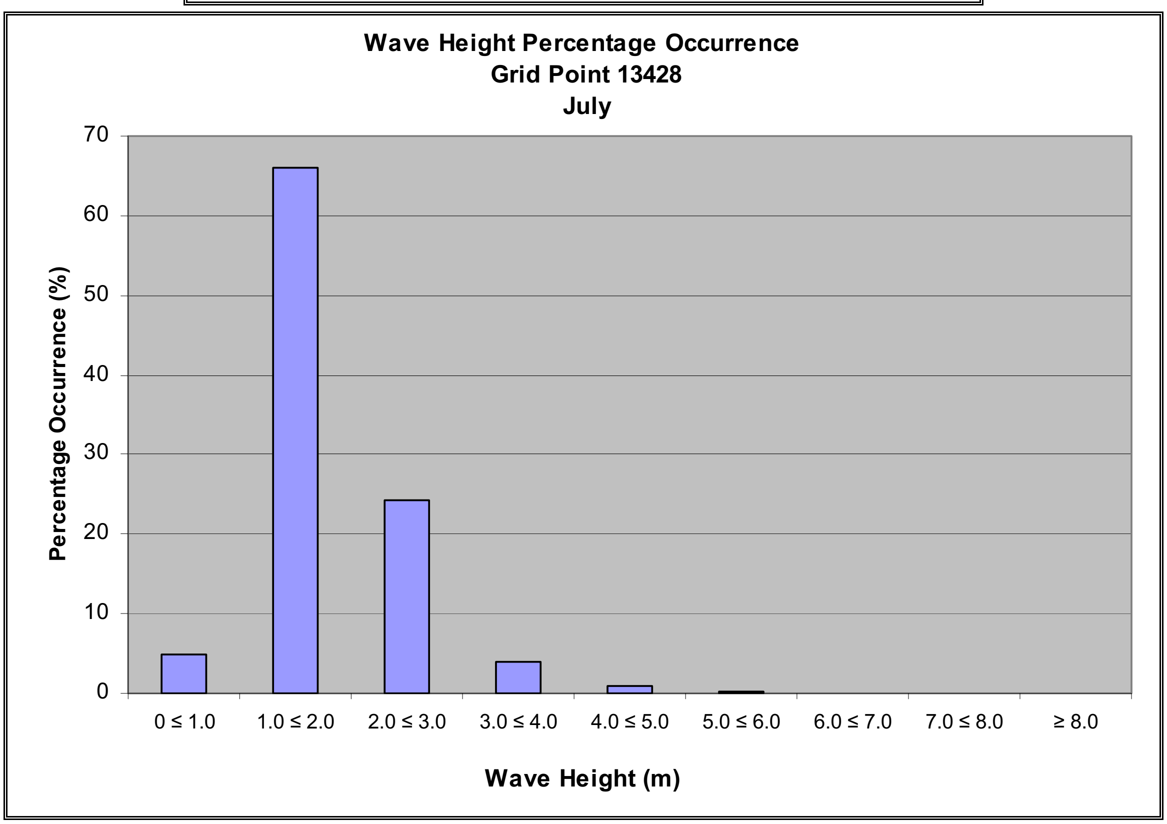


Wave Height Percentage Occurrence
Grid Point 13428
June
Percentage Occurrence (%)
0
10
20
30
40
50
60
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

July

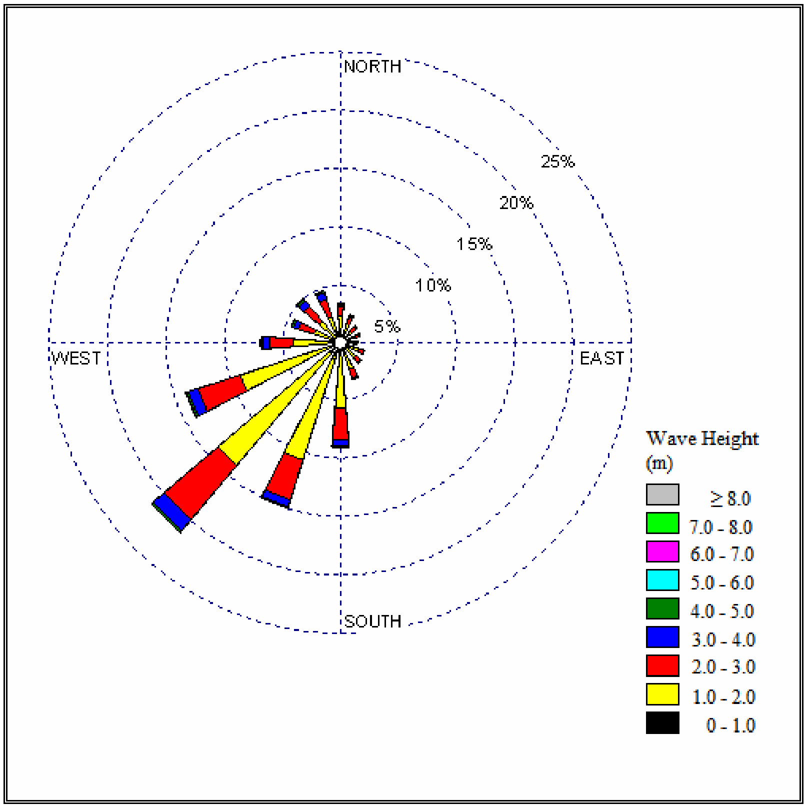


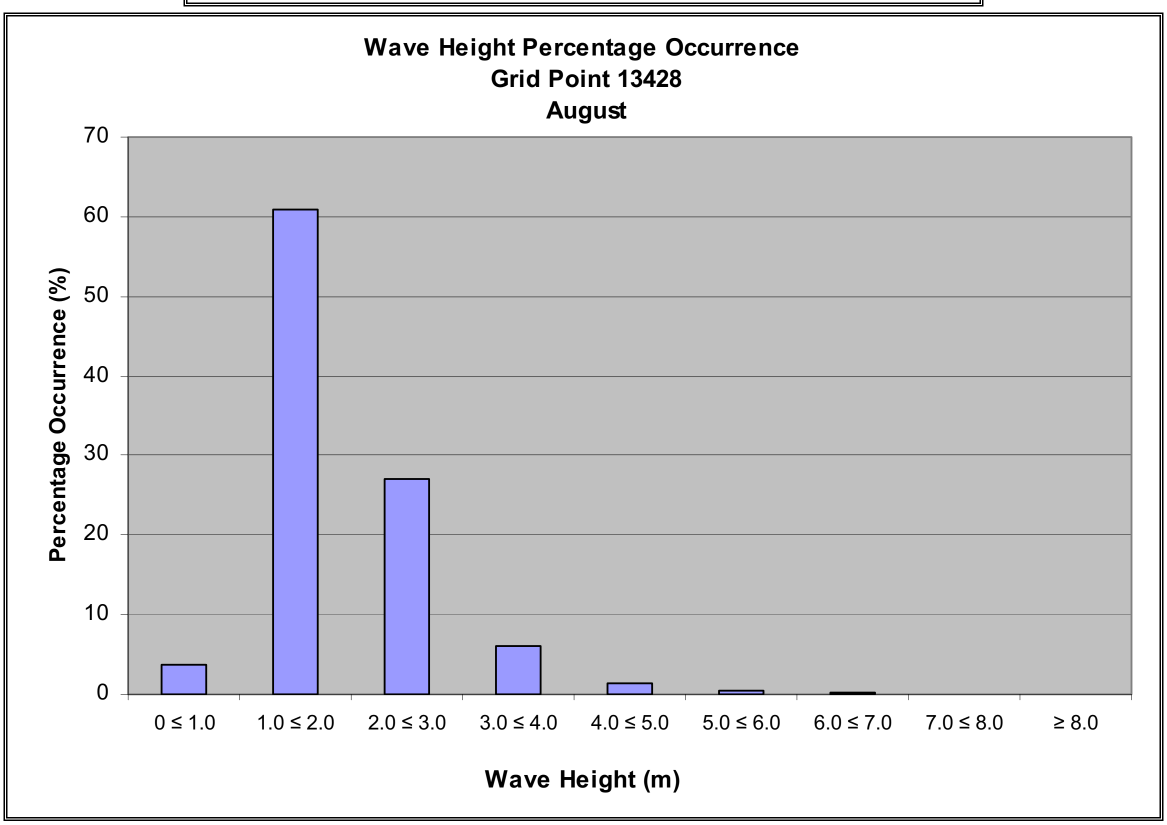
NORTH
SOUTH
WEST
EAST
7%
14%
21%
28%
35%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



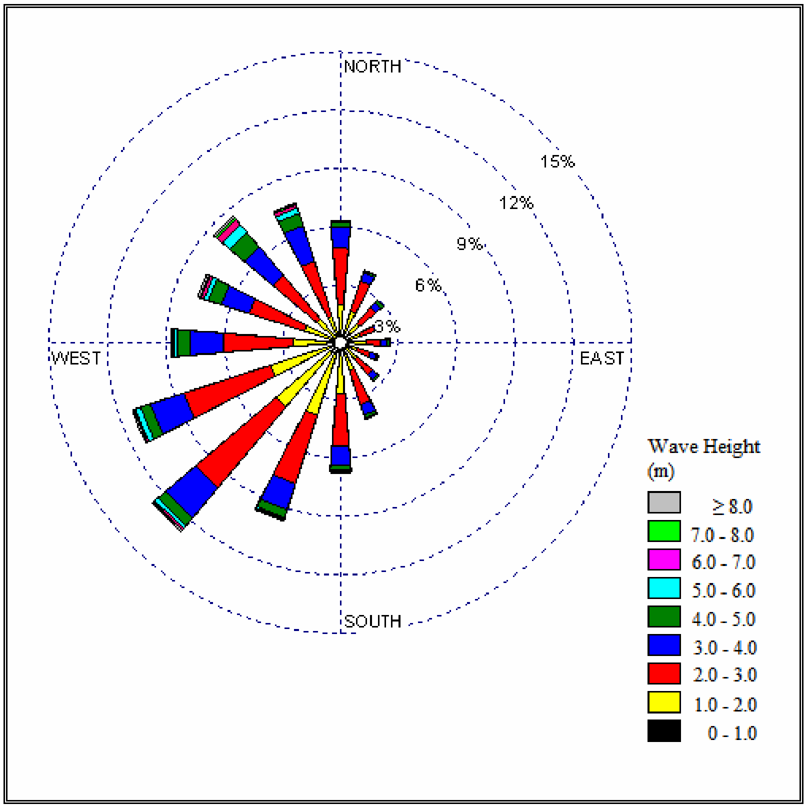
Wave Height Percentage Occurrence
Grid Point 13428
July
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

August

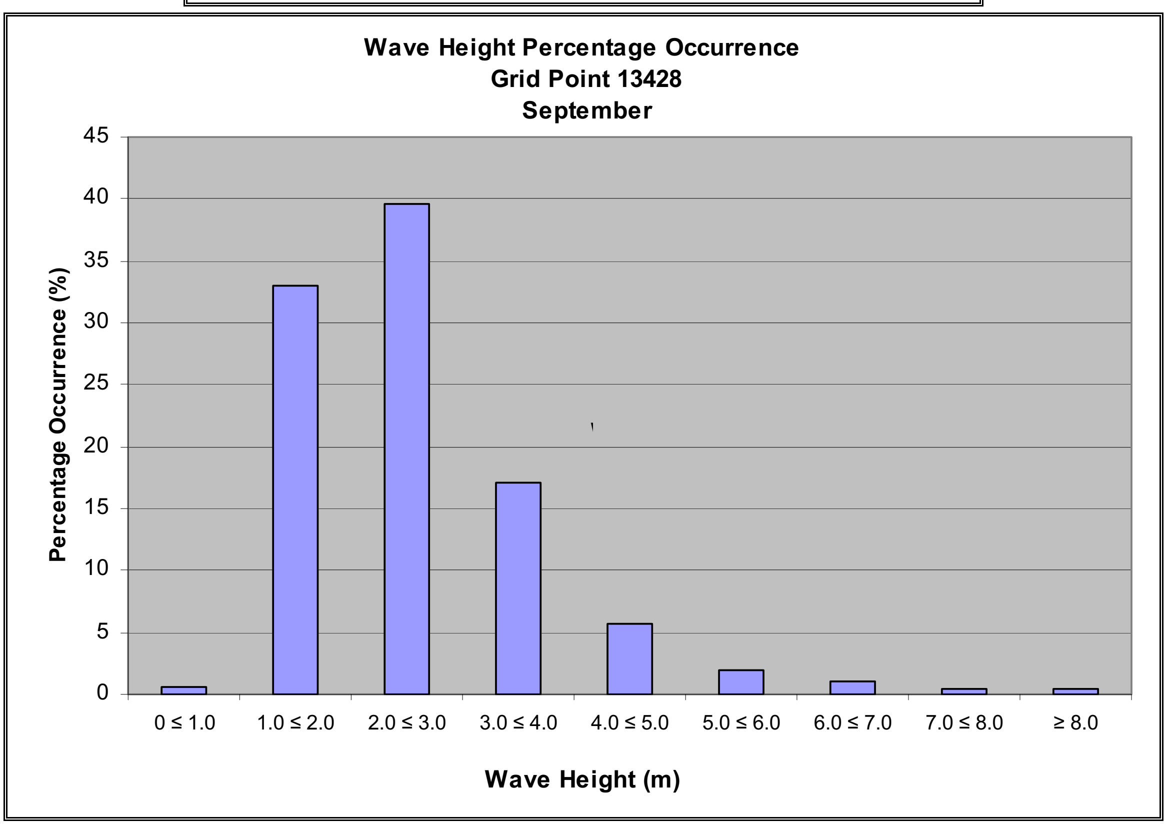

NORTH
EAST
SOUTH
WEST
5%
10%
15%
20%
25%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 13428
August
Percentage Occurrence (%)
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)

September

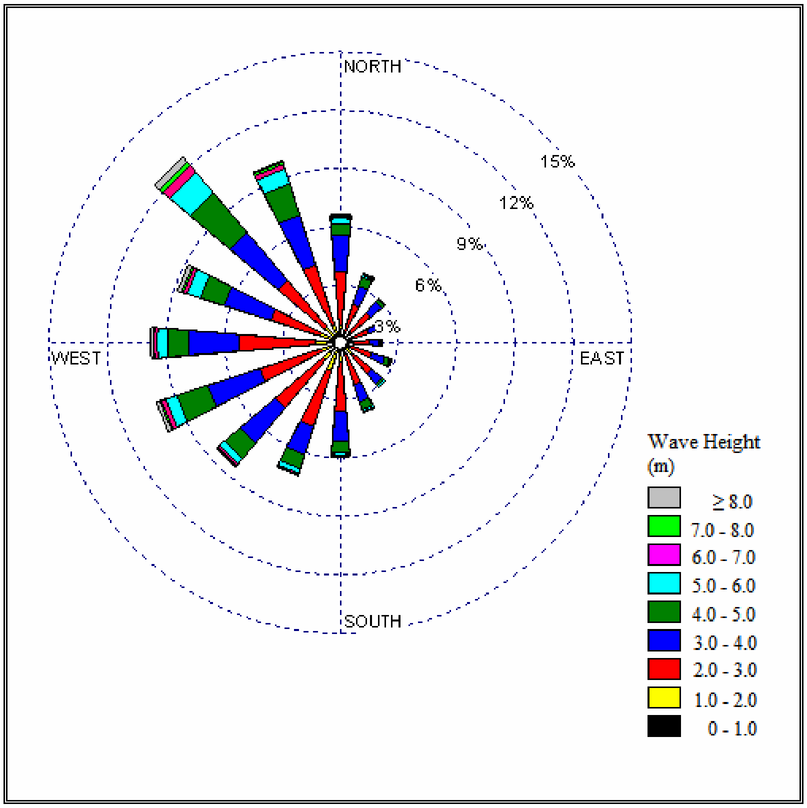


NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
Wave Height
(m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

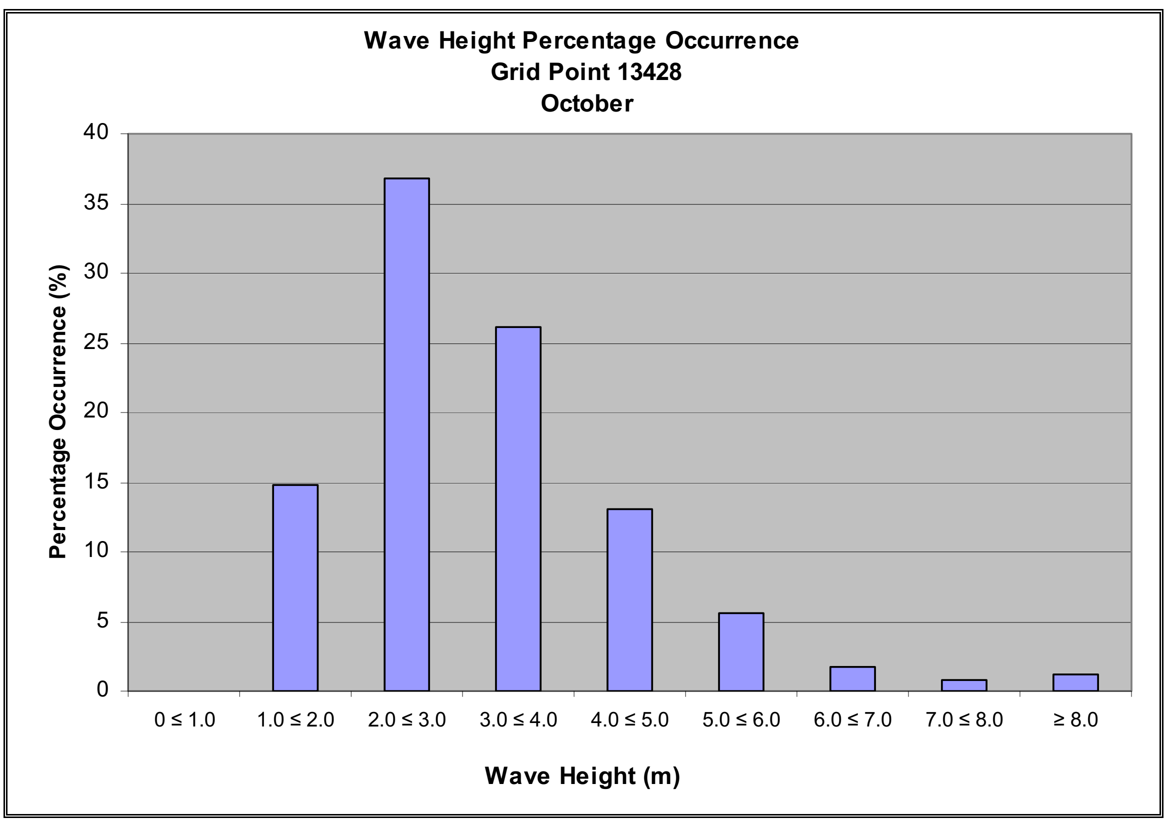


Wave Height Percentage Occurrence
Grid Point 13428
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

October

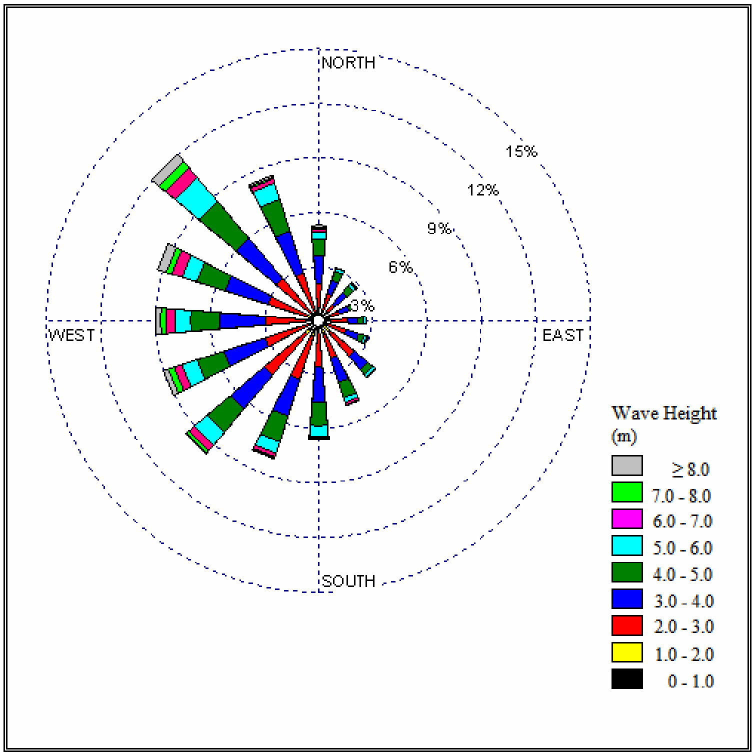


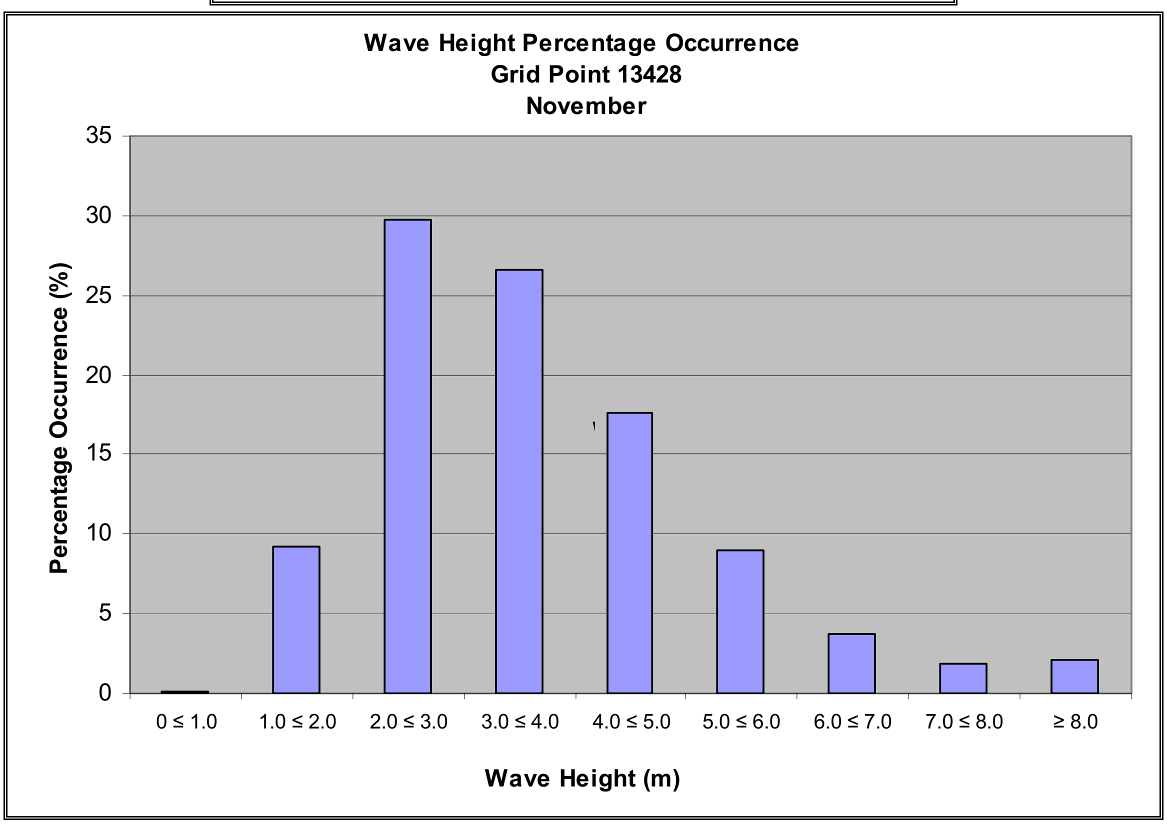
NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



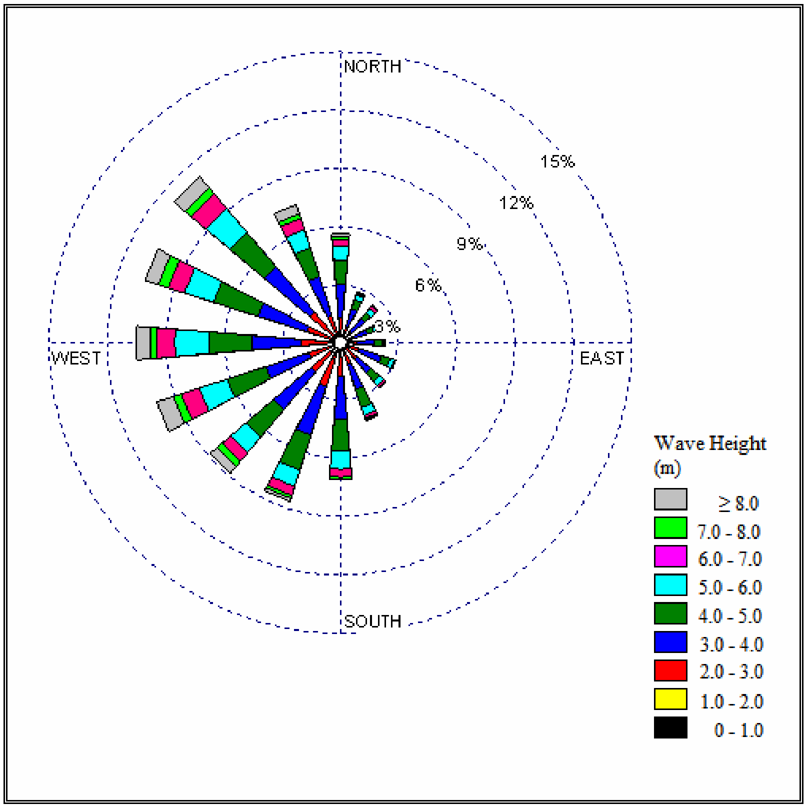
Wave Height Percentage Occurrence
Grid Point 13428
October
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

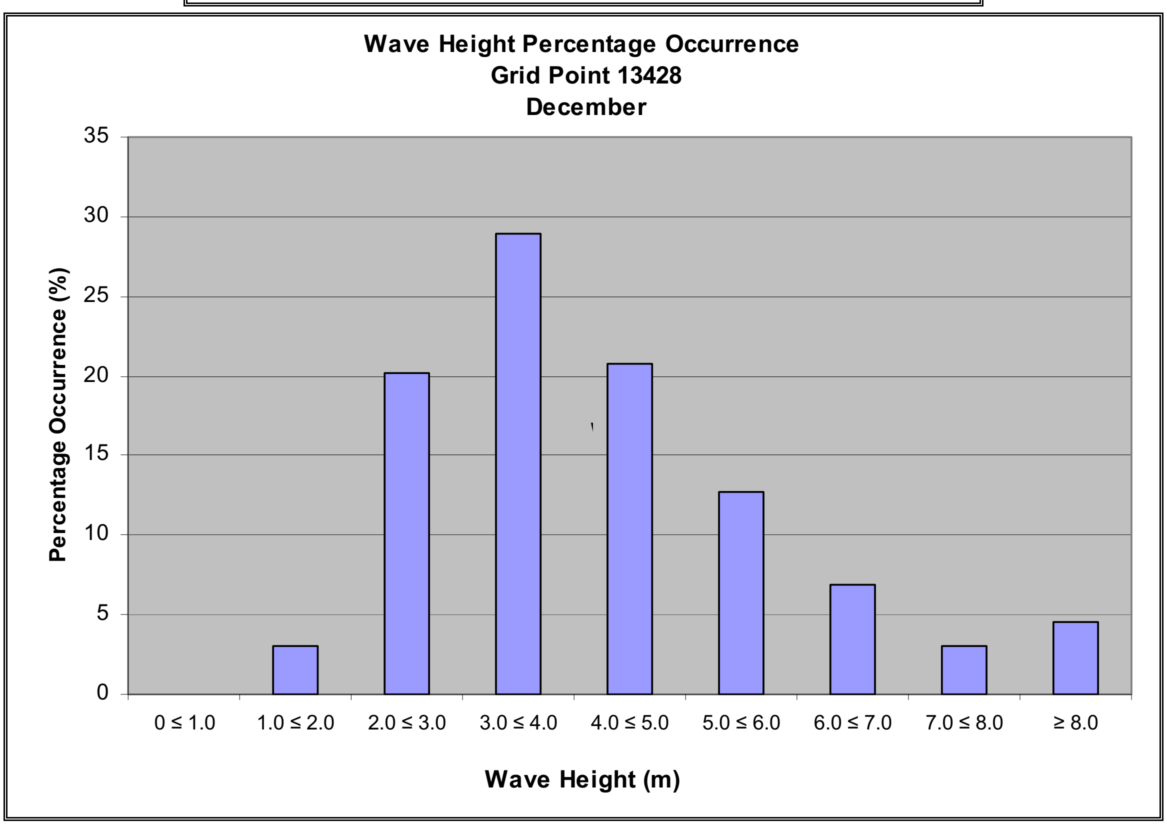
November


NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
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 - 1.0


Wave Height Percentage Occurrence
Grid Point 13428
November
Percentage Occurrence (%)
35
30
25
20
15
10
5
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)

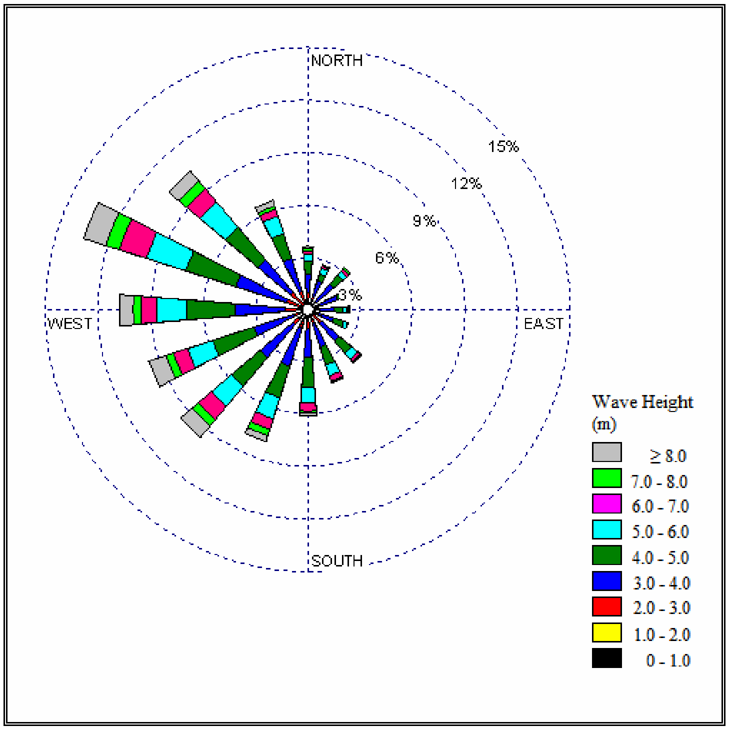
December

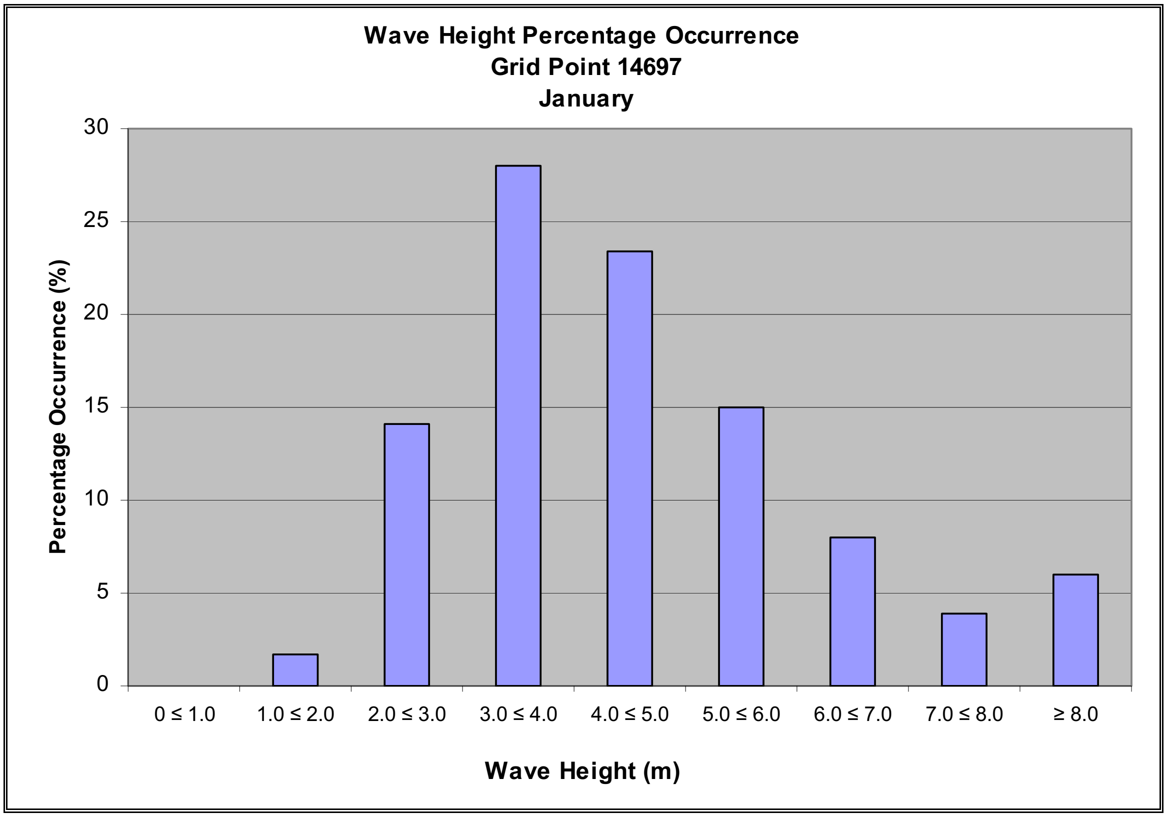

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 13428
December
35
30
25
20
15
10
5
0
Percentage Occurrence (%)
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)

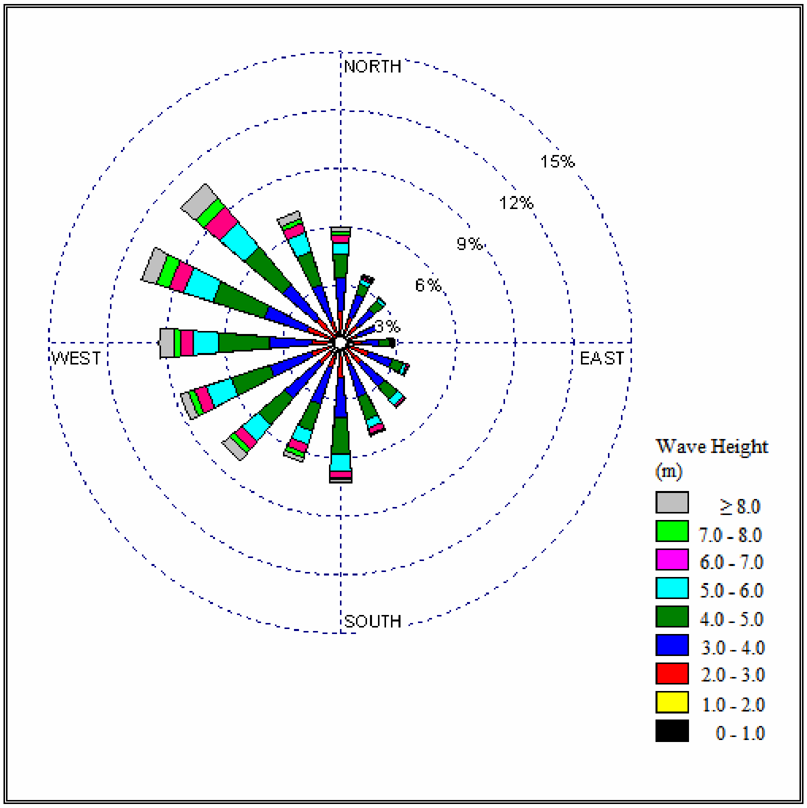
Appendix 8
Wave Roses and
Wave Height Frequency Distributions
for MSC50 GridPoint 14697

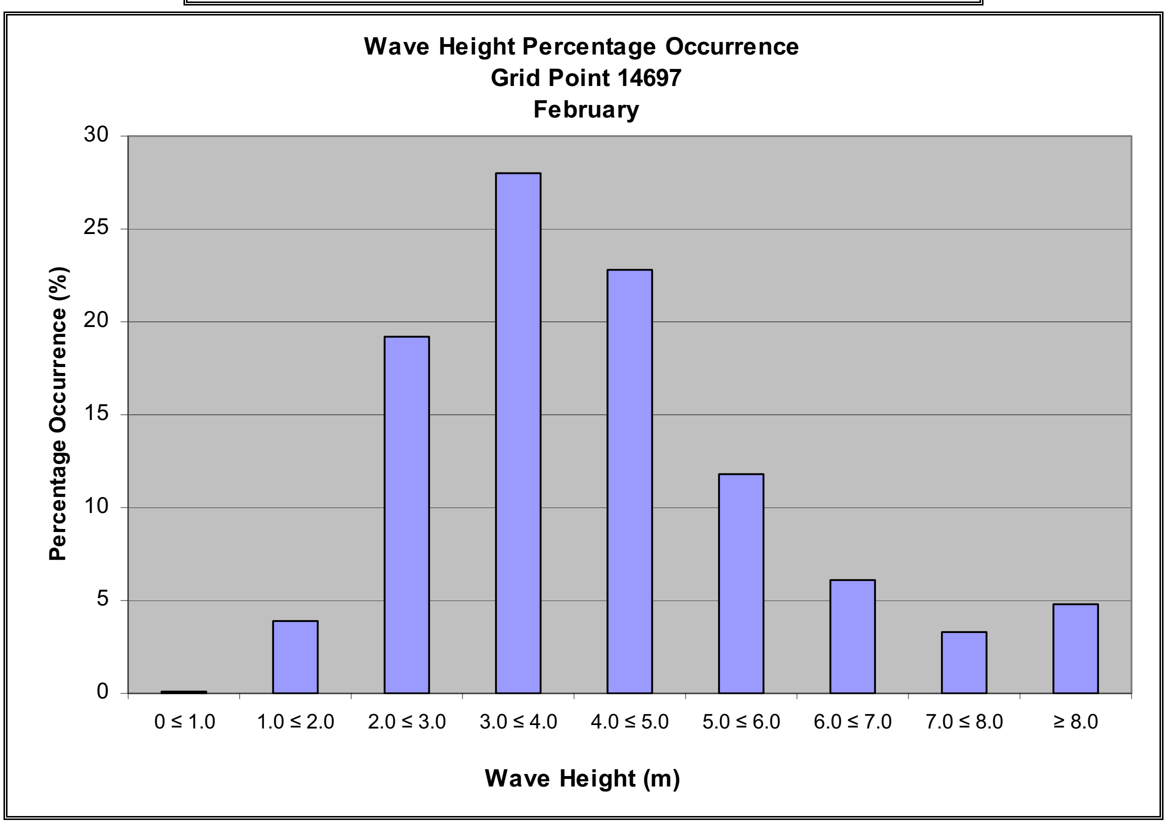
January


NORTH
15%
12%
9%
6%
3%
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 - 1.0

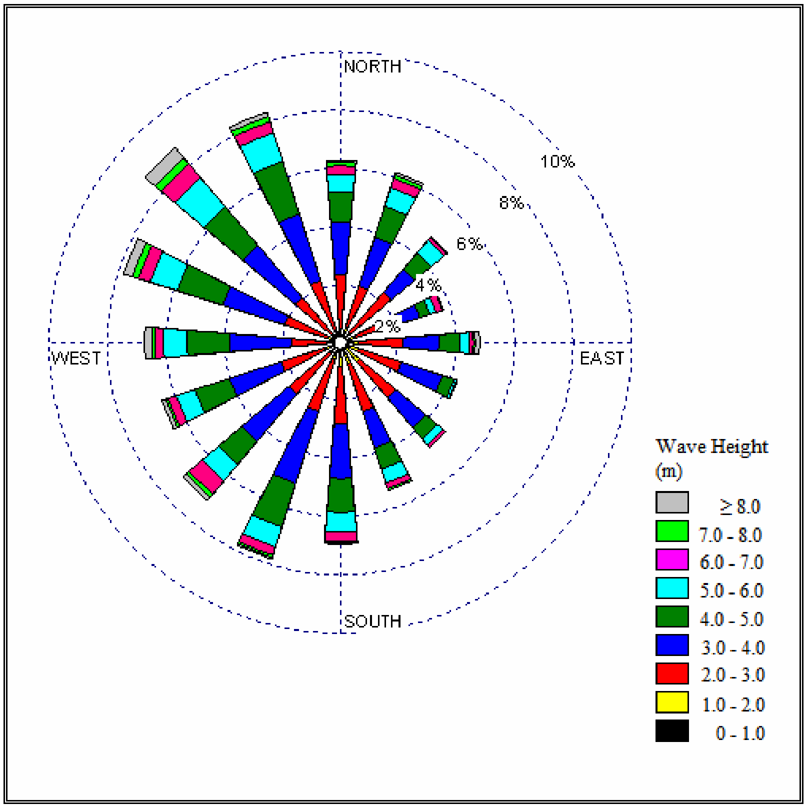

Wave Height Percentage Occurrence
Grid Point 14697
January
Percentage Occurrence (%)
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

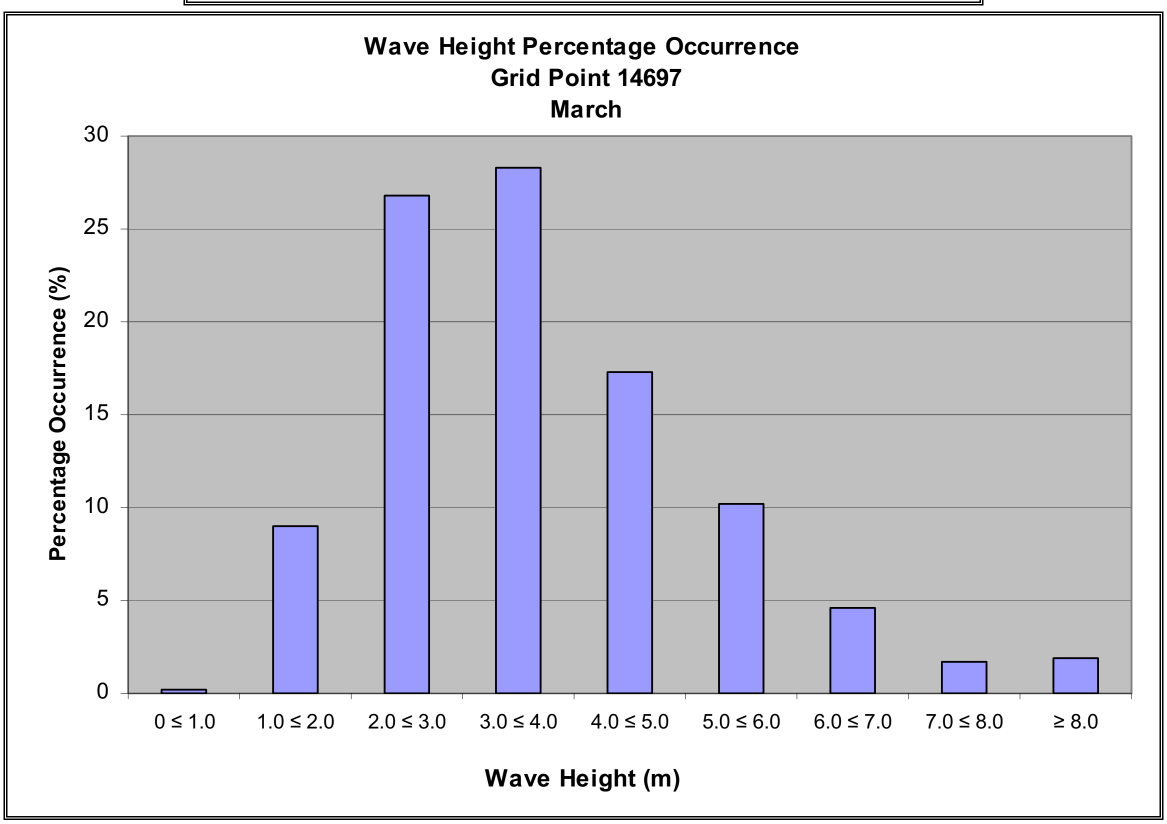
February


NORTH
15%
12%
9%
6%
3%
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 - 1.0

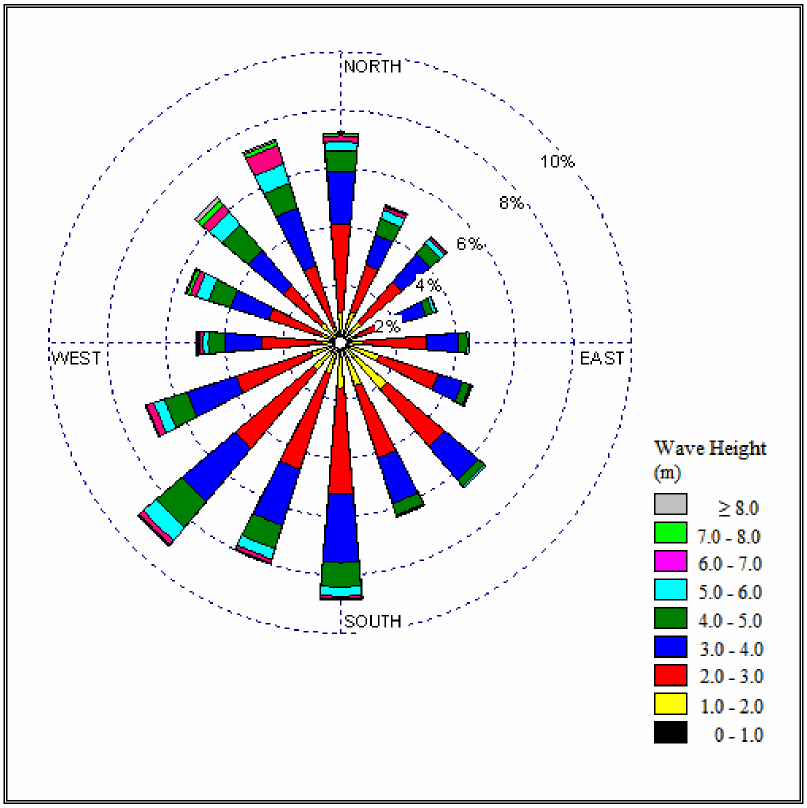

Wave Height Percentage Occurrence
Grid Point 14697
February
Percentage Occurrence (%)
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

March

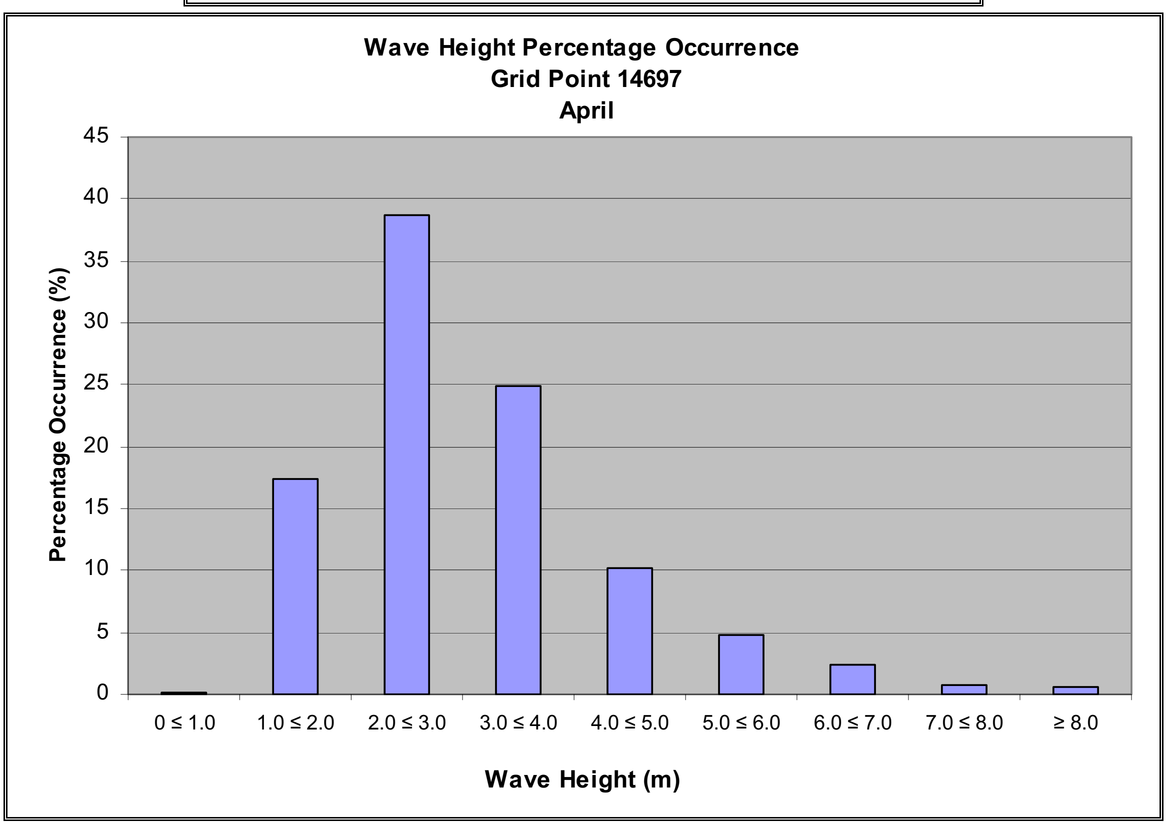

NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
Wave Height
(m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 14697
March
Percentage Occurrence (%)
0
5
10
15
20
25
30
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

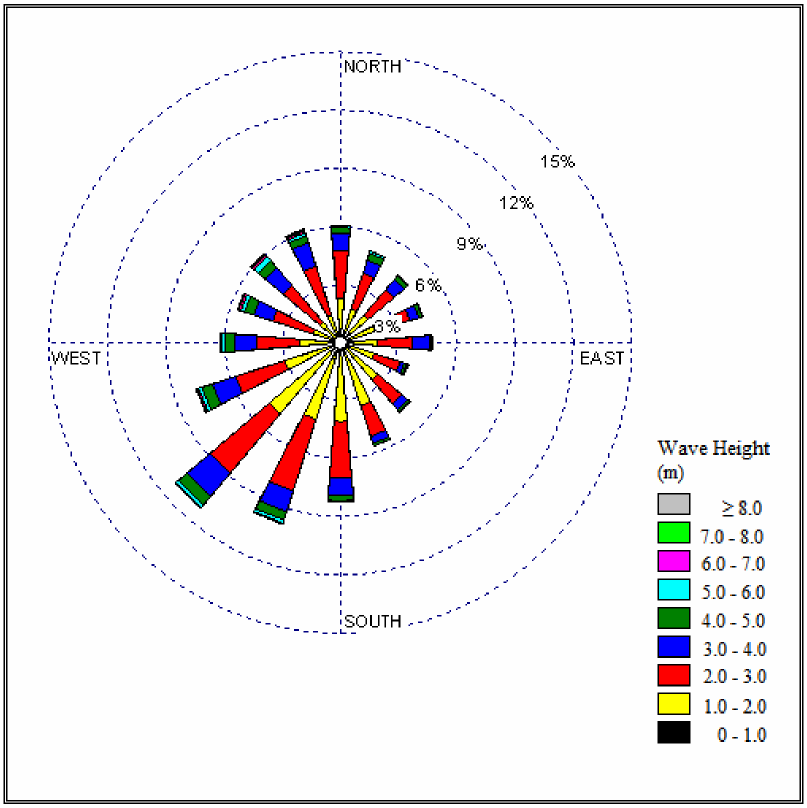


NORTH
SOUTH
EAST
WEST
10%
8%
6%
4%
2%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

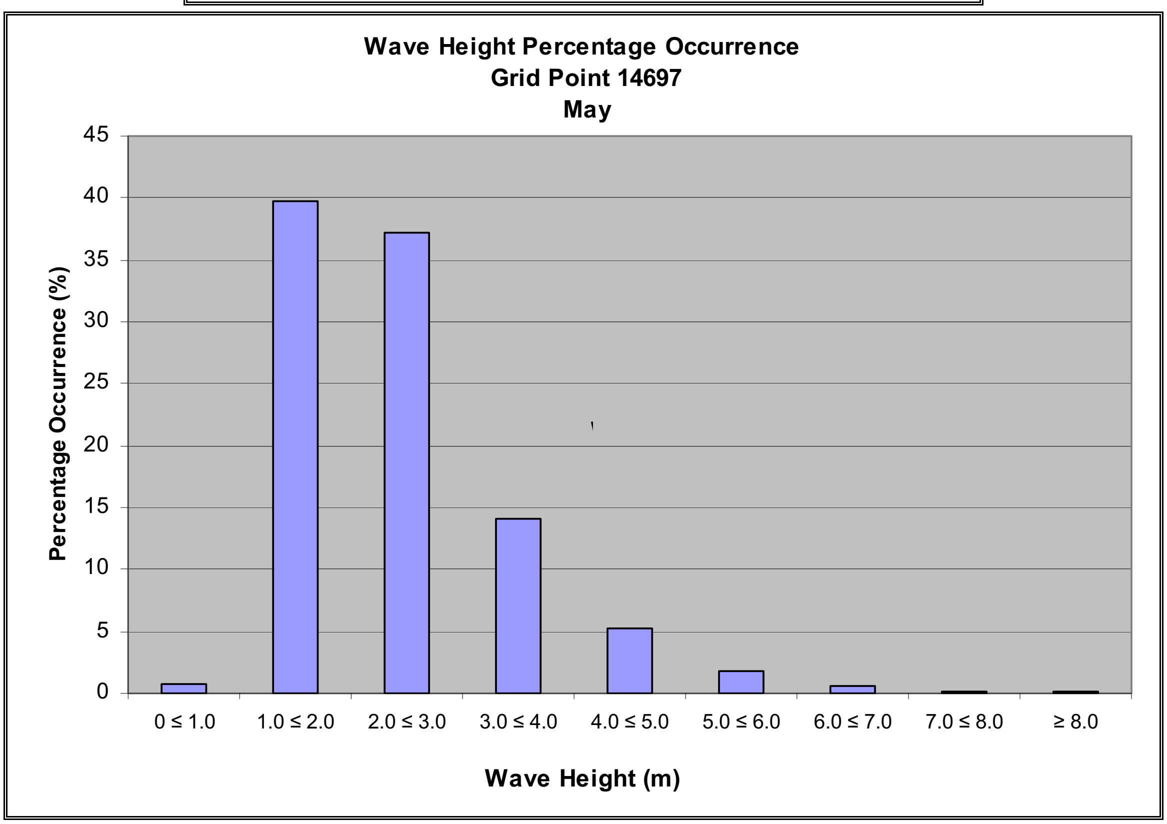


Wave Height Percentage Occurrence
Grid Point 14697
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

May

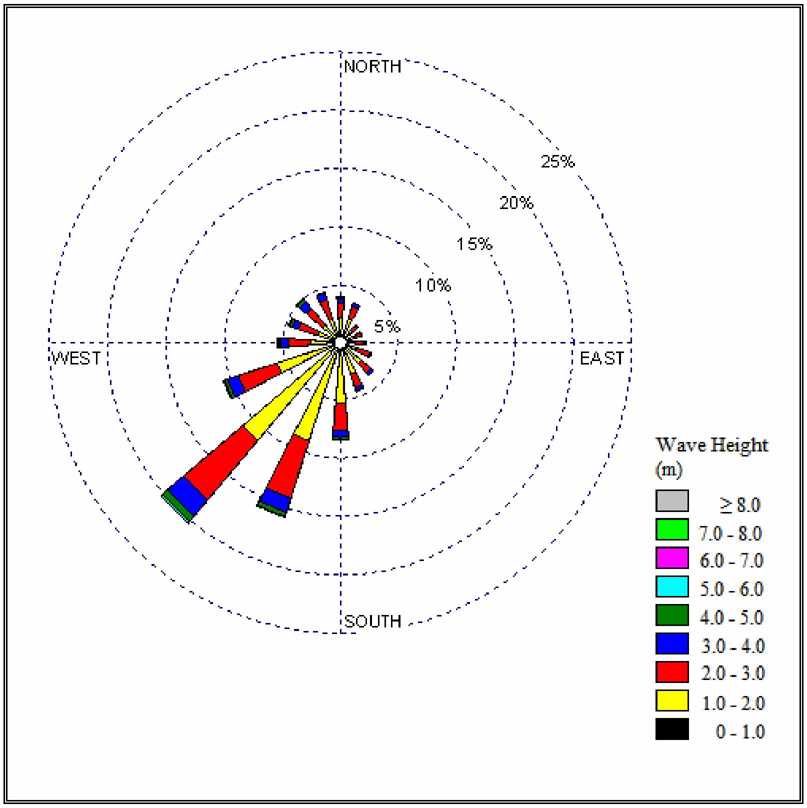


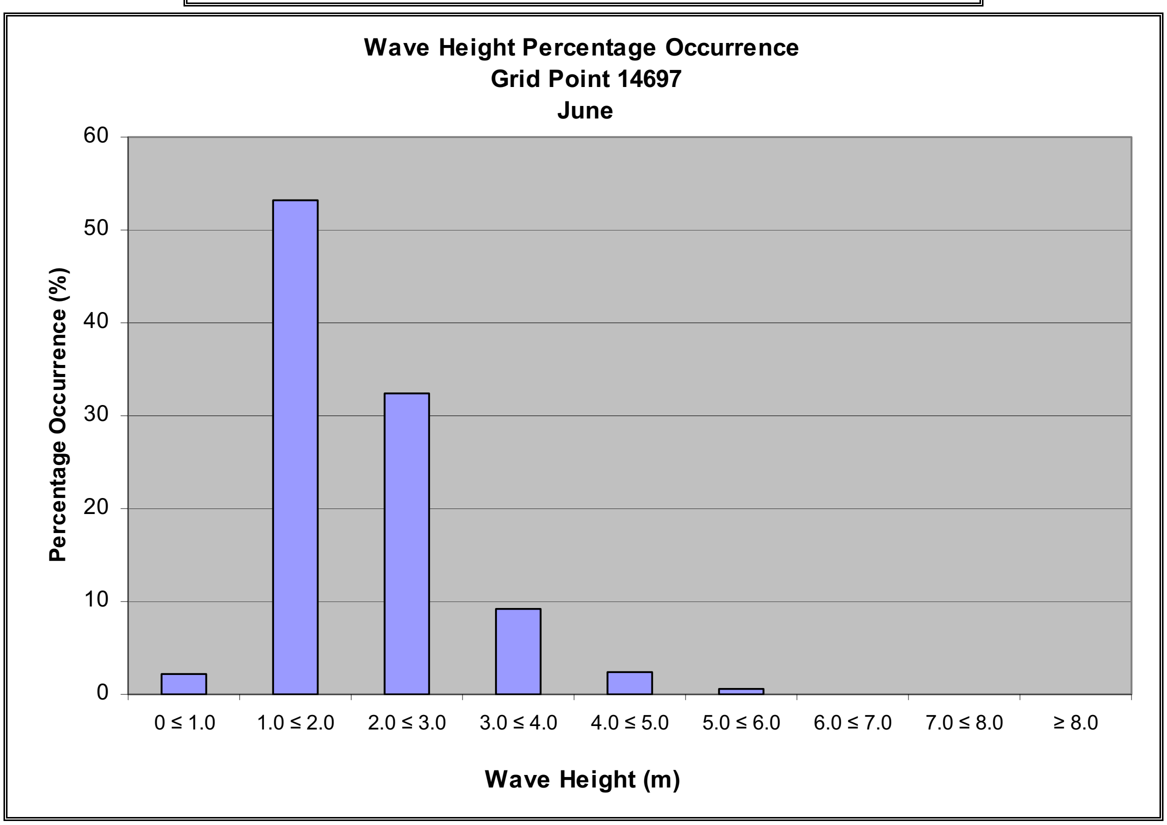
NORTH
SOUTH
WEST
EAST
15%
12%
9%
6%
3%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



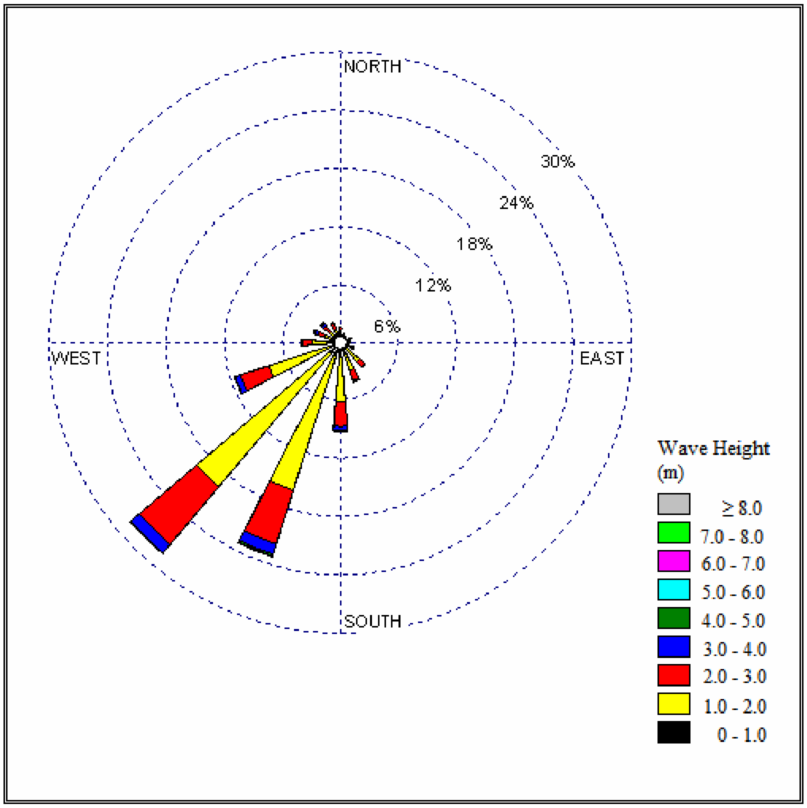
Wave Height Percentage Occurrence
Grid Point 14697
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

June

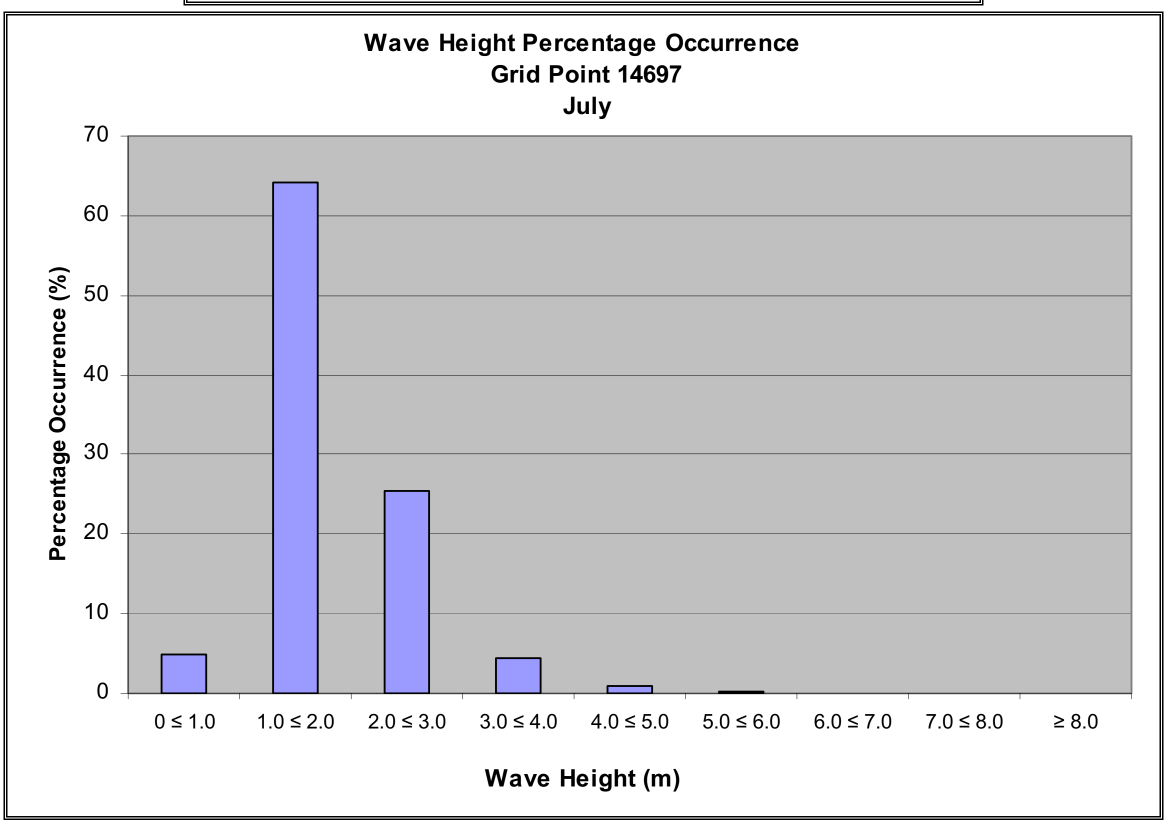

NORTH
SOUTH
WEST
EAST
5%
10%
15%
20%
25%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 14697
June
Percentage Occurrence (%)
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)

July

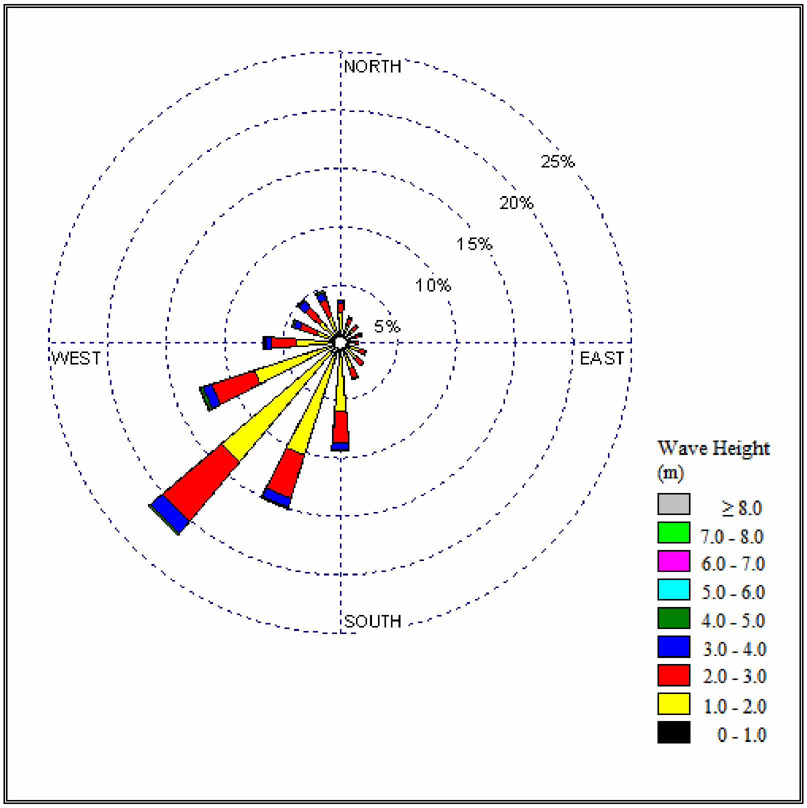


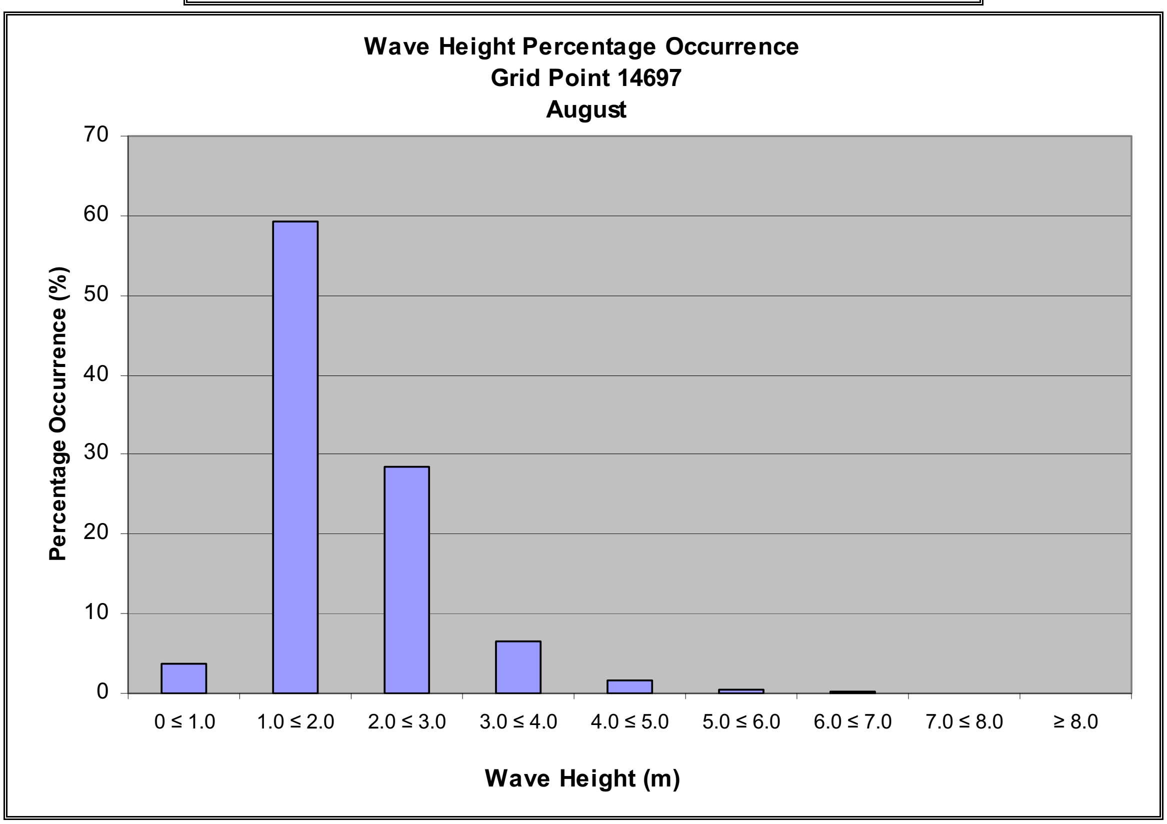
NORTH
30%
24%
18%
12%
6%
WEST
EAST
SOUTH
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0



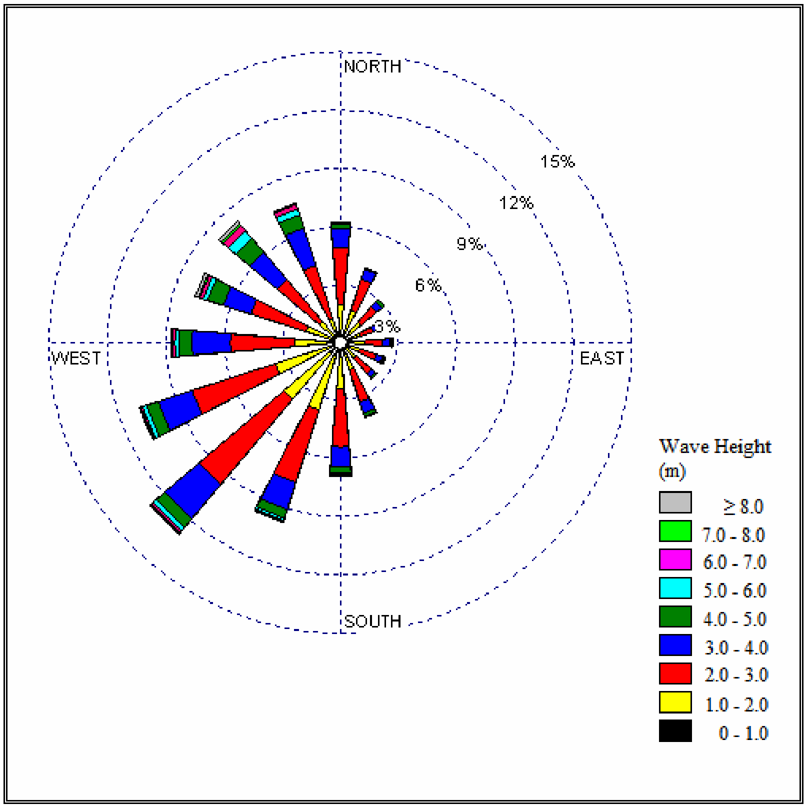
Wave Height Percentage Occurrence
Grid Point 14697
July
Percentage Occurrence (%)
70
60
50
40
30
20
10
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

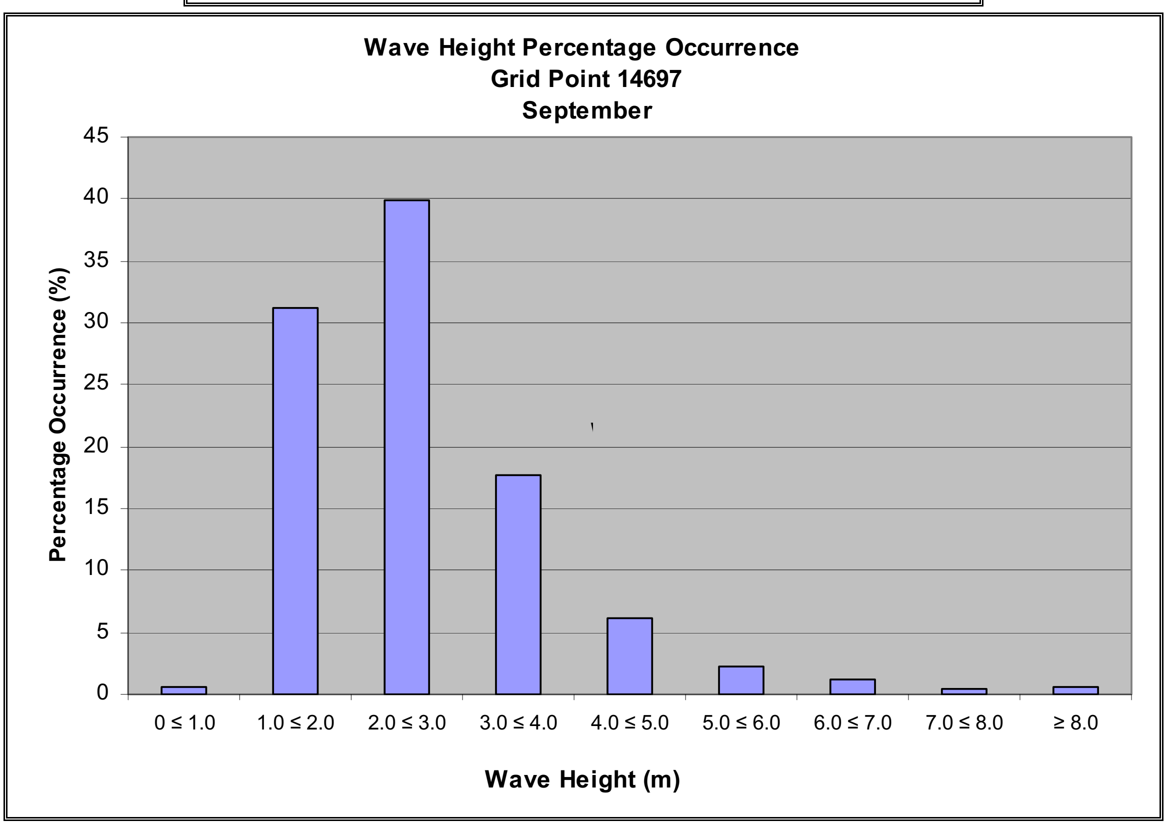
August


NORTH
SOUTH
EAST
WEST
5%
10%
15%
20%
25%
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 - 1.0

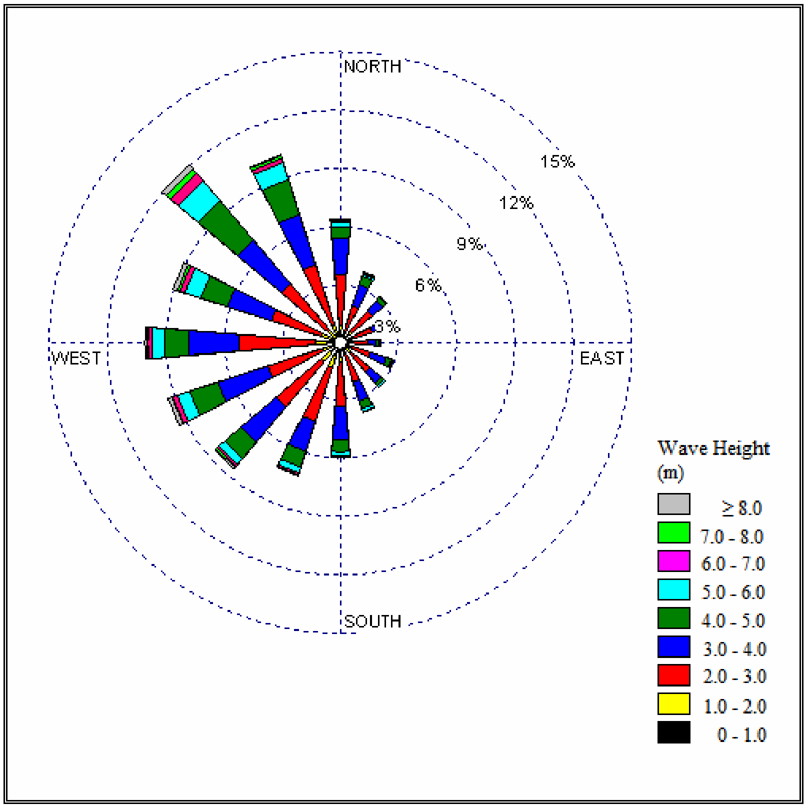

Wave Height Percentage Occurrence
Grid Point 14697
August
Percentage Occurrence (%)
0
10
20
30
40
50
60
70
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

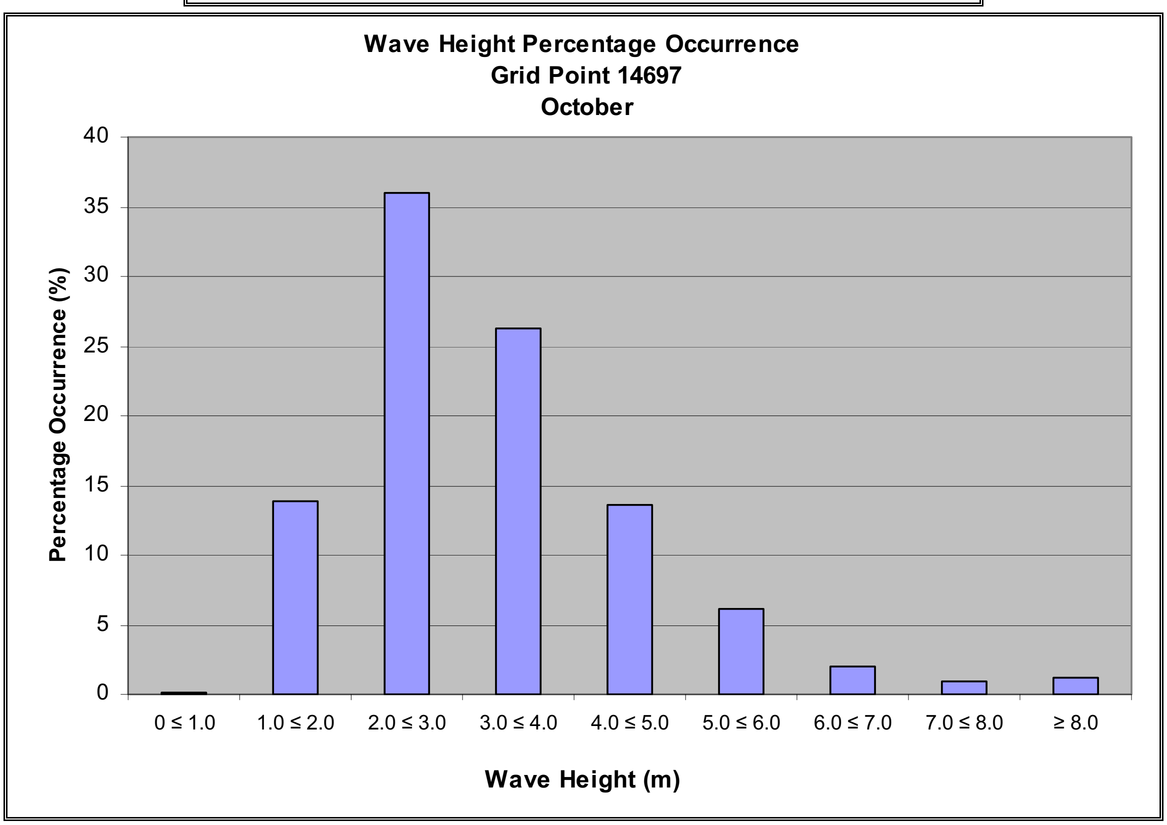
September


NORTH
SOUTH
EAST
WEST
3%
6%
9%
12%
15%
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 - 1.0

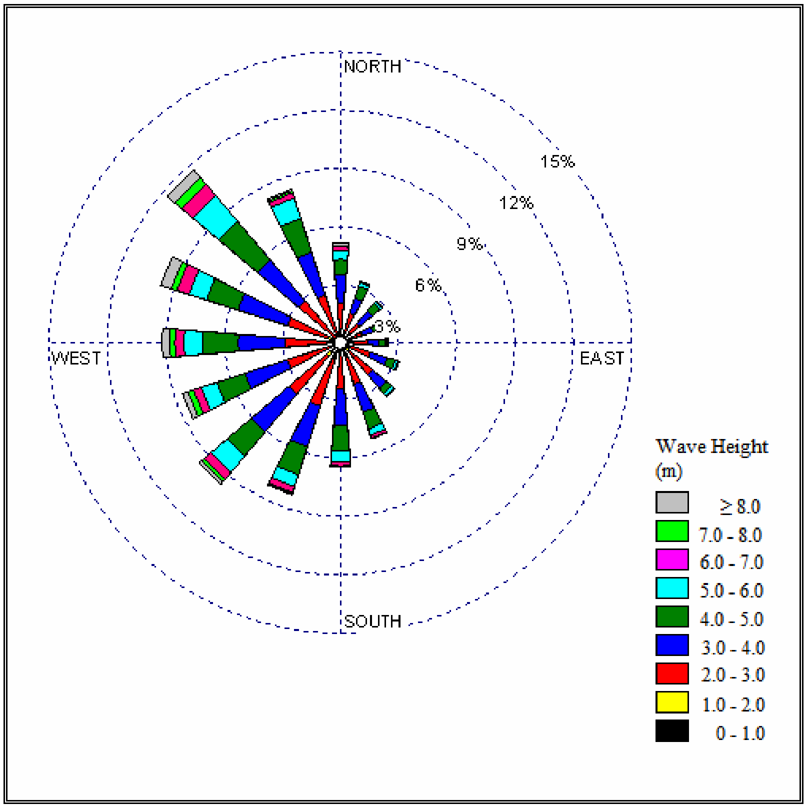

Wave Height Percentage Occurrence
Grid Point 14697
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

October

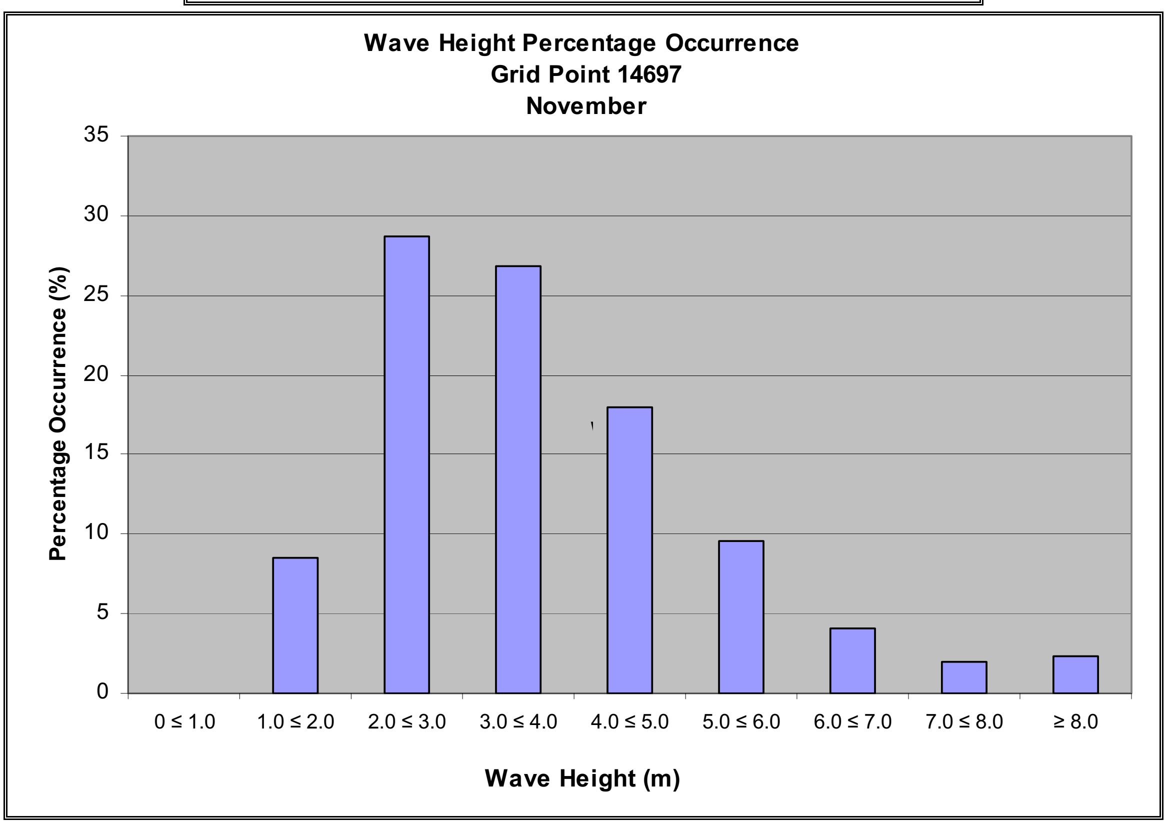

NORTH
EAST
SOUTH
WEST
3%
6%
9%
12%
15%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0


Wave Height Percentage Occurrence
Grid Point 14697
October
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
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

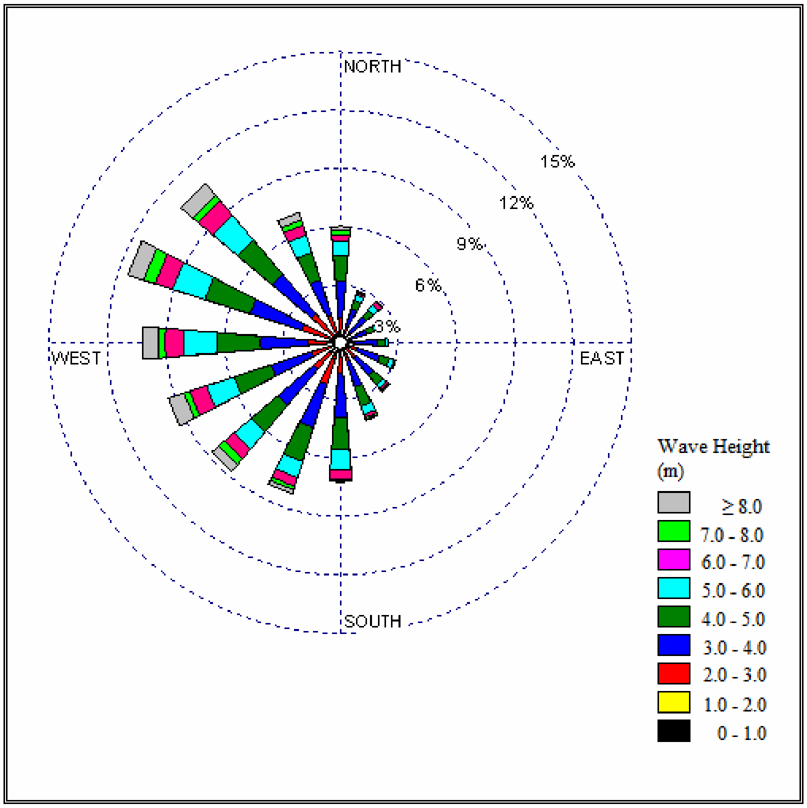


NORTH
SOUTH
EAST
WEST
15%
12%
9%
6%
3%
Wave Height (m)
≥ 8.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0 - 1.0

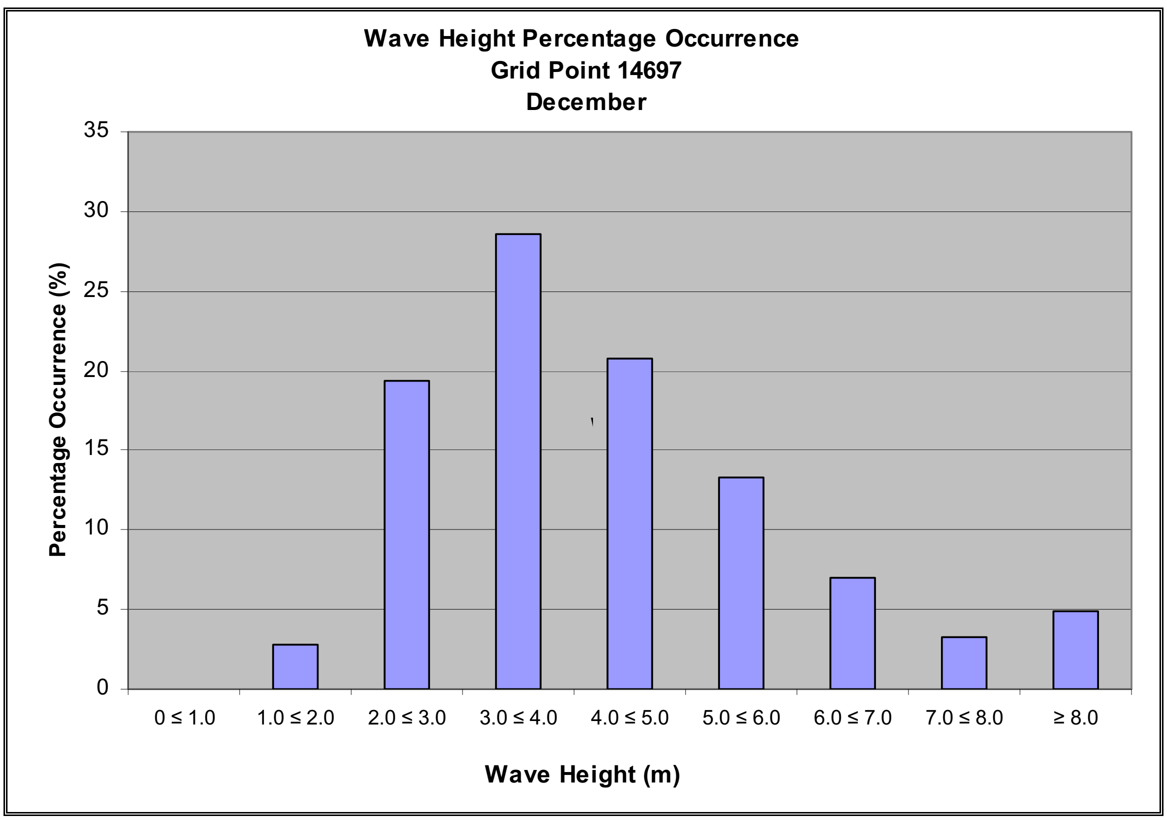


Wave Height Percentage Occurrence
Grid Point 14697
November
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0 ≤ 1.0
1.0 ≤ 2.0
2.0 ≤ 3.0
3.0 ≤ 4.0
4.0 ≤ 5.0
5.0 ≤ 6.0
6.0 ≤ 7.0
7.0 ≤ 8.0
≥ 8.0
Wave Height (m)

December



NORTH
SOUTH
WEST
EAST
15%
12%
9%
6%
3%
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 - 1.0



Wave Height Percentage Occurrence
Grid Point 14697
December
Percentage Occurrence (%)
35
30
25
20
15
10
5
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)