Climatology of the Hebron Project Areas

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Table of Contents

1.0 CLIMATOLOGY 1

1.1 Hebron Nearshore Project Area 1

1.1.1 Data Sources 1

1.1.2 Wind Climatology 1

1.1.3 Wave Climatology 7

1.1.4 Temperature 8

1.1.5 Wind Chill 9

1.1.6 Tropical Systems 9

1.2 Hebron Offshore Project Area 11

1.2.1 Data Sources 13

1.2.2 Wind Climatology 14

1.2.3 Wave Climatology 19

1.2.4 Air and Sea Temperature 26

1.2.5 Wind Chill 28

1.2.6 Precipitation 29

1.2.7 Icing 30

1.2.8 Visibility 32

1.2.9 Tropical Systems 34

2.0 CLIMATE VARIABILITY OF THE HEBRON OFFSHORE PROJECT AREA 36

3.0 EXTREME VALUE ANALYSIS 38

3.1 Hebron Nearshore Project Area 38

3.1.1 Extreme Value Estimates for Winds from the Gumbel Distribution 39

3.1.2 Extreme Value Estimates for Waves from a Gumbel Distribution 40

3.1.3 Extreme Temperature Analysis 42

3.2 Hebron Offshore Project Area 43

3.2.1 Extreme Value Estimates for Winds from the Gumbel Distribution 43

3.2.2 Extreme Value Estimates for Waves from a Gumbel Distribution 45

3.2.3 Joint Probability of Extreme Wave Heights and Spectral Peak Periods 47

3.2.4 Extreme Temperature Analysis 48

REFERENCES **1**

APPENDIX 1 ..... **3**

APPENDIX 2 ..... **16**

List of Figures

Figure 1.1 Annual Wind Rose for MSC50 Grid Point 12874 located near 47.7°N; 53.8°W. 1954 – 2005 2
Figure 1.2 Annual Wind Rose for the Oceans Ltd. weather station (Mosquito Cove, NL). January 1995 – May 1997 3
Figure 1.3 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 12874 located near 47.7°N; 53.8°W. 1954 - 2005 4
Figure 1.4 Percentage Exceedance of 10 m Wind Speed at Grid Point 12874 5
Figure 1.5 Explosive Deepening of a Mid-Latitude Low Pressure February 1967 6
Figure 1.6 Storm Tracks of Tropical Systems Passing within 278 km of 47.8°N 53.9°W, 1950 to 2008 11
Figure 1.7 Annual Wind Rose for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005 16
Figure 1.8 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 10632 located near 46.5°N, 48.5°W. 1954 - 2005 16
Figure 1.9 Percentage Exceedance of 10 m wind speed at Grid Point 10632 17
Figure 1.10 Annual Wave Rose for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005 20
Figure 1.11 Annual Percentage Frequency of Wave Height for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005 21
Figure 1.12 Percentage Exceedance of Significant Wave Height at Grid Point 11028 23
Figure 1.13 Percentage of Occurrence of Peak Wave Period at Grid Point 10632 25
Figure 1.14 ICOADS Monthly Mean Air and Sea Surface Temperature 27
Figure 1.15 Percentage Frequency of Potential Spray Icing Conditions 32
Figure 1.16 Monthly and Annual Percentage Occurrence of Visibility 33
Figure 1.17 Storm Tracks of Tropical Systems Passing within 278 km of 46.5°N 48.5°W, 1950 to 2007 35
Figure 1.18 Five-Year Average of the number of Tropical Storms which formed in the Atlantic Basin since 1960 36
Figure 2.1 Winter North Atlantic Oscillation Index (1950 - 2009) 37
Figure 3.1 Environmental Contour Plot for Grid Point 10632 (46.5°N 48.5°W) 48

List of Tables

Table 1.1 Mean Wind Speed Statistics 4
Table 1.2 Maximum Wind Speeds (m/s) Statistics 6
Table 1.3 Mean Monthly Significant Wave Height Statistics (m) for the MSC50 Data Set 7
Table 1.4 Maximum Significant Wave Height Statistics (m) for the MSC50 Data Set 8
Table 1.5 Bull Arm Air Temperature Statistics 9
Table 1.6 Wind Chill Statistics 9
Table 1.7 Tropical Systems Passing within 278 km of 47.8°N 53.9°W, 1950 to 2008 10
Table 1.8 Locations of MANMAR Observations 14
Table 1.9 Locations of Wave Observations 14
Table 1.10 Mean Wind Speed Statistics 15
Table 1.11 Maximum Wind Speeds (m/s) Statistics 18
Table 1.12 Combined Significant Wave Height Statistics (m) for the MSC50 Data Set 21
Table 1.13 Maximum Combined Significant Wave Height Statistics (m) for the MSC50 Data Set 22
Table 1.14 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 10632 24
Table 1.15 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 10632 26
Table 1.16 ICOADS Air Temperature Statistics 27
Table 1.17 ICOADS Sea Surface Temperature Statistics 28
Table 1.18 Monthly Air Temperature (°C) Statistics for the Terra Nova Field located at 46.4°N 48.4°W 28
Table 1.19 Wind Chill Statistics 29
Table 1.20 Percentage Frequency (%) Distribution of Precipitation 30
Table 1.21 Percentage Frequency of Potential Spray Icing Conditions 31
Table 1.22 Tropical Systems Passing within 278 km (150 nm) of 44.5°N 53.5°W, 1950 to 2007 34
Table 3.1 Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves 38
Table 3.2 1-hr Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years 39
Table 3.3 10-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 39
Table 3.4 1-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 40
Table 3.5 Extreme Significant Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 40
Table 3.6 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 41
Table 3.7 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 42
Table 3.8 Extreme Minimum Temperature Estimates for Return Periods of 2, 10 and 25 Years 42

Table 3.9 Extreme Maximum Temperature Estimates for Return Periods of 2, 10 and 25 Years 43
Table 3.10 Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves 43
Table 3.11 1-hr Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years 44
Table 3.12 10-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 44
Table 3.13 1-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 45
Table 3.14 Extreme Significant Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 46
Table 3.15 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 47
Table 3.16 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years 47
Table 3.17 Annual Extreme Significant Wave Estimates and Spectral Peak Periods for Return Periods of 1, 10, 25, 50 and 100 Years 48
Table 3.18 Extreme Minimum Temperature Estimates for Return Periods of 2, 10, 25, 50 and 100 Years 49
Table 3.19 Extreme Maximum Temperature Estimates for Return Periods of 2, 10, 25, 50 and 100 Years 49

1.0 Climatology

1.1 Hebron Nearshore Project Area

1.1.1 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 m (Harris, 2007). Grid Point 12874 located at 46.7°N 53.8°W near the mouth of Bull Arm was chosen to represent conditions within the Nearshore Study Area described on pg 3-2 of Section 3, Vol 1.

Air temperature statistics were also extracted from MANMAR data from both the *Terra Nova FPSO* and the *Henry Goodrich* located at 46.4°N 48.4°W in the Terra Nova field on the Grand Banks of Newfoundland from February 23, 2000 to June 30, 2009.

A weather station was installed at Bull Arm, NL by Oceans Ltd. from January 1995 to May 1997. This station measured wind direction, speed, air temperature, sea surface temperature and wave heights. Wave height data are only available from May 1995 – June 1996.

In addition, to the MSC50 data set and observations from the Oceans Ltd weather station, wind statistics were compiled from nearby weather stations located in Arnold's Cove and Argentia. The Arnold's Cove climate station recorded wind data at hourly intervals from July 1971 to June 1993. A manned observing station was operated at Argentia during the periods of January 1953 to May 1970 and May 1976 to October 1986. The Argentia station was eventually converted to automatic climate station, recording only wind speed, temperature, relative humidity and pressure data.

Tropical cyclone climatology statistics were calculated from the National Hurricane Centre's best-track data set (Neumann et al. 1993; Jarvinen et al. 1984). This data set provides positions and intensities at 6-hour intervals for every Atlantic tropical cyclone since 1886. In this report, a subset of the NHC data set consisting of all storms of tropical origin from 1957 – 2008 which have tracked within 278 km of 47.8°N 53.9°W was used. This subset was obtained from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center Historical Hurricane Tacks website.

1.1.2 Wind Climatology

The east coast of Newfoundland experiences predominately southwest to west flow throughout the year. Local topography however has a large influence on the wind direction and speed experienced within Bull Arm.

Channeling refers to the tendency of the wind to be deflected by the land. An analysis of data measured by Oceans Ltd. in Mosquito Cove show that the generally west to southwest flow typical of the climatology of the region is more northwesterly due to the effects the topography. Wind roses of the annual wind speed from Grid Point 12874 (Figure 1.1) and the Oceans Ltd. weather station (Figure 1.2) highlight the differences between the climatological winds and those measured within Mosquito Cove, NL.

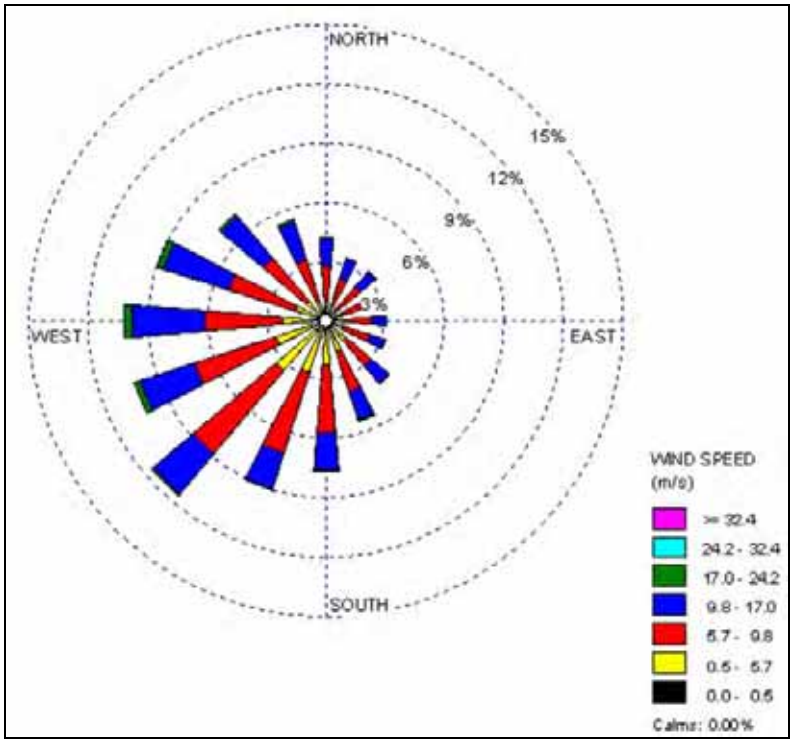


Figure 1.1 **Annual Wind Rose for MSC50 Grid Point 12874 located near 47.7°N; 53.8°W. 1954 – 2005**

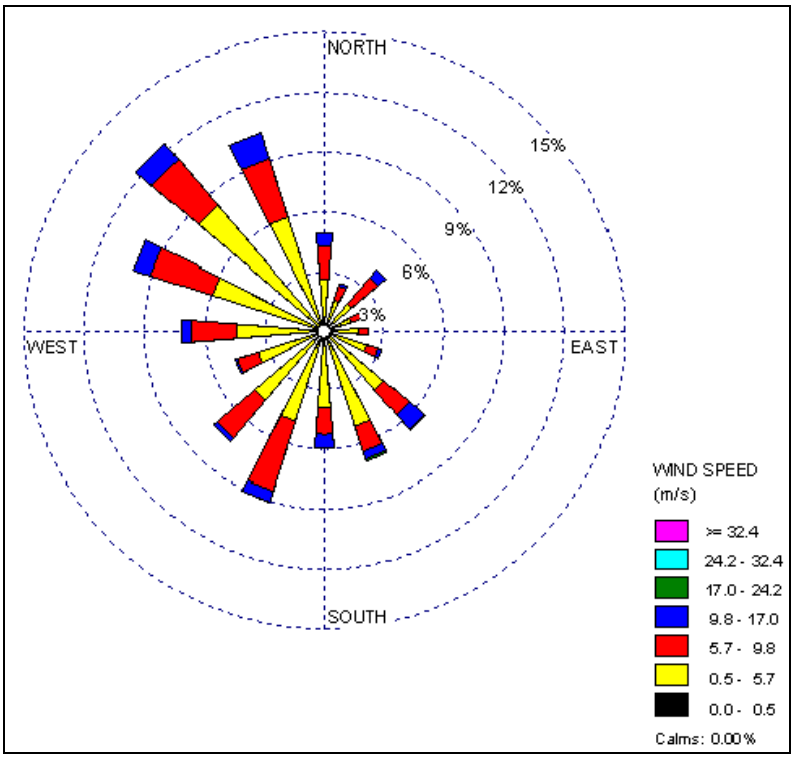


Figure 1.2 Annual Wind Rose for the Oceans Ltd. weather station (Mosquito Cove, NL). January 1995 – May 1997

Low pressure systems crossing the area are more intense during the winter months. As a result, mean wind speeds tend to peak during this season. Mean wind speeds at Grid Point 12874 and in the observation data sets peak during the winter months (Table 1.1). As can be see from this table, wind speeds measured at Bull Arm, NL are lower than those of other stations surrounding it. These lower wind speeds are probably due to the effects of local topography, however may also be an artifact of the smaller data set as well. The smaller difference in wind speed during the winter months between the Environment Canada station and the Oceans Ltd. station however would indicate that topography the main cause of the weaker winds. Since winds are predominately from the northwest during the winter months, the local topography would have less impact on the wind speed than during the summer months when winds are predominately southwesterly. Figure 1.3 presents the percentage occurrence of wind speeds within specific categories. This figure clearly shows that moderate winds are predominant at Grid Point 12874, and that wind speeds higher that strong rarely occur.

Table 1.1 Mean Wind Speed Statistics

Month	MSC50 Grid Point 12874	Bull Arm Environment Canada	Bull Arm Oceans	Argentia	Arnold's Cove
January	10.6	7.7	6.7	7.9	6.9
February	9.9	7.5	5.7	7.5	6.8
March	9.2	7.1	5.7	7.0	6.4
April	8.0	6.3	5.3	6.3	5.4
May	6.4	5.9	4.5	5.5	4.8
June	5.7	5.8	4.0	5.5	4.8
July	5.4	6.0	4.0	5.2	4.6
August	6.0	5.6	3.4	5.4	4.8
September	7.3	6.2	4.7	5.8	5.2
October	8.6	6.5	4.5	6.6	5.9
November	9.5	7.4	5.2	7.1	6.6
December	10.4	7.1	5.7	7.8	7.2

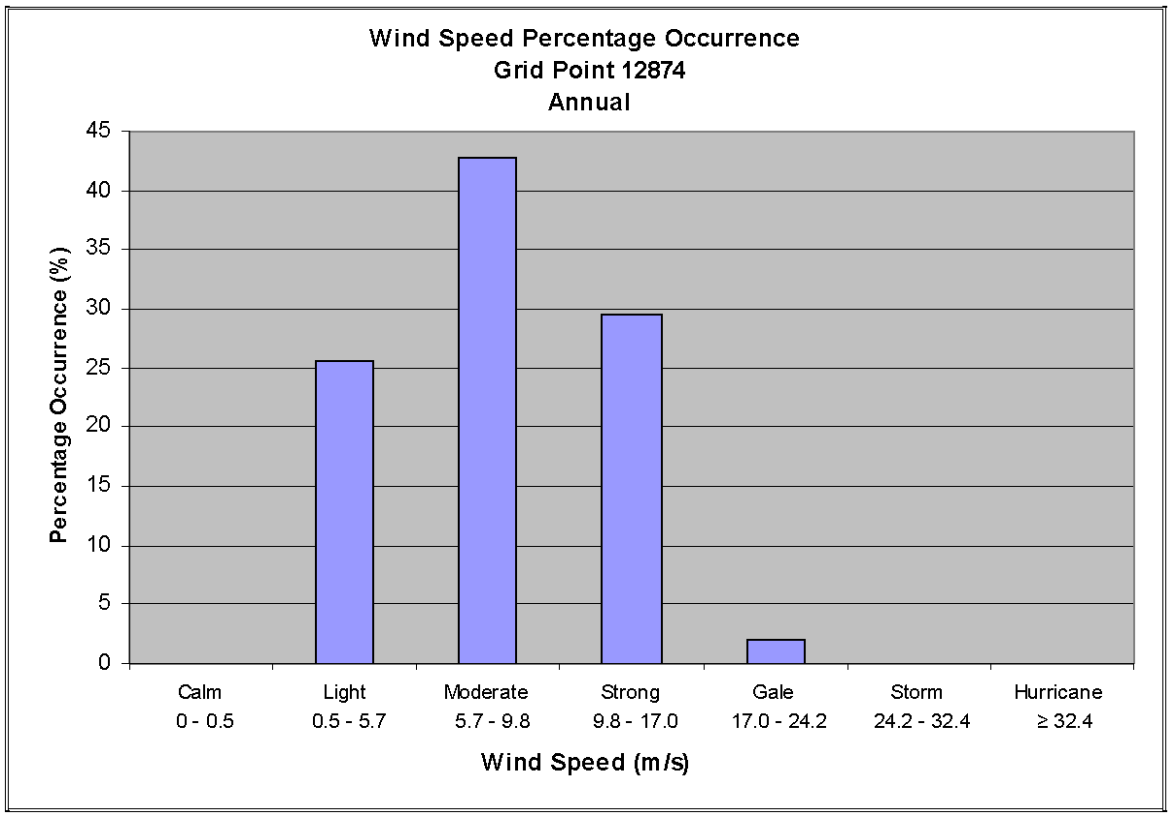


Figure 1.3 Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 12874 located near 47.7°N; 53.8°W. 1954 - 2005

The percentage exceedance of wind speeds at Grid Point 12874 is presented in Figure 1.4.

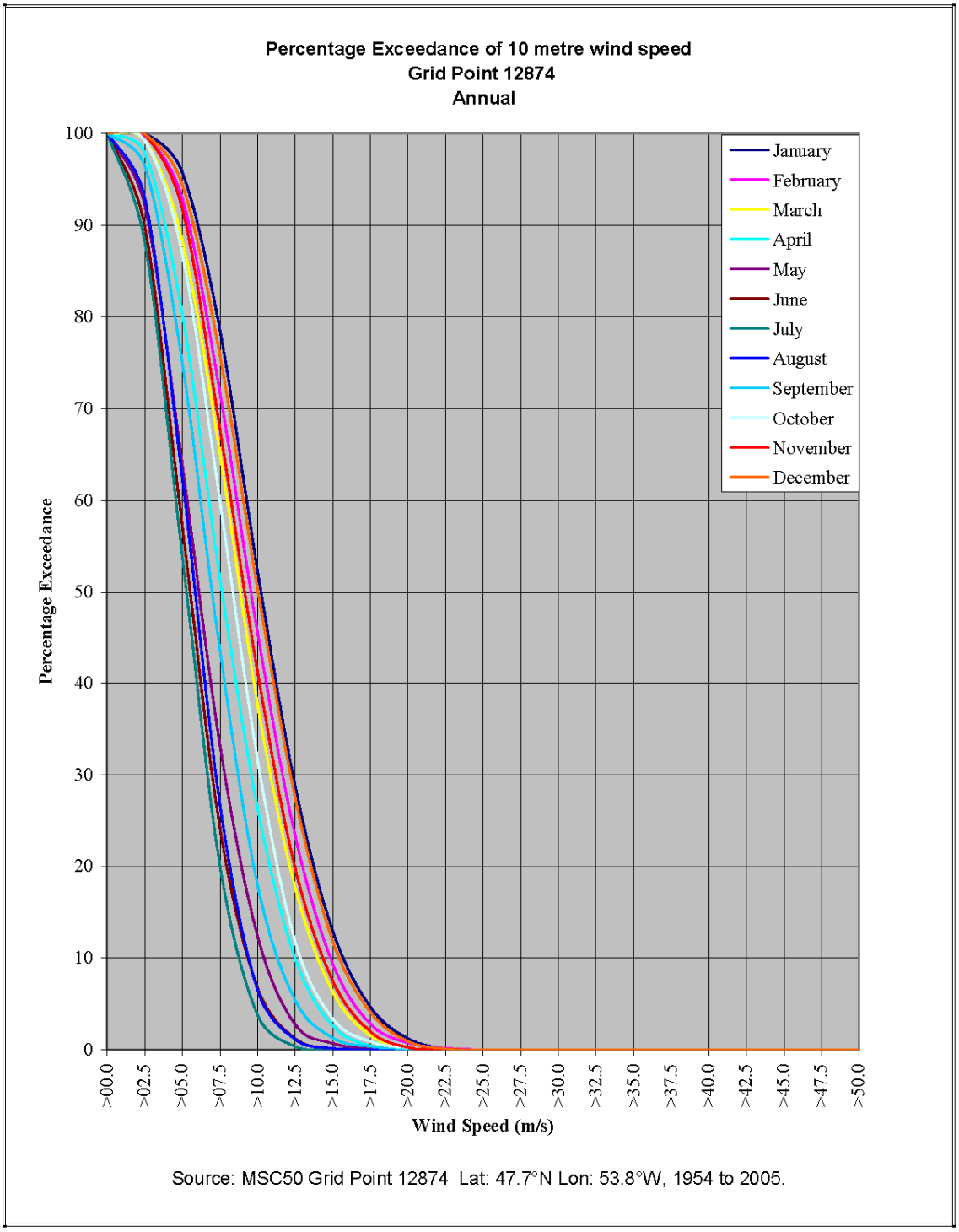


Figure 1.4 Percentage Exceedance of 10 m Wind Speed at Grid Point 12874

Intense mid-latitude low pressure systems occur frequently from early autumn to late spring. In addition, remnants of tropical systems have passed near Newfoundland between spring and late fall. Therefore, while mean wind speeds tend to peak during the winter months, maximum wind speeds may occur at any time during the year. A table of monthly maximum wind speeds for each of the data sets is presented in Table 1.2.

Table 1.2 Maximum Wind Speeds (m/s) Statistics

Month	MSC50 Grid Point 12874	Bull Arm Environment Canada	Bull Arm Oceans	Argentia	Arnold's Cove
January	27.6	24.7	19.6	30.3	25.6
February	26.8	27.8	19.6	30.8	25.0
March	25.7	22.6	20.6	24.2	22.2
April	20.5	17.5	16.5	25.8	22.0
May	19.5	19.6	15.4	23.4	19.2
June	19.6	16.5	14.4	20.6	18.9
July	21.6	17.0	16.0	21.7	18.3
August	22.1	17.5	11.3	22.2	23.4
September	25.2	21.1	16.5	24.7	18.3
October	26.3	18.5	15.4	28.6	22.8
November	24.0	21.1	17.5	28.0	23.4
December	24.5	27.3	19.0	30.0	25.8

Rapidly deepening storm systems known as weather bombs frequently cross Newfoundland. These storms typically experience explosive deepening in the warm waters off Cape Hatteras and move northeast across the Grand Banks. Some of these storms move across the island of Newfoundland. During one such event on February 22, 1967 Argentia wind speeds peaked at 25.0 m/s from the west-southwest while wind speeds at MSC50 Grid Point 12874 peaked at 24.4 m/s. An analysis of the February 1967 storm is presented in Figure 1.5.

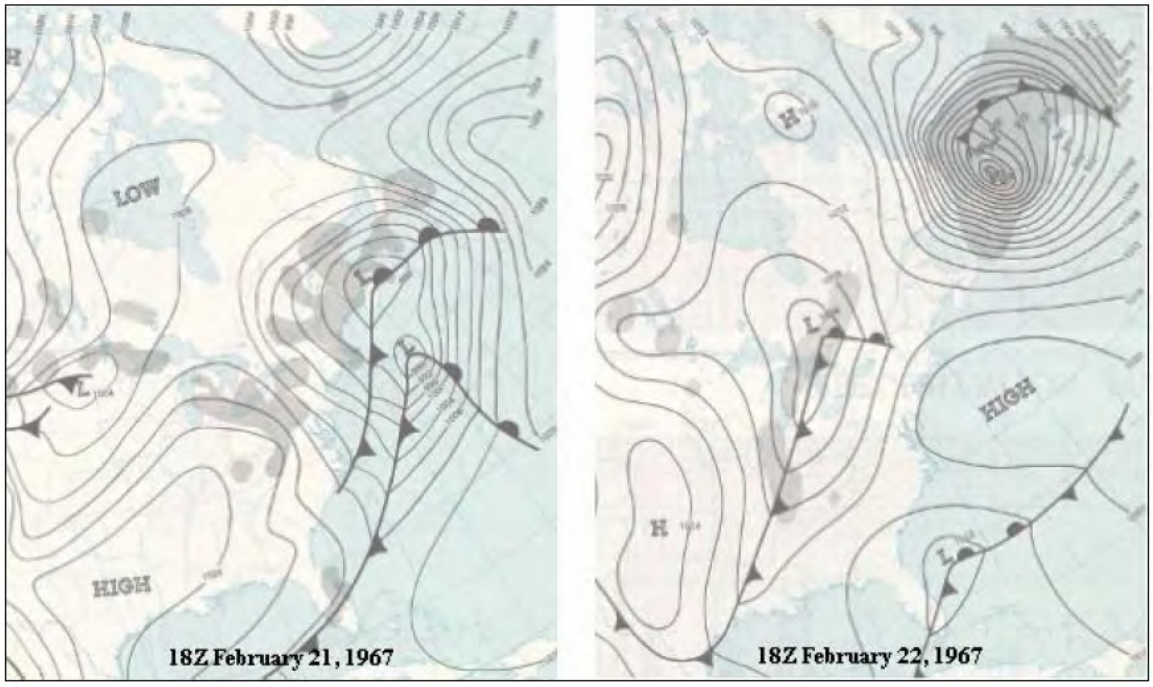


Figure 1.5 Explosive Deepening of a Mid-Latitude Low Pressure February 1967

While mid-latitude low pressure systems account for the majority of the peak wind events, storms of tropical origin can also on occasion pass over the region. Wind speeds of 26.3 m/s in the MSC50 data set occurs October 20, 2000 coinciding with the passing of Hurricane Michael west of the Burin Peninsula. Wind speeds from the observation stations are not available during this event.

1.1.3 Wave Climatology

The wave climate for Bull Arm, NL was compiled using wave data from MSC50 Grid Point 12874 and measured data from an Oceans Ltd. wave buoy located within Bull Arm, NL. Located near the mouth of Bull Arm, the MSC50 Grid Point would be influenced by northeasterly swell energy propagating into Trinity Bay. Due to it's orientation with Trinity Bay however, Bull Arm would see little swell energy.

The MSC50 waves were partitioned using a Pierson-Moskowitz spectrum into a primary and secondary partition, where the primary partition is representative of the wind wave, and the secondary partition is representative of swell. In order to provide statistics representative of conditions within Bull Arm, the wave height statistics were calculated using the total variance of the primary partition and compared to statistics generated using the total spectral energy. The results presented in Table 1.3 and Table 1.4 show little difference between combined sea and wind wave only, indicating little swell energy actually propagates into Trinity Bay. While these results should give a better indication of conditions within Bull Arm, statistics generated will be slightly higher than those within Bull Arm. These differences may be attributed to differences in fetch limiting between Trinity Bay and Bull Arm.

Table 1.3 Mean Monthly Significant Wave Height Statistics (m) for the MSC50 Data Set

Month	MSC50 Grid Point 12874 Combined Sea	MSC50 Grid Point 12874 Wind Wave	Oceans Ltd. Wave Buoy
January	0.64	0.60	0.17
February	0.57	0.54	0.21
March	0.52	0.49	0.00
April	0.41	0.39	0.00
May	0.29	0.26	0.14
June	0.23	0.21	0.15
July	0.21	0.19	0.09
August	0.25	0.23	0.05
September	0.36	0.33	0.11
October	0.47	0.44	0.12
November	0.55	0.52	0.14
December	0.62	0.58	0.14

Table 1.4 Maximum Significant Wave Height Statistics (m) for the MSC50 Data Set

Month	MSC50 Grid Point 12874 Combined Sea	MSC50 Grid Point 12874 Wind Wave	Oceans Ltd. Wave Buoy
January	1.90	1.88	1.37
February	1.53	1.52	1.22
March	1.71	1.62	0.00
April	1.48	1.46	0.00
May	1.52	1.50	0.76
June	1.29	1.28	1.69*
July	1.21	1.17	0.49
August	1.22	1.18	0.22
September	1.41	1.37	0.53
October	1.58	1.57	0.66
November	1.53	1.48	1.21
December	1.92	1.91	1.17

Significant wave heights at the head of Trinity Bay peak during the winter months with Grid Point 12874 having a mean monthly significant wave height of 0.64 m in January. The lowest significant wave heights occur in the summer with July month having a mean monthly significant wave height of only 0.21 m (Table 1.3).

Maximum combined significant wave heights also peak during the winter months; however, significant wave heights of 1.2 m may occur at any time throughout the year as due to tropical systems passing through the area. A quality control was done on the Oceans Ltd. wave rider data set, and numerous spike in the data set were removed. A maximum wave height of 1.69 m recorded on June 13, 1995 could not be conclusively ruled out and is presented in Table 1.4; however is believed to be erroneous

1.1.4 Temperature

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

Air and sea surface temperatures for the area were extracted from the Oceans Ltd. weather station. Temperature statistics presented in Table 1.5 show that the atmosphere is coldest in January and February, and warmest in August.

Monthly mean daily maximum and minimum temperature statistics are also presented. Mean temperatures for each month are the mean of all temperatures recorded at the site during that month. The maximum and minimum temperatures are the highest and lowest temperatures respectively, recorded during the month over the entire data set. The mean daily maximum is the average of all maximum temperatures recorded during the specified month, while the mean daily minimum is the average of all minimum temperatures recorded during the specified month.

Table 1.5 Bull Arm Air Temperature Statistics

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	-4.7	9.0	-16.0	5.09	-1.2	-7.5
February	-4.6	11.2	-16.6	5.43	-0.7	-8.1
March	-3.3	8.7	-17.1	4.94	0.11	-7.37
April	2.2	14.46	-11.31	3.09	5	-0.29
May	5.02	14.8	-2.03	2.50	8.45	2.49
June	9.13	21.36	0.05	3.16	13.43	5.62
July	13.92	23.57	5.33	3.17	17.56	11.25
August	15.33	27.64	6.89	3.39	19.4	12.21
September	12.01	22.64	2.84	3.34	15.14	9.16
October	8.03	16.54	0.25	2.90	10.31	5.98
November	3.59	14.24	-7.99	3.83	6.6	1.34
December	-0.6	12.7	-14.0	4.78	2.3	-3.17

1.1.5 Wind Chill

Wind Chill is the cooling our body feels when the impact of wind and temperature are taken into consideration. In determining the statistics in Table 1.6, only observations with wind speeds above 1.34 m/s and temperatures less than or equal to 10°C were used as input. It is also important to note that the wind chill is not a temperature, but number that quantifies the sensation of cold. Thus, in Canada, wind chill is reported without the degree designation and is rounded to the nearest degree. Wind chill statistics were calculated using wind and air temperature observations from the Oceans Ltd. Bull Arm weather station.

Table 1.6 Wind Chill Statistics

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	-11.8	5.0	-32.0	6.6	-6.2	-17.0
February	-11.4	6.0	-29.0	6.9	-5.3	-17.9
March	-9.42	6.0	-31.0	6.3	-4.1	-16.7
April	-2.68	9.0	-17.0	4.0	1.35	-7.19
May	1.31	9.0	-9.0	2.8	5.76	-3.07
June	4.86	10.0	-4.0	2.5	8.78	1.67
July	6.16	10.0	2	1.7	8.69	5.56
August	7.07	10.0	3	1.4	8.88	5.81
September	5.11	10.0	-1.0	2.1	8.21	2.94
October	3.79	10.0	-6.0	2.8	7.08	1.14
November	-0.97	10.0	-17.0	4.5	3.52	-4.75
December	-6.34	8.0	-28.0	6.0	-1.7	-11.0

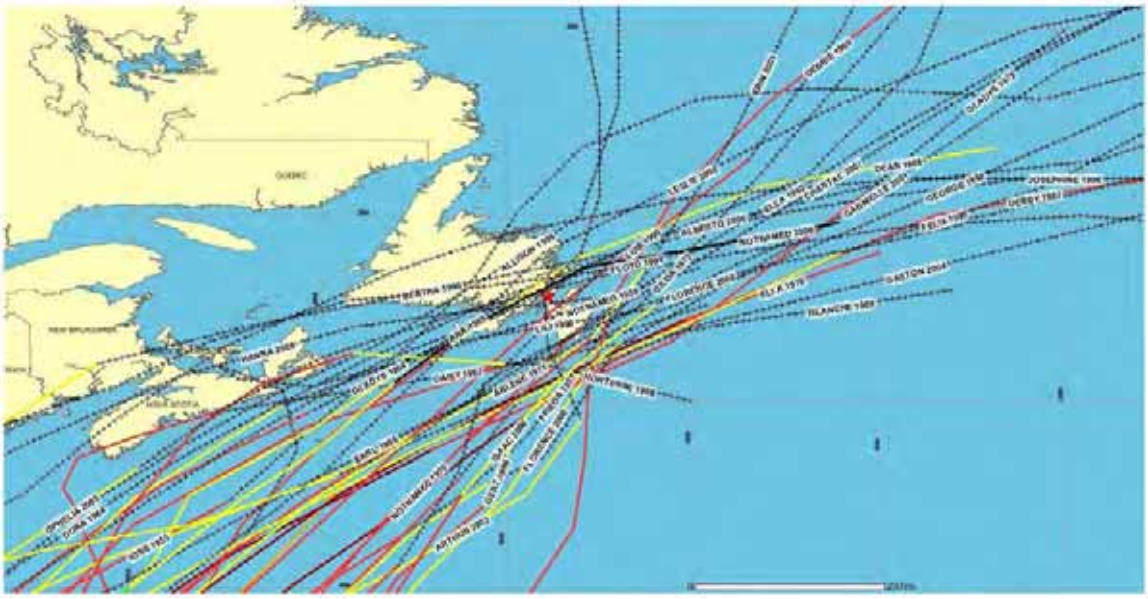
1.1.6 Tropical Systems

A position near Bull Arm, located at 47.8°N 53.9°W was used for the Nearshore Study Area. During the 58-year period from 1950 - 2008, 41 tropical systems have passed within 278km of this location. The names of each cyclone are given in Table 1.7 and the tracks over the Nearshore Project Area are shown in Figure 1.6. It must be noted that the

values in the table are the maximum 1-minute mean wind speeds occurring within the tropical system at the 10-m reference level as it passed. Wind speed in Table 1.7 refers to the maximum sustained wind recorded during the life of the tropical cyclone and not the wind speed at the time it passed.

Table 1.7 Tropical Systems Passing within 278 km of 47.8°N 53.9°W, 1950 to 2008

Year	Month	Day	Hour	Name	Lat	Long	Wind (m/s)	Pressure (mb)	Category
1950	10	5	1200Z	George	47.0	-51.9	30.9	N/A	Extratropical
1955	9	22	0000Z	Oione	48.4	-55.8	23.1	N/A	Extratropical
1957	9	27	0600Z	Frieda	46.3	-52.8	18.0	N/A	Extratropical
1959	6	21	1200Z	NotNamed	47.3	-53.7	23.1	N/A	Extratropical
1962	10	9	0000Z	Daisy	45.5	-57.7	25.7	N/A	Extratropical
1962	10	22	1200Z	Ella	46.7	-53.4	30.9	N/A	Extratropical
1964	9	15	1800Z	Dora	47.6	-55.6	28.3	N/A	Extratropical
1964	9	24	1800Z	Gladys	44.7	-60.3	30.9	990	Extratropical
1969	8	12	1800Z	Blanche	46.0	-54.9	30.9	N/A	Extratropical
1969	8	24	1200Z	Debbie	48.0	-52.0	36.0	N/A	Category 1
1970	10	17	1800Z	NotNamed	42.5	-57.5	36.0	980	Category 1
1971	7	7	1800Z	Arlene	46.5	-53.0	23.1	N/A	Extratropical
1973	10	28	0600Z	Gilda	47.5	-51.5	28.3	968	Extratropical
1975	10	3	1200Z	Gladys	46.6	-50.6	43.7	960	Category 2
1978	9	5	0000Z	Ella	45.0	-55.0	54.0	960	Category 3
1982	9	19	0000Z	Debby	45.3	-53.5	46.3	970	Category 2
1985	7	19	0600Z	Ana	46.0	-57.6	28.3	996	Extratropical
1989	8	8	1800Z	Dean	48.8	-53.2	23.1	995	Tropical Storm
1990	10	15	0600Z	Lili	46.6	-56.4	20.6	994	Extratropical
1995	6	9	0600Z	Allison	48.1	-55.9	20.6	996	Extratropical
1995	8	22	1200Z	Felix	46.8	-50.8	25.7	985	Tropical Storm
1995	9	11	0600Z	Luis	47.1	-54.2	41.2	963	Category 1
1996	7	15	0600Z	Bertha	49.0	-52.0	23.1	996	Extratropical
1996	9	16	0000Z	Hortense	46.0	-54.0	20.6	998	Extratropical
1996	10	10	1200Z	Josephine	49.5	-55.0	23.1	983	Extratropical
1998	9	6	0000Z	Earl	47.0	-54.0	25.7	979	Extratropical
1999	9	19	0600Z	Floyd	48.5	-52.5	18.0	994	Extratropical
1999	9	23	0600Z	Gert	44.6	-54.5	30.9	968	Tropical Storm
2000	9	17	1200Z	Florence	42.5	-55.0	25.7	1000	Tropical Storm
2000	10	8	1800Z	Leslie	49.0	-54.0	18.0	1005	Extratropical
2001	9	15	0000Z	Erin	46.7	-52.7	30.9	981	Tropical Storm
2001	9	19	1800Z	Gabrielle	46.5	-52.0	30.9	986	Extratropical
2002	7	17	1200Z	Arthur	48.0	-54.0	20.6	1002	Extratropical
2004	9	1	1800Z	Gaston	45.0	-55.0	23.1	998	Extratropical
2005	9	19	0000Z	Ophelia	48.4	-52.3	23.1	1000	Extratropical
2006	6	16	1200Z	Alberto	47.4	-55.0	23.1	985	Extratropical
2006	7	19	0000Z	NotNamed	48.6	-52.9	12.9	1012	Tropical Low
2006	9	13	1800Z	Florence	46.4	-54.0	36.0	963	Extratropical
2006	10	2	1800Z	Isaac	45.5	-53.7	28.3	995	Tropical Storm
2007	8	1	1200Z	Chantal	46.0	-54.5	28.3	990	Extratropical
2008	9	8	0600Z	Hanna	47.5	-55.4	20.6	996	Extratropical



Source: NOAA Coastal Services Center Archive.

Figure 1.6 Storm Tracks of Tropical Systems Passing within 278 km of 47.8°N 53.9°W, 1950 to 2008

On occasion, these systems still maintain their tropical characteristics when they reach Newfoundland. On September 11, 1995, Hurricane Luis, made landfall as a Category 1 near Argentia with maximum sustained winds of 41.2m/s and a central pressure of 963 mb. Hurricane Luis then tracked northeast across the Bay de Verde Peninsula and into the Atlantic. Wind speeds at Argentia peaked at 18.6m/s while wind speeds from the MSC50 Grid Point 12874 peaked at 25.2 m/s as this system passed.

1.2 Hebron Offshore Project Area

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

The climate of the Grand Banks 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[1].

[1] 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 flow 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 Grand Banks: 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 centre 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 Offshore Project 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.

In addition to extratropical cyclones, tropical cyclones often retain their tropical characteristics as they enter the Offshore Study Area. Tropical cyclones account for the strongest sustained surface winds observed anywhere on earth. The hurricane season in the North Atlantic basin normally extends from June through November, although tropical storm systems occasionally occur outside this period. Once formed, a tropical storm or hurricane will maintain its energy as long as a sufficient supply of warm, moist air is available. Tropical storms and hurricanes obtain their energy from the latent heat of vapourization that is released during the condensation process. These systems typically move east to west over the warm water of the tropics; however, some of these systems turn northward and make their way towards Newfoundland. Since the capacity of the air to hold water vapour is dependent on temperature, as the hurricanes move northward over

the colder ocean waters, they begin to lose their tropical characteristics. By the time these weakening cyclones reach Newfoundland, they are usually embedded into a mid-latitude low and their tropical characteristics are usually lost.

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. These systems frequently produce 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 altitudes in the early and late hurricane season and at higher latitudes during the peak of the season. (Hart and Evans 2001).

1.2.1 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 m (Harris 2007). Grid Point 10632 located at 46.5°N 48.5°W was chosen to represent conditions within the Offshore Study Area. Wave heights and periods are computed using a Pierson Moskowitz spectrum

Air temperature, sea surface temperature, wind chill 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 encompassing the Offshore Project Area from 46.5°N – 48.6°N to 48.3°W – 48.6°W and covering the period from January 1950 to December 2006 was used in this report. The ICOADS data set has certain inherent limitations in that the observations are not spatially or temporally consistent. In addition, even though the data used in this report were subjected to standard quality control procedures, the data set is somewhat prone to observation and coding errors, resulting in some erroneous observations within the data set. The errors were minimized by using the standard filtering system using source exclusion flags, composite QC flags and an outlier trimming level of 3.5 standard deviations. The ICOADS data set is also suspected to contain a fair-weather bias, due to the fact that ships tend to avoid severe weather or simply do not transmit weather observations during storm situations. The presence of several offshore platforms within the ICOADS region in latter years however would lessen this bias.

Air temperature statistics were also extracted from MANMAR data from both the *Terra Nova FPSO* and the *Henry Goodrich*, located at 46.4°N 48.4°W in the Terra Nova field on the Grand Banks of Newfoundland from February 23, 2000 to June 30, 2009.

In addition to the MSC50 data set, wind direction and speed statistics were also compiled using MANMAR data from several platforms located near the Offshore Project Area. The location and period of observation for each of these stations is presented in Table 1.1.

Table 1.8 Locations of MANMAR Observations

Location	Latitude	Longitude	Anemometer Height	Period
Terra Nova FPSO	46.4°N	48.4°W	50	August 12, 2007 - July 31, 2009
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

Wave statistics were also compiled from wave data measured near the Offshore Project Area. Several wave records exist from within the Offshore Project Area; however, they have been deemed insufficient in length to derive accurate statistics. As a result, longer term wave records from nearby offshore installations have been used. 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 period of these stations is presented in Table 1.2.

Table 1.9 Locations of Wave Observations

Location	Latitude	Longitude	Period
Terra Nova	46.4°N	48.4°W	July 13, 1999 - March 31, 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, 2008

Tropical cyclone climatology statistics were calculated from the National Hurricane Centre's (NHC) best-track data set (Jarvinen et al. 1984; Neumann et al. 1993). This data set provides positions and intensities at 6-hour intervals for every Atlantic tropical cyclone since 1886. In this report, a subset of the NHC data set consisting of all storms of tropical origin from 1957 – 2007 which have tracked within 370 km (200 nm) of 44.5°N 53.5°W (denoted "Hurricane Track" in Figure 2.1) was used. This subset was obtained from the NOAA Coastal Services Centre Historical Hurricane Tacks website.

1.2.2 Wind Climatology

The Grand Banks 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. Mean wind speeds at Grid Point 10632 and in the MANMAR data sets peak during the month of January (Table 1.3).

Table 1.10 Mean Wind Speed Statistics

Month	MSC50 Grid Point 10632	*Terra Nova FPSO*	*Glomar Grand Banks*	*GSF Grand Banks*	*Henry Goodrich*	Hibernia
January	11.5	14.5	12.9	13.7	15.2	16.0
February	11.5	13.9	11.9	12.9	14.9	15.4
March	10.4	13.3	11.9	13.6	13.6	14.6
April	8.8	12.0	11.4	11.3	12.6	13.3
May	7.4	10.7	9.7	11.1	11.7	12.1
June	6.9	9.3	9.4	8.3	11.2	11.4
July	6.4	8.9	9.5	9.2	10.9	10.8
August	6.7	9.6	8.4	9.1	9.8	10.5
September	7.9	9.9	10.3	9.3	10.3	11.2
October	9.3	11.0	12.8	9.7	12.0	13.0
November	10.1	12.7	11.0	11.6	12.7	13.5
December	11.2	15.0	12.6	13.0	14.5	15.5

Wind speed typically increases with increasing heights above sea level. Statistics provided in Table 1.3 are presented in order of increasing height, with the MSC50 data set being the lowest (10 m) and the Hibernia Platform being the highest (anemometer heights for each platform may be found in Table 1.1). Statistics for each anemometer level are presented to give a better idea of winds at varying levels above sea level. Furthermore, methods to reduce wind speeds from anemometer level to 10 m have proven ineffective due to atmospheric stability issues.

Winds speeds from MSC50 data set are 1-hour averages while the MANMAR data sets are 10-minute average winds. For consistency, wind speeds from the MSC50 data set have been adjusted to 10-minute mean 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).

A wind rose of the annual wind speed and histogram of the wind speed frequency from Grid Point 10632 is presented in Figure 1.1 and Figure 1.2. Monthly wind roses along with histograms of the frequency distributions of wind speeds for Grid Point 10632 can be found in Appendix 1. 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.

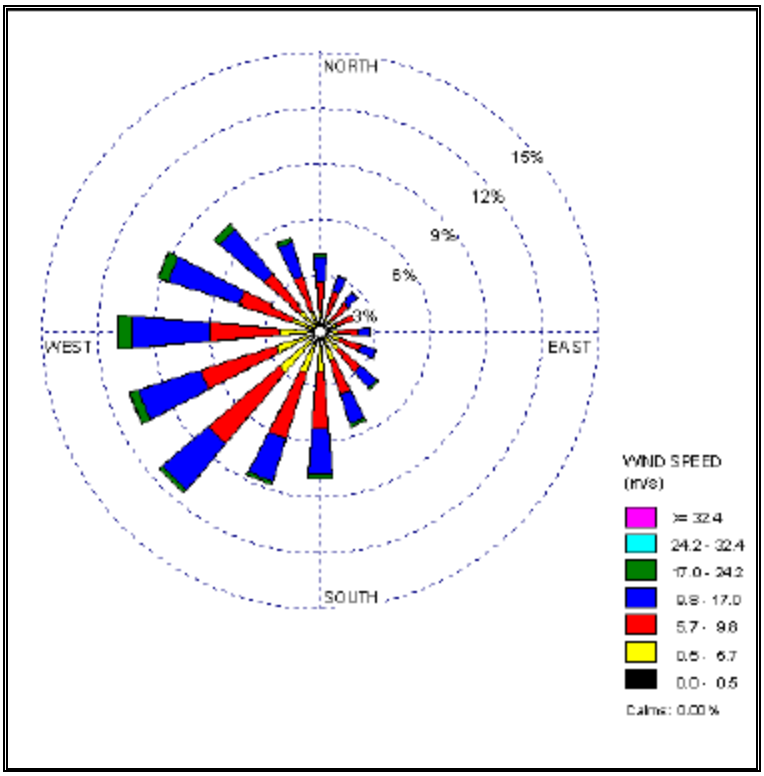


Figure 1.7 **Annual Wind Rose for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005**

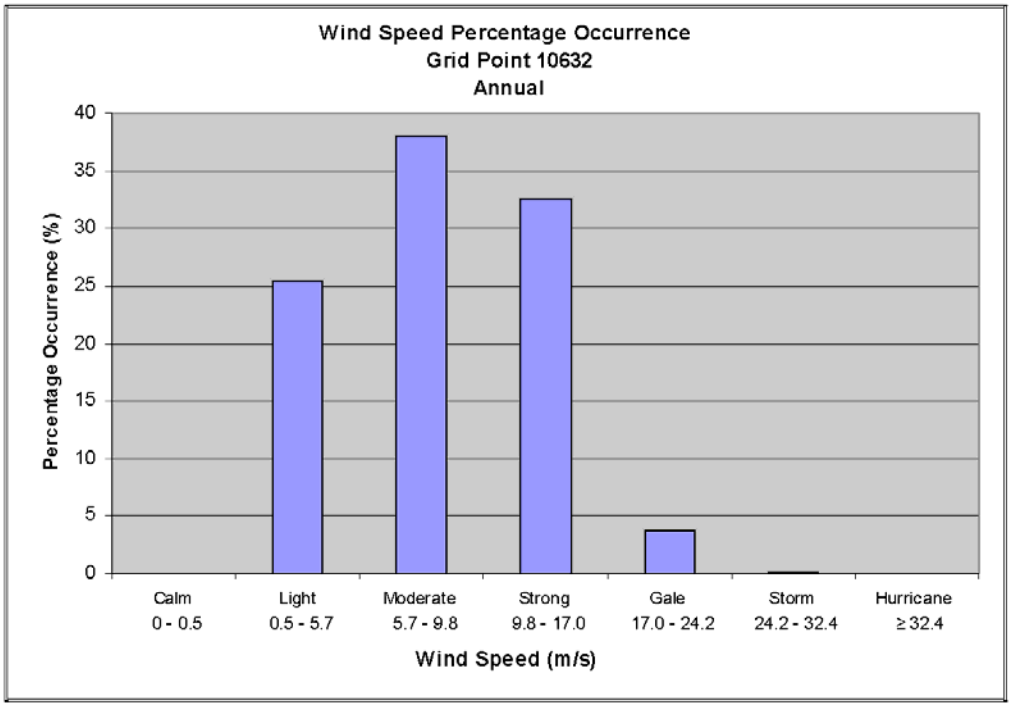


Figure 1.8 **Annual Percentage Frequency of Wind Speeds for MSC50 Grid Point 10632 located near 46.5°N, 48.5°W. 1954 - 2005**

The percentage exceedance of wind speeds at Grid Point 10632 is presented in Figure 1.3.

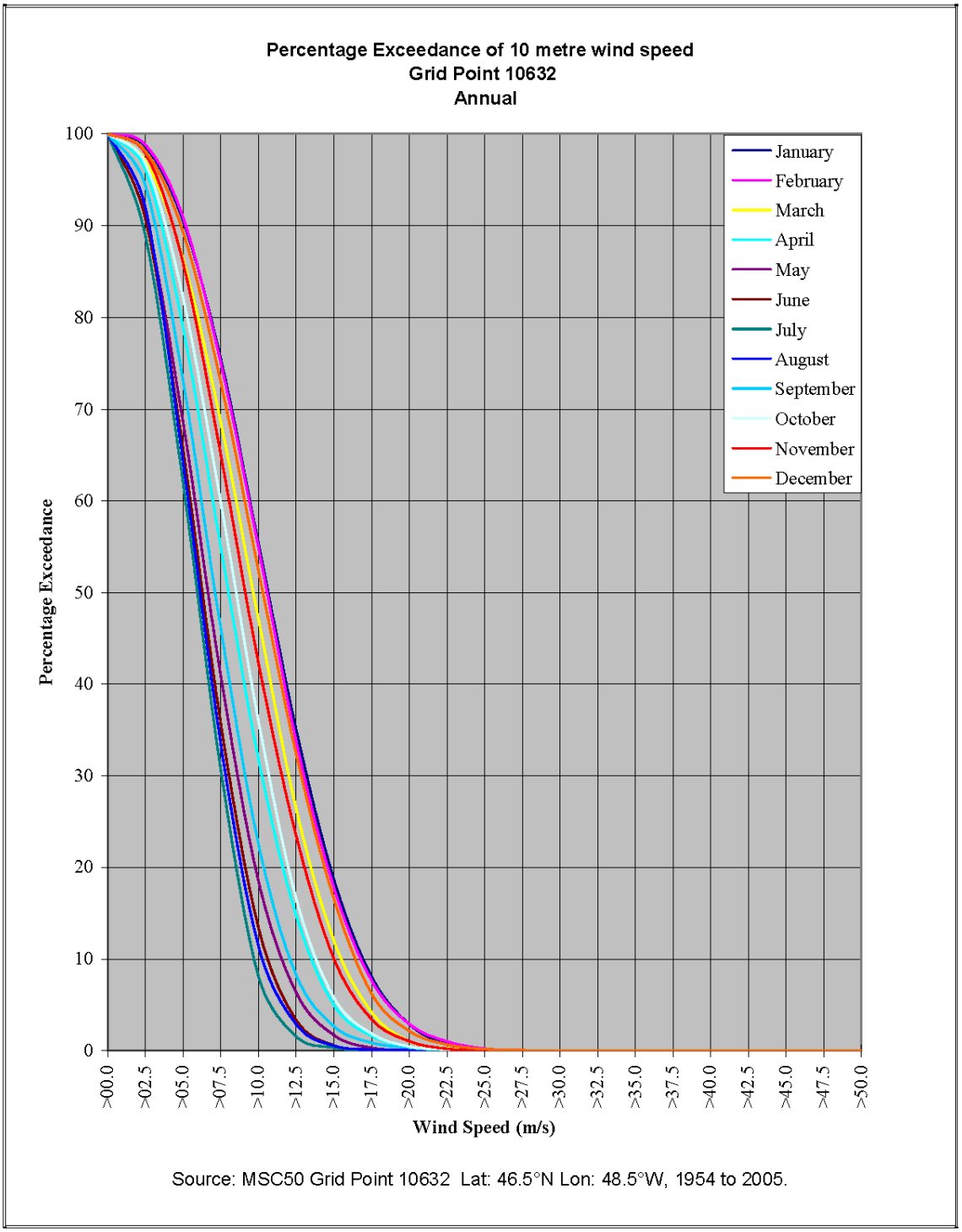


Figure 1.9 Percentage Exceedance of 10 m wind speed at Grid Point 10632

Intense mid-latitude low pressure systems occur frequently from early autumn to late spring. In addition, remnants of tropical systems have passed near Newfoundland between spring and late fall. Therefore, while mean wind speeds tend to peak during the winter months, maximum wind speeds may occur at anytime during the year. A table of monthly maximum wind speeds for each of the data sets is presented in Table 1.4.

Table 1.11 Maximum Wind Speeds (m/s) Statistics

Month	MSC50 Grid Point 10632	*Terra Nova FPSO*	*Glomar Grand Banks*	*GSF Grand Banks*	*Henry Goodrich*	Hibernia
January	29	32	31	38	44	43
February	32	31	27	28	52	49
March	29	30	24	29	33	38
April	26	23	27	21	31	33
May	23	25	22	26	33	32
June	24	23	21	23	28	31
July	21	19	20	17	26	30
August	30	28	26	26	29	36
September	25	22	29	22	28	38
October	29	32	33	31	32	41
November	29	28	26	24	32	38
December	31	33	27	29	38	39

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. On February 11, 2003 wind speeds at Grid Point 10632 peaked at 29.9 m/s. Wind speeds of 49.4 and 52.5 m/s from the southwest were recorded by the Hibernia Platform and *Henry Goodrich* anemometers, respectively, as this system passed. During this storm, a low pressure developing off Cape Hatteras on February 10th rapidly deepened to 949 mb as it tracked northeast across the Avalon Peninsula around 18Z on February 11th.

Another intense storm which developed south of the region passed east of the area on December 16, 1961. This storm resulted in wind speeds similar to that produced during the February 11th storm. During this event, Grid Point 10632 had wind speeds of 29.7 m/s.

While mid-latitude low pressure systems account for the majority of the peak wind events on the Grand Banks, storms of tropical origin can also on occasion pass over the region. On October 19, 1999, the remnants of Category 2 Hurricane Irene passed approximately 74 km (40 nm) west of the region as a tropical storm with maximum sustained 1-minute wind speeds of 41.1 m/s which converts to a 10-minute wind speed of 35.8 m/s. During this event, the 10-minute average wind speeds in the MSC50 data set peaked at 28.8 m/s from the south-southwest. The Hibernia Platform reported a measured wind speed 41.2 m/s (U.S. Geological Survey 1979).

1.2.3 Wave Climatology

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

A sea state may be composed of the wind wave alone, swell alone, or the wind wave in combination with one or more swell groups. A swell is a wave system not produced by the local wind blowing at the time of observation and may have been generated within the local weather system, or from within distant weather systems. The former situation typically arises when a front, trough, or ridge crosses the point of concern, resulting in a marked shift in wind direction. Swells generated in this manner are usually of low period. Swells generated by distant weather systems may propagate in the direction of the winds that originally formed to the vicinity of the observation area. These swells may travel for thousands of miles before dying away. As the swell advances, its crest becomes rounded and its surface smooth. As a result of the latter process, swell energy may propagate through a point from more than one direction at a particular time.

The wave climate 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.

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 have 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 were used, allowing the MSC50 hindcast to better represent the changing ice conditions (Swail et al. 2006).

The annual wave rose from the MSC50 data for Grid Point 10632 are presented in Figure 1.4. The wave rose show that the majority of wave energy comes from the west-southwest to south-southwest, and accounts for 36.2% of the wave energy at Grid Point 10632. Waves were “iced out” for 1.31% of the time over the 50-year record; this value may be somewhat high since monthly ice files were used when generating the 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 again, 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.

The percentage frequency of significant wave height is presented in Figure 1.5. This histogram shows that the majority of significant wave heights are between 1.0 and 4.0 m on the Grand Banks. 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. Monthly wave roses along with histograms of the frequency distributions of wave heights for Grid Point 10632 can be found in Appendix 2.

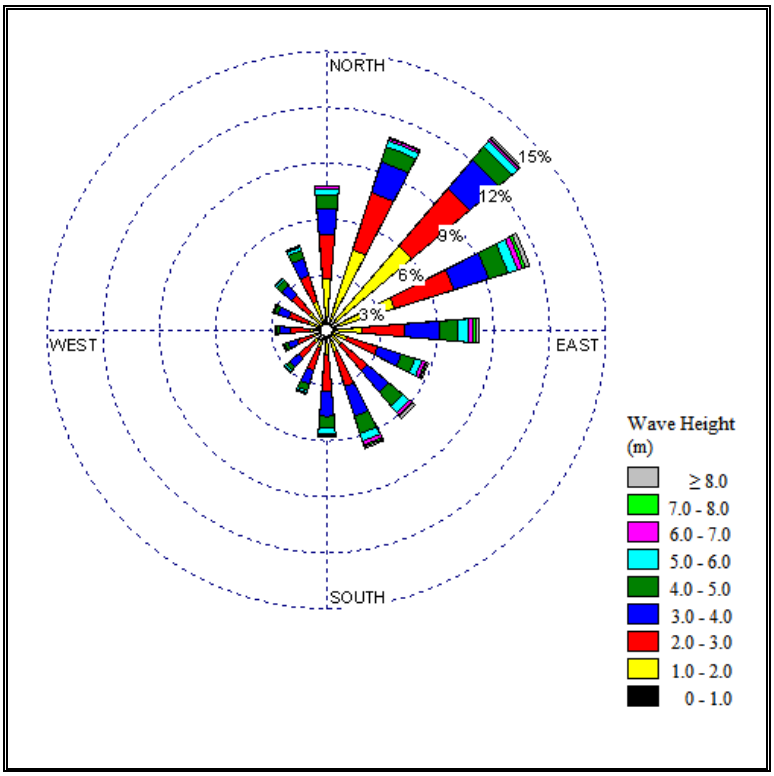


Figure 1.10 **Annual Wave Rose for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005**

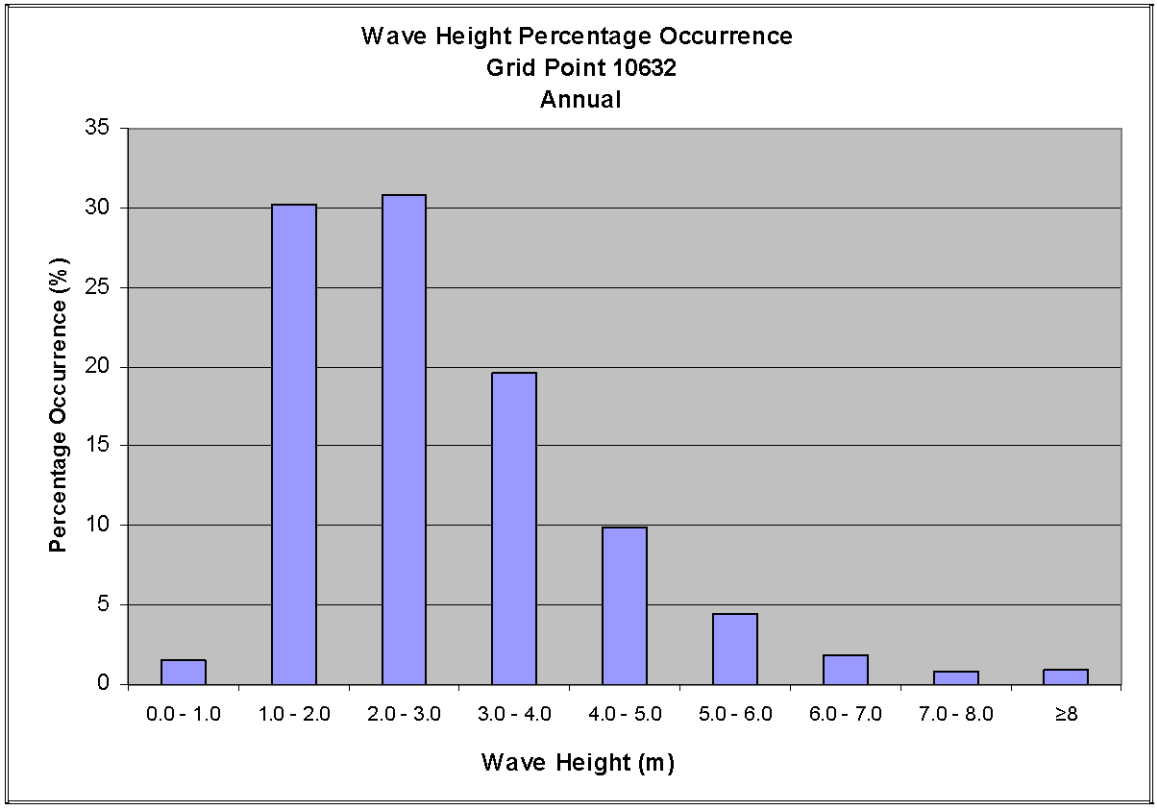


Figure 1.11 **Annual Percentage Frequency of Wave Height for MSC50 Grid Point 10632 located near 46.5°N; 48.5°W. 1954 – 2005**

Significant wave heights on the Grand Banks peak during the winter months with Grid Point 10632 having a mean monthly significant wave height of 3.9 m 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 1.5).

Table 1.12 **Combined Significant Wave Height Statistics (m) for the MSC50 Data Set**

Month	MSC50 Grid Point 10632	Terra Nova	Hibernia (1998-2004)	Hibernia (2005-2008)	*Ocean Ranger*	Buoy 44153
January	3.9	4.1	4.0	3.9	5.2	N/A
February	3.7	3.9	3.7	3.4	4.4	0.2
March	3.2	3.4	3.6	3.1	4.7	N/A
April	2.7	2.6	2.8	2.3	3.7	N/A
May	2.2	2.2	2.3	1.8	1.7	0.7
June	1.9	1.8	2.0	1.8	1.5	0.6
July	1.7	1.5	1.6	1.6	1.8	0.7
August	1.8	1.7	1.9	1.8	1.8	1.0
September	2.4	2.3	2.3	2.4	3.8	1.0
October	2.9	3.0	2.6	3.2	3.0	1.3
November	3.3	3.2	3.2	2.9	4.8	1.6
December	3.9	3.7	3.8	3.6	4.6	2.1

Combined significant wave heights of 10.5 m or more occurred in each month between September and April at Grid Point 10632, with the highest waves occurring during the month of February (Table 1.6). The highest combined significant wave heights of 13.6 m occurred during the February 11, 2003, storm discussed earlier. 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 1.13 Maximum Combined Significant Wave Height Statistics (m) for the MSC50 Data Set

Month	MSC50 Grid Point 10632	Terra Nova	Hibernia (1998 - 2004)	Hibernia (2005 - 2008)	*Ocean Ranger*	Buoy 44153
January	13.0	12.5	12.2	11.5	10.6	N/A
February	13.8	14.6	13.8	9.4	8.3	2.1
March	11.4	9.4	9.7	9.3	7.2	N/A
April	10.7	7.1	9.4	7.5	7.8	N/A
May	9.9	6.3	7.4	6.8	3.8	1.5
June	9.7	6.5	7.2	8.4	3.0	2.6
July	6.2	4.1	6.4	9.1	4.2	2.1
August	8.4	7.8	18.2	8.2	3.3	5.2
September	10.8	10.4	9.9	9.8	8.4	5.0
October	11.8	10.4	9.0	10.2	5.8	5.1
November	11.3	10.2	10.5	9.3	7.0	6.0
December	13.5	11.7	10.8	9.3	8.1	5.9

Figure 1.6 shows percentage exceedance curves of significant wave heights for Grid Point 10632. Percentage exceedance curves for the months of January through April show that the curves do not reach 100% because of the presence of ice on the Grand Banks during these months.

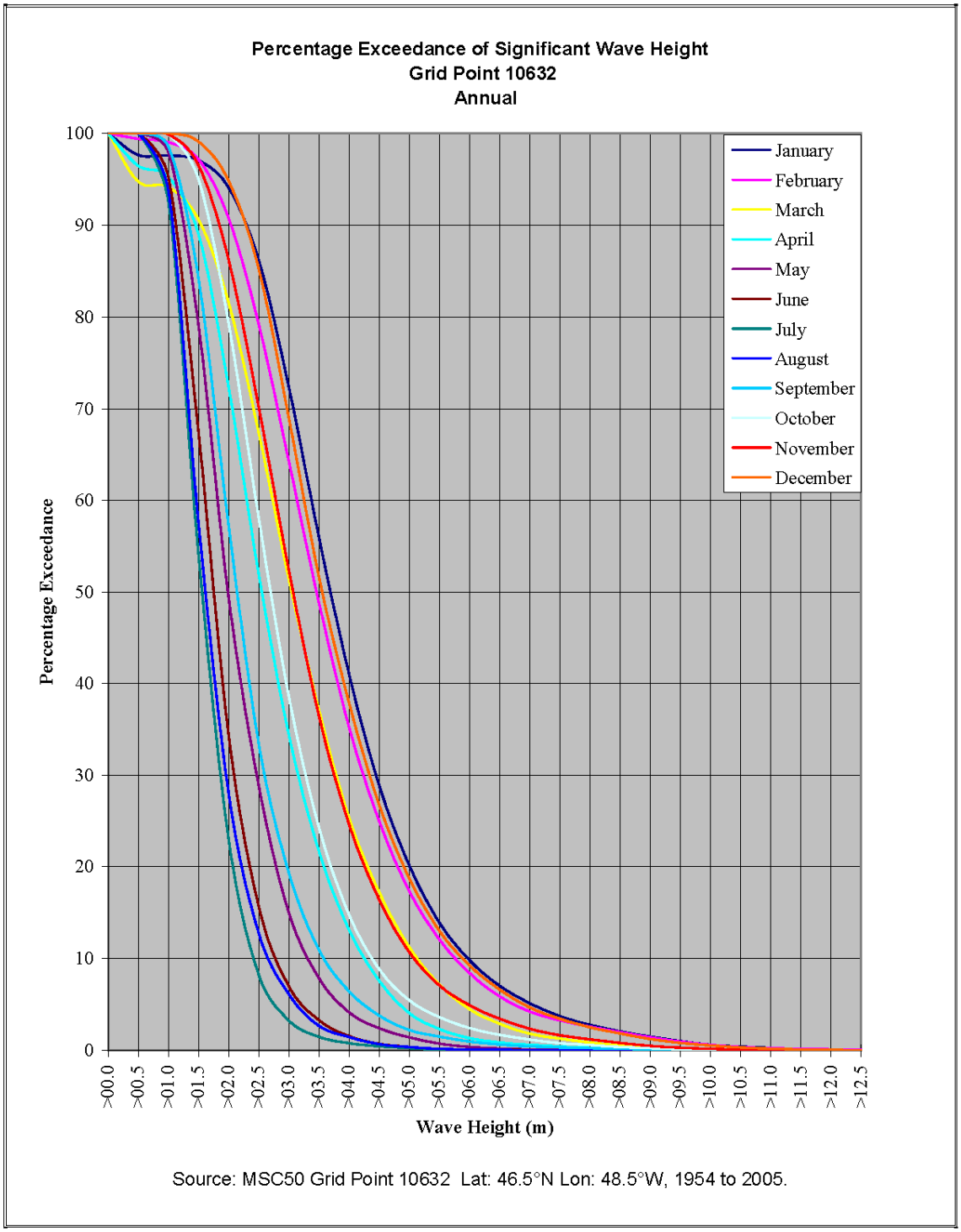


Figure 1.12 Percentage Exceedance of Significant Wave Height at Grid Point 11028

The spectral peak period of waves vary with season with the most common period varying from 7 seconds in July and August to 11 seconds in January and February. Annually, the most common peak spectral period is 9 seconds, occurring 18.70% of the. Periods above 12 seconds occur more frequently during the winter months; though they may occur at anytime during the year. The percentage occurrence of spectral peak period for each month at both grid points is shown in Table 1.7 and in Figure 1.7.

Table 1.14 Percentage Occurrence of Peak Spectral Period of the Total Spectrum at Grid Point 10632

	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	0.3	1.3	5.2	8.8	15.2	19.1	**22.1**	12.3	10.3	4.7	0.5	0.1
February	0.0	0.0	0.0	0.2	1.2	3.0	7.5	10.1	16.2	18.2	**19.5**	12.0	7.5	3.8	0.6	0.2
March	0.0	0.0	0.0	0.3	1.2	3.6	9.3	12.0	17.4	**19.2**	17.3	10.1	5.6	3.4	0.2	0.3
April	0.0	0.0	0.0	0.4	1.3	4.2	9.0	15.1	**24.2**	19.9	13.9	7.2	3.0	1.5	0.2	0.1
May	0.0	0.0	0.0	0.1	1.7	7.0	16.1	**25.7**	23.2	14.3	6.3	3.9	1.4	0.4	0.0	0.0
June	0.0	0.0	0.0	0.2	3.6	10.9	24.9	**27.3**	20.0	8.1	2.2	1.3	1.4	0.1	0.0	0.0
July	0.0	0.0	0.0	0.3	4.6	14.4	**30.4**	27.4	13.6	5.7	1.3	0.4	1.3	0.2	0.1	0.2
August	0.0	0.0	0.0	0.4	5.3	13.0	**29.9**	25.8	14.1	5.2	2.6	1.9	1.3	0.4	0.1	0.0
September	0.0	0.0	0.0	0.1	2.0	6.8	17.5	**21.5**	20.4	10.4	8.5	7.0	4.1	1.3	0.3	0.3
October	0.0	0.0	0.0	0.1	0.9	3.8	11.3	17.8	**22.6**	16.3	12.3	8.0	4.6	1.8	0.2	0.2
November	0.0	0.0	0.0	0.1	0.6	2.9	7.9	11.8	20.6	**20.8**	16.3	9.1	7.1	2.4	0.2	0.2
December	0.0	0.0	0.0	0.0	0.3	1.4	5.1	9.1	16.9	**21.9**	20.4	11.8	9.1	3.3	0.5	0.2
Winter	0.0	0.0	0.0	0.1	0.6	1.9	5.9	9.3	16.1	19.7	**20.6**	12.0	9.0	3.9	0.5	0.2
Spring	0.0	0.0	0.0	0.3	1.4	4.9	11.5	17.6	**21.6**	17.8	12.5	7.1	3.3	1.8	0.1	0.1
Summer	0.0	0.0	0.0	0.3	4.5	12.8	**28.4**	26.8	15.9	6.4	2.0	1.2	1.3	0.2	0.1	0.1
Autumn	0.0	0.0	0.0	0.1	1.2	4.5	12.3	17.0	**21.2**	15.8	12.3	8.0	5.3	1.8	0.3	0.2
Annual	0.0	0.0	0.0	0.2	1.9	6.0	14.5	17.7	**18.7**	14.9	11.9	7.1	4.7	1.9	0.2	0.1

Source: MSC50 Grid Point 10632 Lat: 46.5°N Lon: 48.5°W, 1954 to 2005.

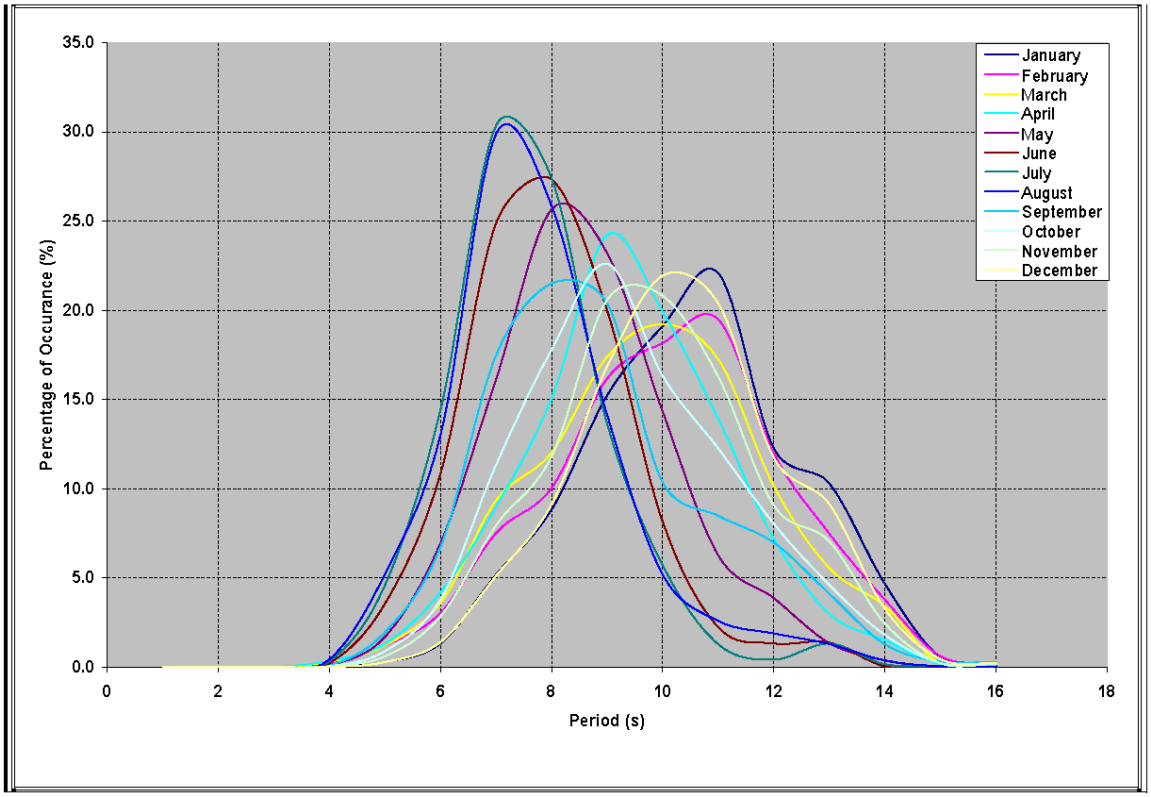


Figure 1.13 Percentage of Occurrence of Peak Wave Period at Grid Point 10632

A scatter diagram of the significant wave height versus spectral peak period is presented in Table 1.8. From this table it can be seen that the most common wave is 2 m with a peak spectral period of 9 seconds, and the second most common wave being 2 m and a peak spectral period of 8 seconds. Note that wave heights in these tables have been rounded to the nearest whole number. Therefore, the 1 m wave bin would include all waves from 0.51 to 1.49 m.

Table 1.15 Percent Frequency of Occurrence of Significant Combined Wave Height and Peak Spectral Period at Grid Point 10632

		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	0.15	0.03												0.19
	5	0.00	1.10	0.77	0.04	0.00										1.91
	6	0.00	1.64	3.96	0.39	0.02	0.00									6.01
	7		4.70	5.97	3.53	0.29	0.01	0.00								14.48
	8	0.00	4.60	6.42	4.44	2.02	0.14	0.00	0.00							17.63
	9	0.00	1.70	8.21	4.00	3.44	1.09	0.06	0.00							18.50
	10	0.01	0.61	4.52	4.31	2.43	2.18	0.61	0.05	0.00						14.72
	11	0.00	0.24	2.13	4.13	2.23	1.32	1.10	0.45	0.07	0.00					11.67
	12	0.00	0.22	1.35	2.03	1.35	0.62	0.48	0.43	0.32	0.14	0.01	0.00			6.95
	13	0.00	0.22	0.68	1.06	1.14	0.60	0.27	0.18	0.16	0.18	0.13	0.02	0.00		4.65
	14	0.00	0.03	0.14	0.43	0.58	0.35	0.13	0.07	0.03	0.03	0.05	0.05	0.01	0.00	1.90
	15		0.01	0.02	0.04	0.06	0.06	0.02	0.00	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	0.00	0.14
	17		0.01	0.01	0.00	0.00	0.00	0.00								0.03
	18		0.00				0.00									0.00
		0.99	15.24	34.23	24.45	13.59	6.38	2.68	1.19	0.58	0.36	0.19	0.07	0.02	0.01	100.00

1.2.4 Air and Sea Temperature

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

Air and sea surface temperatures for the area were extracted from the ICOADS data set as well as air temperature statistics for the Terra Nova Field. It should be noted that temperature data from the Terra Nova Field would be included in the ICOADS data set, however due to the inconsistencies in the ICOADS data set noted earlier, the Terra Nova data were analyzed separately.

A monthly plot of air temperature versus sea surface temperature is presented in Figure 1.8. Temperature statistics presented in Table 1.9 and Table 1.10 show that the atmosphere is coldest in February, and warmest in August, similarly sea surface temperature is warmest in August and coldest in February. The mean sea surface temperature is in the range of 0.1°C to 1.3°C cooler than the mean air temperature from March to August, with the greatest difference occurring in the month of June. From September to February, sea surface temperatures are in the range of 0.1°C to 0.9°C warmer than the mean air temperature. The colder sea surface temperatures from March

to August have a cooling effect on the atmosphere, while relatively warmer sea surface temperatures from September to February tends to warm the overlying atmosphere.

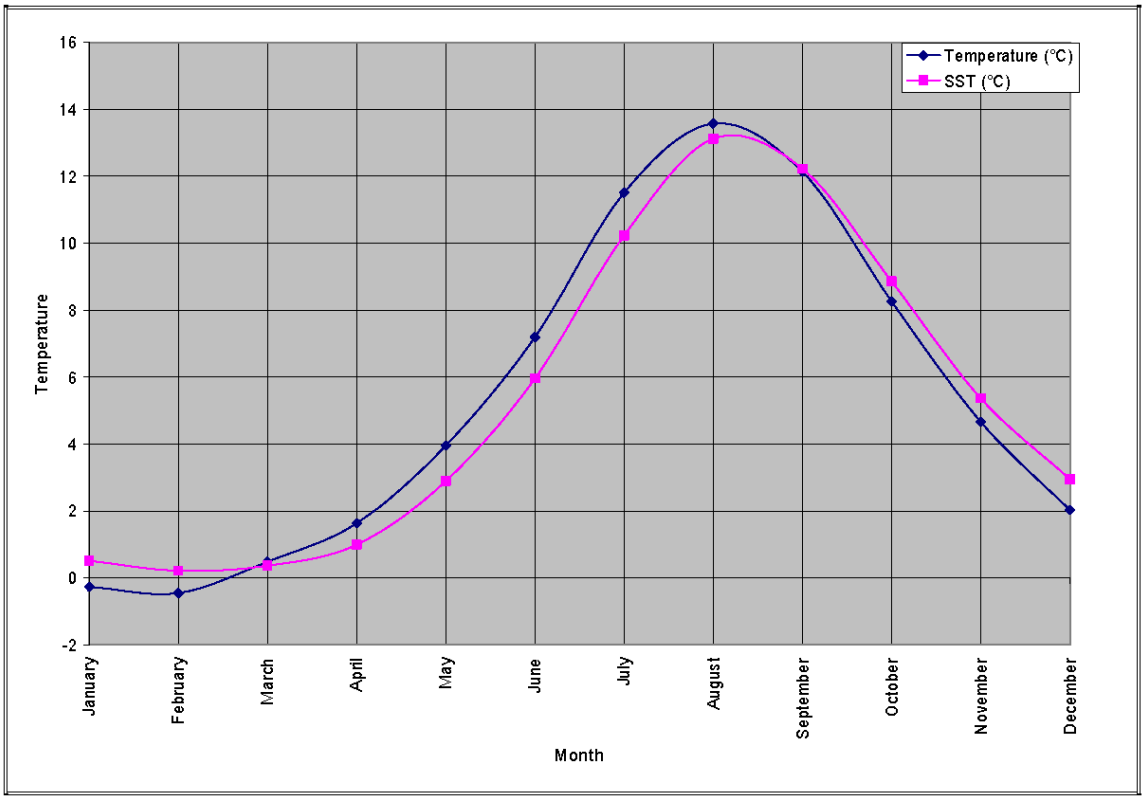


Figure 1.14 ICOADS Monthly Mean Air and Sea Surface Temperature

Table 1.16 ICOADS Air Temperature Statistics

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	-0.26	11.10	-9.70	3.07	0.86	-0.66
February	-0.45	11.10	-11.50	3.26	0.66	-1.04
March	0.49	10.40	-8.50	2.63	1.47	-00.28
April	1.64	11.00	-5.20	2.41	2.74	1.14
May	3.96	13.40	-2.00	2.44	4.86	3.61
June	7.20	16.50	-0.20	2.33	7.79	6.40
July	11.51	20.00	3.50	2.42	12.12	10.68
August	13.57	20.90	4.50	2.44	14.37	13.01
September	12.13	20.50	3.50	2.42	12.65	11.25
October	8.26	18.50	0.60	2.99	8.95	7.76
November	4.67	15.5	-4	2.81	5.61	4.44
December	2.03	12.8	-7.8	3.33	2.68	1.47

Table 1.17 ICOADS Sea Surface Temperature Statistics

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	0.52	10.00	-2.20	1.33	01.60	00.99
February	0.22	9.00	-2.80	1.33	01.08	00.40
March	0.37	8.50	-2.80	1.41	01.14	00.44
April	1.00	9.20	-2.80	1.54	01.73	01.00
May	2.90	11.20	-2.00	1.92	03.44	02.77
June	5.96	14.70	-0.60	1.99	06.21	05.35
July	10.23	18.40	3.00	2.10	10.21	09.44
August	13.12	20.00	5.00	2.10	13.30	12.54
September	12.22	19.00	4.00	2.20	12.11	11.20
October	8.86	17.20	1.50	2.43	08.88	08.14
November	5.37	15.00	0.00	2.26	05.78	05.05
December	2.95	12.00	-2.40	2.11	03.41	02.80

Monthly mean daily maximum and minimum temperature statistics are presented for both the ICOADS data set and the Terra Nova field (Table 1.11). Mean temperatures for each month are the mean of all temperatures recorded at the site during that month. The maximum and minimum temperatures are the highest and lowest temperatures respectively, recorded during the month over the entire data set. The mean daily maximum is the average of all maximum temperatures recorded during the specified month, while the mean daily minimum is the average of all minimum temperatures recorded during the specified month.

Table 1.18 Monthly Air Temperature (°C) Statistics for the Terra Nova Field located at 46.4°N 48.4°W

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	0.65	9.10	-11.00	2.76	2.56	-0.91
February	-0.09	14.60	-11.10	2.76	1.66	-1.51
March	0.44	10.40	-8.00	2.34	1.94	-0.83
April	1.85	8.20	-5.30	2.06	3.10	0.78
May	4.01	10.70	-3.70	1.88	5.16	2.96
June	7.17	13.90	-6.00	2.25	8.31	6.12
July	12.33	18.20	4.20	2.37	13.39	11.35
August	14.88	19.40	9.00	1.89	15.95	13.87
September	13.52	20.00	7.00	2.10	14.76	12.30
October	10.16	16.40	1.00	2.58	11.49	8.91
November	6.53	14.10	-0.80	2.87	7.97	5.23
December	2.91	12.80	-6.20	3.09	4.66	1.38

1.2.5 Wind Chill

Wind Chill is the cooling our body feels when the impact of wind and temperature are taken into consideration. In determining the statistics in Table 1.12, only observations with wind speeds above 1.34 m/s and temperatures less than or equal to 10°C were used as input. It is also important to note that the wind chill is not a temperature, but number

that quantifies the sensation of cold. Thus, in Canada, wind chill is reported without the degree designation and is rounded to the nearest degree.

Table 1.19 Wind Chill Statistics

Month	Mean	Maximum	Minimum	Standard Deviation	Mean Daily Maximum	Mean Daily Minimum
January	-7.93	6.00	-23.00	4.42	-6.05	-8.33
February	-8.18	8.00	-25.00	4.64	-6.34	-8.92
March	-6.40	8.00	-19.00	3.76	-4.73	-7.31
April	-4.83	9.00	-15.00	3.45	-2.86	-5.18
May	-1.54	8.00	-10.00	3.31	-0.09	-1.78
June	2.19	10.00	-6.00	2.31	3.12	1.71
July	5.11	9.00	-1.00	1.89	5.85	4.94
August	6.01	10.00	1.00	1.38	6.34	5.80
September	5.07	9.00	0.00	1.85	5.69	4.92
October	2.38	10.00	-8.00	3.14	3.47	2.25
November	-1.17	8.00	-13.00	3.77	0.35	-1.33
December	-4.89	7.00	-21.00	4.68	-3.72	-5.52

Wind chill statistics were calculated using wind and air temperature observations from the ICOADS data set where wind speed and temperature statistics were measured at varying altitudes. Since the algorithm used for determining the Wind Chill Temperature Index was developed using wind speeds at 10 m and temperature at 1.5 m, statistics provided may not be an accurate depiction of wind chill, however are provided for reference in the absence of a more accurate data set.

1.2.6 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

Frequency of Precipitation Types

The frequency of precipitation type for each region was calculated using data from the ICOADS data set, with each occurrence counting as one event. Precipitation statistics for these regions may be low due a fair weather bias. That is, ships tend to either avoid regions of inclement weather, or simply do not report during these events.

The frequency of precipitation type (Table 1.13) shows that annually, precipitation occurs 24.5% of the time within the ICOADS region. Winter has the highest frequency of precipitation with 39.9% of the observations reporting precipitation. Snow accounts for the majority of precipitation during the winter months, accounting for 63.2% of the occurrences of winter precipitation. Summer has the lowest frequency of precipitation with a total frequency of occurrence of 14.5%. Snow has been reported in each month from September to May.

Table 1.20 Percentage Frequency (%) Distribution of Precipitation

Month	Rain / Drizzle	Freezing Rain / Drizzle	Rain / Snow Mixed	Snow	Hail	Total
January	13.9	0.5	1.0	29.5	0.4	45.4
February	10.4	0.5	0.6	27.3	0.0	38.7
March	10.9	0.8	0.6	15.0	0.0	27.3
April	13.2	0.2	0.3	7.4	0.0	21.1
May	14.6	0.0	0.2	2.1	0.1	16.9
June	13.9	0.0	0.0	0.0	0.0	13.9
July	12.2	0.0	0.0	0.0	0.0	12.2
August	17.5	0.0	0.0	0.0	0.0	17.5
September	21.0	0.0	0.0	0.1	0.0	21.1
October	23.3	0.0	0.4	1.8	0.8	26.3
November	19.0	0.0	0.8	7.6	0.0	27.3
December	15.1	0.1	1.7	17.8	0.2	34.9
Winter	13.1	0.4	1.1	25.2	0.2	39.9
Spring	13.0	0.3	0.4	7.8	0.0	21.5
Summer	14.4	0.0	0.0	0.0	0.0	14.5
Autumn	21.0	0.0	0.3	2.9	0.2	24.5
Total	14.8	0.2	0.4	8.9	0.1	24.5

1.2.7 Icing

Freezing Precipitation

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

The percentage of occurrences of freezing precipitation (Table 1.13) was calculated using the ICOADS data set. Since negative air temperatures are required for freezing precipitation, statistics show the frequency of freezing precipitation occurs only during the months winter and spring months with winter having a slightly higher percentage occurrence than spring. On a monthly basis, the month of March has the highest frequency of freezing precipitation, however it occurs less than 1% of the time.

Sea Spray Vessel Icing

Spray icing can accumulate on vessels and shore structures when air temperatures are below the freezing temperature of water and there is potential for spray generation. In addition to air temperature, icing severity depends on water temperature, wave

conditions, and wind speed influence the amount of spray and the cooling rate of droplets. A review of the spray icing hazard is provided by Minsk (1977). The frequency of potential icing conditions and its severity was estimated from the algorithm proposed by Overland et al. (1986) and subsequently updated by Overland (1990). The algorithm generates an icing predictor based on air temperature, wind speed, and sea surface temperature which was empirically related to observed icing rates of fishing vessels in the Gulf of Alaska. This method will provide conservative estimates of icing severity in the study region as winter sea surface temperatures are colder and wave conditions are lower in the Offshore Study Area compared to the Gulf of Alaska where the algorithm was calibrated (Makkonen et al. 1991). Potential icing rates were computed using wind speed and air sea surface temperature observations from the ICOADS data set. A total of 24,515 observations from vessels within the Offshore Study Area from January 1954 to December 2006 were used to calculate the percentage frequency of icing occurrence and severity for the Offshore Project Area. Monthly, seasonal, and annual summaries are presented in Table 1.14 and Figure 1.9.

Table 1.21 Percentage Frequency of Potential Spray Icing Conditions

Month	None (0 cm/hr)	Light (<0.7 cm/hr)	Moderate (0.7- 2.0 cm/hr)	Heavy (2.0-4.0 cm/hr)	Extreme (>4.0 cm/hr)
January	72.9	18.1	6.4	2.1	0.5
February	69.0	20.7	7.0	2.0	1.3
March	84.8	12.1	2.8	0.4	0.0
April	94.5	4.7	0.8	0.0	0.0
May	100.0	0.0	0.0	0.0	0.0
June	100.0	0.0	0.0	0.0	0.0
July	100.0	0.0	0.0	0.0	0.0
August	100.0	0.0	0.0	0.0	0.0
September	100.0	0.0	0.0	0.0	0.0
October	100.0	0.0	0.0	0.0	0.0
November	99.9	0.1	0.0	0.0	0.0
December	90.4	7.1	2.0	0.4	0.0
Winter	77.5	15.3	5.2	1.5	0.6
Spring	93.1	5.6	1.2	0.1	0.0
Summer	100.0	0.0	0.0	0.0	0.0
Autumn	100.0	0.0	0.0	0.0	0.0
Annual	92.6	5.2	1.6	0.4	0.2

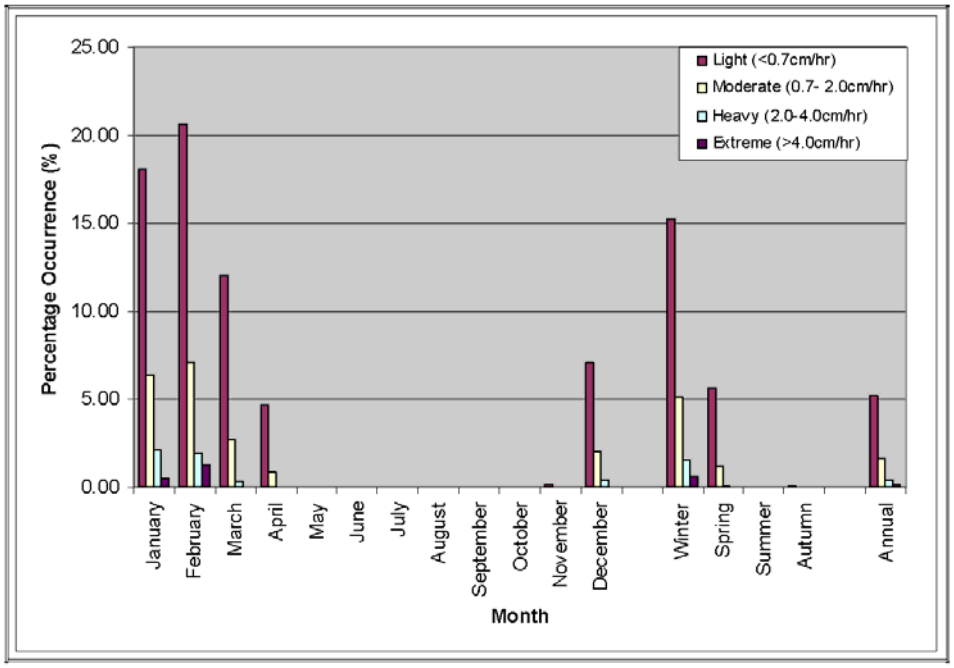


Figure 1.15 Percentage Frequency of Potential Spray Icing Conditions

Potential sea spray icing conditions start in the Offshore Project Area during the month of November, with a frequency of icing potential of just 0.1%. As temperatures cool throughout the winter, the frequency of icing potential increases to a maximum of 31.0% of the time in February. Extreme sea spray icing conditions were calculated to occur 1.3% of the time during February. Icing potential decreases rapidly after February in response to warming air and sea surface temperatures, and by May the frequency of icing conditions is 0.0%.

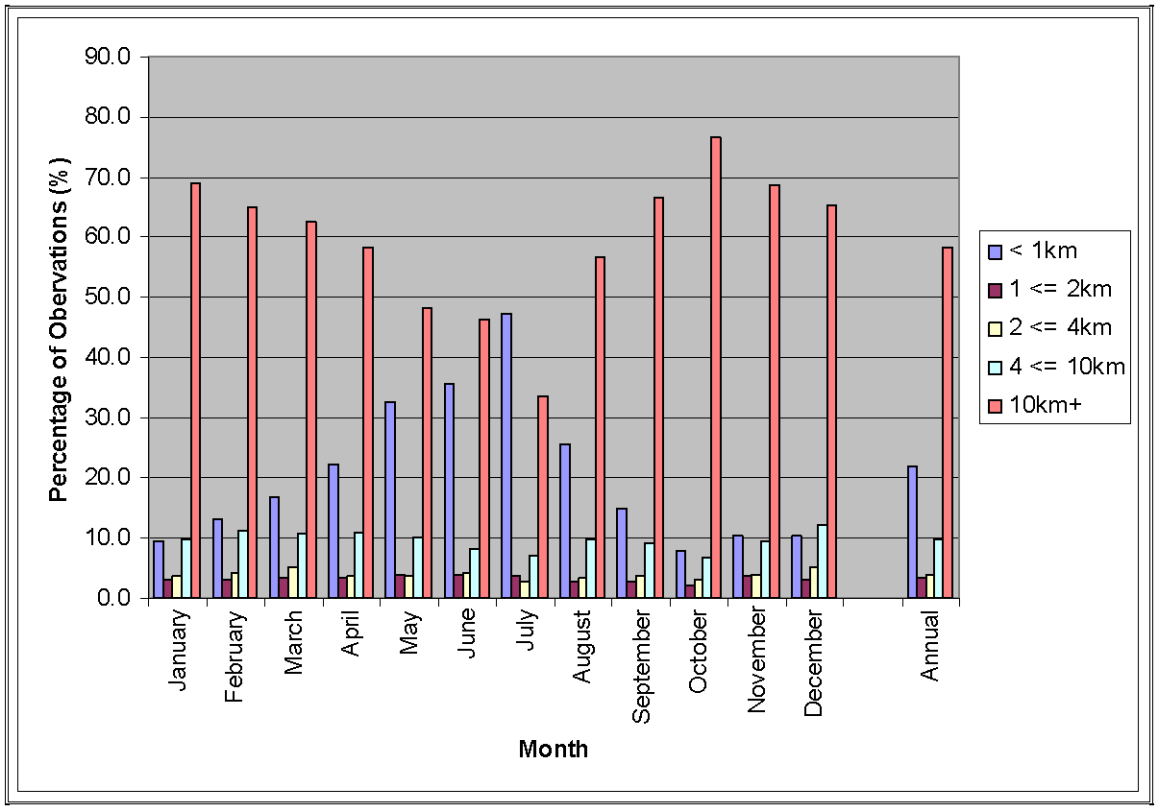
1.2.8 Visibility

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

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

A plot of the frequency distribution of visibility from the ICOADS data set is presented in Figure 1.10. Figure 1.10 shows that obstructions to vision can occur in any month. Annually, 41.6% of the recorded observations had reduced visibilities. 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 the cooler waters of the Labrador Current. By March, the sea surface temperature on the Grand Banks is cooler than the surrounding air. As warm moist air 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. July month has the highest percentage (66.4%) 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. On average, fog reduces visibility below 1 kilometer 47.3% of the time in July. 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 mainly the cause of the reduced visibilities in autumn and snow is the cause of reduced visibilities in the winter. October has the lowest occurrence of reduced visibility (23.3%) since the air temperature has, on average, decreased below the sea surface temperature and it is not yet cold enough for snow.



Source: ICOADS data set (1950-2006).

Figure 1.16 Monthly and Annual Percentage Occurrence of Visibility

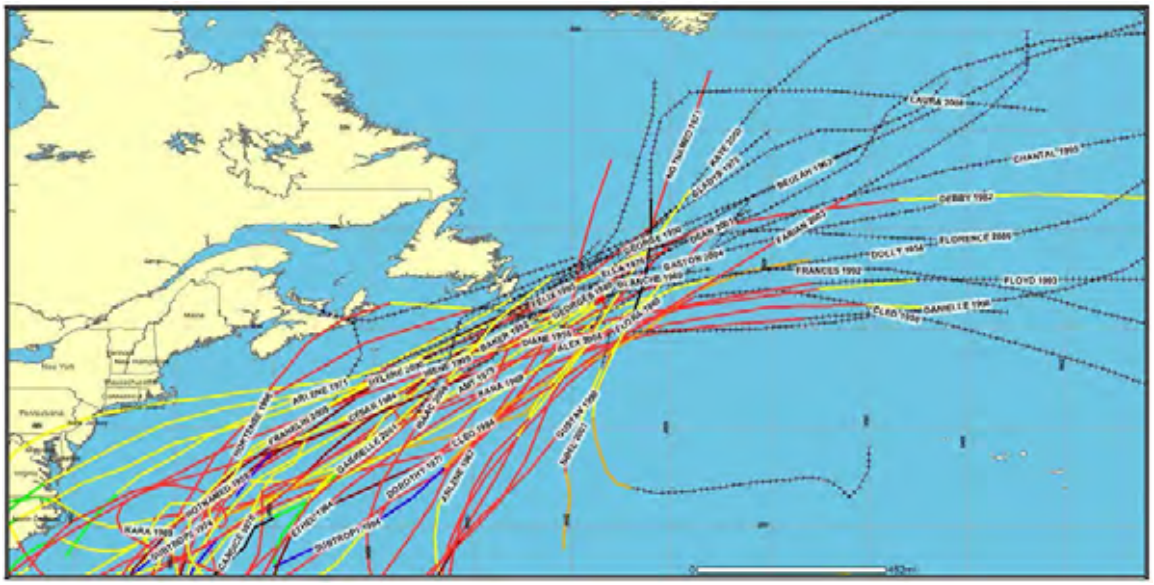
1.2.9 Tropical Systems

A position within the Offshore Study Area, located at 46.5°N 48.5°W, was used for this study. During the 57-year period from 1950 - 2007, 45 tropical systems have passed within 278 km of this location. The names of each cyclone are given in Table 1.15 and the tracks over Offshore Project Area are shown in Figure 1.11. It must be noted that the values in the table are the maximum 1-minute mean wind speeds occurring within the tropical system at the 10-m reference level as it passed. Wind speed in Table 1.15 refers to the maximum sustained wind recorded during the life of the tropical cyclone and not the wind speed at the time it passed.

Table 1.22 Tropical Systems Passing within 278 km (150 nm) of 44.5°N 53.5°W, 1950 to 2007

Year	Month	Day	Hour	Name	Lat	Long	Wind (m/s)	Pressure (mb)	Category
1950	10	5	1200Z	George	47.0	-51.9	60	N/A	Extratropical
1952	9	8	1200Z	Baker	47.8	-49.3	60	N/A	Extratropical
1954	9	3	1200Z	Dolly	46.8	-47.4	50	N/A	Extratropical
1955	8	21	1200Z	Diane	45.0	-49.3	35	N/A	Extratropical
1958	8	20	0600Z	Cleo	46.6	-43.8	65	N/A	Extratropical
1959	6	21	1200Z	NotNamed	47.3	-53.7	45	N/A	Extratropical
1963	8	11	0000Z	Arlene	42.5	-52.0	65	N/A	Extratropical
1963	8	28	0000Z	Beulah	45.8	-48.3	70	N/A	Category 1
1963	10	12	1800Z	Flora	45.2	-47.5	75	N/A	Extratropical
1964	9	4	1800Z	Cleo	46.9	-49.8	70	N/A	Category 1
1964	9	15	0000Z	Ethel	44.0	-49.0	75	N/A	Category 1
1967	9	4	0600Z	Arlene	45.8	-48.6	60	N/A	Tropical Storm
1969	8	13	0000Z	Blanche	47.1	-49.0	50	N/A	Extratropical
1969	10	18	0600Z	Kara	45.2	-45.3	80	980	Category 1
1971	7	7	1800Z	Arlene	46.5	-53.0	45	N/A	Extratropical
1971	8	6	1200Z	NotNamed	46.0	-49.0	75	974	Category 1
1974	7	20	0600Z	Sub-Tropical 2	46.7	-48.0	40	N/A	Extratropical
1975	7	4	0600Z	Amy	44.5	-51.6	50	986	Tropical Storm
1975	10	3	1200Z	Gladys	46.6	-50.6	85	960	Category 2
1976	8	24	0000Z	Candice	45.9	-48.7	80	N/A	Category 1
1977	9	30	0000Z	Dorothy	47.0	-51.0	50	995	Extratropical
1978	9	5	0600Z	Ella	47.2	-50.2	80	975	Category 1
1980	9	8	1200Z	Georges	45.6	-51.1	68	993	Category 1
1982	9	19	0600Z	Debby	47.0	-50.5	75	979	Category 1
1984	8	20	1200Z	Sub-Tropical 1	43.7	-48.3	50	1001	Subtropical Storm
1984	9	2	1200Z	Cesar	46.0	-50.4	50	994	Tropical Storm
1990	9	3	0000Z	Gustav	46.0	-46.5	55	993	Tropical Storm
1992	10	26	1800Z	Frances	46.0	-46.9	55	988	Tropical Storm
1993	9	10	0600Z	Floyd	45.4	-48.3	65	990	Category 1
1995	7	20	1800Z	Chantal	45.4	-48.8	50	1000	Extratropical
1995	8	22	1200Z	Felix	46.8	-50.8	50	985	Tropical Storm
1996	9	16	0000Z	Hortense	46.0	-54.0	40	998	Extratropical
1998	9	4	0000Z	Danielle	44.8	-48.5	65	975	Extratropical
1999	10	19	1200Z	Irene	48.0	-48.0	80	968	Extratropical
2000	9	25	1200Z	Helene	44.0	-55.5	55	988	Tropical Storm

Year	Month	Day	Hour	Name	Lat	Long	Wind (m/s)	Pressure (mb)	Category
2001	8	29	0000Z	Dean	47.0	-48.5	45	999	Extratropical
2001	9	20	0000Z	Gabrielle	48.5	-48.5	60	988	Extratropical
2001	11	6	1200Z	Noel	43.0	-48.5	50	996	Extratropical
2003	9	8	0000Z	Fabian	44.3	-47.9	70	975	Category 1
2003	10	7	1800Z	Kate	47.5	-47.2	60	980	Tropical Storm
2004	8	6	0000Z	Alex	44.5	-49.3	75	978	Category 1
2004	9	2	0000Z	Gaston	47.0	-50.0	45	997	Extratropical
2005	7	30	1800Z	Franklin	46.4	-48.8	40	1006	Extratropical
2006	9	14	0600Z	Florence	48.6	-48.3	60	967	Extratropical
2006	10	3	0600Z	Isaac	48.6	-49.0	45	998	Extratropical
2008	10	1	1200Z	Laura	45.7	-46.9	40	995	Tropical Low



Source: NOAA Coastal Services Centre Archive.

Figure 1.17 Storm Tracks of Tropical Systems Passing within 278 km of 46.5°N 48.5°W, 1950 to 2007

On occasion, these systems still maintain their tropical characteristics when they reach Newfoundland. On October 2, 1975, Hurricane Gladys, a Category 4 Hurricane as it passed east of Cape Hatteras tracked northeast towards the Grand Banks. Gladys, still a Category 2 Hurricane with 43.7 m/s winds and a central pressure of 960 mb on October 03 moved northeast across the Grand Banks and maintained Hurricane strength until it moved north of 50° latitude when it weakened to a post-tropical storm.

There has been a significant increase in the number of Hurricanes that have developed within the Atlantic Basin within the last 15 years. Figure 1.12 shows the five-year average (note: 2005-2008 is only a four-year average) of tropical storms which have developed within the Atlantic Basin since 1960. This increase in activity has been attributed to naturally occurring cycles in tropical climate patterns near the equator called the tropical multi-decadal signal and typically lasts 20 to 30 years (Bell 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, and consequently, a slight increase in the number of tropical storms entering the Offshore Study Area. It should be noted that the unusually high number of tropical storms in 2005 may be skewing the results for the 2005 – 2008 season. The average number of storms for the three-year period of 2006 – 2008 is only 14.7 opposed to 18.5 storms for the four-year period of 2005 – 2008.

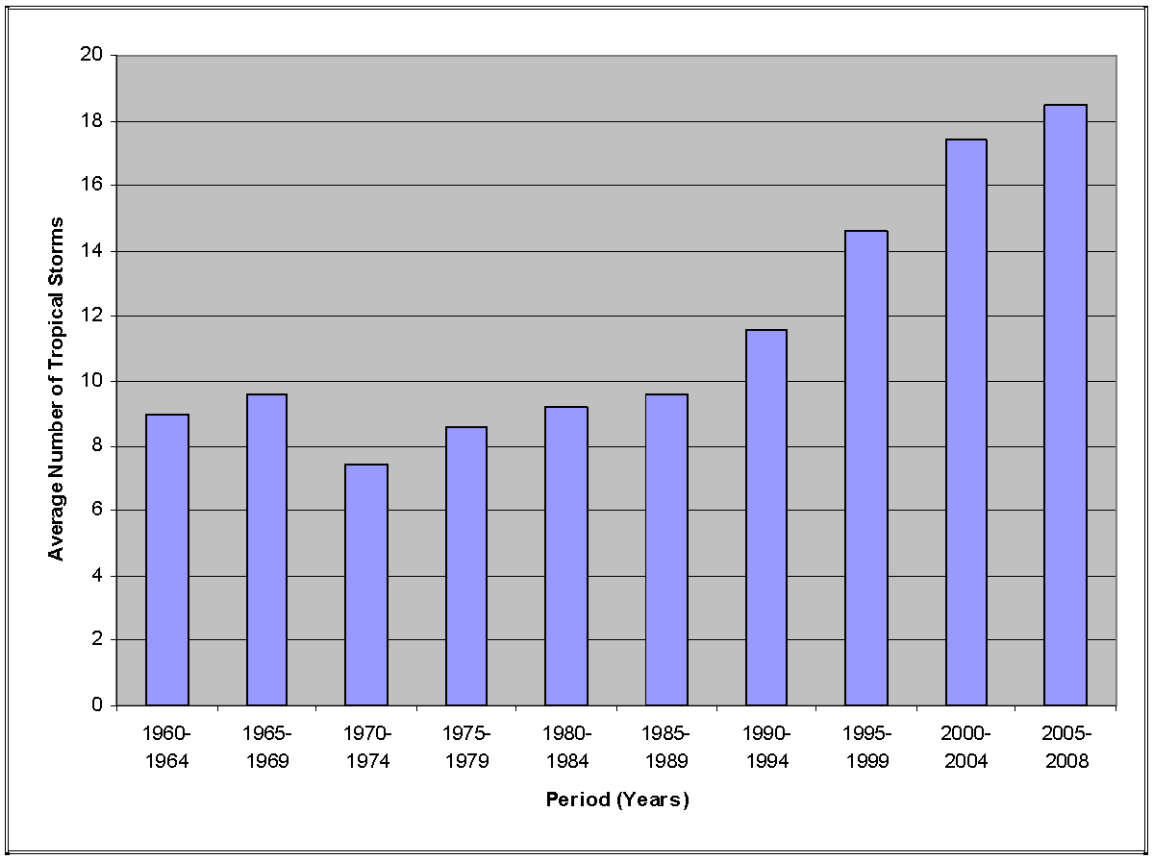


Figure 1.18 Five-Year Average of the number of Tropical Storms which formed in the Atlantic Basin since 1960

2.0 Climate Variability of the Hebron Offshore Project Area

Climate is naturally variable and can change over a range of time scales from the very short term, to seasonally, and to longer time periods in response to small and large-scale changes of atmospheric circulation patterns. Short-term meteorological variations are largely a consequence of the passage of synoptic scale weather systems: low pressure systems, high pressure systems, troughs and ridges. The energetics of these features varies seasonally in accordance with the changes in the strength of the mean tropical - polar temperature gradient. Long-term changes occur in response to small and large-scale changes of atmospheric circulation patterns and in the past in the Northern Hemisphere were the mainly result of changes in the North Atlantic Oscillation (NAO). While the NAO still has an effect on climate patterns, there is a general consensus

amongst the scientific community that Greenhouse Gas emissions have played a significant role in the climate during the last 50 years. However, the high degree of climate variation naturally experienced makes it difficult to identify, with any degree of certainty, trends that are a direct result of climate change. (Environment Canada 1997)

The dominate features of the mean sea level pressure pattern in the North Atlantic Ocean are the semi-permanent area of relatively low pressure in the vicinity of Iceland and the sub-tropical high pressure region near the Azores. The relative strengths of these two systems control the strength and direction of westerly winds and storm tracks in the North Atlantic and therefore play a significant role in the climate of the North Atlantic. The fluctuating pressure difference between these two features is known as the NAO.

A measure of the NAO is the NAO Index, which is the normalized difference in pressure between the Icelandic low and the Azores high. A large difference in pressure results in a positive NAO Index and can be the result of a stronger than normal subtropical high, a deeper than normal sub-polar low, or a combination of both. A time-series of the Winter (DJF) NAO Index is presented in Figure 2.1 and shows that during the period of 1950 – 2009, there is a general trend towards increasing NAO Index, indicating that in recent years either the Icelandic low is deeper or the Azores high is stronger than on average. This trend is also present in the Summer (JJA) NAO Index, albeit significantly weaker.

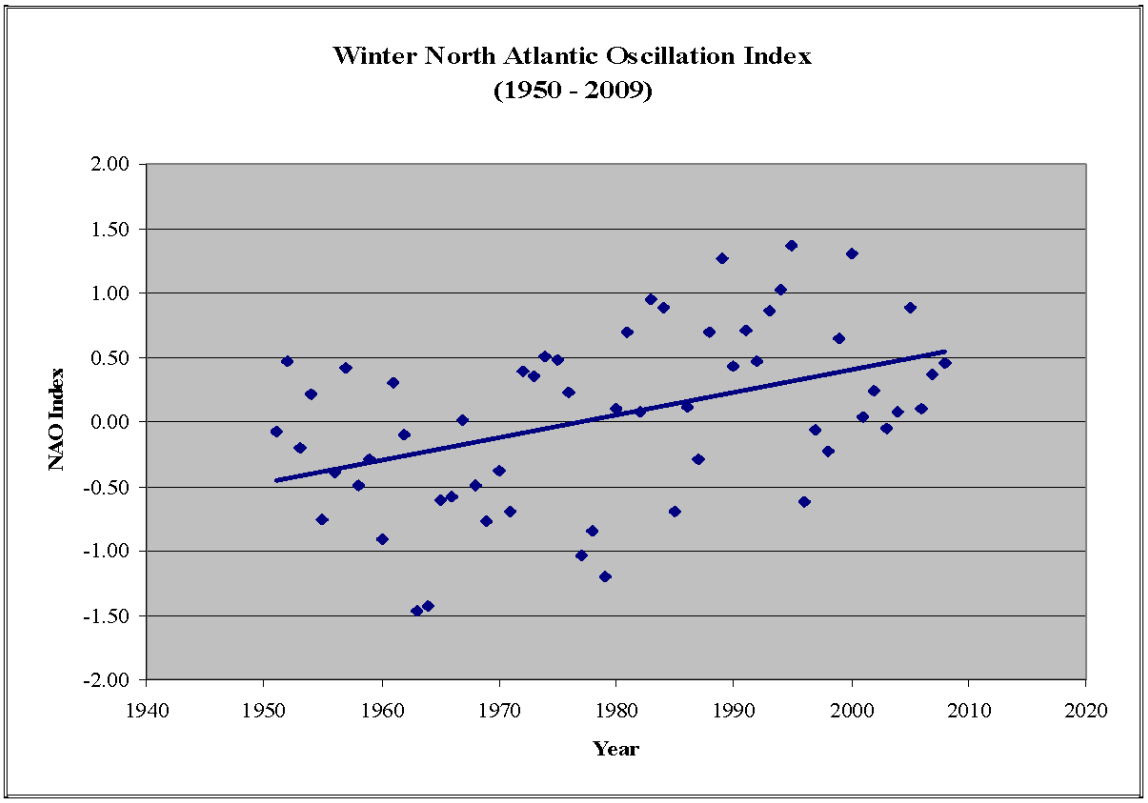


Figure 2.1 Winter North Atlantic Oscillation Index (1950 - 2009)

In general, over the Northwest Atlantic during the winter season, a positive NAO Index brings with it an increase in frequency and strength of westerly winds in the upper atmosphere, which tends to steer storm systems in a more west to east direction. As a

result, a positive NAO Index results in an increase in storm systems coming off of the continent resulting in colder temperatures, increased precipitation, and relatively stronger winds. Due to the weaker trend in NAO Index and other atmospheric patterns however, conclusions could not be drawn about correlations between summer NAO indices and temperature, precipitation and winds during the summer months.

During the summer months, the NAO Index has a less direct effect on the climate of Eastern Canada, however studies have shown that the NAO has an effect on the track of hurricanes in the North Atlantic. During seasons with a negative NAO Index, hurricanes tend to favour a track that parallels lines of latitude often ending up in the Gulf of Mexico and the Caribbean (Elsner 2003), while during seasons with a positive NAO Index, hurricanes tend to curve northward (Elsner and Bosak 2004) along the United States Eastern Seaboard. However, an analysis of the number of tropical storms entering the Canadian Hurricane Centre Response Zone shows no correlation between Tropical cyclone frequency and NAO Index.

3.0 Extreme Value Analysis

3.1 Hebron Nearshore Project Area

An analysis of extreme wind and waves was performed using Grid Point 12874 of 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 hourly data for the Nearshore Study Area. The wind and wave data measured by Oceans Ltd.'s weather station installed from January 1995 to May 1997 were not deemed to be of sufficient length to perform an extreme analysis. The extreme values for wind and waves were calculated using the peak-over-threshold method, and after considering four different distributions, the Gumbel distribution was chosen to be the most representative as it provided the best fit to the data.

Since extreme values can vary depending on how well the data fit the distribution, a sensitivity analysis was carried out to determine the number storms to use. The number of storms determined to provide the best fit annually and monthly for each grid point is presented in Table 2.1.

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

		Annually	Monthly
Grid Point 12874	Wind	234	54
	Wave	430	96

The extreme temperature analysis was carried out using 28 months of temperature observations from the Oceans Ltd. weather station. Out of a possible 853 days within this data set, there were 133 missing days. Of the 720 good days, The 30 lowest daily minimum temperature events and the 30 highest daily maximum temperature events were then chosen. To ensure that all the chosen events were independent of each other, no maximum or minimum temperature events could occur within 5 days of another. This restriction ensures that all the chosen events were independent of each other.

3.1.1 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 calculated annual and monthly values for 1-hour, 10-minutes and 1-minute are presented in Table 2.2 to Table 2.4. The analysis used hourly mean wind values for the reference height of 10 m above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ration of 1.06 and 1.22, respectively (U.S. Geological Survey 1979). The annual 100-year extreme 1-hour wind speed was determined to be 28.3 m/s for Grid Point 12874. Monthly, the highest 100-year extreme winds of 27.7 m/s occur during February.

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

	Grid Point #12874				
Month	1	10	25	50	100
January	19.1	23.7	24.9	25.8	26.7
February	17.6	23.7	25.3	26.5	27.7
March	17.0	21.5	22.8	23.7	24.6
April	15.5	19.0	19.9	20.6	21.3
May	12.9	17.6	18.9	19.9	20.8
June	11.7	16.0	17.1	18.0	18.9
July	9.8	15.5	17.0	18.2	19.3
August	11.3	16.2	17.5	18.5	19.5
September	13.2	20.7	22.8	24.3	25.8
October	15.3	21.4	23.0	24.2	25.5
November	17.3	21.4	22.5	23.4	24.2
December	19.0	23.0	24.1	24.9	25.7
Annual	22.1	25.2	26.4	27.4	28.3

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

	Grid Point #12874				
Month	1	10	25	50	100
January	20.3	25.1	26.4	27.3	28.3
February	18.7	25.1	26.8	28.1	29.4
March	18.0	22.8	24.1	25.1	26.1
April	16.4	20.1	21.1	21.8	22.6
May	13.7	18.7	20.1	21.1	22.1
June	12.3	16.9	18.2	19.1	20.0
July	10.4	16.4	18.1	19.3	20.5
August	11.9	17.2	18.6	19.6	20.7
September	13.9	22.0	24.1	25.8	27.4
October	16.3	22.7	24.4	25.7	27.0
November	18.4	22.7	23.9	24.8	25.6
December	20.1	24.4	25.5	26.4	27.3
Annual	23.4	26.7	28.0	29.0	29.9

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

	Grid Point #12874				
Month	1	10	25	50	100
January	23.4	28.9	30.4	31.5	32.6
February	21.5	28.9	30.8	32.3	33.8
March	20.7	26.3	27.8	28.9	30.0
April	18.9	23.1	24.3	25.1	26.0
May	15.8	21.5	23.1	24.2	25.4
June	14.2	19.5	20.9	22.0	23.0
July	12.0	18.9	20.8	22.2	23.6
August	13.7	19.7	21.4	22.6	23.8
September	16.0	25.3	27.8	29.6	31.5
October	18.7	26.1	28.1	29.6	31.0
November	21.2	26.1	27.5	28.5	29.5
December	23.1	28.0	29.4	30.4	31.4
Annual	26.9	30.8	32.3	33.4	34.5

3.1.2 Extreme Value Estimates for Waves from a Gumbel Distribution

The annual and monthly extreme value estimates for significant wave height for return periods of 1-year, 10-years, 25-years, 50-years and 100-years are given in Table 2.5. The annual 100-year extreme significant wave height was 1.9 m at Grid Point 12874. On a monthly basis, the highest extreme significant wave height of 1.8 m is predicted to occur during the months of December and January.

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

	Grid Point #12874				
Month	1	10	25	50	100
January	1.3	1.6	1.7	1.7	1.8
February	1.2	1.5	1.6	1.6	1.7
March	1.1	1.4	1.5	1.6	1.6
April	1.0	1.3	1.4	1.4	1.5
May	0.9	1.2	1.3	1.3	1.4
June	0.8	1.0	1.1	1.1	1.2
July	0.7	0.9	1.0	1.0	1.1
August	0.8	1.0	1.1	1.1	1.2
September	1.0	1.2	1.3	1.4	1.5
October	1.1	1.4	1.5	1.5	1.6
November	1.2	1.4	1.5	1.5	1.6
December	1.3	1.5	1.6	1.7	1.8
Annual	1.4	1.6	1.7	1.8	1.9

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

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

where h is the significant wave height, T is the wave period, and M_0 and M_1 are the first and second spectral moments of the total spectrum. The associated peak periods are calculated by plotting the peak periods of the chosen storm peak values versus the corresponding significant wave heights. This plot is fitted to a power function ($y = ax^b$), and the resulting equation is used to calculate the peak periods associated with the extreme values of significant wave height. The maximum individual wave heights and extreme associated peak periods are presented in Table 2.6 and Table 2.7. Maximum individual wave heights and the extreme associated peak periods, peak during the month of February.

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

	Grid Point #12874				
Month	1	10	25	50	100
January	2.5	3.0	3.2	3.3	3.4
February	2.3	2.9	3.1	3.2	3.4
March	2.2	2.8	3.0	3.2	3.3
April	2.0	2.5	2.7	2.9	3.0
May	1.7	2.3	2.5	2.7	2.8
June	1.5	1.9	2.1	2.2	2.3
July	1.4	1.8	1.9	2.0	2.1
August	1.5	1.9	2.0	2.1	2.2
September	1.9	2.3	2.5	2.6	2.8
October	2.1	2.7	2.9	3.0	3.2
November	2.3	2.8	2.9	3.0	3.1
December	2.5	3.0	3.2	3.3	3.4
Annual	2.8	3.2	3.4	3.5	3.6

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

	Grid Point #12874				
Month	1	10	25	50	100
January	5.2	5.7	5.9	6.0	6.1
February	4.4	4.8	4.9	5.0	5.1
March	4.3	4.7	4.8	4.9	5.0
April	4.2	4.6	4.7	4.8	4.8
May	3.9	4.5	4.6	4.8	4.9
June	3.7	4.2	4.4	4.5	4.6
July	3.6	4.0	4.1	4.2	4.3
August	3.9	4.4	4.5	4.6	4.7
September	4.1	4.5	4.7	4.8	4.9
October	4.3	4.7	4.9	4.9	5.1
November	4.4	4.8	4.9	5.0	5.1
December	4.5	4.9	5.1	5.2	5.3
Annual	4.8	5.2	5.3	5.4	5.5

3.1.3 Extreme Temperature Analysis

Minimum Temperature

For the minimum temperature analysis, the daily minimum temperature was found for each day in the data set. The lowest minimum temperature event chosen was -17.1°C, which occurred on March 10th, 1997. These temperature events were fitted to a Gumbel distribution and extreme value estimates for minimum temperature were calculated for return periods of 2-years, 10-years, and 25-years. These values are given in Table 2.8. The 95% confidence interval is also given.

Table 3.8 Extreme Minimum Temperature Estimates for Return Periods of 2, 10 and 25 Years

Return Period (years)	Extreme Minimum Temperature (°C)	95% Lower Confidence Bound (°C)	95% Upper Confidence Bound (°C)
2	-12.63	-13.43	-11.84
10	-16.69	-18.68	-14.71
25	-18.74	-21.45	-16.02

Maximum Temperature

For the maximum temperature analysis, the daily maximum temperature was found for each day in the data set. The highest maximum temperature event chosen was 27.6°C, which occurred on August 07, 1996. These temperature events were fitted to a Gumbel distribution and extreme value estimates for maximum temperature were calculated for return periods of 2-years, 10-years and 25-years. These values are given in Table 2.9. The 95% confidence interval is also given.

Table 3.9 Extreme Maximum Temperature Estimates for Return Periods of 2, 10 and 25 Years

Return Period (years)	Extreme Maximum Temperature (°C)	95% Lower Confidence Bound (°C)	95% Upper Confidence Bound (°C)
2	20.17	19.27	21.06
10	24.76	22.51	27.01
25	27.08	24.00	30.15

3.2 Hebron Offshore Project Area

An analysis of extreme wind and waves was performed using Grid Point 10632 of 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 hourly data for the Offshore Study Area. The extreme values for wind and waves were calculated using the peak-over-threshold method, and after considering four different distributions, the Gumbel distribution was chosen to be the most representative as it provided the best fit to the data.

Since extreme values can vary depending on how well the data fit the distribution, a sensitivity analysis was carried out to determine the number storms to use. The number of storms determined to provide the best fit annually and monthly for each grid point is presented in Table 3.1.

Table 3.10 Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves

		Annually	Monthly
Grid Point 10632	Wind	435	96
	Wave	317	72

3.2.1 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 calculated annual and monthly values for 1-hour, 10-minutes and 1-minute are presented in Table 3.2 to Table 3.4. The analysis used hourly mean wind values for the reference height of 10 m above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ration of 1.06 and 1.22, respectively (U.S. Geological Survey 1979). The annual 100-year extreme 1-hour wind speed was determined to be 31.7 m/s for Grid Point 10632. Monthly, the highest 100-year extreme winds of 31.0 m/s occur during February.

A comparison of these values, with actual values measured by platforms on the Grand Banks 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-m and anemometer level would therefore introduce an unnecessary source of error in the results.

Table 3.11 1-hr Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years

	Grid Point #10632				
Month	1	10	25	50	100
January	22.2	25.5	26.7	27.5	28.4
February	22.0	26.8	28.5	29.8	31.0
March	20.2	24.4	25.9	27.0	28.2
April	18.0	22.1	23.6	24.7	25.7
May	15.3	19.1	20.4	21.4	22.4
June	14.2	17.8	19.1	20.1	21.1
July	13.2	16.8	18.1	19.0	20.0
August	14.3	20.0	22.0	23.5	25.0
September	16.9	21.9	23.7	25.0	26.3
October	18.2	23.2	24.9	26.3	27.6
November	19.8	24.3	25.9	27.0	28.2
December	21.5	26.0	27.6	28.8	30.0
Annual	24.6	28.2	29.6	30.6	31.7

Table 3.12 10-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Grid Point #10632				
Month	1	10	25	50	100
January	23.6	27.0	28.3	29.2	30.1
February	23.3	28.4	30.2	31.5	32.9
March	21.4	25.9	27.5	28.7	29.8
April	19.1	23.4	25.0	26.1	27.3
May	16.3	20.3	21.7	22.7	23.8
June	15.1	18.9	20.3	21.3	22.3
July	14.0	17.8	19.2	20.2	21.2
August	15.1	21.2	23.3	24.9	26.5
September	17.9	23.2	25.1	26.5	27.9
October	19.3	24.6	26.4	27.8	29.2
November	21.0	25.7	27.4	28.7	29.9
December	22.8	27.6	29.3	30.5	31.8
Annual	26.1	29.8	31.3	32.4	33.6

Table 3.13 1-minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Grid Point #10632				
Month	1	10	25	50	100
January	27.1	31.1	32.5	33.6	34.6
February	26.8	32.7	34.7	36.3	37.8
March	24.6	29.8	31.6	33.0	34.3
April	21.9	27.0	28.7	30.1	31.4
May	18.7	23.3	24.9	26.2	27.4
June	17.3	21.8	23.3	24.5	25.7
July	16.1	20.5	22.1	23.2	24.4
August	17.4	24.4	26.8	28.7	30.5
September	20.6	26.7	28.9	30.5	32.1
October	22.2	28.3	30.4	32.0	33.6
November	24.2	29.6	31.5	33.0	34.4
December	26.3	31.8	33.7	35.2	36.6
Annual	30.0	34.4	36.1	37.3	38.6

3.2.2 Extreme Value Estimates for Waves from a Gumbel Distribution

The annual and monthly extreme value estimates for significant wave height for return periods of 1-year, 10-years, 25-years, 50-years and 100-years are given in Table 3.5. The annual 100-year extreme significant wave height was 15.1 m at Grid Point 10632. This significant wave height corresponds with a significant wave height of 14.66 m recorded over a 20-minute interval by a waverider buoy in the area on February 11, 2003. A storm with a return period of 100 years means that the calculated significant wave height will occur once every 100 years, averaged over a long period of time. It is entirely possible that this event was a 100-year or longer return period storm. The value recorded on February 11, 2003 was the highest recorded significant wave height in a near continuous waverider data set extending back to early 1999. The previous highest recorded value in this data set was 12.47 m, which occurred on January 25, 2003. The maximum significant wave heights measured during the "*Ocean Ranger*" storm of 1982 was approximately 12 m. If more occurrences of an event of this magnitude were observed, the calculated statistics would consequently begin to increase.

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

	Grid Point #10632				
Month	1	10	25	50	100
January	8.7	11.7	12.7	13.5	14.2
February	8.2	11.9	13.1	14.0	14.9
March	7.1	10.0	11.0	11.7	12.4
April	5.7	8.5	9.4	10.1	10.8
May	4.6	7.0	7.8	8.4	9.0
June	3.7	5.9	6.5	7.1	7.6
July	3.4	5.3	5.9	6.4	6.9
August	3.8	6.1	6.9	7.5	8.1
September	5.2	8.6	9.7	10.6	11.4
October	6.2	9.6	10.7	11.6	12.4
November	7.4	10.2	11.2	11.9	12.5
December	8.6	11.5	12.4	13.1	13.8
Annual	10.5	12.8	13.7	14.4	15.1

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

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

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

During a storm event on January 08, 2007 a maximum individual wave height of 22.63 m was recorded by a waverider in the Terra Nova field. This is slightly lower than the January 25-year return period estimate of 23.5 m. The significant wave height during this event was 9.72 m.

Table 3.15 Extreme Maximum Wave Height Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Grid Point #10632				
Month	1	10	25	50	100
January	16.2	21.7	23.5	24.8	26.2
February	15.4	22.1	24.3	25.9	27.6
March	13.2	18.6	20.3	21.6	22.9
April	10.8	15.7	17.3	18.6	19.8
May	8.7	14.0	15.8	17.1	18.4
June	7.2	11.1	12.4	13.3	14.3
July	6.5	9.9	11.0	11.9	12.7
August	7.0	11.0	12.4	13.3	14.3
September	10.0	15.8	17.7	19.1	20.6
October	11.6	17.8	19.8	21.3	22.8
November	13.7	19.0	20.7	22.0	23.3
December	15.9	21.3	23.1	24.4	25.7
Annual	19.4	23.1	25.4	26.6	27.9

Table 3.16 Extreme Associated Peak Period Estimates for Return Periods of 1, 10, 25, 50 and 100 Years

	Grid Point #10632				
Month	1	10	25	50	100
January	12.5	14.3	14.8	15.2	15.6
February	12.1	14.2	14.9	15.3	15.7
March	11.7	13.2	13.6	13.9	14.1
April	10.7	12.1	12.5	12.8	13.1
May	10.0	11.8	12.3	12.6	12.9
June	8.7	10.7	11.2	11.6	12.0
July	8.5	10.6	11.2	11.7	12.1
August	9.2	11.4	12.0	12.4	12.8
September	10.7	13.0	13.6	14.1	14.5
October	11.3	13.2	13.8	14.1	14.5
November	12.0	13.3	13.6	13.9	14.2
December	12.8	14.0	14.3	14.6	14.8
Annual	13.6	14.7	15.1	15.4	15.7

3.2.3 Joint Probability of Extreme Wave Heights and Spectral Peak Periods

A contour plot depicting the joint wave height and period combinations values for return periods of 1-year, 10-years, 25-years, 50-years and 100-years is presented in Figure 3.1. The annual values for the significant wave height estimates and the associated spectral peak periods are given in Table 3.8. The extreme wave height for all return periods was higher using the Weibull Distribution when compared to the Gumbel Distribution.

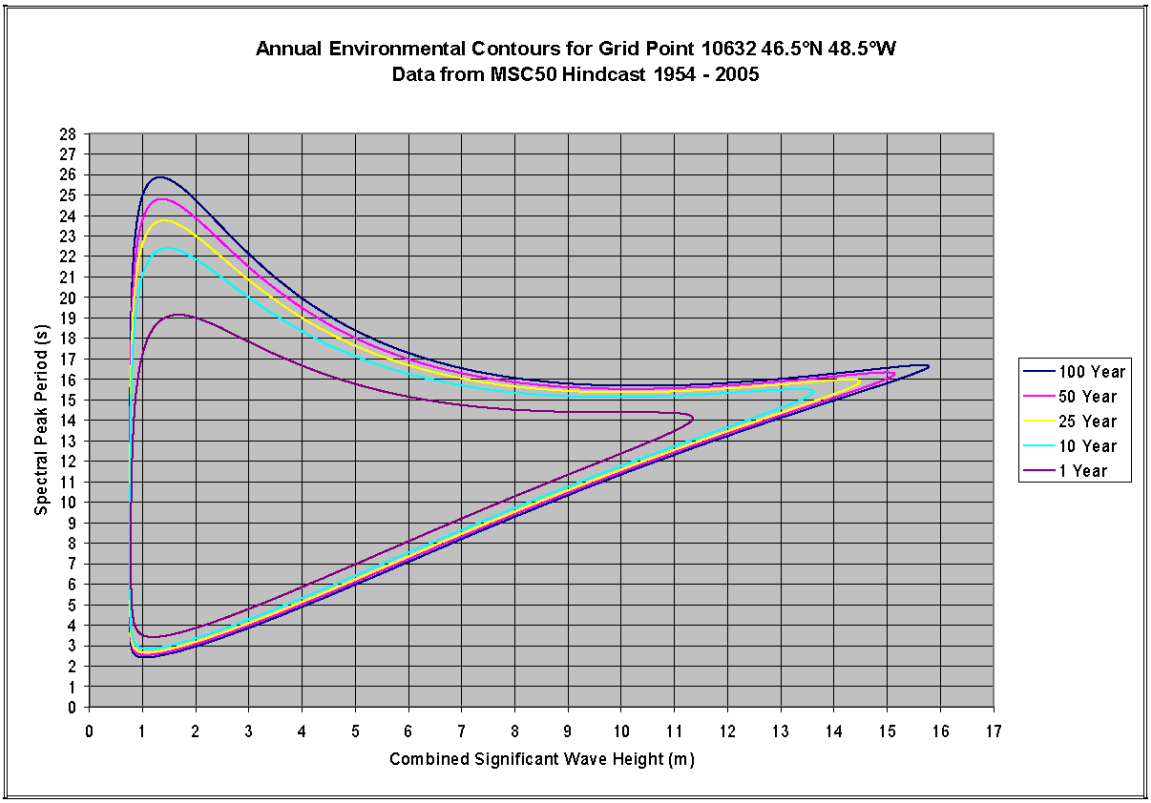


Figure 3.1 **Environmental Contour Plot for Grid Point 10632 (46.5°N 48.5°W)**

Table 3.17 **Annual Extreme Significant Wave Estimates and Spectral Peak Periods for Return Periods of 1, 10, 25, 50 and 100 Years**

	Return Period (years)	Significant Wave Height (m)	Spectral Peak Period Median Value (s)
Grid point 10632	1	11.3	15.5
	10	13.6	16.4
	25	14.5	16.7
	50	15.1	17.0
	100	15.8	17.3

3.2.4 Extreme Temperature Analysis

The extreme temperature analysis was carried out using the ICOADS data set supplemented by observations from different vessels and rigs at or near the Offshore Project Area spanning from February 1984 to August 1988 that were not included in the ICOADS data set.

Minimum Temperature

For the minimum temperature analysis, the daily minimum temperature was found for each day in the data set. The 50 lowest minimum temperature events were then chosen with one restriction; no event could occur within 5 days of another. This restriction ensures that all the chosen events were independent of each other. The lowest minimum

temperature event chosen was -17.3 ^{o}C, which occurred on March 10th, 1986. These temperature events were fitted to a Gumbel distribution and extreme value estimates for minimum temperature were calculated for return periods of 2-years, 10-years, 25-years, 50-years and 100-years. These values are given in Table 3.9. The 95% confidence interval is also given.

Table 3.18 Extreme Minimum Temperature Estimates for Return Periods of 2, 10, 25, 50 and 100 Years

Return Period (years)	Extreme Minimum Temperature (°C)	95% Lower Confidence Bound (°C)	95% Upper Confidence Bound (°C)
2	-10.06	-10.53	-9.60
10	-13.00	-14.13	-11.88
25	-14.48	-16.02	-12.95
50	-15.58	-17.42	-13.74
100	-16.67	-18.82	-14.52

Maximum Temperature

For the maximum temperature analysis, the daily maximum temperature was found for each day in the data set. The 50 highest maximum temperature events were then chosen with one restriction; no event could occur within five days of another. This restriction ensures that all the chosen events were independent of each other. The highest maximum temperature event chosen was 28.0^{o}C, which occurred on August 1, 1974. These temperature events were fitted to a Gumbel distribution and extreme value estimates for maximum temperature were calculated for return periods of 2-years, 10-years, 25-years, 50-years and 100-years. These values are given in Table 3.10. The 95% confidence interval is also given.

Table 3.19 Extreme Maximum Temperature Estimates for Return Periods of 2, 10, 25, 50 and 100 Years

Return Period (years)	Extreme Maximum Temperature (°C)	95% Lower Confidence Bound (°C)	95% Upper Confidence Bound (°C)
2	22.09	22.61	21.56
10	25.43	26.71	24.15
25	27.12	28.86	25.37
50	28.37	30.46	26.27
100	29.61	32.06	27.16

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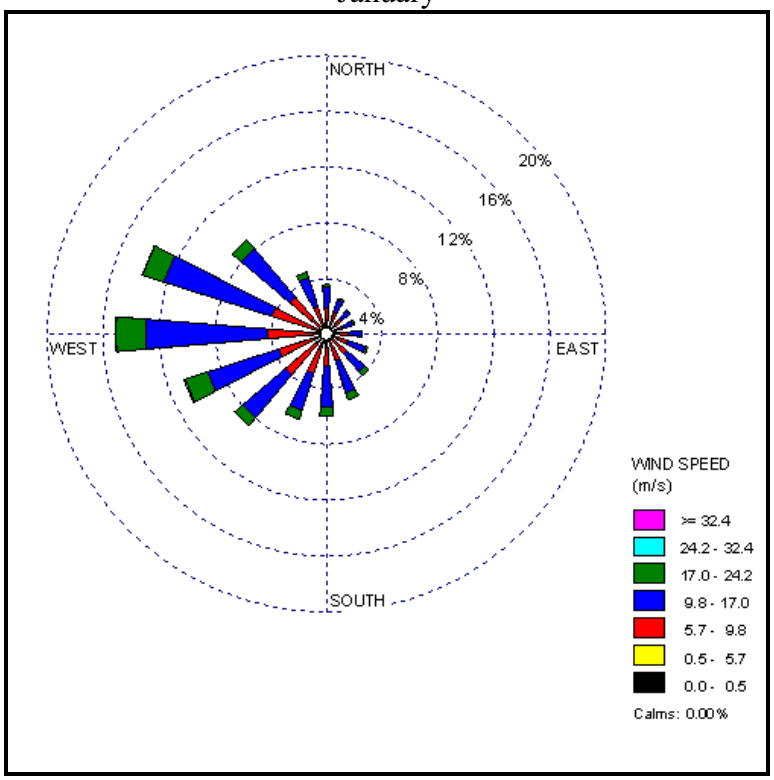
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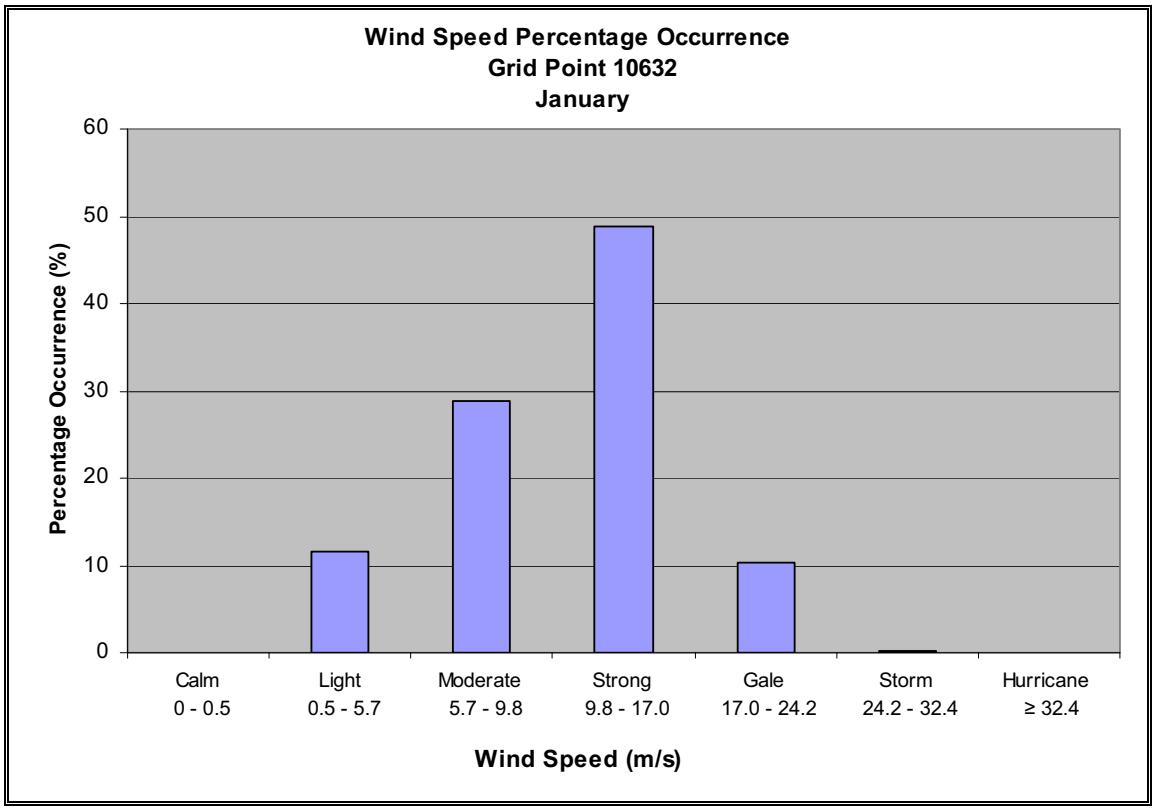
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Appendix 1

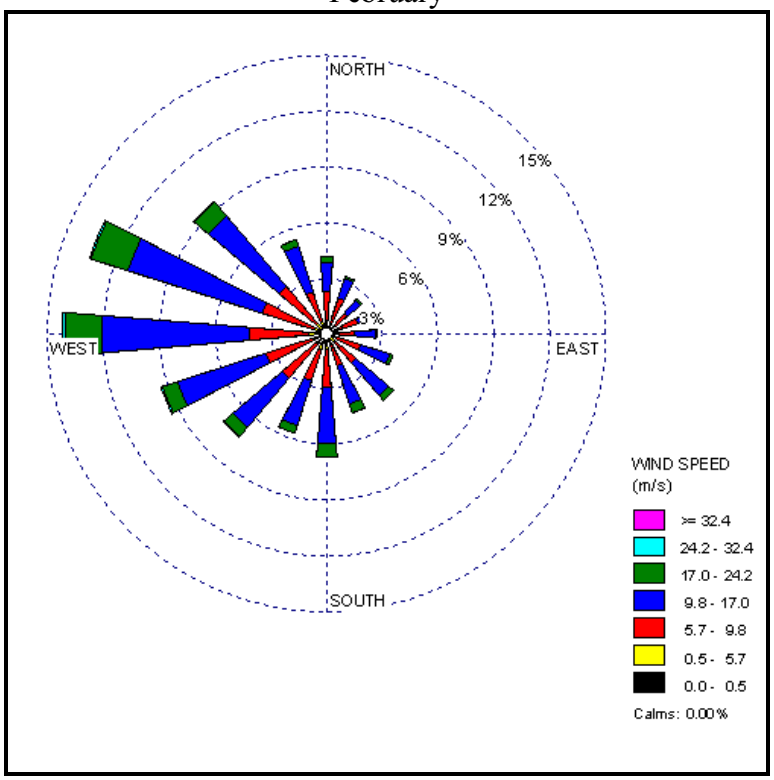
Wind Roses and
Wind Speed Frequency Distributions
for MSC50 Grid Point 10632

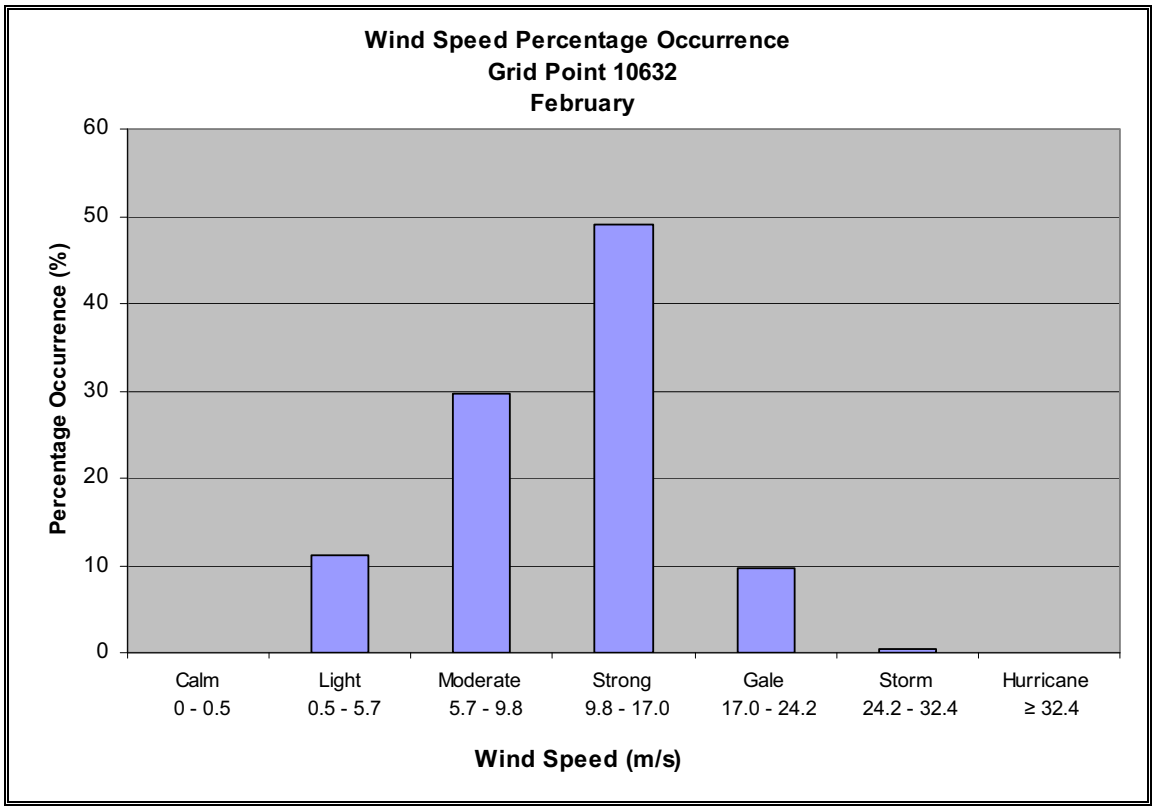
January


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%

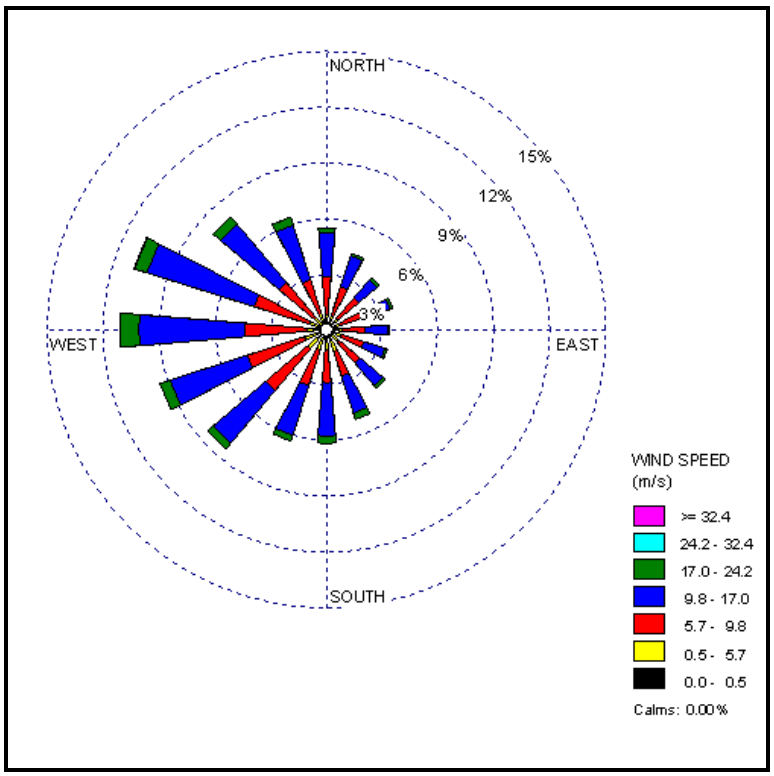

Wind Speed Percentage Occurrence
Grid Point 10632
January
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

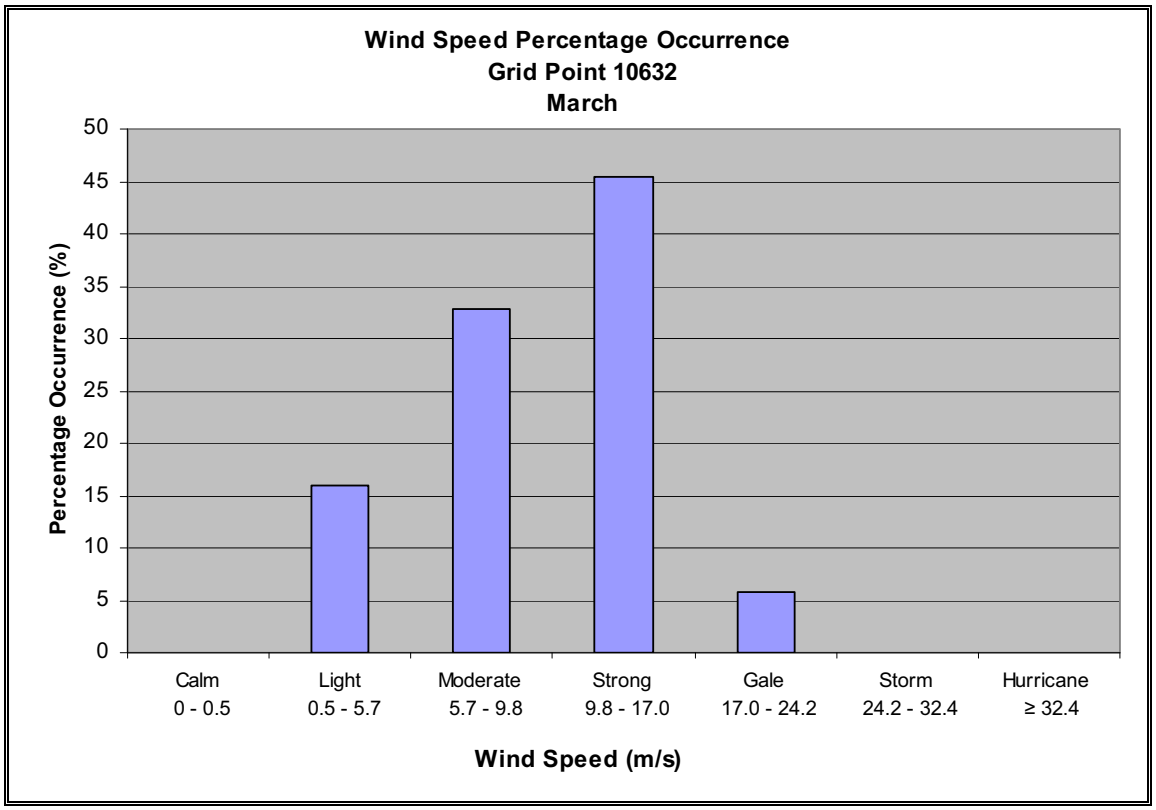
February


NORTH
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%

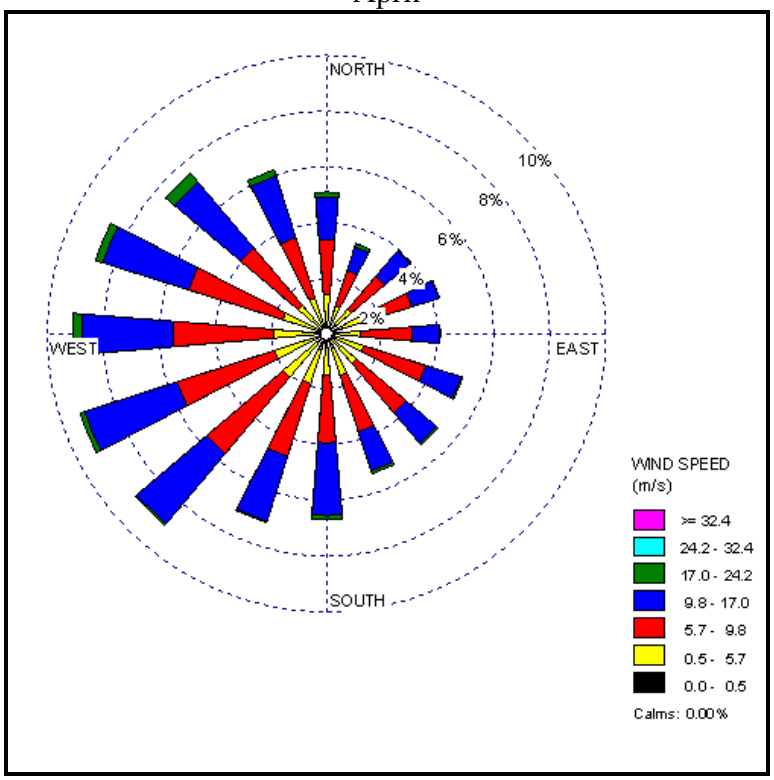

Wind Speed Percentage Occurrence
Grid Point 10632
February
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

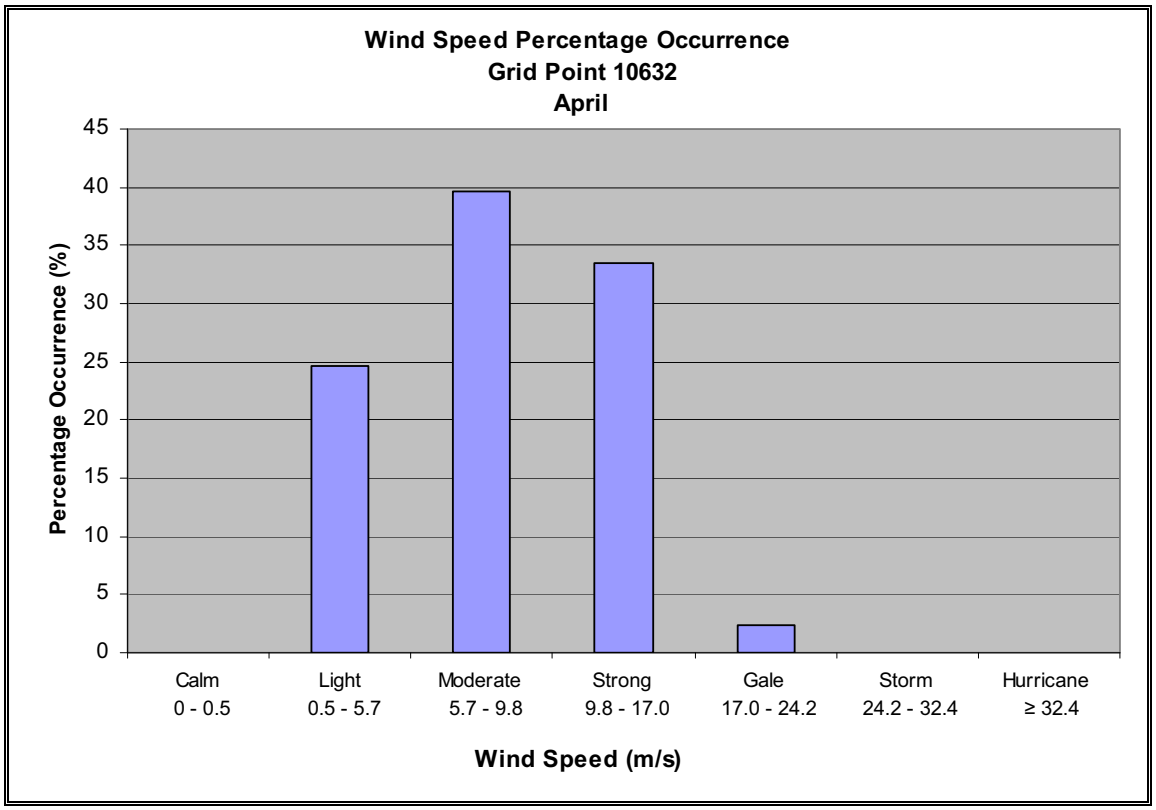
March


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%

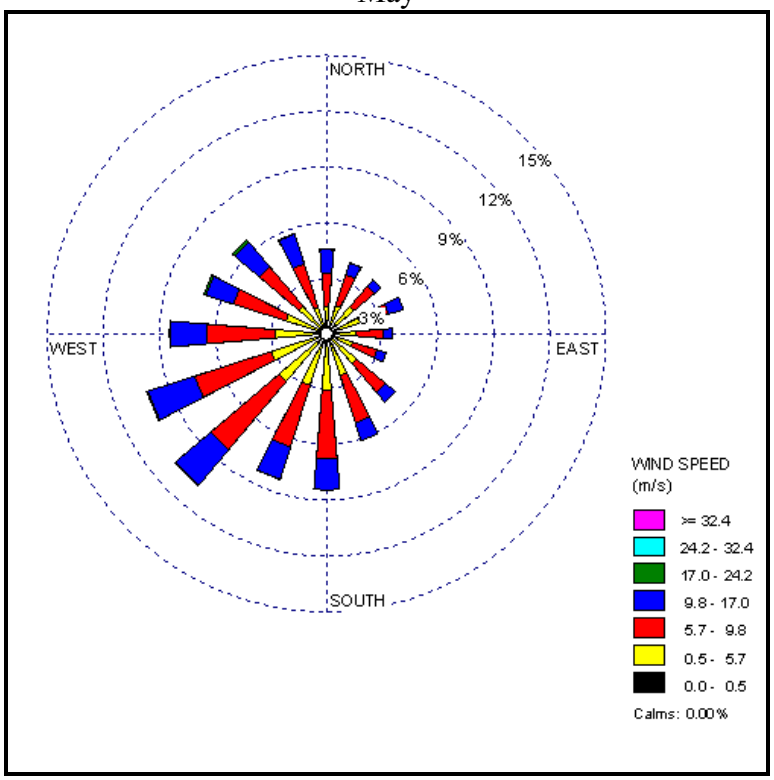

Wind Speed Percentage Occurrence
Grid Point 10632
March
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

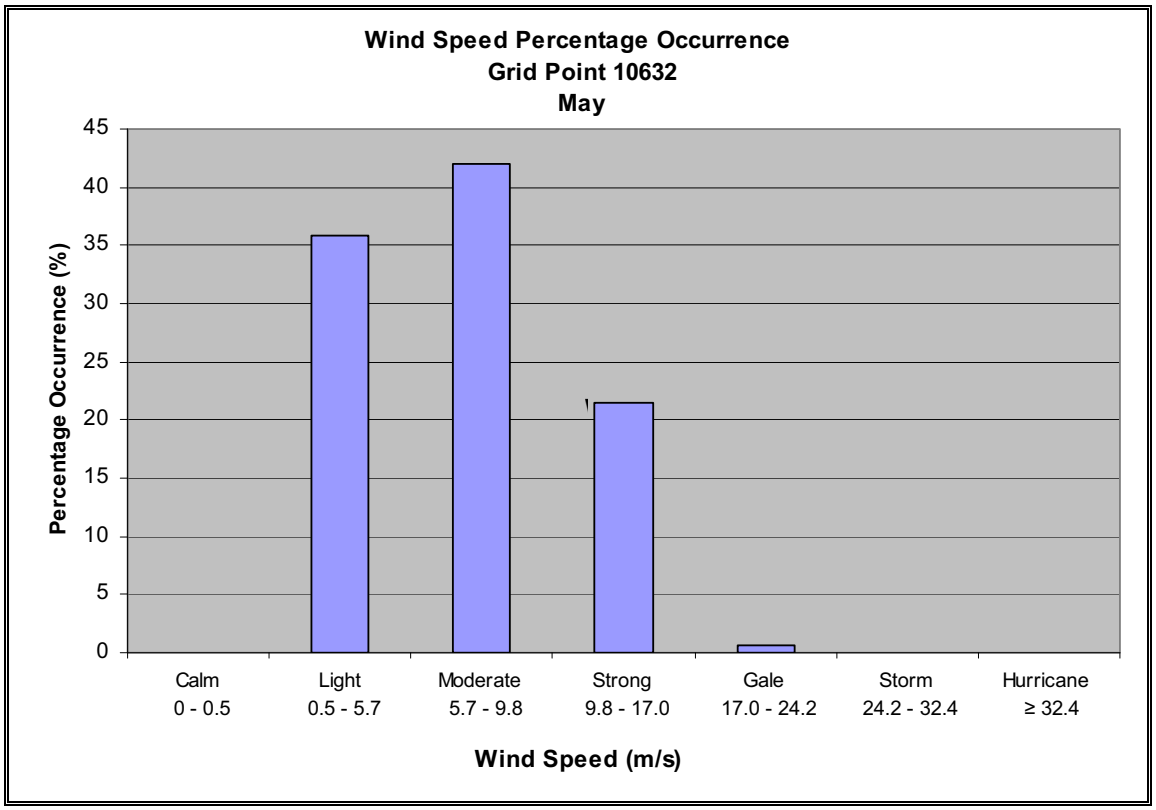
April


NORTH
EAST
SOUTH
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%

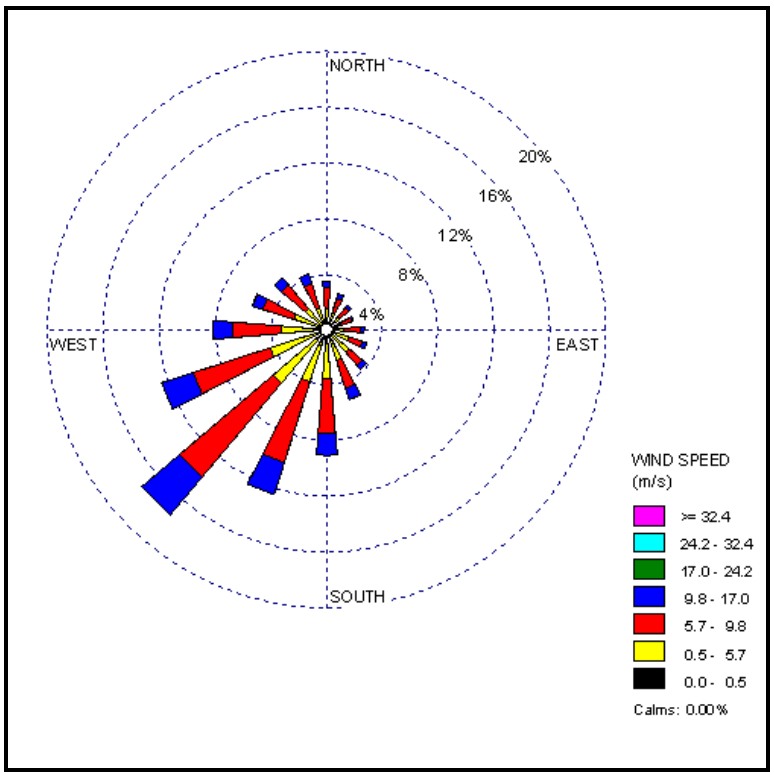

Wind Speed Percentage Occurrence
Grid Point 10632
April
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
45
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

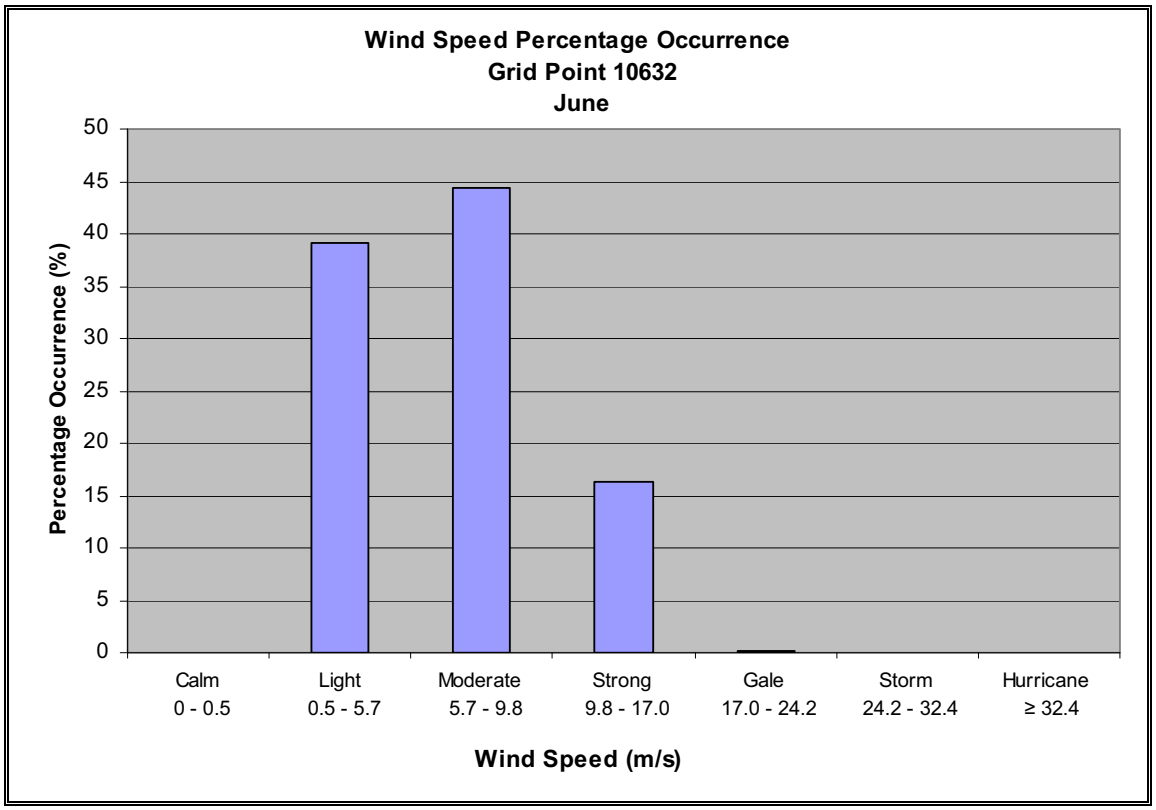
May


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%

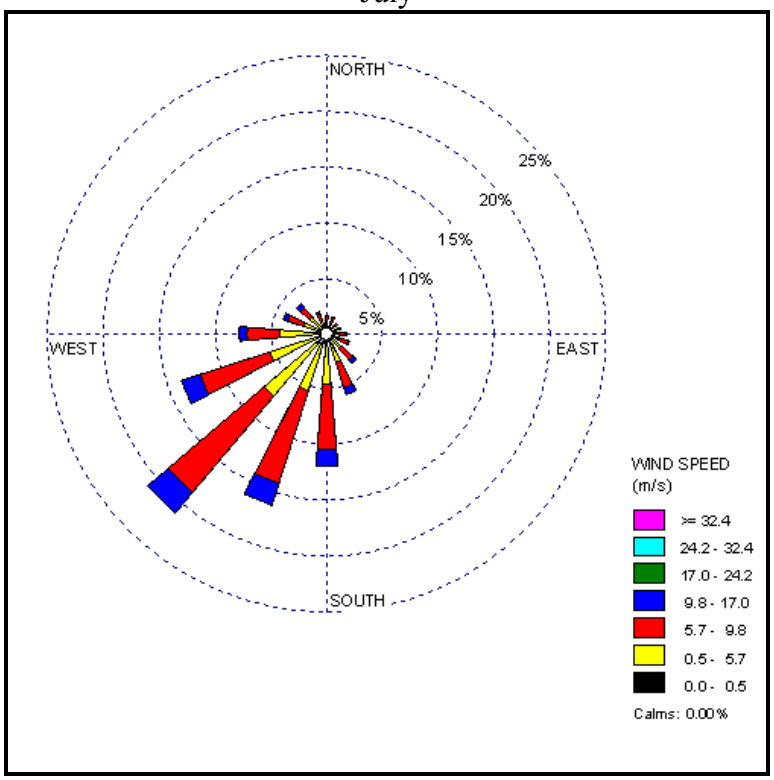

Wind Speed Percentage Occurrence
Grid Point 10632
May
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

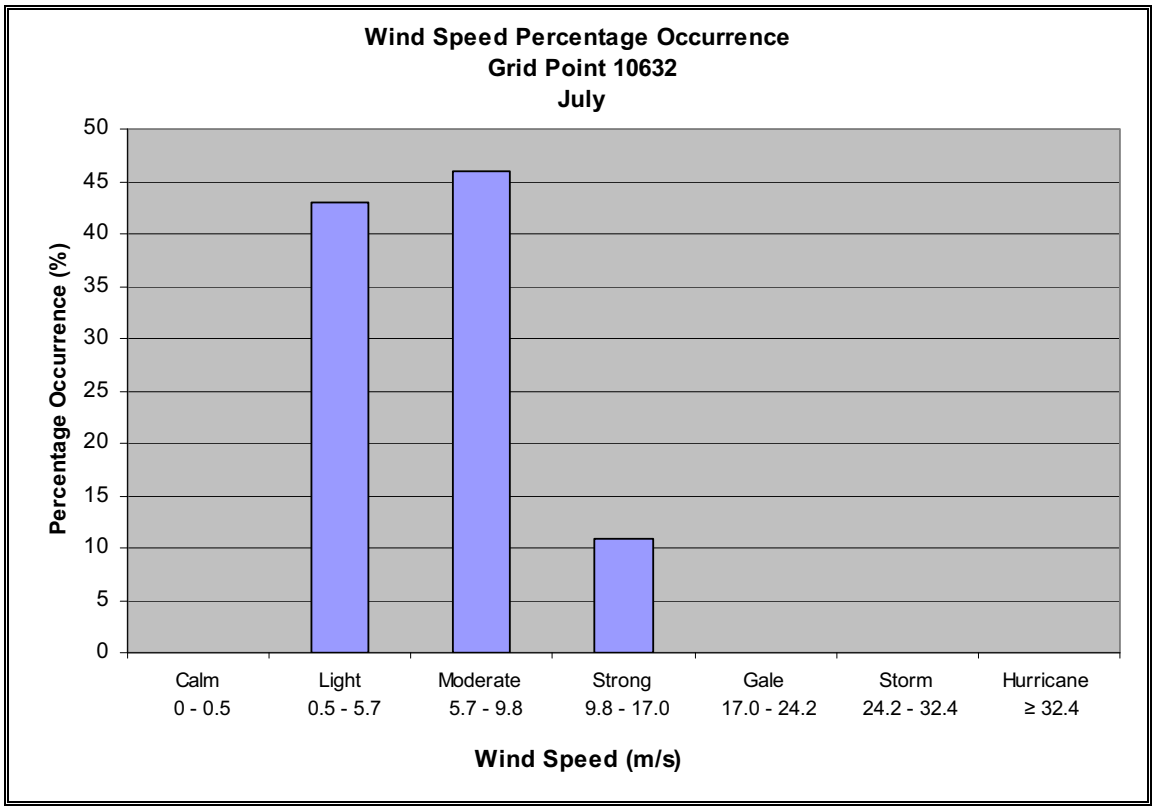
June


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%

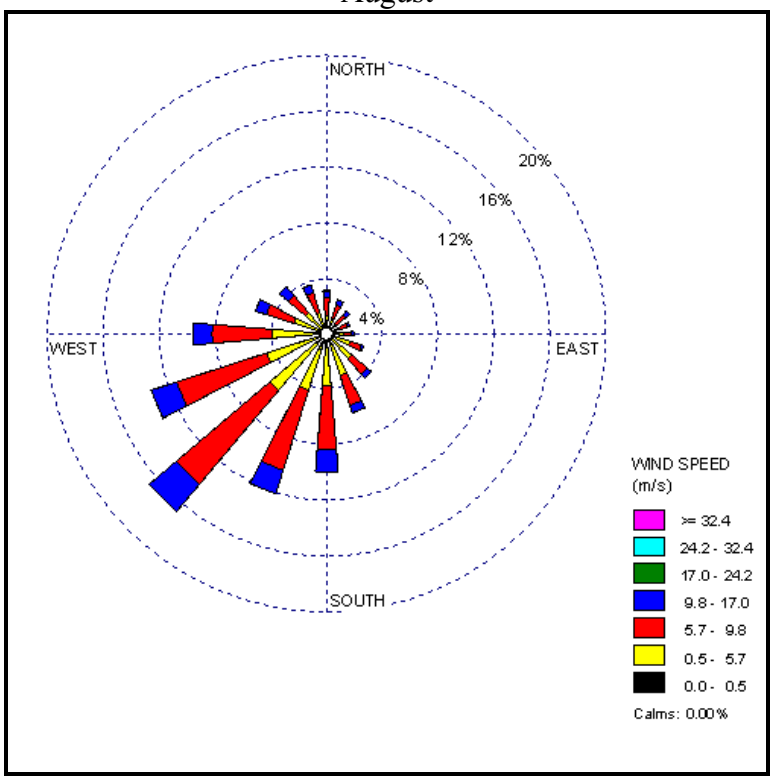

Wind Speed Percentage Occurrence
Grid Point 10632
June
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

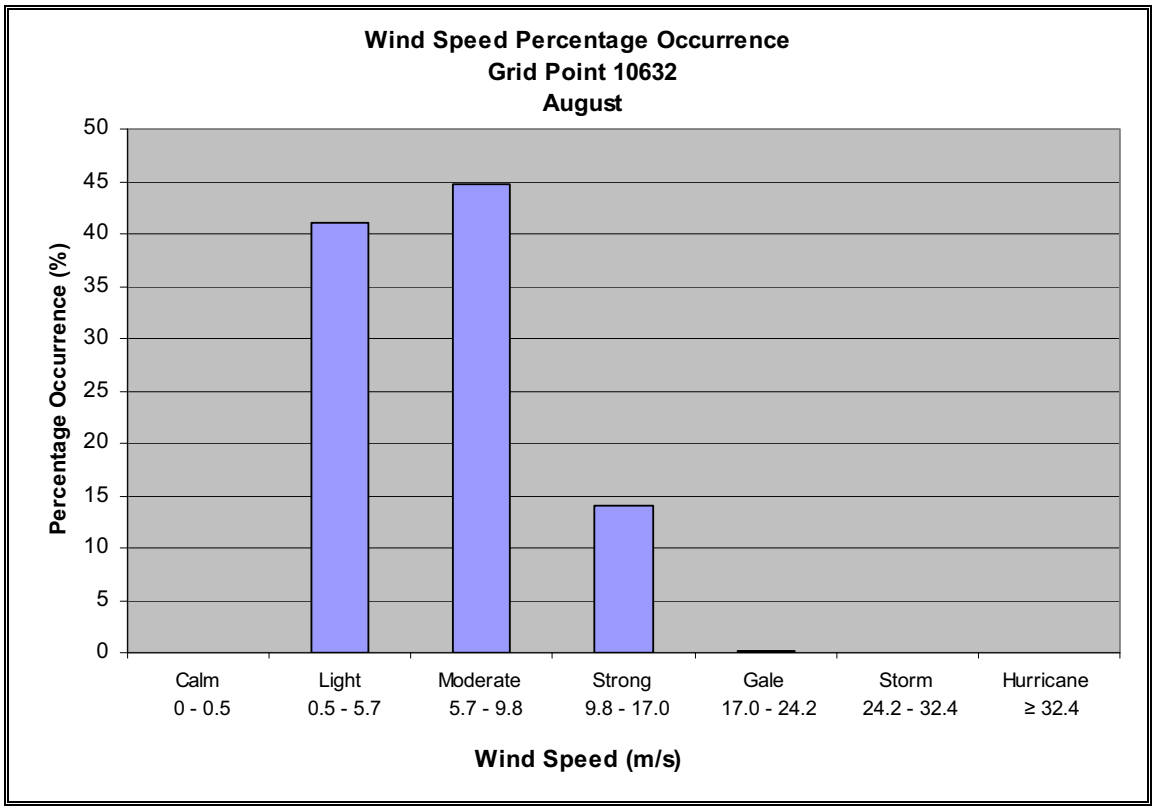
July


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%

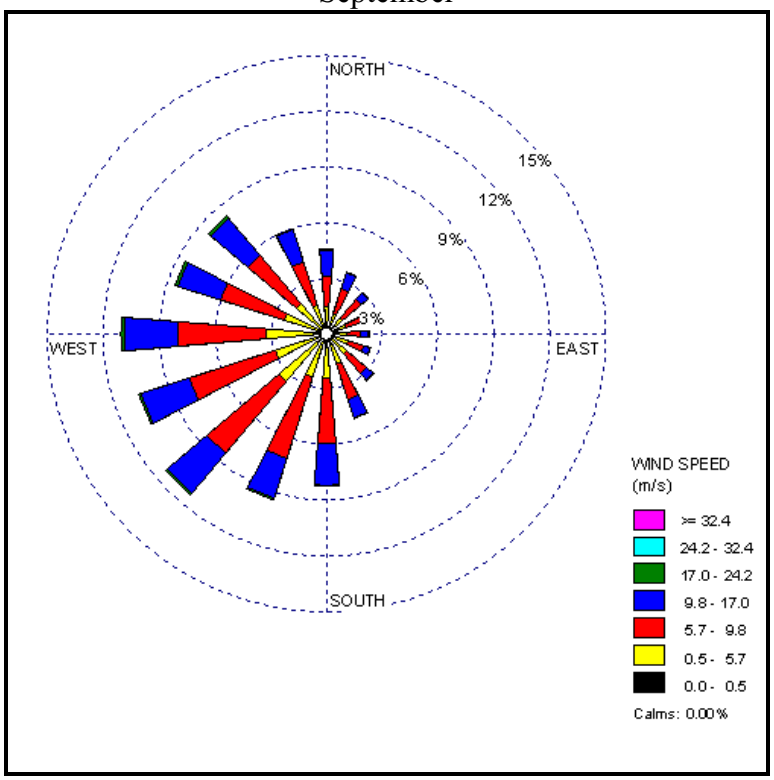

Wind Speed Percentage Occurrence
Grid Point 10632
July
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

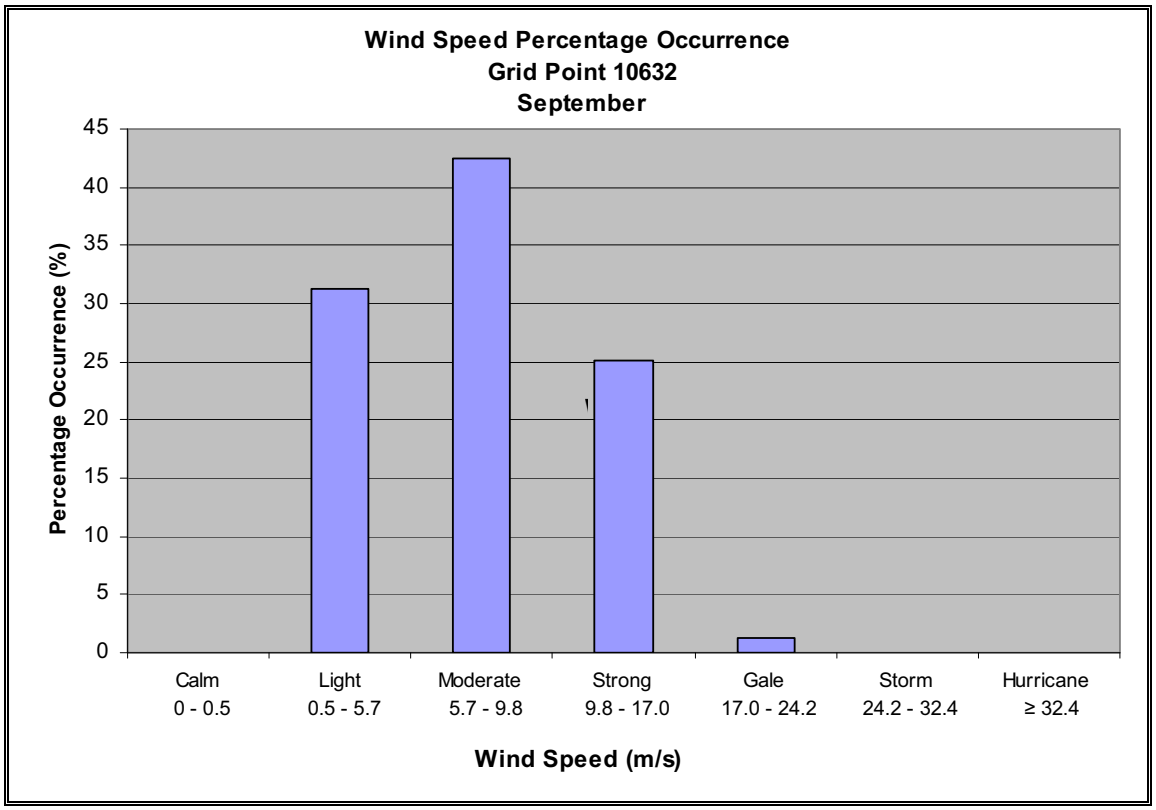
August


NORTH
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%

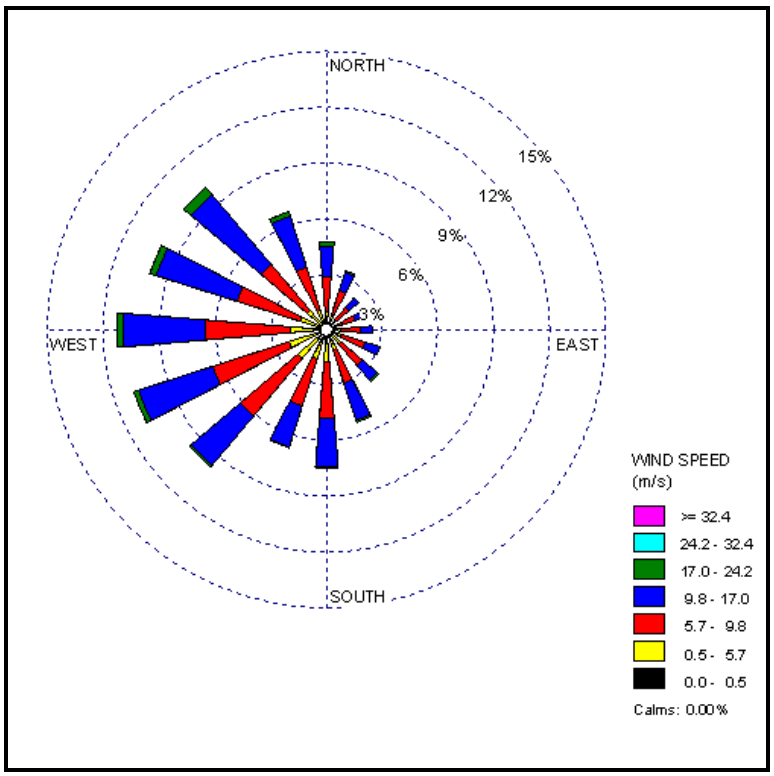

Wind Speed Percentage Occurrence
Grid Point 10632
August
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

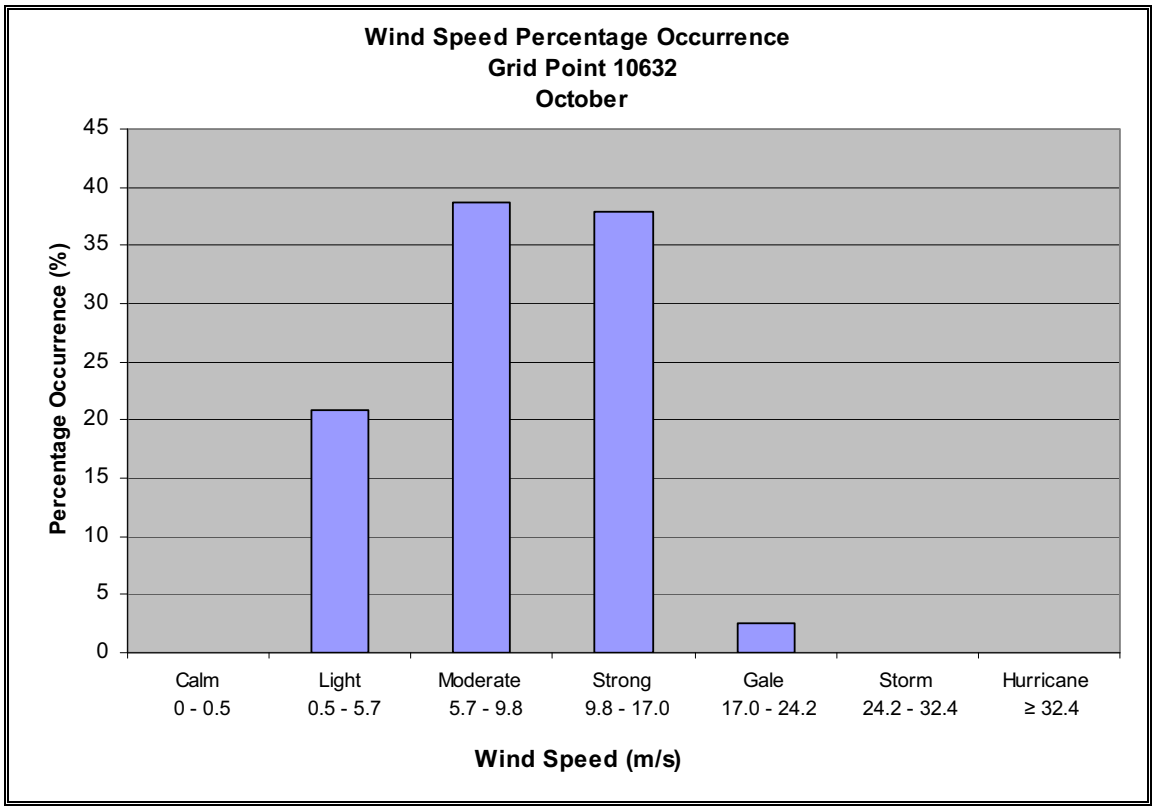
September


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%

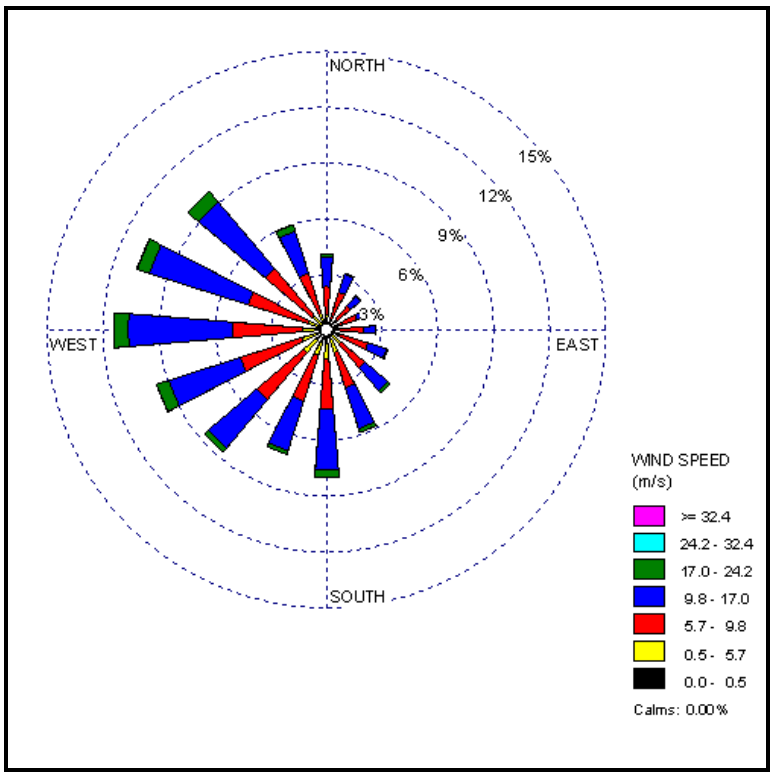

Wind Speed Percentage Occurrence
Grid Point 10632
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

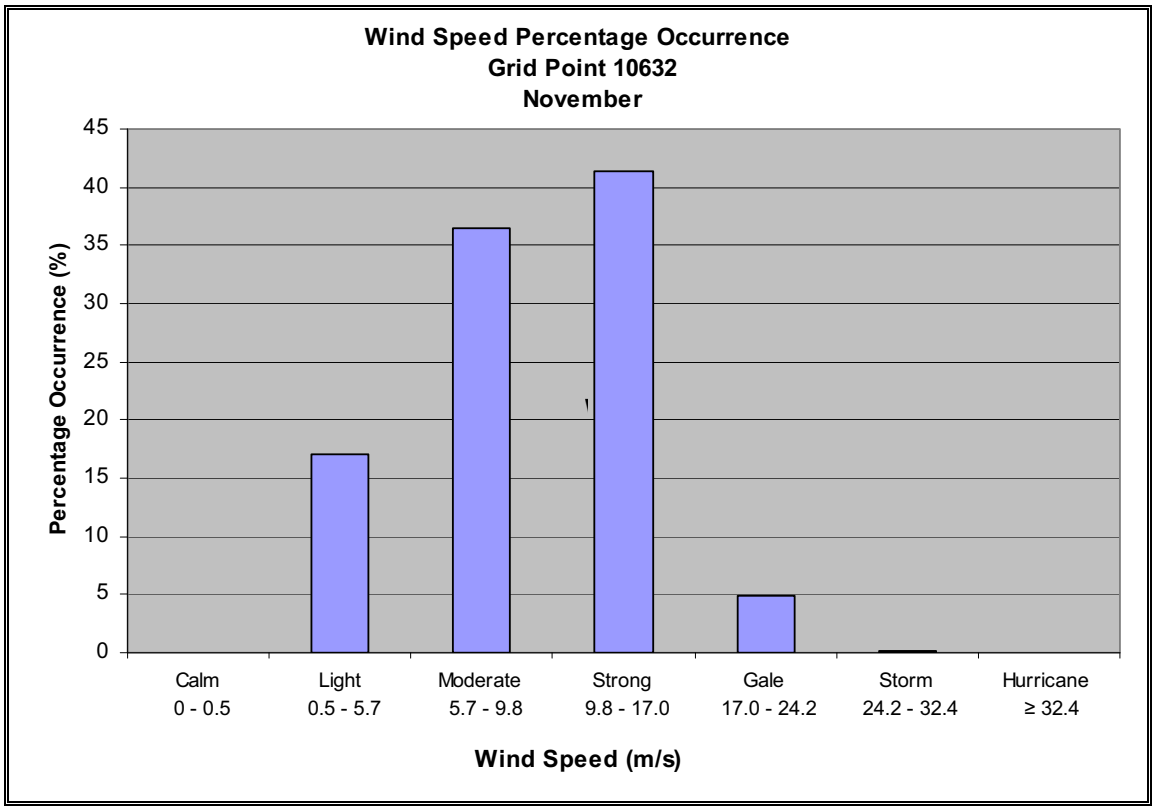
October


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%

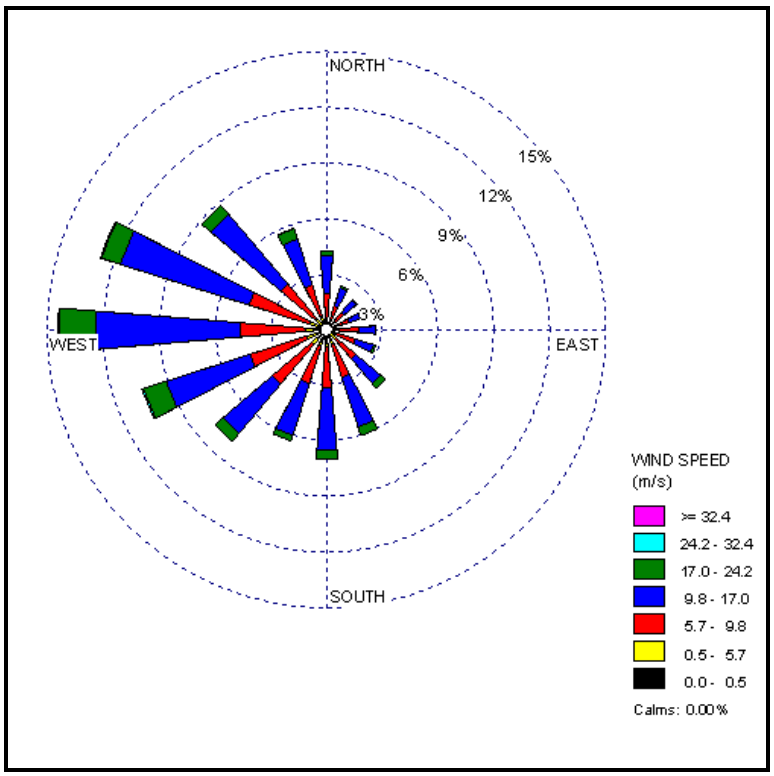

Wind Speed Percentage Occurrence
Grid Point 10632
October
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

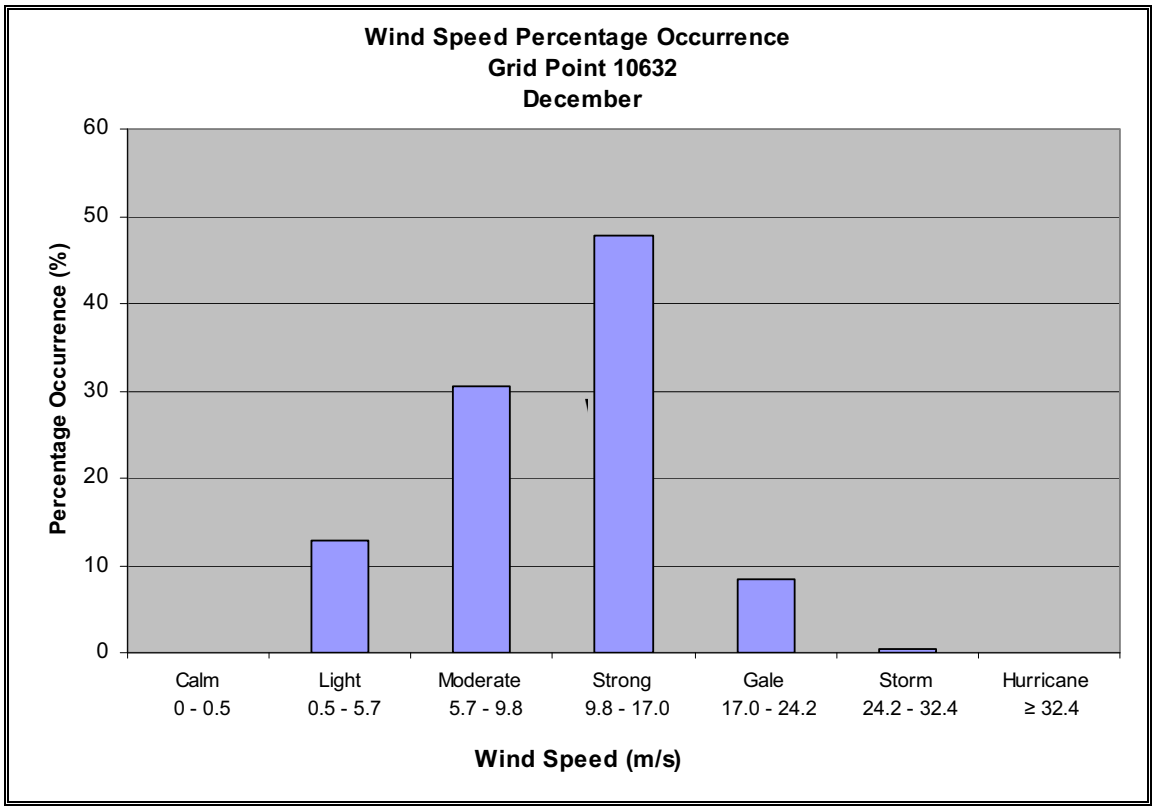
November


NORTH
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 10632
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

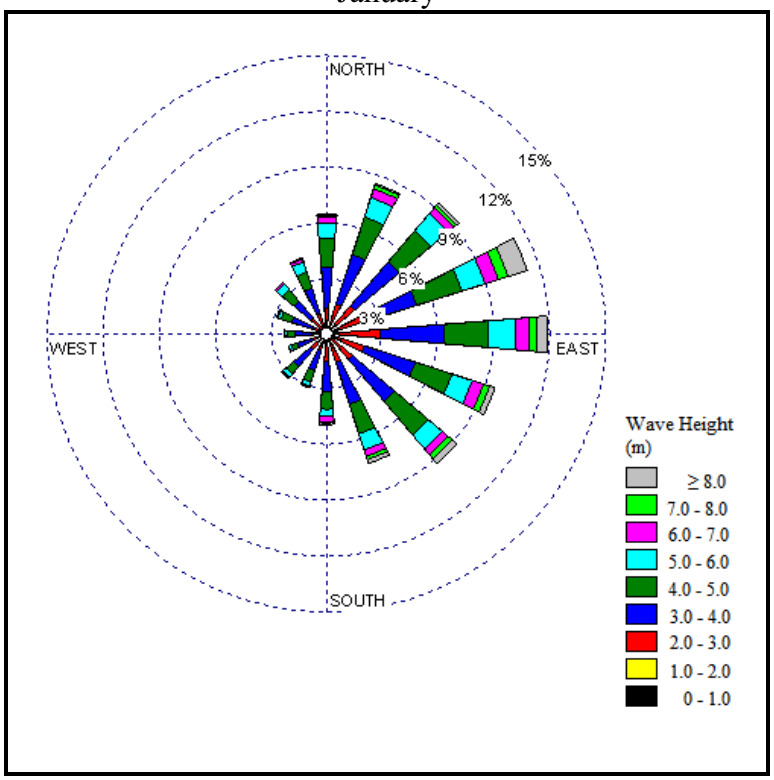

NORTH
15%
12%
9%
6%
3%
WEST
EAST
SOUTH
WIND SPEED
(m/s)
>= 32.4
24.2 - 32.4
17.0 - 24.2
9.8 - 17.0
5.7 - 9.8
0.5 - 5.7
0.0 - 0.5
Calms: 0.00%

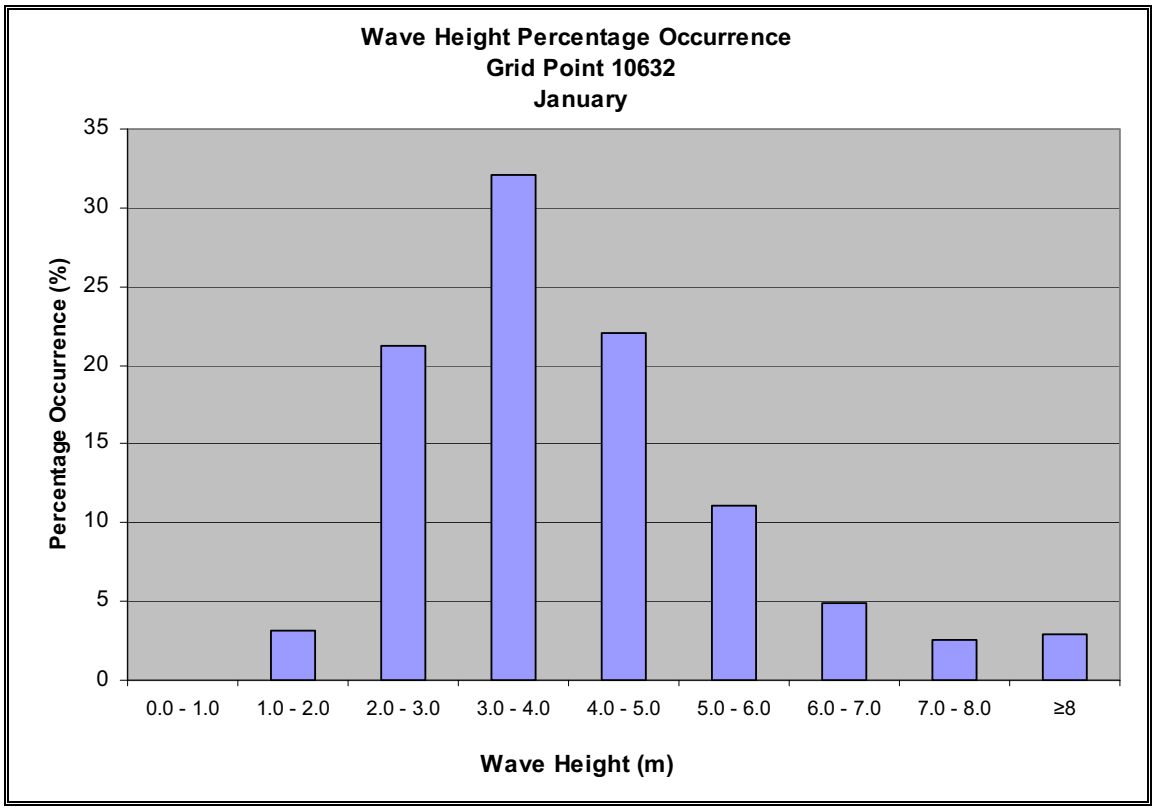

Wind Speed Percentage Occurrence
Grid Point 10632
December
Percentage Occurrence (%)
60
50
40
30
20
10
0
Calm
0 - 0.5
Light
0.5 - 5.7
Moderate
5.7 - 9.8
Strong
9.8 - 17.0
Gale
17.0 - 24.2
Storm
24.2 - 32.4
Hurricane
≥ 32.4
Wind Speed (m/s)

Appendix 2

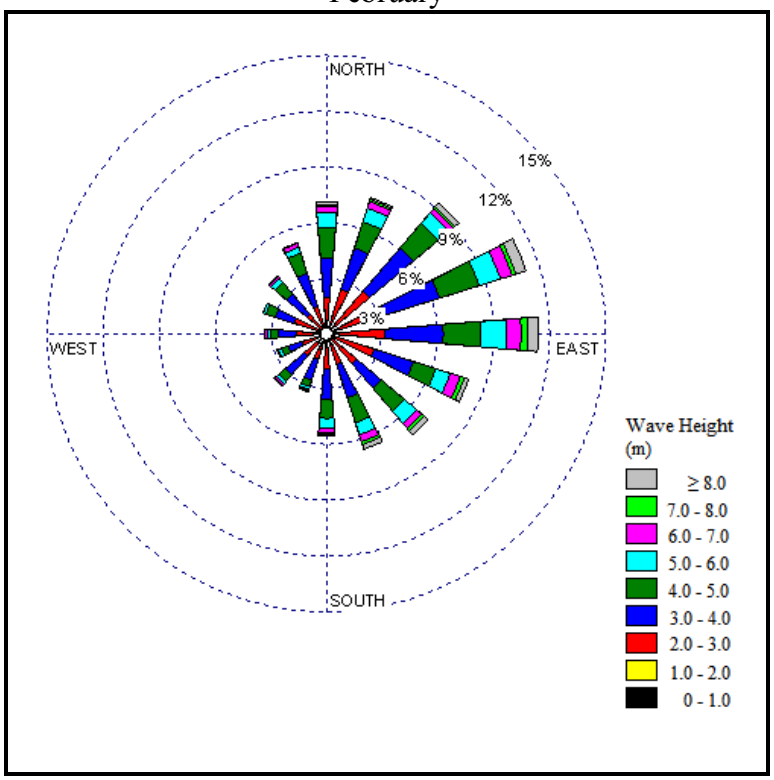
Wave Roses and
Wave Height Frequency Distributions
for MSC50 Grid Point 10632

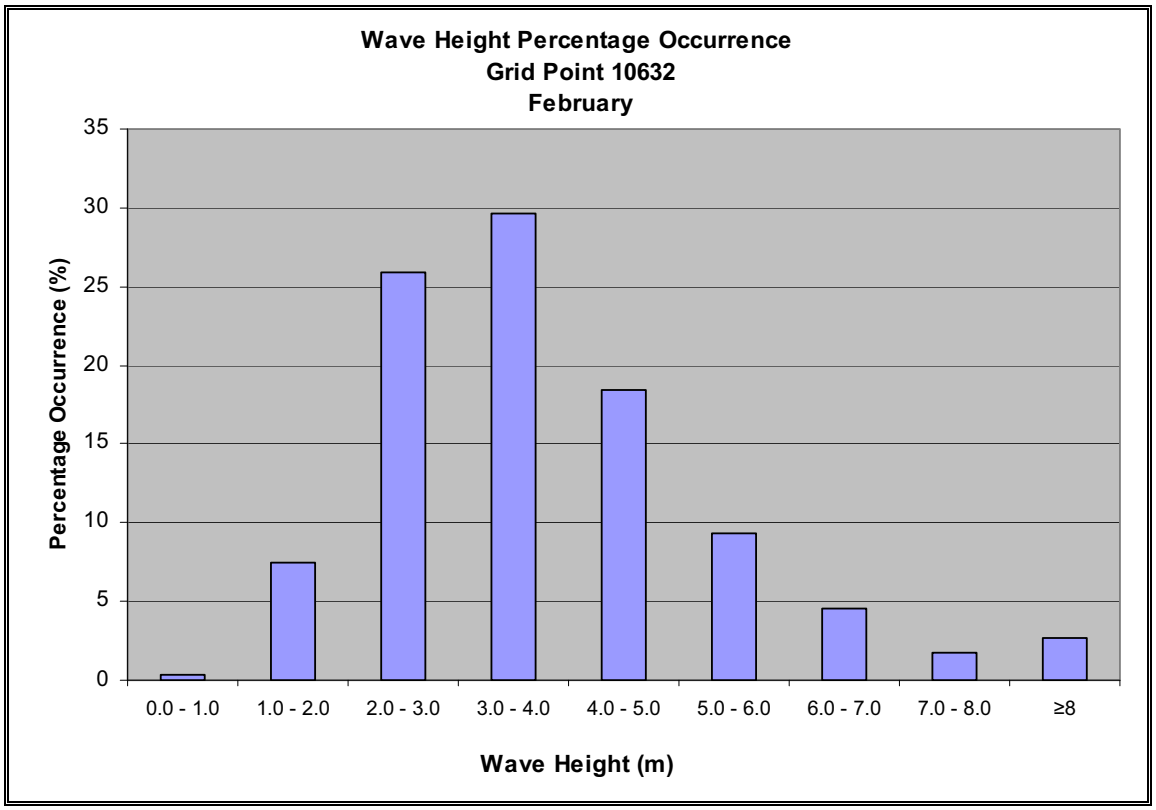
January


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

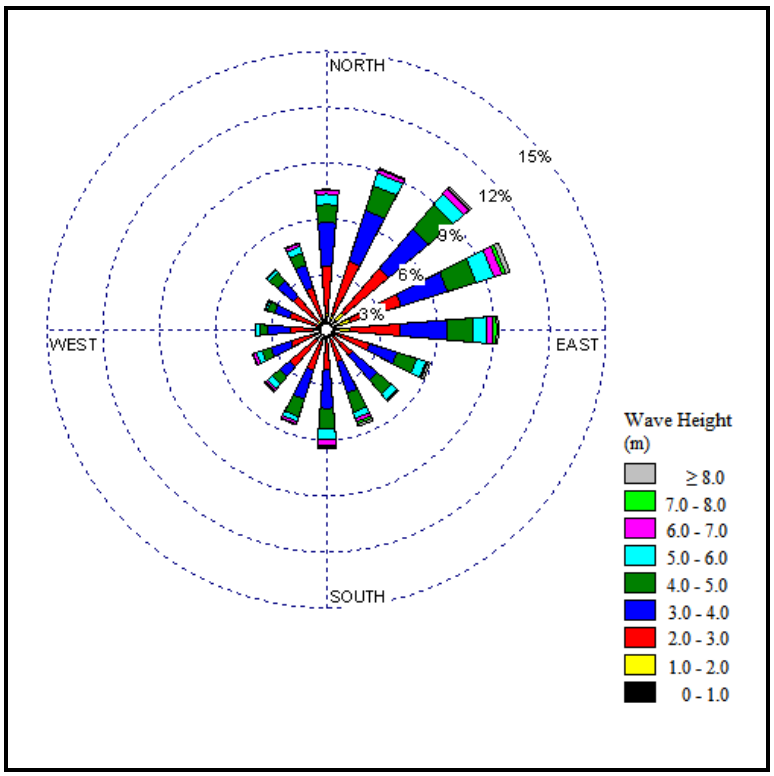

Wave Height Percentage Occurrence
Grid Point 10632
January
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

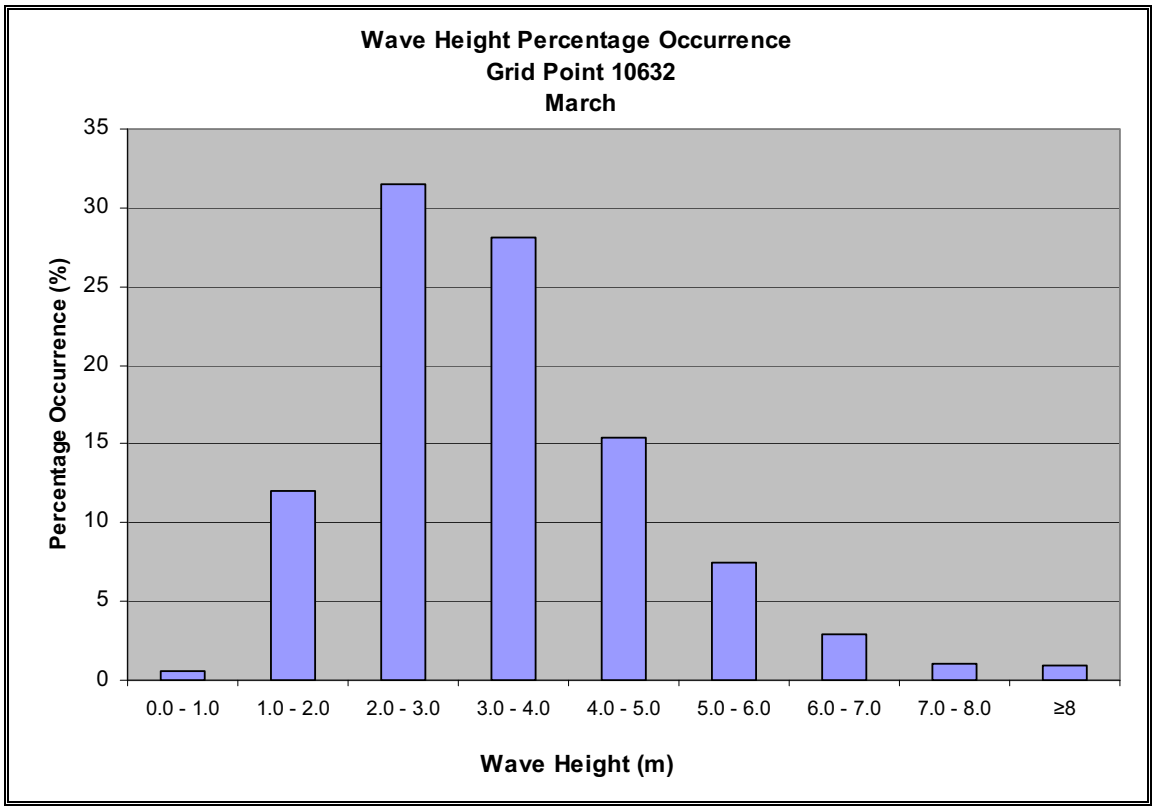
February


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

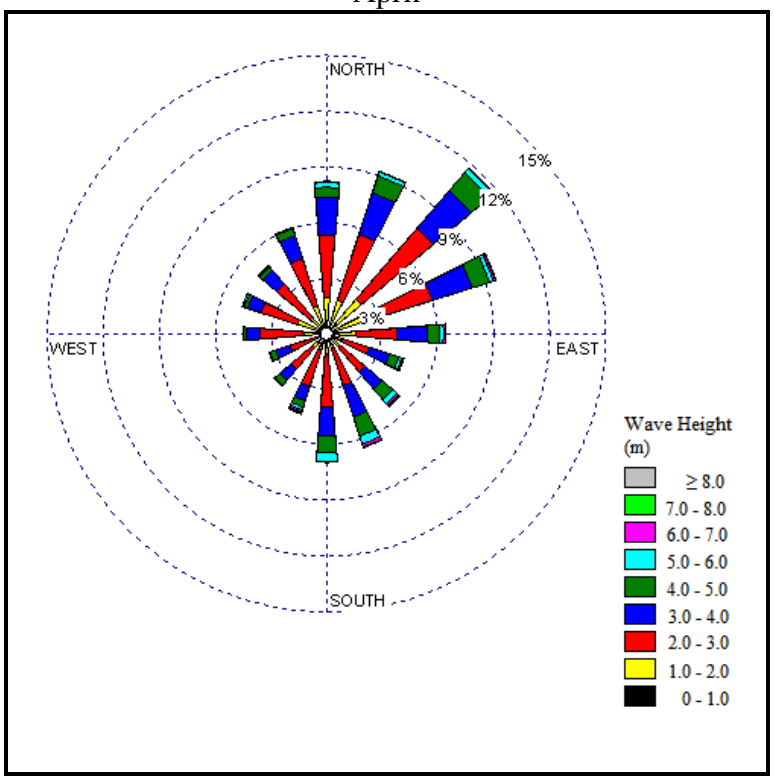

Wave Height Percentage Occurrence
Grid Point 10632
February
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

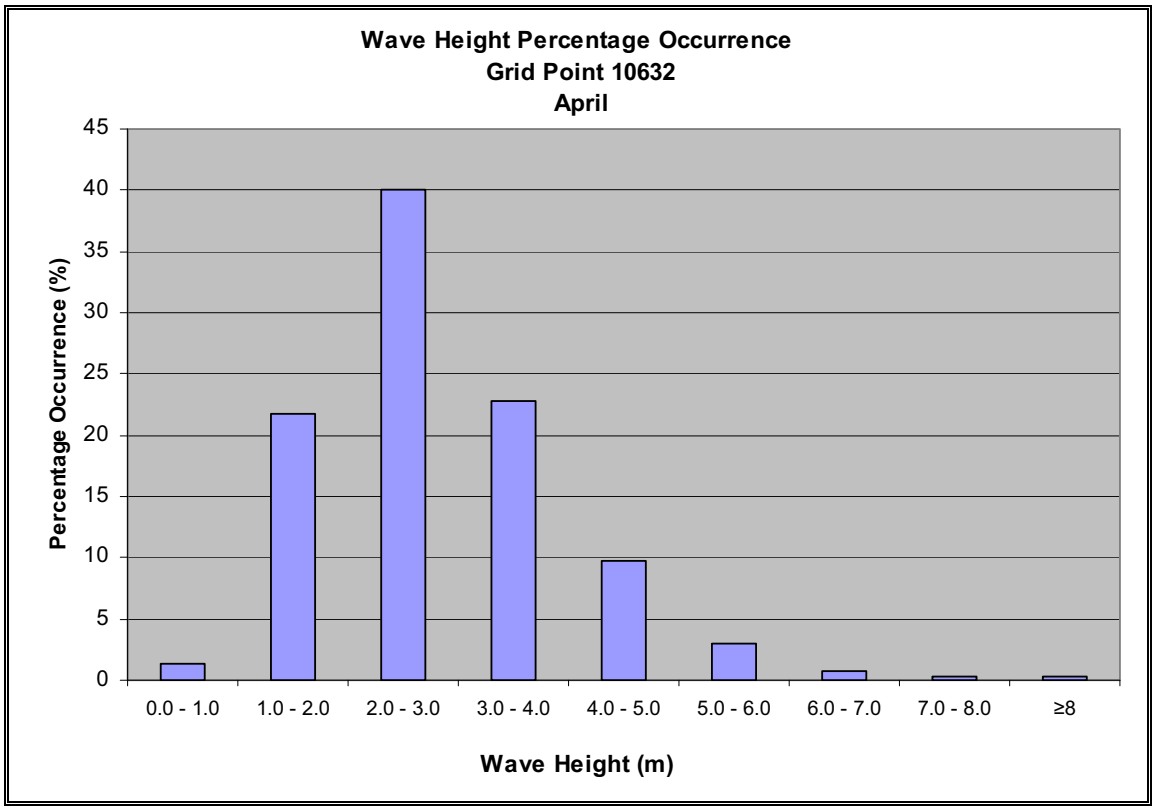
March


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

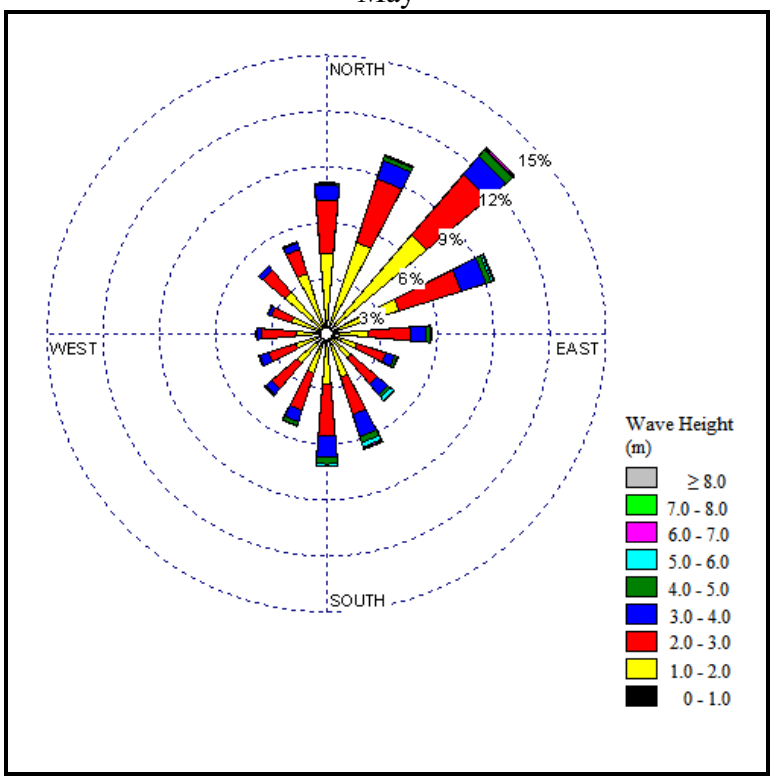

Wave Height Percentage Occurrence
Grid Point 10632
March
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

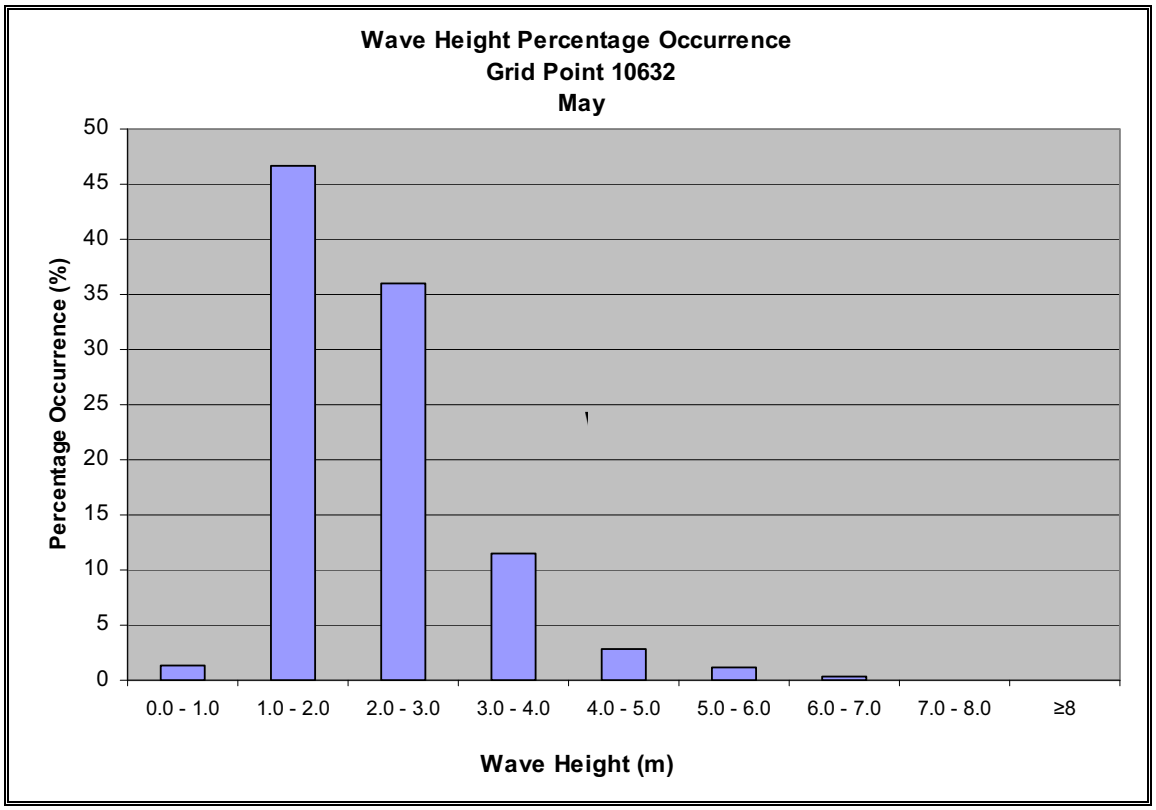
April


NORTH
EAST
SOUTH
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

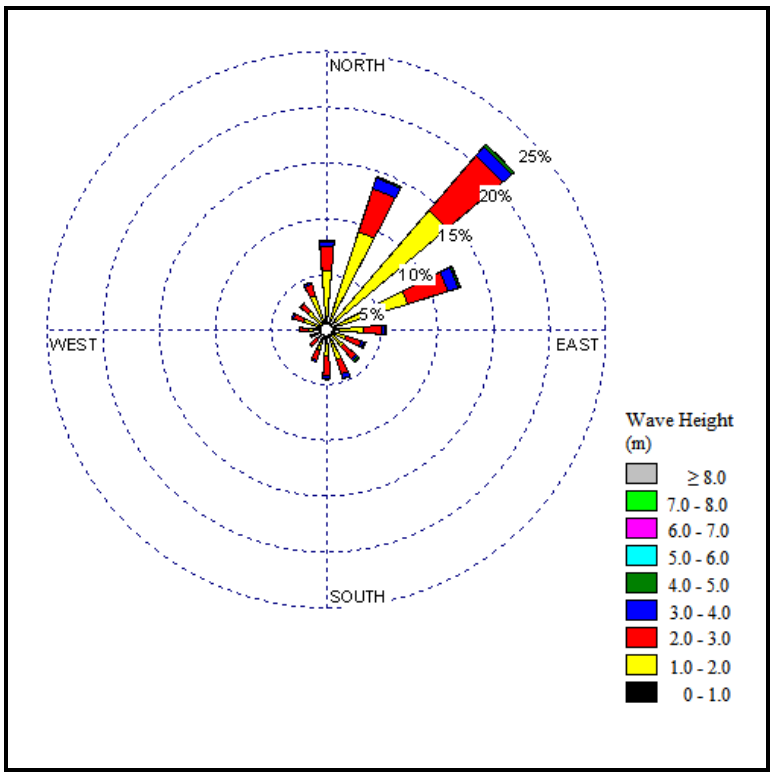

Wave Height Percentage Occurrence
Grid Point 10632
April
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

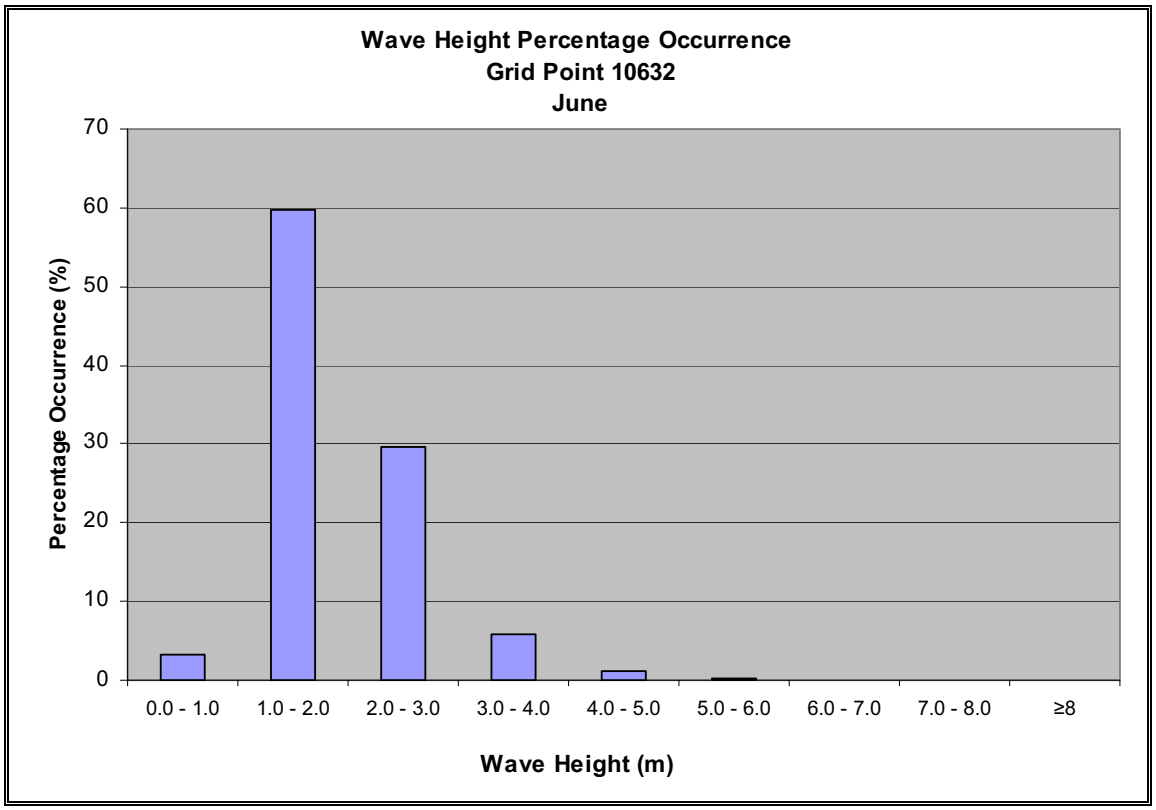
May


NORTH
EAST
SOUTH
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

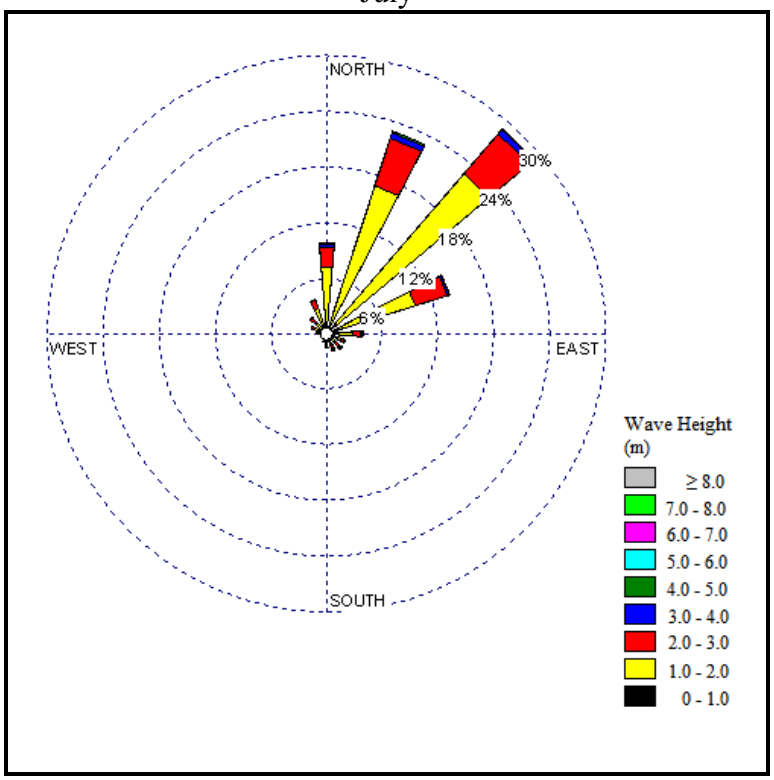

Wave Height Percentage Occurrence
Grid Point 10632
May
Percentage Occurrence (%)
50
45
40
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

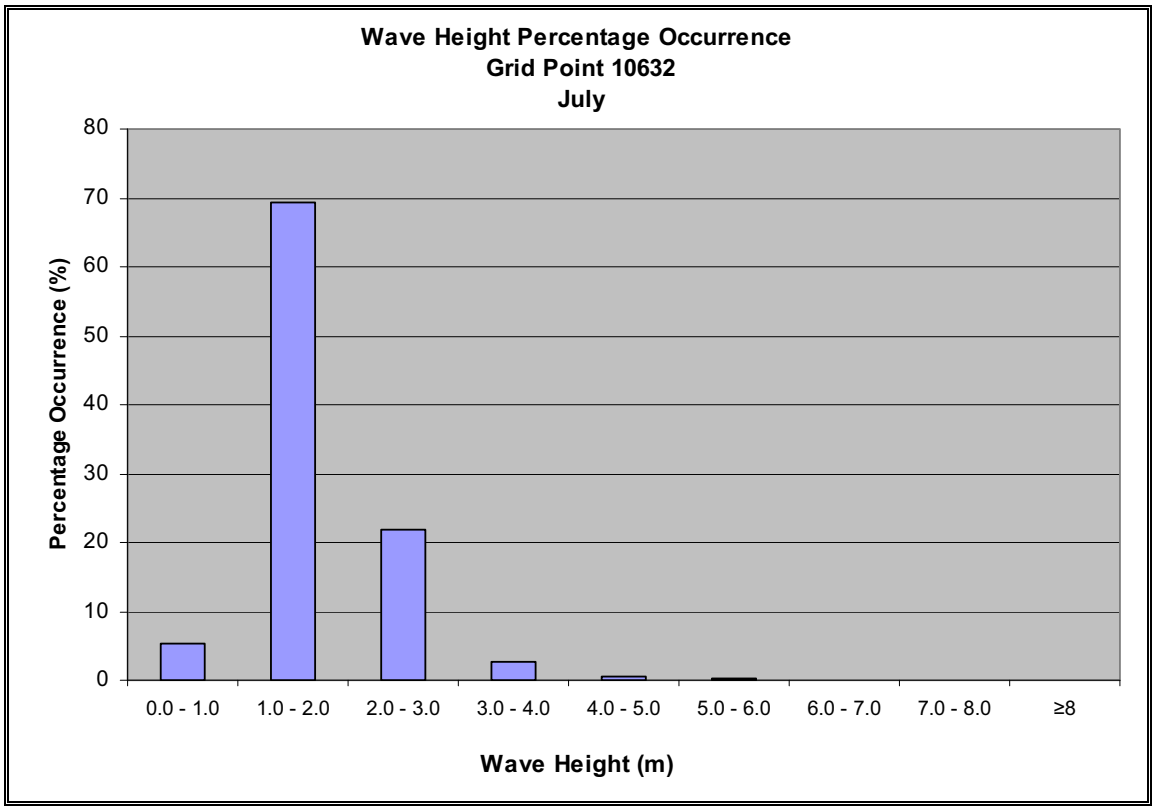
June


NORTH
EAST
SOUTH
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

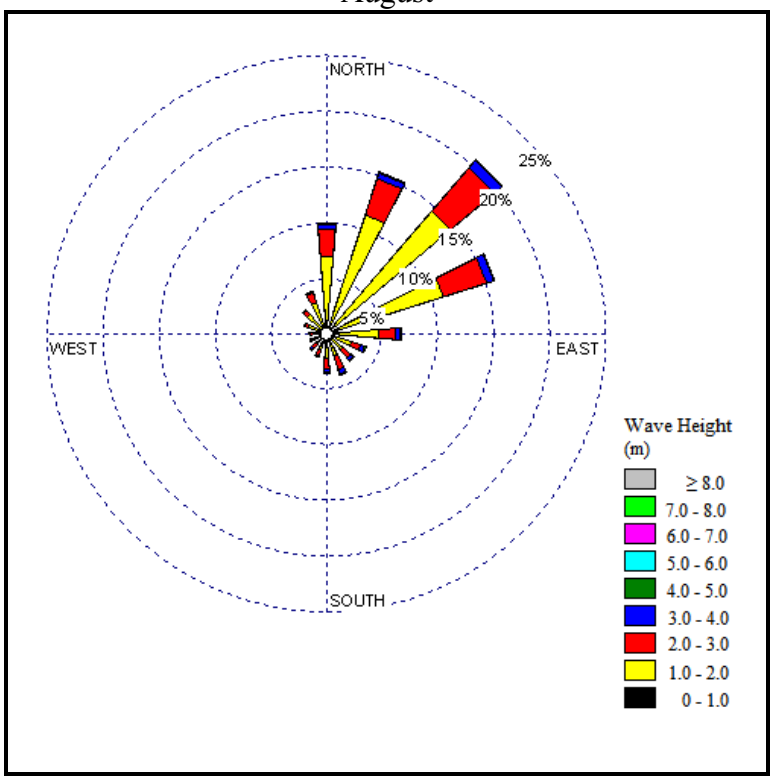

Wave Height Percentage Occurrence
Grid Point 10632
June
Percentage Occurrence (%)
70
60
50
40
30
20
10
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

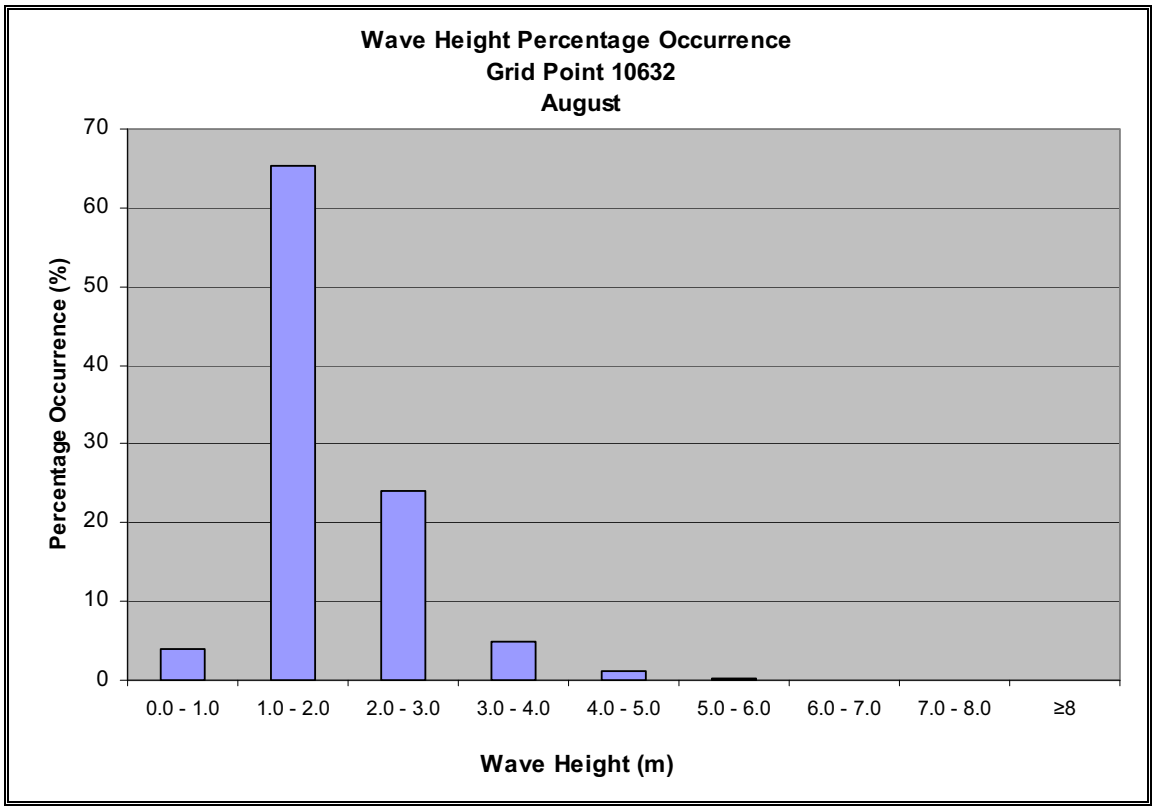
July


NORTH
EAST
SOUTH
WEST
30%
24%
18%
12%
6%
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

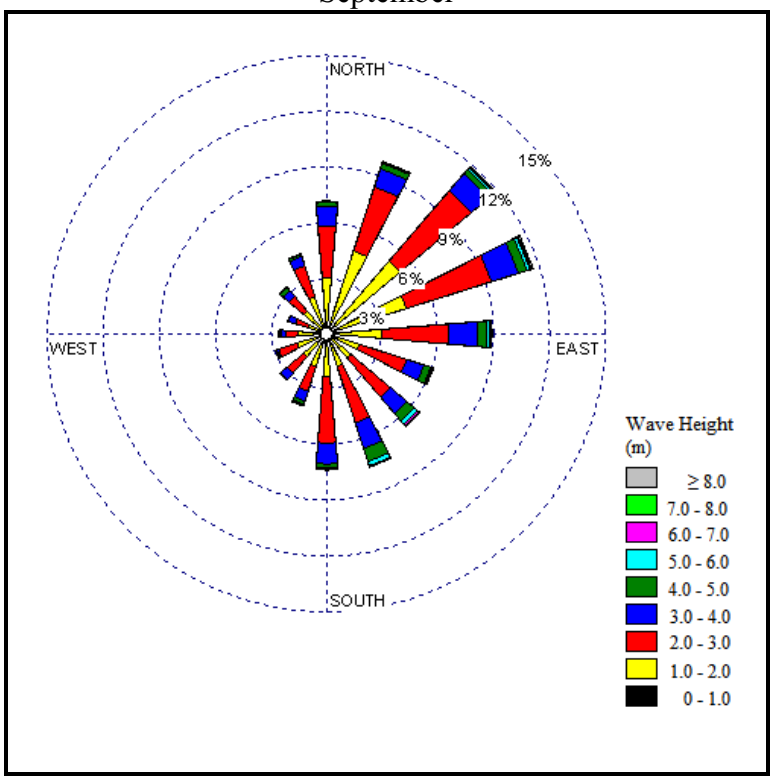

Wave Height Percentage Occurrence
Grid Point 10632
July
Percentage Occurrence (%)
80
70
60
50
40
30
20
10
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

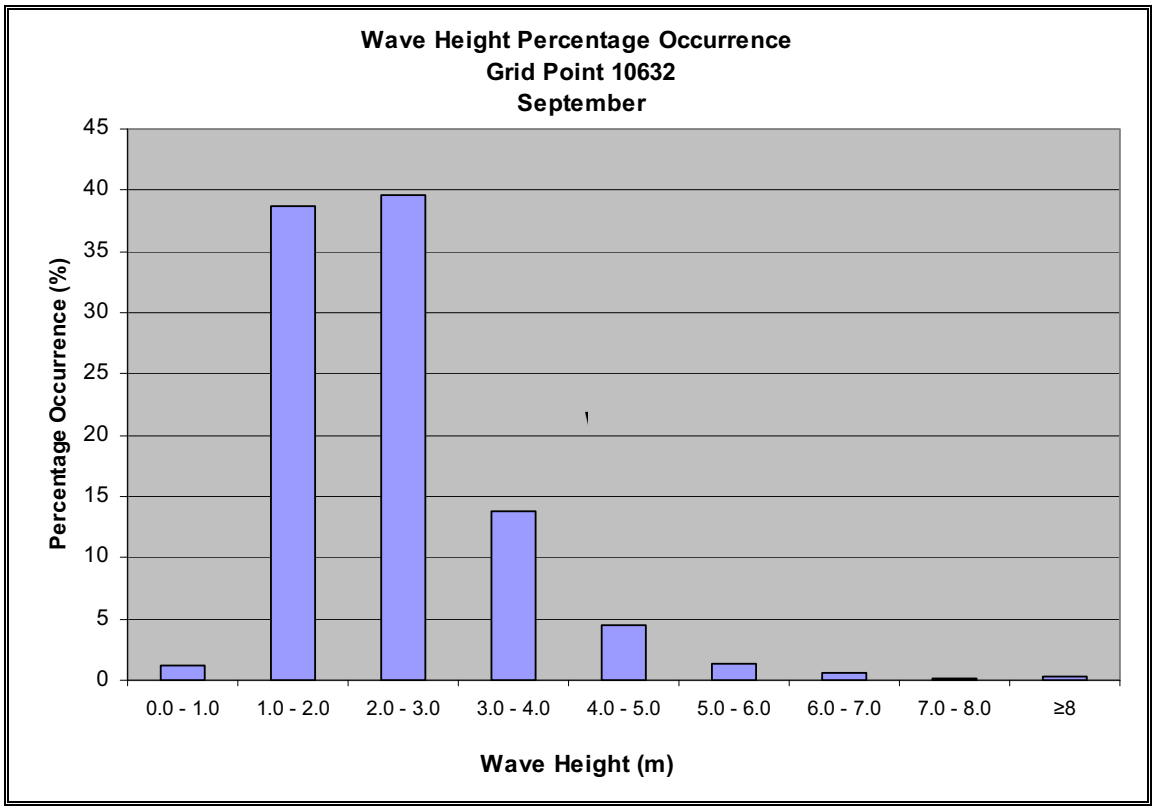
August


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

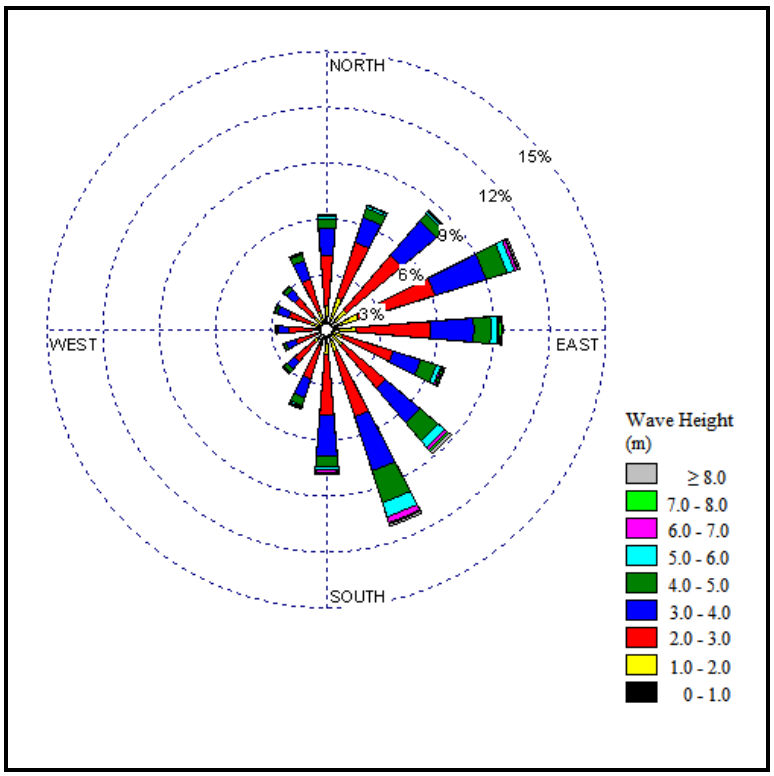

Wave Height Percentage Occurrence
Grid Point 10632
August
Percentage Occurrence (%)
70
60
50
40
30
20
10
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

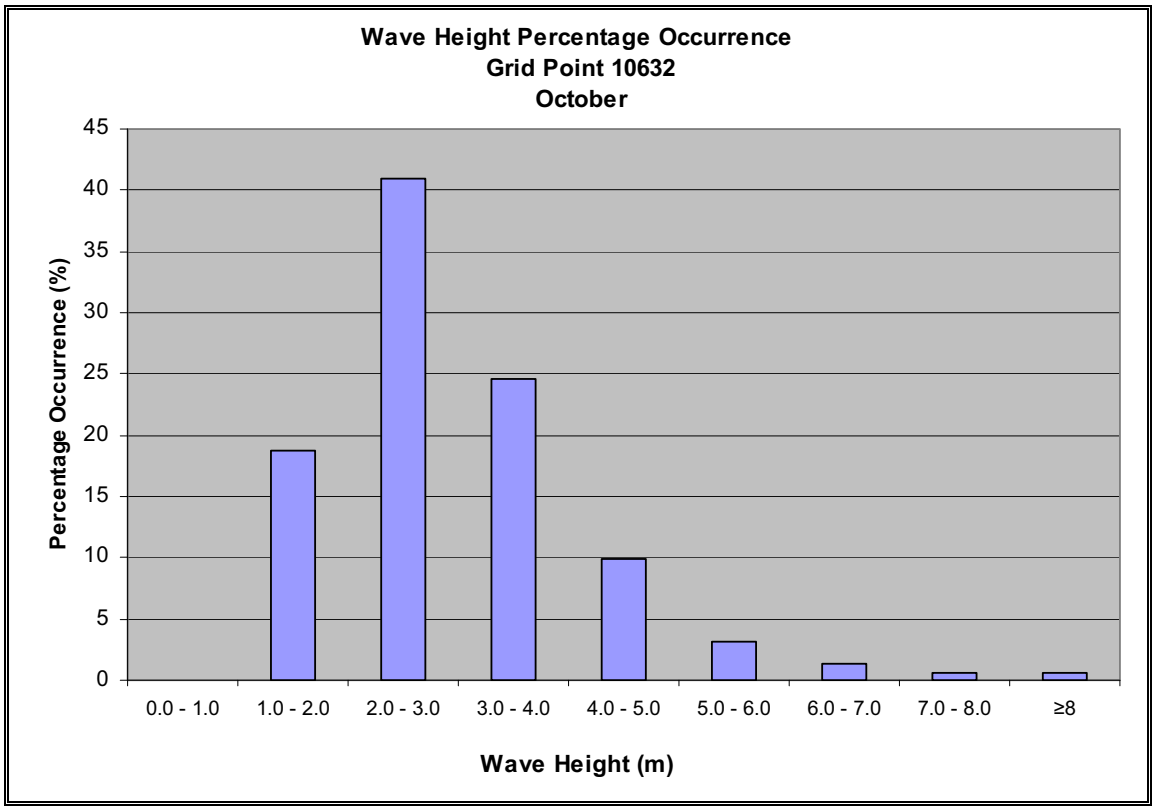
September


NORTH
EAST
SOUTH
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

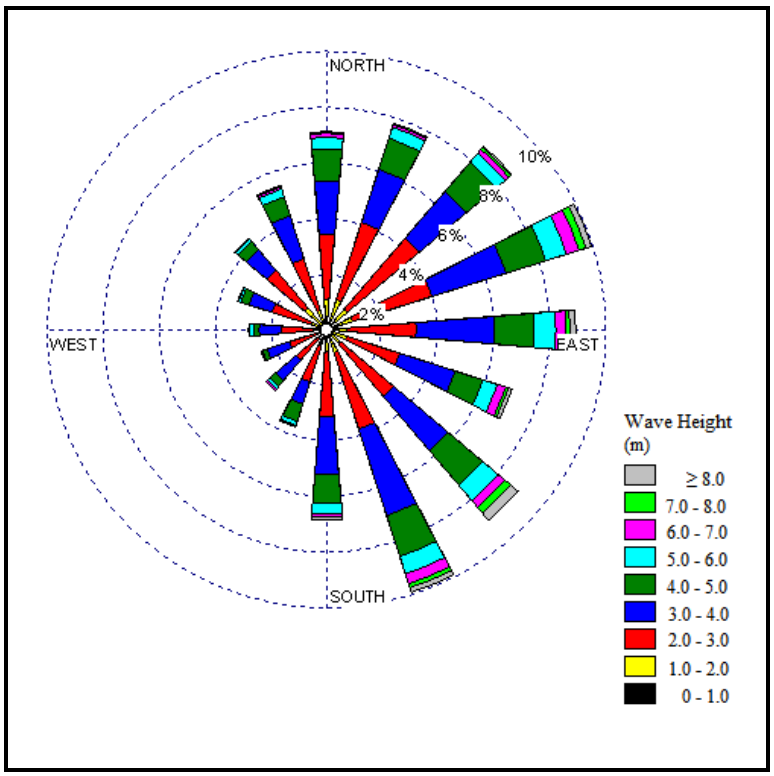

Wave Height Percentage Occurrence
Grid Point 10632
September
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

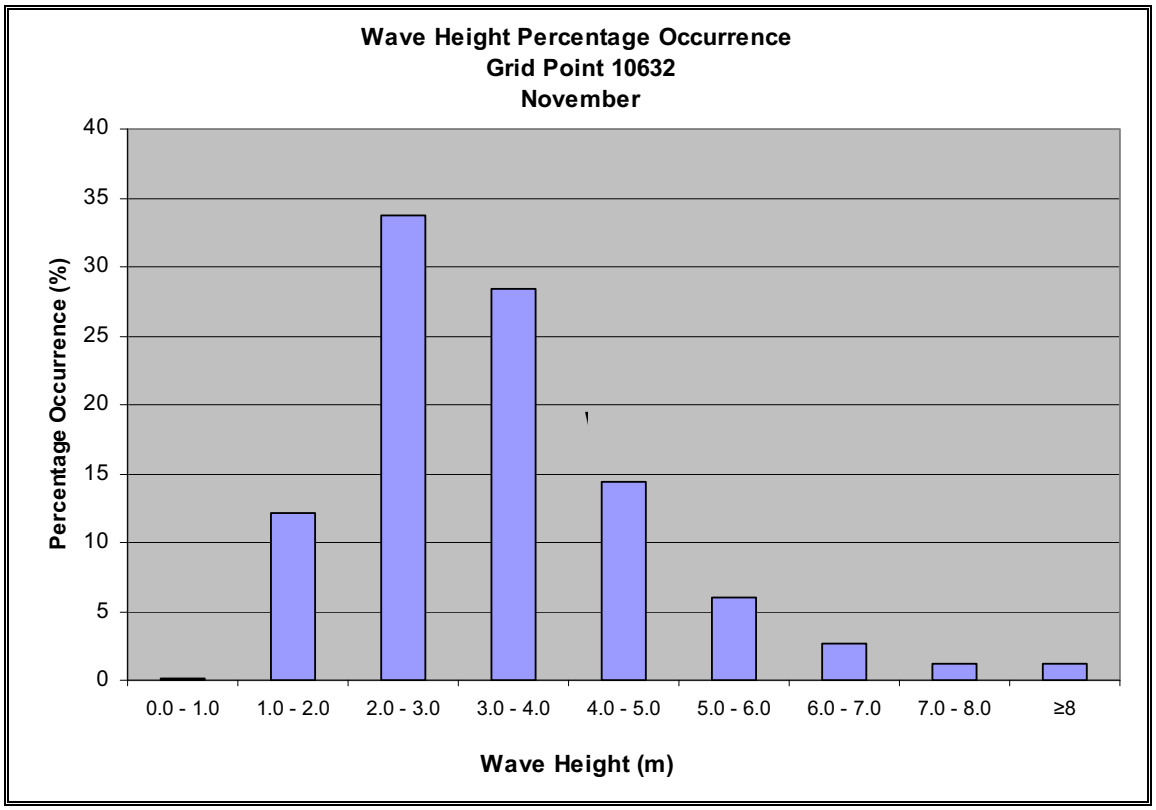
October


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

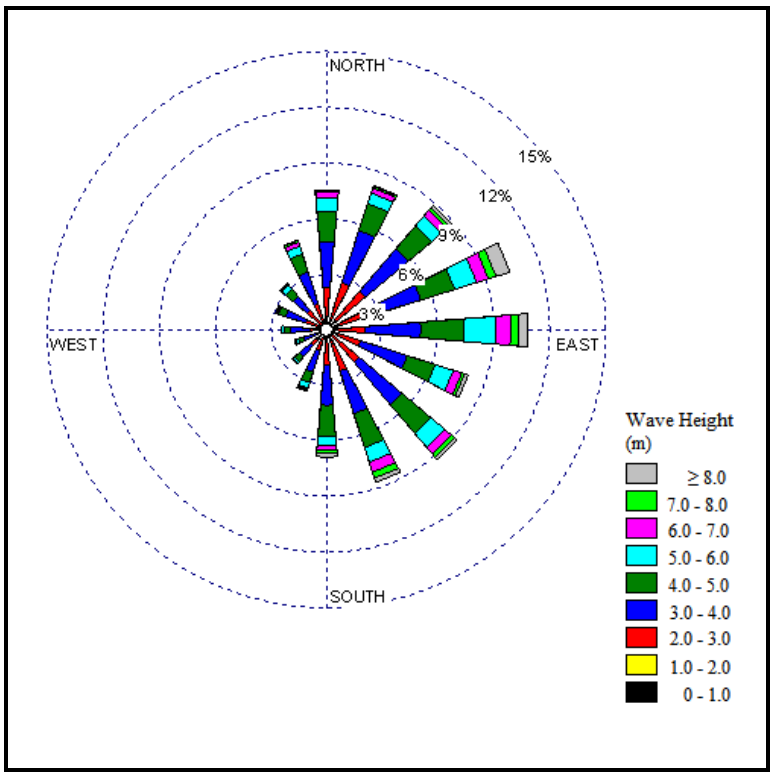

Wave Height Percentage Occurrence
Grid Point 10632
October
Percentage Occurrence (%)
45
40
35
30
25
20
15
10
5
0
0.0 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 6.0
6.0 - 7.0
7.0 - 8.0
≥8
Wave Height (m)

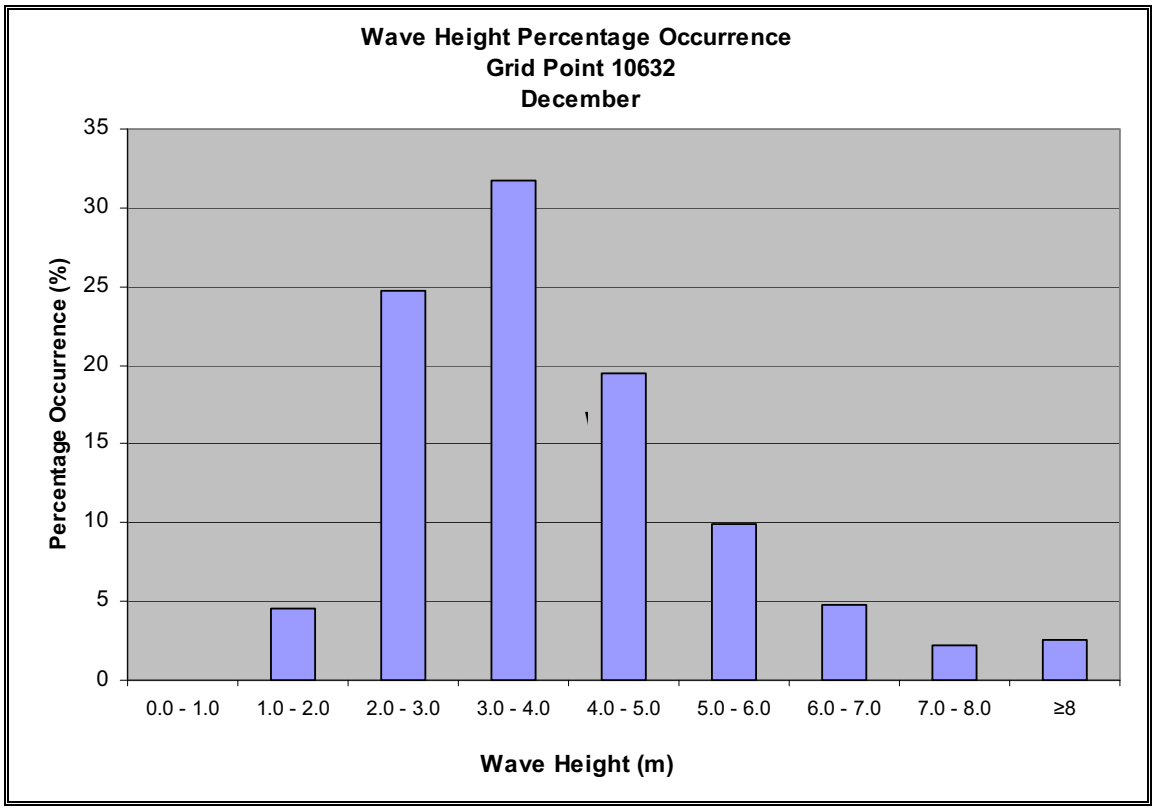
November


NORTH
EAST
SOUTH
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 10632
November
Percentage Occurrence (%)
0
5
10
15
20
25
30
35
40
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
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 10632
December
Percentage Occurrence (%)
35
30
25
20
15
10
5
0
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
Wave Height (m)