CENTRE FOR MARINE APPLIED RESEARCH

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WIND AND WAVE CONDITIONS – ANNAPOLIS BASIN – MARINE FINFISH LEASES 1039, 1040, 1041

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Executive Summary

In support of Centre for Marine Applied Research (CMAR), the following report presents wind and wave conditions at three locations in Annapolis Basin, Nova Scotia, Canada.

In this report, wave and wind conditions are presented for 3 locations:

- Marine Finfish Lease- 1039: 44° 39.209'N, 65° 45.316'W.
- Marine Finfish Lease- 1040: 44° 40.117'N, 65° 43.278'W.
- Marine Finfish Lease- 1041: 44° 38.743'N, 65° 43.182'W.

To determine the wave field evolution closer to shore at a specific site, and to determine more accurate 10 and 50 year return period wave data, near shore wave modelling can be used. For the Annapolis Basin area, STWave was used to model the nearshore wave conditions. The STWave model results are determined using wind and wave boundary condition data from the MSC50 HindCast model of a point in the Bay of Fundy outside of Annapolis Basin. The results show that the largest waves in the Basin are wind-generated waves from the east. Waves in the outer Bay of Fundy largely do not propagate into any of the lease locations assessed, as their energy is dissipated due to bottom friction, breaking, refraction, etc. through Digby Gut. The extreme wave conditions at the locations are determined in part by propagating wave from the offshore hindcast model location into the site of interested.

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1 Introduction

1.1 Overview

For the locations in Annapolis Basin shown in Figure 1, wind and wave conditions have been estimated. The following presents data on the predicted 10 and 50 year wind and wave conditions at these locations.

Figure 1 Three (3) site locations at Annapolis Basin [4]

Annapolis Basin is overall very protected from waves originated in the outer Bay of Fundy by surrounding lands. Offshore swell is not present at the entrance to the Digby Gut, but strong northerly winter storms can generate significant waves on the south coast of the Bay of Fundy. Finfish lease 1039 is potentially exposed to this wind generated waves which originate in the Bay of Fundy from the north-northwest through Digby Gut. Leases 1040 and 1041 are not exposed to waves generated in the Bay of Fundy, as can be seen in Figure 2. Wave modeling of the wind-generated waves in Annapolis Basin will enable accurate determination of wave conditions at the three leases, even though offshore swell nor waves from the Bay of Fundy are largely not present. The model uses a source point in the Bay of Fundy to potentially capture wave propagation through Digby Gut towards lease 1039.

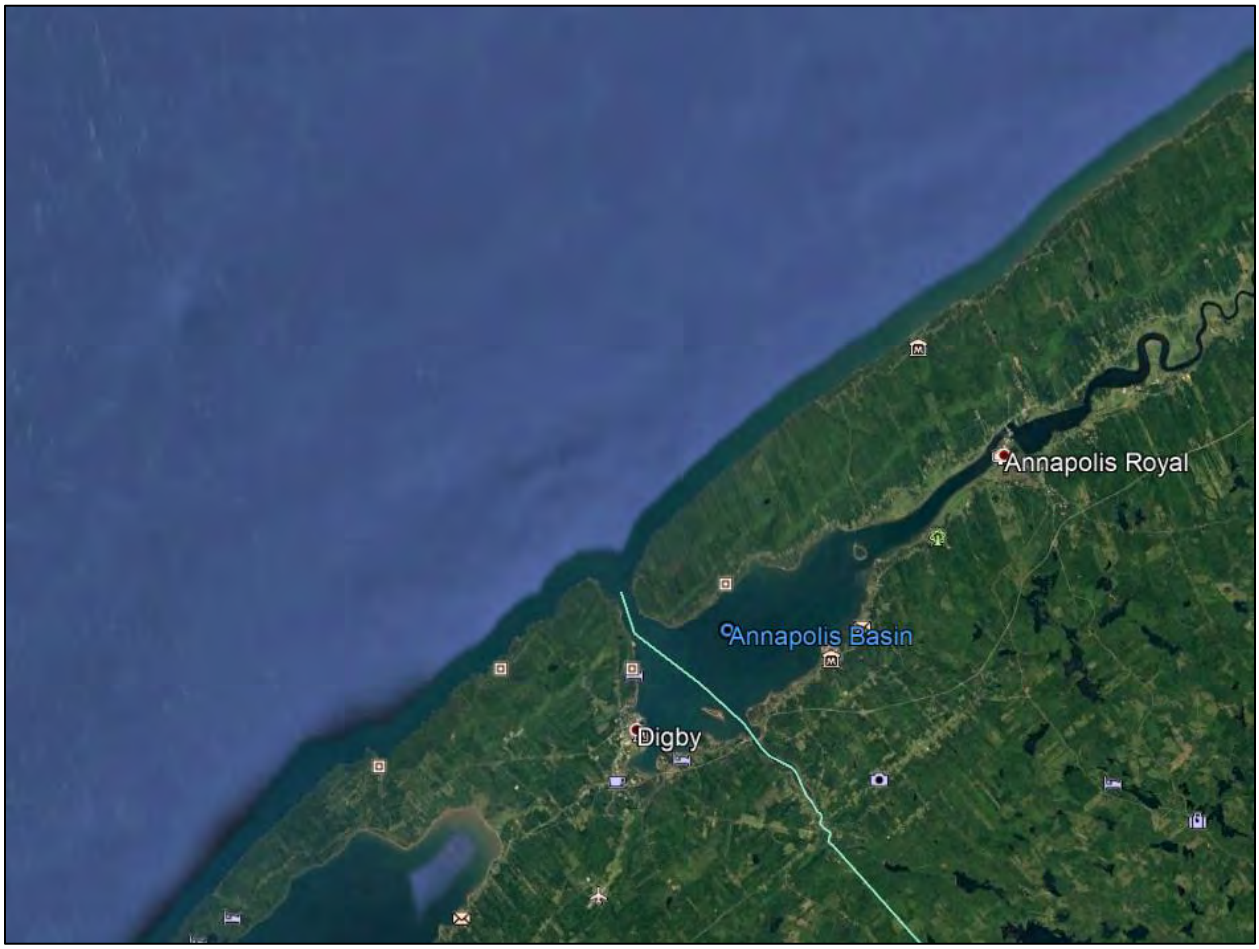


Figure 2 Annapolis Basin, Nova Scotia, Canada

The context of this project is that extreme wind and wave conditions are needed to select engineering load cases for those wishing to install finfish or shellfish farms in the area. For example, extreme environmental conditions with minimum 10-year and 50-year return periods are required for the design of a marine fish farm site, as per guidance in the Scottish Technical Standard [2], and NS9415 [3]. While the locations assessed as part of this modeling exercise are actual aquaculture site locations, the data produced for these locations is useful for understanding the approximate wave climate in the region and can be used to evaluate any proposals for sites in the area. Understanding the wind and wave climates at aquaculture sites is important for mitigating risks.

1.2 Objective(s)

- Determine wave/wind conditions at three locations in Annapolis Basin and find the conditions with 10 and 50 year return periods.

2 Abbreviations and acronyms

DSA	Dynamic Systems Analysis Ltd.
SMS	Surface-water Modeling System
CMAR	Centre for Marine Applied Research
CHS	Canadian Hydrographic Services

3 Reference documents and drawings

[1]	V. Swail, V. Cardone, M. Ferguson, D. Gummer, E. Harris, E. Orelup, and A. Cox, "The msc50 wind and wave reanalysis," in *9th International Workshop On Wave Hindcasting and Forecasting*, 2006.
[2]	Marine Scotland. (2015). A Technical Standard for Scottish Finfish Aquaculture. Ministerial Group for Sustainable Aquaculture's Scottish Technical Standard Steering Group
[3]	Norge, S. (2009). Norwegian Standard NS 9415. E: 2009. Marine Fish Farms—Requirements for Site Survey, Risk Analyses, Design, Dimensioning, Production, Installation and Operation. *Standard Norge, Lysaker*.
[4]	CMAR approved sites -RevB.kmz

4 Wave conditions

4.1 Overview

SMS version 12.2.13 was used to setup the bathymetric and computational grid. This section provides a description of the grid size, mesh size and offshore environmental conditions. Site bathymetry is provided in Figure 3. Note that a CHS hydrographic chart is used to generate the bathymetric data for wave modeling.

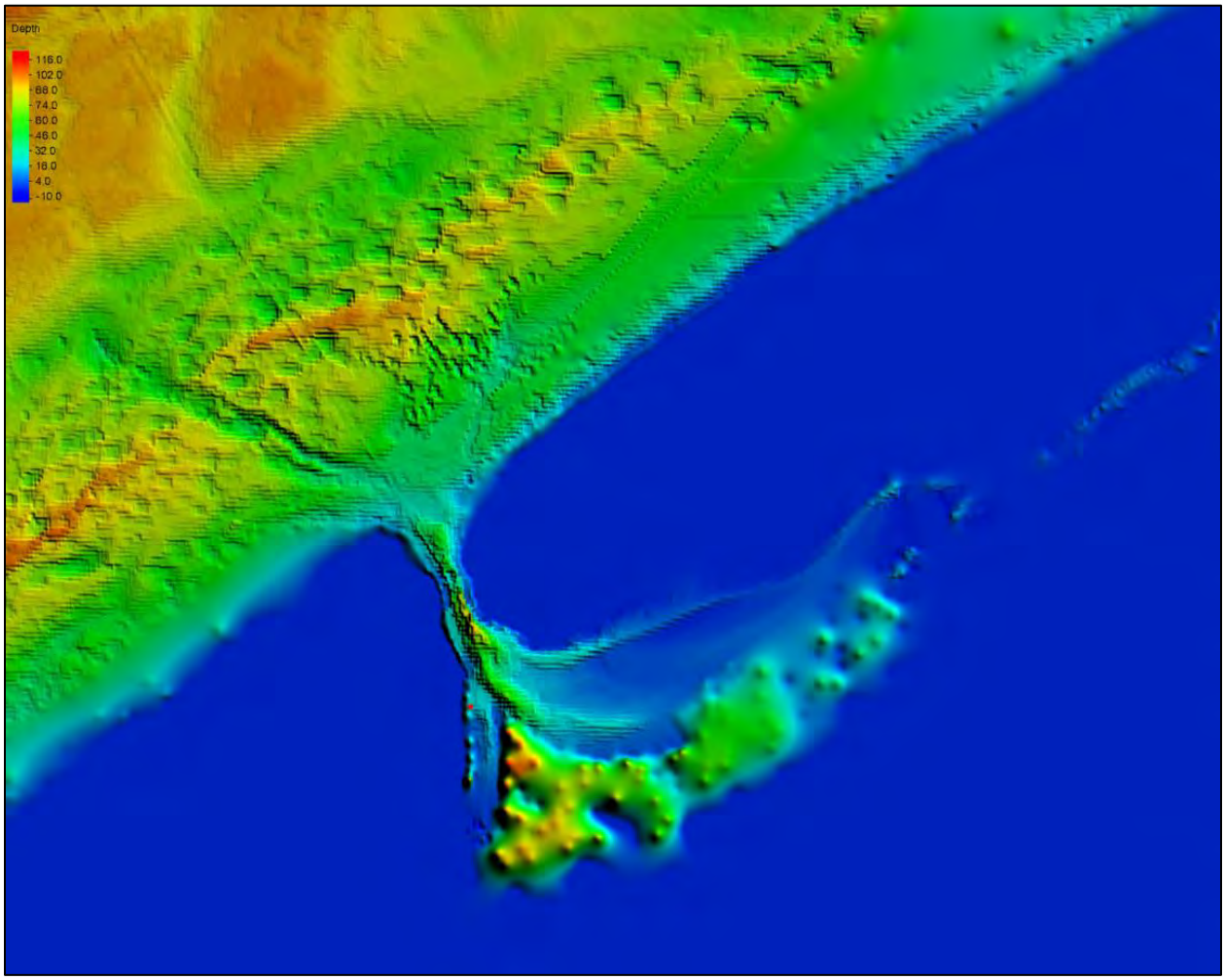


Figure 3 Bathymetry at site on hydrographic charts- Depth reported in meters

4.2 Wave Model Description

SMS, created by Aquaveo, is a modelling suite in which various water surface modelling tools, like wave and flow models, can be used. For this analysis SMS in combination with STWave is used. STWave is a nearshore spectral Hydraulics model, developed by U.S. Army Engineer Research and Development Center (ERDC) and Coastal and Hydraulics Laboratory (CHL). It is capable of modelling accurately wave transformation and propagation.

Two grids were setup, computational grid and spectral grid. The computational grid and its mesh sizes are mainly defined by the bathymetry. The bathymetry in SMS is presented in Figure 4. For this analysis the computational grid size was 22.6km x 25.1km. The mesh size was 15m x 15m, resulting in 1512 x 1675 = 2,532,600 grid cells.

The spectral domain was divided into 72 directions and 50 frequencies, with a minimum frequency of 0.03Hz and a maximum frequency of 1.01Hz.

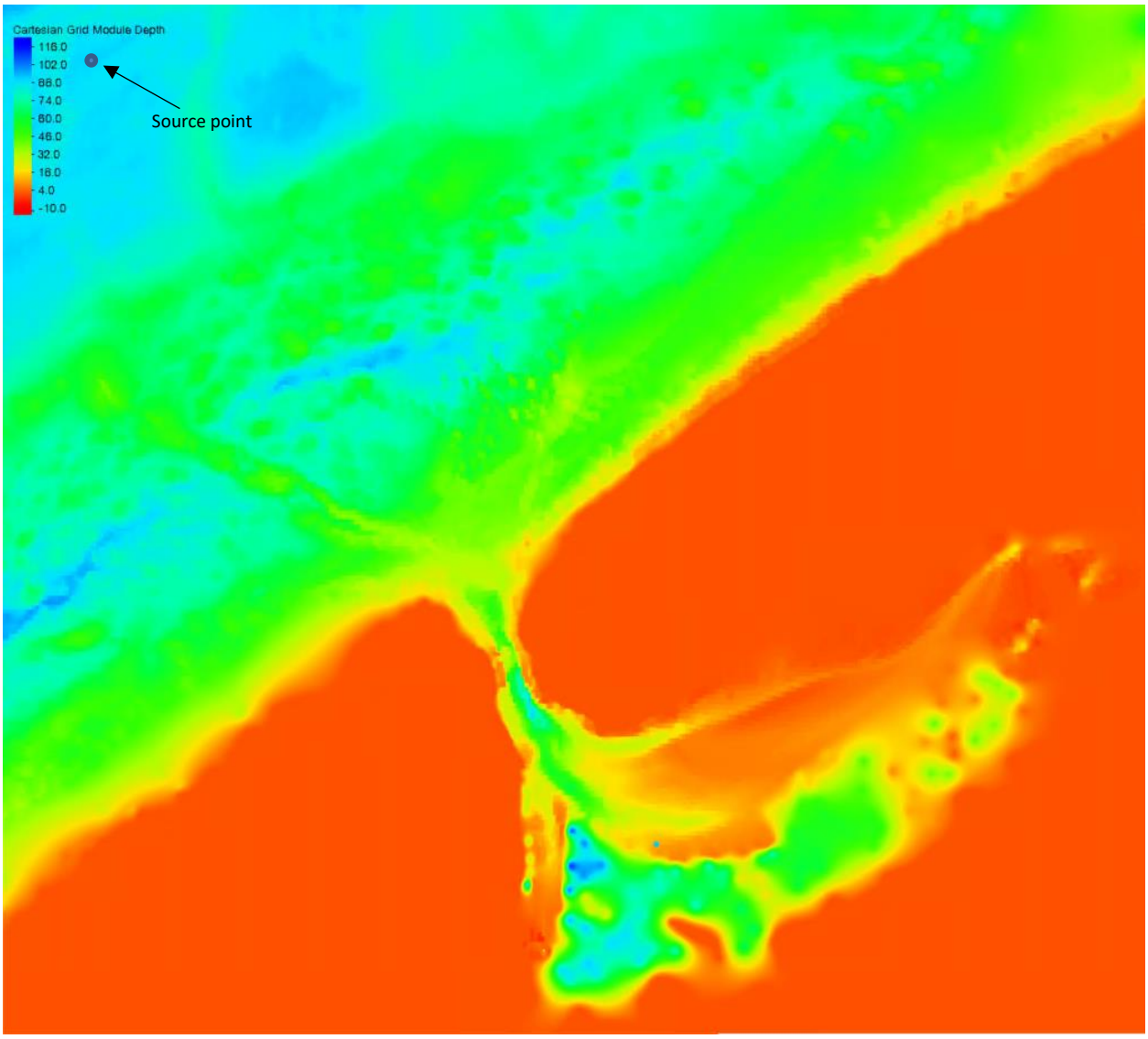


Figure 4 Bathymetry at site on STWave. Note the MSC50 HindCast model source point indicated at 44° 48.000'N, 65° 54.000'W Boundary conditions – offshore wind and wave conditions

The MSC50 HindCast model [1] data from location 44° 48.000'N, 65° 54.000'W was used to determine the 10 and 50 year return periods for wind and wave of the Annapolis Basin reference sites; the location is labelled as the “Source point” in Figure 4. The scatterplot of wave heights versus wave directions for the source point is shown in Figure 5. The scatter plot of wind speeds versus wind directions for the source point is also shown in Figure 6. Extreme waves and wind at the source point appear to originate more frequently from the north and northwest.

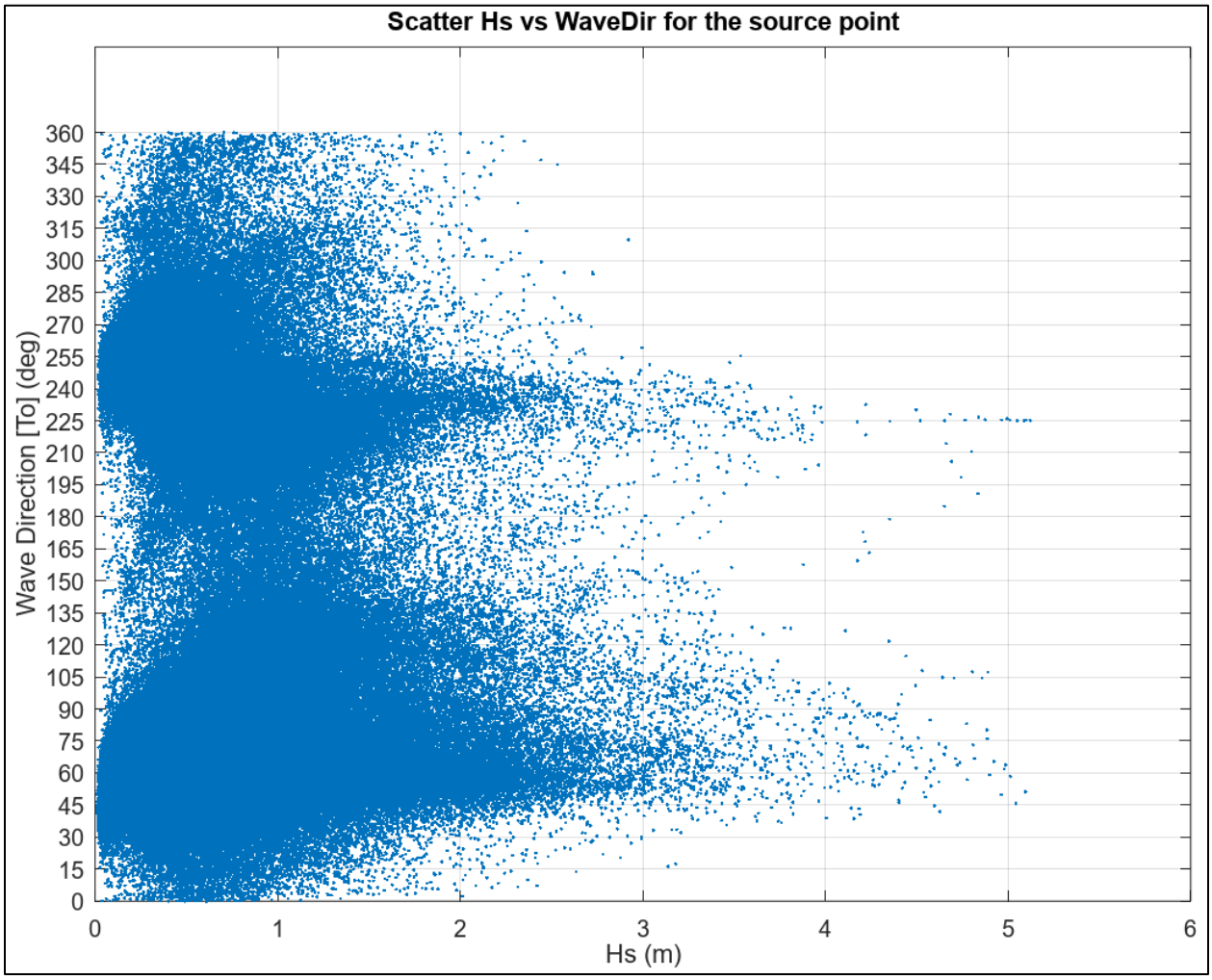


Figure 5 Wave height versus wave direction plot for the source point

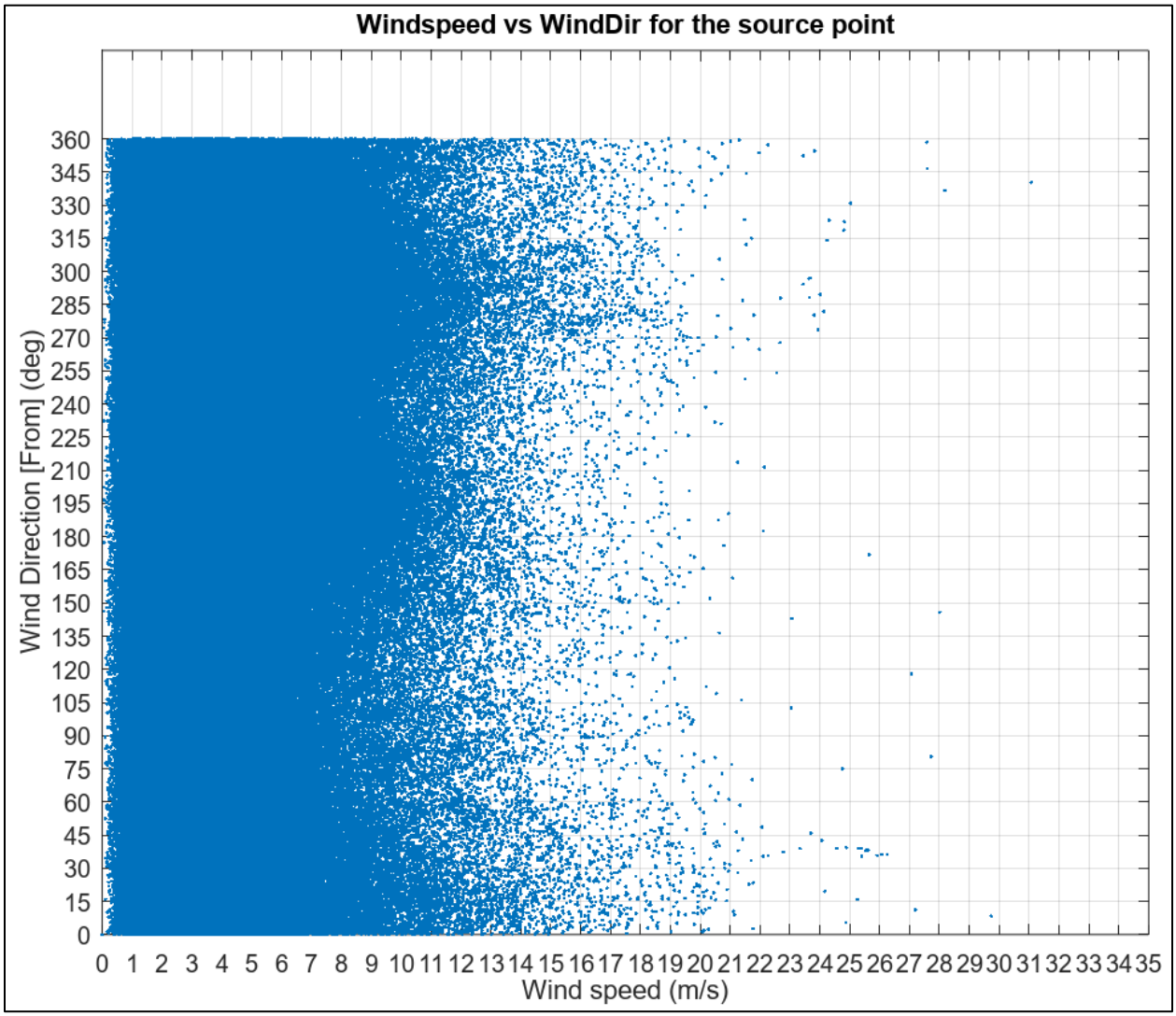
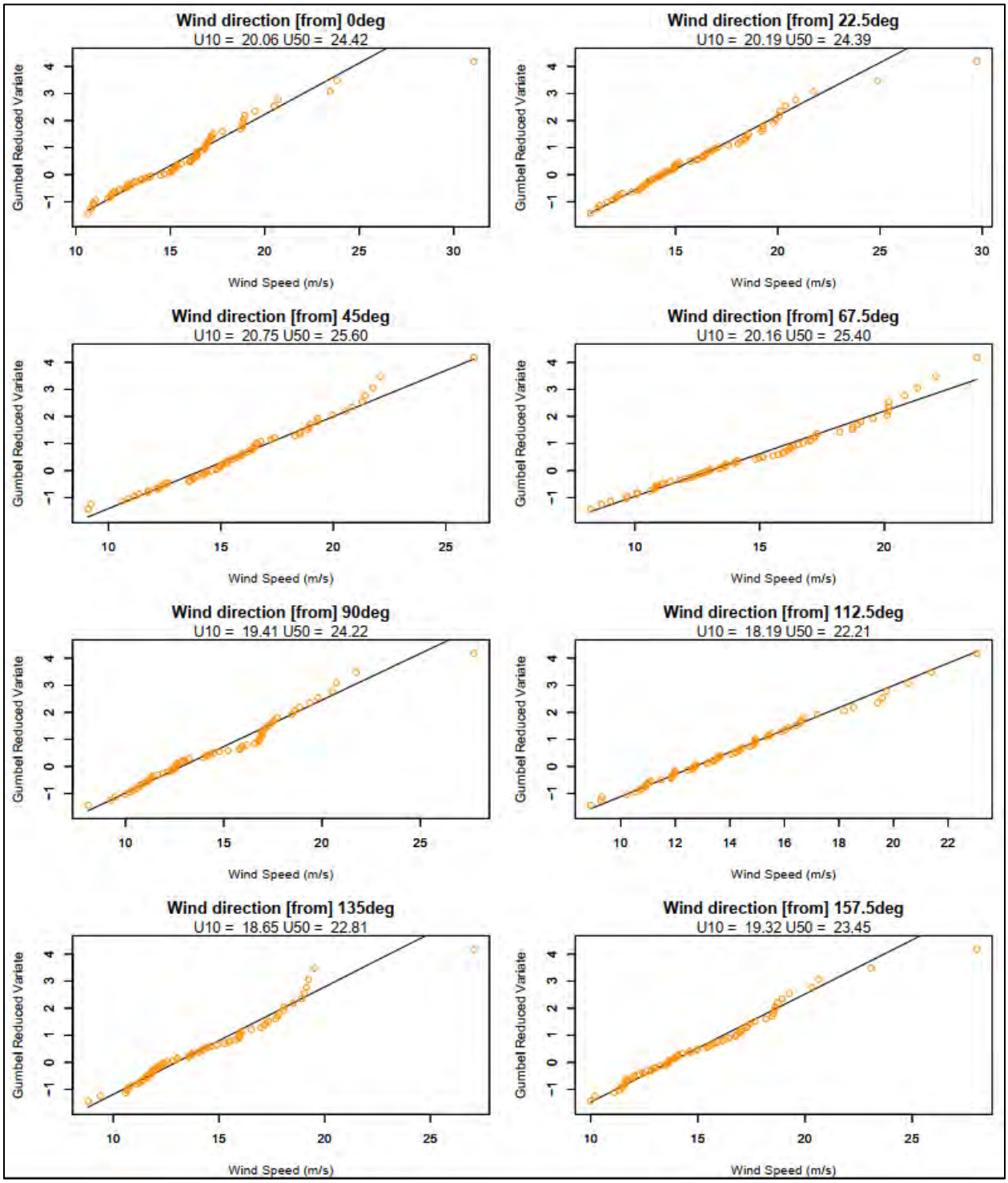


Figure 6 Wind speed versus wind direction plot for the source point

10 and 50 year return period conditions are in general achieved by:

- Obtaining measured or hindcast data for parameter in question
- For each parameter, bin data by direction
- Perform extreme value analysis.
    - Extract annual maxima
    - Fit Gumbel or Weibull distribution to this data
    - Use fitted distribution to calculate values corresponding to 10 and 50 year return period

The extreme value analysis of the wind velocities is presented in Figure 7. U10 and U50 represent the 10 and 50 year return period wind velocities, respectively.


Wind direction [from] 0deg
U10 = 20.06 U50 = 24.42
Wind direction [from] 22.5deg
U10 = 20.19 U50 = 24.39
Wind direction [from] 45deg
U10 = 20.75 U50 = 25.60
Wind direction [from] 67.5deg
U10 = 20.16 U50 = 25.40
Wind direction [from] 90deg
U10 = 19.41 U50 = 24.22
Wind direction [from] 112.5deg
U10 = 18.19 U50 = 22.21
Wind direction [from] 135deg
U10 = 18.65 U50 = 22.81
Wind direction [from] 157.5deg
U10 = 19.32 U50 = 23.45
Gumbel Reduced Variate
Wind Speed (m/s)

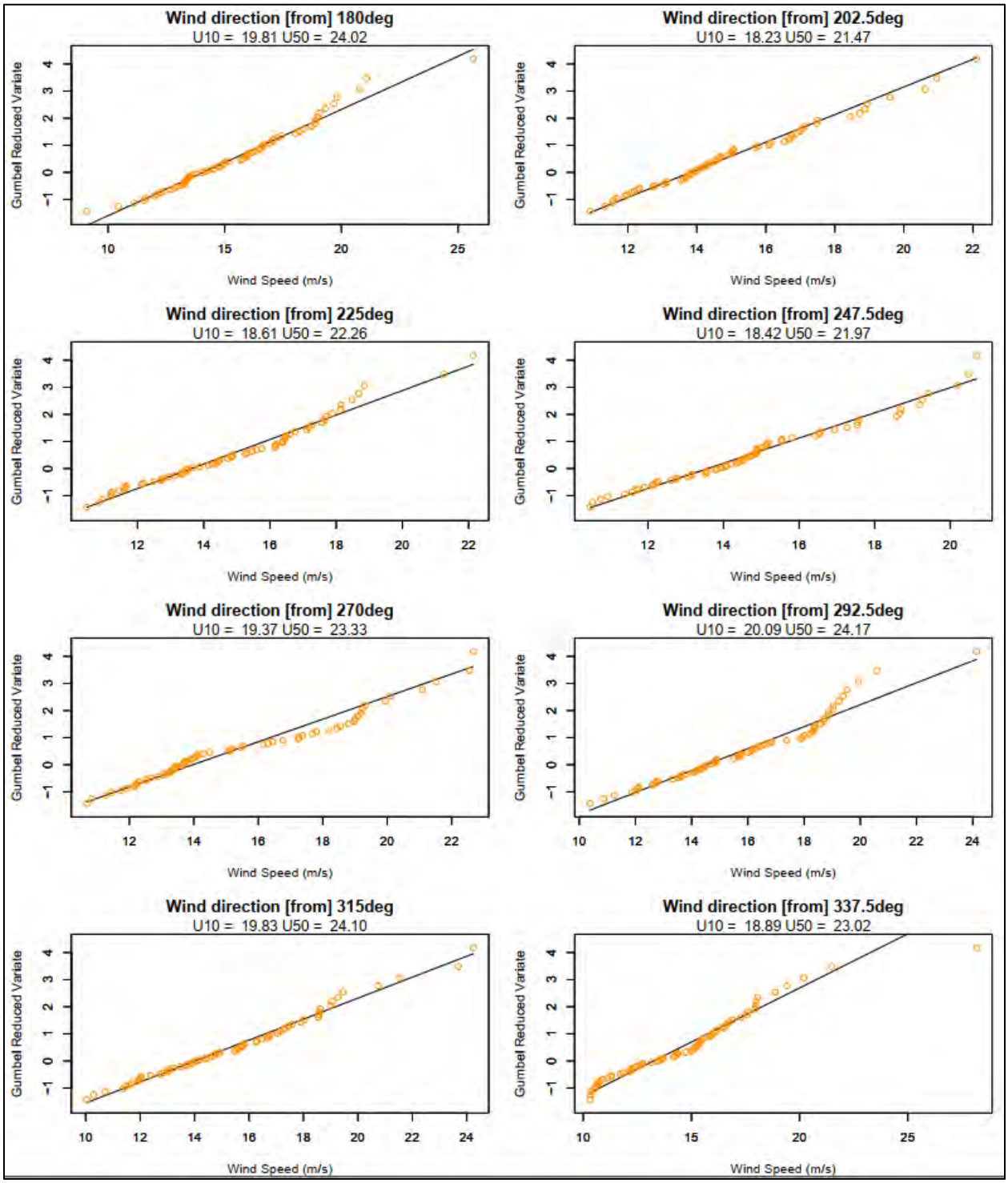
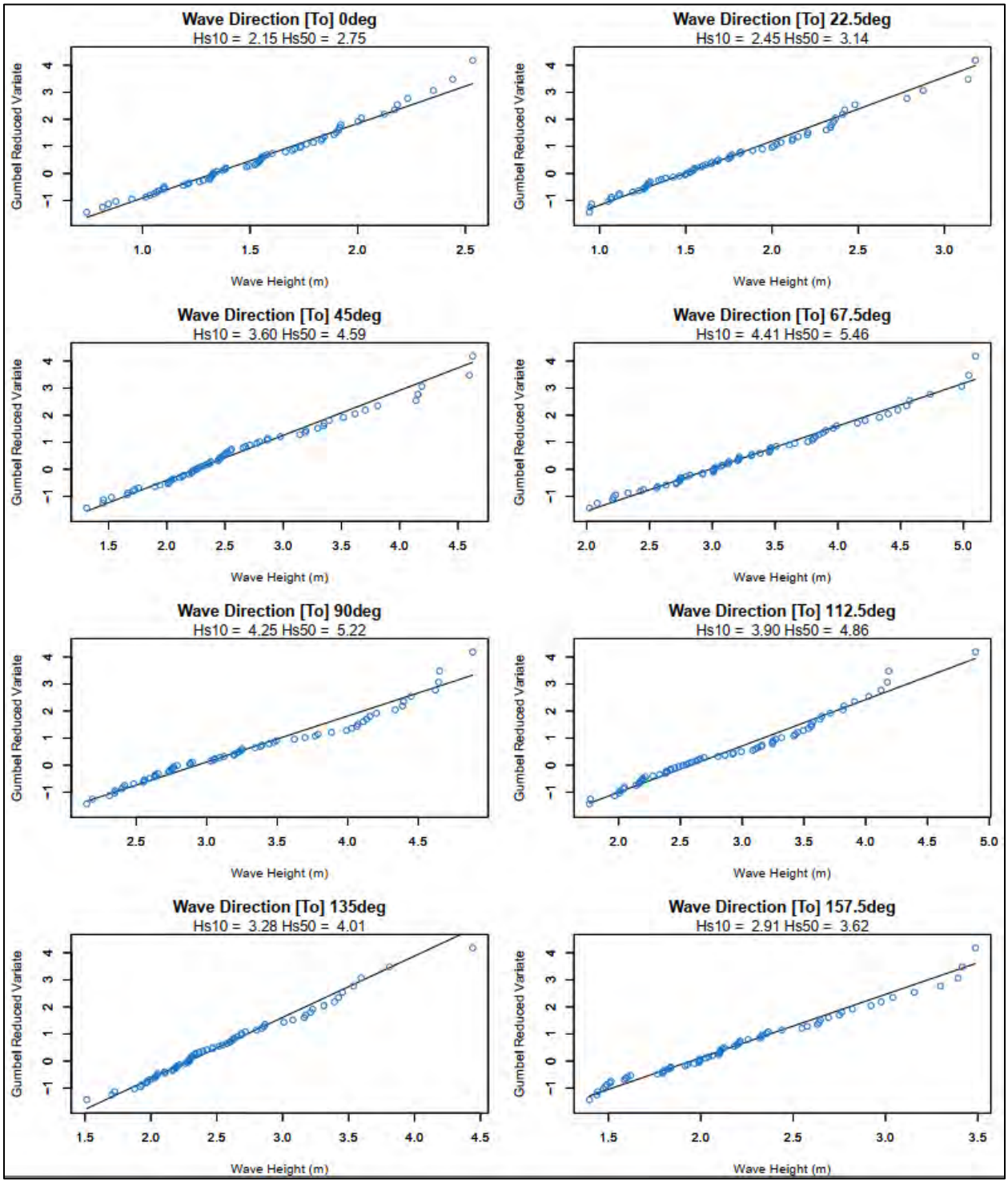


Figure 7: Extreme value analysis on wind data – for Source Point offshore location [1]

The extreme value analysis of the wave heights is presented in Figure 8. Similar to the presentation of the wind data, Hs10 and Hs50 represent the 10 and 50 year return period wave heights, respectively.


Wave Direction [To] 0deg
Hs10 = 2.15 Hs50 = 2.75
Wave Direction [To] 22.5deg
Hs10 = 2.45 Hs50 = 3.14
Wave Direction [To] 45deg
Hs10 = 3.60 Hs50 = 4.59
Wave Direction [To] 67.5deg
Hs10 = 4.41 Hs50 = 5.46
Wave Direction [To] 90deg
Hs10 = 4.25 Hs50 = 5.22
Wave Direction [To] 112.5deg
Hs10 = 3.90 Hs50 = 4.86
Wave Direction [To] 135deg
Hs10 = 3.28 Hs50 = 4.01
Wave Direction [To] 157.5deg
Hs10 = 2.91 Hs50 = 3.62
Gumbel Reduced Variate
Wave Height (m)

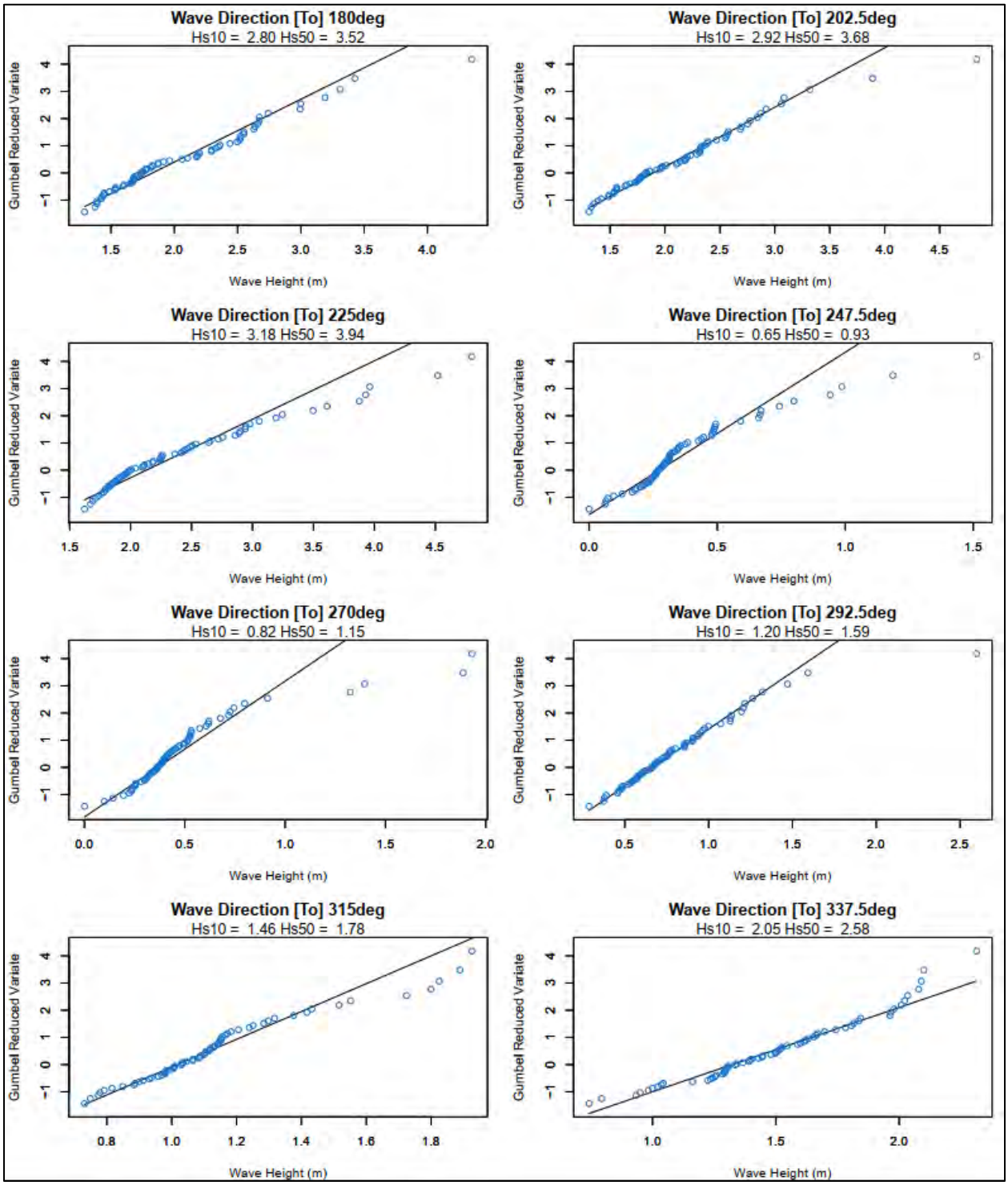


Figure 8: Extreme value analysis on wave data – for Source Point offshore location [1]

In summary, the following data was obtained from the extreme value analysis:

Table 1 Results extreme value analysis for wind and waves at the offshore source point location in Figure 4

Direction [from] [°]		$U_{wind,10year}$ [m/s]	$U_{wind,50year}$ [m/s]	$H_{s,10year}$ [m]	$H_{s,50year}$ [m]
0	N	20.06	24.42	2.8	3.52
23	NNE	20.19	24.39	2.92	3.68
45	NE	20.75	25.6	3.18	3.94
68	ENE	20.16	25.4	0.65	0.93
90	E	19.41	24.22	0.82	1.15
113	ESE	18.19	22.21	1.2	1.59
135	SE	18.65	22.81	1.46	1.78
158	SSE	19.32	23.45	2.05	2.58
180	S	19.81	24.02	2.15	2.75
203	SSW	18.23	21.47	2.45	3.14
225	SW	18.61	22.26	3.6	4.59
248	WSW	18.42	21.97	4.41	5.46
270	W	19.37	23.33	4.25	5.22
293	WNW	20.09	24.17	3.9	4.86
315	NW	19.83	24.1	3.28	4.01
338	NNW	18.89	23.02	2.91	3.62

Polar plots for maximum wind speeds and wave heights at 10 year and 50 year return periods are shown in Figure 9 to Figure 12, respectively.

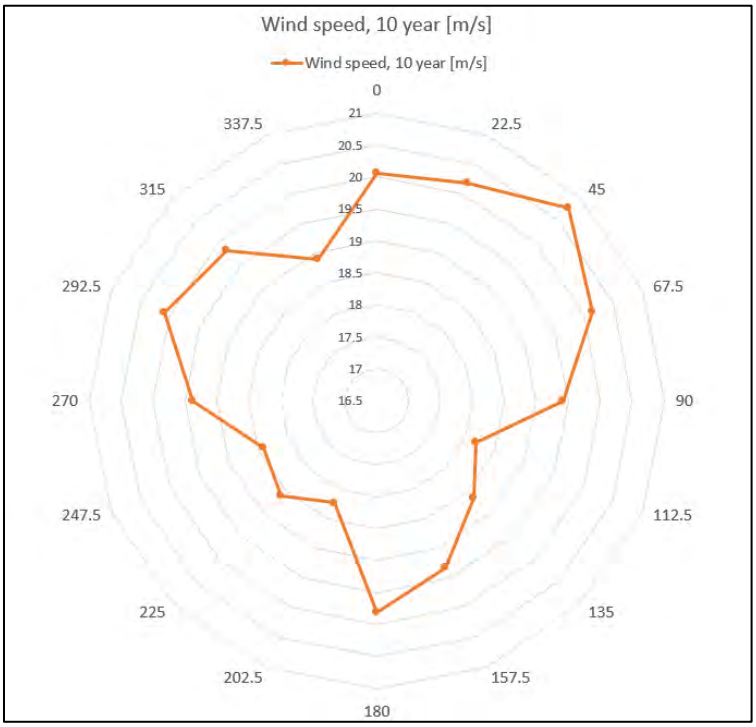


Figure 9 Maximum wind speed at 10 year return period and direction [from]- for Source Point offshore location [1]

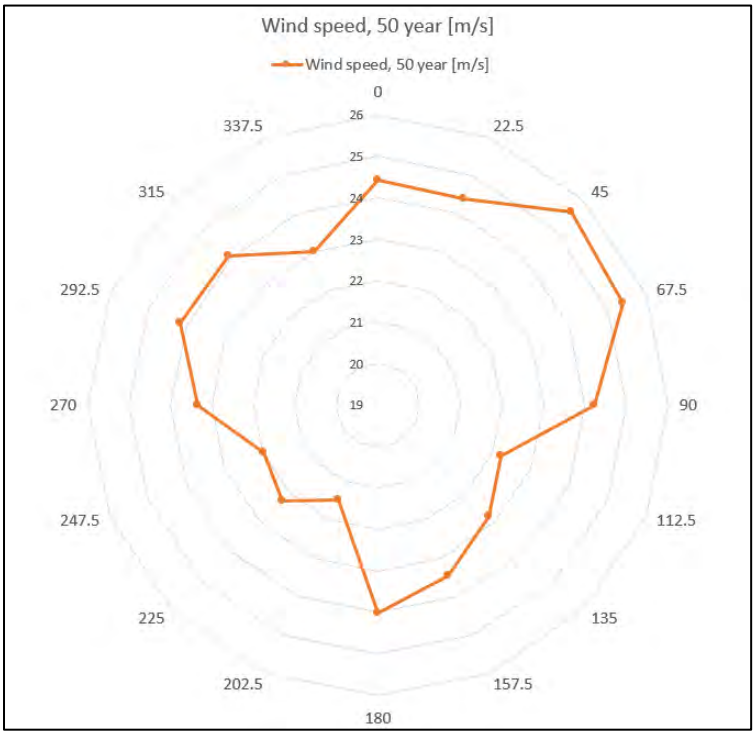


Figure 10 Maximum wind speed at 50 year return period and direction [from]- for Source Point offshore location [1]

Figure 11 Maximum wave height at 10 year return period and direction [from]- for Source Point offshore location [1]

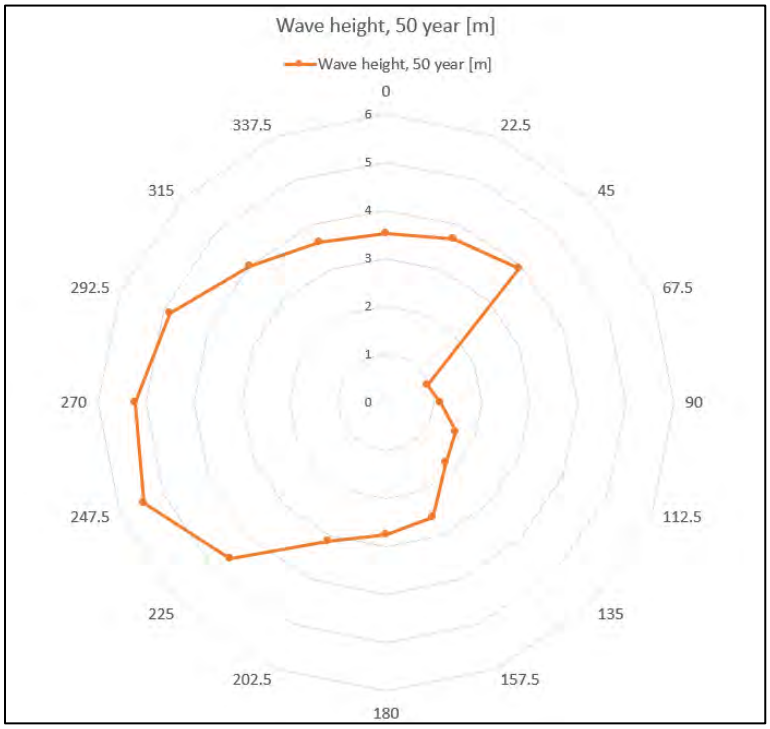


Figure 12 Maximum wave height at 50 year return period and direction [from]- for Source Point offshore location [1]

The wave data, presented in Table 1, was set as boundary condition and specified as a JONSWAP spectrum. The peak-enhancement factor was set to 3.3 and directional spreading was included as a $\cos^m(\theta)$ distribution.

Only wind-wave interaction was considered. Current-wave interaction was not included because local flow velocities are very small.

Eight headings were used, the wind direction was kept constant within its directional bin. T_p was varied in the presented range as shown in Table 2.

Table 2 T_p values used in analysis.

Direction [from] [°]		*T_p [s]*
0	N	4.2_7.9
23	NNE	3.65_8.1
45	NE	4.25_8.84
68	ENE	1.5_10
90	E	1.5_10.1
113	ESE	3_13
135	SE	3.37_13.2
158	SSE	3.65_5.48
180	S	3.4_6.6
203	SSW	3.8_6.7
225	SW	4.9_14
248	WSW	6_12.4
270	W	4.7_11.4
293	WNW	5_8.5
315	NW	5.2_8
338	NNW	4.73_7.4

In this method, wave design conditions for the project location are based on 10 and 50 year return period sea-state and winds for an offshore location, which have subsequently been transferred to the project location. This will provide reasonable design conditions; however, they cannot be linked directly to a return period at the site.

4.3 Wave modeling results

The results of the wave modeling are presented in Figure 13 to Figure 15 for directions from north and northwest, respectively for three key wave headings with the highest wave heights. As stated in the previous section, the wind conditions are assumed to stay constant for the region. The results from STWave represent the maximum significant wave height value at the region including its spectral peak period and wave direction.

The location of sites at the Annapolis Basin are presented in Figure 1. The estimated wave and wind conditions for each site based on the STWave modeling are presented in the following sections.

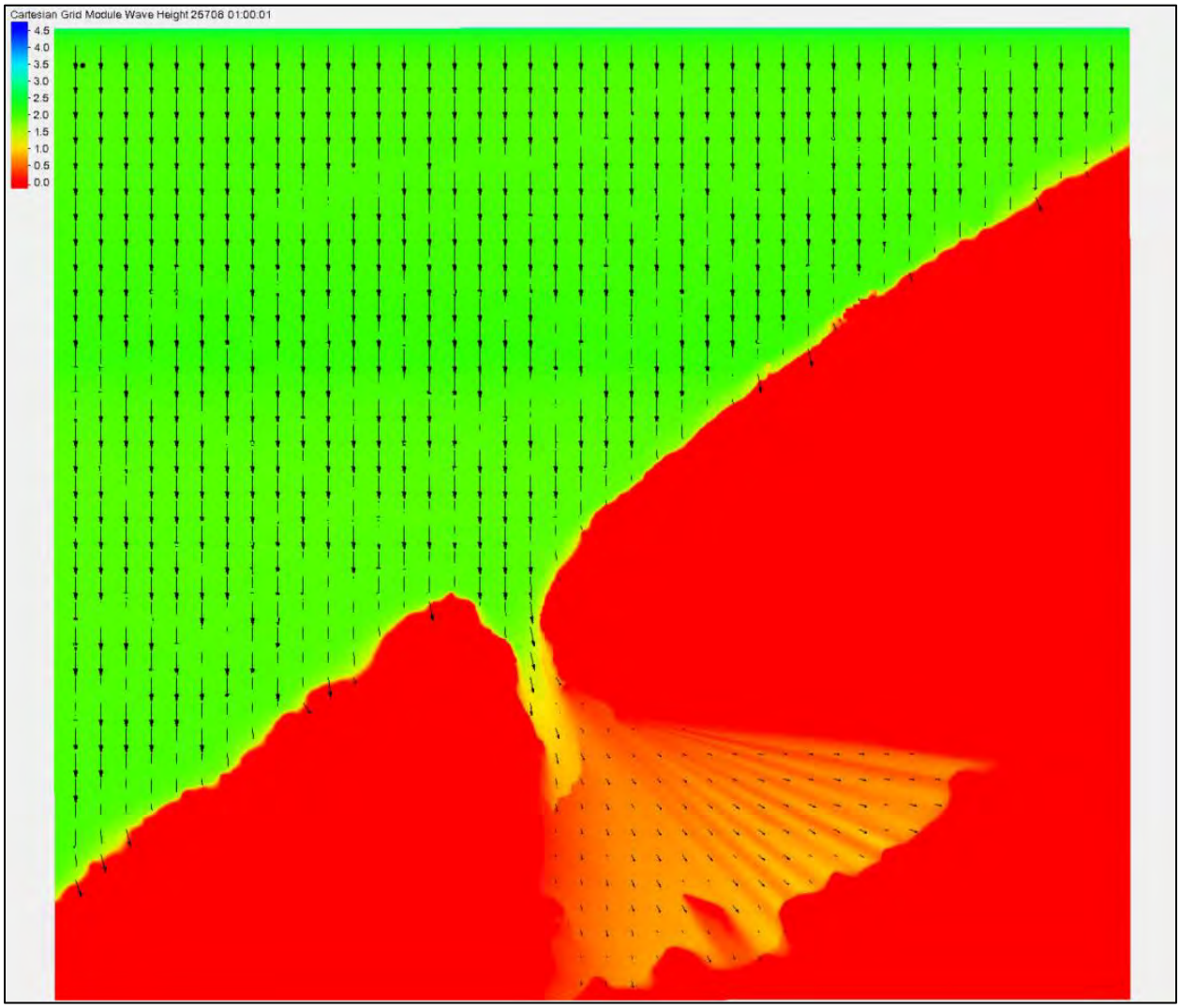


Figure 13 Wave modeling results for direction [From] 0 deg- N

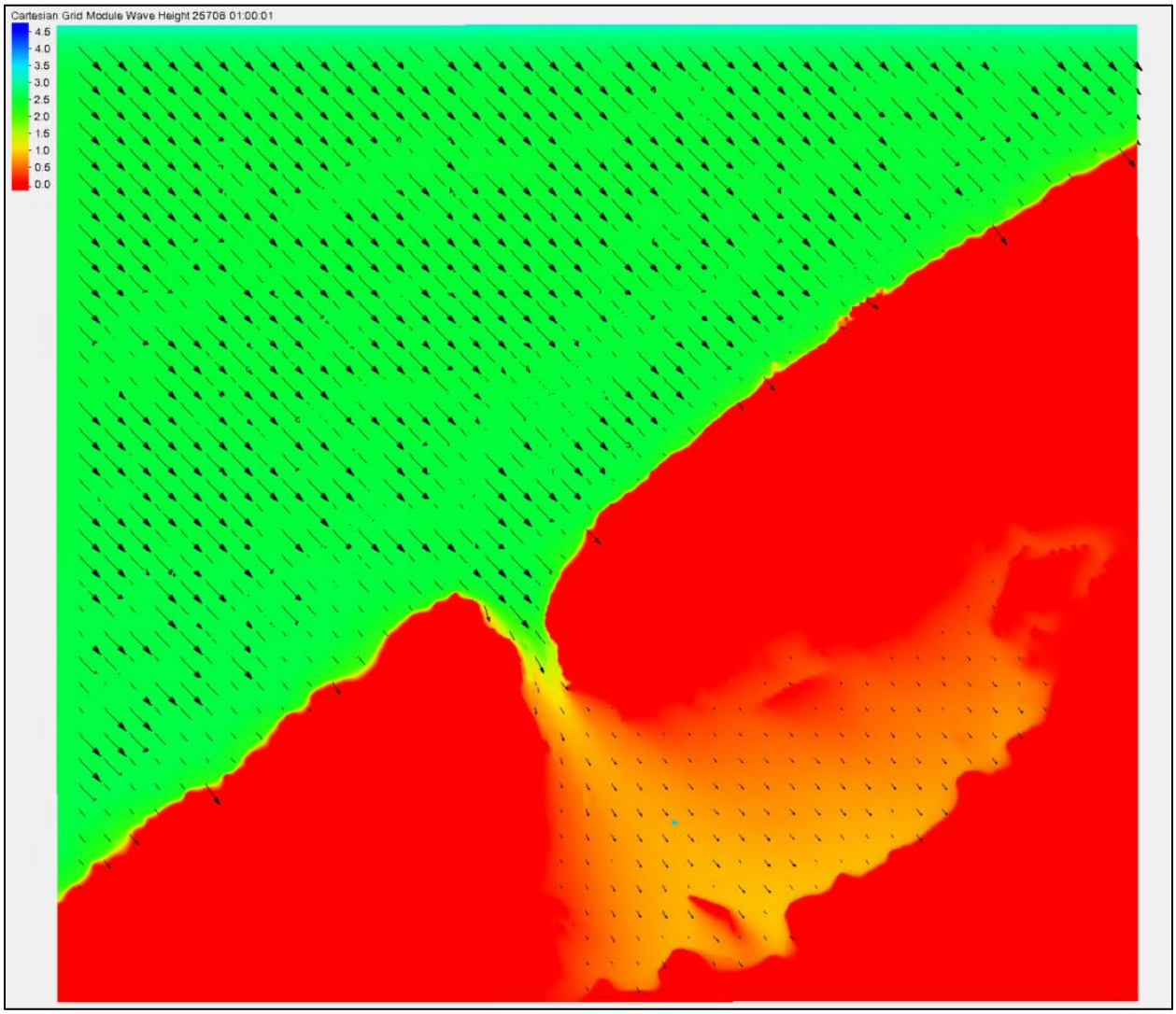


Figure 14 Wave modeling results for direction [From] 315 deg- NW

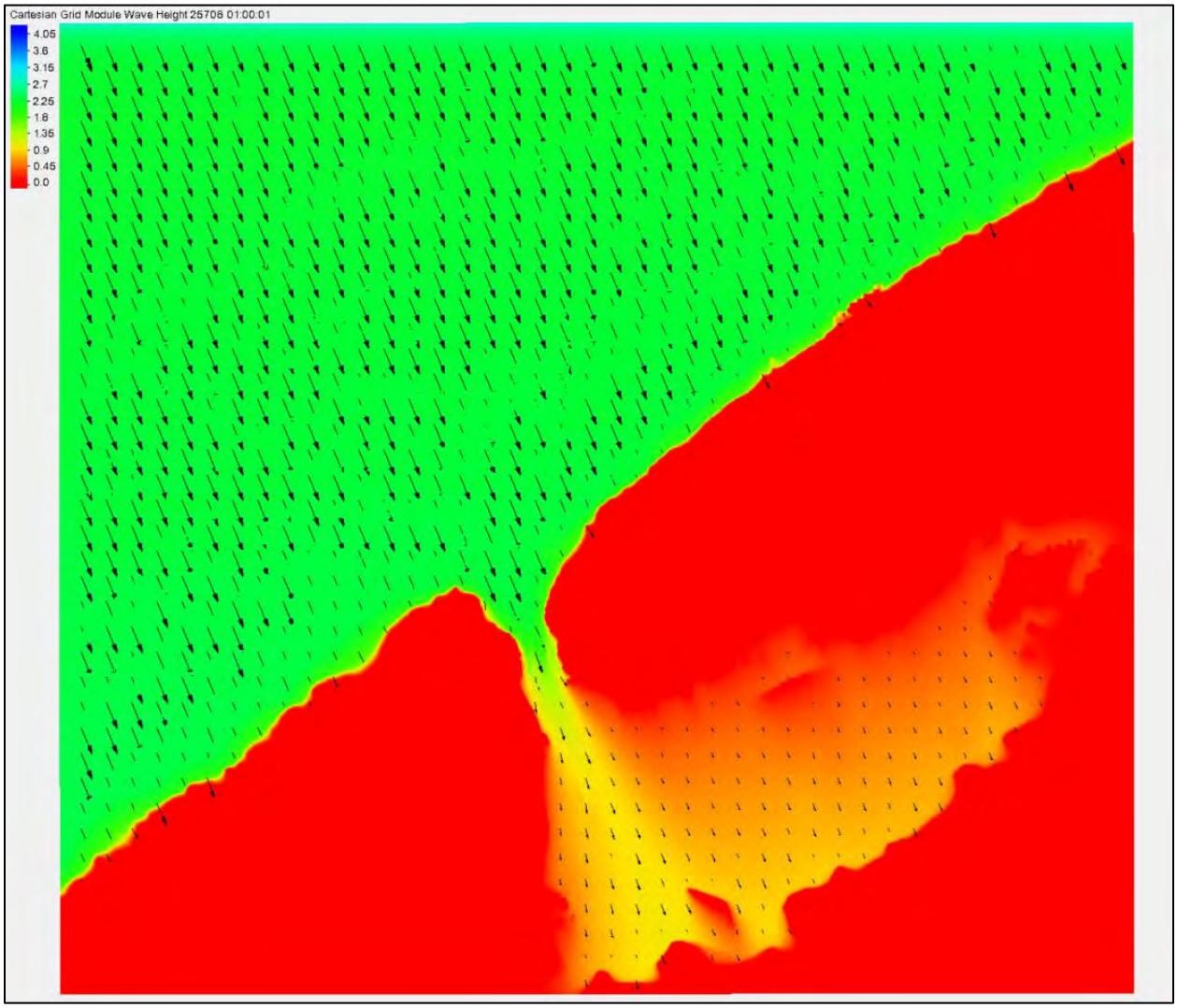


Figure 15 Wave modeling results for direction [From] 338 deg- NNW

4.3.1 Wave/wind conditions for Annapolis Basin- Marine Finfish Lease- 1039

The wave and wind results from the STWave model, for the Annapolis Basin- Marine Finfish Lease- 1039, are summarized in Table 3. Note that the results in Table 3 indicate significant wave height (Hs) and peak period (T_P) for the selected site. These represent the extreme wave conditions at this coordinate: 44° 39.209'N, 65° 45.316'W.

Table 3 Estimated wave and wind design conditions for Annapolis Basin- Marine Finfish Lease- 1039

Wave/Wind conditions	Direction [from] [°]		Wind (m/s)	Hs (m)	Tp (s)
10yr wave/wind	*0*	N	20.06	0.56	3.01
	23	NNE	20.19	0.43	2.13
	45	NE	20.75	0.62	3.73
	68	ENE	20.16	0.96	3.4
	90	E	19.41	1.08	3.27
	113	ESE	18.19	0.62	2.7
	135	SE	18.65	0.74	2.69
	158	SSE	19.32	0.79	2.6
	180	S	19.81	0.61	2.38
	203	SSW	18.23	0.14	1.26
	225	SW	18.61	0.17	1.31
	248	WSW	18.42	0.16	1.29
	270	W	19.37	0.17	1.31
	293	WNW	20.09	0.11	1.9
	315	NW	19.83	0.33	4.84
	338	NNW	18.89	0.6	3.76
50yr wave/wind	*0*	N	24.42	0.66	2.82
	23	NNE	24.39	0.55	2.32
	45	NE	25.6	0.79	4.1
	68	ENE	25.4	1.21	3.74
	90	E	24.22	1.37	3.6
	113	ESE	22.21	0.77	2.95
	135	SE	22.81	0.93	2.92
	158	SSE	23.45	0.98	2.81
	180	S	24.02	0.75	2.58
	203	SSW	21.47	0.2	1.45
	225	SW	22.26	0.22	1.44
	248	WSW	21.97	0.21	1.39
	270	W	23.33	0.22	1.41
	293	WNW	24.17	0.14	1.32
	315	NW	24.1	0.37	4.6
	338	NNW	23.02	0.7	3.62

It should be noted that the return periods indicated for each wave parameter in Table 3 are representative of the boundary condition used to derive that value, not the value itself. Polar plots for maximum wave heights are presented in Figure 16 and Figure 17.

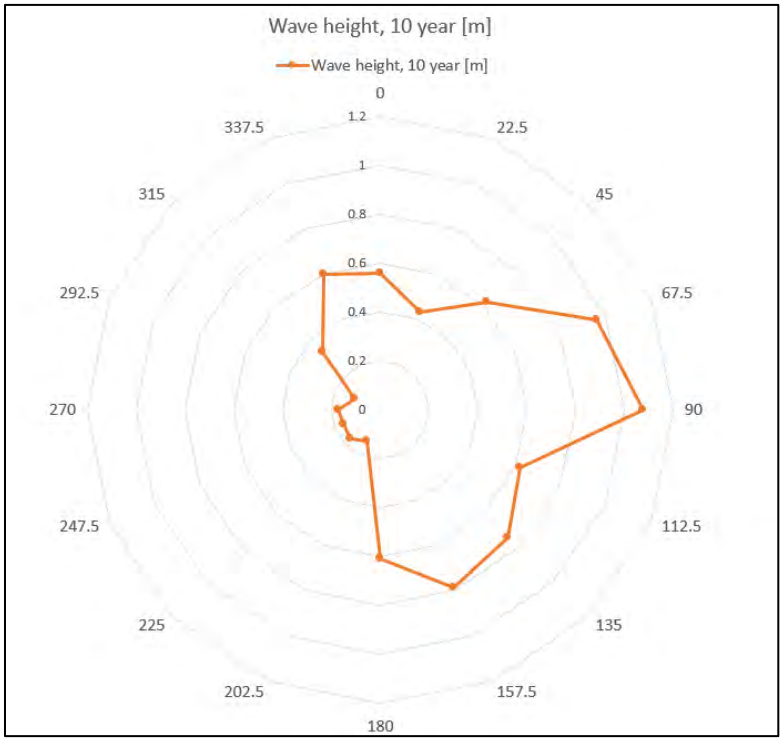


Figure 16 Maximum wave height at 10 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1039

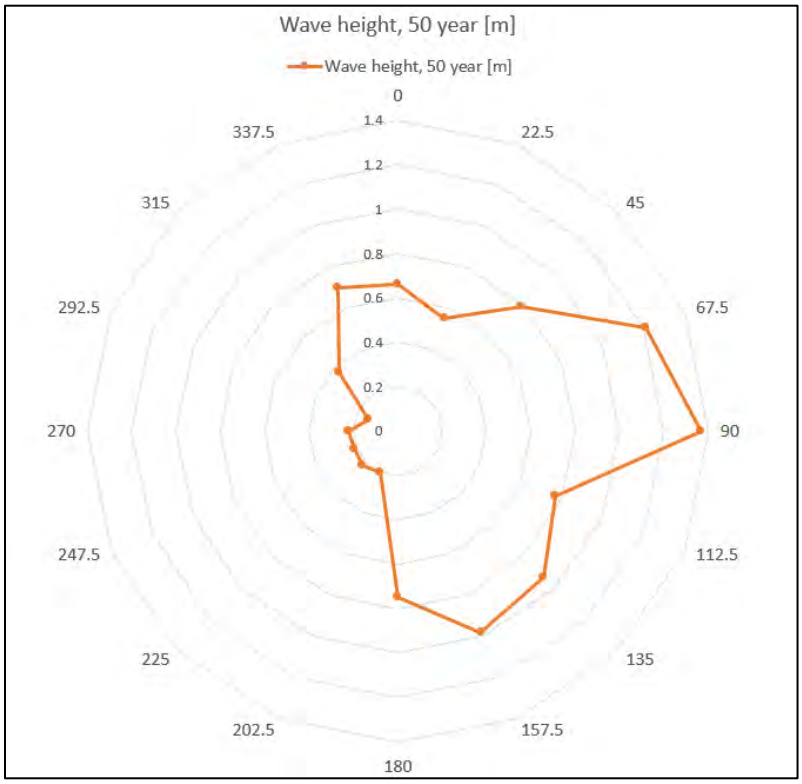


Figure 17 Maximum wave height at 50 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1039

4.3.2 Wave/wind conditions for Annapolis Basin- Marine Finfish Lease- 1040

The wave and wind results from the STWave model, for the Annapolis Basin- Marine Finfish Lease- 1040, are summarized in Table 4. Note that the results in Table 4 indicate significant wave height (Hs) and peak period (T_P) for the selected site. These represent the extreme wave conditions at this coordinate: 44° 40.117'N, 65° 43.278'W.

Table 4 Estimated wave and wind design conditions for Annapolis Basin- Marine Finfish Lease- 1040

Wave/Wind conditions	Direction [from] [°]		Wind (m/s)	Hs (m)	Tp (s)
10yr wave/wind	*0*	N	20.06	0.2	1.37
	23	NNE	20.19	0.12	1.22
	45	NE	20.75	0.18	3.42
	68	ENE	20.16	0.48	3.18
	90	E	19.41	0.69	3.07
	113	ESE	18.19	0.6	2.7
	135	SE	18.65	0.73	2.84
	158	SSE	19.32	0.83	2.8

	180	S	19.81	0.91	2.87
	203	SSW	18.23	0.6	2.63
	225	SW	18.61	0.63	2.42
	248	WSW	18.42	0.51	2.17
	270	W	19.37	0.34	1.9
	293	WNW	20.09	0.12	1.18
	315	NW	19.83	0.16	1.4
	338	NNW	18.89	0.17	1.34
50yr wave/wind	*0*	N	24.42	0.25	1.48
	23	NNE	24.39	0.18	1.4
	45	NE	25.6	0.22	3.7
	68	ENE	25.4	0.57	3.52
	90	E	24.22	0.84	3.33
	113	ESE	22.21	0.74	2.92
	135	SE	22.81	0.9	3.07
	158	SSE	23.45	1.02	3.04
	180	S	24.02	1.13	3.1
	203	SSW	21.47	0.73	2.83
	225	SW	22.26	0.78	2.6
	248	WSW	21.97	0.62	2.31
	270	W	23.33	0.41	2.01
	293	WNW	24.17	0.17	1.3
	315	NW	24.1	0.22	1.55
	338	NNW	23.02	0.22	1.46

It should be noted that the return periods indicated for each wave parameter in Table 4 are representative of the boundary condition used to derive that value, not the value itself. Polar plots for maximum wave heights are presented in Figure 18 and Figure 19.

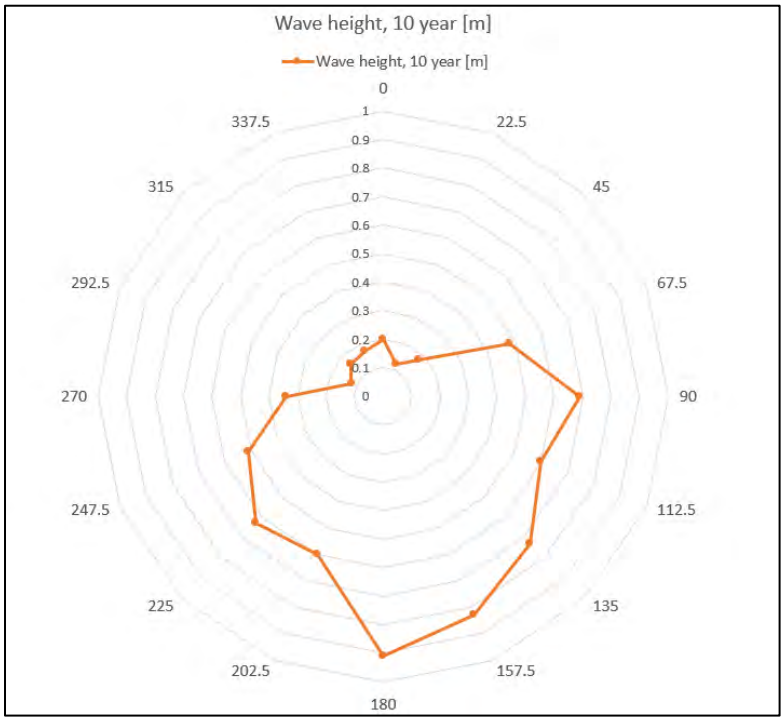


Figure 18 Maximum wave height at 10 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1040

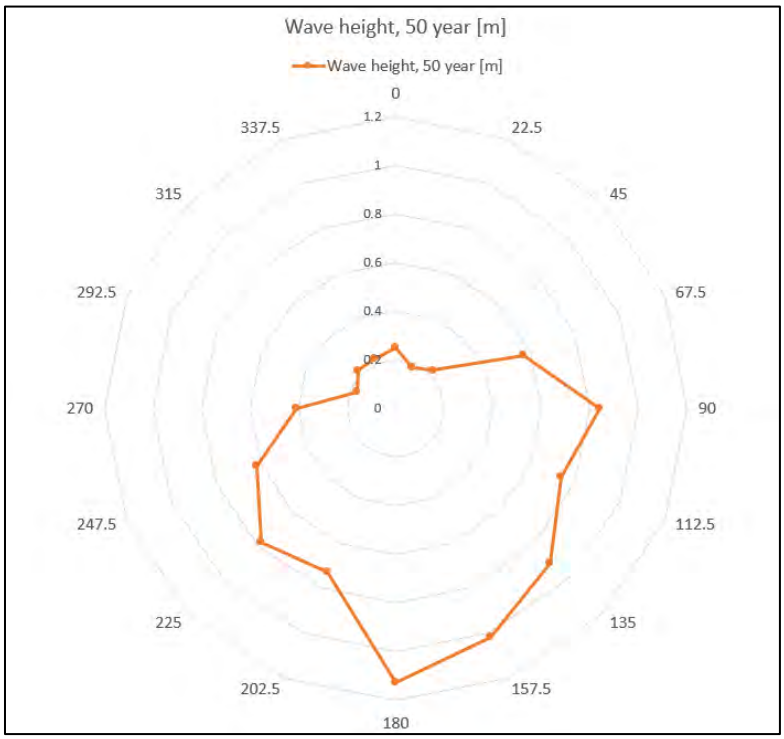


Figure 19 Maximum wave height at 50 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1040

4.3.3 Wave/wind conditions for Annapolis Basin- Marine Finfish Lease- 1041

The wave and wind results from the STWave model, for the Annapolis Basin- Marine Finfish Lease- 1041, are summarized in Table 5. Note that the results in Table 5 indicate significant wave height (Hs) and peak period (T_P) for the selected site. These represent the extreme wave conditions at this coordinate: 44° 38.743'N, 65° 43.182'W.

Table 5 Estimated wave and wind design conditions for Annapolis Basin- Marine Finfish Lease- 1041

Wave/Wind conditions	Direction [from] [°]		Wind (m/s)	Hs (m)	Tp (s)
10yr wave/wind	*0*	N	20.06	0.66	2.38
	23	NNE	20.19	0.57	2.62
	45	NE	20.75	0.78	3.24
	68	ENE	20.16	1.03	3.07
	90	E	19.41	0.91	2.9
	113	ESE	18.19	0.49	2.36
	135	SE	18.65	0.58	2.4
	158	SSE	19.32	0.57	2.38
	180	S	19.81	0.66	2.42
	203	SSW	18.23	0.53	2.42
	225	SW	18.61	0.63	2.52
	248	WSW	18.42	0.63	2.38
	270	W	19.37	0.65	2.38
	293	WNW	20.09	0.52	2.35
	315	NW	19.83	0.74	2.6
	338	NNW	18.89	0.65	2.51
50yr wave/wind	*0*	N	24.42	0.83	2.6
	23	NNE	24.39	0.7	2.85
	45	NE	25.6	0.95	3.54
	68	ENE	25.4	1.29	3.36
	90	E	24.22	1.16	3.17
	113	ESE	22.21	0.63	2.58
	135	SE	22.81	0.73	2.63
	158	SSE	23.45	0.71	2.59
	180	S	24.02	0.83	2.63
	203	SSW	21.47	0.64	2.6
	225	SW	22.26	0.77	2.73
	248	WSW	21.97	0.77	2.56

	270	W	23.33	0.81	2.58
	293	WNW	24.17	0.66	2.57
	315	NW	24.1	0.91	2.8
	338	NNW	23.02	0.79	2.63

It should be noted that the return periods indicated for each wave parameter in Table 5 are representative of the boundary condition used to derive that value, not the value itself. Polar plots for maximum wave heights are presented in Figure 20 and Figure 21.

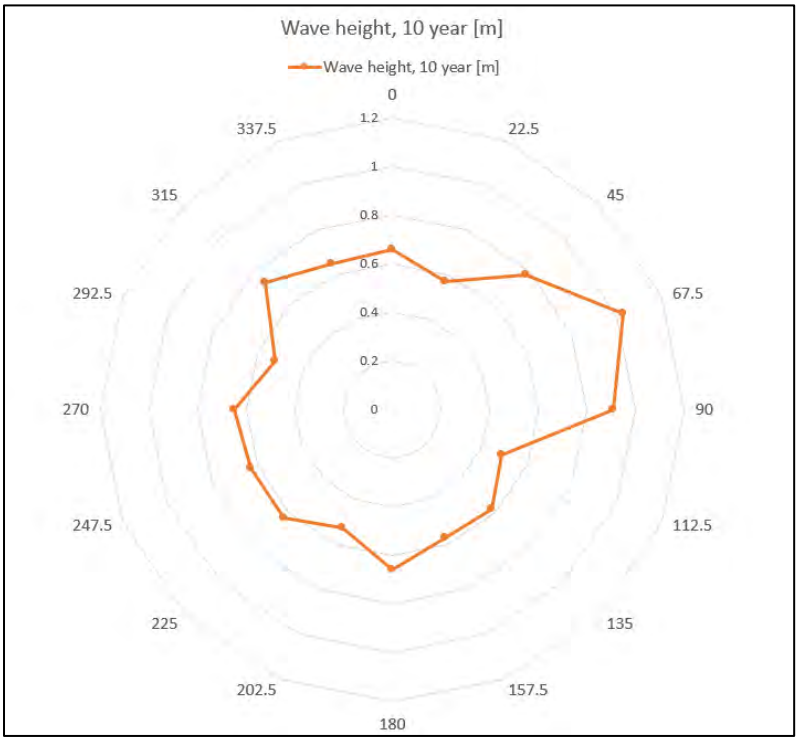


Figure 20 Maximum wave height at 10 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1041

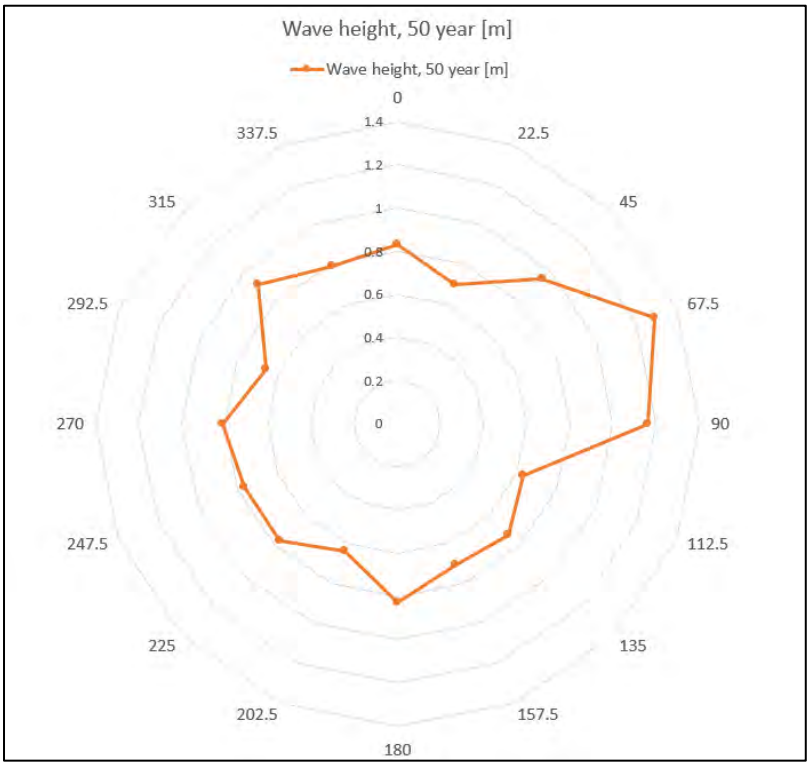


Figure 21 Maximum wave height at 50 year return period and direction [from]- Annapolis Basin- Marine Finfish Lease- 1041